Report #17-UR-054

NSTSCE

National Surface Transportation Safety Center for Excellence

Active and Adaptive Roadway Delineation Systems

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Submitted: October 13, 2017

Technology
Impairment
Mobility
Infrastructure

Housed at the Virginia Tech Transportation Institute
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ACKNOWLEDGMENTS

The authors of this report would like to acknowledge the support of the stakeholders of the National Surface Transportation Safety Center for Excellence (NSTSCE): Tom Dingus from the Virginia Tech Transportation Institute, John Capp from General Motors Corporation, Lincoln Cobb from the Federal Highway Administration, Chris Hayes from Travelers Insurance, Martin Walker from the Federal Motor Carrier Safety Administration, and Cathy McGhee from the Virginia Department of Transportation and the Virginia Transportation Research Council.

The NSTSCE stakeholders have jointly funded this research for the purpose of developing and disseminating advanced transportation safety techniques and innovations.

The authors would also like to acknowledge the support of Intelligent Traffic Equipment Marketing Ltd for providing materials and technical support critical for this project.

ABSTRACT

Heavy fog presents a significant safety hazard to drivers by reducing their ability to see the roadway and other vehicles. Even so, drivers often fail to adjust their speed to account for the reduced visibility, resulting in stopping distances that exceed visibility distance. Active delineators, or in-pavement light emitting diode (LED) markers, are an emerging technology which can be used to assist drivers in traveling through fog-prone areas by marking road or lane boundaries. However, there is a lack of research indicating how the presence of active delineators might also affect a driver's behavior. This study sought to examine how the presence of active delineators in fog might affect drivers' speed. Three lighting patterns and two brightness levels were tested. In daytime conditions, the delineators had no effect on speed. During nighttime conditions, participants often drove faster when the active delineators were present. Participants felt that the active delineators were helpful for navigating through the fog in both daytime and nighttime conditions, but preferred the higher brightness settings in the daytime.

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LIST OF ABBREVIATIONS AND SYMBOLS

ANCOVA	analysis of covariance
DAS	data acquisition system
IPM	in-pavement marker
ITEM	Intelligent Traffic Equipment Marketing Ltd.
LED	light-emitting diode
RPM	reflective pavement marker
SNK	Student-Newman-Keuls
VTTI	Virginia Tech Transportation Institute

CHAPTER 1. INTRODUCTION

BACKGROUND

Active delineation refers to the use of internally lit units for delineating a path or roadway. In-pavement markers (IPMs) are a type of active delineator embedded in a roadway's surface. Initially, IPMs were used to accommodate guidance in airport runways and taxiways. Their usage later expanded to serving as warning tools in pedestrian crosswalks (Douglas, 1978; Katz & Paprocki, 1994; Huang, Hughes, Zegeer, & Nitzburg, 1999; Gallagher, 2001; Boyce & Van Derlofske, 2002; Patterson, 2004; Nambisan, Pulugurtha, & Karkee, 2006). More recently, IPMs have been used on roadways to enhance safety in riskier conditions, such as adverse weather and horizontal curves.

IPMs offer advantages over reflective pavement markers (RPMs) and traditional pavement markings. One primary advantage is that IPMs do not require an external light source, such as vehicle headlamps, to activate. Therefore, they may be visible in situations where RPMs and pavement markings are not due to atmospheric conditions or roadway geometry. This makes them particularly compelling for use in adverse weather, such as fog, where light from a vehicle's headlamps reflected back by RPMs or pavement markings is scattered, and visibility is reduced.

However, by improving the visibility of roadway boundaries in fog, there is a possibility that drivers could increase their speed based on an increased sense of comfort. This could be a dangerous scenario because the visibility of other vehicles is not similarly improved, and an increase in speed could to lead to an increase in crash risk.

PROJECT APPROACH

The purpose of the current study was to investigate whether a driver's speed could be influenced by different configurations of IPMs in foggy conditions. Specifically, the study utilized different brightness levels and different flashing patterns in a simulated fog environment on the Virginia Smart Road and examined the effect on participants' selected speeds.

LITERATURE REVIEW

Previous research has examined the use of active delineators in adverse weather conditions. In 1976, a fog light system was installed on 5.8 mi of I-64. A 19-month before-and-after study showed that inclement weather crashes decreased in comparison to clear weather crashes, but that the severity of inclement weather crashes increased. It should be noted, however, that this result is based on a relatively small number of crashes (Lynn, Schreiner, & Campbell, 2002). Another evaluation of this system was conducted after it was upgraded in 1997. A subsequent study revealed a decrease in the total number of crashes and the number of fog-related crashes (Carson, Tydlacka, Gray, & Voigt, 2008).

In 1992, the South Carolina Department of Transportation started to operate a fog mitigation system on 7 mi of the I-526 Cooper River Bridge, including illuminated pavement lights installed at 110-ft spacing. Based on the visibility conditions, different advisory and control strategies are employed. In order to guide vehicles safely through the fog-prone area, IPMs, located along the edgelines of the bridge, are activated manually when the visibility reaches less than 700 ft. For light fog, every other marker is activated, while in heavier fog conditions all markers are illuminated. After implementation of the system, no fog-related crashes have occurred as of this report's publication date (Carson et al., 2008).

A study by Hagiwara et al. (2001) examined the visibility of road delineators during snowstorms in Hokkaido, Japan. Luminance, illuminance, and transmissivity were recorded over 30 days at intervals of 10 min at an observation distance of 34 m. The authors showed that the background luminance is influenced by illuminance and transmissivity. The results indicated that IPMs had greater visibility in dark snowstorms as opposed to daylight, and that closer spacing of delineators helps with the background light contrast (Hagiwara et al., 2001).

Munehiro, Tokunaga, Asano, and Hagiwara (2007) examined the visibility of three types of LED delineators under natural foggy conditions. On a 200-m road segment, two ambient light conditions (daytime and nighttime) and three weather conditions (one clear and two dense fog conditions) were evaluated. Twenty women participated in the study, and were asked to evaluate visibility, glare, and safety while driving on the road at 50 km/h. Based on the results, under foggy conditions with a visibility distance of 100 m, luminous intensities of 1,000 cd and 70 cd are suitable for daytime and nighttime, respectively, to provide delineator visibility from an observation distance of 200 m. It was also found that in order to decrease the excessive glare, the luminous intensity needs to be adjusted based on the degree of visibility reduction.

Previous research has shown that the use of active delineators in adverse weather conditions can lead to decreases in the number of crashes, but in one case may have also increased the severity of crashes that did occur. Previous research also showed that there are different intensity requirements for active delineators based on ambient light conditions and visibility levels. However, none have actually examined if different configurations or patterns can be used to affect driver behavior. This study sought to fill this knowledge gap specifically by exposing participants to different IPM configurations and examining any effects on participant speed.

CHAPTER 2. EXPERIMENTAL DESIGN

OVERVIEW

A human-subjects experiment was conducted in the Spring of 2015 on the Virginia Smart Road. The study focused on driver performance under various IPM configurations while driving in foggy weather conditions. The study was conducted both during the daytime and the nighttime, and examined a steady (always on) configuration, two of the available flashing patterns (i.e., rabbit and reverse rabbit), and two IPM brightness levels. Table 1 shows each factor examined in the project.

Table 1. Factor levels.

Participant Age	Ambient Light	IPM Pattern	Brightness
Younger	Daytime	Steady On	High
Older	Nighttime	Rabbit	Low
		Reverse Rabbit	
		No Lights (Off)	

The experimental design is a 2 (Age) × 2 (Ambient Light) × 4 (Pattern) × 2 (Brightness) mixed-factors design (Table 2). A total of 34 participants completed the study, with 18 participating during the day, and 16 participating at night.

Table 2. Mixed-factors design.

<table>
<tr><th>Ambient</th><th>Brightness</th><th>Pattern</th><th>Participant Groups</th></tr>
<tr><td rowspan="7">Day</td><td rowspan="3">Low</td><td>Steady On</td><td rowspan="7">11 Older
7 Younger</td></tr>
<tr><td>Rabbit</td></tr>
<tr><td>Reverse Rabbit</td></tr>
<tr><td rowspan="3">High</td><td>Steady On</td></tr>
<tr><td>Rabbit</td></tr>
<tr><td>Reverse Rabbit</td></tr>
<tr><td>NA</td><td>No Lights</td></tr>
<tr><td rowspan="7">Night</td><td rowspan="3">Low</td><td>Steady On</td><td rowspan="7">5 Older
11 Younger</td></tr>
<tr><td>Rabbit</td></tr>
<tr><td>Reverse Rabbit</td></tr>
<tr><td rowspan="3">High</td><td>Steady On</td></tr>
<tr><td>Rabbit</td></tr>
<tr><td>Reverse Rabbit</td></tr>
<tr><td>NA</td><td>No Lights</td></tr>
</table>

INDEPENDENT VARIABLES

Several variables were manipulated or controlled during the study. They are 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 but was not used in the analysis.

- Age (2 levels): Younger (18–34), Older (65+). Two age groups were selected to study the differences in behavior and perception between younger and older drivers.

- Ambient Light (2 levels): Daytime, Nighttime. This variable was chosen because the perception of IPMs may greatly differ based on the ambient light conditions. What works best at night may not necessarily work best in daylight.

Within-Subjects Variables

- Brightness (2 levels): Low, High. This variable was chosen to determine how the brightness of the IPM markings interacts with the fog to affect driver behavior. Brighter lights are generally more visible, but light scattering in the fog may serve to illuminate the fog bank and actually make it more difficult to see the delineation system.

- Pattern (4 levels): No Lights, Steady On, Rabbit, and Reverse Rabbit. This variable was chosen to determine how different patterns affect driver behavior. The patterns are described in detail in the Equipment and Facilities portion of the report.

DEPENDENT VARIABLES

Objective and subjective variables were measured. They are described below.

Mean Speed

Vehicle speed was recorded as participants drove laps on the Virginia Smart Road. Their mean speed was calculated each time they drove past a delineation system within the fog or through an area of fog beyond the systems.

Participant Ratings

Participants rated their level of agreement with the following statements about aspects of the delineation system, to subjectively assess visibility, glare, and helpfulness.

- This configuration helped me predict the road ahead.
- This configuration had a comfortable level of brightness.
- This configuration was difficult to see in the fog.
- This configuration was glaring.

Covariate

Because this study sought to examine driver speed behavior in fog conditions, visibility was measured and used as a covariate in the analyses. A custom-built sensor mounted to the top of each experimental vehicle measured the transmissivity of the fog as participants drove through the fog bank. This measurement was then converted into a visibility distance.

EQUIPMENT AND FACILITIES

Virginia Smart Road

The experiment was conducted on the Virginia Smart Road. The Smart Road is a 2.2-mi, two-lane, restricted-access road. The Smart Road is equipped with weather-making towers, which were used to create fog over a 750-ft section of the roadway (Figure 1).

Figure 1. Photo. The Smart Road weather-making section.

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 and other data from the vehicle's network. A custom-built fog measuring system was mounted to the top of each vehicle. This system measured the transmissivity of the fog by shining a laser near the front of the vehicle to a sensor at the rear (Figure 2). This measurement was then converted to visibility distance, which was used as a covariate in the data analysis.

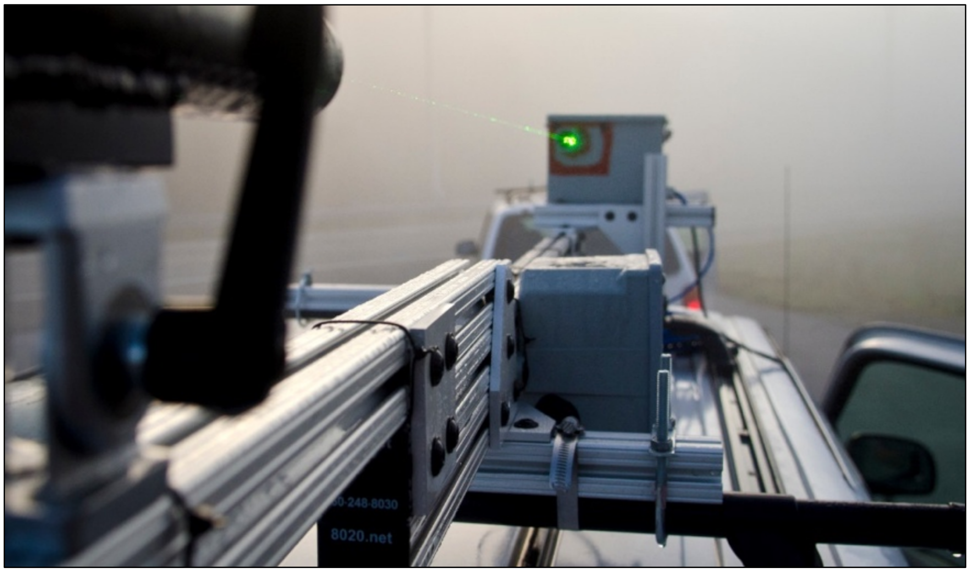


Figure 2. Photo. Fog measurement system.

In-pavement Markers

The IPMs consisted of two 1,000-ft custom-made strands of amber LaneLight™ IPMs supplied by Intelligent Traffic Equipment Marketing Ltd (ITEM), with a unit spacing of 20 ft (the 20-ft spacing of the heads was proposed by the manufacturer). Each system was temporarily placed on each shoulder of the Smart Road, approximately 18 inches from the white shoulder line (Figure 3). The system used custom firmware designed by ITEM to allow the research team to adjust the light pattern and brightness. The standard specifications can be found in Appendix A.

Figure 3. Photo. Temporary LaneLight™ delineation system.

A characterization of a single LaneLight™ unit was conducted at the two brightness settings used for this project (100, or “high,” and 25, or “low”). The vertical illuminance was measured directly in front of the unit, facing parallel to the ground in the direction of the unit. Figure 4 shows the illuminance, in lux, as measured every 2 ft from the unit, up to 14 ft.

Brightness 100

Height (ft) \ Distance (ft)	2	4	6	8	10	12	14
6			0.21	0.22	0.26	0.27	0.28
5.5			0.24	0.28	0.31	0.33	0.3
5			0.32	0.34	0.39	0.38	0.34
4.5			0.39	0.46	0.46	0.45	0.34
4		0.47	0.54	0.58	0.58	0.47	0.34
3.5		0.66	0.72	0.79	0.63	0.47	0.35
3		0.93	1.05	0.96	0.65	0.46	0.75
2.5		1.5	1.48	1.05	0.66	1.13	1.57
2	1.72	2.22	1.87	0.99	1.93	2.98	7.94
1.5	3.44	3.8	1.84	4.18	11.86	15.73	12.71
1	9.5	4.88	15.9	34.3	27.24	22.91	19.39
0.5	24.3	142.9	93.6	62.3	39.9	28.37	19.59
0	493	189.3	88.4	47.9	31.9	20.63	15.93

Brightness 25

Height (ft) \ Distance (ft)	2	4	6	8	10	12	14
6			0.07	0.07	0.09	0.09	0.09
5.5			0.08	0.08	0.1	0.1	0.1
5			0.1	0.1	0.12	0.12	0.11
4.5			0.12	0.13	0.14	0.14	0.11
4		0.15	0.16	0.16	0.17	0.14	0.1
3.5		0.2	0.2	0.22	0.19	0.14	0.11
3		0.27	0.3	0.27	0.19	0.14	0.22
2.5		0.43	0.42	0.3	0.2	0.33	0.45
2	0.5	0.64	0.53	0.28	0.55	0.85	2.23
1.5	0.98	1.08	0.53	1.17	3.34	4.41	3.6
1	2.7	1.37	4.48	9.62	7.68	6.52	5.41
0.5	6.8	43.4	26.6	17.57	11.26	7.96	5.55
0	143	53.4	25.2	13.47	8.86	5.83	4.5

Figure 4. Chart. Vertical illuminance (lux) of a single IPM at high (100) and low (25) brightness settings.

Patterns

Three delineation lighting patterns were used in this study. They are described below.

- Steady On – All units were active at all times.
- Rabbit – All units were active except for a group of three adjacent units, which created a negative space. The units activated and deactivated in such a way that this negative space appeared to travel from one end of the system to the other (i.e., moving in the same direction as the participant). The rabbit pattern traveled in the same direction as the participant vehicle.
- Reverse Rabbit – This pattern worked in the same way as the rabbit pattern, but in the opposite direction. This gave the impression that the negative space was moving toward the participant.

Figure 5 illustrates the rabbit pattern. Animated versions can be found at http://i.imgur.com/3hfJKQL.gifv (rabbit), and at http://i.imgur.com/hGatHul.gifv (reverse rabbit).

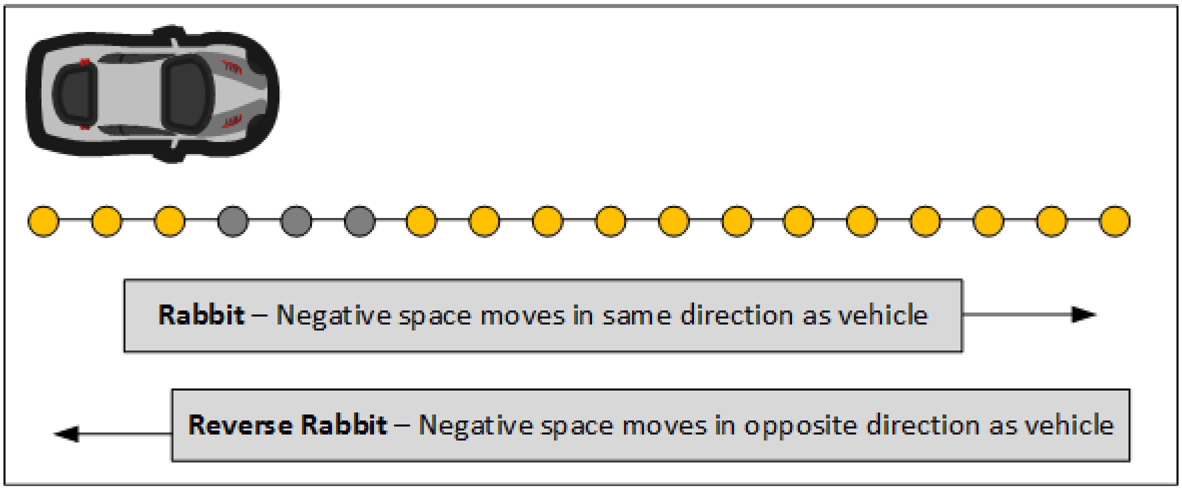


Figure 5. Diagram. Rabbit and reverse rabbit patterns.

A pattern similar to the reverse rabbit was used to delineate a horizontal curve on an exit ramp of I-95 in Florida (Figure 6). For this particular curve, the delineators were activated when a vehicle was detected driving at 45 mph or more, with the IPMs furthest from the vehicle activating first, and then activating in sequence toward the vehicle. The idea was to give drivers a sense of driving faster to encourage them to slow down. The system received positive public feedback, and was shown to increase safety on the exit ramp (Carson et al., 2008). There are no known examples of delineators with a forward moving pattern, but the research team felt that the apparent forward motion of the blank space might provide a sense of direction for participants.

Figure 6. Photo. Horizontal curve IPM system with a reverse chase pattern (courtesy of Intelligent Traffic Equipment Marketing Ltd.).

EXPERIMENTAL PROCEDURE

Participant Recruitment, Consent, and Compensation

Participant recruitment was performed via the Virginia Tech Transportation Institute (VTTI) participant database and word of mouth. A general description of the study was provided to the participants over the phone before they decided if they were willing to participate. If they were interested, participants were then screened with a verbal questionnaire to determine whether they were licensed drivers and whether they had any health concerns that should exclude them from the study. Demographic information was collected, and participants were asked about their experience driving at night. Eligible participants were scheduled to come to VTTI to participate, and 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 that they may have had about the consent form. Participants were paid $30 per hour of participation.

Participants

A total of 34 participants completed the study. Drivers met the following criteria:

1. Held a valid driver's license.
2. Had normal (or corrected to normal) vision, with a minimum visual acuity of 20/40.
3. Were willing to drive through heavy fog on a closed test track.
4. Were willing to provide a Social Security Number or Virginia Tech ID for payment purposes.
5. Did not have more than two moving violations in the past 3 years.
6. Were able able to drive an automatic transmission vehicle without assistive devices.
7. Did not cause an injurious accident in the past three years.
8. If pregnant, were encouraged to speak to their physician about participation before being scheduled and were emailed a copy of the consent form to show the physician.
9. Did not have lingering effects of a heart condition, brain damage from stroke, tumor, head injury, recent concussion, or infection. Did not have had epileptic seizures within 12 months, uncontrolled current respiratory disorders, or require oxygen. Did not have motion sickness, inner ear problems, dizziness, vertigo, balance problems, uncontrolled diabetes for which insulin was required, chronic migraines, or tension headaches.
10. Did not, at the time of the experiment, take any substances that interfered with driving ability, caused drowsiness, or impaired motor abilities.
11. Were eligible for employment in the U.S.
12. Were 18–34 or 60+ years old.

After passing an initial screening and visual acuity test, participants were scheduled to come to VTTI to participate. Participants were scheduled in groups of four. Upon arrival, participants first reviewed an informed consent form, which explained every aspect of their participation. They also filled out a questionnaire about their driving history and a W-9 tax form. Before being taken to the Smart Road in a shuttle vehicle, participants were read a script, which gave an overview of the study procedures, and were given an opportunity to ask questions.

Once on the Smart Road, participants exited the shuttle vehicle in a turn-around location. Two in-vehicle experimenters escorted two of the participants to the experimental vehicles while the remaining two participants entered a bus parked in the turn-around. In the experimental vehicles, the in-vehicle experimenters read a script to the participants that gave specific instructions regarding their task on the Smart Road. Participants were informed that they would drive through a simulated fog and that a delineation system would be present. They were asked to drive at whatever speed they felt was comfortable, but not to exceed 55 mph.

The participants in the experimental vehicles then took turns driving one lap on the Smart Road. The in-vehicle experimenters rode in the back seat and ran the data collection equipment as participants drove. Each time a participant passed through the fog, the in-vehicle experimenter would ask them to indicate how much they agreed or disagreed with a series of statements about the delineation system. When a participant completed a lap and returned to the starting turn-around, the participant would exit the vehicle and board the bus, and another participant would enter the vehicle and drive a lap. This continued until all four participants had each driven four laps.

The delineation systems were placed on each shoulder of the roadway, each facing a different direction (Figure 7). Only the system nearest the participant vehicle was active when driving through the test area. For each lap, participants always saw the low-brightness system first, when traveling downhill, and then the high-brightness system when traveling back uphill. Four counterbalanced orders were created to determine which pattern would be displayed for each system, on each lap.

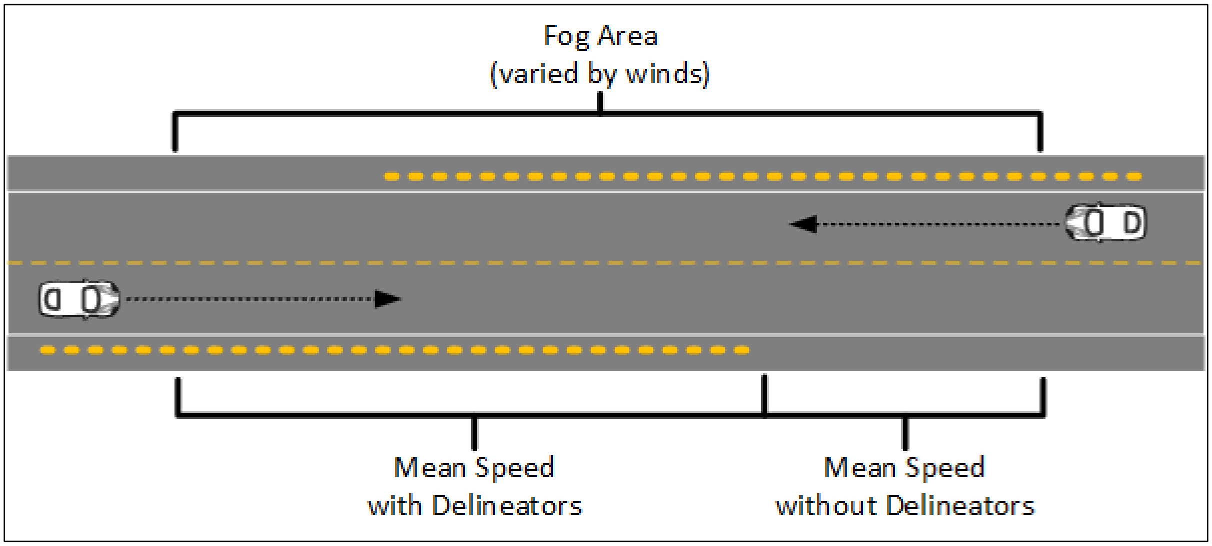


Figure 7. Diagram. IPM configuration.

CHAPTER 3. DATA ANALYSIS

DATA CLEANING

Prior to analysis, data cleaning was performed to remove erroneous data. In some cases, fog was not present on the roadway due to ambient weather conditions that either made fog creation difficult or blew the fog off the roadway. In other cases, the fog measurement computer malfunctioned, and no fog visibility data were recorded. Any data collected when there was no fog or visibility data were omitted from the analysis.

Additionally, ambient weather conditions could shift the size and location of the fog bank. Any data in which the participant was in the fog bank for less than 5 seconds were omitted from the analysis, as the research team felt this would not allow enough time for the participant to adapt their speed to the visibility conditions.

Removing these data decreased the total number of observations of the delineators from 178 to 145, and the baseline (no delineation) observations from 97 to 44. The baseline data were affected the most since they were collected at a location near the end of the weather section, making them more susceptible to wind decreasing the amount of fog at that location.

SPEED

Several analyses of covariance (ANCOVAs) were performed to determine if the pattern or brightness of the delineators had an impact on drivers' speed. Fog visibility was used as a covariate, as the density of the fog would also have an impact on drivers' speed. Separate analyses were performed for day and nighttime conditions. Significance was determined with an alpha of 95% ($p < 0.05$).

DRIVER PERCEPTION

Simple descriptive statistics such as means were used to analyze participants' responses to questionnaires.

DAYTIME RESULTS

Table 3 shows the ANCOVA results for daytime conditions. As indicated by the empty "Sig" column on the far right, no factors were found to have a significant effect on drivers' mean speed.

Table 3. ANCOVA results for speed in daytime conditions.

Source	DF	Type III SS	Mean Square	*F* Value	Pr > *F*	Sig
Age	1	12.0259	12.0259	0.04	0.8445	
Brightness	1	63.1226	63.1226	1.05	0.3302	
Age*Brightness	1	26.9792	26.9792	0.45	0.5186	
Pattern	2	36.9816	18.4908	0.66	0.5270	
Age*Pattern	2	10.0760	5.0380	0.18	0.8368	
Brightness*Pattern	2	8.9857	4.4929	0.3	0.7546	
Age*Brightness*Pattern	2	72.5773	36.2886	2.38	0.1730	
Total	11	230.7484				

While no factors were found to significantly affect drivers' mean speed, the delineator pattern may have showed a slight impact. For all daytime conditions, all three patterns had mean speeds of approximately 34 mph. In order to examine the effect of pattern without the potential confound of the grade, additional ANCOVAs were conducted to examine the effect of pattern within each brightness level. Table 4 shows the results of these two analyses. The baseline no-lights condition used in these analyses include both uphill and downhill runs due to the limited number of uphill baseline runs.

Table 4. ANCOVA results by brightness for daytime conditions.

Brightness	Source	DF	Type III SS	Mean Square	*F* Value	Pr > *F*	Sig
Low	**Age**	1	1.8257	1.8257	0.01	0.9176	
	Pattern	3	33.6404	11.2135	0.87	0.4748	
	Age*Pattern	3	21.4964	7.1655	0.56	0.6508	
High	**Age**	1	3.2901	3.2901	0.03	0.8664	
	Pattern	3	52.6140	17.5380	0.71	0.5545	
	Age*Pattern	3	21.4876	7.1625	0.29	0.8309	

Within each brightness level, pattern was still not found to significantly affect mean speed in daytime conditions. Figure 8 shows the mean speed and visibility by pattern for low brightness, daytime conditions. While the rabbit pattern did have a slightly higher mean speed, it also had a higher mean visibility, which could explain the difference.

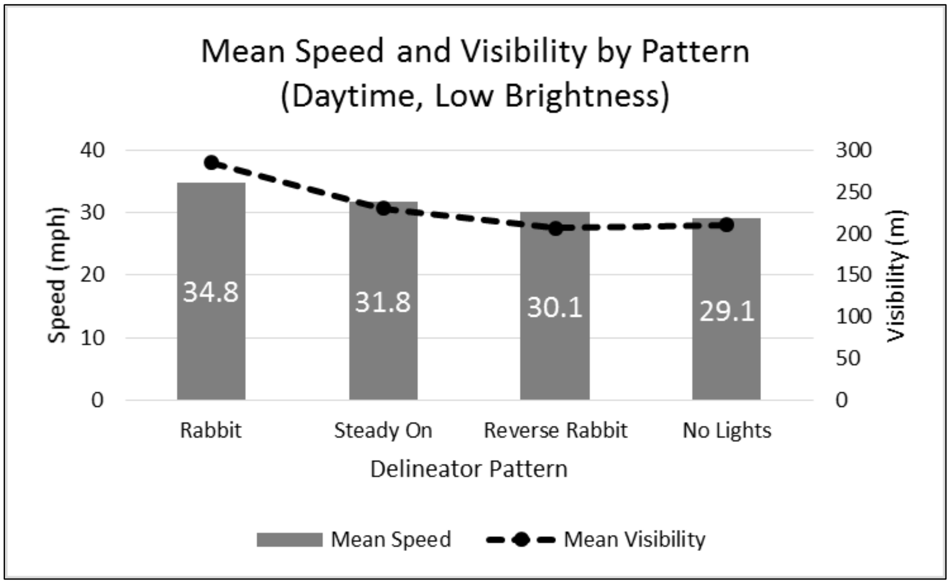


Figure 8. Graph. Mean speed and visibility by pattern for low brightness, daytime conditions.

Figure 9 shows the mean speed and visibility by pattern for high brightness, daytime conditions. Here, the differences between means is slightly larger, but due to the amount of variability (a standard error of roughly ±2 mph), no significant difference was found. It is interesting to note, however, that mean speeds when delineators were present were 5 to nearly 10 mph faster than when no delineators were present.

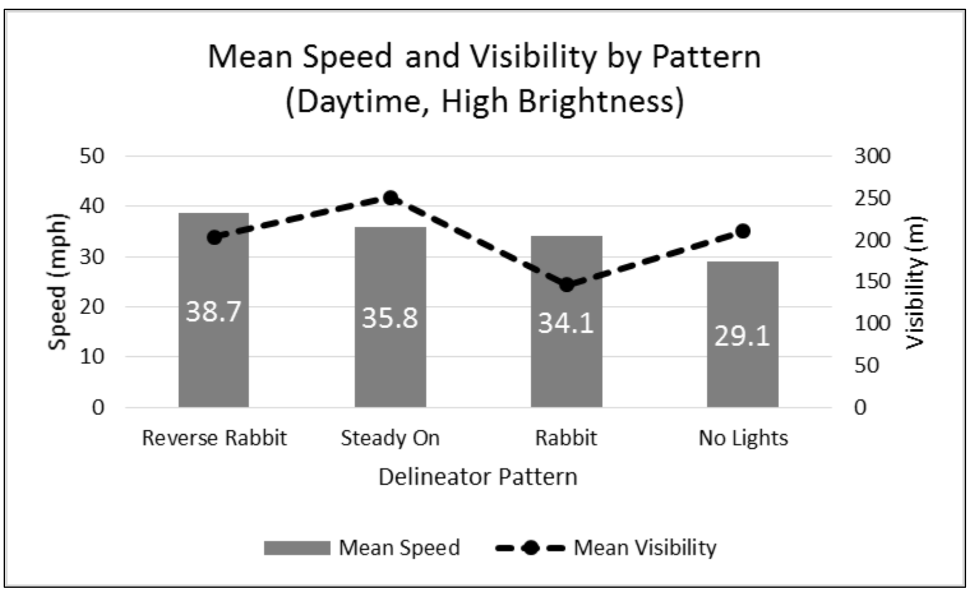


Figure 9. Graph. Mean speed and visibility by pattern for high brightness, daytime conditions.

Each time a participant drove through the fog with the assistance of the delineation system, they were asked the extent to which they agreed or disagreed with the following statements:

- This configuration helped me predict the road ahead.
- This configuration had a comfortable level of brightness.
- This configuration was difficult to see in the fog.
- This configuration was glaring.

Figure 10 shows the mean response for whether a configuration helped in predicting the road ahead for daytime conditions. For both high and low brightness settings, participants tended to agree that the delineators helped them to predict the road ahead, though the feeling was stronger for the high brightness setting. For the low brightness setting, participants tended to feel that the rabbit pattern was more helpful in predicting the road ahead.

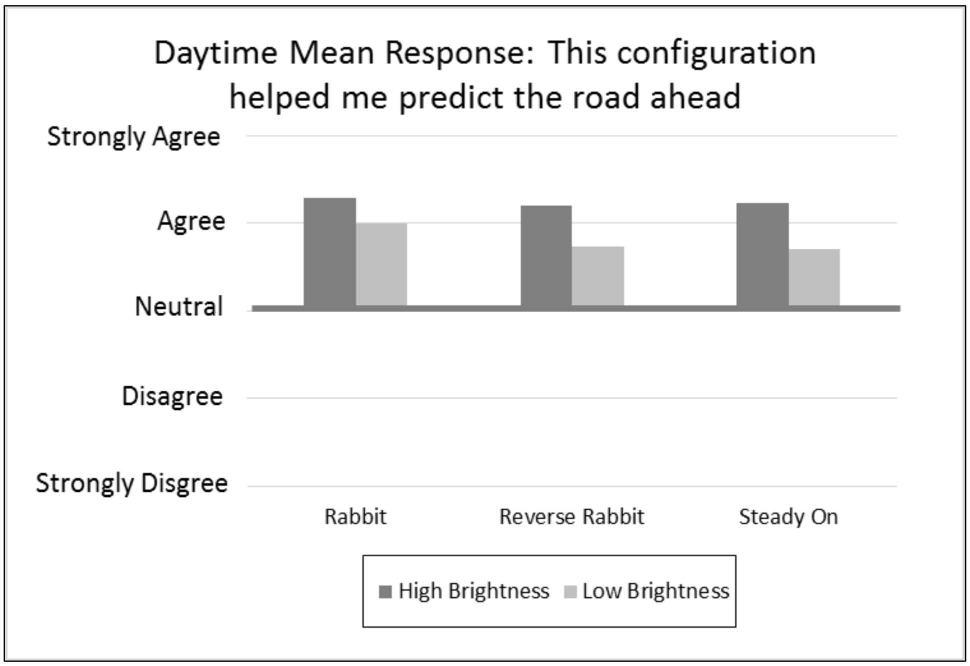


Figure 10. Chart. Daytime mean response: "This configuration helped me predict the road ahead."

Figure 11 shows the mean response for whether the delineators had a comfortable level of brightness. Participants tended to agree that both the high and low brightness delineators had a comfortable level of brightness, but were more in agreement about the comfort level for the high brightness setting. It is likely that the higher brightness made the delineators more visible in the daylight, and therefore participants could more easily see them. While there was no difference in the brightness between patterns that used the high brightness setting, participants nevertheless felt the rabbit pattern had a more comfortable level of brightness than the other patterns.

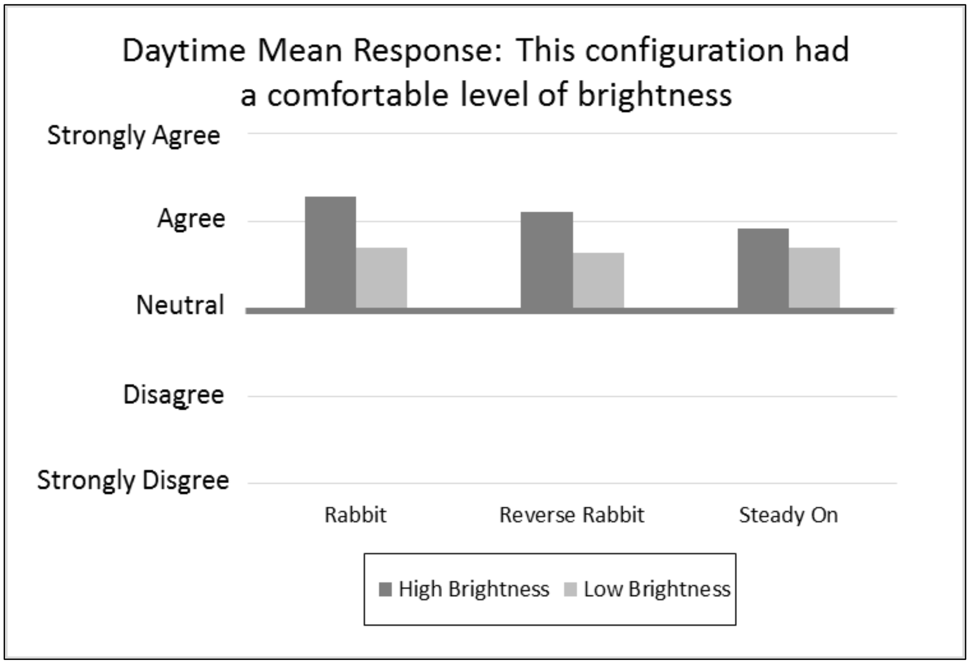


Figure 11. Chart. Daytime mean response: "This configuration had a comfortable level of brightness."

Figure 12 shows the mean response for whether a configuration was difficult to see in the fog. For all patterns, participants disagreed that the high-brightness configurations were difficult to see in the fog. However, for the low-brightness configurations, participants were "neutral" for all but the rabbit pattern. This may indicate that the apparent forward motion of the rabbit pattern helped to compensate for the lower brightness, making it more visible.

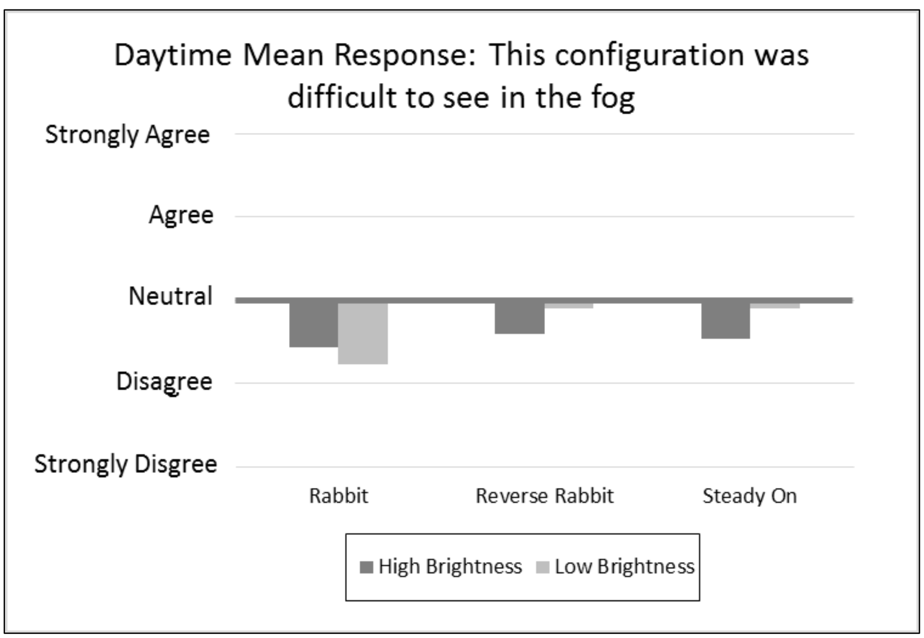


Figure 12. Chart. Daytime mean response: "This configuration was difficult to see in the fog."

Figure 13 shows the mean response for whether a configuration was glaring. For daytime conditions, participants did not agree that any of the configurations were glaring.

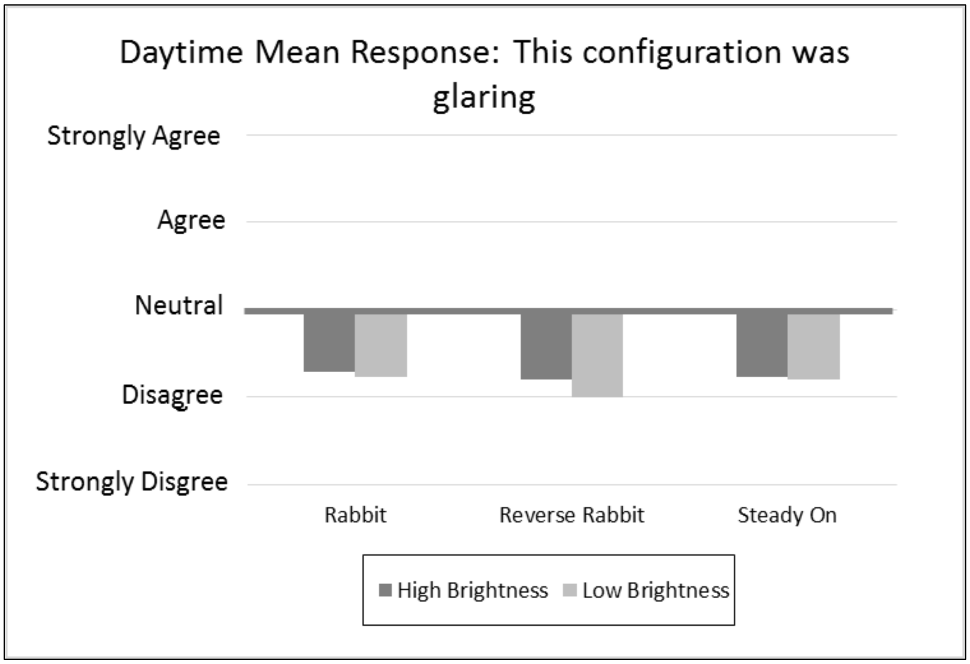


Figure 13. Chart. Daytime mean response: "This configuration was glaring."

NIGHTTIME RESULTS

As with the daytime data, the nighttime data were separated by brightness due to the confound of the roadway grade. Table 5 shows the ANCOVA results for the low-brightness and high-brightness analyses. Pattern was found to have a significant main effect for both.

Table 5. ANCOVA results for nighttime conditions.

Brightness	Source	DF	Type III SS	Mean Square	*F* Value	Pr > *F*	Sig
Low	**Age**	1	272.7399	272.7399	2.29	0.1584	
	Pattern	3	1211.3720	403.7907	14.68	<.0001	*
	Age*Pattern	3	98.2424	32.7475	1.19	0.3299	
High	**Age**	1	118.2431	118.2431	0.8	0.3876	
	Pattern	3	327.0519	109.0173	4.25	0.0132	*
	Age*Pattern	3	81.5790	27.1930	1.06	0.3815	

Figure 14 shows the mean speed and visibility by pattern for the low-brightness configurations. The letters above each bar represent Student-Newman-Keuls (SNK) groupings. The SNK is a post hoc test which looks for differences among pairs of factors. Factors which share a letter are not statistically significantly different. In this case, no statistical difference was found among the three patterns, but each pattern resulted in mean speeds significantly higher than when there were no delineators.

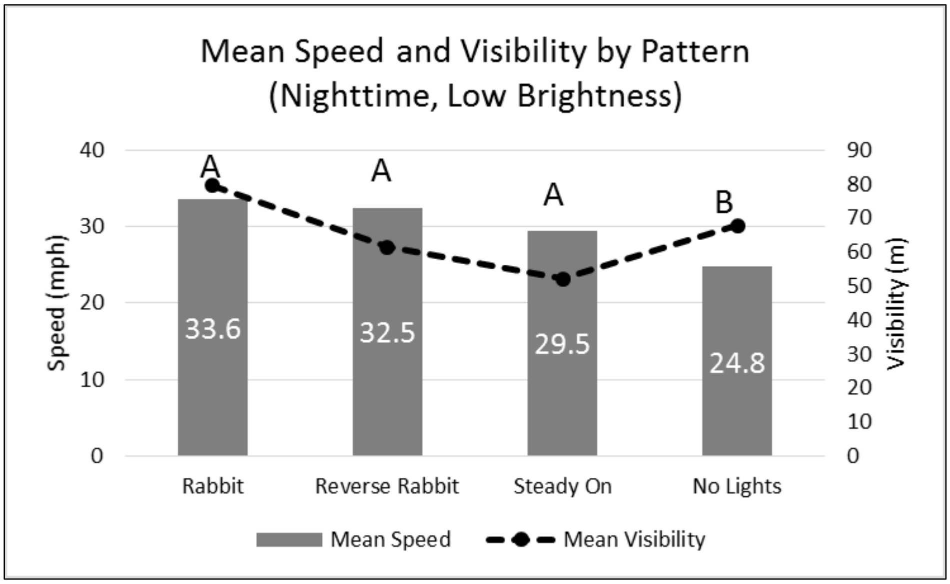


Figure 14. Chart. Mean speed and visibility by pattern (nighttime, low brightness).

Figure 15 shows the mean speed and visibility by pattern for the high-brightness configurations. There was no statistical significance found among the three delineation patterns, and only the rabbit pattern had a mean speed significantly higher than when no delineators were present.

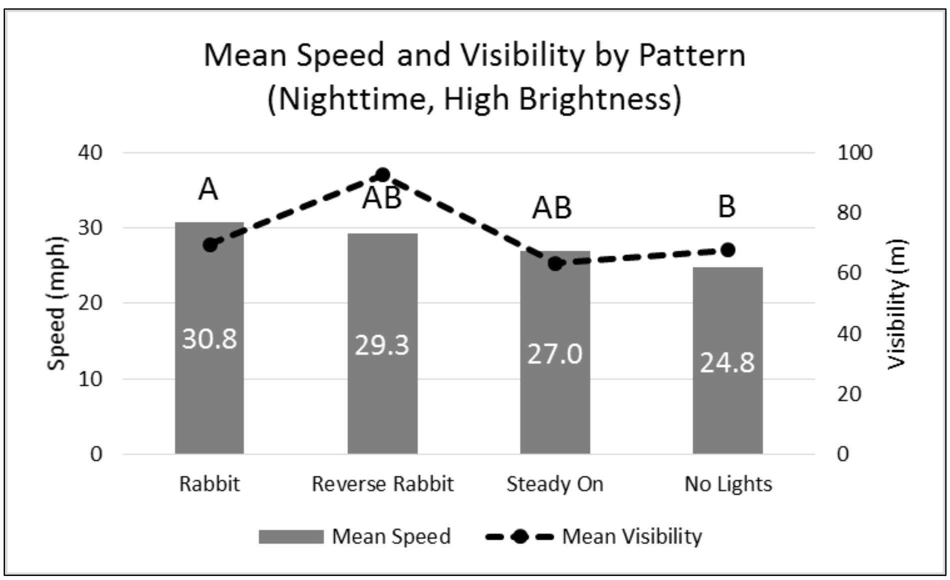


Figure 15. Chart. Mean speed and visibility by pattern (nighttime, high brightness).

Figure 16 shows the mean response for whether a configuration helped the participant predict the road ahead. Participants agreed that all configurations helped them to predict the road ahead, with the high-brightness rabbit pattern being rated the most strongly.

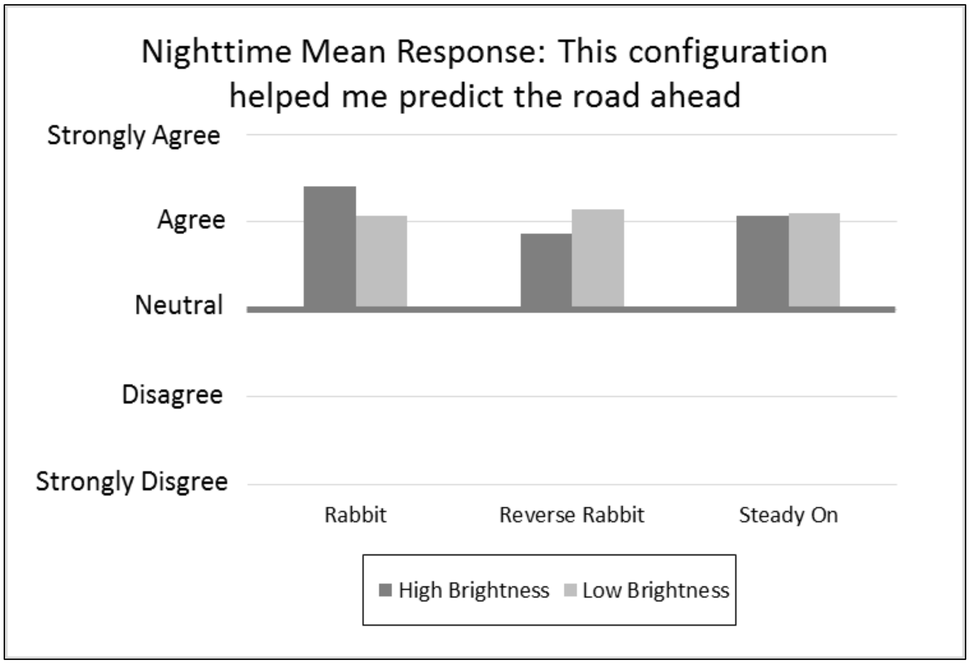


Figure 16. Chart. Nighttime mean response: "This configuration helped me predict the road ahead."

Figure 17 shows the mean response for whether a configuration had a comfortable level of brightness. Interestingly, participants' level of agreement seemed to differ by pattern as much as with brightness, though they tended to agree that all configurations had a comfortable brightness.

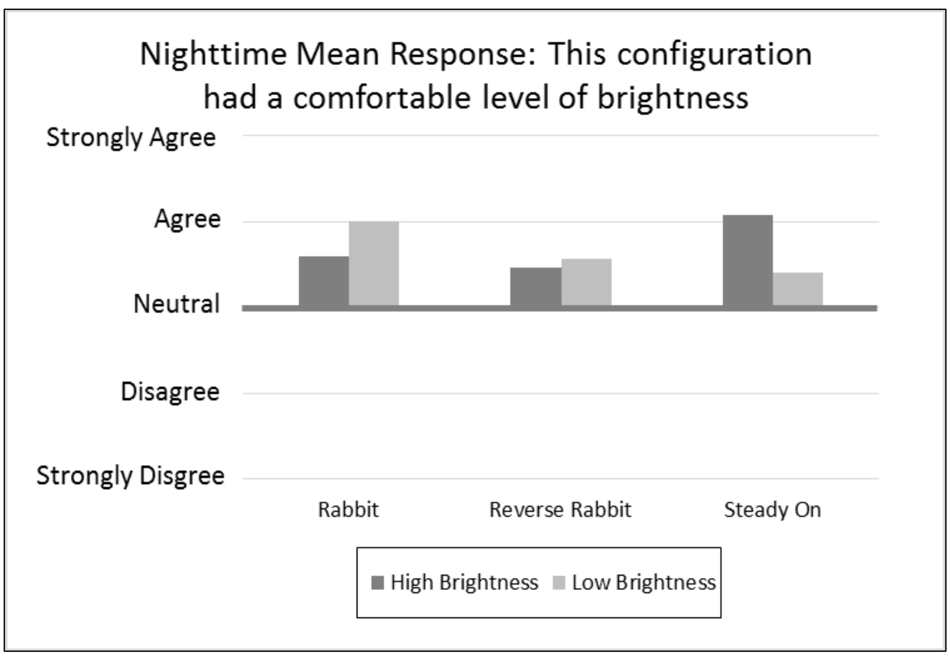


Figure 17. Chart. Nighttime mean response: "This configuration had a comfortable level of brightness."

Figure 18 shows the mean response for whether a configuration was difficult to see in the fog. Participants disagreed that any of the configurations were difficult to see in the fog.

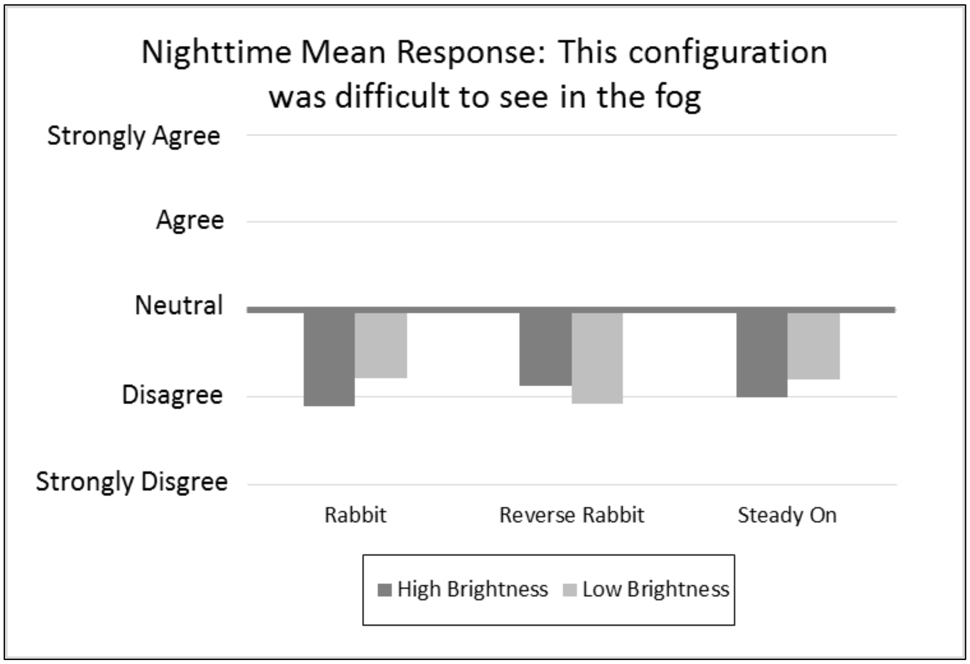


Figure 18. Chart. Nighttime mean response: "This configuration was difficult to see in the fog."

Figure 19 shows the mean response for whether a configuration was glaring. Participants tended to disagree that any configuration was glaring; however, the disagreement response was stronger for the low-brightness configurations except for all the steady-on pattern.

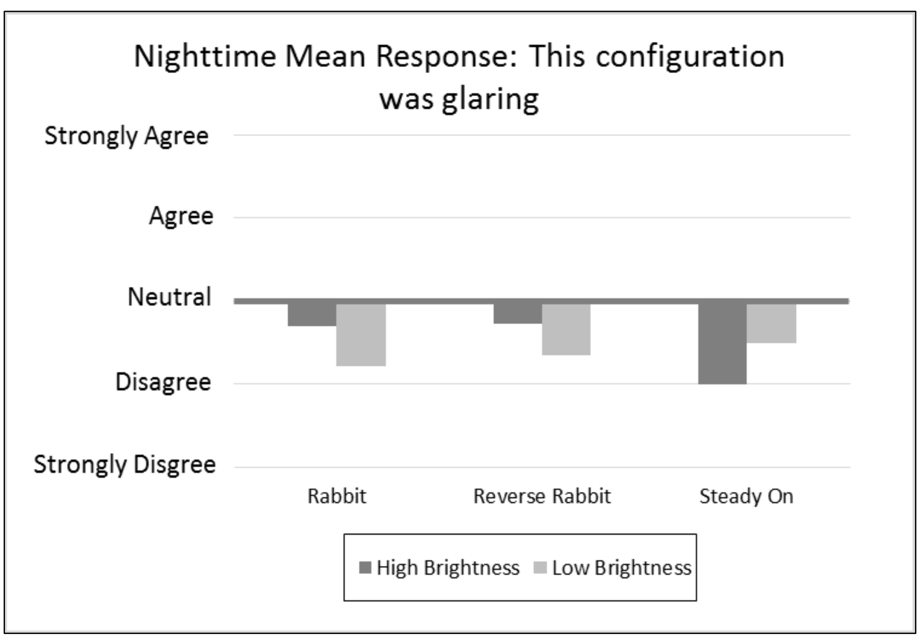


Figure 19. Chart. Nighttime mean response: "This configuration was glaring."

CHAPTER 4. DISCUSSION

SUMMARY OF RESULTS

This study sought to determine if advanced active delineators could be controlled in such a way to affect drivers' speeds, but found no difference in speeds for the three tested patterns. In daytime conditions, drivers' speeds were not significantly affected by the presence of the delineators compared to no delineators. However, participants did feel that the delineators helped them to predict the roadway ahead. Participants particularly felt that the high-brightness delineators were more helpful and had a more comfortable brightness.

In nighttime conditions, participants tended to drive faster when active delineators were present, more so when the rabbit pattern was used. Participants felt that all delineator configurations helped them to predict the road ahead at night, with the level of agreement being highest for the high-brightness rabbit pattern.

At night the presence of the active delineators seems to make participants more comfortable by increasing their ability to predict the roadway ahead, which then leads them to drive slightly faster. However, the safety implications are not clear. Being able to more clearly see the boundaries of the roadway may reduce the risk of run-off-road crashes, but any associated increase in speed could lead to increased risk and/or severity of crashes between vehicles. This concept is similar to Lynn et al.'s (2002) findings that the fog light system on I-64 reduced the number of crashes but increased the severity of the crashes that did occur.

LIMITATIONS

Speed Variability

Because this study sought to examine how active delineators affected drivers' speed in foggy conditions, the research team tried to minimize other factors that may have also affected drivers' speed. Rather than asking participants to try to maintain a specific speed, and seeing how they deviated from that, participants were simply instructed to drive at whatever speed they felt was comfortable while driving through the fog. The only limitation put on their self-selected speed was to not exceed 55 mph, which the research team felt participants were not likely to do anyway due to the reduced visibility. The research team expected to see a convergence of speeds, but participants' self-selected speeds varied wildly. Figure 20 illustrates the range of speeds at which participants traveled when driving past the low-brightness delineators. At the slowest point, participants' speeds ranged from less than 10 mph to almost 45 mph.

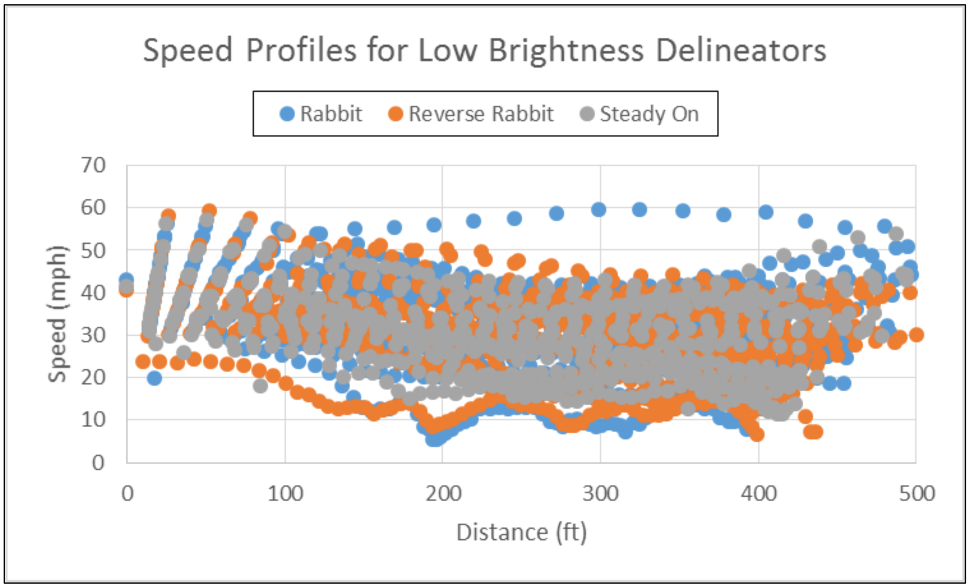


Figure 20. Graph. Speed profiles for low-brightness delineators.

Limited Patterns

This study found no difference among the tested patterns, but it is possible that other patterns could yield different results. In each of the tested patterns, the bulk of the units were active, providing a good sense of the lane boundary line. An alternative might be to have the bulk of the system inactive, with a segment of active units that travels from one end of the system to the other at a speed that matches a safe driving speed. In this condition, it is possible that drivers would match their speed to the active portion of the delineators in order to remain in its active zone. Another option may be to have the entire system "blink." However, further research would be needed to examine how drivers behave in the presence of such patterns.

CHAPTER 5. CONCLUSIONS

Despite the limitations noted above, the research team felt that several conclusions could be made based on the results found in this project. They are listed below, separated for daytime and nighttime conditions.

In foggy daytime conditions:

- Active delineators did not have an effect on speed.
- High-brightness delineators had a more comfortable level of brightness, were more helpful in predicting the roadway ahead, and were easier to see in the fog.

In foggy nighttime conditions:

- Low-brightness delineators resulted in higher mean speeds compared to when no delineators were present.
- The high-brightness rabbit pattern resulted in a higher mean speed than when no delineators were present.
- The pattern of the active delineators had no effect on speed.
- All delineator configurations were successful in helping drivers predict the road ahead, had comfortable brightness, and were easy to see in the fog.

APPLICABILITY TO PRACTICE

Active delineators increased participants' comfort levels in fog by aiding their ability to predict the geometry of the roadway ahead. However, their presence sometimes led participants to increase their travel speeds, which should be avoided. As such, the use of active delineators could be reserved for locations where the geometry of the roadway presents the greatest hazard, such as sharp horizontal curves that may be difficult to see in fog, or areas with steep drop-offs. It is also possible that combining active delineators with speed control devices, such as the variable speed limit signs on I-77 in Fancy Gap, could provide a more holistic system that increases drivers' lane-keeping abilities while also maintaining speeds more appropriate for low-visibility conditions.

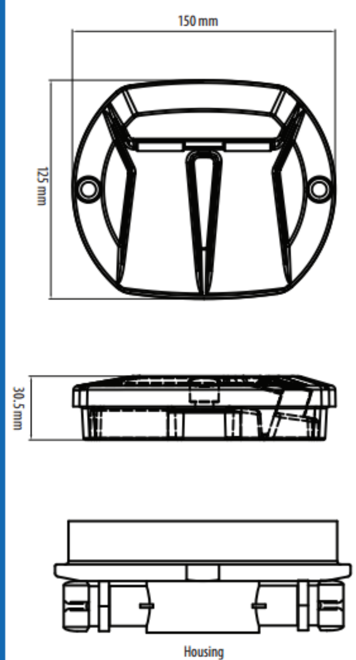
APPENDIX A. LANELIGHT™ UNIT SPECIFICATIONS

SPECIFICATIONS

LaneLight

LaneLight™ MLK150
LED-Illuminated In-Road Marker System UNI DIRECTIONAL

DIMENSIONS



STANDARD SPECIFICATIONS

Technology	Active LED
Dimensions -LED module	150mm x 125mm (5.9"x 5")
Dimensions - Housing	175mm (7")
Protrusion from pavement	3 mm (.12") or Flush Mount option
Housing depth (incl.sub base)	65mm (2.56")
Daytime visible	Yes, to 3000 ft (dimmable by PWM at night)
Snowplowable	Yes, with Flush Mount option
Housing - LED module	Stainless Steel
- Housing	Aluminum
Sealing	IP68
Load rated	5,000 kg compression
Operating temperature	-20C to +50C
Lens	Boron/glass
LED face	Uni-directional
LEDs per unit	16
LED color	Amber, Red, Green, White, or bi-color
Light intensity	Over 3,500,000 cd/m2
Activation	Optional
Power	Hardwired; Low voltage AC, DC models ; 2.5w (nominal)
Controller	Microprocessor; (sold separately)
Wiring	18 AWG direct burial or drain equipped conduit 2 or 3 wire configurations
MUTCD compliant	YES

OPTIONS

LED Colour : Amber, Red, Green, White, or bi-color

Special Voltages

Passive Activtion Systems

Integration with traffic control devices.

Addressable chip for control (chasing, flashing, etc.)

Intelligent Traffic Equipment Marketing Ltd.
16-755 Vanalman Ave.
Victoria, BC, Canada V8Z 3B8
1.866.466.4836 www.ItemLtd.com

ITEM

Source:
http://www.itemltd.com/media/attachments/view/doc/bid_specifications_lanelight_03_2015/pdf

Accessed October 5, 2016.

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