INTERNALLY ILLUMINATED SIGN LIGHTING

Effects on Visibility and Traffic Safety

UNITED STATES SIGN COUNCIL

RESEARCH CONCLUSIONS / PENNSYLVANIA STATE UNIVERSITY

The Effects of Internally Illuminated On-Premise Sign Brightness on Nighttime Sign Visibility and Traffic Safety

A Research Project Of The
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Background and Objectives

A substantial body of research has established that illuminated, on-premise commercial signs play a critical role in providing both wayfinding information and more general situational awareness to motorists at night (see Kuhn et al., 1997). By supplying drivers with important navigational cues at critical decision points where traffic signs and even GPS systems leave off, illuminated on-premise signs clearly play a positive role in traffic safety. This traffic safety contribution is especially relevant after dark, when both visual performance and environmental cues decline and fatal crash rates are three to four times higher than during daytime (Opiela et al., 2003).

For an on-premise sign to be optimally effective, it must be readable from a distance at which a driver can process the sign's content and respond to its information in a safe manner. In the United States Sign Council literature, this is known as viewer reaction distance. Many factors contribute to sign legibility at this distance, with one of the most important being sign brightness (Garvey and Kuhn, 2004). Documented research shows most on-premise sign lighting to be within reasonable bounds (Garvey, 2005); however at night, dimly illuminated on-premise signs can be very difficult or impossible to read at appropriate distances, overloading a driver's perceptual and cognitive resources, leading to erratic driving maneuvers such as inappropriate rates of deceleration and untimely lane changes.

When discussing on-premise sign lighting, it is important to understand that these signs can be illuminated using two very different basic strategies, and that the selection of which strategy to use can have a dramatic impact on their brightness and the uniformity of the light distribution across the sign face. While a sign might be lit in many ways, including with neon tubes, LEDs, and either incandescent or halogen lamps, all on-premise signs fall into one of two major lighting categories: internally illuminated or externally illuminated. These terms were defined by the Illuminating Engineering Society of North America (IESNA, 2001) as follows:

1. Externally Illuminated Signs: signs on which a fixed message is illuminated by an external source of light.
2. Internally Illuminated Signs: signs for which the source of light is enclosed within the sign and the message becomes understandable because of the varying transmittance of the sign face.

On most roadways in commercial, industrial, and office building environments, the method of sign illumination is internal. Previous studies have demonstrated that internally illuminated signs provide significantly longer visibility distances and longer available reading times than externally illuminated signs. In fact, internally illuminated signs have been shown to have 40 percent longer average nighttime recognition distances and 60 percent longer legibility distances than externally illuminated signs and can be comfortably read while traveling 10 mph faster (Garvey et al., 2004). The present research concentrated on internally illuminated signs. The objectives of this research were to: (1) compare the daytime and nighttime visibility of on-premise, internally illuminated signs; (2) evaluate the impact of varying sign brightness level on the nighttime visibility of these signs; and (3) quantify the safety effect of varying sign brightness levels in terms of viewer reaction distance.

Methodology

The general methodology involved a controlled, test-track data collection strategy wherein a representative sample of the driving population read on-premise signs in the daytime and at night. The nighttime tests involved internally illuminated signs that varied in brightness.

Test Site and Apparatus

The test site was the Thomas D. Larson Pennsylvania Transportation Institute's (LTI) Bus Research and Testing Facility. The 5,042-foot-long, oval track is located four miles from LTI's offices. The track is equipped with seven overhead luminaires, which were lit during nighttime testing to better simulate real-world commercial sign viewing conditions. The observation vehicle was a 2004 Dodge Stratus sedan instrumented with a NiteStar distance-measuring instrument (DMI).

Two 4-ft-square sign cabinets were used in the testing. Each sign face was internally illuminated with a bank of fluorescent tubes. These sign cabinets were fabricated to standards used in the on-premise sign industry. For the purposes of this study, seven lighting levels were developed. The middle level (sign brightness level 4) was the standard sign lighting construction and lighting level used in 99 percent of all internally illuminated, on-premise signs installed across the United States. The seven levels are as follows:

1. Brightness Level 1 – 40 percent of Level 4
2. Brightness Level 2 – 55 percent of Level 4
3. Brightness Level 3 – 95 percent of Level 4
4. Brightness Level 4 – Industry Standard
5. Brightness Level 5 – 1.50 times brighter than Level 4

6. Brightness Level 6 – 1.75 times brighter than Level 4
7. Brightness Level 7 – 2.15 times brighter than Level 4

The signs varied in letter and background colors, contrast orientation (positive contrast being lighter letters on a darker background and negative contrast being darker letters on a lighter background), and contrast between letters and background brightness. The sign designs were:

1. Black letters on a white background (100 percent negative contrast)
2. White letters on a black background (100 percent positive contrast)
3. Yellow letters on a green background (approximately 15 percent (i.e., 7:1) positive contrast)
4. Green letters on a yellow background (approximately 15 percent (i.e., 1:7) negative contrast)

The signs were ground mounted on the right shoulder of the test track at two points along a 1,500-ft tangent section that allowed for a minimum of 750 ft of clear sight distance for each sign. The font was Helvetica with an uppercase letter height of 6 inches. Each sign displayed three 6-letter words. The words were displayed in mixed case (Figure 1).

White on Black (positive contrast)

Green on Yellow (negative contrast)

Black on White (negative contrast)

Yellow on Green (positive contrast)

Figure 1. Examples of test signs in daytime and at night.

Daytime Procedure

A total of 60 subjects, representing the driving population in age and gender (USDOT, 2003), participated in both daytime and nighttime testing for a total of 120 one-hour data collection sessions (Table 1).

Table 1. Subject age distribution.

Subject Age Group	Percent of U.S. Driving Population	Number of Subjects Tested
18-29	21.9	13
30-44	29.9	18
45-59	27.6	17
60+	20.6	12

Two measures of effectiveness were used to evaluate the sign conditions:

1. **Recognition Distance:** Given a target word on a sign (e.g., Blythe), the greatest distance from which a participant identified its location on that sign (top, middle, or bottom). This represented a scenario where a motorist knows the name of the business establishment he or she is trying to find and merely has to distinguish that name from different names on other on-premise signs.

2. **Legibility Distance:** Given a target word location on a sign (top, middle, or bottom), the greatest distance at which a participant could accurately read the word on that sign. This represented a scenario where a motorist does not know the exact name of the business establishment he or she is trying to find and has to fully read the content of each on-premise sign encountered.

Subjects were tested individually. The subject was seated in the front passenger seat of the observation vehicle with an experimenter in the driver seat. The vehicle was driven to the 750-ft mark upstream of the sign and parked in the center of a 12-ft-wide travel lane. The experimenter instructed the subject to find the word “Blythe” on the sign (recognition condition). The vehicle was driven toward the sign at approximately 20 miles per hour, and the subject attempted to find the target word and respond by saying “top,” “middle,” or “bottom.” The subjects were instructed to state the target word position only when they were certain. When a subject correctly stated the target word position, the distance measuring instrument was used to record that distance as the *recognition threshold* for that condition.

The experimenter then instructed the subject to read one of the other words on the sign (e.g., “now read the bottom word”). The experimenter continued to drive toward the sign until the subject correctly read the second word, at which point the experimenter recorded the distance as the *legibility threshold* for that condition. The car was then driven toward the second sign. The procedure was repeated until recognition and legibility thresholds for all signs were established.

To avoid learning or fatigue effects, the order of sign presentation was counterbalanced across subjects. The entire procedure was repeated four times using different words on each sign for each repetition. This served the dual purposes of providing more stable data (replication) and avoiding the possibility of confounding the effect of sign design with any potential word superiority effect (counterbalancing).

Nighttime Procedure

The nighttime data collection procedure was identical to the daytime testing, with the exception that legibility and recognition distances for each of the four sign color combinations were tested at seven levels of brightness, one being the dimmest, seven being the brightest and four being an intermediate level that is the generally agreed-upon sign industry standard. The various light levels were obtained by activating a combination of seven Sylvania Daylight 60-watt fluorescent tubes (Figure 2). This resulted in an inevitable non-uniform light distribution on the sign face; however this was only noticeable for the two dimmest conditions. Photometric measurements were taken of each sign color combination under all seven brightness levels.

Photometry

Photometry is the measurement of light as people see it (this discussion draws from Garvey et al., 1995). Photometric equipment is designed and calibrated to match the human eye's sensitivity to color and to daytime-versus-nighttime lighting. The two most important photometric measurements used to describe signs are illuminance and luminance (see Figure 3). These measurements are expressed using various units (Table 2).

Table 2. Photometric units and conversion factors.

Photometric Attribute	Unit of Measurement (SI)	Other Units	Conversion Factor
Illuminance	Lux (lx)	Footcandle	1.076
Luminance	Candela per square meter (cd/m^2)	Nit Footlambert cd/ft^2	1.0 3.426 10.76

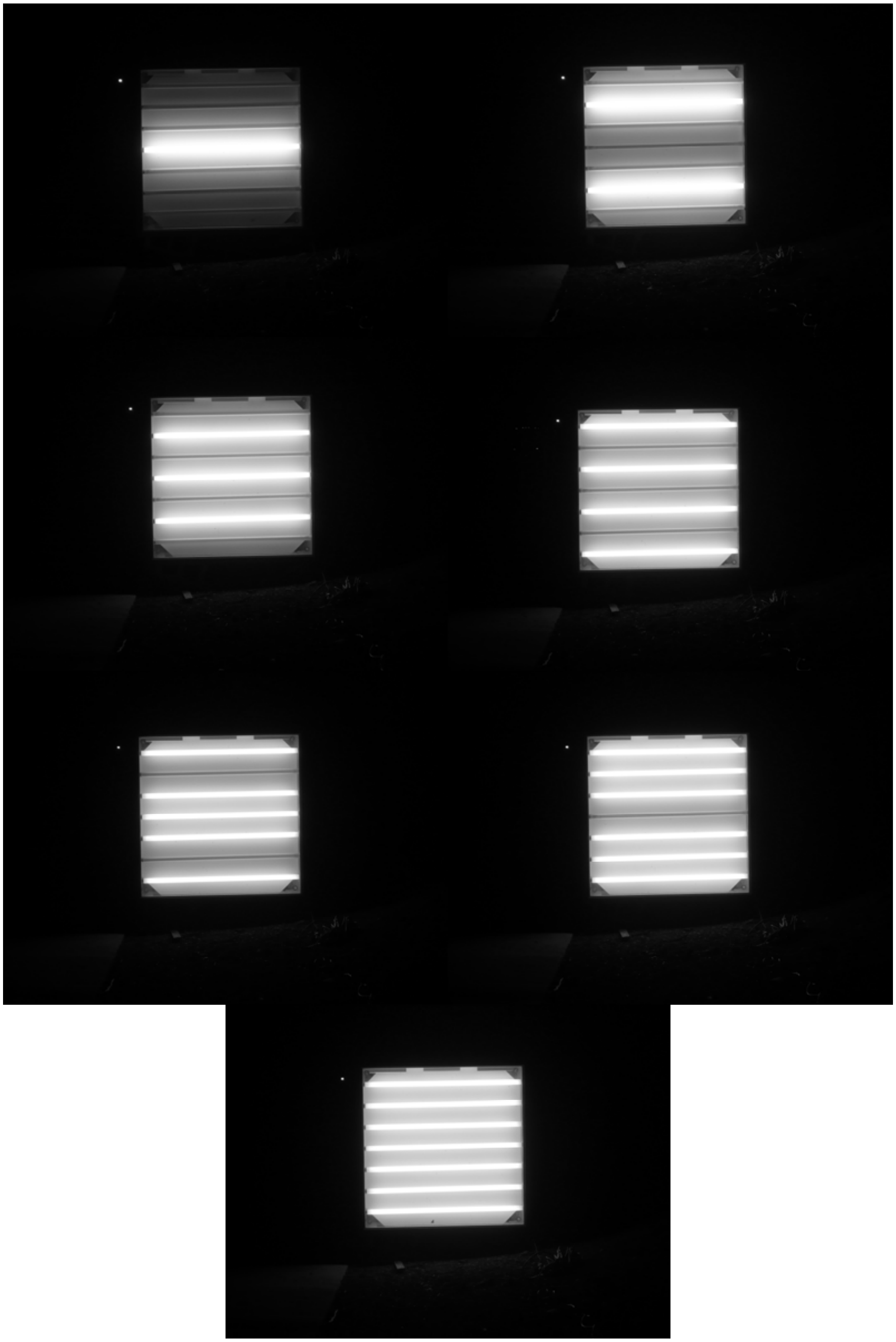

Figure 2. Light bulb activation to achieve the seven sign brightness conditions.

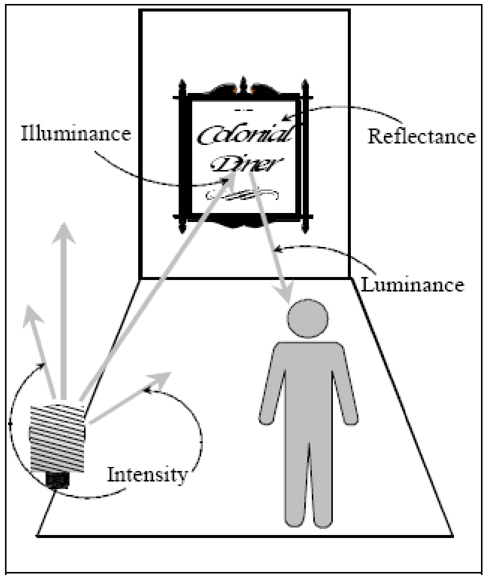

Figure 3. Light measurement relationships.

Illuminance

Illuminance is the amount of light that reaches a surface from a light source. Illuminance is a function of distance and, in fact, decreases by the distance squared. For example, if a sign's illuminance is 18 lux at 3 m, at three times that distance (9 m) it would be producing 2 lux ($18/3^2$). Illuminance is measured with an illuminance meter placed at the distance of interest facing the light source.

Luminance

Luminance is the photometric measure that most closely depicts the psychological experience of "brightness." Luminance can refer to either the light that is emitted by a sign (for internally illuminated signs) or the light that the sign surface reflects (externally illuminated signs). A source's luminance is constant regardless of distance. To measure luminance, a luminance meter is placed at the observer's position, aimed at the sign, and a reading is taken.

Photometrics of the Test Signs

The luminance of each sign at each brightness level was measured with a Minolta LS-110 luminance meter with a 20-min of arc aperture. The measurements were taken toward the top, in the middle, and toward the bottom of each sign face. For the green and yellow signs, luminance measurements were taken of the letters and background. The results can be found in Table 3 with mean luminance graphed in Figure 4.

Table 3. Nighttime sign luminance levels (cd/m^2).

Sign Color	Sign Brightness Level													
	1		2		3		4		5		6		7	
White on Black	210		330		600		600		900		1200		1200	
	420		225		590		690		1100		1100		1500	
	200		300		530		550		800		1100		1300	
Black on White	150		460		730		700		1000		1350		1600	
	460		340		715		760		1225		1180		1650	
	160		500		620		660		880		1240		1440	
	G	Y	G	Y	G	Y	G	Y	G	Y	G	Y	G	Y
Green on Yellow	34	140	60	315	80	450	80	480	140	670	150	880	170	1000
	45	290	32	215	80	500	80	520	125	850	120	800	170	1100
	23	115	55	325	80	450	80	480	110	640	130	850	150	990
Yellow on Green	18	130	37	250	60	375	60	440	88	580	110	730	130	850
	35	250	23	165	65	410	56	430	105	680	93	620	130	875
	16	80	33	250	55	350	47	400	78	490	97	680	120	780

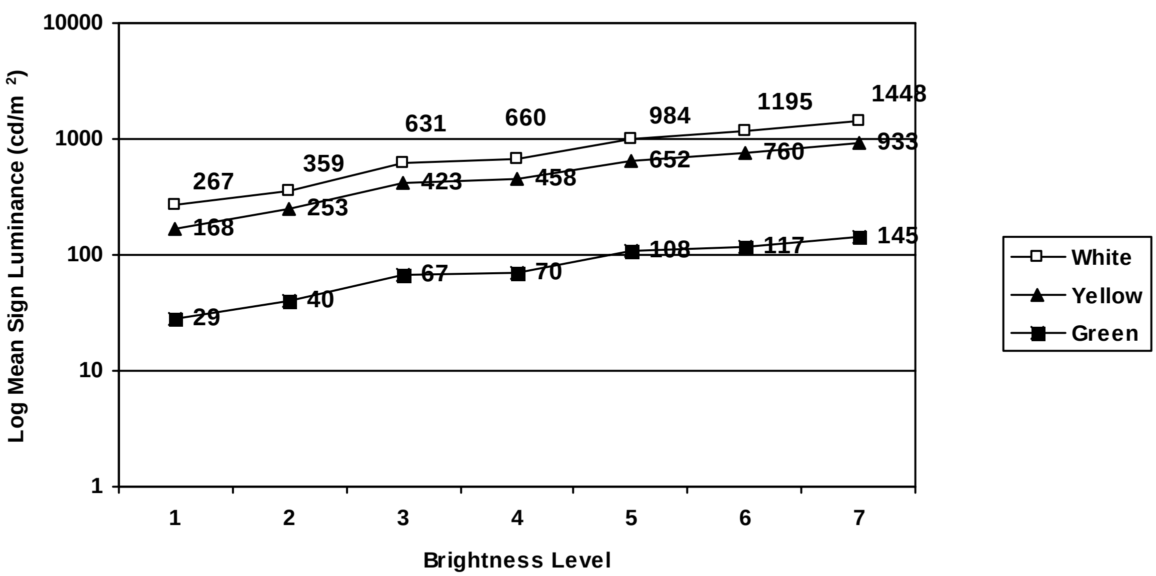

Figure 4. Log mean luminance (cd/m^2) for the seven brightness levels and three colors.

Analysis

To determine if any of the four independent variables (time of day, color, contrast orientation, and brightness) had a statistically significant effect on legibility or recognition distances, a multivariate analysis of variance (MANOVA) was conducted using the statistical package MINITAB. Conducting a single MANOVA is a more powerful analysis than running separate

ANOVAs for each of the two dependent variables (i.e., one for legibility and one for recognition) when the dependent variables are correlated. An initial scatter plot of the data indicated that the two dependent variables were in fact correlated.

The MANOVA analysis used in this study involved a nested model. A nested factor is a factor that is included in another factor. For this study, sign brightness level was nested within time of day because it was only tested at night, and color was nested within contrast orientation because any given color sign can only be either positive or negative contrast.

If the MANOVA showed significant main effects of any of the variables, a post-hoc (or follow-up) ANOVA was conducted to determine whether that effect was on legibility, recognition, or both. As time of day and contrast orientation had only two levels (i.e., day/night and positive/negative), any significant effect shown in the ANOVA would mean that the level with the higher average legibility or recognition distance was better. For color and brightness, which have four and seven levels, respectively, a final analysis (*Hsu's test for best* - a statistical test used to determine which of several means is the best) was required to determine which of the levels of the variables resulted in the greatest visibility distances.

Results

The overall MANOVA showed significant main effects for all four independent variables (time of day, color, contrast orientation, and brightness), meaning that all of the variables significantly influenced either legibility distance, recognition distance, or both. Separate ANOVAs were therefore conducted to see which dependent variable was affected. The ANOVA on legibility distance showed significant main effects for time of day, color, contrast orientation, and brightness. The ANOVA on recognition distance showed significant main effects for time of day, color, and brightness, but not contrast orientation.

Time of Day

Sign visibility research invariably shows that signs are less legible under dark conditions than they are in daylight, even when they are illuminated. One of the goals of the current research was to see if, by optimizing internally illuminated commercial sign brightness, nighttime sign legibility and recognition distances could be brought up to daytime levels. The MANOVA showed a significant time-of-day effect ($F=183.1$, $p<.05$) with daylight conditions producing greater visibility distances than nighttime (Table 4). The follow-up ANOVAs showed that this was true for both legibility and recognition ($F=219.62$, $p<.05$ and $F=360.16$, $p<.05$, respectively).

Table 4. Mean legibility and recognition distances (ft) as a function of time of day.

Time of Day	Measure of Effectiveness	
	Legibility	Recognition
	209.21	461.52
Nighttime	167.01	364.58

These analyses compared daytime visibility with the combined average of all the nighttime sign brightness levels. However, even when daytime is compared to the best nighttime lighting levels the same trend is revealed, although the absolute loss at night is less (Table 5).

Table 5. Mean legibility and recognition distances in feet as a function of time of day (numbers in parentheses indicate reduction compared to daytime).

Time of Day	Measure of Effectiveness	
	Legibility	Recognition
Daytime	209.21	461.52
Best Nighttime Lighting Level	184.54 (-13%)	385.80 (-20%)
Worst Nighttime Lighting Level	146.52 (-43%)	332.20 (-40%)

Contrast Orientation

The MANOVA showed a statistically significant effect of contrast orientation (F=99.8; p<.05). As stated above, the follow-up ANOVA showed that that effect was coming from the legibility dependent variable (F=100.37; p<.05), with contrast orientation having no effect on recognition distance (F=0.14; p=0.71). Mean legibility distance for the negative-contrast signs was 196 ft versus 169 ft for the positive-contrast signs.

Color

The MANOVA showed a statistically significant effect for color (F=35.37; p<.05). The follow-up ANOVAs showed that this variable produced significant differences in both legibility and recognition (F=61.85; p<.05 and F=14.78; p<.05, respectively). Because there were four levels of this variable (i.e., four color combinations), a post-hoc evaluation was conducted to determine which colors were, statistically, significantly better than the others (Figure 5). The analysis revealed that the signs with black letters on a white background performed significantly better than any of the other combinations for both legibility and recognition.

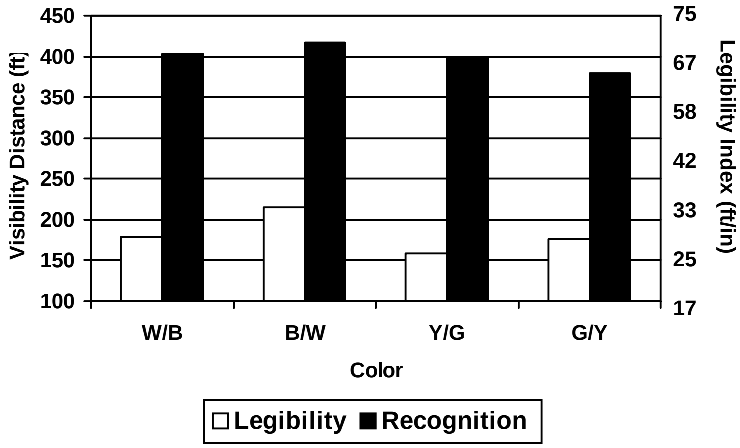

Figure 5. Mean legibility and recognition distance for the four color combinations.

Sign Brightness

The MANOVA showed a statistically significant effect for sign brightness (F=6.31; p<.05). The follow-up ANOVA showed that this effect was significant for both legibility and recognition distances. Hsu's test was used to determine which of the brightness levels were statistically superior to the others. In the legibility evaluation, performance peaked at level four ("industry standard"), with performance dropping off at lower and higher brightness levels (Figure 6).

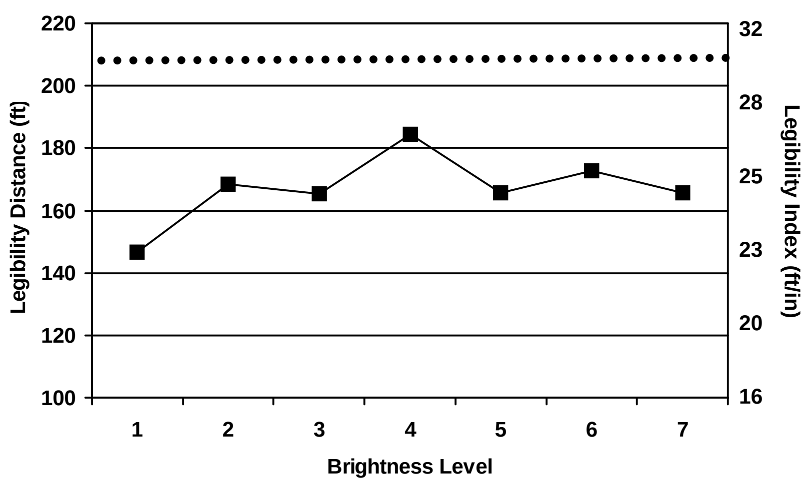

Figure 6. Mean legibility distance as a function of sign brightness
(dotted line indicates mean daytime recognition distance).

In the recognition evaluation, performance continued to increase until it reached a peak at level six and then dropped off again when the sign was illuminated at the highest level (Figure 7).

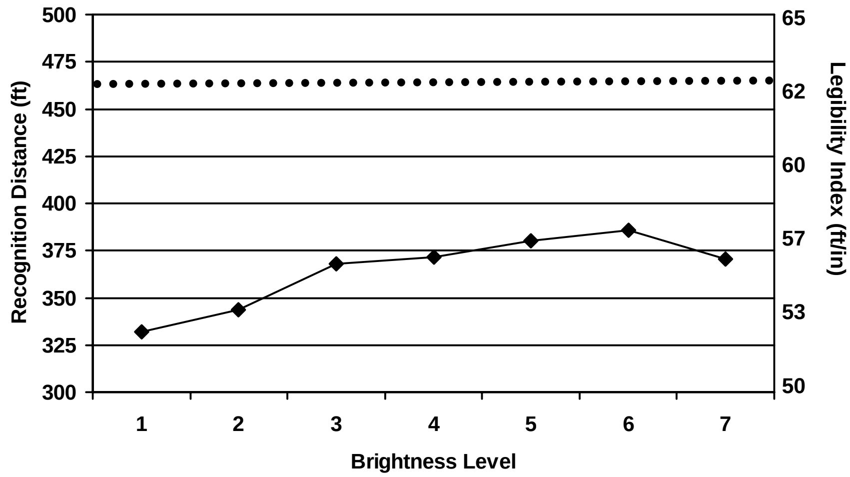

Figure 7. Mean recognition distance as a function of sign brightness (dotted line indicates mean daytime recognition distance).

Conclusions

The main objectives of this research were to test the effect that varying lighting levels has on internally illuminated, on-premise sign recognition and legibility at night and to evaluate the relative day and night visibility of these signs. Overall, the findings were consistent with previous research in that the subjects in this study were better at reading signs in the daytime than they were at night. However, the quality of sign lighting had a large impact on how much closer the subjects had to be to read the signs at night. Daytime signs were 43 percent more legible and 40 percent more recognizable than the most poorly lit nighttime signs. However, compared to the best nighttime lighting, daytime signs were only 13 percent more legible and 20 percent more recognizable.

These performance differences are significant because drivers who have more time to read signs are less likely to exhibit erratic driving maneuvers such as inappropriate rates of deceleration and untimely lane changes. This study demonstrated that maintaining the brightness of internally illuminated, on-premise signs at optimum levels could improve driver safety and comfort by giving drivers more time to read the signs. This is not to say that internally illuminated, on-premise signs should be as bright as possible, as this study also demonstrated that there is a peak in both sign legibility and recognition distance as a function of sign brightness, such that performance falls off as these signs becomes overly bright. As shown in Figures 6 and 7, the sign brightness levels that performed best for recognition and legibility combined were levels 4 through 6, which correspond closely to the current agreed-upon industry standard.

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