Illuminated Sign Conspicuity
What Factors Make a Sign Noticeable and Legible?

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SIGN RESEARCH FOUNDATION™

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INTRODUCTION

The present document summarizes activities undertaken by the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute for the project "Illuminated Sign Conspicuity: What Factors Make a Sign Noticeable and Legible" conducted for the Sign Research Foundation.

The initial portion of the report contains a summary of published research studies, technical reports and codes and standards related to the visual effectiveness (i.e., conspicuity and legibility) of signage. Subsequent sections describe two experimental pilot studies conducted to provide preliminary information in areas identified as knowledge gaps in the initial review. An additional section of the report describes techniques for using an illuminance meter to estimate the luminance of a large-format, self-illuminated sign. Finally, several preliminary guidelines based on the project findings are included for maximizing the conspicuity and legibility of illuminated signs.

KNOWLEDGE REVIEW

In the summary that follows, publications are grouped and discussed according to several different topics. First, the typographic and symbolic characteristics of signs and the information they carry are described (e.g., letter size, font selection, etc.); second, photometric, colorimetric and temporal properties of signs as they affect visual effectiveness; finally, environmental considerations (e.g., daytime versus nighttime viewing, whether a sign is located in a rural or urban area, etc.) as they influence sign design are reviewed.

Annotated summaries of each publication in the knowledge survey are included at the end of this report.

TYPOGRAPHIC AND SYMBOLIC CHARACTERISTICS

CONSPICUITY

Perhaps because signs, by their nature, are supposed to attract attention of drivers and pedestrians, conspicuity (the ability to detect the sign) is less studied than legibility (the ability to read and process the information on the sign). Nonetheless, a few typographic and symbolic factors have been demonstrated to affect conspicuity of signs.

One of the most obvious may be the size of the sign itself. The U.S. Small Business Association (U.S. SBA, 2003) provides guidelines for the size of signs based on the speed of approaching traffic; for example, larger signs are recommended for posted speeds of 55 mph than for 25 mph. Bertucci (2003) describes a calculation method for determine the necessary size of a sign based not only on a vehicle's traveling speed but also on the type of reaction needed (e.g., whether a driver will need to make a driving maneuver based on the content of the sign).

Forbes (1972) devised a model for estimating the distance at which a sign can be detected, and one of the factors incorporated into the model is the contrast between the letters on the sign and the rest of the sign itself. Higher contrast is predicted to ease detection of the sign at a greater distance, making it more conspicuous.

Finally, adding a border around the sign itself will often enhance the conspicuity of the sign. Possibly because the exact contrast between a sign and its background cannot always be known, when a sign is outlined by a border it may be easier to pick out as a (usually) rectangular object among other visual stimuli along the road, and FHWA (2004) requires this for almost all highway signs. Gates et al. (2004) found that a red reflectorized border around highway speed limit signs increased conformity with the sign's posted speed limit, suggesting that the border may have helped make the sign more difficult to ignore.

LEGIBILITY

Many more studies of the legibility of signs and factors that influence the reader's ability to process the information on the sign have been conducted. Reading and understanding a sign and being able to respond to it (by executing a turning maneuver, for example) takes time, during which the sign must be legible. That time is estimated by Kuhn et al. (1997) to be about 5.5 seconds; the Town of Bermuda Run (2013) uses a processing time of 8 s in its design guidelines for signs. Related to processing time, the amount of information that should be included on a sign has been addressed in research as well as municipal standards. While Hawkins and Rose (2005) found that there are few negative consequences of combining dual logos into a single logo space on blue service signs used along highway exits, there are cautions against packing too much information on a sign (City of Davis, 2010). The City of Saratoga Springs (2012) suggests a maximum of 8 words per sign.

The amount of information on a sign can also be related to the size of the sign itself. Several municipal codes limit the percentage of a sign's area that can be covered by letters or symbols on the basis that an overly crowded sign will be less legible. The maximum amount of a sign's area that it permitted to contain characters ranges from 40% (Town of Huntersville, 2009) up to 75% (City of West Hollywood, 2002; City of Davis, 2010; City of Bellflower, 2016).

Evidence suggests that legibility can also be improved by using graphical symbols rather than alphanumeric characters (Kuhn et al., 1997) and this is also reflected in municipal code language (City of West Hollywood, 2002). It may be worth noting, however, that the use of symbols can lead to longer and more frequent visual fixations by drivers, which is not always a desirable response (Pankok et al., 2015). Additionally, text has a natural visual scan pattern (e.g., left to right, from top to bottom) whereas the presence of symbols may result in less consistent and less efficient visual scanning (Pankok et al., 2015). When symbols are used, they should be simple (Duncanson, 1994), since not all symbols are equally legible (Schnell et al., 2004). Nonetheless, in addition to aiding in legibility, symbols can reinforce desired behaviors in drivers (e.g., yielded to pedestrians in crosswalks) when they accompany other types of visual information (Van Houten et al., 1998) and are powerful elements of communication.

For signs using alphanumeric characters, the impacts of typeface or font on legibility have been investigated by many researchers. Appropriate font use can result in smaller footprints of the text on a sign while simultaneously improving legibility (Garvey et al., 2004). On highway signs, an alternative font, Clearview, was found in several studies (Garvey et al., 1997, 2016; Hawkins et al., 1999) to result in greater legibility distances. Studies using other fonts led to several empirical conclusions: Bank Gothic Light, Dutch Regular and Dutch Bold fonts were found to result in superior acuity than Commercial Script Regular (Garvey et al., 2001); the latter is a script font similar to cursive handwriting. The Futura font was found to be as legible as standard highway fonts for wayfinding signs in another study (Garvey, 2007). Municipalities tend to discourage the use of script-type fonts that emulate handwriting because of their reduced legibility (Town of Bermuda Run, 2013; City of Bellflower, 2016).

One of the distinguishing features among different fonts is the presence or not of serifs, and a few studies have evaluated the extent to which serifs impact legibility. The bulk of the evidence (Carter et al., 1985; Kuhn et al., 1998) suggests that there are no legibility differences between serif and non-serif fonts. In contrast, Tinker (1966) summarizes research stating that serifs aid in legibility. Arditi and Cho (2005) found no differences at suprathreshold visibility levels, but near the acuity limit, found fonts with serifs to be beneficial. Only one example in which non-serif fonts outperformed serif fonts was identified (Yager et al., 1998), but this effect only occurred at low light levels; at higher light levels, serifs made no difference on legibility.

Fonts can also differ in their geometric characteristics (e.g., aspect ratio, stroke width, etc.). The width of the individual characters seems to have a large impact on legibility, larger than stroke width or the spacing between characters (Young et al., 1992; Garvey et al., 2001). Further, character width seems to influence the relationships between factors like the spacing between characters and legibility; reducing space between characters may be beneficial for wider characters, but detrimental for narrow ones (Young et al., 1992). Some guidelines suggest that when a character's width and height are the same, its legibility is maximized (CIDEA, 2010). While it may be a less important factor than character width, stroke width has received much interest in the research literature leading to guidelines for optimal stroke width (Forbes et al., 1965; Tinker, 1966; Kuhn et al., 1997; Holick and Carlson, 2002). One recommendation is that stroke width be 18% of the character height (Tinker, 1966), but even this factor interacts with others like the contrast polarity of the text (Kuhn et al., 1997). A font factor that impacts legibility for "dotted" fonts like those used in exposed-lamp or matrix signs is the spacing between lamps or matrix elements; Rea (2000) provides guidelines on spacing between elements for ensuring legibility.

Obviously, the size of text influences legibility (Rea and Ouellette, 1991). Unsurprisingly, many studies (Duncanson, 1994; Bernard et al., 2001; Ullman et al., 2005; Bullough and Skinner, 2016) suggest that larger letter sizes result in improved legibility, but the range of conditions used in those studies are important for generalization of these findings, since some authors report that there is a range of letter sizes above which legibility can degrade (Carter et al., 1985). A wealth of guidelines derived from research (Bertucci, 2006; CIDEA, 2010; Bertucci and Crawford, 2015) and employed in municipal and other standards on font size exist, most specifying minimum letter size (City of West Hollywood, 2002; U.S. SBA, 2003; FHWA, 2004; ISA, 2007; Town of Huntersville, 2009; Millar, 2011), but sometimes recommending a range of appropriate sizes (Carter et al., 1985; Town of Bermuda Run, 2013). Most of the time, the letter height is used to quantify the letter size, but as found by Rea and Ouellette (1991) and Cai and Green (2009), the projected area of the character is a more complete specification of the size of the stimulus for letters and symbols on signs.

Other properties of sign characters aside from font and size influence legibility. The contrast of letters against the sign itself is one of the most critical (Rea and Ouellette, 1991; Schnell et al., 2004). Similar to research on letter size, higher contrast is generally thought to improve legibility (Shurtleff et al., 1966) and this is included in municipal standards (City of West Hollywood, 2002; Town of Huntersville, 2009; City of Davis, 2010) but some sources report an optimal contrast value, perhaps to avoid excessive brightness of characters or of the sign (see "Photometric, Colorimetric and Temporal Characteristics"). For example, Kuhn et al. (1997) report that the contrast between a sign and its characters best supports legibility when the luminance ratio between the brighter and the less bright of the two is 12:1. Importantly, it should be recalled that luminance contrast differs from color contrast; green letters on a red sign might have no luminance contrast but could still be visible because of the difference in colors. However, luminance contrast is substantially more important to legibility than color contrast (Forbes et al., 1965; Tinker, 1966), which only significantly affects legibility when the luminance contrast is low (Eastman, 1968), a situation that should be avoided in signs.

The polarity of contrast can also impact the degree of legibility a sign exhibits. A majority of the research evidence reviewed (Tinker, 1966; Kuhn et al., 1997, 1998; CIDEA, 2010) is consistent of the notion that positive contrast (letters with higher luminances than the sign face) offers better legibility than negative contrast text. Because of this municipal guidance seems to favor positive contrast text (Town of Bermuda Run, 2013). Nonetheless, there are several reports that report no difference in legibility between positive and negative contrast text (Shurtleff et al., 1966; Lerner and Collins, 1983).

Contrast can also be a factor within individual characters on a sign, particularly for illuminated signs. Freyssinier et al. (2003) conducted evaluations of sign letters and found that they began to be judged as unacceptable when the luminance contrast within different portions of the letters exceeded 0.2-0.4. Intentional contrast variations within letters occur when letters and other characters are rendered in an outline form rather than as a solid character. All of the research that has investigated the relative impact of outline versus solid sign letters has found outline characters to provide less legibility than solid ones (Lerner and Collins, 1983; Duncanson, 1994; Arditi et al., 1997).

Finally, many investigations have been conducted regarding the use of all-uppercase versus mixed-case text on signs. In principal, because uppercase letters are larger than lowercase, the legibility of individual uppercase letters ought to be better than that of lowercase letters, and one investigation using single short, isolated words on an otherwise empty display screen did find slight advantages to displaying those words in all-uppercase text (Kinney and Showman, 1967). Nonetheless, most researchers who have investigated this question concluded that mixed-case text improves legibility (Carter et al., 1985; Kuhn et al., 1997; Bertucci and Crawford, 2015), because it better differentiates among word-forms that would otherwise be similar using all-uppercase text. Accordingly, municipal guidance (Town of Bermuda Run, 2013) recommends mixed-case text on signs.

PHOTOMETRIC, COLORIMETRIC AND TEMPORAL CHARACTERISTICS

CONSPICUITY

Among the photometric properties of signs most related to conspicuity is the sign luminance (Elstad et al., 1962; Allen et al., 1967; Rea, 2000; AASHTO, 2005). In addition to ensuring that a sign is conspicuous, there are also concerns about ensuring that the luminance of a sign does not lead to distraction (ILE, 2001; Bullough and Skinner, 2011), especially among municipalities (City of Hutto, 2014; City of Mesa, undated). Table 1 summarizes research findings and recommendations from codes and standards regarding the range of luminances recommended for sign conspicuity while aiming to prevent distraction from overly bright signs.

Forbes (1972) developed a calculation method for estimating the detection distance, which uses the luminance of the sign (in contrast with the luminance of the ambient environment) as one of the factors crucial for detection. Not surprisingly, higher sign luminances tend to make signs easier to detect at night (Forbes et al., 1967) but not always in the daytime, where both dark signs and bright signs may be advantageous for conspicuity over intermediate sign brightness (Forbes et al., 1967), presumably because it is the contrast between a sign and its ambient environment that assists in detection (Kuhn et al., 1997). The impact of sign luminance on conspicuity interacts with factors such as the visual complexity of the ambient environment (Schieber and Goodspeed, 1997) where improvements with higher luminance are only seen in the more complex visual environments, and this would explain why illumination levels recommended for signs are higher in brighter ambient environments (Rea, 2000). Increases in sign luminance have not always been accompanied by a higher proportion of

appropriate driving maneuvers in response to the signs (Powers, 1965). It should also be noted that the color of a sign may impact its conspicuity; Gates et al. (2004) found advantages of fluorescent colors on highway signs in terms of the driving maneuvers that were exhibited when they were present, potentially indicating that those colors assisted in detecting the signs.

Source	Minimum Luminance (cd/m²)	Maximum Luminance (cd/m²)	Relevant Conditions
Allen et al. (1962)	35	100	Night, rural
	70	340	Night, illuminated highway
	700	1700	Night, very bright urban
AASHTO (2005)	20	40	Night, low ambient brightness
	45	90	Night, medium ambient brightness
	90	180	Night, high ambient brightness
Bullough and Skinner (2011)		280	Night
		23,000	Day
City of Hutto (2014)		500	Night
		7000	Day
City of Mesa (undated)		1125 red 2250 green 1675 amber 2500 full color	Night
		3150 red 6300 green 4690 amber 7000 full color	Day
Elstad et al. (1962)	35	70	Night, rural or suburban
	250	400	Night, bright urban
ILE (2001)		300	Night, large sign, low ambient brightness
		600	Night, large sign, medium/high ambient brightness
		100	Night, small sign, intrinsically dark area
		600	Night, small sign, low ambient brightness
		800	Night, small sign, medium ambient brightness
		1000	Night, small sign, high ambient brightness
Rea (2000)	70	350	Night, lighted fascia
	250	500	Night, bright fascia
	450	700	Night, low ambient brightness
	1000	1400	Night, average commercial area
	1400	1700	Night, emergency traffic control

Table 1. Sign luminance recommendations for conspicuity and minimizing distraction.

An approach for limiting the apparent brightness of a digital billboard sign was proposed by Lewin (2008). The illuminance from the sign at a particular distance from the sign along the road should not exceed 3 lx. This approach can allow the user to approximate the average luminance of a sign whose dimensions are known, but it cannot identify whether the luminance of the brightest portion of the sign might be judged excessive by observers. This is important because ratings of the discomfort glare from large-area sources depend not only on the illuminance from the source but the maximum luminance of that source. Two sources with the same average luminance can differ substantially in the amount of discomfort glare they produce (Bullough and Sweater Hickcox, 2012).

An additional factor that can influence a sign's conspicuity is the presence of flashing, moving or animated content on the sign. Temporal changes in luminance or color will make a sign more conspicuous (Crawford, 1962; Forbes et al., 1965) and will attract more glances from drivers than static sign content (Beijer et al., 2004). Despite little hard evidence that dynamic sign content reduces driving safety in terms of crashes (Smiley et al., 2005), many municipal codes prohibit flashing or moving sign content (City of Melbourne, 2009; City of Davis, 2010; City of Hutto, 2014; City of Mesa, undated) to avoid distraction from overly conspicuous signs.

LEGIBILITY

Sign luminance can have important effects on legibility. Recommendations for sign luminances to ensure legibility are shown in Table 2. Luminances need to be high enough to ensure adequate readability, but if luminances are too high legibility can be reduced (Garvey et al., 2009) by factors such as irradiation (Cornog and Rose, 1967). Increasing luminance can sometimes help counteract reduced visibility caused by factors such as small letter size (Tinker, 1966), but if legibility is already high, increasing luminance may have little effect on further legibility improvements (Bullough and Skinner, 2016). Several studies have investigated the interactions between luminance and other factors such as typographic and observer characteristics (Yager et al., 1998; Holick and Carlson, 2002; Schnell et al., 2004, 2009). The uniformity of sign luminance can also influence legibility, and recommendations for uniformity as well as its absolute value can be found (AASHTO, 2005).

Source	Minimum Luminance (cd/m²)	Optimal Luminance (cd/m²)	Relevant Conditions
Allen (1958)		35	Night, rural
Charness et al. (1999)		100	For reading
Fletcher et al. (2009)		20	Dark conditions, character luminance, positive contrast
		60	Bright conditions, character luminance, positive contrast
		1	Positive contrast
Freyssinier et al. (2006)		40-190	No adjacent signs present
		65-230	Adjacent signs present
Graham et al. (1997)		30	Night, younger observer from 90 m
		2	Night, younger observer from 60 m
		40	Night, older observer from 90 m
		7	Night, older observer from 60 m
Kuhn et al. (1997)	2.4	75	Night
Shurtleff et al. (1966)		70-140	For reading

Table 2. Minimum and optimal sign luminance recommendations for legibility.

In addition to luminance, the impacts of sign color(s) on legibility have also been addressed, albeit in a more limited manner than luminance. Funkhouser et al. (1999) compared green and purple signs during daytime and nighttime driving tests and found drivers responded to them equivalently. Flashing or animated content, while increasing conspicuity (see above) will also tend to make text more difficult to read (Milburn and Mertens, 1997).

The type of lighting used on illuminated signage will strongly influence the ease with which the sign can be read. Kuhn et al. (1998) and Garvey and Kuhn (2011) report that internally-illuminated and neon signs provide superior legibility to externally-illuminated signs. This is also reflected in municipal standards that indicate a preference for internal or back-lighting over external illumination (City of Bellflower, 2016). However, some municipalities also discourage the use of neon signage (City of West Hollywood, 2002; City of Davis, 2010).

Possible reasons for reduced legibility with external illumination systems include the potential for glare, which is why many standards require external light sources to be shielded from view (City of West Hollywood, 2002; AASHTO, 2005; City of Davis, 2010). External lighting might also serve as a distraction from the message content on a sign, so it should be designed to be as inconspicuous as possible (City of Saratoga Springs, 2012). Because of such difficulties with external lighting, as well as challenges with maintenance and costs like energy use, highway signs often use retroreflective sign sheeting materials in lieu of lighting to support nighttime legibility (Bullough et al., 2010).

ENVIRONMENTAL CHARACTERISTICS

CONSPICUITY

Not all factors that alter the visual effectiveness of signs are under the direct control of sign designers. The environment in which a sign is located can strongly affect its visibility. In terms of sign conspicuity, one factor that will impact the conspicuity of a sign is the ambient brightness level, which can lead to different recommendations for sign luminance (Elstad et al., 1962; Rea, 2000; ILE, 2001; AASHTO, 2005; Fletcher et al., 2009) or the illuminance on signs (Rea, 2000), as illustrated by many of the findings listed in Table 1. Indeed, the contrast between a sign and its ambient background is an important predictor of how far away the sign can be detected (Forbes, 1972; Kuhn et al., 1997), such that the darkest and brightest signs may be most conspicuous against daytime background conditions (Forbes et al., 1967) but signs similar in luminance to the background will be less conspicuous.

The degree of visual complexity where a sign is located will also impact how easily it can be detected. For example, under visually simple conditions, sign detection distances were reported by Akagi et al. (1996) to be nearly twice their value under visually complex conditions.

LEGIBILITY

The ambient environmental conditions play an important role in the legibility of signs. One of the more obvious factors may be daytime versus nighttime. Even though many signs at night are equipped with some type of illumination (e.g., internal, back-lighting or external), legibility distances under daytime conditions will tend to be substantially longer than under nighttime conditions (Zwahlen and Schnell, 1998; Ullman et al., 2005; Garvey et al., 2009).

The visual complexity of the ambient environment not only impacts a sign's conspicuity, but also its legibility. Bertucci and Crawford (2015) reported that it is necessary to reduce the legibility index (the distance at which a sign of a given size can be read) under medium- and high-complexity visual environments, relative to low-complexity environments. In addition, Freyssinier et al. (2006) found that the luminances needed to achieve high levels of sign readability increased when a sign was adjacent to other nearby signs, compared to when the sign was visually isolated from other signs.

The viewing geometry and location of a sign will also influence the degree to which it can be easily read. An important factor related to signage is the viewing angle. Highway signs, for instance, are generally mounted such that the sign face is perpendicular to the lines of sight for oncoming traffic, while some building-mounted signs are mounted with the sign face nearly parallel to the line of sight. This has the effect of reducing the projected solid angle of letters in the direction of a driver trying to read the sign (Cai and Green, 2009) even if the letter height is unchanged, and will accordingly reduce its legibility. Garvey (2006) reports that legibility begins to be compromised when the viewing angle exceeds 20o-40o from the perpendicular.

Finally, the specific location of the sign can also make it more or less legible, perhaps because of driver expectations about where signs are likely to be located. Since many signs are located along the right-hand side of the road (in locations with right-side traffic patterns), drivers may be less attentive to signs on the left-hand side of the road, and it has been estimated (U.S. SBA, 2003) that signs mounted on the left require letters to be larger to achieve equivalent legibility as signs on the right side of the road.

SUMMARY OF KNOWLEDGE REVIEW

This knowledge survey has identified several sources of technical research, industry rules of thumb and best practices, and consensus-based standards and codes, which describe how sign properties can affect visibility in terms of conspicuity and legibility. From this review, it seems feasible that visual performance modeling can be used to predict the visual effectiveness of signs. However, current models may be incomplete regarding the influence of factors beyond luminance, size and contrast of signs and sign characters.

For example, highway sign characters subtending similar solid angles, and with similar photometric characteristics, will not yield similar legibility distances (see discussion of Garvey et al., 2016). A fruitful area of exploration may be in developing quantitative adjustment factors relating the aspect ratio of sign characters to visual performance when size, luminance and contrast are held constant.

Another factor that has not been considered in much of the reports reviewed here is the role of a sign's maximum luminance or luminance distribution on the noticeability of the sign or its potential to create distraction or glare. To the extent this factor may be important for consideration, techniques and measurements for measuring using both illuminance and luminance measurement equipment have been considered as part of this project.

The following section of this report describes two laboratory studies conducted to provide further information about these two areas. Subsequently, simple guidelines are provided to assist users with measuring the photometric characteristics of illuminated signs in the field.

HUMAN FACTORS LABORATORY INVESTIGATIONS

The experimental studies described in this section were not designed to provide comprehensive information about the gaps identified in the knowledge review; rather, they were conducted to identify whether empirical research in these areas could be fruitful. The first investigation used the luminance contrast and character aspect ratio of text to help in understanding the relative influence of these factors on sign legibility. The second investigation evaluated whether sign elements producing the same illuminance at an observer's eyes would elicit similar levels of discomfort and perceived conspicuity to the observer.

SIGN CHARACTER LEGIBILITY

Ten participants aged 21 to 47 years (mean 37) viewed a random five-digit number for two seconds in the center of a computer display screen, followed by presentation of four random five-digit numbers at the top, bottom, left and right sides of the display (one of which was the number they had initially seen, in one of the four locations). They were asked to indicate, as quickly as possible, the location of the number that was first shown in the center. The ratio between the height and width of the characters during each trial was either 0.26, 0.46, 0.78, 1.26 or 5.25 (see Figure 1). All of the characters subtended the same solid angle.

The luminance contrast (C) of the characters during each trial was either 0.9 or 0.13 (see Figure 2), defined by:

$$C = |Lb - Lc|/Lb$$

where Lb is the luminance of the background (always 100 cd/m2) and Lc is the luminance of the characters (target; 10 cd/m2 for high contrast and 87 cd/m2 for low contrast).

Figure 1. Character aspect ratios investigated in the legibility study. From top to bottom, aspect ratios (height/width) are 5.25, 1.26, 0.78, 0.46 and 0.26.

Figure 2. Illustration of luminance contrast values used in the legibility study. The contrast (C) at left is 0.9; the contrast at right is 0.13. (Exact contrasts might not match what was displayed during the actual experiment.)

Each subject made 100 identification trials. Accuracy of identification was always at least 96%. The identification times (Figure 3) were statistically significantly impacted by both contrast ($F_{1,9}=106.06$, $p<0.001$) and the aspect ratio ($F_{4,36}=3.99$, $p<0.01$), based on a within-subjects analysis of variance (ANOVA), and there was no statistically significant interaction ($F_{4,36}=0.38$, $p>0.05$) between contrast and aspect ratio.

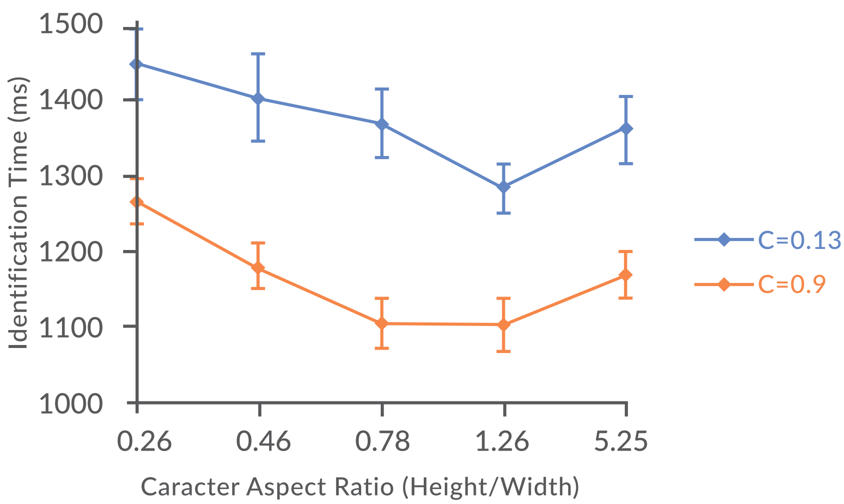

Figure 3. Mean identification times (±standard error of the mean) for the five-digit numbers as a function of contrast and character aspect ratio.

Visual performance models that use the solid angular size of the object to be seen as the characterization of size, such as the Relative Visual Performance (RVP) model (Rea and Ouellette, 1991), would predict all aspect ratios to have the same size, but the results in Figure 3 suggest that very narrow or wide characters are not identified as quickly as those with aspect ratios closer to one. Of interest however, the RVP model predicts (for a 37-year-old observer, the mean age of the subjects in this experiment) a visual response time for the low-contrast characters that is 18% longer than for the high-contrast characters. The average increase in identification times for the low-contrast characters in the present study over the high-contrast characters was also 18%. This correspondence supports the notion that the RVP model, which allows the user to estimate visual response times based on light level, size and contrast (Rea and Ouellette, 1991), can be a useful tool in assessing the legibility properties of sign characters, provided differences in character aspect ratio are also considered. The algorithm for calculating RVP quantities is given in Appendix 1 of this report.

The RVP model could, therefore, be used to assess the relative impacts of different aspect ratios in terms of differences in contrast. For example, the optimal aspect ratio in the present study was 1.26, whereas the aspect ratio (among the ones tested) that elicited the longest identification times was 0.26. On average, characters with an aspect ratio of 0.26 had identification times that were 14% longer than those with an aspect ratio of 1.26. Using the RVP model (assuming the same character size and observer average age as in the experiment), it can be determined that the luminance contrast reduction that results in a 14% increase in visual response time is a reduction from 0.9 to 0.16. In other words, under the conditions of the present experiment, characters with a contrast of 0.9 and an aspect ratio of 0.26 are equally legible (if legibility means being able to quickly identify characters) to characters with a contrast of 0.16 and an aspect ratio of 1.26. Figure 4 illustrates these conditions that would be expected to result in equal legibility.

Figure 4. Left: Characters with a contrast of 0.9 and an aspect ratio of 0.26. Right: Characters with a contrast of 0.16 and an aspect ratio of 1.26. Both sets of characters would be expected to be equally legible.

ILLUMINATED SIGN LUMINANCE, VISUAL COMFORT AND CONSPICUITY

As described previously in this report, limits on illuminated sign brightness have been based on the maximum luminance of the sign (as illustrated in Tables 1 and 2) and on the illuminance from the sign [e.g., a maximum of 3 lux (Lewin, 2008)]. Municipalities who might be interested in conducting field measurements of sign brightness are probably more likely to be able to purchase an illuminance meter than a luminance meter, because an illuminance meter can cost less than one-tenth that of a luminance meter. However, Bullough and Sweater Hickcox (2012) found that both the illuminance from a light source and its maximum luminance impacted ratings of discomfort glare. The light sources in that study were generally smaller than the size subtended by a sign, so the present experiment was conducted to test whether a sign's maximum luminance or the illuminance it produces affect visual comfort. At the same time, the signs were also judged for their attention-getting characteristics.

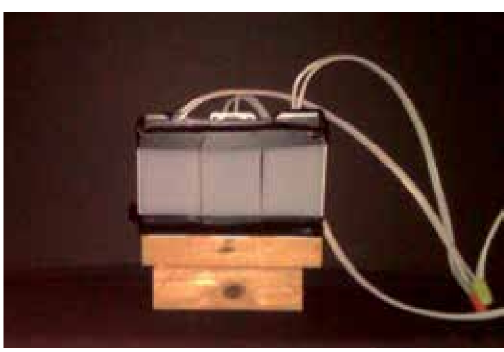

Figure 5. Scale model display used in the experiment.

A total of ten participants (aged 20 to 47 years, mean 31) participated in this experiment. Inside a darkened laboratory with black-painted walls, a modular scale-model display was set up (Figure 5). The display consisted of three illuminated panels covered with white plastic acrylic diffusers. Behind the diffusers were 100 W halogen capsule lamps inside white-painted metal enclosures. The lamps could be operated independently with dimming switches to illuminate each panel.

Three luminous conditions were set up (Figure 6), each producing a vertical illuminance of 3 lux at a location 1 meter in front of the display:

- All three panels illuminated with a luminance of 333 cd/m2.
- The two outer panels only, each illuminated to a luminance of 500 cd/m2.
- The center panel only, illuminated to a luminance of 1000 cd/m2.

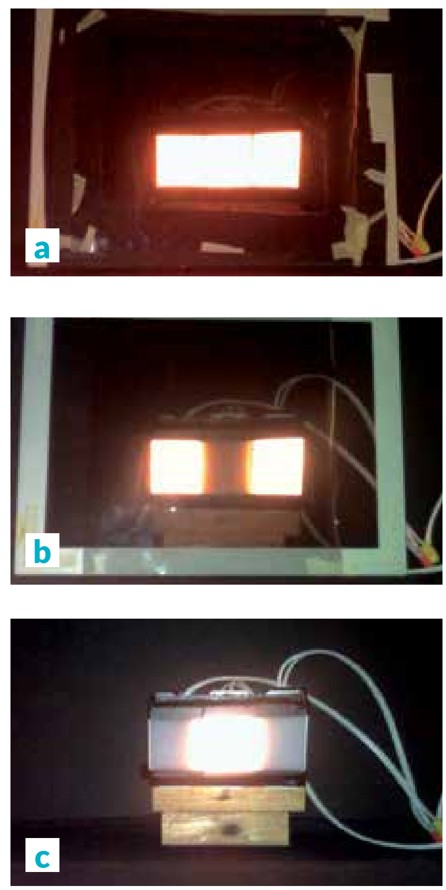

Figure 6.
a: Display with all panels at 333 cd/m2.
b: Display with outer panels at 500 cd/m2.
c: Display with center panel at 1000 cd/m2

The luminances were adjusted through a combination of neutral density gel filters placed in front of the display, and minor dimming adjustments to keep the correlated color temperature (CCT) of each condition within a range of approximately 100 K.

Subjects in this experiment viewed each condition in a random order and made judgments of conspicuity by answering the question "How attention-getting would this be if it were a sign along the road at night (1=not at all attention-getting, 4=very attention-getting)?" Subjects also rated their visual comfort using the De Boer (1967) rating scale (1=unbearable, 3=disturbing, 5=just permissible, 7=satisfactory, 9=just noticeable glare).

A within-subjects ANOVA was conducted on the ratings for each question. No statistically significant effect of lighting condition was found for the judgments of attention-getting characteristics ($F_{2,18}=2.25$, ,$p>0.05$); mean ratings for each condition were between 3 (somewhat attention getting) and 4 (very attention getting). Likely, this is related to the fact that the sign display was presented in an otherwise dark room with no other sources of light visible. The ANOVA revealed a statistically significant effect of lighting conditions on ratings of visual comfort ($F_{2,18}=15.67$, $p<0.001$), as illustrated in Figure 7.

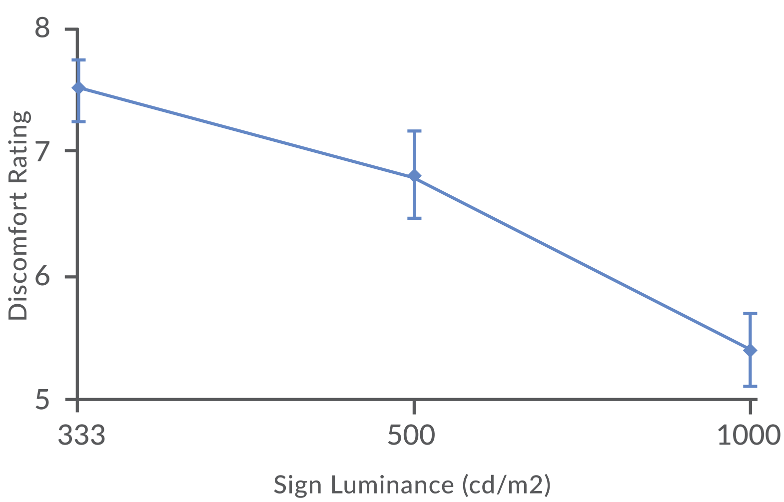

Figure 7. Mean discomfort ratings (+/- standard errors of the mean) for each of the lighting conditions used in the present experiment.

Specifically, the mean ratings for the conditions where the display luminance increased from 333 to 1000 cd/m2 decreased monotonically in numerical value (decreases indicate increased discomfort). At the highest luminance (1000 cd/m2) the mean rating approached the "just permissible" value of 5 on the De Boer (1967) scale.

The results in Figure 7 suggest that using an illuminance criterion of 3 lux will not guarantee a similar level of discomfort experienced by observers. Of course, the range of conditions tested in this experiment was very limited. Only a single, dark, background condition was tested with no other sources of light present, and only a single illuminance value (3 lux) was used. Additionally, the display module used in the experiment did not actually contain any information such as a business name or other graphical elements. Further, the overall angular size of the panel changed for the different luminance conditions, and this could have influenced the subjective judgments. Future research could use an array with a larger number of elements resulting in a much more similar overall angular size, to minimize the size differences. All of these factors could influence the degree to which a sign might be judged as uncomfortable to view. Nonetheless, it seems worthwhile to be able to assess a sign's luminance as well as the amount of illuminance it might produce toward a driver or other observer.

GUIDELINES FOR FIELD MEASUREMENT

Bullough and Skinner (2011) discussed luminance measurement considerations in their study of light emitting diode (LED) billboard brightness, and suggested that for any measurement distance greater than 50 ft, an illuminated sign consisting of a matrix of self-luminous elements like LEDs should be suitably uniform in order to estimate the luminance of a portion of the sign display using a luminance meter. Luminance measurements made closer to the sign could use slightly offset aperture locations to check for variations; little to no variations would likely indicate that a sign was sufficiently uniform.

Lewin (2008) suggested that measuring the vertical illuminance from a sign set to produce its maximum brightness (e.g., an all-white display) and its minimum brightness (e.g., off) could be done from any relevant distance from the sign, and that as long as the difference between these two illuminances did not exceed 3 lux the sign would not be considered excessively bright. This type of measurement could result in differences in rated discomfort analogous to those illustrated in Figure 7 if different sized signs produce the same illuminance using this method.

If it is possible to approach an illuminated sign, its maximum luminance can be estimated using an illuminance meter. By holding an illuminance meter so that it is facing the sign (and generally, so that it is measuring the vertical illuminance from the sign) and so that the portion of the sign being measured largely fills the illuminance meter's field of view (e.g., from less than 1 foot away), it is possible to estimate the luminance as follows:

$$L \cong E / \pi$$

where L is the luminance (in cd/m2) and E is the vertical illuminance from the sign (in lux).

It is critical that the portion of the sign being measured fills or nearly fills the illuminance meter's field of view. This can be checked by moving the illuminance meter a few inches closer to and further from the face of the sign; if the measured illuminance does not fluctuate substantially as the distance changes, them this criterion is likely to be met. If the sign consists of a matrix of self-luminous elements, moving the illuminance meter along the face of the sign should not result in large fluctuations in measured values. If this is the case it may be necessary to take the average of the highest and lowest illuminance values for a portion of a sign to use in the equation above.

It should be noted that this measurement method does not, however, yield high precision. If a municipality were to set a maximum allowable illuminated sign luminance of 350 cd/m2, for example, and the estimation of luminance using an illuminance meter yielded a value of 370 cd/m2, the excess of less than 6% over the allowable limit should probably not be a basis for corrective action. On the other hand, an estimated luminance of 450 cd/m2 using this technique would be nearly 30% higher than allowed, and would be much more likely to justify action.

PRELIMINARY GUIDELINES FOR ILLUMINATED SIGN DESIGN

Based on the findings from the present project, a few preliminary guidelines for the design of visually effective illuminated signs can be derived:

- **Use a border around the perimeter of the sign, especially in cluttered or urban environments.**
- **Avoid clutter within the sign by providing sufficient white space.**
- **Do not use ornate typefaces or fonts.**
- **Ensure that characters and symbols have high luminance contrast against the background of the sign, regardless of their colors.**
- **Avoid large luminance variations within individual characters or symbols.**
- **Dim sign luminance at night, especially in rural or uncluttered environments; use higher luminances during daytime and in urban or cluttered locations.**
- **Select a character aspect ratio that ensures rapid visual acquisition for all intended viewing angles of the sign.**

REFERENCES AND ANNOTATIONS

Akagi Y, Seo T, Motoda Y. 1996. Influence of visual environments on visibility of traffic signs. Transportation Research Record 1553: 53-58.

- The average detection distances for signs decreased from 110 ft with minimum visual noise to 60 ft with high levels of visual noise.

Allen TM. 1958. Night legibility distances of highway signs. Highway Research Bulletin 191: 3-40.

- Optimal sign luminances for nighttime legibility were found to be around 35 cd/m².

Allen TW, Dyer FN, Smith GM, Janson MH. 1967. Luminance requirements for illuminated signs. Highway Research Record 167: 16-37.

- Minimum nighttime sign luminances of 35 cd/m² are appropriate in rural locations, with a maximum of 100 cd/m².

- On illuminated highways or in the presence of substantial glare from opposing vehicle headlights, sign luminances between 70 and 340 cd/m² are recommended.

- In very brightly lighted urban locations, a minimum luminance of 700 cd/m² with a maximum of 1700 cd/m² might be appropriate.

American Association of State Highway and Transportation Officials. 2005. Roadway Lighting Design Guide. Washington, DC: American Association of State Highway and Transportation Officials.

- Nighttime sign luminances in areas of low, medium and high ambient luminance should be 20-40 cd/m², 45-90 cd/m² and 90-180 cd/m², respectively.

- A maximum-to-minimum sign luminance ratio of 6:1 is recommended.

- External lighting, if used, should not direct light into drivers' eyes.

Arditi A, Cho J. 2005. Serifs and font legibility. Vision Research 45: 2926-2933.

- Reading speed for normal-sighted and low vision observers did not differ whether fonts has serifs or not.

- Acuity was slightly improved when a font with serifs was used in place of one without serifs.

Arditi A, Liu L, Lynn W. 1997. Legibility of outline and solid fonts with wide and narrow spacing. Trends in Optics and Photonics, 5 p.

- Acuity for outline fonts was worse for outline fonts than for solid fonts.

- Outline characters needed to be 1.8 times larger than solid characters for equivalent legibility.

Beijer D, Smiley A, Eizenman M. 2004. Observed driver glance behavior at roadside advertising signs. Transportation Research Record 1899: 96-103.

- Signs with dynamic content made up half of the signs observed in one study, but received 70% of glances by drivers.

- Active signs received twice as many glances as non-active ones.

Bernard M, Liao CH, Mills M. 2001. The effects of font type and size on the legibility and reading time of online text by older adults. Proceedings of the Conference on Human Factors in Computing Systems, pp. 175-176.

- On average, legibility by older people of 14-point type was greater than for 12-point type.

- A 12-point serif font was less legible than a 12-point non-serif font, but the reverse effect of serifs occurred at 14 points.

Bertucci A. 2003. On-Premise Signs: Guideline Standards. Bristol, PA: United States Sign Council Foundation.

- A methodology for calculating the necessary size of a sign for various conditions (e.g., vehicle speed, type of reaction needed, letter type) is presented.

Bertucci A. 2006. Sign Legibility: Rules of Thumb. Bristol, PA: United States Sign Council Foundation.

- A legibility index of 30 ft/in is recommended for signage.

Bertucci A, Crawford R. 2015. Best Practice Standards for On-Premise Signs. Bristol, PA: United States Sign Council Foundation.

- Letter height needs to increase by 15% when all-uppercase letters are used, compared to mixed case.

- A legibility index of 30 ft/in. is recommended for adequate sign legibility.

- In conditions of moderate visual complexity, the recommended legibility index should be multiplied by 0.83; under high complexity, the legibility index should be multiplied by 0.67.

Bullough JD, Skinner NP. 2011. Luminance criteria and measurement considerations for light-emitting billboards. Transportation Research Board Annual Meeting, 7 p.

- A maximum allowable daytime billboard luminance of 23,000 cd/m² is proposed.
- A maximum allowable nighttime billboard luminance of 280 cd/m² is proposed.

Bullough JD, Skinner NP. 2016 [in press]. High visibility reflective sign sheeting materials: Field and computational evaluations of visual performance. Transport, 9 p.

- The relative visual performance model shows that large changes in luminance have small impacts on visibility for highway signs.
- Font size is a primary reason signs are not legible from large distances.

Bullough JD, Skinner NP, O'Rourke CP. 2010. Legibility of urban highway traffic signs using new retroreflective materials. Transport 25: 229-236.

- Retroreflective materials can compensate for a lack of external sign illumination in overhead guide signs.

Bullough JD, Sweater Hickcox K. 2012. Interactions among light source luminance, illuminance and size on discomfort glare. Society of Automotive Engineers International Journal of Passenger Cars - Mechanical Systems 5(1): 199-202.

- Ratings of discomfort glare from large-area sources are influenced by the illuminance produced by the source at observers' eyes and by the maximum luminance of the source of glare.

Cai H, Green PA. 2009. Legibility index for examining common viewing situations: A new definition using solid angle. Leukos 5(4): 279-295.

- A legibility index based on the subtended solid angle of a sign character rather than its height is proposed,
- The revised legibility index performed well at predicting critical legibility levels for many different viewing angles in which the characters' subtended angle would differ.

Carter R, Day B, Meggs P. 1985. Typographic Design: Form and Communication. New York, NY: Van Nostrand Reinhold.

- Text in all-uppercase letters is more difficult to read than mixed-case text.
- Serif and non-serif fonts can provide equal legibility.
- Research is described that finds the optimal font size at normal reading distances to be 9-12 points.

Center for Inclusive Design and Environmental Access. 2010. Design Resources: Text Legibility and Readability of Large Format Signs in Buildings and Sites, DR-11. Buffalo, NY: University at Buffalo.

- Research is cited stating that setting letter width to be the same as letter height results in greater legibility distances.
- A legibility index of 35 ft/in. is recommended.
- Positive contrast text is recommended.

Charness N, Dijkstra K., 1999. Age, luminance, and print legibility in homes, offices, and public places. Human Factors 41(2): 173-193.

- Reading task background luminances of 100 cd/m² are recommended for proficient reading.

City of Bellflower. 2016. Signage Design Guidelines. Bellflower, CA: City of Bellflower.

- Intricate typefaces for signs are prohibited.
- Lettering on a sign should not occupy more than 75% of the sign face area.
- The number of colors used on a sign should not exceed three.
- Excessively bright and fluorescent colors should be avoided.
- Internally-illuminated or back-lighted signs are preferred over external illumination.

City of Davis. 2010. Davis Citywide Sign Design Guidelines. Davis, CA: City of Davis.

- Messages on signs should be brief.
- Letters should occupy no more than 75% of the sign face area.
- High contrast between letters/symbols and their backgrounds should be used.
- External lighting should be shielded from view.
- Neon light signs are discouraged.
- Animation, blinking or other changes in intensity and color are prohibited.

City of Hutto. 2014. Site Design Standards. Hutto, TX: City of Hutto.

- Blinking or flashing on signs is prohibited.
- Electronic signs should not exceed a luminance of 7000 cd/m² during the daytime and 500 cd/m² during the nighttime.

City of Melbourne. 2009. An Ordinance of the City of Melbourne, Brevard County, Florida, Relating to Signs and Advertising. Melbourne, FL: City of Melbourne.

- Rotating or animated signs (except for changeable copy) are prohibited.

City of Mesa. [Undated.] Sign Regulations. Mesa, AZ: City of Mesa.

- Signs with flashing illumination or other animation or movement are prohibited.
- A sign with an LED display cannot exceed a luminance of 3150, 6300, 4690 or 7000 cd/m² for red, green, amber or full color signs, respectively, during daytime; or 1125, 2250, 1675 or 2500 cd/m² for red, green, amber or full color signs, respectively, during nighttime.
- Light sources for any external illumination should not be directly visible.

City of Saratoga Springs. 2012. Signage: Historic District Design Guidelines. Saratoga Springs, NY: City of Saratoga Springs.

- Sign messages should be short (no more than 8 words) and use three or fewer colors.
- Light sources for external illumination should be inconspicuous.

City of West Hollywood. 2002. Sign Design Guidelines. West Hollywood, CA: City of West Hollywood.

- Contrasting colors between letters and the sign background should be used to maximize legibility.
- An excessive number of sign colors can reduce legibility.
- A sign designed to be viewed from 60 ft requires 3.5 in. letters; to be viewed from 100 ft requires 5.5-6 in. letters.
- Symbols and pictograms are stated to be more effective than text.
- Letters should not take up more than 75% of the space on a sign panel.
- External sign lighting should be shielded to avoid glare; back lighting is encouraged.

Cornog DY, Rose FC. 1967. Legibility of Alphanumeric Characters and Other Symbols, II: A Reference Handbook. Washington, DC: National Bureau of Standards.

- Excessive brightness of a display can lead to irradiation that reduces legibility of characters and symbols.

Crawford A. 1962. The perception of light signals: The effect of the number of irrelevant lights. Ergonomics 5: 417-428.

- Flashing lights increase their conspicuity relative to steady lights.

De Boer J. 1967. Public Lighting. Eindhoven, Netherlands: Philips Technical Library.

- A subjective rating scale for discomfort glare is introduced (1=unbearable, 3=disturbing, 5=just permissible, 7=satisfactory, 9=just noticeable glare).

Duncanson JP. 1994. Visual and Auditory Symbols: A Literature Review. Atlantic City, NJ: Federal Aviation Administration.

- It is proposed that an effective sign symbol is simple rather than complex, large rather than small, and solid rather than hollow or outlined.

Eastman AA. 1968. Color contrast versus luminance contrast. Illuminating Engineering 63: 67.

- Color contrast has little to no influence on visibility of objects unless the luminance contrast approaches zero.

Elstad JO, Fitzpatrick JT, Woltman HL. 1962. Requisite luminance characteristics for reflective signs. Highway Research Bulletin 336: 51-60.

- Optimal nighttime sign luminances were found in rural and suburban locations to be between 35 and 70 cd/m².
- In bright urban locations, nighttime sign luminances between 250 and 400 cd/m² were judged as prominently visible.

Federal Highway Administration. 2004. Standard Highway Signs. Washington, DC: Federal Highway Administration.

- Guide signs on conventional roads in rural locations should have letters at least 6 in. high; in urban locations with low speed limits (25 mph) letter height should be at least 4 in.
- Street name signs should have a letter height of 6 in.
- For signs other than on interstate highways, a legibility index of 40 ft/in. should be used.
- Nearly all signs should have borders of the same color as the sign letters.

Fletcher K, Sutherland S, Nugent K. 2009. Identification of Text and Symbols on a Liquid Crystal Display, Part II: Contrast and Luminance Settings to Optimise Legibility. Edinburgh, Australia: Defence Science and Technology Organisation.

- For a positive contrast display, character luminance is recommended to be 20 cd/m² under dark lighting conditions, and 60 cd/m² under bright conditions.
- The background screen luminance is recommended to be 1 cd/m².

Forbes TW. 1972. Visibility and legibility of highway signs. In Human Factors in Traffic Safety Research. New York, NY: Wiley.

- A formula relating the conspicuity detection distance for a sign to its luminance, the contrast between the sign letters and their background, and the letter height is provided.

Forbes TW, Pain RF, Fry JP, Joyce RP. 1967. Effect of sign position and brightness on seeing simulated highway signs. Highway Research Record 164: 29-37.

- At night, higher sign luminance tended to be more likely to be detected.
- Under daytime conditions, darker signs were often most likely to be detected, but so were brighter signs, for many observers. The contrast between letters and the sign background might sometimes overcome the contrast between the sign and its own background.

Forbes TW, Snyder TE, Pain RF. 1965. Traffic sign requirements: I. Review of factors involved, previous studies and needed research. Highway Research Record 70: 48-56.

- Research is cited finding about 85% legibility to signs with a legibility index (ft of legibility distance per in of letter height) of 50 ft/in.
- Only 3-4 short, familiar words can be read in a single glance at a sign.
- Letter-height to stroke-width ratios of 4-6 appear to be optimal for legibility.
- Color combinations providing the highest luminance contrast tend to provide the highest legibility.
- Use of fluorescent colors appears to have some advantages for sign detection.
- Brightness changes and motion are salient cues for peripheral vision.

Freyssinier JP, Narendran N, Bullough JD. 2006. Luminance requirements for lighted signage. Proceedings of the SPIE, Vol. 6337, 63371M.

- Illuminated sign luminances between 40 and 190 cd/m² are optimal when no nearby signs are present.
- Illuminated sign luminances between 65 and 230 cd/m² are optimal when nearby signs are present.

Freyssinier JP, Zhou Y, Ramamurthy V, Bierman A, Bullough JD, Narendran N. 2003. Evaluation of light-emitting diodes for signage applications. Proceedings of the SPIE, Vol. 5187, pp. 309-317.

- The contrast of luminance variations within a sign character should be no greater than 0.2-0.4 to achieve 80% acceptability.
- The size or spatial frequency of the luminance variations are relatively unimportant to judgments of acceptability.

Funkhouser D, Chrysler S, Nelson A, Park ES. 2008. Traffic sign legibility for different sign background colors: Results of an open road study at freeway speeds. Proceedings of the Human Factors and Ergonomics Society 52nd Annual Meeting, pp. 1855-1859.

- Green and purple highway signs performed equivalently in a driving test in terms of legibility distances during daytime and nighttime.

Garvey PM. 2006. On-Premise Signs: Determination of Parallel Sign Legibility and Letter Heights. Bristol, PA: United States Sign Council Foundation.

- Reading performance begins to decline as the viewing angle changes from perpendicular with the sign surface to between 20o and 40o from perpendicular.

Garvey PM. 2007. Urban wayfinding signs: Evaluating exceptions to FHWA's standard alphabet. Transportation Research Board Annual Meeting, 17 p.

- A study of the use of the Futura font in wayfinding signs in Miami Beach found that it resulted in equivalent legibility as standard highway sign fonts.

Garvey PM, Chirwa KN, Meeker DT, Pietrucha MT, Zineddin AZ, Ghebrial RS, Montalbano J. 2004. New font and arrow for National Park Service guide signs. Transportation Research Record 1862: 1-9.

- A new highway sign font resulted in smaller word "footprints" but increased legibility distances by 10%.

Garvey PM, Klena MJ, Eie W-Y, Meeker DT, Pietrucha MT. 2016. Legibility of the Clearview typeface and FHWA standard alphabets on negative- and positive-contrast signs. Transportation Research Record 2555: 28-37.

- Signs using the Clearview font outperformed identical signs using standard highway alphabets in terms of legibility distance.
- Predictions of relative visual performance were correlated with legibility distances for individual fonts, but legibility distances were lower than predicted by the visual performance model when the font aspect ratio was narrow.

Garvey PM, Kuhn BT. 2011. Highway sign visibility. In Handbook of Transportation Engineering (Kutz M, editor). New York, NY: McGraw-Hill.

- Internally-illuminated signs and neon signs resulted in 40%-60% improvements in nighttime legibility over externally-illuminated signs.

Garvey PM, Pietrucha MT, Cruzado I. 2009. The Effects of Internally Illuminated On-Premise Sign Brightness on Nighttime Sign Visibility and Traffic Safety. Bristol, PA: United States Sign Council Foundation.

- Recognition distances at night to signs tend to increase as sign luminance increases, but decrease at the very highest luminances.
- Daytime signs were 43% more legible than poor nighttime signs, but only 13% more legible than well designed nighttime signs.

Garvey PM, Pietrucha MT, Meeker D. 1997. Effects of font and capitalization on legibility of guide signs. Transportation Research Record 1605: 73-79.

- Nighttime legibility distances to highway signs increased by 16% when Clearview font was used in place of the standard highway font.

Garvey PM, Zineddin AZ, Pietrucha MT. 2001. Letter legibility for signs and other large format applications. Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting, pp. 1443-1447.

- A study of visual acuity using various fonts found Bank Gothic Light, Dutch Regular and Dutch Bold to be most legible, with Commercial Script Regular least legible.
- Letter width serves as a better predictor of legibility than stroke width.

Gates TJ, Carlson PJ, Hawkins HG. 2004. Field evaluations of warning and regulatory signs with enhanced conspicuity properties. Transportation Research Record 1862: 64-76.

- Use of fluorescent colors in highways signs increased desired driving maneuvers.
- A red border around speed limit signs reduced daytime driving speeds and reduced the number of speed violators during daytime and nighttime.

Goodspeed C, Rea MS. 1999. The significance of surround conditions for roadway signs. Journal of the Illuminating Engineering Society 28(1): 164.

- The speed with which observers could identify Landolt ring target orientation was correlated with the predicted relative visual performance model quantity.

Graham JR, Fazal A, King LE. 1997. Minimum luminance of highway signs required by older drivers. Transportation Research Record 1573: 91-98.

- Young drivers require sign luminances of 30 cd/m² for correct identification from 90 m, and 2 cd/m² from 60 m.
- Older drivers require sign luminances in excess of 40 cd/m² for correct identification from 90 m, and 7 cd/m² from 60 m.

Hawkins HG, Picha DL, Wooldridge MD, Greene FK, Brinkmeyer G. 1999. Performance comparison of three freeway guide sign alphabets. Transportation Research Record 1692: 9-16.

- A comparison of different highway sign fonts showed increased legibility with Clearview over the standard highway font; the advantage was between 2% and 8%.

Hawkins HG, Rose ER. 2005. A human factors study of the effects of adding dual logo panels to specific service signs. Transportation Research Board Annual Meeting, 18 p.

- Using two logos in the space normally allocated to a single logo on service signs resulted in lower recognition, but not so much that using dual logos should be prohibited in the authors' opinion.

Holick AJ, Carlson PJ. 2002. Model of overhead-sign luminance needed for legibility. Transportation Research Record 1801: 80-86.

- An equation for the sign luminance needed to achieve legibility as a function of driver age, visual acuity, stroke width and viewing distance is provided.

Institution of Lighting Engineers. 2001. Brightness of Illuminated Advertisements. Warwickshire, UK: Institution of Lighting Engineers.

- Large illuminated sign luminance at night should be limited to 300 cd/m² in low district brightness areas and 600 cd/m² in medium and high district brightness areas; large illuminated signs should not be used in intrinsically dark areas.
- Small illuminated sign luminance at night should be limited to 100 cd/m² in intrinsically dark areas, 600 cd/m² in low district brightness areas, 800 cd/m² in medium district brightness areas and 1000 cd/m² in high district brightness areas.

International Sign Association. 2007. Conspicuity and readability. Signline 51: 1-8.

- At a speed of 55 mph, a sign should be legible from a distance of 440 ft; at a speed of 30 mph, it should be legible from 240 ft.
- On-premise signs should use letter heights of 7 in. for traffic at 25 mph, and 15 in. for traffic at 55 mph.

Kinney GC, Showman DJ. 1967. Studies in Display Symbol Legibility: Part XVIII. The Relative Legibility of Uppercase and Lowercase Typewritten Words. Bedford, MA: The Mitre Corporation.

- Word forms produced by combinations of uppercase and lowercase letters were equivalent in legibility to those by all-uppercase letters.

- Uppercase letters are recommended for displays and applications other than "normal reading" of text.

Kuhn BT, Garvey PM, Pietrucha MT. 1997. Model guidelines for visibility of on-premise advertising signs. Transportation Research Record 1605: 80-87.

- The contrast between a sign and its immediate background is the primary determinant of one's ability to detect the sign in visually simple environments, perhaps more than size.
- Increased sign luminance results in increased conspicuity and can help overcome visual complexity of the sign's background in most cases.
- Sign color can increase the sign's conspicuity.
- Contrast between sign letters and the sign background is important for legibility with a luminance ratio of 12:1 being close to optimal.
- Increasing sign luminance generally improves nighttime legibility up to an optimal value of 75 cd/m². Sign luminance at night should not be below 2.4 cd/m².
- Legibility distances for graphical symbols were nearly always longer than for alphanumeric characters.
- Mixed-case characters result in greater legibility distances than uppercase-only.
- The optimal stroke-width to height ratio for positive contrast is 1:5, and 1:7 for negative contrast text.
- Positive contrast results in greater legibility than negative contrast.
- To read a sign, process the information, and execute a driving maneuver in response to it requires 5.5 seconds with signs containing five or fewer critical elements.

Kuhn BT, Garvey PM, Pietrucha MT. 1998. Sign Legibility: The Impact of Color and Illumination on Typical On-Premise Sign Font Legibility. Bristol, PA: United States Sign Council Foundation.

- Internal illumination and neon signs outperformed externally-lighted signs in terms of sign legibility.
- Positive contrast signs outperformed negative contrast signs in terms of legibility.
- No legibility differences between serif and non-serif fonts were identified.

Lerner ND, Collins BL. 1983. Symbol sign understandability when visibility is poor. Proceedings of the Human Factors Society 27th Annual Meeting, pp. 944-946.

- The polarity of symbols and backgrounds made little difference on the recognition of symbolic signs.
- Filled symbols outperformed outline symbols in terms of recognition.

Lewin I. 2008. Digital Billboard Recommendations and Comparisons to Conventional Billboards. Scottsdale, AZ: Lighting Sciences, Inc.

- It is recommended that the illuminance from a digital billboard at a distance between 150 ft (for small billboards) and 350 ft (for very large billboards) not exceed 3 lx.

Milburn NJ, Mertens HW. 1997. Evaluation of a Range of Target Blink Amplitudes for Attention-Getting Value in a Simulated Air Traffic Control Display, DOT/FAA/AM-97/10. Washington, DC: Federal Aviation Administration.

- Flashing or blinking text is more difficult to read than steady text.

Millar K. 2011. Designing for legibility. SignCraft (January/February): 42-44.

- A rule of thumb for letter height at various viewing distances is given: 4 in. per 100 ft of viewing distance.
- At 30 mph, 8 in. letters are needed to ensure 5 seconds of readability; 4 in. letters ensure 3 seconds of legibility.
- At 60 mph, 16 in. letters are needed to ensure 5 seconds of readability; 8 in. letters ensure 3 seconds of legibility.

Pankok C, Kaber D, Rasdorf W, Hummer J. 2015. Driver attention and performance effects of guide and logo signs under freeway driving. Transportation Research Board Annual Meeting, 11 p.

- A comparison of guide signs and logo signs on the highway showed that guide signs received fewer and shorter visual fixations.
- Guide signs had more consistent eye-scan patterns than logo signs, probably because of the left-to-right nature of reading text on guide signs.

Powers LD. 1965. Effectiveness of sign background reflectorization. Highway Research Record 70: 74-86.

- Study participants were instructed to drive along a highway at night and exit following the presence of test signs equipped with no, low or highly-reflective green background sheeting material (resulting in different background luminances), with white reflectorized letters.
- No differences among the background conditions were found in terms of accuracy in responding to the test signs.

Rea MS (editor). 2000. IESNA Lighting Handbook: Reference and Application, 9th ed. New York, NY: Illuminating Engineering Society.

- Equations are provided for the spacing of individual lamps in exposed-letter signs, and for lamp wattages in different ambient environments.
- Sign luminance recommendations include 70-350 cd/m² for lighted fascia signs, 250-500 cd/m² for bright fascia signs, 450-700 cd/m² for low brightness areas, 700-1000 cd/m² for average commercial areas, 1000-1400 for areas with high sign competition, and 1400-1700 cd/m² for emergency traffic control.
- Floodlighted signs in bright surrounds should be illuminated to 1000 lx if reflectance is low, and 500 lx if reflectance is high; in dark surrounds, half these illuminances are recommended.

Rea MS, Ouellette MJ. 1991. Relative visual performance: A basis for application. Lighting Research and Technology 23(3): 135-144.

- The speed and accuracy of visual processing such as identifying characters in printed text is systematically related to its contrast, size, and the luminance of the background.

Schieber F, Goodspeed CH. 1997. Nighttime conspicuity of highway signs as a function of sign brightness, background complexity and age of observer. Proceedings of the Human Factors and Ergonomics Society 41st Annual Meeting, pp. 1362-1366.

- Increasing sign luminance had no benefit in terms of response times or response accuracy to signs when backgrounds were simple, but did improve detection times and accuracy in visually complex environments.

Schnell T, Atkan F, Li C. 2004. Traffic sign luminance requirements of nighttime drivers for symbolic signs. Transportation Research Record 1862: 24-35.

- Sign luminance, letter contrast and the type of symbol displayed all influenced the legibility distance of sign symbols.

Schnell T, Yekhshatyan L, Daiker R. 2009. Effect of luminance and text size on information acquisition time from traffic signs. Transportation Research Record 2122: 52-62.

- The relative visual performance model resulted in close agreement with visual acquisition times in a study of sign character legibility under different luminances, sizes and contrasts.

Shurtleff D, Botha B, Young M. 1966. Studies in Display Symbol Legibility: Part IV. The Effects of Brightness, Letter Spacing, Symbol Background Relation and Surround Brightness on the Legibility of Capital Letters. Bedford, MA: The Mitre Corporation.

- Letters with high contrast against their backgrounds are recommended for highest acuity.
- Polarity of contrast is unimportant to legibility.
- Background luminances of 70 to 140 cd/m² are recommended.

Smiley A, Persaud B, Bahar G, Mollett C, Lyon C, Smahel T, Kelman WL. 2005. Traffic safety evaluation of video advertising signs. Transportation Research Record 1937: 105-112.

- Video advertising is stated to have potential to distract drivers inappropriately, but overall impacts on safety are likely to be small.

Tinker MA. 1966. Experimental studies on the legibility of print: An annotated bibliography. Reading Research Quarterly 1(4): 67-118.

- Research is cited stating that letters with serifs are more legible than those without serifs.
- A study found that white numbers printed on a black background were 8% more legible than black numbers printed on a white background.
- The poorest color combinations for reading text were found in one study to be red type on black background, or vice versa. Luminance contrast is one of the most important factors in legibility.
- The optimal character stroke width was identified in research as being 18% of the character height or width.
- Research stating that increasing illumination could overcome a type size change from 12 to 6 points is cited.

Town of Bermuda Run. 2013. Sign Design Guidelines. Bermuda Run, NC: Town of Bermuda Run.

- A viewer reaction time of 8 seconds is recommended for signs along roads with a speak limit of 45 mph, when six or fewer words are on the sign.
- The ideal letter height for signs is stated to be between 8 and 13 in.
- For improved legibility, block (non-script) text and mixed case is preferred.
- Using no more than two colors is stated to increase legibility.
- Positive contrast signs are stated to increase legibility, but the degree of improvement depends upon illumination and contrast.

Town of Huntersville. 2009. Suggestions for Designing Effective Signs. Huntersville, NC: Town of Huntersville.

- High contrast between sign letters and their backgrounds is desirable for legibility.
- Light letters on dark backgrounds are preferable to the opposite for ease of reading.
- For 2-lane roads, 30 mph traffic requires 8-in. letters and 55 mph traffic requires 12-in. letters.
- For 4-lane roads, 30 mph traffic requires 10-in. letters and 55 mph traffic requires 15-in. letters.
- Sign letters should occupy no more than 40% of the sign area.

Ullman BR, Ullman GL, Dudek CL, Ramirez EA. 2005. Legibility distances of smaller letter light-emitting diode changeable message signs. Transportation Research Board Annual Meeting, 23 p.

- LED letters on a changeable message sign with a height of 9 in. were legible from 228 ft in the daytime and 114 ft at night.
- LED letters on a changeable message sign with a height of 10.6 in. were legible from 324 ft in the daytime and 203 ft at night.

U.S. Small Business Administration. 2003. The Signage Sourcebook. Washington, DC: U.S. Small Business Administration.

- It is recommended that a sign be legible from a distance (in ft) equal to a vehicle's speed limit (in mph) multiplied by 8.
- Signs mounted on the left side of the road require letters to be one-third larger than those on the right side of the road, for equal legibility.
- Recommended sign heights range from 12 ft for 25-mph traffic to 50 ft for 55-mph traffic.

Van Houten R, Healey K, Malenfant JEL, Retting R. 1998. Use of signs and symbols to increase the efficacy of pedestrian-activated flashing beacons at crosswalks. Transportation Research Record 1636: 92-95.

- Adding a pedestrian symbol sign near a flashing warning beacon increased the number of drivers who yielded to pedestrians.

Yager D, Aquilante K, Plass R. 1998. High and low luminance letters, acuity reserve, and font effects on reading speed. Vision Research 38: 2527-2531.

- At a high background luminance (150 cd/m^2) there is no difference in reading rates between serif and non-serif fonts.
- At a low background luminance (0.15 cd/m^2) a non-serif font resulted in improved reading rates over a serif font.

Young SL, Laughery KR, Bell M. 1992. Effects of two type density characteristics on the legibility of print. Proceedings of the Human Factors Society 36th Annual Meeting, pp. 504-508.

- Type width is stated to affect legibility more than inter-character spacing.
- Reducing the space between characters improved legibility for standard type widths, but decreased legibility for the narrowest fonts.

Zwahlen HT, Schnell T. 1998. Legibility of traffic sign text and symbols. Transportation Research Record 1692: 142-151.

- Sign legibility distances are 1.8 times longer in the daytime than they are at night.

APPENDIX 1:
RELATIVE VISUAL PERFORMANCE CALCULATION PROCEDURE

1. Let A be the observer's age in years. Let L be the background luminance in cd/m². Let C be the luminance contrast. Let S be the size of the target in microsteradians:

   S = T/(1,000,000 d2) (Equation A-1)

   where T is the projected area of the target (in m2) and d is the viewing distance (in m).

2. Calculate the pupil radius P in millimeters:

   P = 2.39 - 1.22 tanh(0.3 log L) (Equation A-2)

3. Calculate the age-corrected retinal illuminance Er in trolands:

   Er = πP2L[1 - 0.017(A - 20)] (Equation A-3)

4. Calculate five intermediate values x1, x2, x3, x4 and x5:

   x1 = log[tanh(20,000 S)]
   x2 = log[log(10 Er/π)]
   x3 = 1 + [0.0025(A - 20)] (Equations A-4a through A-4f)
   x4 = log[tanh(5000 S)]
   x5 = log[tanh(0.04 Er/π)]

5. Calculate the threshold luminance contrast Ct:

   Ct = x3 10^(-1.36 - 0.18x1 - 0.81x2 + 0.23x12 - 0.077x22 + 0.17x1x2)
   (Equation A-5)

6. Calculate the half-saturation constant K:

   K = 10^(-1.76 - 0.18x4 - 0.031x5 + 0.11x42 + 0.17x52 + 0.062x4x5)
   (Equation A-6)

7. Calculate the maximum response Rmax:

   Rmax = 0.0002 log(Er) + 0.0027 (Equation A-7)

8. Calculate the visual response time in milliseconds:

   V = [(C - Ct)0.97 + K0.97]/[(C - Ct)0.97 Rmax] (Equation A-8)

9. Calculate the relative visual performance (RVP):

   RVP = 1.42 - V/778.56 (Equation A-9)

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