CHAPTER 7
HIGHWAY SIGN VISIBILITY

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7.1 MEASURES OF SIGN EFFECTIVENESS

Sign visibility is an imprecise term in that it encompasses both sign detectability and sign legibility. Sign detectability refers to the likelihood of a sign being found in the driving environment and is integrally associated with sign conspicuity. Sign conspicuity is a function of a sign's capacity to attract a driver's attention that depends on sign, environmental, and driver variables (Mace, Garvey, and Heckard 1994). Sign legibility describes the ease with which a sign's textual or symbolic content can be read. Sign legibility differs from sign recognizability in that the former refers to reading unfamiliar messages while the latter refers to identifying familiar sign copy. Sign legibility and recognizability in turn differ from sign comprehensibility in that the latter term implies understanding the message while the former merely involve the ability to discern critical visual elements.

While other measures of sign visibility such as blur tolerance (Kline et al. 1999) and comprehension speed (Ells and Dewar 1979) are sometimes used, sign visibility is most often assessed by determining threshold distance. The two thresholds often used are detection distance (the distance at which an observer can find a sign in the driving environment) and legibility distance (the distance at which an observer can read a sign's message). The intent of a sign designer is to provide the sign's observer with the maximum time to read the sign, and to do that the observer must find it prior to or at its maximum reading distance. Therefore, in designing a sign it is desirable to achieve a detection distance that is equal to or greater than that sign's legibility distance.

To describe legibility distance across signs with different letter heights, the term legibility index is often used. Legibility index (LI) refers to the legibility distance of a sign as a function of its text size. Measured in feet per inch of letter height (ft/in.), the LI is found by dividing the sign's legibility distance by its letter height. For instance, a sign with 10-inch letters legible at 300 feet has an LI of 30 ft/in. (300/10 = 30).

7.2 VISUAL PERCEPTION

In the initial stages of vision, light passes through the eye and is focused by the cornea and lens into an image on the retina. The retina is a complex network of nerve cells or light receptors composed of rods and cones. So named because of their basic shape, rods and cones perform different functions. Cones function best under high light intensities and are responsible for the perception of color and fine detail. In contrast, rods are more sensitive in low light but do not discriminate details or color. Rods and cones are distributed across the retina in varying densities.

The region of the central retina where a fixated image falls is called the fovea. The fovea has only cones for visual receptors and is about 1.5 to 2° in diameter. Beyond 2°, cone density rapidly declines reaching a stable low point at about 10°. Conversely, rod density rapidly increases beyond 2° and reaches a maximum at about 18° before dropping off (Boff, Kaufman, and Thomas 1986). From 18° outward toward the nose and ears, forehead, and chin, the number of rods decreases but still continues to be higher than the number of cones.

Functional detail vision extends to about 10°, worsening in the near periphery from about 10 to 18° and significantly deteriorating in the far periphery from about 18 to 100°. Occasionally the term *cone of vision* appears in the visibility literature. Although this expression is used freely, it is not well defined. In general, the cone of vision can be taken to refer to an area within the near periphery. The *Traffic Control Devices Handbook* (FHWA 2001) section on driver's legibility needs states:

> When the eye is in a fixed position it is acutely sensitive within a 5 or 6 degree cone, but is satisfactorily sensitive up to a maximum cone of 20 degrees. It is generally accepted that all of the letters, words, and symbols on a sign should fall within a visual cone of 10 degrees for proper viewing and comprehension.

7.2.1 Visual Acuity

Visual acuity is the ability to discern fine objects or the details of objects. In the United States, performance is expressed in terms of what the observer can see at 20 feet, referenced to the distance at which a "normal" observer can see the same object. Thus, we have the typical Snellen expressions 20/20, where the test subject can see objects at 20 feet that the standard observer can see at 20 feet, and 20/40, where the test subject can see objects at 20 feet and the standard observer can see at 40 feet. Visual acuity can be measured either statically and/or with target motion, resulting in static visual acuity (SVA) and dynamic visual acuity (DVA). Although there are questions as to its relationship to driving ability, static visual acuity is the only visual performance measure used with regularity in driver screening, with 20/40 visual acuity in one eye being the de facto threshold standard.

7.2.2 Contrast Sensitivity

Contrast threshold is the minimum detectable *luminance* difference between the dark and light portions of a target. (The term *luminance* is defined and discussed later in section 7.3.) Contrast sensitivity is the reciprocal of the contrast threshold; that is, contrast sensitivity = 1/contrast threshold. Therefore, a high contrast threshold represents low contrast sensitivity—in other words, a large difference between the darkest and lightest portions of a target is necessary for target visibility.

7.2.3 Visual Field

A driver's field of vision or visual field is composed of foveal and peripheral vision, or literally everything the driver can see. Visual acuity is highest in the central fovea. Beyond the fovea, vision deteriorates rapidly. In the near periphery, individuals can see objects but color and detail discriminations are weak. The same holds true for far peripheral vision. Aside from these general visual field break points, no specific designations of intermediate vision exist.

The related concept of useful field of view (UFOV) has gained widespread acceptance as a potentially useful tool to describe vision in natural settings (Ball and Owsley 1991). Proponents of UFOV assert that while an individual's visual field is physically defined by anatomical characteristics of the eye and facial structure, it can be further constricted by emotional or cognitive states, as with the common phenomenon of "tunnel vision" experienced under stressful conditions.

7.2.4 Glare

Another set of terms related directly to drivers' visual abilities concerns the adverse effects of light from external sources, which include, but are not limited to, signs, headlamps, and overhead lights. While signs are included in this listing, research has shown that they are not generally a source of glare or another measure of light pollution known as *light trespass* (Garvey 2005). Four types of glare exist: direct, blinding, disability, and discomfort. Direct glare comes from bright light sources or the reflectance from such sources in the driver's field of view (FHWA 1978a). Blinding glare and disability glare differ only in degree. Blinding glare results in complete loss of vision for a brief period of time, whereas disability glare causes a temporary reduction in visual performance ranging from complete to minor. Discomfort glare reduces viewing comfort for the observer.

7.3 PHOTOMETRY

Photometry is the measurement of radiant energy in the visual spectrum; that is, the measurement of light. Photometric equipment is designed and calibrated to match the human eye's differential sensitivity to color and to daytime-versus-nighttime lighting. Therefore, photometry is the measurement of light as people see it. The four most important photometric measurements used to describe sign visibility are luminous intensity, illuminance, luminance, and reflectance.

Luminous intensity, expressed in candelas (cd), is a description of a light source itself and is therefore independent of distance. That is, no matter how far away an observer is from a lamp, that lamp always has the same intensity. Luminous intensity is the photometric measurement most often specified by lamp and LED manufacturers.

Illuminance, or incident light, is expressed in units of lux (lx) and is a measure of the amount of light that reaches a surface from a light source. Illuminance is affected by distance and is equal to luminous intensity divided by the distance squared ($\text{lx} = \text{cd}/d^2$). For example, if a source emits a luminous intensity of 18 cd, the illuminance level measured 3 meters away would be 2 lx($18/3^2$). If the source's intensity is unknown, illuminance is measured with an illuminance or lx meter placed on the surface of interest facing the light source.

Luminance is expressed in candelas per square meter (cd/m^2). Luminance is the photometric that most closely depicts the psychological experience of "brightness." Luminance can refer to either the light that is emitted by or reflected from a surface, and is an expression of luminous intensity (cd) over an extended area (m^2). Like luminous intensity, 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 target of interest, and a reading is taken.

Reflectance is the ratio of illuminance to luminance and, as such, reflectance describes the proportion of incident light that is absorbed and the proportion that is reflected by a surface. If, for example, 100 lx hits an object's surface and that surface has a luminance level of 5 cd/m^2, that surface has a reflectance of 5 percent (5/100).

A related term often found in traffic sign literature is retroreflection. Retroreflection describes material that, unlike normal matte (i.e., diffuse) or specular (i.e., mirror-like) surfaces, reflects most incident light directly back to the light source. With regard to signs and other vertical surfaces, retroreflection is represented by a coefficient of retroreflection, known as R_A, although it is also commonly referred to as the "specific intensity per unit area," or SIA (ASTM 2001). A material's SIA is the ratio of reflected light to incident light. SIA values for signs are commonly expressed in candelas per lux per square meter (cd/lx/m^2).

7.4 FEDERAL TRAFFIC SIGN REGULATIONS

The *Manual on Uniform Traffic Control Devices* (*MUTCD*) (FHWA 2009) is the legal document that governs traffic control device design, placement, and use in the United States. All local, county, and state transportation departments must use this document as a minimum standard. According to the document, traffic control devices are "all signs, signals, markings, and other devices used to regulate, warn, or guide traffic, placed on, over, or adjacent to a street, highway, pedestrian facility, bikeway, or private road open to public travel . . . by authority of a public agency or official having jurisdiction, or, in the case of a private road, by authority of the project owner or private official having jurisdiction" (FHWA 2009).

7.4.1 Sign Height

The *MUTCD* requires that any sign placed at the side of a roadway have a minimum vertical height ranging from 5 to 7 feet, depending on the general location and the number of installed signs. For instance, a sign in a rural area or on freeways must have a vertical height of at least 5 feet, while a sign in a business, commercial, or residential area must have a vertical clearance of at least 7 feet (FHWA 2009). The reason behind this variation is that more vertical clearance is needed in areas where pedestrian traffic is heavier. To allow for the passage of the largest vehicles, overhead signs must have a vertical clearance of 17 feet.

7.4.2 Lateral Offset

As with sign height, lateral clearance requirements vary with sign location. For instance, the *MUTCD* states that traffic signs placed along a roadway should have a minimum lateral clearance of 6 feet from the edge of the shoulder. However in urban areas where lateral offset is often limited, offsets can be as small as 1 to 2 feet (FHWA 2009). These small lateral clearances reflect the lower vehicle speeds found in urban areas. The basic premise behind even the smallest minimum standards is a combination of visibility, safety, and practicality.

7.4.3 Longitudinal Sign Placement

The placement of directional signs must be far enough in advance of the location of the intended action so that the motorist can react and slow the vehicle or change lanes if necessary, after passing the sign and prior to reaching the appropriate crossroad or access road. The *MUTCD* (FHWA 2009) states, "When used in high-speed areas, Destination signs [i.e., conventional road guide signs] should be located 200 ft or more in advance of the intersection. . . . In urban areas, shorter advance distances may be used." The distance of 200 feet at 65 mph translates to approximately 2.0 seconds. For the more critical Warning Signs, such as Merge and Right Lane Ends, the *MUTCD* (FHWA 2009) states, ". . . [in] locations where the road user must use extra time to adjust speed and change lanes in heavy traffic because of a complex driving situation, . . . the distances are determined by providing the driver . . . [with] 14.0 to 14.5 seconds for vehicle maneuvers."

The *MUTCD* recommendations can best be thought of as absolute minimums. To establish more conservative recommended distances for longitudinal sign placement for the National Park Service, a formula developed by Woods and Rowan (1970) was combined with deceleration rates from the AASHTO green book. Table 7.1 contains the results of that formula for single lane approaches. Adding 4.0 seconds to the single lane approaches results in the multilane recommendations.

In some cases, such as high-speed highways, two signs may be necessary. In fact, the *MUTCD* (FHWA 2009) recommends, "major and intermediate interchanges Advance Guide signs should be placed at ½ mile and at 1 mile in advance of the exit with a third Advance Guide sign placed at 2 miles in advance of the exit if spacing permits."

7.4.4 Reflectorization and Illumination

Regulatory, warning, and guide signs must be illuminated in such a manner that they have the same appearance at night as in daytime. The *MUTCD* provides general regulations regarding

TABLE 7.1 Recommended Reading Time, Letter Height, and Longitudinal Sign Placement for Various Operating Speeds and Number of Words on a Sign

Operating speed (mph)	Number of words	Reading time (sec)	Letter height (in.)	Longitudinal sign placement distance (ft/sec)	
				Single-lane approach	Multilane approach
25–40	1–3	3.0–4.5	4–6		
	4–8	6.0	8	375/6.4	600/10.4
41–50	1–3	3.5–4.5	6–8		
	4–8	5.5–7.0	10–12	500/6.8	800/10.8
51–60	1–3	4.0–5.0	8–10		
	4–8	5.5–7.0	12–14	650/7.4	1000/11.4
61–70	1–3	4.0	10		
	4–8	5.5	14	725/7.1	1100/11.1

the illumination of traffic signs. For instance, signs may be illuminated in four ways: (1) by internal lighting (e.g., fluorescent tubes or neon lamps) that illuminates the main message or symbol and/or background through some type of translucent material, (2) by external lighting (including high-intensity discharge lamps or fluorescent lighting sources) that provides uniform illumination over the entire face of the sign, (3) by light-emitting diodes (LEDs) that illuminate the main message or symbol or portions of the sign border, and (4) by some other method such as luminous tubing, fiberoptics, incandescent panels, or the arrangement of incandescent lamps (FHWA 2009).

On freeway guide signs, all copy (legends, borders, and symbols) must be retroreflectorized with the sign background either retroreflectorized or otherwise illuminated. On overhead sign mounts, headlight illumination of retroreflective material may not be sufficient to provide visibility (FHWA 2009). In such situations, supplemental external illumination is necessary. Supplemental illumination should be reasonably uniform and sufficient to ensure sign visibility. Furthermore, the *MUTCD* provides standards for maintaining minimum retroreflectivity for signs and provides guidance on assessment or management methods for maintaining minimum levels to ensure nighttime sign visibility (FHWA 2009). The document also provides information on minimum maintained retroreflectivity levels according to sign color, sheeting type, placement, and text and symbol size (FHWA 2009).

7.4.5 Message Design

Both the *MUTCD* and *Standard Highway Signs* (FHWA 2002) specify guide sign content characteristics. Although they allow some flexibility for overall sign layout, these two federal documents provide detailed specifications for message design.

7.4.6 Font

With regard to font, the federal specifications are very specific. The letter style used must be one of the Standard Highway Alphabet series (e.g., Figure 7.1) (FHWA 2004). However, in 2004, the FHWA granted interim approval for use of the Clearview font for positive-contrast legends (i.e., lighter letters on a darker background) on guide signs, allowing any state to use this font in place of Standard Highway Alphabets on written request to the FHWA (e.g., Figure 7.2).

FIGURE 7.1

FIGURE 7.2

7.4.7 Case

With the exception of destination names, all signs must use only upper-case letters. For destination names (i.e., places, streets, highways) using mixed-case legends, the lower-case loop height should be 75 percent of the upper-case height.

7.4.8 Letter Height

As stated in the *MUTCD* (FHWA 2009), the general guidance for selecting letter height is based on a legibility index (LI) of 30 feet per inch of letter height (LI = 30). This is a 10 ft/in. reduction from the LI of 40 recommended in Standard Highway Signs (FHWA 2002) and the LI of 50 that was the standard for almost 50 years (FHWA 1988) prior to that. In addition to the general rule, the *MUTCD* (FHWA 2009) establishes 8 inches as the minimum letter height for freeway and expressway guide signs, although overhead signs and major guide signs require larger lettering. For example, on expressways, the minimum height ranges from 20 inches/15 inches (upper-/lower-case) for a major roadway to 10.6 inches/8 inches for a road classified as minor and 20 inches/15 inches to 13.3 inches/10 inches for freeways, respectively, for these two roadway types. Standard Highway Signs (FHWA 2004) states that the minimum letter height for the principal legend on conventional road guide signs on major routes is 6 inches; this drops to 4 inches for urban and less important rural roads. The long-held 4-inch minimum for street name signs found in previous versions of Standard Highway Signs (FHWA 1978b) was changed to 6 inches with the 2002 edition.

7.4.9 Border

All signs are required to have a border. The border must be the color of the legend and, in general, should not be wider than the stroke width of the largest letter used on that sign. Guide sign borders should extend to the edge of the sign, while regulatory and warning sign borders should be set in from the edge.

7.4.10 Spacing

Intercharacter spacings for the Standard Highway Alphabets must follow the spacing charts in the Standard Highway Signs book (FHWA 2004), whereas spacings for the Clearview font must follow the spacing tables for Clearview found under Interim Approvals in the *MUTCD* (FHWA 2009). The spacing between the sign copy and the border should be equal to the height of the upper-case letters. The spacing between lines of text should be 75 percent of the upper-case letter height. Spacing between unique copy elements (e.g., words and symbols) should be 1 to 1.5 times the upper-case letter height (FHWA 2004).

7.5 SIGN VISIBILITY RESEARCH

When reviewing the sign visibility literature, it is useful, if somewhat artificial, to divide the research by the type of visibility studied. The two main sign visibility research areas focus on sign detection and sign legibility. These areas are interdependent; one cannot read a sign that one cannot find, and there is little point in detecting a sign that cannot be read from the road. However, from a sign design and placement viewpoint, the characteristics that affect detection and legibility differ enough qualitatively to warrant separate consideration.

7.5.1 Detection

A sign's detectability is directly related to its conspicuity. However, while conspicuity is often thought of simply as target value, in that it describes how readily a sign is perceived, in reality, it is produced by a complex combination of sign factors, environmental qualities, and observer variables. Mace and Pollack (1983) wrote that "conspicuity . . . is not an observable characteristic of a sign, but a construct which relates measures of perceptual performance with measures of background, motivation, and driver uncertainty." This section addresses conspicuity and the characteristics of the environment, sign, and driver that directly affect both the likelihood and distance of sign detection.

Sign-Placement Variables. One of the most important factors in sign detection has nothing to do with characteristics of the sign itself. That factor is sign placement. Because a sign that is not well placed cannot be seen and therefore cannot be read, a sign's positioning relative to its environment is key to its effectiveness. This section covers sign mounting height and offset and the immediate sign environment, or the sign's "surround."

Lateral and Vertical Offset. Careful placement of signs along the roadway ensures that a driver has sufficient time to detect the sign and take necessary action. Pietrucha, Donnell, Lertworawanich, and Elefteriadou (2003) reported that for low-mounted storefront signs, the time a driver has to detect, read, and comprehend the sign depends on the position of the vehicle on the road's cross-section, the amount of traffic in both directions, and the sign's lateral offset. Upchurch and Armstrong (1992) found placement of signs with respect to restricting geometric features of the roadway, such as hills and curves, to be important in maximizing detection distance. Mace and Pollack (1983) stated that as the distance between a target sign and "noise" items increases, the sign becomes more conspicuous, although this conspicuity is eroded as the sign becomes located further from the center of the driver's visual field. Claus and Claus (1975) quantified this when they wrote that signs should be placed within 30° of the driver's line of sight. Matson (1955) suggested "that a sign should fall within a visual cone of 10° to 12° on the horizontal axis and 5° to 8° on the vertical axis" (in Hanson and Waltman 1967). Jenkins and Cole (1986) took this statement a step further when they wrote, "[I]f a sign is to be noticed . . . it will be within 10 degrees of his line of sight. When the eccentricity . . . becomes greater than this, the sign is most unlikely to be noticed at all." Jenkins and Cole's statement is supported by Zwahlen's (1989) study of nighttime traffic sign conspicuity in the peripheral visual field. Zwahlen found that retroreflective signs placed in the foveal region resulted in twice the detection distances of those located 10° outside this central visual area. A further result from Zwahlen's study was that signs located 20° and 30° outside the fovea resulted in one-third and one-quarter the detection distances, respectively, of centrally located signs.

As indicated by Zwahlen's study, sign placement is particularly important for retroreflective signs. This is because the angle between the vehicle and the sign strongly influences sign brightness and therefore nighttime sign detection (McNees and Jones 1987). A retroreflective material returns light back to its source as a function of entrance angle which describes the relative positions of the headlamps and sign. As a general rule, when this angle increases, the amount of reflected light seen by the driver decreases (King and Lunenfeld 1971). Thus, when placing retroreflective signs it is important to obtain entrance angles as close to the manufacturer's recommendations as is practically possible.

Surround. Where a sign is placed in relation to other visual stimuli defines the visual complexity of the sign's surround. The factors that affect visual complexity include the number and overall density of noise in the driver's visual field and the density of noise items immediately adjacent to the sign (Mace and Pollack 1983). Research conducted on signs with various levels of retroreflectivity in different environments reveals that virtually any retroreflective sign can be seen at a reasonable distance in an environment that is not visually complex (Mace and Pollack 1983). In other words, if a sign does not have to compete with many other objects in a driver's cone of vision, it is conspicuous, even if its retroreflectivity is low. However, in an area that has more visual distractions, sign conspicuity becomes more a function of its retroreflectivity, size, color, and other variables (Mace and Pollack 1983; Mace, Garvey, and Heckard 1994). McNees and Jones (1987) supported Mace and his colleagues when they asserted that as the number of objects in the driver's cone of vision increases, the conspicuity of a sign decreases. However, when a sign is located in a visually complex environment, retroreflectivity may not be enough to ensure sign detection (Mace and Pollack 1983). Thus, in more complex environments, conspicuity boosters will be needed to achieve a desired detection distance. In such situations, additional lighting or sign redundancy may be necessary to provide adequate conspicuity to ensure timely sign detection. In such situations, additional lighting or sign redundancy may be necessary to provide adequate conspicuity to ensure timely sign detection. The *MUTCD* (FHWA 2009) discusses 11 methods for enhancing sign conspicuity, including adding LEDs to the legend, symbol, or border of a sign; increasing sign size; putting signs on the right- and left-hand sides of the road across from each other; adding red or orange flags to the signs; and reflectorizing the signpost.

Lighting Variables. The first step in visual perception is the detection of light. Differences in the quantity (e.g., luminance) and quality (e.g., color) of light are necessary to differentiate objects. A sign with the same luminance and color as its background is undetectable. Therefore, the term *lighting variables,* as used in this section, refers not only to illuminated nighttime sign display, but to all factors that fall within the category of photometric sign properties. While this category includes nighttime illumination techniques, it also covers daytime and nighttime sign luminance, sign color, and luminance and color contrast between the sign and surround.

External Luminance Contrast. Sign contrast affects both conspicuity and legibility distance. In sign visibility research, there are two types of luminance contrast: external and internal. Detection distance is affected by external sign contrast, which is the ratio of the sign's average luminance and the luminance of the area directly surrounding the sign. Legibility distance is affected by internal sign contrast, defined by the ratio of the luminance of a sign's content and its background.

As a sign's external contrast ratio increases, so does the sign's conspicuity (Forbes et al. 1968a; Mace and Pollack 1983). Mace, Perchonok, and Pollack (1982) concluded that in low visual complexity locations, external contrast and sign size are the major determinants of sign detection. Cooper (1988) goes a step further in stating that external contrast plays a far greater role in sign conspicuity than does sign size. While no research provides optimal and minimum values for external contrast, McNees and Jones (1987) found high-intensity background sheeting (i.e., ASTM type III, or encapsulated lens) with high-intensity copy, opaque background sheeting with button copy (i.e., letters embedded with "cat's eye" reflectors), and engineer-grade background sheeting (i.e., ASTM type I, or enclosed lens) with button copy to provide acceptable freeway guide sign-detection distances.

Sign Luminance. Mace and Pollack (1983) stated that sign conspicuity increases with higher sign luminance. Furthermore, Mace, Perchonok, and Pollack (1982) concluded that, with the exception of black-on-white signs, increasing sign luminance could even offset the detrimental effects of increased visual complexity. Pain (1969) stated, "a higher [overall] brightness enhances a high brightness ratio [external contrast] by roughly 10 percent." Zwahlen (1989) buttressed these findings when he concluded that increasing retroreflective sign SIA values can offset the negative effects of peripheral location. Research conducted on various types of commonly used retroreflective background sheeting combined with reflective copy concurs, indicating that conspicuity increases as sign retroreflectivity increases (McNees and Jones 1987). Research on white-on-green signs (Mace, Garvey, and Heckard 1994) goes further in reporting that sign brightness can actually compensate for sign size. Mace et al. found that small (24-inch) diamond-grade (i.e., ASTM type VII, or microprismatic) signs produced the same legibility distance as large (36-inch) engineer-grade signs.

Nighttime conspicuity research conducted by Mace, Garvey, and Heckard (1994) indicated that the relationship between sign brightness and detection distance is mediated by sign color. They found no difference in detection distance for either black-on-white or black-on-orange signs as a function of retroreflective material. However, higher-reflectance materials resulted in an improvement in detection distance for white-on-green signs at high and low visual complexity sites.

Color. Forbes et al. (1968b) concluded that "relative brightness is of most importance, but hue [color] contrast enhances the brightness effects in some cases." Of the background sign colors black, light gray, and yellow, Cooper (1988) found yellow to be the most effective for sign detection. Mace, Garvey, and Heckard (1994) reported that black-on-orange and white-on-green signs were detected at greater distances than black-on-white signs. This is consistent with the research of Jenkins and Cole (1986), which found black-on-white signs to provide particularly poor conspicuity. Mace, Garvey, and Heckard (1994) concluded that the reason for this was that white signs were being confused with other white light sources and that it was necessary to get close enough to the sign to determine its shape before recognizing it as a sign. Mace et al.'s research punctuates the interaction between various sign characteristics (such as shape and color) in determining sign conspicuity. Zwahlen and Yu (1991) furthered the understanding of the role color plays in sign detection when they reported their findings that sign color recognition distance was twice that of shape recognition and that the combination of a highly saturated color and specific shape of a sign could double a sign's average recognition distance.

Sign Variables. In addition to environmental and photometric variables, there are a number of characteristics related to sign structure and content that have been found to affect sign detection. These characteristics include the size and shape of the sign and the message design.

Size and Shape. The size and shape of a sign relative to other stimuli in the driver's field of vision play a role in determining the sign's conspicuity. Mace, Garvey, and Heckard (1994) found significant increases of around 20 percent in both nighttime and daytime detection distances with increases in sign size from 24 to 36 inches for black-on-white, black-on-orange, and white-on-green signs. In 1986, Jenkins and Cole conducted a study that provides corroborative evidence that size is a key factor in sign detection. Jenkins and Cole concluded that sign sizes between 15 and 35 inches are sufficient to ensure conspicuity, and that if signs of this size or bigger are not detected, the problem is with external contrast or surround complexity. In addition to the effects of sign size, Mace and Pollack (1983) concluded that conspicuity also increases if the shape of the sign is unique compared to other signs in the area.

Display. Forbes et al. (1968b) found green signs with high internal contrast to improve sign detection. In particular, these researchers found signs with bright characters on a dark background to have the highest conspicuity under light surround conditions and the reverse to be true for dark or nighttime environments. Hughes and Cole (1984) suggest that bold graphics and unique messages increase the likelihood of meaningful detection.

7.5.2 Legibility

Once a sign has been detected, the operator's task is to read its content; this is sign legibility. *Legibility* differs from *comprehensibility* in that *legibility* does not imply message understanding. Symbol signing provides a good example of this distinction. An observer could visually discern the various parts of a symbol and yet be unable to correctly report that symbol's meaning. The same is true for alphanumeric messages with confusing content. The problem with drawing a distinction between legibility and comprehension, however, is that familiar symbolic and textual messages are accurately reported at much greater distances than novel sign copy (Garvey, Pietrucha, and Meeker 1998). This well-documented phenomenon leads to the need to distinguish legibility from recognition.

Because recognition introduces cognitive factors, message recognition does not require the ability to discriminate all the copy elements—such as all the letters in a word, or all the strokes in a symbol—in order for correct identification to occur (Proffitt, Wade, and Lynn 1998). Familiar word or symbol recognition can be based on global features (Garvey, Pietrucha, and Meeker 1998). Sign copy recognition distances are, therefore, longer than would be predicted by either visual acuity or sign characteristics alone (Kuhn, Garvey, and Pietrucha 1998). In fact, one of the best ways to improve sign-reading distance is not through manipulation of sign characteristics, but rather by making the sign copy as familiar to the target audience as possible, a concept not lost on the advertising community.

However, modifications in sign design that improve sign legibility will enhance the reading distance for both novel and familiar content. The following sections provide an overview of more than 60 years of research on how to improve sign legibility. The research emphasizes the importance of sign characteristics such as photometric properties and symbol and textual size and shape.

Lighting Variables. The role of lighting variables in sign legibility is probably one of the best-researched areas in the sign visibility field. In this research, negative-contrast sign legibility (i.e., dark letters on a lighter background; e.g., regulatory and warning signs) is typically measured as a function of sign background luminance, and positive-contrast sign legibility (i.e., light letters on a darker background; e.g., guide signs) as a function of internal luminance contrast ratio.

Internal Contrast. Sivak and Olson (1985) derived perhaps the most well-accepted optimum contrast value for sign legibility. These researchers reviewed the sign legibility literature pertaining to sign contrast and came up with a contrast ratio of 12:1 for "fully reflectorized" or positive contrast signs using the average of the results of six separate research efforts. This 12:1 ratio would, for example, result in a sign with a 24 cd/m^2 legend and a 2 cd/m^2 background. This single, optimal ratio was expanded in a 1995 synthesis report by Staplin (1995) that gave a range of acceptable internal contrast levels between 4:1 and 50:1.

McNees and Jones (1987) found that the selection of retroreflective background material has a significant effect on sign legibility. These researchers found four combinations of sheeting and text to provide acceptable legibility distances for freeway guide signs: button copy on super engineer-grade (ASTM type II, or enclosed lens) background sheeting, high-intensity text on high-intensity background, high-intensity on super engineer, and high-intensity on engineer grade. Earlier research by Harmelink et al. (1985) concurs. These researchers found that observers favored high-intensity text on engineer-grade background, stating that this combination provided contrast ratios as good as those produced by high-intensity text on high-intensity background.

Sign Luminance. Khavanin and Schwab (1991) and Colomb and Michaut (1986) both concluded that only small increases in nighttime legibility distance occur with increases in sign retroreflectivity. More recently, however, Carlson and Hawkins (2002a) found that signs made of microprismatic sheeting resulted in longer legibility distances than those using encapsulated materials. The research of McNees and Jones (1987), Mace (1988), and Garvey and Mace (1996) supports that of Carlson and Hawkins.

Based on a review of the literature, Sivak and Olson (1983) suggested an optimal nighttime sign legend luminance of 75 cd/m^2 and a minimum of 2.4 cd/m^2 for negative contrast signs. With positive contrast signs, Garvey and Mace (1996) found 30 cd/m^2 to provide maximum nighttime legibility distance. Again using positive contrast signs, Garvey and Mace (1996) found that daytime legibility distance continued to improve with increases in luminance up to 850 cd/m^2, after which performance leveled off. In a study of on-premise sign visibility, Garvey, Pietrucha, and Cruzado (2008) found that nighttime legibility distance threshold for black-on-white (negative contrast) signs continued to increase until background sign luminance reached about 600 cd/m^2, above which legibility distance began to decrease.

Lighting Design. Overall, the literature indicates that a sign's luminance and contrast have a greater impact on legibility than does the specific means used to achieve these levels. Jones and Raska (1987) found no significant differences in legibility distance between lighted and unlighted overhead-mounted retroreflective signs for a variety of sign materials (McNees and Jones 1987). Other research extends this finding, indicating no significant difference in legibility distances for up to 10 different sign-lighting system types for freeway guide signs (McNees and Jones 1987; Upchurch and Bordin 1987). However, in a test track study that evaluated the effects of sign illumination type on storefront signs, Kuhn, Garvey, and Pietrucha (1999) found internally and neon-illuminated signs to perform 40 to 60 percent better at night than externally illuminated signs. A follow-up study (Garvey et al. in press) showed that even greater improvements (almost 70 percent on average and 240 percent in the best case) can be made when actual in-use, externally illuminated signs in the real world are upgraded to ones that use internal illumination.

In a study of changeable message sign (CMS) visibility, Garvey and Mace (1996) found retroreflective and self-illuminated lighting design to provide equivalent legibility distances. Garvey and Mace did, however, find that the use of "black light" ultraviolet lighting severely reduced legibility. This was attributed to a reduction in internal luminance contrast and color contrast. Hussain, Arens, and Parsonson (1989) addressed this problem when they recommended the use of "white" fluorescent lamps for optimum color rendition and metal halide for overall performance (including color rendition) and cost-effectiveness.

Sign-Placement Variables.

Lateral Sign Placement. Sign placement is as important to sign legibility as it is to detection. First, there is the obvious need to place signs so that traffic, pedestrians, buildings, and other signs do not block their messages. A less intuitive requirement for sign placement, however, involves the angle between the observer location and the sign (Prince 1958, in Claus and Claus 1974). Signs set off at large angles relative to the intended viewing location result in letter and symbol distortion. Prince recommended that the messages on signs at angles greater than 20° be manipulated (i.e., increased in height and/or width) to appear "normal" to the observer. Garvey (2006) took this a step further by developing a mathematical model to calculate letter heights for signs as a function of lateral offset.

Sign Variables.

Letter Height. If a response to a guide sign is required, the typical behavior is speed reduction and a turning maneuver at the appropriate crossroad or interchange. On multilane roadways, the motorist may also have to change lanes. For warning and regulatory signs the motorist may have to reduce speed and will sometimes be required to change lanes or make a steering adjustment. Whether the sign is regulatory, warning, or for guidance, sign placement should allow sufficient time to comfortably react to the sign message after passing the sign. With the exception of corner-mounted street name signs, what occurs before the driver passes the sign should be limited to sign detection and reading for comprehension. Appropriate letter heights ensure sufficient time to accomplish the reading task.

READING SPEED. Proffitt, Wade, and Lynn (1998) reported that the average normal reading speed for adults is about 250 words per minute (wpm), or 4.2 words per second. Research evaluating optimum acuity reserve (the ratio between threshold acuity and optimal print size) has demonstrated that optimal reading speeds result from print size that may be as much as four times size threshold (Bowers and Reid 1997; Yager, Aquilante, and Plass 1998; Lovie-Kitchin, Bowers, and Woods 2000). In fact, Yager, Acvilante, and Plass (1998) reported 0.0 wpm reading speed at size threshold. This explains some of the disparity between "normal" reading speed of above size threshold text and the time it takes to read a sign, which often begins at acuity threshold.

Research on highway sign reading provides evidence that it takes drivers approximately 0.5 to 2.0 seconds to read and process each sign word. Dudek (1991) recommended a minimum exposure time of "one second per short word . . . or two seconds per unit of information" for unfamiliar drivers to read changeable message signs. In a study conducted by Mast and Balias (1976), average advance guide sign reading was 3.12 seconds and average exit direction sign reading was 2.28 seconds. Smiley et al. (1998) found that 2.5 seconds was sufficient for 94 percent of their subjects to read signs accurately that contained three destination names; however, this dropped to 87.5 percent when the signs displayed four or five names.

McNees and Messer (1982) mentioned two equations to determine reading time: $t = (N/3) + 1$ and $t = 0.31N + 1.94$ (where t is time in seconds and N is the number of familiar words). In a literature survey on sign comprehension time, Holder (1971) concluded that the second equation was appropriate if the sign was located within an angular displacement of 10°. In their own research, McNees and Messer (1982) found that the time it takes to read a sign depends, among other things, on how much time the driver has to read it; in other words, signs are read faster when it is necessary to do so. However, they also found that as reading speed increases, so do errors; an example of the well-documented speed-accuracy tradeoff. McNees and Messer (1982) concluded that, "a cut-off of approximately 4.0 sec to read any sign was critical for safe handling of a vehicle along urban freeways." If the 4.0 seconds are plugged back into the second equation, the number of familiar words on the sign would be 6.7, or 1.7 words per second.

While it is impractical to specify a single minimum reading time that will allow all drivers to read and understand all signs, the research on sign-reading speed indicates that signs with four to eight words could be comfortably read and comprehended in approximately 4.0 seconds and signs with one to three words in about 2.5 seconds.

TASK LOADING. In addition to sign reading, the driver must also watch the road and perform other driving tasks. Considering overhead guide signs, McNees and Messer (1982) estimated that a 4.5-second sign-reading time would actually require an 11.0-second and sign-legibility distance. This results from adding 2.0 seconds for sign-clearance time (when the vehicle is too close to the sign for the driver to read it) and dividing the remaining 9.0 seconds equally between sign reading and other driving tasks. In looking at shoulder-mounted signs, Smiley et al. (1998) provide more practical estimates. These researchers allowed for 0.5 seconds clearance time and a 0.5-second glance back at the road for every 2.5 seconds of sign reading (based on eye movement research by Bhise and Rockwell 1973). This would require a 5.0-second legibility distance for 4.0 second of sign reading and 3.0 seconds legibility distance for 2.5 seconds of sign reading. This is assuming that the driver begins to read the sign as soon as it becomes legible. Allowing an additional 1.0 seconds for sign acquisition after it becomes legible, appropriate legibility distance for signs displaying four to eight words would be 6.0 seconds and for signs with one to three words would be 4.0 seconds. Based on these calculations and assuming a legibility index of approximately 40 ft/in., Table 7.1 provides reading times and recommended letter heights as a function of the number of words on the sign and travel speeds.

DIMINISHING RETURNS. While research indicates that legibility distance increases with letter height, a point of diminishing return exists (Allen et al. 1967; Khavanin and Schwab 1991). For example, doubling letter height will increase, but will not double, sign reading distance. Mace, Perchonok, and Pollack (1994) and Garvey and Mace (1996) found that increases in letter height above about 8 inches resulted in nonproportional increases in legibility distance. Garvey and Mace (1996) found that a sign with 42-inch characters produced only 80 percent of the legibility index of the same sign with 18-inch characters. That is, the 42-inch character produced a legibility distance of approximately 1,350 feet (LI = 32 ft/in.) while the 18-inch characters resulted in a legibility distance of about 800 ft (LI = 44 ft/in.).

Text versus Symbols. In a study of traffic sign comprehension speed, Ells and Dewar (1979) found symbolic signs to outperform those with textual messages. These researchers also discovered that symbolic signs were less susceptible than were text signs to visual degradation. In a 1975 visibility study, Jacobs, Johnston, and Cole assessed the legibility distance of almost 50 symbols and their textual counterparts. These researchers found that in the majority of cases the legibility distances for the symbols were twice that of the alphanumeric signs. This finding was replicated in Kline and Fuchs' (1993) research for a smaller set of symbols using young, middle-aged, and older observers. Kline and Fuchs' research also introduced a technique to optimize symbol legibility: recursive blurring, which results in symbols designed to "maximize contour size and contour separation." In other words, optimized symbols or logos will have elements that are large enough to be seen from a distance and spaces between the elements wide enough to reduce blurring between elements.

The literature clearly indicates that, from a visibility standpoint, symbols are superior to text. Symbols, however, require a different kind of comprehension than words. Symbol meaning is either understood intuitively or learned. Although traffic sign experts and traffic engineers agree that understandability is the most important factor in symbol design (Dewar 1988), other research has shown that what is intuitive to designers is not always intuitive to drivers, and that teaching observers the meaning of more abstract symbols is frequently unsuccessful. For example, in one study (Kline et al. 1990) even the relatively simple "HILL" symbol resulted in only 85 percent comprehension, while the "ROAD NARROWS" symbol accommodated only 52 percent of the respondents. In researching the Slow Moving Vehicle emblem, Garvey (2003) found correct symbol recognition to be approximately 30 percent for older and younger subjects under daytime and nighttime viewing conditions.

Upper-Case versus Mixed-Case. Forbes, Moskowitz, and Morgan (1950) conducted perhaps the definitive study on the difference in sign legibility between text depicted in all upper-case letters and that shown in mixed-case. When upper- and mixed-case words subtended the same sign area these researchers found a significant improvement in legibility distance with the mixed-case words. Garvey, Pietrucha, and Meeker (1997) replicated this result with new sign materials, a different font, and older observers. They found a 12 to 15 percent increase in legibility distance with mixed-case text under daytime and nighttime conditions. It must be noted, however, that these results were obtained with a recognition task—that is, the observers knew what words they were looking for. In instances where the observer does not know the text, improvements with mixed-case are not evident (Forbes, Moskowitz, and Morgan 1950; Mace, Garvey, and Heckard 1994; and Garvey, Pietrucha, and Meeker 1997).

Font. Assessing the effect of letter style on traffic signs has been limited by state and federal governments' desire to keep the font "clean," in other words, a sans serif alphabet that has a relatively constant stroke width. While sans serif letters are generally considered to provide greater legibility distance than serif letters (Prince 1957, in Claus and Claus 1974), a comparison of the sans serif Standard Highway Alphabet with Clarendon, the serif standard National Park Service font, revealed a slight improvement with the Clarendon font (Mace, Garvey, and Heckard 1994).

Currently, the only font allowed by FHWA on road signs is the Standard Highway Alphabet (FHWA 2004). However, research on highway font legibility (Garvey, Pietrucha, and Meeker 1997, 1998; Hawkins et al. 1999; and Carlson and Brinkmeyer 2002) has led the FHWA to allow any state that requests it to use Clearview on all their positive-contrast signs (Figure 7.3). Clearview was designed to reduce halation (Figure 7.4) resulting from the use of high-brightness retroreflective materials (i.e., microprismatic sheeting) and improve letter legibility for older drivers. Related research for the National Park Service has led that agency to accept NPS Roadway as an alternate to the NPS's current Clarendon font (Figure 7.5). NPS Roadway has been shown to increase sign legibility by 10.5 percent while reducing word length by 11.5 percent (Garvey et al. 2001).

Stroke Width. Kuntz and Sleight (1950) concluded that the optimal stroke width-to-height ratio for both positive and negative-contrast letters was 1:5. Forbes et al. (1976) found increases in legibility distance of fully reflectorized, positive-contrast letters and decreases in legibility for negative-contrast letters when the stroke width-to-height ratio was reduced from 1:5 to 1:7. That is, light

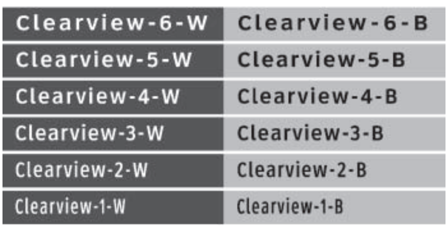

FIGURE 7.3

FIGURE 7.4

FIGURE 7.5

letters on a darker background should have a thinner stroke and dark letters on a lighter background should have a bolder stroke. Improved legibility for fully reflectorized, white-on-green signs with thinner stroke width was also found by Mace, Garvey, and Heckard (1994) for very high contrast signs, and for mixed case text by Garvey, Pietrucha, and Meeker (1998).

Abbreviations. In a study of changeable message sign comprehension, Huchingson and Dudek (1983) developed several abbreviation strategies. These researchers recommended the technique of using only the first syllable for words having nine letters or more; for example, *Cond* for *Condition*. This technique should not, however, be used if the first syllable is in itself a new word. A second method using the key consonants was suggested for five-to seven-letter words; for example, *Frwy* for *Freeway*. The *MUTCD* (FHWA 2009) provides lists of "acceptable" and "unacceptable" abbreviations for traffic control devices. Abbreviations, however, are to be used only as a last resort if limitations in sign size demand it, as they increase the possibility of incorrect sign interpretation. Alternative suggestions to deal with sign size limitations include selecting a synonym for the abbreviated word, reducing letter size, reducing message length, and increasing sign size.

Contrast Orientation. The research on this issue is clear; with the possible exception of tight inter-character spacing (Case et al. 1952), positive-contrast signs provide greater legibility distances than negative-contrast signs. As far back as 1955, laboratory research by Allen and Straub found that white-on-black signs (positive-contrast) provided longer legibility distances than black-on-white signs when the sign luminance was between 3 and 30 cd/m^2. Allen et al. (1967) replicated these results in the field. Garvey and Mace (1996) extended these results in their changeable message sign research with the addition of orange, yellow, and green signs. Positive-contrast signs resulted in improvements of about 30 percent over negative-contrast signs (Garvey and Mace 1996).

Color. Schnell et al. (2001) found small legibility improvements when comparing signs using fluorescent colors versus signs using matching nonfluorescent colors. However, in an evaluation of normal sign colors, Garvey and Mace (1996) found no difference in legibility distance that could not be accounted for by luminance, luminous contrast, or contrast orientation between signs using the following color combinations: white/green, black/white, black/orange, black/yellow, and black/red. This is also consistent with the findings of research on computer displays (Pastoor 1990). In general, the research indicates that if appropriate luminance contrast, color contrast, and luminance levels are maintained, the choice of specific colors for background and text does not affect legibility distance.

7.6 FINAL REMARKS

For any type of highway sign to be visually effective, it must be readable. While this seems like a fairly simple objective to achieve, the information presented herein indicates that the ability of a driver to detect and read a sign is a function of numerous human, environmental, and design factors with complex interrelationships. For example, visual acuity, contrast sensitivity, visual field, and glare can significantly impact the driver's ability to see the sign and read its message. Furthermore, the basic design and placement of the sign can greatly impact the detectibility and legibility of any highway sign. Features such as height, lateral offset, reflectorization, illumination, message design, font, case, letter height, border, and letter spacing are so critical that federal guidelines dictate these features to maximize the potential for a driver to see the sign within the highway environment. The photometric characteristics of the sign, including the internal contrast, luminance, and light design, can also directly impact how well a driver sees a sign. And if all of these factors are not enough, the location of a sign relative to the rest of the highway environment can either enhance its detectibility or force it to compete with other signs and objects for visibility. Thus, the task of designing detectible, legible, and understandable highway signs is a challenge that continues to be refined as we learn more about their role in the highway environment and their interaction with the driver. Ultimately, we hope to provide critical information to the traveler that they can use in a timely manner to navigate safely through the highway environment.

REFERENCES

Allen, T. M., and Straub, A. L. 1955. "Sign Brightness and Legibility." *Highway Research Board Bulletin* 127, 1–14.

Allen, T. M., F. N. Dyer, G. M. Smith, and M. H. Janson. 1967. "Luminance Requirements for Illuminated Signs." *Highway Research Record* 179, 16–37.

American Society for Testing and Materials (ASTM). 2001. *Standard Test Method for Coefficient of Retroreflection of Retroreflective Sheeting Utilizing the Coplanar Geometry.* Document Number ASTM E810-01, ASTM International.

Ball, K., and C. Owsley. 1991. "Identifying Correlates of Accident Involvement for the Older Driver." *Human Factors* 33(5):583–95.

Bhise, V. D., and T. H. Rockwell. 1973. *Development of a Methodology for Evaluating Road Signs.* Final Report, Ohio State University.

Boff, K. R., L. Kaufman, and J. P. Thomas. 1986. *Handbook of Perception and Human Performance,* vols. 1 and 2. New York: John Wiley & Sons.

Bowers, A. R., and V. M. Reid. 1997. "Eye Movement and Reading with Simulated Visual Impairment." *Ophthalmology and Physiological Optics* 17(5):492–02.

Carlson, P. J., and G. Brinkmeyer. 2002. "Evaluation of Clearview on Freeway Guide Signs with Microprismatic Sheeting." *Transportation Research Record* 1801, 27–38.

Carlson, P. J., and G. Hawkins. 2002a. "Legibility of Overhead Guide Signs Using Encapsulated versus Microprismatic Retroreflective Sheeting." Presented at the 16th Biennial Symposium on Visibility and Simulation, Iowa City, IA.

———. 2002b. "Minimum Retroreflectivity for Overhead Guide Signs and Street Name Signs." *Transportation Research Record* 1794, 38–48.

Case, H. W., J. L. Michael, G. E. Mount, and R. Brenner. 1952. "Analysis of Certain Variables Related to Sign Legibility." *Highway Research Board Bulletin* 60, 44–58.

Claus, K., and J. R. Claus. 1974. *Visual Communication through Signage,* vol. 1, *Perception of the Message.* Cincinnati: Signs of the Times.

Colomb, M., and G. Michaut. 1986. "Retroreflective Road Signs: Visibility at Night." *Transportation Research Record* 1093, 58–65.

Cooper, B. R. 1988. "A Comparison of Different Ways of Increasing Traffic Sign Conspicuity." *TRRL Report* 157.

Dewar, R. E. 1988. "Criteria for the Design and Evaluation of Traffic Sign Symbols." *Transportation Research Record* 1160, 1–6.

Dudek, C. L. 1991. *Guidelines on the Use of Changeable Message Signs.* Final Report, DTFH61-89-R00053, U.S. DOT, Federal Highway Administration, Washington, DC.

Ells, J. G., and R. E. Dewar. 1979. "Rapid Comprehension of Verbal and Symbolic Traffic Sign Messages." *Human Factors* 21, 161–68.

Federal Highway Administration (FHWA). 1978a. *Roadway Lighting Handbook.* U.S. Department of Transportation, FHWA, Washington, DC.

———. 2004. *Standard Highway Signs*. Washington: U.S. Department of Transportation, FHWA.

———. 2009. *Manual on Uniform Traffic Control Devices for Streets and Highways*. Washington: U.S. Department of Transportation, FHWA.

Forbes, T. W., J. P. Fry, R. P. Joyce, and R. F. Pain. 1968a. "Letter and Sign Contrast, Brightness, and Size Effects on Visibility." *Highway Research Record* 216, 48–54.

Forbes, T. W., K. Moskowitz, and G. Morgan. 1950. "A Comparison of Lower Case and Capital Letters for Highway Signs." *Proceedings, Highway Research Board* 30, 355–73.

Forbes, T. W., R. F. Pain, R. P. Joyce, and J. P. Fry. 1968b. "Color and Brightness Factors in Simulated and Full-Scale Traffic Sign Visibility." *Highway Research Record* 216, 55–65.

Forbes, T. W., B. B. Saari, W. H. Greenwood, J. G. Goldblatt, and T. E. Hill. 1976. "Luminance and Contrast Requirements for Legibility and Visibility of Highway Signs." *Transportation Research Record* 562, 59–72.

Garvey, P. M. 2003. "Motorist Comprehension of the Slow Moving Vehicle (SMV) Emblem." *Journal of Agricultural Safety and Health* 9(2):159–169.

Garvey, P. M. 2005. "On-Premise Commercial Sign Lighting and Light Pollution." *Leukos: The Journal of the Illuminating Society of North America* 1, 7–18.

Garvey, P. M. (2006). "Determination of Parallel Sign Legibility and Letter Heights." *United States Sign Council Foundation (USSCF) Research Project*, Final Report, Bristol, PA.

Garvey, P. M., M. T. Pietrucha, and I. Cruzado. 2008. "The Effect of Internally Illuminated On-Premise Sign Brightness on Nighttime Sign Visibility and Traffic Safety." *United States Sign Council Foundation (USSCF) Research Project*, Final Report, Bristol, PA.

Garvey, P. M., M. T. Pietrucha, S. J. Damin, and D. Deptuch. In press. "Relative Visibility of Internally vs. Externally Illuminated On-Premise Signs." *TRR. Journal of the Transportation Research Board*.

Garvey, P. M., and D. M. Mace. 1996. *Changeable Message Sign Visibility.* Publication No. FHWA-RD94-077.

Garvey, P. M., M. T. Pietrucha, and D. Meeker. 1997. "Effects of Font and Capitalization on Legibility of Guide Signs." *Transportation Research Record* 1605, 73–79.

———. 1998. "Development of a New Guide Sign Alphabet." *Ergonomics in Design* 6(3)7–11.

Garvey, P. M., A. Z. Zineddin, M. T. Pietrucha, D. T. Meeker, and J. Montalbano. 2001. *Development and Testing of a New font for National Park Service Signs.* U.S. Department of the Interior, National Park Service Final Report.

Hanson, D. R., and H. L. Waltman. 1967. "Sign Backgrounds and Angular Position." *Highway Research Record* 170, 82–96.

Harmelink, M. D., G. Hemsley, D. Duncan, R. W. Kuhk, and T. Titishov. 1985. "Evaluation of Reflectorized Sign Sheeting for Nonilluminated Freeway Overhead Guide Signs." *Transportation Research Record* 1010, 80–84.

Hawkins, H. G., D. L. Picha, M. D. Wooldridge, F. K. Greene, and G. Brinkmeyer. 1999. "Performance Comparison of Three Freeway Guide Sign Alphabets." *Transportation Research Record* 1692, 9–16.

Holder, R. W. 1971. "Consideration of Comprehension Time in Designing Highway Signs." *Texas Transportation Researcher* 7(3):8–9.

Huchingson, R. D., and C. L. Dudek. 1983. "How to Abbreviate on Highway Signs." *Transportation Research Record* 904, 1–3.

Hughes, P. K., and B. L. Cole. 1984. "Search and Attention Conspicuity of Road Traffic Control Devices." *Australian Road Research Board* 14(1):1–9.

Hussain, S. F., J. B. Arens, and P. S. Aparsonson. 1989. "Effects of Light Sources on Highway Sign Color Recognition." *Transportation Research Record* 1213, 27–34.

Jacobs, R. J., A. W. Johnston, and B. L. Cole. 1975. "The Visibility of Alphabetic and Symbolic Traffic Signs." *Australian Road Research* 5(7):68–86.

Jenkins, S. E., and B. L. Cole. 1986. "Daytime Conspicuity of Road Traffic Control." *Transportation Research Record* 1093, 74–80.

Khavanin, M. R., and R. N. Schwab. 1991. "Traffic Sign Legibility and Conspicuity for the Older Drivers." In *1991 Compendium of Technical Papers.* Washington, DC: Institute of Transportation Engineers, 11–14.

Kuhn, B. T., P. M. Garvey, and M. T. Pietrucha. 1998. "The Impact of Color on Typical On-Premise Sign Font Visibility." Presented at TRB's 14th Biennial Symposium on Visibility, Washington, DC, April.

———. 1999. "On Premise Sign Legibility and Illumination." In *1999 Compendium of Technical Papers.* Washington, DC: Institute of Transportation Engineers.

King, G. F., and H. Lunenfeld. 1971. *Development of Information Requirements and Transmission Techniques for Highway Users.* NCHRP Report 123, National Cooperative Highway Research Program, Washington, DC.

Kline, D. W., and P. Fuchs. 1993. "The Visibility of Symbolic Highway Signs Can Be Increased among Drivers of All Ages." *Human Factors* 35(1):25–34.

Kline, D. W., K. Buck, Y. Sell, T. L. Bolan, and R. E. Dewar. 1999. "Older Observers' Tolerance of Optical Blur: Age Differences in the Identification of Defocused Test Signs." *Human Factors* 41(3):356–64.

Kline, T. J. B., L. M. Ghali, D. W. Kline, and S. Brown. 1990. "Visibility Distance of Highway Signs among Young, Middle-Aged, and Older Observers: Icons Are Better than Text." *Human Factors* 32(5):609–19.

Kuntz, J. E., and R. B. Sleight. 1950. "Legibility of Numerals: The Optimal Ratio of Height to Width of Stroke." *American Journal of Psychology* 63:567–75.

Lovie-Kitchin, J. E., A. R. Bowers, and R. L. Woods. 2000. "Oral and Silent Reading Performance with Macular Degeneration." *Ophthalmology and Physiological Optics* 20(5):360–70.

Mace, D. J. 1988. "Sign Legibility and Conspicuity." In *Transportation in an Aging Society.* Special Report 218, vol. 2. Washington, DC: National Research Council, Transportation Research Board, 270–93

Mace, D. J., and L. Pollack. 1983. "Visual Complexity and Sign Brightness in Detection and Recognition of Traffic Signs." *Transportation Research Record* 904, 33–41.

Mace, D. J., P. M. Garvey, and R. F. Heckard. 1994. *Relative Visibility of Increased Legend Size vs. Brighter Materials for Traffic Signs.* Report FHWA-RD-94-035, U.S. Department of Transportation, Federal Highway Administration, Washington, DC.

Mace, D., K. Perchonok, and L. Pollack. 1982. *Traffic Signs in Complex Visual Environments.* Report FHWA-RD-82-102, U.S. Department of Transportation, Federal Highway Administration, Washington, DC.

Mast, T. M., and J. A. Balias. 1976. "Diversionary Signing Content and Driver Behavior." *Transportation Research Record* 600, 14–19.

McNees, R. W., and H. D. Jones. 1987. "Legibility of Freeway Guide Signs as Determined by Sign Materials." *Transportation Research Record* 1149, 22–31.

McNees, R. W., and C. J. Messer. 1982. "Reading Time and Accuracy of Response to Simulated Urban Freeway Guide Signs." *Transportation Research Record* 844, 41–50.

Pain, R. F. 1969. "Brightness and Brightness Ratio as Factors in the Attention Value of Highway Signs." *Highway Research Record* 275, 32–40.

Pastoor, S. 1990. "Legibility and Subjective Preference for Color Combinations in Text." *Human Factors* 32(2): 157–71.

Pietrucha, M. T., E. T. Donnell, P. Lertworawanich, and L. Elefteriadou. 2003. "Traffic Volume, Traffic Speed, Mounting Height, and Lateral Offset on the Visibility of On-Premise Commercial Signs." *United States Sign Council Foundation (USSCF) Research Project*, Final Report, Bristol, PA.

Proffitt, D. R., M. M. Wade, and C. Lynn. 1998. *Creating Effective Variable Message Signs: Human Factors Issues.* Final Contract Report, Proj No. 9816-040-940, VTRC 98-CR31, Virginia Department of Transportation, Richmond, VA.

Schnell, T., K. Bentley, E. Hayes, and M. Rick. 2001. "Legibility Distances of Fluorescent Traffic Signs and Their Normal Color Counterparts." *Transportation Research Record* 1754, 31–41.

Sivak, M., and P. L. Olson. 1983. *Optimal and Replacement Luminances of Traffic Signs: A Review of Applied Legibility Research.* UMTRI-83-43, University of Michigan Transportation Research Institute, Ann Arbor, MI.

———. 1985. "Optimal and Minimal Luminance Characteristics for Retroreflective Highway Signs. *Transportation Research Record* 1027, 53–56.

Smiley, A., C. MacGregor, R. E. Dewar, and C. Blamey. 1998. "Evaluation of Prototype Tourist Signs for Ontario." *Transportation Research Record* 1628, 34–40.

Staplin, L. 1995. *Older Driver and Highway Safety Literature Review and Synthesis.* Working Paper in Progress. U.S. Department of Transportation, FHWA, Washington, DC.

———. 1983. *Traffic Control Device Handbook.* U.S. Department of Transportation, FHWA, Washington, DC.

Upchurch, J. E., and J. D. Armstrong. 1992. "A Human Factors Evaluation of Alternative Variable Message Sign Technologies." In *Vehicle Navigation and Information Systems.* Oslo: Norwegian Society of Chartered Engineers, 262–67.

Upchurch, J. E., and J. T. Bordin. 1987. "Evaluation of Alternative Sign-Lighting Systems to Reduce Operating and Maintenance Costs." *Transportation Research Record* 1111, 79–91.

Woods, D. L., and N. J. Rowan. 1970. "Street Name Signs for Arterial Streets." *Highway Research Record* 325, 54.

Yager, D., K. Aquilante, and R. Plass. 1998. "High and Low Luminance Letters, Acuity Reserve, and Font Effects on Reading Speed." *Vision Research* 38:2527–31.

Zwahlen, H. T. 1989. "Conspicuity of Suprathreshold Reflective Targets in a Driver's Peripheral Visual Field at Night." *Transportation Research Record* 1213, 35–46.

Zwahlen, H. T., and J. Yu. 1991. "Color and Shape Recognition of Reflectorized Targets under Automobile Low-Beam Illumination at Night." *Transportation Research Record* 1327, 1–7.