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Visibility of SMV Signs during Twilight

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SUMMARY:

During the darker half of civil twilight, low levels of natural illumination make slow-moving-vehicle (SMV) signs less visible. Their visibility decreases then because drivers must rely more on luminance contrast than color contrast, and a SMV sign's fluorescent orange actually reflects less luminance than does a white surface. Furthermore, about 10%-15% of drivers do not use their headlights during twilight's darker half, and this behavior renders ineffective the red retroreflective edge of the SMV sign. My spectroradiometric measurements show that adding a white border (reflectance = 90%) to the SMV sign would make its contrast exceed the threshold contrast (and thus make the sign detectable) during more of twilight, even for unalerted drivers who do not use their headlights. This added margin of safety for farmers, farm workers, and motorists suggests a simple, but significant, improvement to current SMV sign design.

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Introduction

Since the introduction of the slow-moving-vehicle (SMV) sign in the 1960s (see Dennis *et al.* 1993; ASAE 1988), the sign's high visibility has prevented many highway collisions between SMVs and other vehicles. As a passive warning device, the SMV sign is especially important in alerting motorists to potential collisions with the rear of slow-moving agricultural equipment. According to the National Highway Traffic Safety Administration's Fatal Accident Reporting System (FARS), fatal rear-end SMV accidents happen most often when visibility is poor — 65% occur at night or during twilight, compared with 24% during daylight hours (Gerberich *et al.* 1996).

Because the red and orange SMV triangle has been a familiar sight on rural roads for so long, we might assume that improvements to it are neither necessary nor possible. However, the brighter retroreflectivity standards recently established for SMV signs by the American Society of Agricultural Engineers (ASAE) clearly show that this is not so. The new ASAE S276.5 standard greatly improves the SMV sign's nighttime visibility (Reichenberger 1998a; Dennis *et al.* 1993), but we know very little about its visibility during another very demanding time for drivers — civil twilight. Understanding the SMV sign's excellent daytime and nighttime visibility helps us analyze its twilight performance, so I first consider these lighting extremes.

Visibility of SMV signs: Day and night

During daytime hours, the *fluorescence* of a sunlit SMV sign's orange interior seems to make it look "brighter than white." Fluorescence is the near-instantaneous emission of light in one region of the spectrum (*e.g.*, orange) in response to the absorption of light in another spectral region (*e.g.*, ultraviolet). Thus at orange wavelengths, the fluorescent orange of a SMV sign reflects and emits more light than a non-fluorescing white surface reflects (see Fig. 1 between 585 nanometers (nm) and 680 nm). At daytime levels of ambient illumination (*illuminance*, measured in lux), this property gives fluorescent orange an unusual, attention-getting combination of high brightness and color purity (Reichenberger 1998b).

Yet Fig. 1 also shows that, compared to wood or fluorescent orange, a bright white surface reflects most incident light at nearly *all* visible wavelengths and not just in one part of the spectrum. In fact, a sunlit white surface with mean reflectance R = 90% reflects about 1.6 times as much visible light as does SMV orange, so the SMV sign's superior daytime visibility actually depends on its bright, literally unnatural color (Dennis *et al.* 1993) and on the resulting *color contrast* with its surroundings. At night, a SMV sign's red *retroreflective* border reflects much more headlight luminance back to drivers than do ordinary diffusely-reflecting materials (Rennilson 1997). Because headlights usually are the only significant source of lighting on nighttime rural roads, much attention has been given to making the SMV border as retroreflective as possible (Dennis *et al.* 1993).

Visibility of SMV signs: Twilight

How well does the current SMV sign perform during twilight? As evening twilight progresses and reflected luminances decrease, research shows that a driver's ability to detect unlit objects in the road steadily changes from excellent to poor (Leibowitz and Owens 1991; Owens *et al.* 1989). Note that *luminance* quantifies object brightness and can be measured in candela/meter^2. We define civil twilight as the period between sunset or sunrise and when the unrefracted sun elevation $h_0 = -6^\circ$, about 1/2 hour at most latitudes (note that h_0 is calculated for the sun's center and with respect to a level horizon). During twilight, outdoor illumination consists solely of skylight. Yet even when $h_0 < +5^\circ$, many shaded outdoor surfaces are lit mostly by skylight rather than direct sunlight. Because this period before sunset and after sunrise has lighting conditions similar to those during twilight proper, I extend the astronomical definition of twilight slightly to include it as well.

We all know that our surroundings get darker during evening twilight as h_0 decreases. Figure 2 summarizes many of my measurements of twilight illuminances falling on a horizontal surface, and it shows that outdoor illuminances depend not only on h_0, but also on site topography, shading, and cloud cover. The illuminance range between the beginning and end of civil twilight is enormous and may exceed 4500:1. Practically speaking, color vision begins to degrade for $h_0 < -2^\circ$ (assuming clear skies), and drivers increasingly rely on *luminance contrast* for detection rather than on color contrast.

If all drivers used their headlights throughout twilight, they could detect retroreflective SMV signs fairly easily. However, my surveys show that 10%-15% of drivers do not turn on their headlights until near the end of evening civil twilight (or even later), and some will turn off their headlights well before sunrise. For these drivers, neither the fluorescence nor retroreflectivity of a SMV sign yields enhanced visibility when $h_0 < -2^\circ$, a time when farm vehicles and implements are often on public roads. Thus for about 1/2 hour total each day, the current SMV sign does not enhance SMV visibility on the highway, even if the sign is brand new. In fact, we have very little quantitative data on just how visible the colorful SMV sign is under dim twilight illumination.

Quantifying the twilight visibility of SMV signs

To quantify SMV twilight visibility, I start by defining luminance contrast C as:

$$C = \frac{L_{obj} - L_{surr}}{L_{surr}}, \qquad \text{(Eq. 1)}$$

where L_{obj} is the luminance of an object to be detected and L_{surr} that of its immediate surroundings. Equation 1 is a widely used definition of contrast (*e.g.*, Neuberger 1957, p. 33). In order for a driver to see an object in the road, the object's C must exceed some threshold contrast C_{thresh}. Among other factors, C_{thresh} depends on (a) the object's angular size, (b) L_{surr} (and thus on twilight illuminance), and (c) a hard-to-quantify factor called *driver expectancy*. Practically speaking, driver expectancy means that drivers who do not expect to encounter a SMV on the highway will have a higher C_{thresh} than those who do. Call the former group of drivers "unalerted" and the latter "alerted," noting that many drivers are unalerted for purposes of detecting SMVs.

Research shows that unalerted drivers need C_{thresh} to be 5 times (or more) greater than for alerted drivers (Bhise *et al.* 1977, pp. 26, 47). So I now define $C5 \equiv 5 * C_{thresh}$, meaning that a SMV sign with C > C5 will alert all but a few drivers. To measure the contrast of two new SMV signs, I use a spectroradiometer to measure L_{surr} for a fairly typical SMV sign background (unpainted wood) and L_{obj} for either (a) a photographer's white card (R = 90%) or (b) a SMV sign's fluorescent orange. Figure 3 shows a continuous series of these measurements made during a clear evening twilight. In Fig. 3, note how the Eq. 1 contrasts of the white card and SMV orange change during twilight compared with C5. My measurements show that the fluorescent (as opposed to retroreflective) properties of the ASAE S276.3 and S276.5 signs are about the same.

As evening twilight proceeds, the problem is not that C decreases (it actually increases slightly in Fig. 3), but that C_{thresh} and C5 increase greatly. This quantifies our daily experience that the darker it gets, the harder things are to see. Figure 4 displays the same data as Fig. 3, but instead plots the ratio C:C5 *vs.* time after sunset. If C:C5 < 1, an unalerted driver will not detect the SMV sign. This does *not* mean that the sign would be invisible if a driver looked directly at it then. Instead, when C:C5 < 1, the SMV sign's contrast is too small to prompt the unalerted driver (who by definition is not looking for the sign) that a hazard exists.

Figure 4 shows that if the current SMV sign's fluorescent orange is (a) lit only by ambient outdoor illumination (*i.e.*, is unlit by car or truck headlights), and (b) 250' from an unalerted driver, then at about 5 minutes after sunset this SMV sign will fail to attract the driver's attention. By comparison, a white sign of equal size and R = 90% can alert an unalerted driver until about 16 minutes after sunset. The net result is that, compared to an unlit orange SMV sign, a white sign with R = 90% provides ~ 11-12 more minutes of detection time for the unalerted driver during twilight. Furthermore, Fig. 4 shows that the twilight contrast of a white sign is consistently much greater than that of SMV orange.

Several points are worth making here. First, increasing C_{thresh} fivefold may demand too much of either sign (*i.e.*, unalerted drivers *might* detect the signs several minutes later in twilight), but my C5 values in Fig. 4 err on the side of safety. Second, 250' is a reasonable 45-mph stopping sight distance (Owens *et al.* 1989). At distances < 250', a sign of either color would be effective until several minutes later in twilight because each sign's angular size would be larger, thus making it easier to detect. However, at distances < 250' an unalerted driver might not be able to stop in time to avoid colliding with the SMV. Third, twilight h_0 changes faster in winter than in summer (*i.e.*, the sun sets faster in winter). So is "time after sunset" a good substitute for h_0 in Fig. 4? The answer is that because Fig. 4's winter and summer C:C5 trends are essentially the same, in midlatitudes we can legitimately substitute time after sunset for h_0, at least given the uncertainties involved in measuring C.

How might we improve the current SMV sign?

During the day, SMV orange is very effective in alerting motorists to the presence of SMVs in the road. Yet in principle, a white target is more visible during twilight and would make the SMV sign much more effective then. How do we make practical use of this knowledge? First, any changes to the current SMV sign/emblem must show in real-world tests that they actually improve the twilight visibility of SMVs. In addition, these changes should (a) best exploit the extra visibility that white affords (*i.e.*, present a large white target), and (b) be conservative (*i.e.*, not change the shape of the current SMV sign).

Figure 5 shows one alternative that meets these criteria — it simply adds a white border around the red edge of the existing SMV sign, simultaneously increasing the sign's size (and thus its visibility) while preserving its widely recognized shape. In fact, juxtaposing red and white in order to enhance an object's low-light contrast is a time-tested idea, as traffic signs (*e.g.*, yield and stop signs) and radio towers demonstrate every day. Thus Fig. 5's alternative to the current SMV sign has both theory and practice to recommend it.

Conclusions

During twilight, color contrast is often less important for detection than luminance contrast. I have shown that a 90%-reflectance white consistently has much higher contrast than does SMV orange. Because some drivers do not use their headlights during all or part of civil twilight, the current SMV sign's retroreflective edge cannot help these drivers detect

SMVs. Adding white to the current SMV sign/emblem (possibly as a white border) would warn drivers for an extra 11-12 minutes during twilight, thus yielding a significant safety advantage for farmers, farm workers, and motorists alike.

References

ASAE, 1988: "Slow-Moving Vehicle Identification Emblem" (ASAE Standard S276.3) in *ASAE Standards 1988* (American Society of Agricultural Engineers, St. Joseph, MI; 35th edition), pp. 102-104.

Bhise, Vivek D., Eugene I. Farber, Carol S. Saunby, George M. Troell, James B. Walunas, and Arthur Bernstein, 1977: *Modeling Vision with Headlights in a Systems Context*, SAE Technical Paper Series # 770238 (Society of Automotive Engineers, Warrendale, PA).

Dennis, Ronald E., Randall K. Wood, Thomas L. Bean, Thomas G. Carpenter, and Robert G. Holmes, 1993: "Enhancement of the SMV emblem," presented at the ASAE 1993 International Winter Meeting, paper # 931514. American Society of Agricultural Engineers, 2950 Niles Rd., St. Joseph, MI 49085-9659.

Gerberich, Susan G., Leon S. Robertson, Robert W. Gibson, and Colleen Renier, 1996: "An epidemiological study of roadway fatalities related to farm vehicles: United States, 1988 to 1993," *Journal of Occupational and Environmental Medicine*, v. 38, pp. 1135-1140.

Leibowitz, Herschel W. and D. Alfred Owens, 1991: "Can normal outdoor activities be carried out during civil twilight?," *Applied Optics*, v. 30, pp. 3501-3503.

Neuberger, Hans, 1957: *Introduction to Physical Meteorology* (Penn State Press, University Park, PA).

Owens, D. Alfred, Ellie L. Francis, and Herschel W. Leibowitz, 1989: *Visibility Distance with Headlights: A Functional Approach*, SAE Technical Paper Series # 890684 (Society of Automotive Engineers, Warrendale, PA).

Reichenberger, Larry, 1998a: "SMV overhaul," *Successful Farming*, v. 96, # 3 (mid-February), pp. 36-39.

Reichenberger, Larry, 1998b: "Up-close look at SMV failures," *Successful Farming*, v. 96, # 3 (mid-February), p. 40.

Rennilson, Justin J., 1997: "Retroreflection" in *Handbook of Applied Photometry* (American Institute of Physics Press, Woodbury, NY; Casimer DeCusatis, ed.), pp. 289-325.

Figures

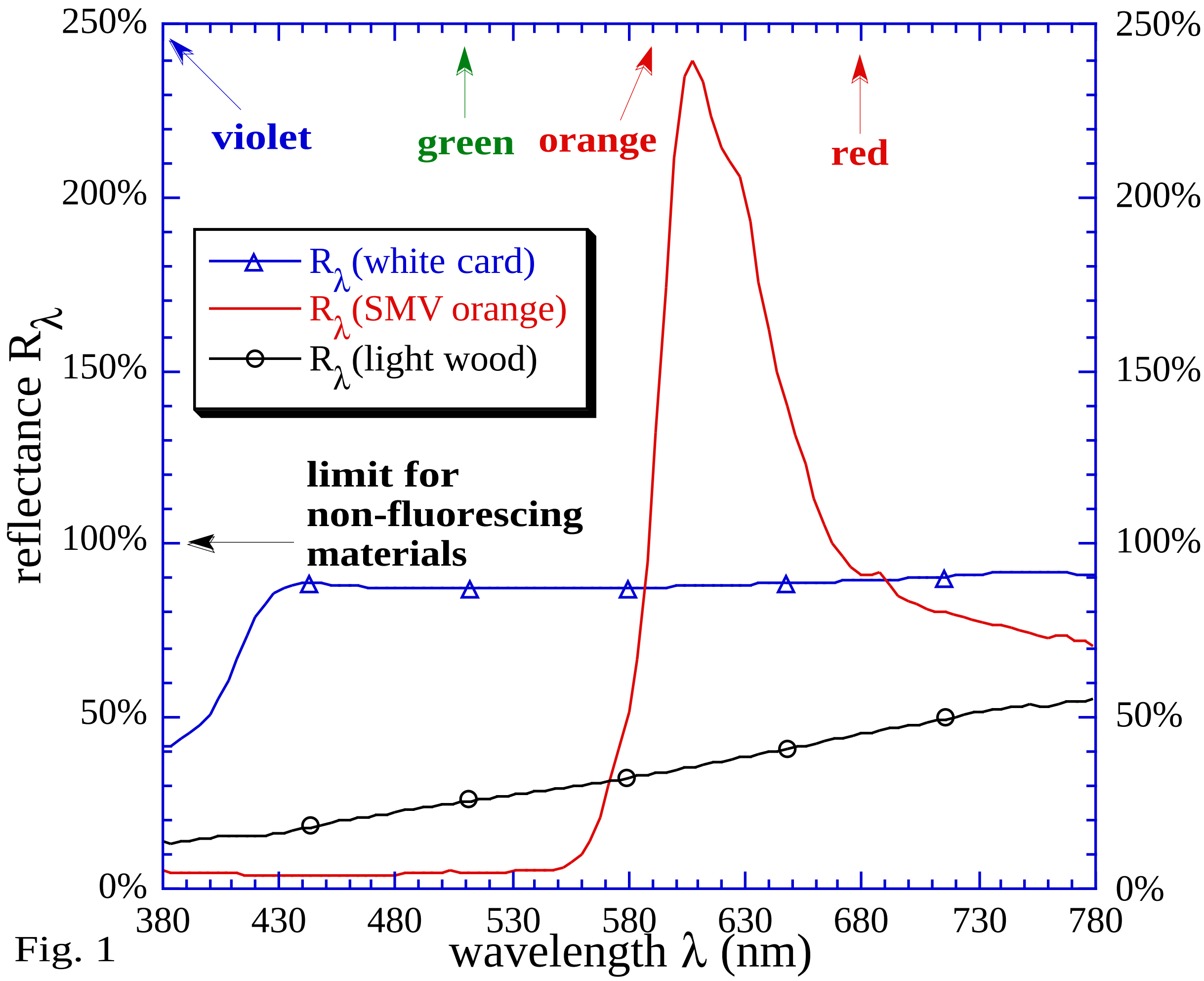

Fig. 1

Figure 1: Visible-wavelength spectral reflectances R_λ for three materials: (a) a photographer's white card (mean R = 90%), (b) a SMV sign's fluorescent orange interior, (c) unpainted wood (a likely background for some SMV signs). Along the top of the figure are labels showing the approximate mapping between wavelength and color. In the orange part of the spectrum, SMV orange's combined reflection and emission exceed the 100% upper limit for reflection by non-fluorescing materials.

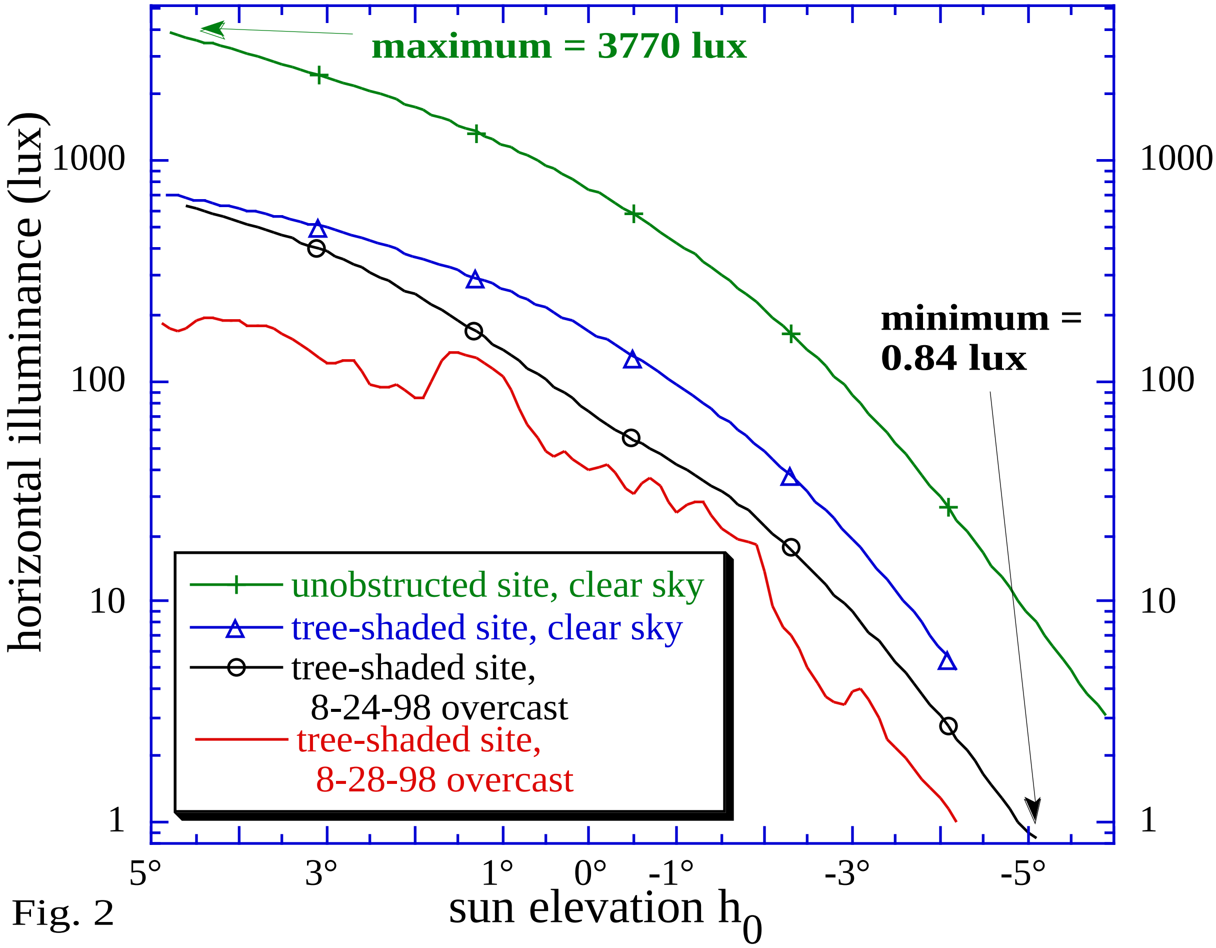

Fig. 2

Figure 2: Illuminance on a horizontal surface *vs*. unrefracted sun elevation h_0 during twilight. I calculate h_0 with respect to a level horizon and for the center of the sun's disc. Because of refraction and the sun's angular width, sunrise and sunset occur when unrefracted $h_0 \sim -0.8^\circ$. Although h_0 chiefly determines twilight illuminance, a site's topography, shading, and cloud cover also affect it.

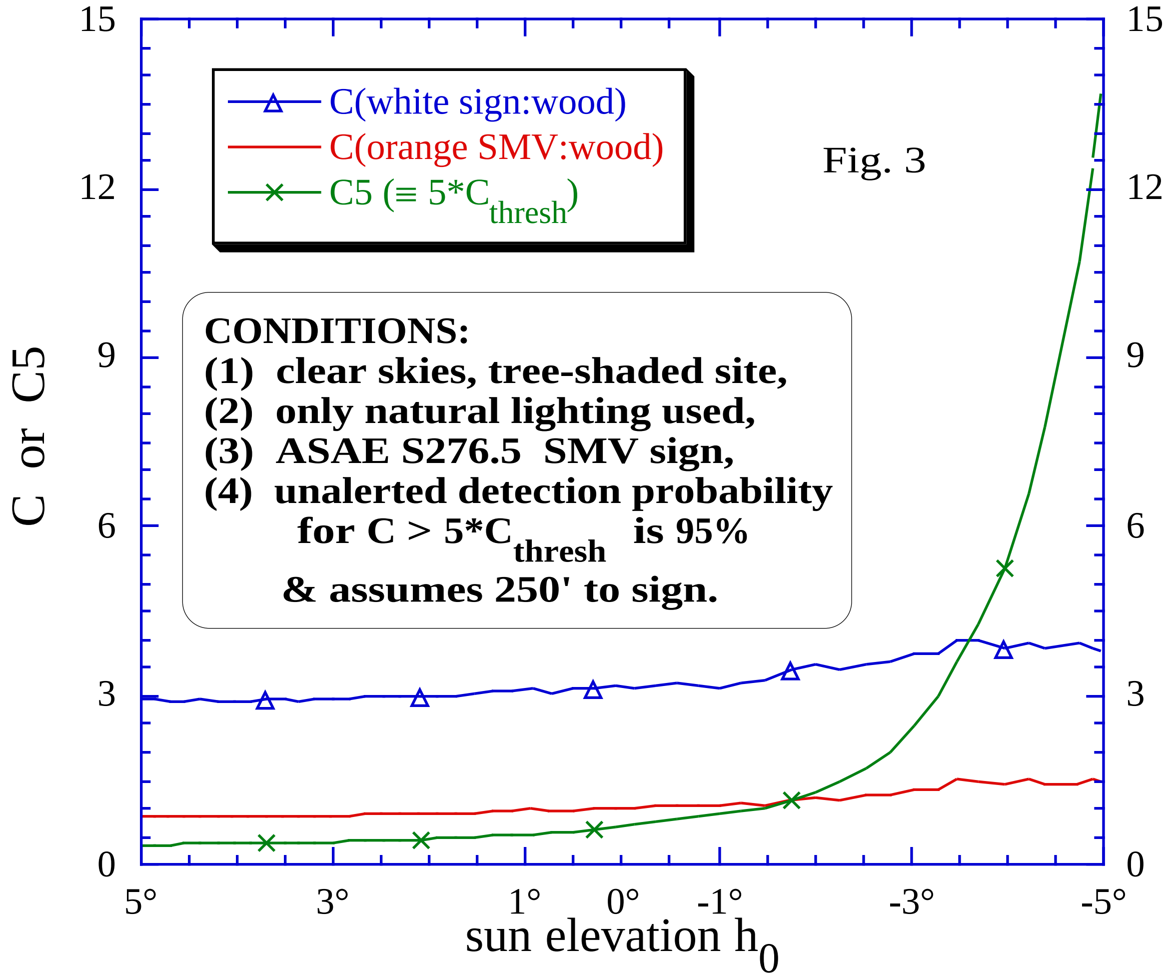

Figure 3: Luminance contrast C for a white sign and for SMV orange against a wood background, plotted as functions of unrefracted sun elevation h_0. A fivefold multiple of the variable contrast threshold C_{thresh} (≡ C5) is shown as the curve with xs. Although C increases slightly after sunset, C5 increases much more, making both the white and orange signs progressively more difficult to detect.

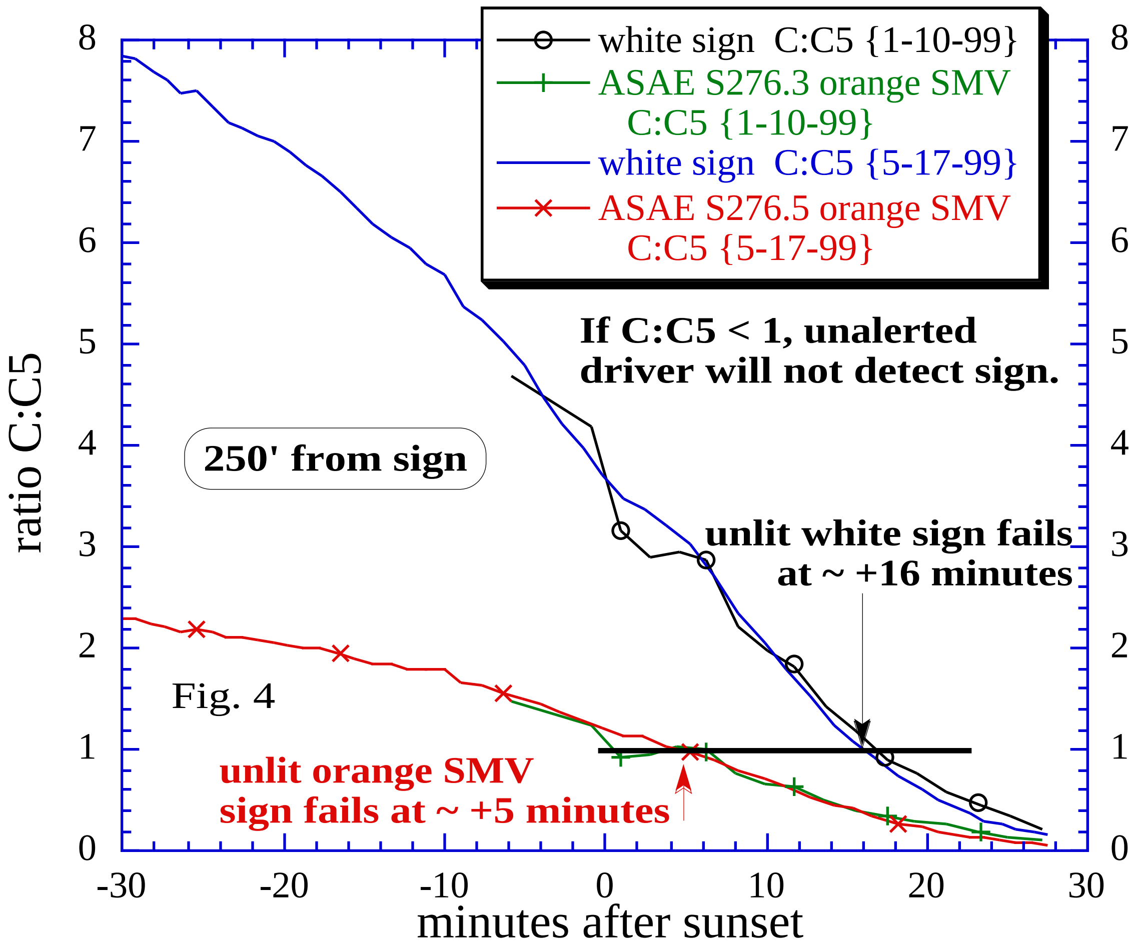

Figure 4: The data of Fig. 3 redrawn using the ratio C:C5 *vs*. time after sunset (alternatively, time before sunrise), and now including trends for both a wintertime and summertime sunset. A white sign (R = 90%) that is lit only by skylight could attract the attention of an unalerted driver at 250' until about 16 minutes after sunset, while an orange SMV sign would first fail to do so at 5 minutes after sunset.

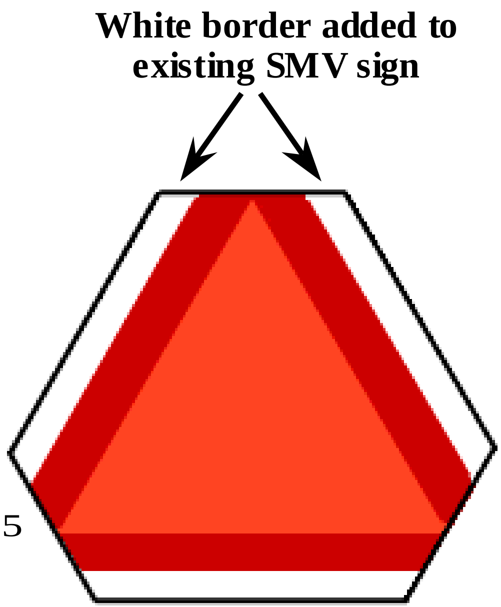

Fig. 5

Figure 5: One possible alternative to the current SMV sign simply adds a white border to it, thereby preserving the sign's shape while increasing its size (and thus its visibility). In principle, this more reflective SMV sign would be detected more easily by those drivers whose headlights are off during civil twilight.