Sign Luminance as a Methodology for Matching Driver Needs, Roadway Variables, and Signing Materials

H. L. WOLTMAN AND T. J. SZCZECH

The widespread use of retroreflective materials for information, regulation, and warning signs and the inclusion of retroreflective materials in many official standards suggest that a framework of luminance standards for minimum visual performance be adopted. Such a construct assumes that a variety of signing materials are available from which predictions of performance may be made. A methodology is provided to compare signing materials in a variety of placements, road geometries, and distances for existing types of retroreflective materials. The study compares the performance of retroreflective materials for existing headlamps and under many circumstances of use. Information is also provided on allowances for such factors as complex nighttime surroundings, the unalerted driver, and the relative importance of sign priority.

Retroreflective materials enhance the nighttime visibility of traffic control signs and other devices. Various official standards require that signs which must be seen by a motorist at night be either retroreflecting or illuminated. Retroreflectorization alone is sufficient for sign visibility under reasonable conditions. These conditions include satisfactory alignment of the vehicle with the sign, an uncluttered surround to permit timely discovery, headlights in satisfactory alignment, and the use of specified retroreflective materials (*1–5*). Sign perception also depends on an adequate level of luminance. There are numerous factors that alter both the luminance capability of the retroreflective material and the adequate level of luminance required by the driver.

The factors that determine the luminance capability of retroreflective materials are highly mechanical. They have to do with headlamp output, choice of retroreflective material, and alignment of the sign with respect to the road. The factors that influence the level of luminance deemed adequate for the driver deal exclusively with the driver's perceptual process and state of mind. Therefore, a research methodology that explores a variety of scenarios representative of actual use may be a more satisfactory descriptor of the retroreflector than retroreflectance, its traditional descriptor.

The use of luminance as a criterion for evaluating performance of signs instead of retroreflectance provides a means to directly match driver needs. Estimates of luminance to satisfy driver needs can be obtained from a number of investigations. Driver needs from a review of nighttime sign legibility studies by Sivak (*6*) are presented below:

Level	*Sign Legend Luminance (cd/m^2)*
Optimal	75
Replacement	
85th percentile	16.8
75th percentile	7.2
50th percentile	2.4

Studies dealing with Stop sign conspicuity by Morales (*7*), sign conspicuity for various background complexities and driver expectancy by Olson (*8*), and estimates for sign priority by Perchonok (*9*) show that satisfactory performance depends on sign luminance.

The level of luminance depends on sign position, roadway approach, and headlamp quality. It is correlated with such factors as retroreflectance, the weathered state of the sign, and cleanliness. Direct inspection of signs or reference to luminance tables that predict performance assures this necessary quality.

To determine the effects of vehicle and roadway variables on sign luminance, we have employed our previous findings of sign luminance for United States guide sign legends and backgrounds and the luminance enhancement from stream traffic and rainfall. These assessments used cars operating on both low and high beams and measured the luminance intensity of a variety of retroreflective materials from the position of the driver's eye in standard size passenger vehicles. Samples were taken in typical sign positions, from distances corresponding to the longest decision sight distance models to relatively short sign-reading distances. Headlamps used were either typical of new vehicle equipment or were supplied by equipment manufacturers following photometric testing. Aim was adjusted to correspond to SAE recommendations, usually employing the aiming screen method (SAE J 599). Level tangent sections of roadway were used. A full description of the method is contained in three separate papers by Youngblood and Woltman (*10–12*).

The findings are well-suited for adaptation to the problem at hand: Retroreflective materials will provide the same response curve given similar vehicle dimensions. Luminance values are proportional to illuminance, so that an accurate

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comparison may be made between headlamps. Beyond this relationship, careful characterization of the retroreflective materials is required, as is the headlamp/driver-eye relationship. Angularity of signs with respect to the approach should be considered. Allowance for dirt on signs is the same as for dirt on headlamps; both are treated as a diminution of illuminance.

The procedure used in this study to model sign luminance was first detailed by Elstad et al. (*13*), with further refinement by Szczech (*14*). The model uses a detailed headlamp output (of the Westinghouse 6014) in a matrix encompassing all directions of interest for sign positions at any distance. The values derived for sign luminance involve complex geometric and retroreflective response relationships. Nevertheless, they correspond with the previously cited field studies and permit comparisons of sign luminances for three types of retroreflective materials, over a selection of limited alignment conditions.

SIGNING MATERIALS

The signing materials studied were representative of new white retroreflective materials used for traffic control signs. Luminances for other colors and their ratios to white may be expected to fall within the following limits:

Color	*Luminance Ratio to White (%)*
Yellow	61 to 76
Orange	33 to 42
Red	17 to 30
Green	13 to 19
Blue	7 to 10

The materials studied are described below.

Reflective Sheeting			*Coefficient of Retroreflection (cd/lux/m²) at 0.2° Observation −4° Entrance*
Material	*Type*	*Color*	
A	Enclosed lens	White	120
B	Encapsulated lens	White	310
C	Microprism	White	1100

The coefficients of retroreflection, which are essential for sign luminance computations, are determined according to ASTM E 810-81.

SIGN POSITIONS

Sign positions are shown in Figure 1. The positions are typical of regulatory and warning signs commonly displayed on the right shoulder; overhead signs over the driver's lane of travel; and signs on the left side, such as No Passing Zone pennants and bridge end barricades. The offsets and elevations used are specified in the *Manual on Uniform Traffic Control Devices* (*15*).

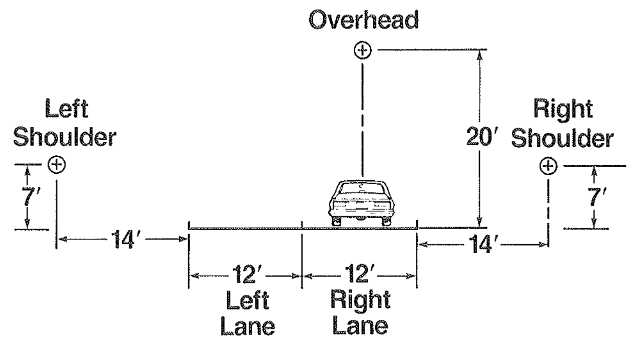

FIGURE 1 Sign positions.

ROADWAY

The approach to the sign is not always a straight, level tangent section. It is frequently a horizontal or vertical curve. Five cases were chosen that, although they are an incomplete scenario, are representative and illustrative of a variety of approach conditions. These roadway geometries are diagrammed in Figure 2. They include a straight tangent approach, right and left curves with 2,000-ft radii, a sag, and a hill with a 6,000-ft radius. Curves of significantly smaller radii could not be considered because of the limitations of the headlamp matrix used for the computations.

SIGN LUMINANCE ESTIMATES

Estimates of sign luminance for the three retroreflective materials at six approach distances and three sign positions are given in Tables 1 through 5. The values presented are for ideal conditions and do not have allowances or reductions for atmospheric transmissivity or windshield losses. These may be from 2 or 3 percent to 30 percent, respectively, for clear atmospheres and normal windshields. Allowance for weathering of signing materials is not included. The tables are arranged for separate roadway geometrics. The data presented in Tables 1 through 5 are further illustrated in Figures 3 through 6 to show the effect of road curvature, sign placement, and material type.

Two estimates are provided for signs seen at angles. Approximately 6 percent of the entrance angles of over 1,300 signs (*16*) are seen by the motorist at an angle of 30° or greater. Estimates are provided for shoulder signs angled 30° away from and 30° toward the road in Tables 6 and 7, respectively. It must be noted that the photometrics of the retroreflective materials are reasonably accurate for the entrance and observation angles actually encountered on all of the above approaches.

DISCUSSION OF RESULTS

Tables 1 through 7 present estimates of sign luminance for distances from 366 m (1200 ft) to 61 m (200 ft) in increments of 61 m (200 ft). The luminance estimates are for a motorist

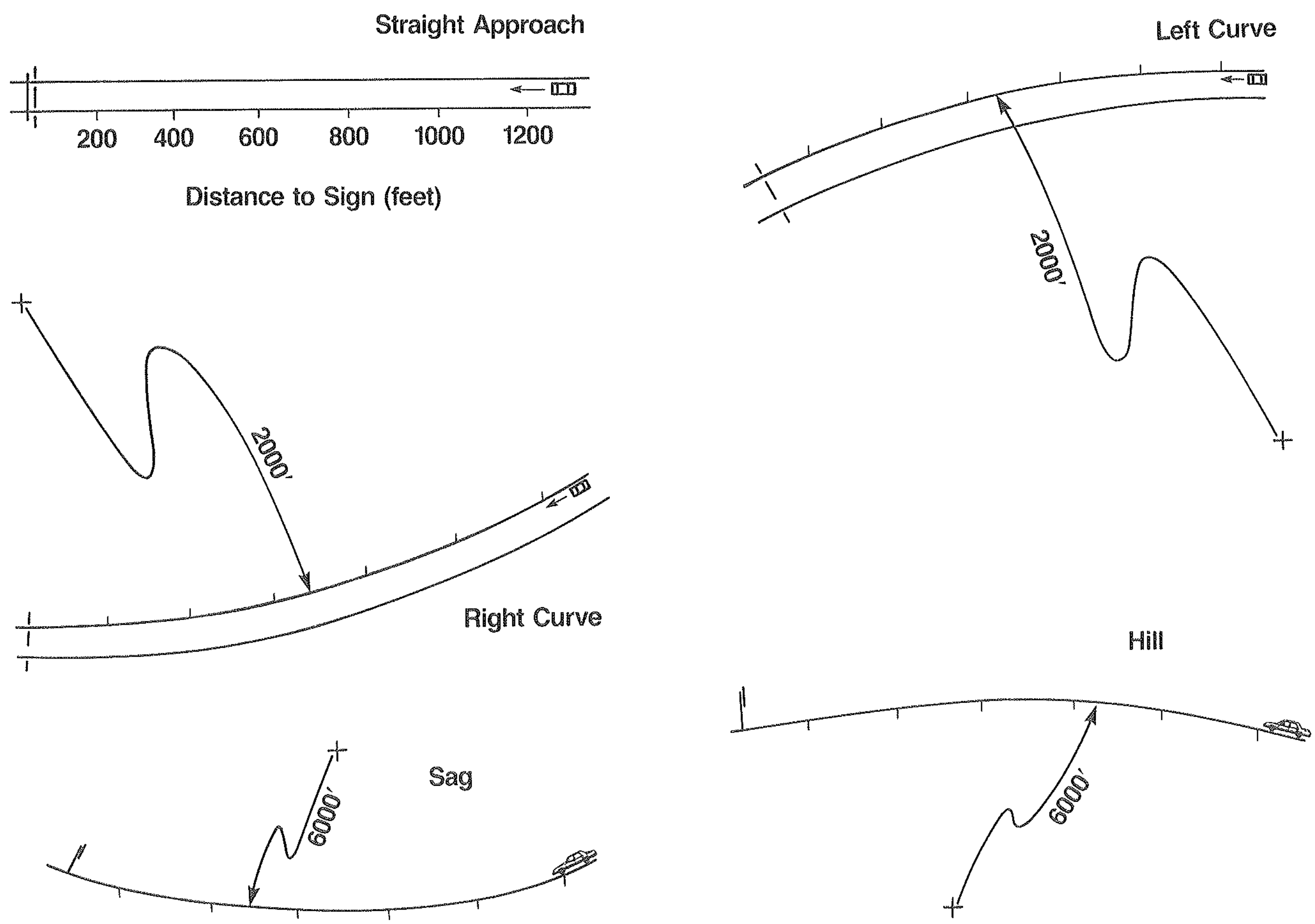

FIGURE 2 Roadway geometries.

TABLE 1 RETROREFLECTIVE SIGN LUMINANCE, U.S. LOW-BEAM LAMPS—STRAIGHT TANGENT ROAD

	Distance -- meters/feet					
Sign Mounting	366/1200	305/1000	244/800	183/600	122/400	61/200
	7.32	9.53	12.15	14.67	15.58	9.53
Right	18.17	24.16	31.59	38.60	36.31	7.90
	52.42	72.07	94.74	119.43	101.76	15.75
	1.80	2.16	2.62	3.33	4.15	4.68
Left	4.49	5.49	6.79	8.87	9.83	7.86
	12.83	15.63	18.80	24.45	33.53	16.99
	1.97	2.21	2.44	2.52	3.07	2.21
Overhead	4.91	5.62	6.34	6.53	6.85	1.83
	14.22	16.62	18.78	20.28	19.76	3.12

Materials: Enclosed Lens
(White) Encapsulated Lens
Micro-prism

Luminance in Cd/m2

TABLE 2 RETROREFLECTIVE SIGN LUMINANCE, U.S. LOW-BEAM LAMPS—RIGHT CURVE

	Distance -- meters/feet					
Sign Mounting	366/1200	305/1000	244/800	183/600	122/400	61/200
	O.18	1.04	1.74	2.64	5.71	9.53
Right	0.46	2.68	4.60	7.34	14.39	7.90
	1.16	9.24	17.14	23.94	33.17	15.75
	0.82	1.34	2.61	7.25	14.74	5.13
Left	2.17	3.58	7.16	20.42	35.42	9.01
	4.25	8.10	20.13	62.87	113.11	17.96
	0.53	0.85	1.14	1.89	2.63	2.33
Overhead	1.41	2.26	3.10	5.34	6.31	1.79
	2.83	5.81	10.75	18.07	15.71	3.11

Materials: Enclosed Lens
(White) Encapsulated Lens
Micro-prism

Luminance in Cd/m2

TABLE 3 RETROREFLECTIVE SIGN LUMINANCE, U.S. LOW-BEAM LAMPS—LEFT CURVE

Sign Mounting	Distance -- meters/feet					
	366/1200	305/1000	244/800	183/600	122/400	61/200
	0.64	1.01	1.68	2.78	5.43	9.53
Right	1.74	2.71	4.36	6.80	12.33	7.90
	3.53	6.85	12.59	20.87	40.71	15.75
	0.66	0.97	1.47	2.24	4.05	3.74
Left	1.79	2.60	3.77	5.26	8.82	5.47
	3.54	6.43	11.16	16.66	29.73	10.82
	0.40	0.64	0.84	1.17	1.76	2.06
Overhead	1.10	1.73	2.21	2.86	3.84	1.79
	2.06	3.69	6.01	9.64	12.62	3.82

Materials: (White) Enclosed Lens
Encapsulated Lens
Micro-prism

Luminance in Cd/m2

TABLE 4 RETROREFLECTIVE SIGN LUMINANCE, U.S. LOW-BEAM LAMPS—SAG

Sign Mounting	Distance -- meters/feet					
	366/1200	305/1000	244/800	183/600	122/400	61/200
	*	0.28	0.63	1.60	4.22	9.53
Right	*	0.71	1.66	4.25	9.66	7.90
	*	2.29	5.31	13.21	25.53	15.75
	*	0.37	0.60	1.00	1.84	3.09
Left	*	0.96	1.59	2.54	4.04	4.48
	*	2.96	4.80	7.93	12.79	9.87
	*	0.36	0.59	0.99	1.55	1.62
Overhead	*	0.95	1.57	2.58	3.21	1.20
	*	2.99	4.90	7.84	8.53	2.08

*Range exceeds headlamp field

Materials: (White) Enclosed Lens
Encapsulated Lens
Micro-prism

Luminance in Cd/m2

TABLE 5 RETROREFLECTIVE SIGN LUMINANCE, U.S. LOW-BEAM LAMPS—HILL

Sign Mounting	Distance -- meters/feet					
	366/1200	305/1000	244/800	183/600	122/400	61/200
	*	*	*	148.29	225.81	9.53
Right	*	*	*	386.61	526.84	7.90
	*	*	*	1130.50	1548.40	15.75
	*	*	*	28.33	25.60	9.11
Left	*	*	*	70.79	55.73	17.32
	*	*	*	187.54	198.71	37.65
	*	*	*	43.87	12.78	3.39
Overhead	*	*	*	112.64	30.48	3.14
	*	*	*	340.86	97.16	5.84

*Sign obscured by hill

Materials: (White) Enclosed Lens
Encapsulated Lens
Micro-prism

Luminance in Cd/m2

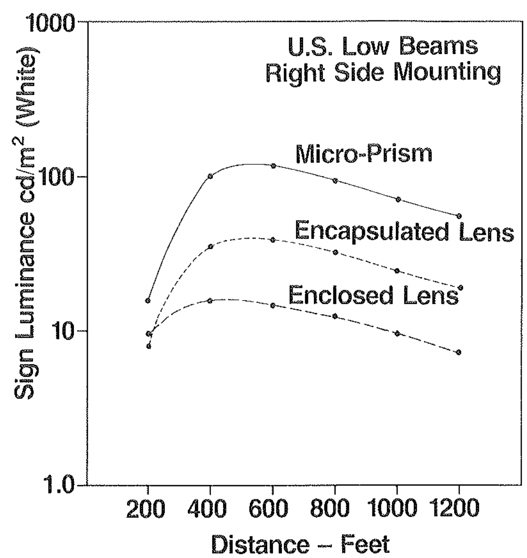

FIGURE 3 Sign luminance—three retroreflective materials, straight tangent road.

in a standard size passenger vehicle and are intended to provide a number of scenarios in which various approaches can be studied. The tables also permit comparisons for three differing sign positions, and two horizontal and vertical curves. Thus various retroreflective material types can be reviewed for a specific approach condition or distance and the appropriate type chosen that satisfies a given luminance criterion.

Figure 3 shows the performance difference for the three retroreflective materials. Figure 4 shows the effect of positioning the sign overhead or left relative to the right side. The effect of road curvature is given in Figures 5 and 6. As explained earlier, the headlamp matrix did not permit calculation of smaller radius curves, but, as can be visualized from the figures, sign luminance will be further impaired as compared to the data shown.

Tables 6 and 7 give sign luminance values for shoulder-mounted signs facing 30° away from and toward the roadway. A substantial number of these signs, some of which are highly critical, have been found at this entrance angle or greater. The luminance estimates of Tables 6 and 7 are derived from photometrically determined retroreflectance values appropriate for these entrance and observation angles.

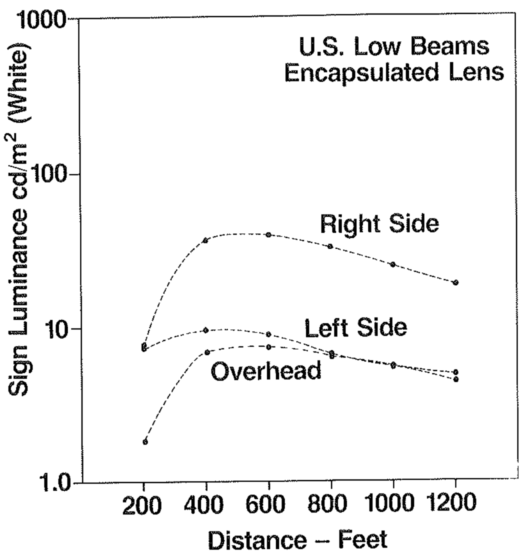

FIGURE 4 **Sign luminance—three sign positions, straight tangent road.**

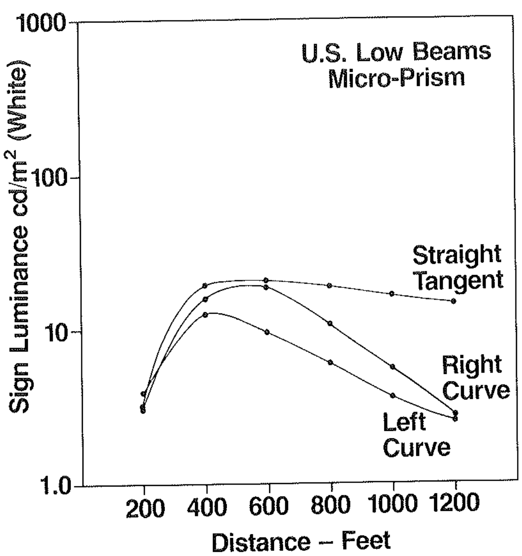

FIGURE 5 **Overhead sign luminance—straight tangent versus right and left curves.**

CONCLUSIONS

The use of luminance instead of retroreflectance for evaluating sign performance provides a means to match materials to roadway situations and driver needs. The driver's luminance needs must account for the variability of the driver population with a suitable factor of safety to accommodate driver age, expectancy, the complexity of the surround, and the criticality of the sign. These important factors are beyond the scope of this investigation. The luminance supply may be estimated from the table that offers the closest match to the

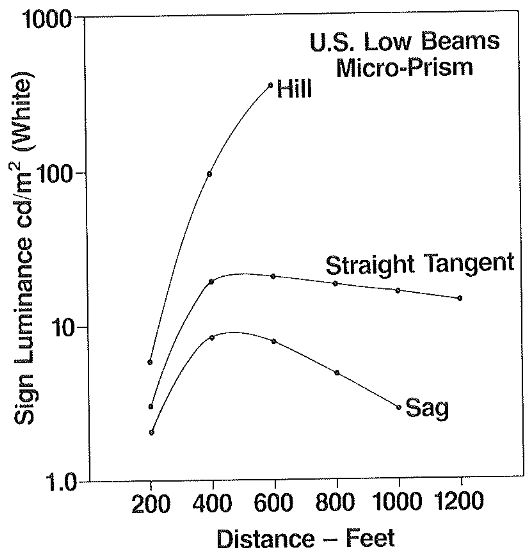

FIGURE 6 **Overhead sign luminance—straight versus hill and sag.**

TABLE 6 RETROREFLECTIVE SIGN LUMINANCE, U.S. LOW-BEAM LAMPS—STRAIGHT TANGENT ROAD SIGNS ROTATED +30°

	Distance -- meters/feet					
Sign Mounting	366/1200	305/1000	244/800	183/600	122/400	61/200
	4.38	5.66	7.14	8.47	8.69	4.76
Right	13.01	17.21	22.33	26.92	24.58	4.93
(Away)	29.84	39.46	51.24	64.58	58.66	11.12
	1.18	1.43	1.77	2.30	3.28	3.94
Left	3.42	4.21	5.26	6.59	7.89	6.99
(Toward)	7.69	9.26	11.57	15.70	17.51	11.94

Materials: Enclosed Lens
(White) Encapsulated Lens
Micro-prism

Luminance in Cd/m2

TABLE 7 RETROREFLECTIVE SIGN LUMINANCE, U.S. LOW-BEAM LAMPS—STRAIGHT TANGENT ROAD SIGNS ROTATED −30°

	Distance -- meters/feet					
Sign Mounting	366/1200	305/1000	244/800	183/600	122/400	61/200
	4.71	6.17	7.94	9.80	10.81	7.37
Right	13.65	18.24	24.03	29.73	28.68	6.66
(Toward)	31.18	41.47	54.41	70.34	61.43	8.95
	1.06	1.25	1.50	1.85	2.37	2.03
Left	3.17	3.84	4.70	5.68	6.42	4.48
(Away)	7.20	8.64	10.65	13.83	15.75	12.51

Materials: Enclosed Lens
(White) Encapsulated Lens
Micro-prism

Luminance in Cd/m2

roadway situation. Practitioners may then select the materials that offer the luminance level desired through the range of distances that may be of interest. In this manner, material selection can become a part of the design process.

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Publication of this paper sponsored by Committee on Visibility.