Requisite Luminance Characteristics For Reflective Signs

J. O. ELSTAD, J. T. FITZPATRICK and H. L. WOLTMAN, Reflective Products Division, Minnesota Mining and Manufacturing Company

Signing on urban and rural roadways exhibits a complex of sign positions and ambient illumination levels suggesting need for determining optimum characteristics for retro-reflective materials under these conditions. Other studies have evaluated available reflective materials for individual effectiveness. This study is designed to establish reflective characteristics required for any installation and suggests a brightness range for typical sign environments.

Ideally, consistent luminance would be maintained through approach distances for all sign positions. Iso-illuminance and iso-divergence data indicate varying illuminance and retro-reflective efficiency throughout the approach. However, inverse relationship at generally useful distances indicates little modification of the classic divergence curve is necessary for materials considered.

Ambient illumination of sign surfaces commonly ranges from 0.4 foot-candles in illuminated areas to less than 0.1 in rural locales. Current reflective materials provide good high beam performance and adequate low beam performance where ambient illumination incident on the sign surface does not exceed 0.4 foot-candles. In excess of 0.4 foot-candles, stream traffic provides additional useful luminance. Sufficiency values for sign luminance are presented for dark and illuminated locales.

• IT IS generally acknowledged that sign performance is dependent on attention value and legibility. Forbes (1) has reported that these are functions of target and priority value, pure and glance legibility, respectively. Each factor is related directly to contrast—the sign with surround, providing attention value; letters with background, for legibility.

Literally, contrast is the result of apparent differences in brightness and color alone, and a subjective experience given to extreme variation at night. Excessive stimuli from glare sources (such as opposing headlights and luminaires, colored tail lamps, and electric advertising) contrast with the generally inadequate luminance for effective nighttime perception elsewhere in the highway scene. In the absence of minimal luminance of conventional sign surfaces at night, the Manual of Uniform Traffic Control Devices (2) prescribes the reflectorization or illumination of essential traffic signs.

Most studies of reflective treatments have been largely confined to a comparison of the performance of available materials in a dark environment at one or two sign positions. Yet marked differences are experienced in field brightness and headlight illumination with varying sign location and position. Ranging from total darkness to brilliant illumination, these conditions seem to impose widely different luminance demands on signs and legends for optimum contrast prompting investigation of the characteristics required for desirable retro-reflective performance in a number of common situations.

Consideration of night traffic sign environments suggests three representative conditions: (a) dark rural, (b) illuminated suburban, and (c) bright urban. Each is a qualitative expression of ambient illumination and invites separate consideration of contrast needed for maximum attention value and legibility. Unfortunately, techniques for the quantitative determination of field brightness and attention value are still largely unsuitable for field use. Accordingly, this study is limited to the evaluation of luminance needs and consequent necessary reflective performance for satisfactory sign legibility in the several environments.

LEGIBILITY AND REFLECTION

Legibility Criteria

Legibility criteria are generally employed in the assessment of luminance for optimum performance. The luminance desirable for dark conditions has been reported by Allen (3) for letter sizes from 8 through 18 in. Under the test conditions maximum legibility for the modified BPR Series E illuminated letters on dark backgrounds occurred at approximately 10 to 20 ft-Lamberts (ft-L) (see Fig. 1).

It is apparent that a satisfactory confidence level results within a range of letter luminances from 1.5 to 100 ft-L. The reduction in legibility distance at 100 ft-L has been attributed to halation or "overglow." At 1 ft-L, legibility is reduced to approximately 80 percent of maximum; 0.1 ft-L is shown to yield 45 percent of maximum.

Despite the relatively large luminance span from 1.5 to 100 ft-L, the corresponding legibility is shown to range from 63 to 74 ft per in. of letter height. A similar study performed by the authors led to legibility distances essentially consistent with those reported by Allen. Slight differences are attributable to variations in test conditions.

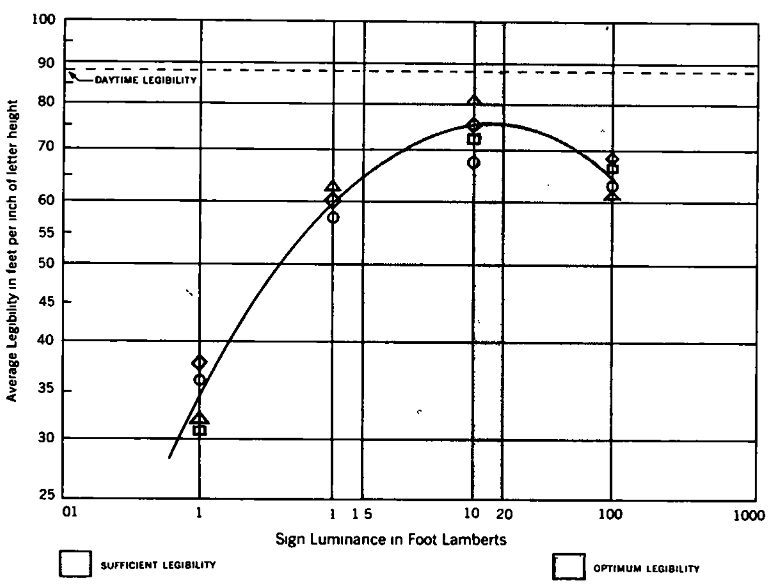

Figure 1. Optimum and satisfactory legibility distances for 8- to 18-in. BPR Series E (Mod.) shown relative to letter luminance. Legibility data from Allen (3).

Reflective Characteristics

The luminance attained by reflective treatments is dependent on their specific luminance, illuminance, angular position relative to the vehicle (incidence), and the angle subtended at the sign by the motorist and his headlights (divergence). With the exception of specific luminance, each is affected by sign position and distance. The influence of the independent variables—sign position, distance, and specific luminance—must be determined from an analysis of the highway scene.

Derivation of Luminance Data.—Sign placement was found to exist in a vertical field of approximately 2,000 sq ft. This is represented graphically by a plane extending 55 ft from the right edge of the lane of travel, 24 ft to the left and 28 ft above the lane. For reference, the right headlamp assembly is positioned 2 ft to the left of the road edge. Standard traffic signs—overhead, edge, median, and shoulder mounted—fall within the field boundaries (see Fig. 2).

Conventional traffic and Interstate signs employ letters varying in height from approximately 3 to 24 in. with corresponding legibility varying from less than 100 ft to more than 1,000 ft. For the purpose of this study, the limits of visual observation were 75 and 1,200 ft. Luminance calculations were also made for intermediate distances of 150, 300, 450, 600, and 900 ft (see Fig. 3).

Headlamp Illumination.—Varying headlamp intensity throughout the sign field necessitated a plot of illumination for each headlight assembly for high and low beams. To establish headlamp distribution for the seven distances, appropriate areas of iso-candle charts for the dual headlamp system were photographically enlarged and plotted for each distance. Illuminance values were calculated by application of the inverse square law. Illuminance for a typical information sign is shown in Figure 3. Headlamp illumination was found to vary from a minimum on low beams of 0.001 ft-candle to a maximum on high beams of 7 ft-candles.

Divergence Fields.—Retro-reflective materials exhibit varying efficiency expressed in terms of specific luminance with respect to the divergence angle (Fig. 4). Specific luminance has been defined as foot-Lamberts luminance per incident foot-candle and is determined photometrically at specified divergence angles with a 1,000-watt tungsten light source and a photronic cell chromatically corrected for the spectral response of the human eye.

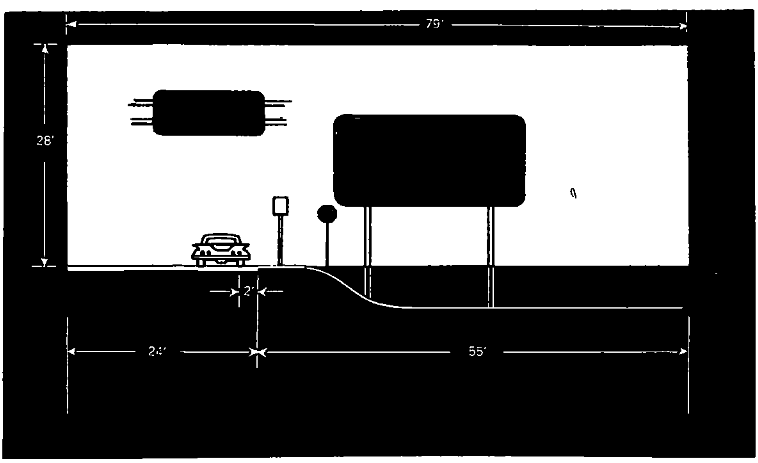

Figure 2. Sign field showing relative position of typical roadway, vehicle, and traffic signs.

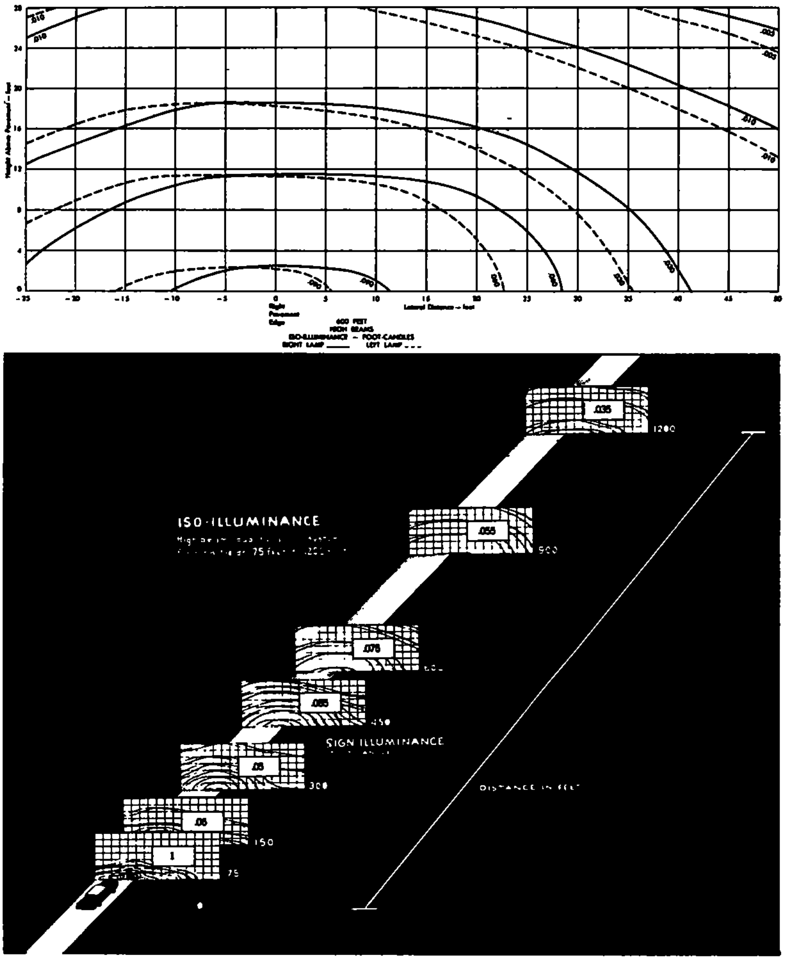

Figure 3. Distribution of high beam illumination for seven distances indicating illuminance values for typical information sign.

The divergence angle is the angle subtended by incident light from the source and the reflected light beam at the observer. The trigonometric expression for this angle is

$$\cos \theta = \frac{a^2 + b^2 - c^2}{2ab}$$

in which

θ = divergence angle;
a = headlamp-to-sign distance;
b = eye-to-sign distance; and
c = eye-to-headlamp distance.

To determine the divergence angle appropriate for each headlamp, average figures were obtained from measurements of a number of late model automobiles (1958-61).

Distance between headlamps	5.1 ft
Height of headlamps from road	2.5 ft
Eye height above road	4.1 ft

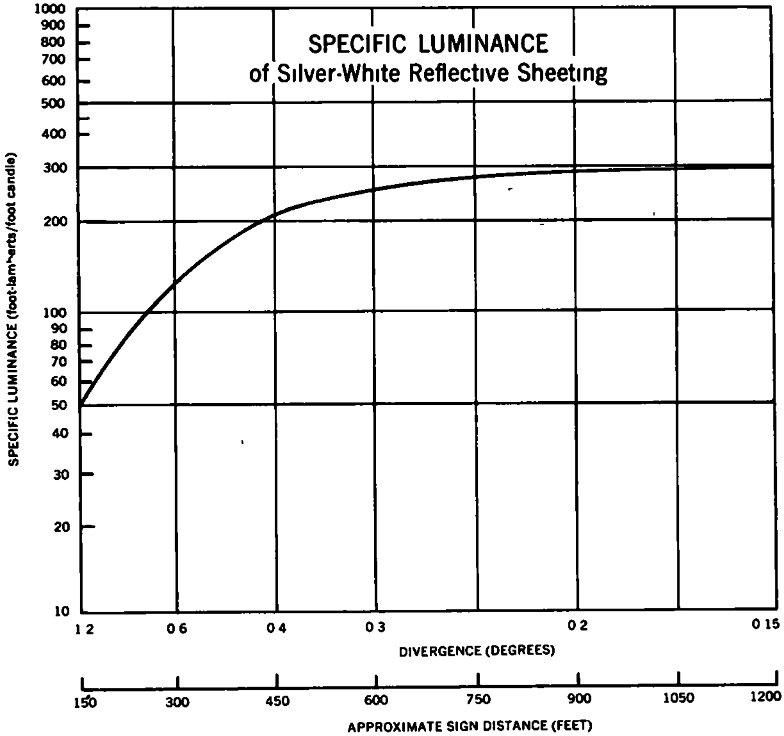

Figure 4. Specific luminance for silver-white reflective sheeting relative to divergence angle and corresponding average distance.

Lateral distance, line of sight to left headlamp	1.05 ft
Horizontal distance from eyes to headlamps	7.5 ft

The resulting expression was programed for computer calculation. Values for 136 divergence angles per headlamp assembly were obtained for the seven sign fields (4). The data reveal that the value of the divergence angle varies from right to left lamp by a factor ranging from 2x to 4x. Inasmuch as each headlamp assembly supplies a factorially different part of the total illumination, right and left lamp assemblies and related divergence angle must be independently considered.

Sign Luminance.—Sign luminance is determined by reference to the graphical data which provide illumination and divergence for each headlamp. The sign luminance for each lamp assembly is the product of the specific luminance and illuminance at the sign. The sum of the products for each headlamp assembly is the apparent sign luminance to the driver in foot-Lamberts.

The resultant luminance is shown in Figure 5 for several typical sign positions based on the performance of retro-reflective sheeting employed on traffic signs. From 100 to 1,200 ft, high beams provide a 2 ½ to 1 ratio between minimum and maximum luminance with an average value of 20 ft-L. Large panels of silver-white reflective materials exhibiting specific luminance characteristics shown in Figure 4 were used to confirm calculated luminance values. Measurements made with a Luckiesh-Taylor brightness meter at representative positions, and distances were found to agree with the calculations.

Ideally, the luminance curve would be flat, affording uniform brightness at all distances, a characteristic of daylight illumination. Fortunately, changing distance ex-

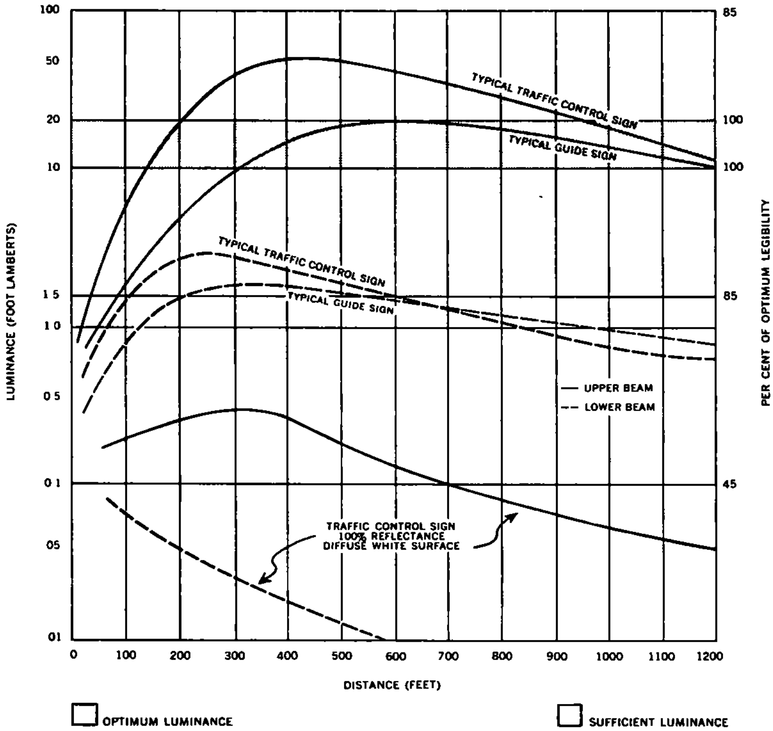

Figure 5. Reflective sign luminance for distances from 75 to 1,200 ft for high and low beams. Optimum and sufficient ranges provide 100 and 85 percent of maximum legibility distance for the modified alphabets, 8 to 18 in. Luminance of perfectly diffusing white surface shown for comparison.

hibits an inherent dichotomy in the optical performance of retro-reflective systems as illustrated by the related but contradictory effects of changing headlamp intensities and divergence angles on sign approach.

At great distance, headlamp illumination is understandably low. Concurrently, divergence angles are small, contributing to high efficiency (Fig. 4) and compensating for generally low illuminance. With decreased distance, exponential increases in headlamp illumination largely offset corresponding reductions in efficiency at the higher divergence angles.

The combined result of these changes is illustrated by the luminance values shown in Figure 5. The degree of compensation offered by these conflicting effects is seen to provide a maximum luminance variation of 2 ½ to 1 within generally useful distances. This compares with the 4 to 1 ratio considered suitable for roadway illumination.

It is possible to design a divergence curve for reflective materials which would yield uniform luminance throughout the approach. This function will cross the present divergence curve at 0.2° and 0.85°, corresponding to approximately 900 and 200 ft, respectively. Between these distances, present materials are in excess of most brightness requirements.

Ambient Illumination.—A number of previous studies have suggested that sign legibility is related to the degree of ambient illumination provided by the environment. To establish prevailing luminance levels, measurements were made of a diffusing white surface exhibiting 90 percent reflectance with a Luckiesh-Taylor brightness meter. In each case this standard reference surface was held normal to traffic flow in representative sign positions.

With good-sized reference panels this instrument permits determination of a wide range of luminance at distances of a few feet to over 200 ft. Because data from this meter are related to the operator's experience, a 9-ft-L standard source was employed to confirm observer accuracy. Numerous measurements in several illuminated locales were averaged to determine the levels of incident illumination. Review of the data suggested the three categories under which performance tests should be conducted.

DARK RURAL

Within this range, illumination was found to be negligible. Light levels incident on sign surfaces in this category vary from minimal to 0.1 ft-L. Legibility studies by Allen, previously reviewed, fit these data. Reflective sheeting luminance of 10 to 20 ft-L, as shown in Figure 5, provides 100 percent legibility with the 85 percent level occurring at 1.5 and 100 ft-L. Calculated luminance, confirmed by measurements with the brightness meter, indicates that reflective sheeting luminance provides in excess of 1.5 ft-L at distances from 150 to 650 ft with low beams. High beams provide 3 to 50 ft-L of reflective sheeting luminance at distances ranging from 100 to 1,200 ft.

ILLUMINATED SUBURBAN

Light levels incident on sign surfaces in this category vary from 0.1 to 0.4 ft-L. Road illumination with attendant glare sources increases prevailing light levels. The disabling effect of glare sources on vision has been determined by Fry (5). Bright glare sources subtending narrow angles with the object viewed were shown to impart a marked veiling influence rapidly diminishing with angular increases. The substantial difference in height between luminaires and typical shoulder mounted signs may provide the necessary angular displacement.

To determine the prevailing illumination and its effect on legibility where highway lighting is used, a number of illuminated interchanges and their approaches were mea-

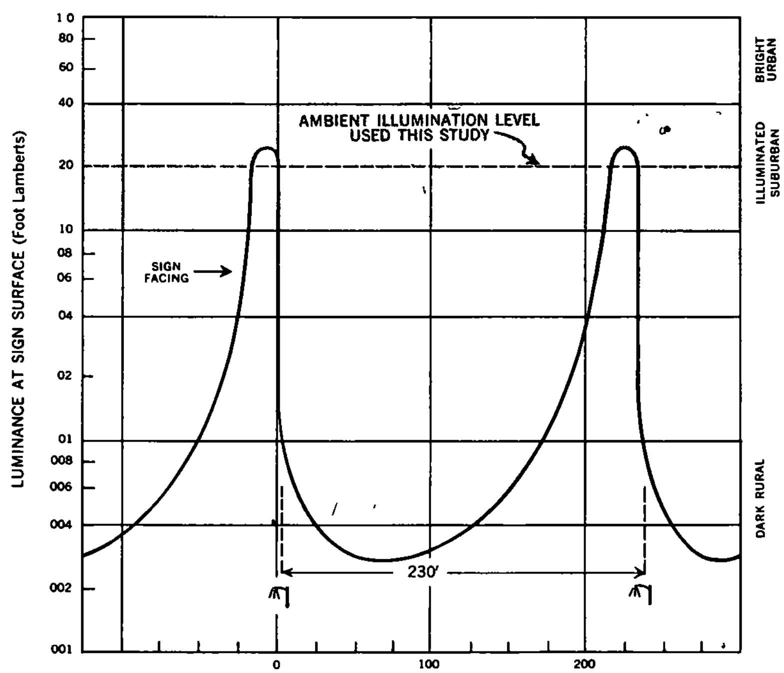

Figure 6. Luminance exhibited by 90 percent reflectance vertical sign surface relative to luminaire location shown for guide sign position. Illumination provided by mercury vapor luminaires (20,000 lumen, H-33 1CD at 30-ft mounting height).

sured along sections of Interstate highway employing mercury vapor luminaires (20,000 lumens, H-33 1CD) at 30-ft mounting height. Light incident on the sign surface was found to vary extensively with luminaire placement as shown (see Fig. 6).

In illuminated suburban areas the typical night view comprises a series of mercury vapor luminaires, interchanges with their extensive illumination, suburban residences, and occasional electric signs. The data illustrate that luminance of a perfectly diffusing white surface in this environment is often less than 0.1 ft-L. Individual signs in illuminated suburban areas with ambient illumination in this lower range properly belong in the dark rural category.

Test at 0.2-ft-L Illumination

A legibility test was conducted on a section of roadway with illumination provided by luminaires on 190-ft spacing at 30-ft mounting height. The legibility of 12-in. letters was evaluated on a straight, level section of roadway 1,200 ft in length. The essentially linear relationship between legibility distance and letter height has been established by Allen (3) and others. This condition holds where consistent letter luminance prevails whether provided by daylight, illumination, or reflective materials. Under these conditions of ambient illumination a test of 12-in. letters, the size predominantly in use, could thus be expected to reveal the measure of change produced in legibility distance for every letter size.

Test Signs.—Letters tested were standard Bureau of Public Roads 12-in. Interstate upper case, with a stroke width 0.2 times the letter height, spaced according to BPR recommendations. The reflective material used for letters exhibited specific luminance characteristics similar to those shown in Figure 4. A front illuminated sign with white letters was also used having nine independently controlled fluorescent lamps to vary illuminance.

Signs were mounted at a height of 14 ft from the pavement to the bottom edge and 16 ft from the left edge of the sign to the right pavement edge. Luminaire alignment and sign placement were representative of highway practice. Signs were located with respect to adjacent luminaires to obtain 0.2-ft-L luminance, within the range of 0.1 to 0.4 ft-L observed in typical installations.

Legends.—Two legends, GOAL and LOAN, were used for each condition. The legends contain straight and curved letters, the letters G and N more difficult to resolve; O and L, least difficult. Legibility distances for both legends were averaged to obtain the legibility distance for each condition.

Observers.—Forty-five male observers were used ranging in age from 20 to 62 years with an average age of 34. Observers were asked to discriminate individual letters before recording distances. Observations were made from ten cars. No headlamp checks or adjustments were made because legibility results were averaged and should yield data more representative of actual road viewing conditions.

Design of Experiment.—Each observer viewed the illuminated sign and reflective materials with high and low beams in dark and illuminated conditions, permitting correlation with results of Allen's legibility studies in dark field conditions.

Results

Average legibility distances for reflectorized 12-in. letters for different conditions of illumination (see Fig. 7) are given in Table 1.

The nearly identical results under conditions of moderate illumination and total darkness indicate that the effect of highway luminaires on legibility is negligible with either low or high beams as shown in Figure 7. Legibility differences slightly favor the 0.2 ft-L ambient condition indicating that legibility does not deteriorate but, in fact, marginally improves in changing the dark condition to illuminated suburban. Luminance requirements for the dark condition, therefore, do not require change for optimum legibility in most illuminated locales.

Higher traffic volumes associated with illuminated highways discourage the use of high beams, correspondingly reducing sign luminance and legibility. Despite generally satisfactory performance at lower luminance levels, current practice frequently involves the use of larger signs and letters on such roadways, providng substantially increased absolute legibility distance. An increase from 10- to 12-in. size yields a 20 percent improvement in legibility as shown by Allen (3).

TABLE 1

AVERAGE LEGIBILITY DISTANCES

Sign	Head-lamp Beam	Distance from Luminaire (ft-L)	Avg. Legibility Distance Light (ft)	Dark (ft)	Diff. (%)	Light (ft/in. letter height)	Dark (ft/in. letter height)
With white reflective letters	High	0.2	798	780	+2.4	66.5[a]	65.0
	Low	0.2	705	684	+2.8	58.5[a]	57.0
Front illus. with white letters on black	Low	15	802			66.8[b]	

[a]0.2 ft-L ambient incident to sign surface.
[b]15 ft-L.

Although roadway illumination up to 0.4 ft L in no way reduces sign legibility, associated higher traffic volumes and roadway design contribute to more general use of low beams. The separation of roadways or the employment of glare screens would markedly improve night visibility by permitting general use of the high beams.

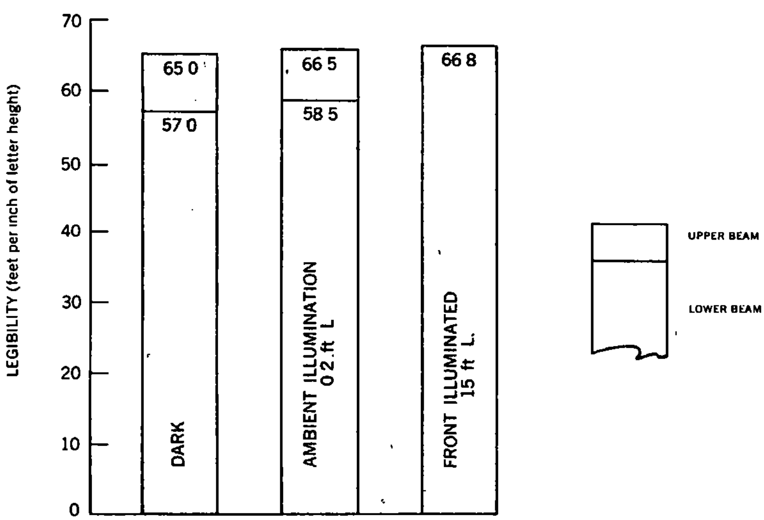

Figure 7. Average legibility distances for 12-in. reflective letters in dark-rural and illuminated-suburban conditions (0.2 ft-L) with upper and lower beams. Legibility data for front illuminated letters in illuminated suburban condition exhibiting 15 ft-L is shown for comparison.

BRIGHT URBAN

Light levels incident on sign surfaces in this category range from 0.4 to approximately 4.0 ft-L. Urban street lighting studied consisted of 33-ft M.H. 6-tube fluorescent fixtures (G.E. Type 606) at 45-ft spacing, producing an average of 4 ft-candles on the pavement surface. Results of measurements of white test panels, in such brightly illuminated locales, vary from 0.4 to 4.0 ft-L dependent on luminaire proximity.

The determination of desirable luminance levels for maximum contrast and legibility in this environment led to measurement of signs selected on the basis of their comparative visibility. Prominently visible signs exhibit luminances from 75 to 125 ft-L. Though it has not been established that signs with lower luminance are less legible, they are less visible unless of large size.

The substantial traffic volumes usually associated with this type of roadway frequently involve the presence of closely preceding and following vehicles supplying additional headlight luminance at useful divergence angles. In effect, stream traffic was found to increase sign luminance factorially, from two to six times for a combination of two vehicles, with additional benefits for more than two.

CONCLUSIONS

Graphical data are presented that describe the effects of changing divergence and headlamp illuminance within the sign field. Coupled with knowledge of specific luminance, this data permits reliable calculation of reflective traffic sign luminance. Calculation and field measurements indicate normal shoulder-mounted reflective signs provide luminances of 1.5 to 3 ft-L with low beams, and 10 to 50 ft-L with high beams at generally useful legibility distances. Field measurements of the effects of no light to moderate illumination in rural and suburban surrounds disclose that ambient luminance on signs can range from the negligible to 0.4 ft-L.

In these environments, sign luminance of 10 to 20 ft-L provides optimum brightness for maximum legibility. Luminance provided by low beams results in 85 percent of the maximum legibility figure. The results of measurements in standard highway lighting conditions show improvement in reflective sign legibility compared to the dark condition, notwithstanding presence of luminaires and associated glare. The luminance of existing reflective materials provides adequate brightness for good legibility of most information and traffic control signs in rural and illuminated suburban environments.

Surrounds of greatly varying brightness require assessment of the contrast afforded by sign luminance, color, and shape. An investigation by Finch and Howard (6) of the detection of traffic signal lights against a background of electric advertising signs suggests the manner and merit of such a study. Further research should be particularly directed toward a generally useful quantitative test of attention value.

REFERENCES

1. Forbes, T.W., "A Method for Analysis of the Effectiveness of Highway Signs." Jour. Appl. Psychol., Vol. 23 (1939).
2. "Manual on Uniform Traffic Control Devices for Streets and Highways." U.S. Dept. of Commerce, Bureau of Public Roads (1961).
3. Allen, T.M., "Night Legibility Distances of Highway Signs." HRB Bull. 191, 33-40 (1958).
4. Johnson, M.D., "Motor Vehicle Headlamp Evaluation—Calculation of Divergence Angles for Various Sign Positions." Minnesota Mining and Mfg. Company, Tech. Service Report 310.1 (1961).
5. Fry, G.A., "Physiological Basis of Disability Glare." Internat. Commission on Illumination (1955).
6. Finch, D.M., and Howard, J., "A Color Comparator for Lights in the Vicinity of Traffic Signals." HRB Bull. 191, 1-6 (1958).