

A BRIGHTNESS INVENTORY OF CONTEMPORARY SIGNING MATERIALS FOR GUIDE SIGNS

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The purpose of this study is to measure the brightness of contemporary sign materials in actual use situations, as observed by the driver under normal daytime and nighttime viewing conditions. Determinations were made for 7 approach distances for high and low beams at night and for 2 distances by day. Luminance readings were obtained for 4 legend materials, 3 background materials, and 18 conditions of sign surround. Results indicate that luminances for sign legends of over 1 foot-lambert are available on low beams for encapsulated lens and button reflective materials on unlighted overhead signs for the legibility distances available. Three legend materials are in excess of this level for the shoulder-mounted location on low beams. This luminance level has been suggested by earlier investigators as the minimum level for adequate legibility. With high beams, luminances of 10 to 20 foot-lamberts, equivalent to those exhibited for illuminated overheads, are available for several materials on both overhead and shoulder-mounted signs. Maximum reflective sign luminance occurs at distances similar to the maximum legibility distances for the letter sizes employed on Interstate guide signs, a circumstance of the head-lamp distribution pattern, sign offset, material efficiency, and the letter sizes commonly encountered.

•SIGN visibility in the traffic environment is dependent on the detection, identification, and legibility of the sign. Each factor has its special importance as the sign is approached, and each requires an adequate degree of visibility for its effectiveness. Forbes (1) quantified factors of sign detectability and legibility, and the literature reviewed by him plus that assembled by Richards (2) represents a substantial body of knowledge directed to identifying and understanding these factors. Of interest to the sign designer are the factors that influence detection, identification, and legibility of signs. These factors include the choice of legend (symbols, abbreviations, route numbers, and place names), color and shape, sign size and position, and materials. Color and shape are regulated to achieve uniformity, and sign size and position are frequently determined by policy or custom.

The interrelationships of legend brightness, contrast with the sign background, and resulting legibility distance have been investigated by Straub and Allen (3, 4); Allen, Dyer, Smith, and Janson (5); and Elstad, Fitzpatrick, and Woltman (6). Studies in dark surrounds have generally evaluated the legibility of Interstate-sized letters at varying levels of luminance while considering additional sources of luminance and glare that might impede or enhance legibility. In general, legibility of white letters on dark colored backgrounds are reported to be at a maximum in the range of 10 to 30 foot-lamberts brightness with approximately 85 percent of the possible legibility available at luminances as low as 1.5 foot-lamberts. Levels as high as 100 foot-lamberts may be desirable under some circumstances. The many effects of opposing head-lamp glare, light from luminaires and other sources, adequate contrast with sign backgrounds

of lower luminance levels, and color are dealt with by the investigators previously mentioned. Although all factors tend to influence the legibility distance, the desirable luminance levels generally conform to the values cited.

The luminance values for the background and surround have not been thoroughly quantified. These values have an important role in factors of detection and identification. The work by Forbes, Fry, Joyce, and Pain (7) indicates that signs seen "first and best" must have good contrast within the sign and good contrast with the surround. Several mathematical models were advanced to describe the factors of detection and identification of the sign against many natural surrounds. The contrast levels between the legend and sign background, and between the sign background and its surround, were found to be of equal importance. Of significance is the total luminance of the sign, other things being equal. An evaluation of the relative merits of sign position favored the overhead location.

Hanson and Woltman (8) inventoried more than 4,000 Interstate signs and reported on their angular position relative to the center of the visual field. The subjective brightness and nature of the sign surround near the legibility threshold were also assessed.

It is clear from the foregoing that the luminance of legends, backgrounds, and surrounds is of signal importance. This study is an inventory of sign luminances presented by current signing practices and materials.

LUMINANCE CHARACTERISTICS

Sign luminance for illuminated signs is directly measured with footcandle meters and comparatively straightforward instruments of little greater sophistication than that required of the photographer's light meter. The determination of the luminance of reflective signs is less straightforward and must generally be calculated in the manner first described by Allen (3). Elstad, Fitzpatrick, and Woltman (6) used planes to describe luminances for several signing positions for sign viewing distances from 75 to 1,200 ft. A refinement of this system was employed by King and Lunenfeld (9) in their study wherein computer analysis permitted the investigation of the problems presented by severe horizontal and vertical curvature on sign luminance.

These techniques employ careful determination of reflective luminance in absolute values. Because reflective efficiency varies widely over useful divergence angles, the resulting values are expressed as specific luminance (2) versus divergence for each type of reflective material under consideration. Divergence angle is the angle subtended by the head lamps, the sign, and the reflected light beam at the observer. This angle undergoes significant change as the motorist approaches the sign and greatly influences the resulting luminance. As shown in Figure 1, this angle increases substantially as sign reading distances shorten. Further, the greater lateral distance of the right head lamp makes the luminance contribution from this source approximately half that of the left lamp at shorter distances. Both changes necessitate separate calculation of the luminance for each head lamp and for each divergence angle.

Illuminance depends on the alignment of the sign with the head-lamp beam and its determination requires the location of the reflective device in the appropriate area of the head lamp isocandle diagram for both high and low beams and for typical conditions of highway alignment. Calculation for each lamp is required, as is change in sign position or distance. Luminance values are then obtained by application of the inverse square law. Inherent differences in individual lamps are to some extent compensated for by the presence of two or four lamps. However, voltage variation, lamp misalignment (10), and changes in car loading all contribute to variation in illuminance, thus providing results that are not always consistent.

DESIGN OF EXPERIMENT

It has only been in recent times that field photometers of portable size, high sensitivity, and small angular resolution have become available to make in situ luminance measurements of overhead and shoulder-mounted guide signs. This has resolved those questions that always occurred when theoretical calculations were used. The present study is a field inventory of guide signs of contemporary legend and background

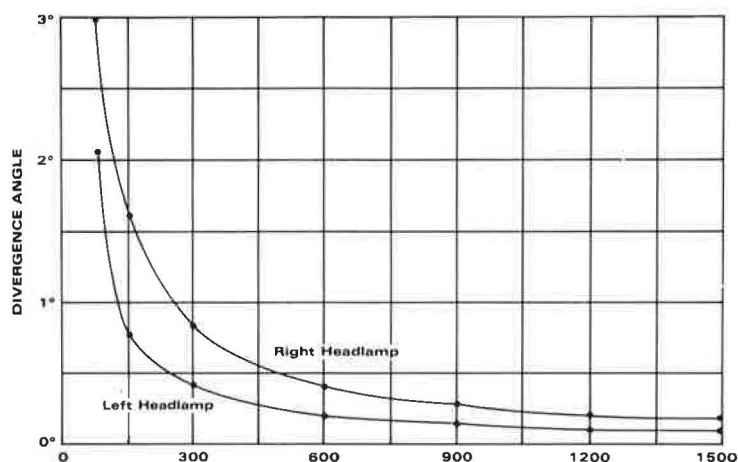


Figure 1. Divergence angle versus distance for shoulder-mounted signs.

materials made by direct measurement at the driver eye position for a variety of conventional automobiles for both daytime and nighttime driving situations.

SIGNING MATERIALS

The contemporary signing materials studied are relatively standardized within each state but differ in combination of materials used from state to state. The luminance of legend and background materials are reported separately for both high and low beams. Shoulder-mounted, overhead unlighted, and overhead lighted signs were measured. The signing materials measured include:

1. Opaque—unreflectorized legend or background having white or green paint or porcelain finish;
2. Button—plastic prismatic retroreflective buttons in white opaque metal frames;
3. Encapsulated lens sheeting—white or green retroreflective sheeting with sealed septa;
4. Enclosed lens sheeting—white or green retroreflective plastic sheeting; and
5. Lighted—diffuse illumination by fluorescent fixtures positioned immediately below and in front of the sign surface.

A combination of materials may be installed if lighted. Current practice is not to illuminate shoulder signs, whereas overhead signs may be. These materials are illustrated in Figure 2.

PHOTOMETRIC INSTRUMENTATION

Measurements were made with a Gamma Scientific, Inc., Model 2000 Telephotometer (Figure 3). This instrument has a transistorized photomultiplier and electrometer amplifier, independent battery power supply, 2 minutes of angle sensing probe (acceptance angle), measurement span from 0.001 to 35,000 foot-lamberts, photopic color correction (correlation curve for the filter used is shown in Figure 4), and internal standardization and calibration. At the outset and at the conclusion of the tests the instrument was calibrated with a NBS standard source, and over a number of tests it averaged ± 2.5 percent.

Although five acceptance angles are available with the instrument, the 2-minute acceptance angle was chosen because it approaches closely the acuity threshold for normal eyesight. As Connolly points out in his review of driver visual examination practices,

the licensing of motorists to a 20/40 acuity standard indicates that 2 minutes resolution is equivalent and entirely appropriate (11, 12). Further, the generally accepted 50-foot-per-inch of letter height criterion (13) for letter legibility and the Interstate letter stroke width of $\frac{1}{5}$ the letter height (14) yields a stroke width at legibility thresholds for the acuity standards allowed of approximately 2 minutes width. Thus the acceptance angle of the instrument approximates the letter stroke width at the useful legibility distances. Both points are important, for a probe of either larger or smaller size seems less appropriate for the measurement of letter luminance. As shown in Figure 3, the instrument was mounted on a tripod above the driver seat back at the driver eye position. In normal use, two operators are required: one to align the optical head with the object in the field of view, the other to record the result.

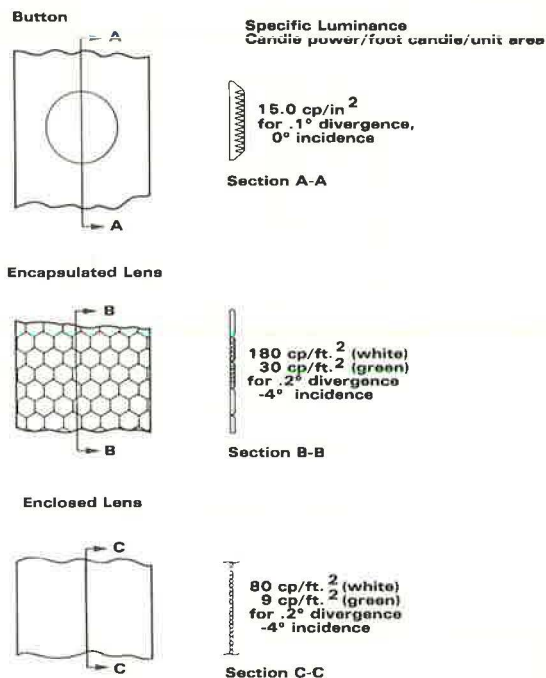


Figure 2. Reflective signing materials.



Figure 3. Gamma Scientific, Inc., Model 2000 Telephotometer.

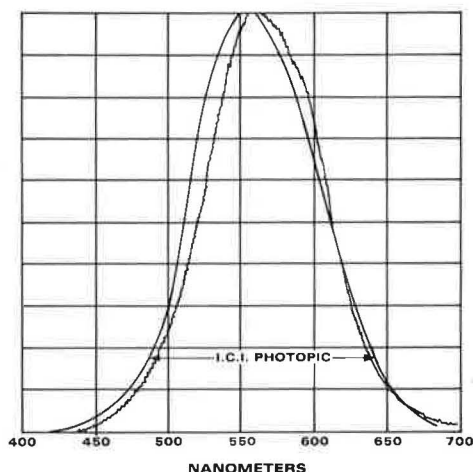


Figure 4. Spectral characteristics of Model 2000 Telephotometer with photopic correction filter.



Figure 5. Marking visibility distances.

STUDY SITES

Study sites were chosen for recentness of installation and the type of materials available. Prospective sites were examined for alignment to avoid those where circumstances of grade or curvature restricted viewing distances to less than 1,500 ft. In general sites were chosen on tangent sections without vertical curvature. Measurements were taken from the paved shoulder in all cases.

Measurements were taken for sign width, height, and offset and elevation above grade, and the materials used were recorded. Recording distances were determined as shown in Figure 5 and marks were applied to the roadway surface on the sign approach at 150, 300, 450, 600, 900, 1,200, and 1,500 ft. It was felt that these distances encompass the range of interest accorded detection, identification, and legibility factors. As a matter of observation the authors are of the opinion that approximately 10 percent of Interstate guide signs are not visible beyond approximately 1,500 ft because of visual obstructions from alignment conditions such as sign bridges, overpass structures, cuts, and other physical impediments. The 12- to 18-in. legend size generally used renders signs legible in the 600- to 900-ft range. At 150 ft both the overhead structure and the shoulder-mounted sign are nearly displaced into the tinted windshield band or the rear-vision mirror. Thus, as a practical matter, the distance surveyed provides a thorough knowledge of sign performance that encompasses the far to near distance at increments where performance changes are of interest, particularly throughout the useful legibility range. In all, 127 such sites were selected and inventoried in five states.

TEST VEHICLES

Automobiles used for data-taking were rented from one of the nationally recognized agencies. All were standard domestic full-sized four-door passenger cars or station wagons (Table 1). Eight of the 11 cars used had tinted windshields. The vehicles were set up with the photometric equipment and were loaded with needed accessories. The gas tanks were filled, and the vehicles were taken to a local dealer for head-lamp alignment check, except in two states where the official state alignment station was used. The intent was to procure an automobile representative of the late-model car population that had lamp adjustment in conformance with commercial practice or state requirement. Prior to readings, all windshield and head-lamp surfaces were cleaned.

TABLE 1
VEHICLES USED IN STUDY

Year	Make and Model	Number of Vehicles	Windshield Tinted
1969	Oldsmobile Cutlass station wagon	2	No
1969	Plymouth 4-door sedan	1	Yes
1970	Chevrolet Bel Aire station wagon	2	Yes
1970	Oldsmobile Vista Cruiser station wagon	1	Yes
1970	Mercury Monterey station wagon	2	1 Yes, 1 No
1970	Pontiac Catalina station wagon	1	Yes
1970	Pontiac Catalina 4-door sedan	2	Yes
Total vehicles		11	

CAR ALIGNMENT

In commencing readings at 1,500 ft, care was taken to align the car in normal tangent alignment with the lane lines and roadway. This was done by traveling for several hundred feet in approaching this distance and stopping without last-second steering wheel correction. Thereafter the reticle in the optical head was aligned on a reference target (photometric standard for reference readings) and locked in position. The car was moved and stopped at the next reading distance by alignment of the car while the reticle was sighted on the target. In this manner deviations in head-lamp alignment were minimized initially and between readings.

Areas Measured

As shown in Figure 6, the instrument was used to measure sign-legend luminances on route shields or arrows, which have ample areas for measurement with the 2-minute probe at 900, 1,200, and 1,500 ft. At closer distances, letter strokes could be measured. Sign background luminances were measured at the four corners within the borders in available background space. Sign surround luminances were measured to the right and left, above and below the sign, as illustrated. A photometric standard consisting of a 12-in. square panel of known reflectance was placed on a tripod 30-in. above

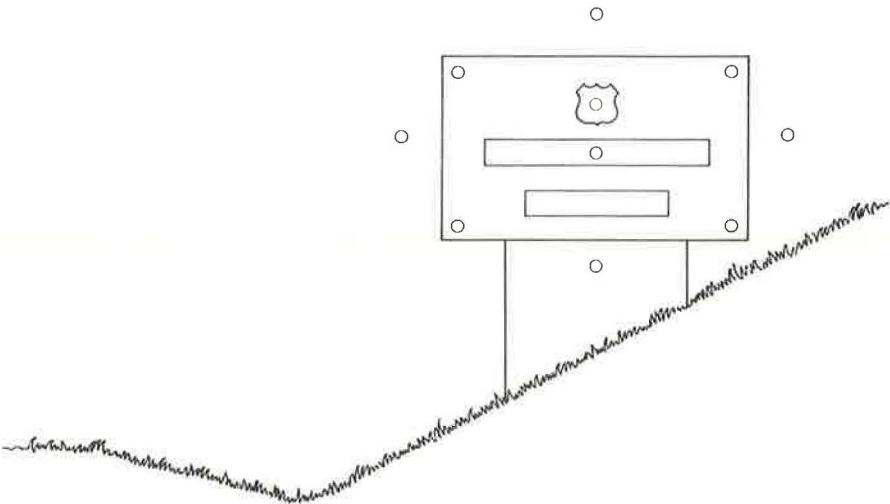


Figure 6. Brightness measurement locations for shoulder-mounted signs.

the roadway, centered in the shoulder lane and in the sign plane for reference readings. In all cases, the probe was held to the area intended and particular care was taken with legend and background readings to measure that portion of the sign face exclusively.

Sign luminance readings were taken for the copy and background positions noted during daytime at distances of 1,500 and 600 ft and at night on high and low beams for the seven distances noted. Surround luminances were recorded at 1,500 and 600 ft during both daytime and nighttime. The photometric standard was read at the onset of testing for every station. For the 127 signs measured, 11,552 readings were recorded.

DATA RECORDED

Data taken for each sign were recorded on two data sheets developed for simple transposition to punch cards. In addition to luminance readings, 2,356 additional facts were recorded including information on sky cover, direction facing (sun or shade), presence of external illumination, position of sign (by lane if overhead and offset for shoulder-mount), sign dimensions, materials employed for copy and background, and identification of the surround at 1,500 and 600 ft to one of 18 categories.

DISCUSSION OF RESULTS

Nighttime luminance data are shown in Figures 7 through 14 and in Tables 2 and 3 for signs of the shoulder-mounted, overhead lighted, and overhead unlighted types, by legend and background material. Daytime luminance data are also given in Table 4 for these categories.

The overhead lighted signs display a relatively uniform luminance to the motorist throughout the approach. Comparable uniformity ratios of background luminance on overhead lighted signs are given in Table 5, with the brightest background material

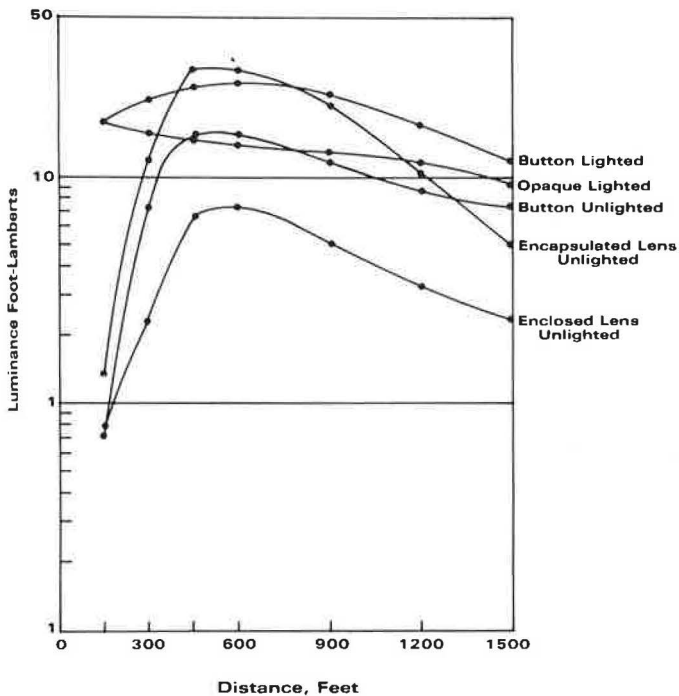


Figure 7. Nighttime luminance of sign legends versus distance for overhead signs, high beams.

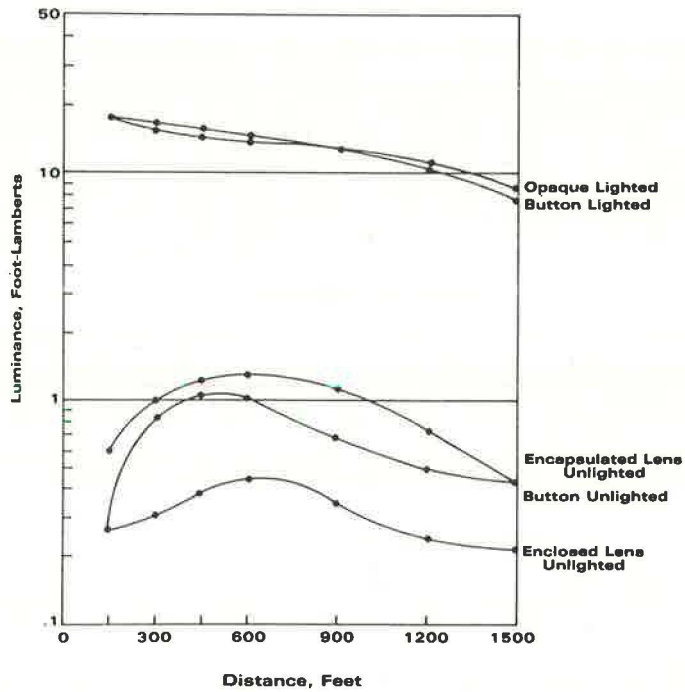


Figure 8. Nighttime luminance of sign legends versus distance for overhead signs, low beams.

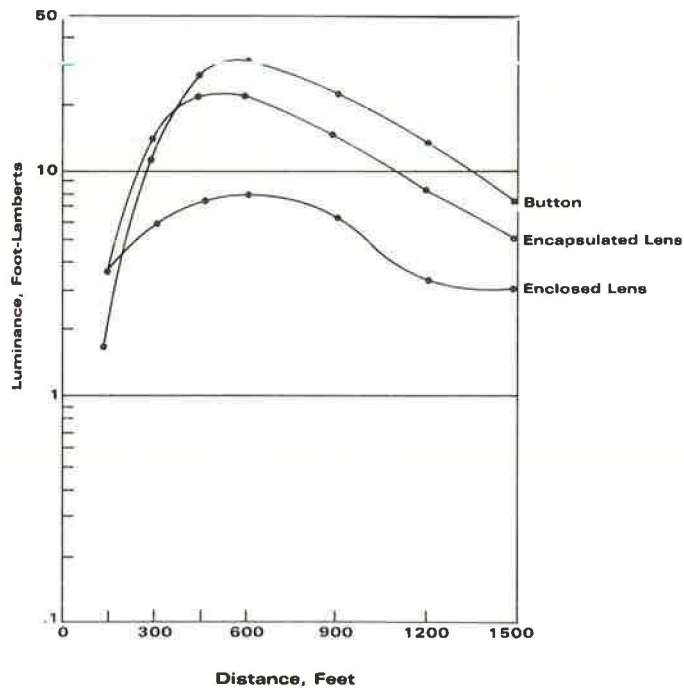


Figure 9. Nighttime luminance of sign legends versus distance for shoulder-mounted signs, high beams.

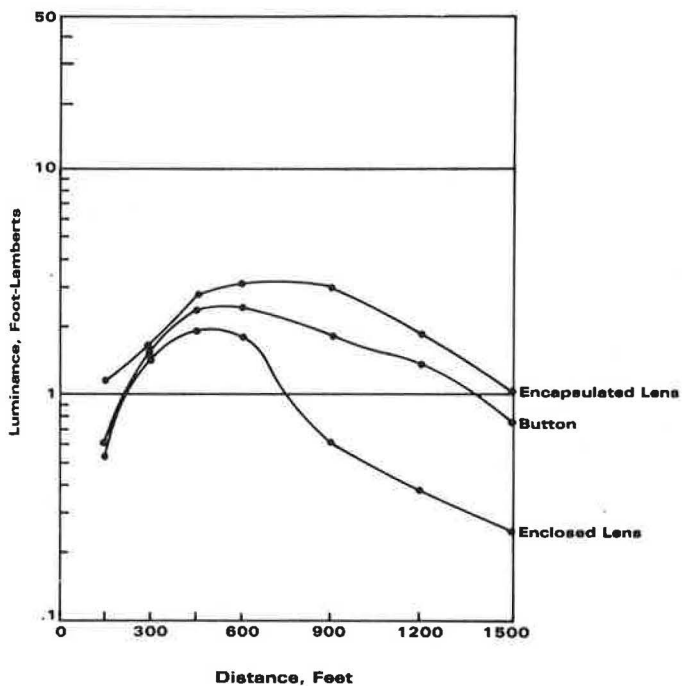


Figure 10. Nighttime luminance of sign legends versus distance for shoulder-mounted signs, low beams.

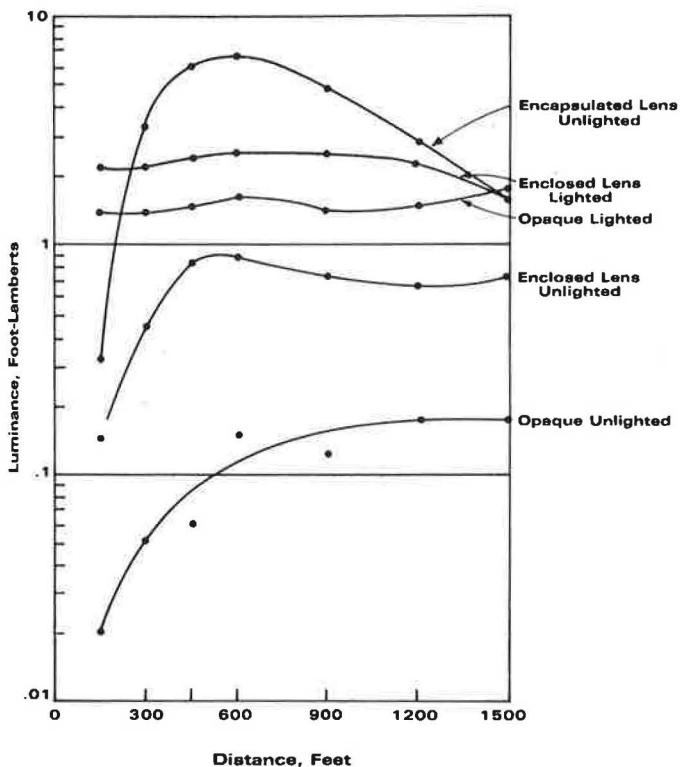


Figure 11. Nighttime luminance of sign backgrounds versus distance for overhead signs, high beams.

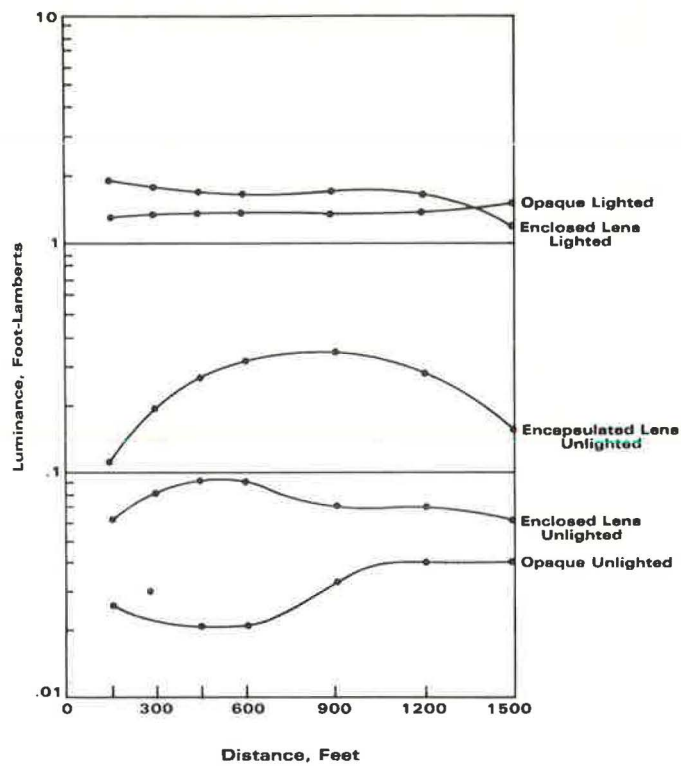


Figure 12. Nighttime luminance of sign backgrounds versus distance for overhead signs, low beams.

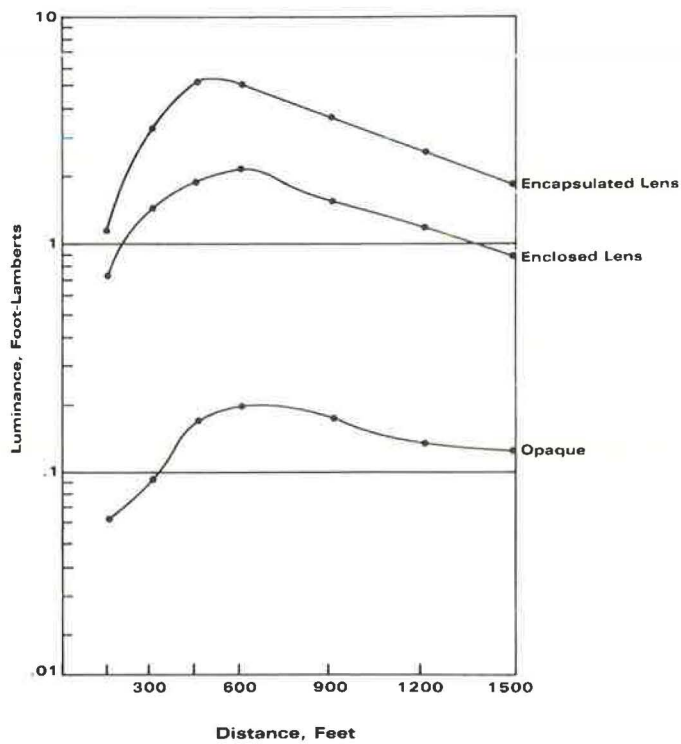


Figure 13. Nighttime luminance of sign backgrounds versus distance for shoulder-mounted signs, high beams.

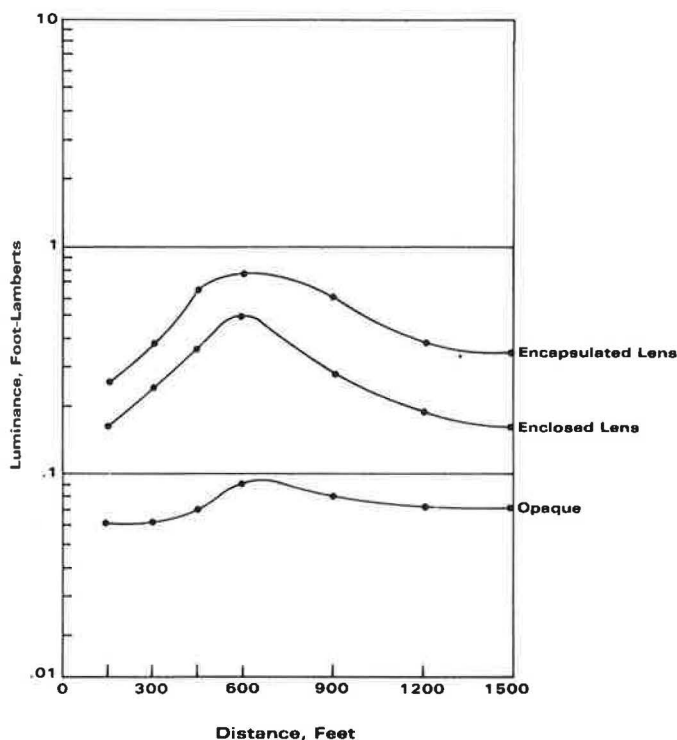


Figure 14. Nighttime luminance of sign backgrounds versus distance for shoulder-mounted signs, low beams.

TABLE 2

NIGHTTIME AVERAGE LUMINANCE IN FOOT-LAMBERTS OF SIGN
LEGEND MATERIALS

Legend Materials	Distance (ft)						
	1,500	1,200	900	600	450	300	150
Shoulder-Mounted Unlighted Signs							
Encapsulated lens							
High beam	5.17	8.64	15.24	21.31	22.47	14.52	3.66
Low beam	1.07	1.88	3.05	3.02	2.85	1.65	1.16
Button							
High beam	7.55	13.30	21.61	30.42	28.37	11.52	1.66
Low beam	0.87	1.40	1.86	2.46	2.41	1.57	0.53
Enclosed lens							
High beam	3.17	3.30	6.48	8.00	7.37	5.88	3.55
Low beam	0.25	0.39	0.62	1.85	1.92	1.46	0.61
Overhead Lighted Signs							
Button							
High beam	11.49	17.56	22.68	25.11	24.98	20.63	17.20
Low beam	7.97	10.79	12.95	14.19	15.65	16.71	17.40
Opaque							
High beam	9.20	11.25	12.79	14.47	14.72	15.35	17.57
Low beam	8.97	11.17	12.60	14.37	14.62	15.29	17.57
Overhead Unlighted Signs							
Encapsulated lens							
High beam	4.28	10.02	20.86	28.70	29.16	11.82	1.30
Low beam	0.42	0.73	1.15	1.36	1.19	0.73	0.58
Button							
High beam	7.02	8.40	11.27	15.13	15.19	7.26	0.73
Low beam	0.43	0.50	0.70	1.02	1.06	0.80	0.26
Enclosed lens							
High beam	2.32	3.26	5.17	7.37	6.92	2.33	0.80
Low beam	0.22	0.24	0.35	0.44	0.38	0.30	0.27

TABLE 3

NIGHTTIME AVERAGE LUMINANCE IN FOOT-LAMBERTS OF SIGN BACKGROUNDS

Background Material	Distance (ft)						
	1,500	1,200	900	600	450	300	150
Shoulder-Mounted Unlighted Signs							
Encapsulated lens							
High beam	1.79	2.49	3.60	4.94	5.10	3.06	1.16
Low beam	0.34	0.38	0.58	0.67	0.62	0.37	0.25
Enclosed lens							
High beam	0.94	1.17	1.52	2.15	1.84	1.46	0.74
Low beam	0.16	0.19	0.27	0.33	0.32	0.26	0.18
Opaque							
High beam	0.12	0.13	0.17	0.19	0.17	0.09	0.06
Low beam	0.08	0.07	0.08	0.08	0.07	0.06	0.06
Overhead Lighted Signs							
Enclosed lens							
High beam	1.61	2.20	2.42	2.47	2.43	2.15	2.19
Low beam	1.22	1.65	1.68	1.70	1.74	1.78	1.90
Opaque							
High beam	1.73	1.47	1.40	1.60	1.43	1.38	1.38
Low beam	1.48	1.37	1.35	1.38	1.38	1.36	1.33
Overhead Unlighted Signs							
Encapsulated lens							
High beam	1.51	2.76	4.64	6.60	5.83	3.26	0.31
Low beam	0.15	0.27	0.33	0.30	0.26	0.19	0.11
Enclosed lens							
High beam	0.71	0.66	0.74	0.94	0.85	0.44	0.14
Low beam	0.06	0.07	0.07	0.09	0.09	0.08	0.06
Opaque							
High beam	0.17	0.17	0.12	0.15	0.06	0.05	0.02
Low beam	0.04	0.04	0.04	0.02	0.02	0.03	0.02

TABLE 4

DAYTIME AVERAGE LUMINANCE IN FOOT-LAMBERTS OF SIGN LEGENDS AND BACKGROUNDS

Material	Distance (ft)	Luminance (foot-lamberts)	Number of Readings
Sign Background			
Encapsulated lens	1,500	222	22
	600	167	22
Enclosed lens	1,500	389	38
	600	372	38
Opaque	1,500	476	21
	600	307	21
Sign Legend			
Encapsulated lens	1,500	331	24
	600	291	24
Enclosed lens	1,500	266	10
	600	325	10
Button	1,500	698	47
	600	852	47
Opaque	1,500	494	11
	600	418	11

providing the more uniform background. The data show that the illuminance of high beams may be observed by the driver to enhance the luminance of lighted signs under certain conditions (as for reflective materials).

The comparison of overhead unlighted to overhead lighted is revealing. It indicates the availability of virtually equivalent performance if the motorist is driving on or switches to high beams for two of three available legend materials. These materials on the average exceed 1 foot-lambert luminance on low beams at reading distances for the overhead unlighted situation, and all exceed this level for the shoulder-mounted signs. The luminance levels established by the legibility studies cited earlier appear to be realistic insofar as numerous signs exhibiting this level of luminance are presently operational. An examination of the

TABLE 5
UNIFORMITY RATIO OF OVERHEAD LIGHTED SIGN BACKGROUNDS

Background Material	Distance (ft)							Average All Distances	Grand Average
	1,500	1,200	900	600	450	300	150		
Encapsulated lens									
High beam	1.42	1.31	1.61	1.49	1.70	2.68	—	1.70	1.73
Low beam	1.18	1.81	1.66	1.78	1.59	2.59	—	1.77	
Enclosed lens									
High beam	2.37	2.08	2.09	2.38	2.63	2.94	4.27	2.68	2.91
Low beam	3.07	2.75	2.65	3.13	3.17	2.97	4.22	3.14	
Opaque									
High beam	2.29	2.11	2.36	1.80	2.56	2.77	3.02	2.41	2.40
Low beam	2.35	2.51	2.33	1.19	2.63	2.63	3.11	2.39	

shoulder-mounted sign data indicates that low-beam performance favors this sign position. The general alignment of the low beams with the lower right quarter of the visual field suggests higher luminances for these signs, which the measurements confirm.

The performance of sign backgrounds is indicated to be approximately one-tenth of the legend luminance for the overhead lighted signs and approximately one-fourth to one-twelfth for reflective materials, depending on the combinations compared. To facilitate rapid detection and identification and yet provide an adequate level of contrast with the legend and night surround, a level above approximately 0.2 foot-lambert should be given as desirable.

The apparent irregularity of data points for opaque data may be attributed to occasional specular glare arising from head lamps or the proximity of luminaires. The peaking of luminances for reflective materials at the 450- to 600-ft distances confirms previous laboratory studies cited that indicate that conditions of illuminance distribution and divergence angle are optimized at this distance for signs with the present offset and clearances. It is notable that most legend sizes employed for Interstate signing are not only legible at these distances but also possess their maximum luminance at these distances as well. For positions closer to the roadway, shorter distances will provide greater luminance.

Apparent ambiguities in graphical data for legend-to-background comparisons for similar materials and conditions may be ascribed to the inherent differences of their specific luminance curves. The numerical data are given in Tables 2 and 3. Data given are computed averages; further information on the standard deviations, 95 percent confidence limits, and number of readings are given in the Appendix in Tables 9 through 14 and Figures 15 and 16.

Daytime surrounds have widely varying luminance and color, and much of this is confirmed by the data in Table 6. As indicated, sky and snow backgrounds are the brightest; however, cloud cover is the most significant factor. The night luminances immediately surrounding the signs are surprisingly uniform despite large additions of light from luminaires, nearby buildings, signs, etc., which appear to fall largely on the roadway. For the

TABLE 6
AVERAGE LUMINANCE OF SIGN SURROUNDS, AT
1,500-FT DISTANCE

Sky Cover	Surround	Luminance (foot-lamberts)	Number of Readings
Clear	Snow	2,650	3
	Sky	1,950	150
	Green grass	860	16
	Green trees	700	6
	Tan grass	600	36
	Bridge	470	8
Light overcast	Sky	900	65
	Green trees	455	17
	Dark hill	400	8
	Tan grass	285	23
Dark overcast	Snow	745	14
	Sky	290	27
	Bridge	255	6
	Green trees	195	8
	Dark hill	190	9
	Green grass	175	3
	Tan grass	106	21
Night	All back-grounds	0.02	504

TABLE 7

PERCENTAGE OF MAXIMUM EXPECTED RECOGNITION DISTANCE FOR OVERHEAD SIGNS

Background Material	Legend Material			
	Lighted Button	Reflectorized Button	Encapsulated Lens	Enclosed Lens
Lighted opaque				
High beam	92	—	—	—
Low beam	95	—	—	—
Encapsulated lens				
High beam	—	88	83	—
Low beam	—	76	75	—
Enclosed lens				
High beam	—	94	91	83
Low beam	—	54	57	50
Unlighted opaque				
High beam	—	63	62	61
Low beam	—	46	46	46

vast majority of signs, this light seems to have little effect on the immediate sign surround, leaving the sign in generally good contrast.

Table 7 gives the percentage of expected recognition distance calculated from the legend, background, and surround contrasts according to the formula developed by Forbes, Fry, Joyce, and Pain (7) for determining the likely distance at which the sign is first detected and identified. The formula requires legend, background, and surround luminance and sign size. The average percentages of contrast of legend to background, and background to surround, are multiplied by a constant and minimum sign dimension. The product is the expected recognition distance. The maximum theoretical distance obtains for maximum legend-to-background contrast and background-to-surround contrast where sign size is constant. The percentage of maximum expected recognition distance is shown for a variety of legend and background materials for overhead signs against the night surround employing luminance data from 1,500 ft. The percentage values provide a method of comparing materials of various contrasts independent of sign size. As might be expected, the combinations having maximum contrast and maximum luminance against the rather low surround value provide values closest to 100 percent of the maximum expected recognition value.

The total sign luminance for a lighted or reflectorized overhead sign is given in Table 8 for various legend and background materials in combination. Values shown are computed for an overhead sign having a typical legend area from luminance data

TABLE 8

TOTAL LUMINANCE IN CANDLEPOWER OF 120-SQ FT OVERHEAD SIGNS AT 600 FT

Background Material	Legend Material			
	Lighted Button	Reflectorized Button	Encapsulated Lens	Enclosed Lens
Lighted opaque				
High beam	2,210	—	—	—
Low beam	1,345	—	—	—
Encapsulated lens				
High beam	—	3,008	3,735	—
Low beam	—	154	168	—
Enclosed lens				
High beam	—	1,172	1,920	717
Low beam	—	87	101	54
Unlighted opaque				
High beam	—	910	1,672	472
Low beam	—	71	85	38

derived at 600 ft. At this distance, total sign luminance is dependent on sign size, materials, and position.

STREAM TRAFFIC

For traffic volumes over approximately 10,000 ADT, the presence of other vehicles ahead of or behind the driver will be a common occurrence. Under this circumstance, the contribution of other head lamps in the traffic stream is easily observed and was informally noted on many occasions while waiting for vehicles to pass so that only the test vehicle was illuminating the sign. The illuminance contribution of stream traffic was observed to increase sign luminance from 2 to 5 times when all vehicles were on low beam. However, one vehicle in the stream on high beam will produce sign luminance that closely approaches normal high beam luminance of the test vehicle. If the test vehicle is on high beams, the contribution from stream traffic is less noticeable and was observed to increase luminance up to 50 percent.

CONCLUSION

Previous studies of sign luminance have reported essentially laboratory determinations of calculated luminance in the absence of satisfactorily sensitive and reliable instruments for field work. Sufficiently wide-scale deployment of current materials and the most recent availability of satisfactory instrumentation prompted an extensive design experiment to inventory the contemporary signing materials for a large number of Interstate signs of the guide sign category. Luminance measurements from 150 to 1,500 ft are reported using typical current model automobiles viewed from the driver position.

The study provides tables and graphs of sign luminance presently attained and experienced by the motorist for normal Interstate signing materials during the day and at night for high and low beams. Sign surround luminance values are also given for daytime and nighttime. Graphical presentation of the results permits separate comparison of legend as well as background materials in current use. The figures show the luminance of overhead lighted signs and the availability of similar luminance levels by unlighted signs having several of the currently available retroreflective materials when viewed with high beams. Low beams provide average luminances in the range established by other investigators as necessary for satisfactory legibility. The many currently operational unlighted overhead and shoulder-mounted signs exhibiting satisfactory low-beam luminances attest to the soundness of these original findings. An interesting fact concerning the reflective legends recorded is that, for distances where maximum legibility might be expected, maximum luminance also occurs. The effect of adjacent vehicles in the traffic stream is to raise sign luminance for low beams from two to five times for adjacent vehicles on low beams up to the level of high-beam luminance if adjacent vehicles are using high beams.

Sign background luminance should be sufficient to contrast with the nighttime surround yet provide adequate contrast for letter legibility. Taken together, the three luminance levels yield the expected recognition distance that is tabulated for all materials as a percentage of the maximum expected recognition distance.

It is hoped that this extensive inventory of sign luminance in this vital signing category will be informative and contribute to a greater understanding of the importance of factors contributing to early sign detection and identification as an official traffic device coupled with maximum legibility as these factors relate to materials performance.

ACKNOWLEDGMENT

The nearly 14,000 luminance readings and other data collected would not have been possible without the interest and cooperation of the state highway departments of Arizona, California, Iowa, Minnesota, and Tennessee and the Texas Transportation Institute of Texas A&M University. The authors' appreciation is also extended to many individuals without whose assistance this study could not have been made.

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APPENDIX

TABLE 9
NIGHTTIME LUMINANCE IN FOOT-LAMBERTS OF LEGEND MATERIALS FOR OVERHEAD LIGHTED SIGNS

Distance Feet	High Beam Average	Std. Dev.	95% Confi- dence Limits		Number of Readings	Low Beam Average	Std. Dev.	95% Confi- dence Limits		Number of Readings
			Upper	Lower				Upper	Lower	
1500	11.49	4.85	14.18	8.88	15	7.97	4.82	10.64	5.30	15
1200	17.56	5.63	20.68	14.44	15	10.79	5.61	13.91	7.68	15
900	22.68	7.12	26.63	18.74	15	12.95	6.44	16.52	9.38	15
600	25.11	7.18	29.09	21.13	15	14.19	6.50	17.80	10.59	15
450	24.98	9.52	30.26	19.71	15	15.65	8.61	20.43	10.88	15
300	20.63	8.44	25.31	15.95	15	16.71	7.75	21.01	12.42	15
150	17.20	9.19	22.75	11.64	13	17.40	9.22	22.97	11.82	13

OPAQUE

Distance Feet	High Beam Average	Std. Dev.	95% Confi- dence Limits		Number of Readings	Low Beam Average	Std. Dev.	95% Confi- dence Limits		Number of Readings
			Upper	Lower				Upper	Lower	
1500	9.20	2.02	12.41	5.98	4	8.97	2.24	12.54	5.40	4
1200	11.25	3.03	16.08	6.41	4	11.17	3.09	16.10	6.24	4
900	12.79	1.55	15.27	10.32	4	12.60	1.91	15.64	9.55	4
600	14.47	3.68	20.33	8.61	4	14.37	3.83	20.48	8.26	4
450	14.72	2.89	19.33	10.11	4	14.62	2.89	19.23	10.01	4
300	15.35	1.48	17.71	12.98	4	15.29	1.45	17.62	12.97	4
150	17.57	3.35	22.91	12.23	4	17.57	3.35	22.91	12.23	4

TABLE 10

NIGHTTIME LUMINANCE IN FOOT-LAMBERTS OF LEGEND MATERIALS FOR OVERHEAD UNLIGHTED SIGNS

ENCAPSULATED LENS

Distance Feet	High Beam Average	Std. Dev.	95% Confi- dence Upper	Limits Lower	Number of Readings	Low Beam Average	Std. Dev.	95% Confi- dence Upper	Limits Lower	Number of Readings
1500	4.88	2.06	5.84	3.91	20	.42	.19	.51	.33	20
1200	10.02	4.10	11.84	8.20	22	.73	.41	.91	.54	22
900	20.86	6.66	23.67	18.04	24	1.15	.50	1.37	.94	24
600	28.70	18.89	36.68	20.72	24	1.36	.55	1.58	1.14	24
450	29.16	24.09	39.11	19.22	25	1.19	.34	1.33	1.05	25
300	11.82	11.40	16.53	7.12	25	.73	.25	.84	.62	25
150	1.30	.37	1.46	1.15	25	.58	.71	.87	.28	25

BUTTON

Distance Feet	High Beam Average	Std. Dev.	95% Confi- dence Upper	Limits Lower	Number of Readings	Low Beam Average	Std. Dev.	95% Confi- dence Upper	Limits Lower	Number of Readings
1500	7.02	4.91	9.54	4.49	17	.43	.20	.53	.32	17
1200	8.40	3.55	10.23	6.57	17	.50	.19	.60	.40	17
900	11.27	3.77	13.21	9.33	17	.70	.19	.80	.60	17
600	15.13	5.24	17.83	12.44	17	1.02	.23	1.15	.90	17
450	15.19	4.43	17.47	12.92	17	1.06	.27	1.20	.91	17
300	7.26	4.00	9.32	5.20	17	.80	.27	.94	.66	17
150	.73	.28	.88	.58	17	.26	.11	.32	.21	17

TABLE 11

NIGHTTIME LUMINANCE IN FOOT-LAMBERTS OF LEGEND MATERIALS FOR SHOULDER-MOUNTED SIGNS

ENCAPSULATED LENS

Distance Feet	High Beam Average	Std. Dev.	95% Confi- dence Upper	Limits Lower	Number of Readings	Low Beam Average	Std. Dev.	95% Confi- dence Upper	Limits Lower	Number of Readings
1500	5.17	1.77	6.00	4.34	20	1.07	.73	1.41	.73	20
1200	8.64	3.04	10.07	7.22	20	1.88	1.12	2.41	1.35	20
900	15.25	4.48	17.51	12.97	20	3.05	1.76	3.87	2.22	20
600	21.31	8.33	24.60	18.01	27	3.02	1.78	3.73	2.31	27
450	22.47	12.20	27.30	17.64	27	2.85	1.56	3.47	2.23	27
300	14.52	11.40	19.12	9.91	26	1.65	.64	1.91	1.39	26
150	3.66	3.14	4.93	2.39	26	1.16	1.45	1.76	.56	25

BUTTON

Distance Feet	High Beam Average	Std. Dev.	95% Confi- dence Upper	Limits Lower	Number of Readings	Low Beam Average	Std. Dev.	95% Confi- dence Upper	Limits Lower	Number of Readings
1500	7.55	3.01	9.16	5.94	16	.87	.52	1.16	.59	16
1200	13.30	5.61	16.30	10.31	16	1.40	1.01	1.94	.86	16
900	21.61	9.80	26.84	16.39	16	1.86	.97	2.38	1.35	16
600	30.42	16.70	39.32	21.52	16	2.46	1.58	3.30	1.61	16
450	28.37	14.24	35.96	20.78	16	2.41	1.39	3.15	1.66	16
300	11.52	7.30	15.42	7.63	16	1.57	.96	2.09	1.06	16
150	1.66	.87	2.13	1.20	16	.53	.30	.70	.37	15

ENCLOSED LENS

Distance Feet	High Beam Average	Std. Dev.	95% Confi- dence Upper	Limits Lower	Number of Readings	Low Beam Average	Std. Dev.	95% Confi- dence Upper	Limits Lower	Number of Readings
1500	3.17	.52	3.61	2.74	8	.25	.06	.31	.20	8
1200	3.30	1.89	4.88	1.72	8	.39	.12	.50	.29	8
900	6.48	1.84	8.02	4.94	8	.62	.46	1.01	.23	8
600	8.00	3.44	10.88	5.12	8	1.85	1.32	2.96	.75	8
450	7.37	4.45	11.10	3.65	8	1.92	1.60	3.27	.58	8
300	5.88	3.46	8.78	2.99	8	1.46	.93	2.24	.68	8
150	3.55	3.96	6.86	.24	8	.61	.41	.96	.26	8

TABLE 12
NIGHTTIME LUMINANCE IN FOOT-LAMBERTS OF BACKGROUND MATERIALS FOR
OVERHEAD LIGHTED SIGNS

ENCLOSED LENS										
Distance Feet	High Beam Average	Std. Dev.	95% Confi- dence Upper	Limits Lower	Number of Readings	Low Beam Average	Std. Dev.	95% Confi- dence Upper	Limits Lower	Number of Readings
1500	1.61	.89	2.44	.78	28	1.22	.66	1.83	.60	28
1200	2.20	.90	3.04	1.36	28	1.65	.65	2.26	1.05	28
900	2.42	.97	3.32	1.53	28	1.68	.66	2.29	1.06	28
600	2.47	.79	3.20	1.73	28	1.70	.62	2.28	1.12	28
450	2.43	.83	3.21	1.66	28	1.74	.68	2.37	1.11	28
300	2.15	.86	2.95	1.35	28	1.78	.70	2.43	1.13	28
150	2.19	.73	2.96	1.42	24	1.90	.68	2.63	1.18	24

OPAQUE										
Distance Feet	High Beam Average	Std. Dev.	95% Confi- dence Upper	Limits Lower	Number of Readings	Low Beam Average	Std. Dev.	95% Confi- dence Upper	Limits Lower	Number of Readings
1500	1.73	.84	2.24	1.22	52	1.48	.66	1.89	1.08	52
1200	1.47	.72	1.91	1.03	48	1.37	.61	1.74	.99	52
900	1.40	.59	1.76	1.05	52	1.35	.60	1.72	.99	52
600	1.60	.86	2.12	1.08	52	1.38	.61	1.75	1.01	52
450	1.43	.65	1.82	1.03	52	1.38	.63	1.76	.99	52
300	1.38	.62	1.76	1.00	52	1.36	.60	1.72	.99	52
150	1.38	.63	1.76	.99	52	1.33	.67	1.74	.93	52

TABLE 13
NIGHTTIME LUMINANCE IN FOOT-LAMBERTS OF BACKGROUND MATERIALS FOR
OVERHEAD UNLIGHTED SIGNS

ENCAPSULATED LENS										
Distance Feet	High Beam Average	Std. Dev.	95% Confi- dence Upper	Limits Lower	Number of Readings	Low Beam Average	Std. Dev.	95% Confi- dence Upper	Limits Lower	Number of Readings
1500	1.51	.72	1.87	1.15	70	.15	.10	.20	.09	70
1200	2.76	1.45	3.39	2.13	92	.27	.20	.36	.16	92
900	4.64	2.42	5.69	3.59	92	.33	.20	.42	.24	92
600	6.60	5.68	9.06	4.14	92	.30	.15	.37	.23	92
450	5.83	5.20	8.09	3.58	90	.26	.08	.29	.22	92
300	3.26	3.97	4.97	1.54	92	.19	.08	.23	.16	90
150	.31	.07	.34	.28	90	.11	.06	.14	.08	92

ENCLOSED LENS										
Distance Feet	High Beam Average	Std. Dev.	95% Confi- dence Upper	Limits Lower	Number of Readings	Low Beam Average	Std. Dev.	95% Confi- dence Upper	Limits Lower	Number of Readings
1500	.71	.34	.96	.47	40	.06	.02	.08	.04	40
1200	.66	.27	.85	.47	44	.07	.02	.08	.05	44
900	.74	.27	.92	.55	44	.07	.01	.08	.06	44
600	.94	.43	1.23	.65	44	.09	.02	.11	.07	44
450	.85	.31	1.06	.63	44	.09	.02	.11	.07	44
300	.44	.15	.54	.33	44	.08	.02	.09	.06	44
150	.14	.05	.18	.11	44	.06	.02	.07	.04	44

OPAQUE										
Distance Feet	High Beam Average	Std. Dev.	95% Confi- dence Upper	Limits Lower	Number of Readings	Low Beam Average	Std. Dev.	95% Confi- dence Upper	Limits Lower	Number of Readings
1500	.17	.13	.29	.06	32	.04	.01	.06	.03	32
1200	.17	.18	.33	.02	32	.04	.01	.05	.02	32
900	.12	.05	.16	.07	32	.04	.00	.04	.03	32
600	.15	.19	.32	.00	32	.02	.01	.03	.02	32
450	.06	.03	.09	.03	32	.02	.00	.03	.02	32
300	.05	.06	.10	.00	32	.03	.02	.05	.00	32
150	.02	.03	.06	.00	32	.02	.02	.04	.00	32

TABLE 14
NIGHTTIME LUMINANCE IN FOOT-LAMBERTS OF BACKGROUND MATERIALS FOR
SHOULDER-MOUNTED SIGNS

ENCAPSULATED LENS										
Distance Feet	High Beam Average	Std. Dev.	95% Confi- dence Limits Upper	Lower	Number of Readings	Low Beam Average	Std. Dev.	95% Confi- dence Limits Upper	Lower	Number of Readings
1500	1.79	.67	2.12	1.46	72	.34	.33	.51	.18	72
1200	2.49	.79	2.88	2.10	72	.38	.31	.53	.22	72
900	3.60	1.21	4.20	3.00	72	.58	.56	.86	.30	72
600	4.94	1.62	5.74	4.13	72	.67	.51	.93	.42	72
450	5.10	1.78	5.98	4.21	72	.62	.32	.73	.46	72
300	3.06	1.34	3.73	2.39	72	.37	.09	.42	.32	72
150	1.16	.60	1.46	.86	72	.25	.07	.28	.21	72

ENCLOSED LENS										
Distance Feet	High Beam Average	Std. Dev.	95% Confi- dence Limits Upper	Lower	Number of Readings	Low Beam Average	Std. Dev.	95% Confi- dence Limits Upper	Lower	Number of Readings
1500	.94	.29	1.05	.82	108	.16	.09	.19	.12	108
1200	1.17	.33	1.30	1.03	108	.19	.10	.23	.15	108
900	1.52	.43	1.69	1.35	108	.27	.16	.33	.21	108
600	2.15	.96	2.53	1.77	108	.33	.15	.40	.27	108
450	1.84	.93	2.21	1.47	108	.32	.13	.37	.26	108
300	1.46	.79	1.78	1.15	108	.26	.09	.30	.23	108
150	.74	.53	.95	.52	108	.18	.08	.21	.15	108

OPAQUE										
Distance Feet	High Beam Average	Std. Dev.	95% Confi- dence Limits Upper	Lower	Number of Readings	Low Beam Average	Std. Dev.	95% Confi- dence Limits Upper	Lower	Number of Readings
1500	.12	.08	.19	.04	32	.08	.07	.14	.02	32
1200	.13	.10	.21	.05	32	.07	.07	.14	.01	32
900	.17	.13	.28	.06	32	.08	.07	.14	.01	32
600	.19	.16	.33	.05	30	.08	.08	.15	.01	30
450	.17	.16	.32	.03	32	.07	.07	.13	.01	32
300	.09	.06	.15	.03	32	.06	.06	.12	.01	32
150	.06	.06	.12	.00	32	.06	.06	.11	.00	32

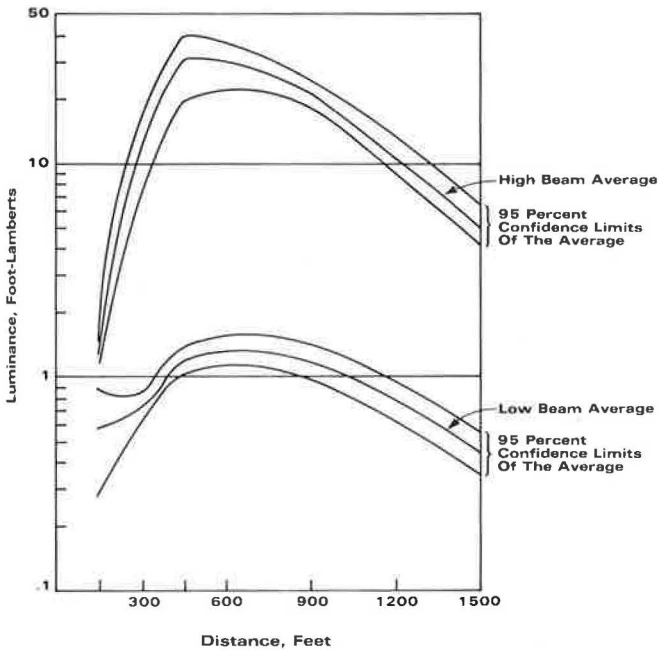


Figure 15. Nighttime luminance of encapsulated lens legend for unlighted overhead signs.

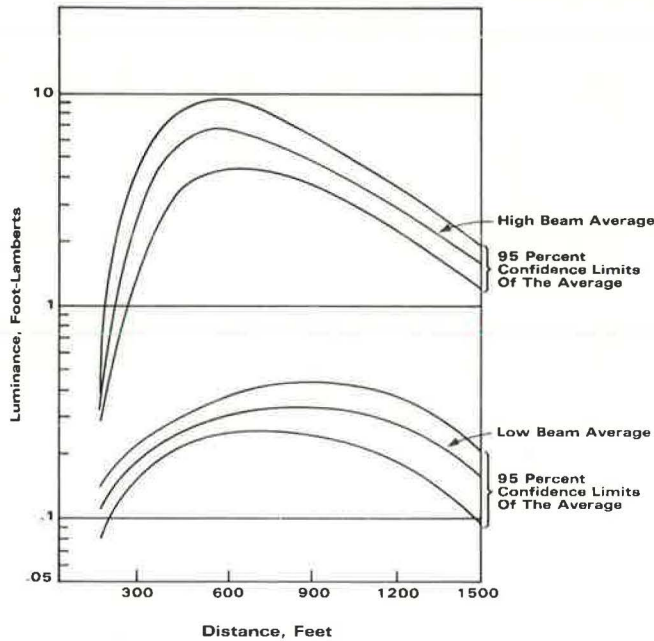


Figure 16. Nighttime luminance of encapsulated lens background for unlighted overhead signs.

DISCUSSION

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The authors are to be complimented for a substantial contribution. We do not feel, however, that the study gives answers to questions that engineers should have answered in order to ensure adequate legibility at night. First, the statement that 1.5 foot-lamberts is adequate for signs per se needs to be qualified. Where glare from opposing traffic is present or on lighted freeways, at 1.5 foot-lamberts, legibility distances are about 80 percent of maximum, but below 1.5 foot-lamberts legibility falls off rapidly. For this condition, one could call 1.5 foot-lamberts "marginal" rather than "adequate." It gives about 50 ft per in. of legibility for 20/20 vision rather than for the 20/40 vision that the authors suggest for design purposes. For brightly lighted urban areas 1.5 foot-lamberts is definitely inadequate—even 10 foot-lamberts is "marginal" (17).

One might question the use of the word "inventory" for the 127 signs especially selected for measurement. The sampling procedure is not completely described, but several points raise questions regarding the representativeness of the sample:

1. Signs were chosen for recentness of installation, apparently indicating that readings were taken only on new, clean signs. Allowance should be made for aging, dew, haze, etc.
2. Sites were chosen to avoid alignments involving "unusual" grade changes or curvature. From the description of the procedure of aiming the telephotometer, it is apparent that only tangent sections on flat or uniform grades were used for measurements. In any event, the roadway alignments used are not documented. Alignment effects have been reported elsewhere (15, 21, 22, 23). Modern Interstate alignments commonly use vertical and horizontal curvatures that cause reflectorized sign luminances to be markedly different from those found in the special case of a tangent on a flat or uniform grade.

The important effects of roadway alignment on sign brightnesses have not been recognized or acknowledged by the authors in this study or in a previous publication (19).

3. All measurements were made from a test vehicle parked on the paved shoulder. Undoubtedly, safety of the field crew dictated the necessity of taking measurements from the shoulder, but the authors offer no discussion of the differences between the data collected and the luminances as they would have been seen from a traffic lane.

What we seem to have then are averages for new, clean signs on straight, level roadways as measured from shoulders. It is unfortunate that the authors did not carry out the theoretical calculations they described so that the observed data could be compared with computed data.

The additive effects of sign brightness resulting from other vehicles in the traffic stream (with the implication that the increased brightness makes up for the loss of legibility due to glare from the opposing traffic) may be overestimated. The factors affecting this additive effect have been recently reported (22):

1. For traffic volumes of 10,000 ADT (used by the authors), many vehicles are likely to be spaced so close as to create interference in the sight lines between head lamp, sign, and driver's eyes.

2. Observed readings from the shoulder may be much higher than those seen by the driver in the traffic stream. Further data are needed to evaluate this effect.

The legibility of "button" signs has not been adequately studied and related to photometric calculations. The data presented by the authors are a contribution (better than no data) and seem to check roughly, at least, with data not cited (16). However, the authors do not describe how the button signs were measured. The use of a sensitive telephotometer with a 2-minute acceptance angle provided a means of measuring luminances of selected sign areas. Without legibility data, the best aperture to use to make measurements is a matter of opinion. If a 1-minute aperture had been used, the slight superiority reported for encapsulated lens letters over button letters might have been reversed.

One must accept the authors' conclusions about the performance of some present materials with high beams. However, certain studies (18, 20) have shown the predominance of low-beam use even on Interstate rural locations. From the authors' statements, the reader might conclude that most overhead signs have sufficient legibility with low beams, in spite of previous findings (16, 23) and their own results for their most commonly used material (enclosed lens). Artificial illumination has often been found necessary for overhead signs to be operationally satisfactory.

Finally, the authors stress the use of field measurements of sign luminance (as opposed to photometric calculations) without giving sufficient attention to their limitations. Practical problems of making valid field measurements of nighttime luminances of reflectorized signs are numerous. In any event, they are made after the fact, i.e., after it is too late or impractical to make changes in the sign if any are indicated. There are distinct advantages in using systematic analytic computations to estimate brightness of proposed signs early in design when the designer still has choices (e.g., to select a larger letter height). Recently developed computer programs facilitate easy solution to the computations involved (15). Still further development of computer programming now permits the analysis of an individual sign related to specific alignment data taken from highway construction plans (21).

What the engineer needs is a design procedure that will enable him to ensure that each sign will be legible at the distance necessary for it to perform its function. First, it should identify those signs that have special legibility requirements (such as gore signs that need to be legible at unusually long distances). Second, the procedure should identify certain conditions that place special requirements on sign reflectorization (such as overhead signs on sag vertical curves and signs in brightly lighted urban areas). Finally, it should provide procedures for ensuring the necessary legibility to suit the special conditions identified. With the combined use of photometric calculations and field measurements, the data necessary for the development of such a design procedure can now be obtained. Because the solution to this engineering problem is almost within our

grasp, funding should be made available so that the authors, or other researchers, can complete the work—providing engineers with means of designing adequate nighttime legibility of highway signs.

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AUTHORS' CLOSURE

The authors are pleased with the discussion by Straub and Allen and appreciate their interest and pertinent comments. The current paper is certainly not the last statement to be made, nor is it intended to go beyond the parameters suggested by the title.

In recognition of the importance of the various lighting levels cited and out of consideration for additional information on alignment conditions employed in the current study, the authors have carefully reviewed the paper and added information relative to alignment conditions and suggested luminance levels for glare situations. The primary objective of this paper is to report sign brightness as seen by the driver on the highway. Apart from legibility considerations, much has been written about laboratory analytic derivations of luminance that can scarcely resolve all of the real-life considerations suggested by the authors: head-lamp variance from the norm, wide sign offsets, reflection variance from the norm, tinted windows, adjacent vehicles, normal dirt accumulation, and sign surround light levels and contrasts, which, taken together, do seem ample justification for the extensive field measurements undertaken.

With respect to specific questions of the discussion, we make the following comments.

1. Signs chosen varied from new to 3 or 4 years of age, with an average age of approximately 2 years. Signs were not cleaned prior to reading. Many other fairly obvious variables such as age, dew, haze, and fog, together with a host of alignment conditions and situations, were specifically avoided in the interest of obtaining sufficiently reliable information on the usual and normal condition.

2. The effect of taking measurements from the shoulder lane may be judged by comparing luminances from side to side of the large guide signs, from overhead to overhead on a cluster, etc. The authors carefully examined data by offset in their original analysis and were unable to report average luminances as having sufficiently significant differences to warrant inclusion. A degree of imprecision is inherent in field examinations whenever a number of variables coexist. Thus, although the subject was examined, data were taken for analysis, and analysis was performed, differences attributable to this variable cannot be reported to be of significance. This may be quite understandable

in view of the fact that the offset amounts to only 9 ft, a distance corresponding to only half the sign dimension for the majority of signs.

3. The authors have performed theoretical computations and compared them with field observations. The cases of substantial variation led the authors to the conclusion that the really satisfactory determination would have to be made with a number of current model cars with normal production lamps, aligned to commercial standards, using the design experiment essentially set forth in the paper. There is no question that both processes of arriving at sign luminances possess utility. To the authors' knowledge, systematic field work on a sufficiently large scale has never been reported. The information thus derived has had the benefit of statistical analysis and presents standard deviations, 95 percent confidence limits of the averages, number of measurements, etc., which reveals much of the variation apt to be encountered and much of the effort required for what has been presented.

4. The discussion points relative to the use of the 2-minute probe and its effect on various legend materials is substantially discussed in the text. The 2-minute probe is equivalent to 20/40 visual acuity, the minimum standard of acuity to which motorists are licensed where a visual standard is employed. The discussers' statement, "the slight superiority reported for encapsulated lens letters over button letters might have been reversed," suggests insufficient examination of the data because they are, in fact, reversed for nine of the values reported.

5. The luminance contribution of stream traffic is a contribution that is quite real and was identified by one of the present authors in an earlier study (24). The evaluation of this contribution is fairly stated in the paper, is observable with or without instrumentation, and is variable by material; its discovery is decidedly unlikely when using theoretical computation. Because it is a dynamic phenomenon, it is all the more challenging to evaluate, particularly for the variety of materials and geometrics possible.

Many questions have been raised about the intelligibility of some signing, and this rather broad subject offers a potentially valuable vein for further efforts. The approach employed by D. L. Woods (25) of diagnostic day and night field inspection by both professional and lay drivers of many traffic situations, including signing, offers convincing evidence of essentially fundamental problems to which considerable effort should be directed. The sign designer should benefit from such knowledge in addition to the more extensive and well-documented work on legibility and sign brightness where even more work is possible.

References

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