



COMMONWEALTH OF KENTUCKY

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June 21, 1972

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MEMORANDUM TO: J. R. Harbison  
State Highway Engineer  
Chairman, Research Committee

SUBJECT: Research Report 330; "High-Intensity Reflective Materials for Signs"; Supplement to "Development of Specifications for Reflex-Reflective Materials;" KYHPR-65-37, HPR-1(6), Part II, issued in October 1970; reissued March 1972.

Class B reflectivity, as specified in Special Provision No. 89-A, approved 11-4-71, embraces a higher range of reflective materials than the Department has used heretofore. Class A, there, includes materials which have been in use since the beginning of the Interstate System. Interstate signing materials, of course, were superior to those used theretofore. A decision was made then to reflectorize the backgrounds of all signs, although the national codes then did not require it. Neither the Kentucky Turnpike, nor the Watterson Expressway was signed originally with background-reflectorization. You may remember that both of those projects served somewhat as a proving ground for many design innovations just prior to the Interstate program. Anyhow, those projects led to the decision to reflectorize signs totally. Fortunately, in that interim, an improved material became available (3 M's 2200 Series, commonly called "flat-top"); this type of material is presently Class A (S.P. No. 89-A). That material, in contrast to exposed bead surfaces, was not critically dimmed by dew or rain but gave superior reflectivity and durability. Its use was justified on the basis of benefits overriding increased costs.

The supplemental report submitted herewith presents results of tests and observations which were begun in connection with the 1970 report which had not then run their course. It concerns a high-intensity, exceedingly durable product, which at this time too has not diminished significantly in artificial weathering tests. The product is 3 M's 3800 Series.

It is my understanding that Class B materials have been specified by the Traffic Division for at least some of the current parkway projects but that similar proposals for Federal-aid projects have been rejected. The reason given was that additional brightness was not necessary and might be detrimental. I would be remiss in duty if I failed to advise you that the later suspicion stands disproven. Likewise, I may state factually that the greater reflectivity compensates for low-beam illumination and otherwise provides reserve capabilities. Undoubtedly, the Department would continue to specify Class A material if the higher quality were not available. However, the long-term economy now evident in the newer material seems to reduce the decision ladder to a mere exercise.

Respectfully submitted,

*Jas. H. Havens*  
Jas. H. Havens  
Director of Research

Attachment

cc: Research Committee

JHH/dw



Research Report  
330

**HIGH-INTENSITY REFLECTIVE MATERIALS  
FOR SIGNS**

KYP-72-31, HPR-1(7), Part III

by

R. L. Rizenbergs  
Research Engineer Chief

Division of Research  
DEPARTMENT OF HIGHWAYS  
Commonwealth of Kentucky

June 1972



## INTRODUCTION

The intuitive need for improved sign legibility has increased through the years as traffic volumes, speeds and roadway designs have advanced. Because of increased traffic volumes, low-beam headlight illumination at night has become more imperative. Signs are being located farther from the travelled lanes; higher speeds are requiring messages to be more legible at greater distances (for driver decision and response). Recent studies have indicated that even Engineering Grade (2200 and 3200 Series<sup>1</sup>) Scotchlite or materials designated as Type I, Class A in S.P. No. 89-A, may be inadequate for some signing situations. Signs may be made larger and(or) incorporate materials which are brighter. Thus far, neither brightness nor sign size has exceeded optimum.<sup>2</sup> Obviously, economics and other considerations come into issue.

A 1970 report issued by the Division of Research, entitled "Development of Specifications for Reflex-Reflective Materials" encompassed all materials available commercially at that time. Calculations were made then of minimum luminance for optimum legibility for a typical sign installation on interstate highways. The results and proposed reflectivity levels for Type I, Class A (Scotchlite, 2200 and 3200 Series) and Class B (Scotchlite, 3800 Series<sup>3</sup>), and Type II-B (button inserts; Stimsonite W-900 Series and Stratolite) were shown in Table XIII of the report. A copy of that table is included here. On high-beam illumination, all of the materials were shown to perform quite adequately. In fact, the brightness of Class B material (silver white), as well as Type II-B, was found to exceed the needed or minimum luminance (10 to 20 foot-Lamberts) for 100 percent of optimum legibility. The luminance of any sign legend above 20 foot-Lamberts tends to diminish the distance to the sign at which the message becomes legible. Sign legibility, of course, is also related to the contrast provided between the legend and the material used for the background. On low beam, the specified reflectivity for Class A materials was shown to be 55 percent of optimum legibility while Class B materials was 80 percent. Specifications for various materials were proposed, and S.P. No. 89-A was subsequently adopted by the Department. The reflectivity requirements

specified for sign surfaces properly included concerns for adequate sign legibility under existing traffic, headlight illumination, and roadway geometrics, and were based on the available Class A materials in all colors and Class B materials in silver-white and green. It was clearly evident then, as now, that Class A materials did not fully satisfy the brightness requirements for signs under low-beam illumination and that the Department may need to consider the use of brighter (Class B) materials wherever possible.

The above-cited findings and opinions on sign legibility are in general agreement with the investigative efforts of others. Youngblood and Woltman (3 M Co.) measured brightness in several states, and a copy of their report is attached for review and information (Attachment No. 1). Adler and Straub (Attachment No. 2) examined sign design from the standpoint of legibility and brightness and concluded that: "In general, to account for night legibility, signs must be made larger and/or brighter." Their study considered only Scotchlite, 2200 Series, etc. (equivalent to Class A in S.P. No. 89-A). The comments offered by Woltman in a discussion entitled "Brighter is Better" (Attachment No. 3) puts the overall problem in a good perspective; Mr. Woltman's discussion is most timely.

No evidence has been found to indicate that materials in the reflectivity level of Class B (S.P. No. 89-A) are excessively bright under high-beam illumination or perceptibly reduce sign legibility.

1. Enclosed-Lens Type

2. Try to recall one instance in your travels where you thought a highway sign was too bright or too large.

3. Encapsulated-Lens Type

## HIGH-INTENSITY SIGNS I 65, TENNESSEE

Recently our staff made a night tour of I 65 between Elizabethtown and Nashville, Tennessee, for the explicit purpose of viewing and photographing signs reflectorized with several types of materials. Signs in Tennessee were surfaced with High-Intensity Scotchlite (3800 Series) whereas those in Kentucky consisted of Engineering Grade Scotchlite -- but some with Type II-B (button inserts) legends. Signs were viewed from traffic and passing lanes under low- and high-beam illumination. The brightness and legibility of signs constructed with the High-Intensity Scotchlite were adjudged to be significantly superior under all viewing conditions. Photos taken under low-beam and strobe-light illumination are presented herein. The relative brightness of the various signs are not apparent in the photos. A more direct illustration of the two Scotchlite materials is shown in Photo 9. There the upper half of the sign consists of High-Intensity materials; the lower half is Engineering Grade materials. Six additional demonstration signs (portable) are being fabricated by the Division of Traffic. Each sign will contain different materials or combination of materials and will be stationed at the same location for viewing.

## DURABILITY

Durability and life expectancy of sign surfaces is an important criterion in specifying and purchasing these materials. Reflective materials deteriorate from natural causes -- as do paints and many other organic coatings. The point of failure of a sign, however, is difficult to define because it may depend upon the minimum level of reflectivity chosen for the particular type of sign. Engineering Grade Scotchlite may retain "adequate" level of reflectivity for about nine years -- depending somewhat on the position of the sign with respect to exposure to the sun. In daylight, a sign may show visible evidences of deterioration (surface cracking, etc.) and be considered failing even though the intensity remains "adequate". Either replacement or clear-coating the sign face must then be considered.

Introduction of 3 M's front-window, air-cavity-type materials (Scotchlite 3800 Series) has generated considerable interest in its performance characteristics. The reflectivity of this material is relatively unaffected by dew, fog, and rain. Only impacting snow or sleet causes blackout. Accelerated weathering tests were conducted on specimens of silver-white and green sheeting according to the method outlined in S.P. No. 89-A. The results are shown in the attached graphs. The

submerged-lens sheeting, 2200 and 3200 Series (Class A, S.P. No. 89-A), deteriorated rapidly after 1,300 hours in the weatherometer; whereas, the 3800-material (Kentucky Class B) remained relatively unaffected throughout the period of weathering. At the end of 5,000 hours, the super-class material showed no visible evidence of deterioration. Weathering tests will be continued to fully ascertain durability of this material.

## COST CONSIDERATIONS

The weathering tests have been sufficiently conclusive to justify the use of the high-intensity, super-grade materials (silver-white and green). These materials may be expected to last at least two and one-half times longer than the best grade of material available heretofore. The cost of the material is 68 percent greater (\$0.90 per sq. ft. compared to \$1.50). The net savings to the Department, therefore, would amount to more than \$0.75 per sq. ft. Vandalism or damage from accidents, of course, would likely diminish the cited savings. Nevertheless, the high-intensity materials excel all others in every respect.

TABLE XIII

SIGN LUMINANCE  
(at 600 feet)

Silver-White Material	Luminance (foot-Lamberts)		Approximate Percent of Optimum Legibility	
	High Beam	Low Beam	High Beam	Low Beam
		<u>Selected Material Samples</u>		
Type I, Class A	12.3	0.8	100	75
Type I, Class B	24.6	1.6	95	85
Type II-B	58.0	3.9	90	90
		<u>Minimum Specified Reflectivity of Materials</u>		
Type I, Class A	6.1	0.4	95	55
Type I, Class B	17.9	1.2	100	80
Type II-B	47.5	3.2	90	90

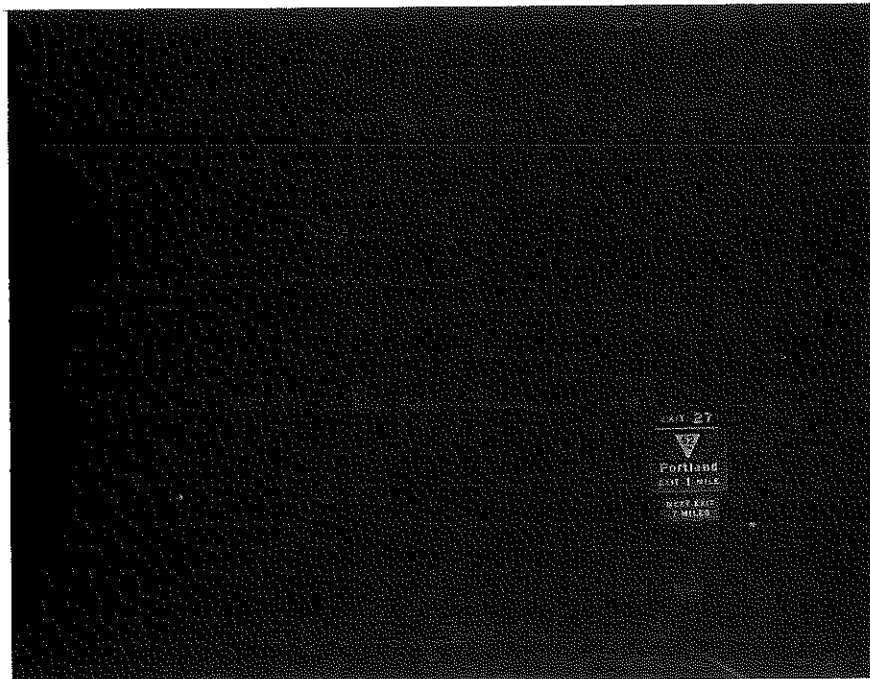
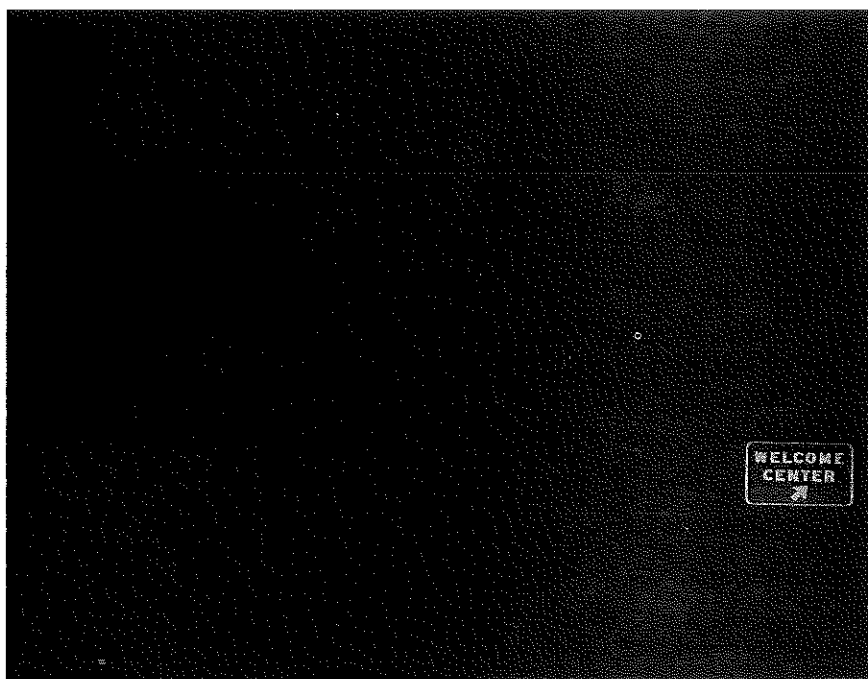


Photo 1. Kentucky Class B; 3 M's 3800 Series; I  
65, Tenn.



**Photo 2.      Kentucky Class B; 3 M's 3800 Series; I  
65, Tenn.**

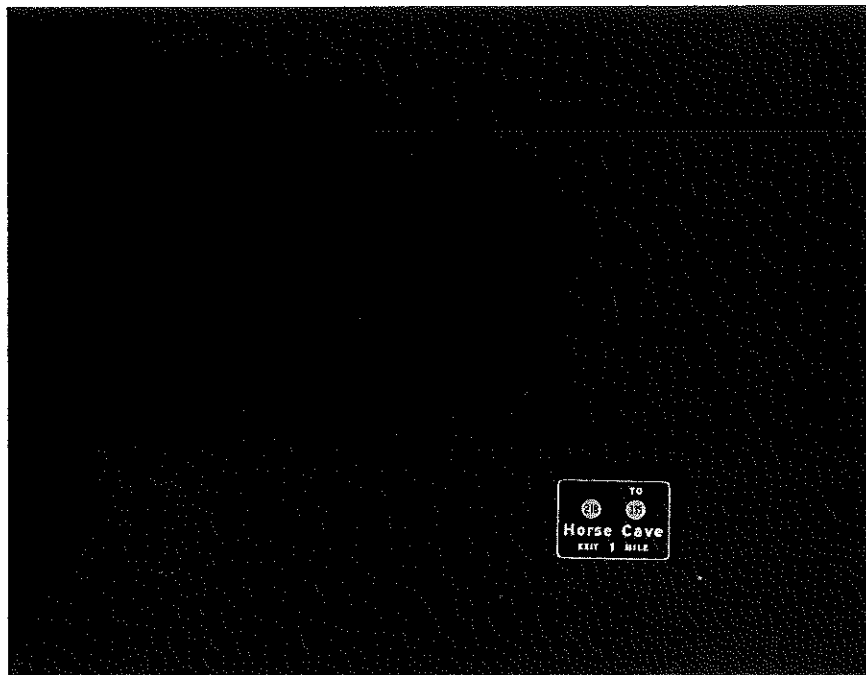


**Photo 3.      Kentucky Class B; 3 M's 3800 Series; I  
65, Tenn.**

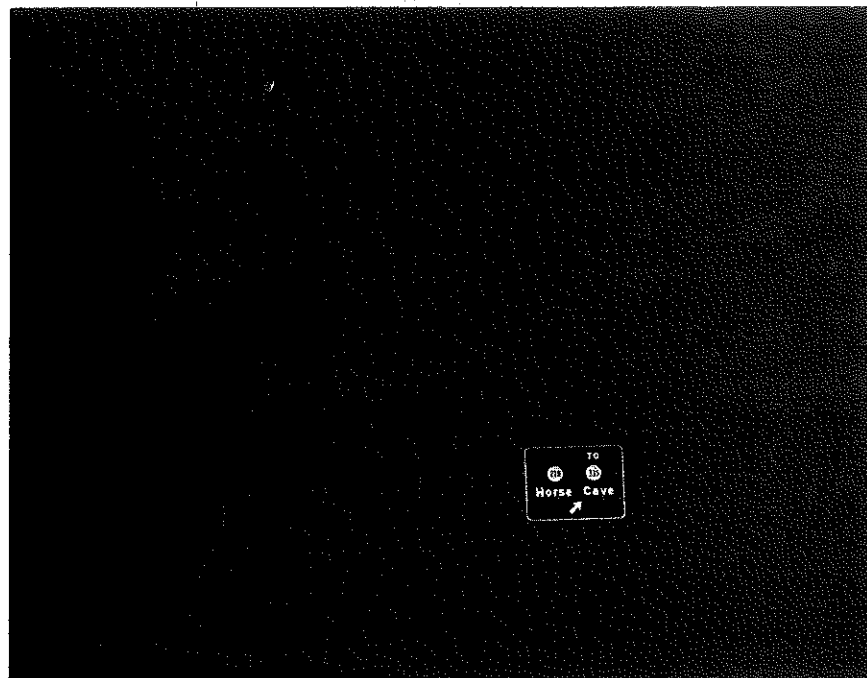




**Photo 4. Kentucky Class B; 3 M's 3800 Series; I  
65, Tenn.**



**Photo 5. Kentucky Class A; 3 M's 2200 Series; I  
65, Ky.**



**Photo 6. Kentucky Class A; 3 M's 2200 Series; I 65, Ky.**



**Photo 7. Message and Border Constructed with Button Inserts (Type II-B) and Background Constructed with Kentucky Class A; I 65, near Tennessee Line.**

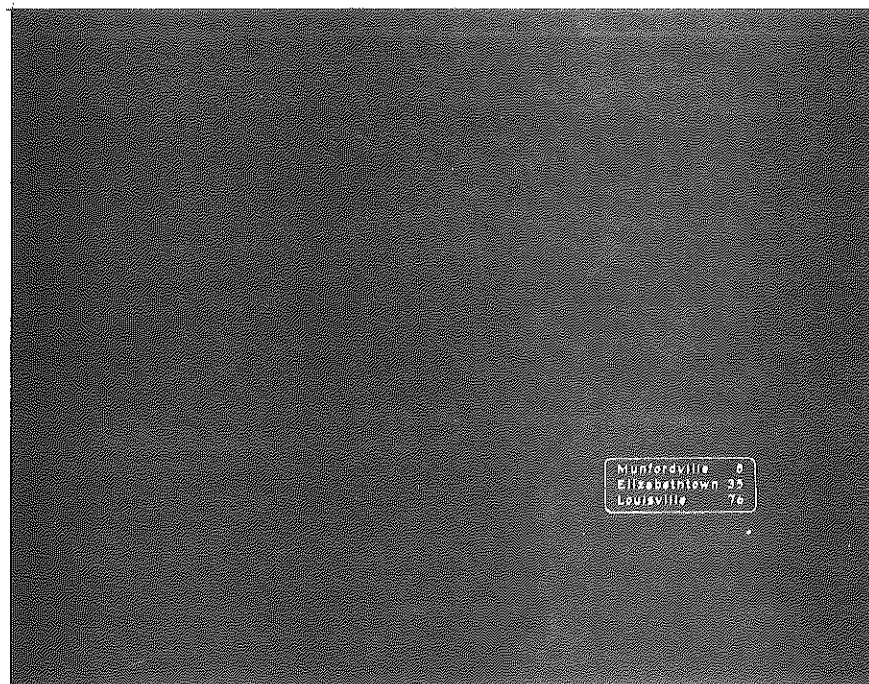


Photo 8. Message and Border Constructed with Button Inserts (Type II-B) and Background Constructed with Kentucky Class A; I 65, Ky.

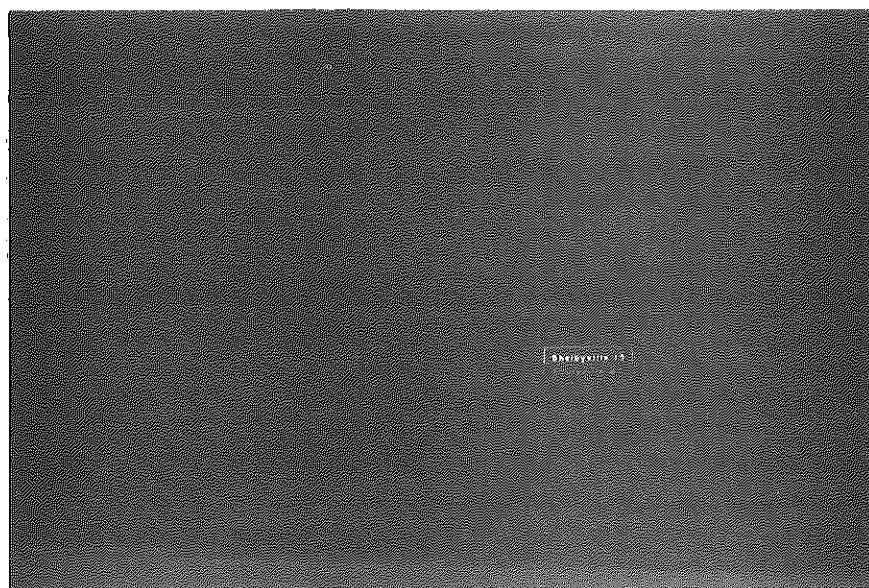
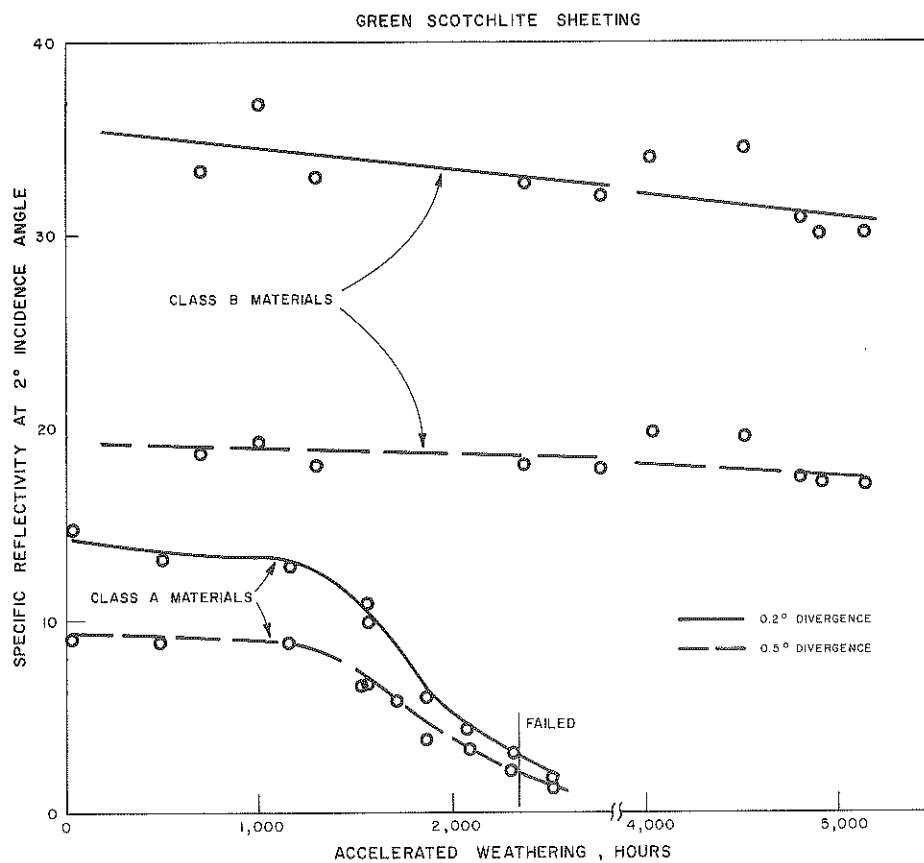
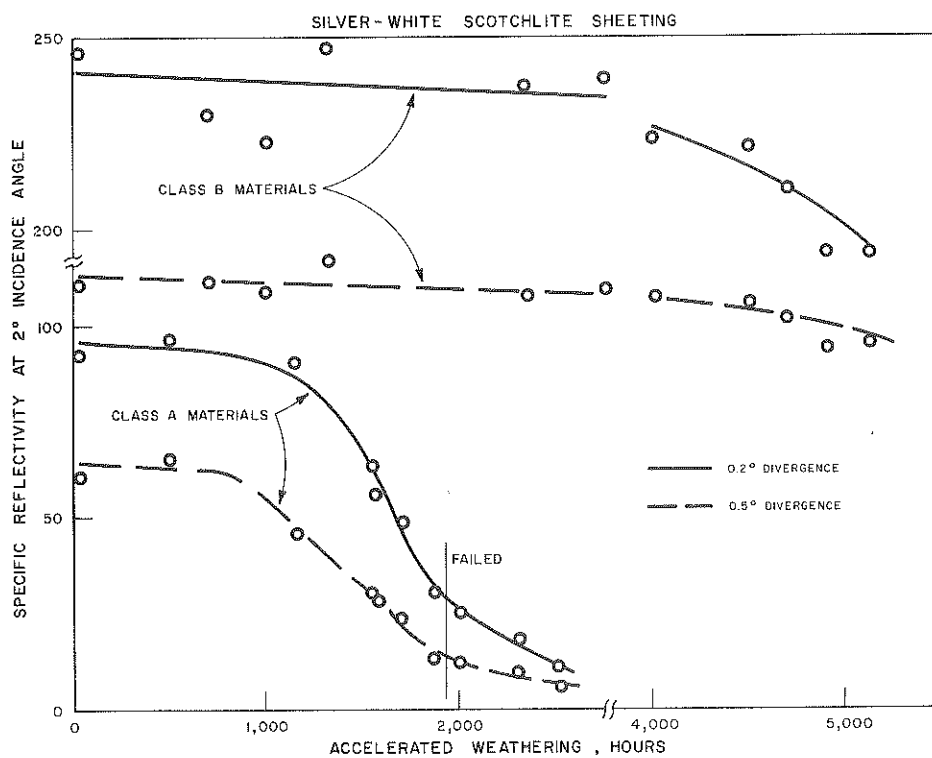


Photo 9. Kentucky Class B on Upper Half of Sign and Class A on Lower Half; I 64, Ky.



**ATTACHMENT NO. 1**



## INFORMATIVE ABSTRACT

### A BRIGHTNESS INVENTORY OF CONTEMPORARY SIGNING MATERIALS FOR GUIDE SIGNS

by W. P. Youngblood and H. L. Woltman

The purpose of this study is to measure the brightness of contemporary sign materials used on guide signs in actual use situations, as observed by the driver under normal day and nighttime viewing conditions.

Previous attempts to determine sign luminance for reflective signs have employed indirect means, combining laboratory photometric determinations with application of the principals of geometrical optics to yield theoretical luminances for a given condition. The lack of "real life" data has been attributable to difficulty of instrumentation, the numerous readings required and the lack of wide scale deployment of materials.

The present design experiment is an in situ inventory conducted to determine guide sign luminances. Determinations were made for seven approach distances for high and low beams at night and for two distances by day. Luminance readings were obtained for four legend materials, three background materials, and eighteen conditions of sign surround.

Results are presented graphically and numerically and 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. Enhanced reflective performance is available where higher traffic volumes place immediately preceeding or following cars in the driver's traffic stream adding two to five times to the single car low beam luminance.

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 headlamp distribution pattern, sign offset, material efficiency and the letter sizes commonly encountered.



## A BRIGHTNESS INVENTORY OF CONTEMPORARY SIGNING MATERIALS FOR GUIDE SIGNS

by W. P. Youngblood and H. L. Woltman

The visibility of signs in the traffic environment and the resulting communication with the motorist is dependent on detection, identification, and legibility; each factor having its special importance as the sign is approached, and each requiring an adequate degree of visibility for its effectiveness. Forbes<sup>1</sup> has quantified factors of sign detectability and legibility and the literature reviewed by him plus that annually assembled by Richards<sup>2</sup> represents a substantial body of knowledge directed to identifying and understanding these factors. Of interest to the sign designer are those factors which influence detection, identification and legibility of signs. These factors include the choice of legend; symbols, abbreviations, route numbers and place names; the choice of color and shape, the choice of sign size and position, and lastly, a choice of materials to yield the visible result. 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<sup>3</sup>, Allen, Dyer, Smith and Janson<sup>4</sup> and Elstad, Fitzpatrick and Woltman<sup>5</sup>. 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 which 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% of the possible legibility available at luminances as low as 1.5 foot-Lamberts and as high as 100 foot-Lamberts. A reduction in legibility occurs at higher brightness due to halation or "overglow." The many effects of opposing headlamp glare, light from luminaires and other sources, adequate contrast with sign backgrounds of lower luminance levels and color are dealt with by the above investigators; and while 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<sup>6</sup> 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<sup>7</sup> inventoried over 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 foot candle meters and comparatively straight-forward instruments of little greater sophistication than required of the photographer's light meter. The determination of the luminance of reflective signs is less straight-forward and must generally be calculated in the manner first described by Straub and Allen<sup>3</sup>. Elstad, Fitzpatrick, and Woltman<sup>5</sup> employed planes to describe luminances for several signing positions for sign viewing distances from 1200 to 75 feet. A refinement of this system was employed by Adler<sup>8</sup> for "Analytical Determination of Sign Brightness" 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. Since reflective efficiency varies widely over useful divergence angles, the resulting values are expressed as specific luminance<sup>3</sup> versus divergence for each type of reflective material under consideration. Divergence angle is the angle subtended by the headlamps, 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 illustrated in Figure 1, this angle increases substantially as sign reading distances shorten. Further, the greater lateral distance of the right headlamp makes the luminance contribution from this source approximately 1/2 that of the left lamp at shorter distances. Both changes necessitate separate calculation of the luminance for each headlamp and for each divergence angle.

Illuminance depends on the alignment of the sign with the headlamp beam and its determination requires the location of the reflective device in the appropriate area of the headlamp iso-candle 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,

Figure  
1

voltage variation, lamp misalignment<sup>9</sup>, changes in car loading all contribute to variation in illuminance providing results which 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 thereby resolving the inherent questions raised with theoretical calculations. The present study is a field inventory of guide signs of contemporary legend and background materials, made by direct measurement at the driver eye position for a variety of conventional automobiles for both day and night 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:

- A. Opaque - Unreflectorized legend or background having white or green paint or porcelain finish.
- B. Button - Plastic prismatic retro-reflective buttons in white opaque metal frames.

- C. Encapsulated lens sheeting - White or green retro-reflective sheeting with sealed septa.
- D. Enclosed lens sheeting - White or green retro-reflective plastic sheeting.
- E. Lighted - Diffuse illumination by fluorescent fixtures positioned immediately below and in front of the sign surface. Combination of materials A thru D may be installed if lighted. Current practice is not to illuminate shoulder signs, overheads may be.

Materials are further identified in Appendix A.

#### Photometric Instrumentation

Measurements were made with a Gamma Scientific Inc. Model 2000 Telephotometer. This instrument is suited for such an inventory having a transistorized photomultiplier and electrometer amplifier, independent battery power supply, two minute of angle sensing probe (acceptance angle), measurement span from .001 to 35,000 foot-Lamberts, photopic color correction (correlation curve for the filter employed is shown in Appendix B) 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 averaged  $\pm 2.5\%$ .

Although five acceptance angles are available with the instrument, the two minute acceptance angle was chosen because it approaches closely the acuity threshold for normal eyesight. As Connolly<sup>10</sup> points out in his review of driver visual examination practices, the licensing of motorists to a 20-40 acuity standard



indicates that two minutes resolution is equivalent and entirely appropriate.<sup>11</sup> Further, the generally accepted 50 foot per inch of letter height criteria<sup>12</sup> for letter legibility and the Interstate letter stroke width of 1/5 the letter height<sup>13</sup> yields a stroke width at legibility thresholds for the acuity standards allowed of approximately two 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 illustrated in Figure 2, 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

### Study Sites

Study sites were chosen for recency of installation and the type of materials available. Prospective sites were examined for alignment to avoid those where unusual circumstances of grade or curvature required either an abnormal approach or restricted viewing distances to less than 1500 feet. Measurements were taken from the paved shoulder in all cases.

Measurements were taken for sign width, height and off-set, elevation above grade, and the materials employed were recorded. Recording distances were determined as illustrated in Figure 3 and marks were applied to the roadway surface on the sign approach at 150', 300', 450', 600', 900', 1200', and 1500'. It was felt that these distances encompass the range of interest accorded detection, identification and legibility factors. As a matter

Figure

3

of observation the authors are of the opinion that approximately 10% of Interstate Guide Signs are not visible beyond approximately 1500 feet owing to obstructions to vision from such alignment conditions as sign bridges, overpass structures, cuts and other physical impediments. The 12" to 18" legend size generally employed renders signs legible in the 600' to 900' range. At 150' 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 encompassing the far to near distance at increments where performance changes are of interest, particularly throughout the useful legibility range. A total of 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, and are further described in Appendix C. Eight of the eleven cars used had tinted windshields. The vehicle was set-up with the photometric equipment and was loaded with needed accessories. The gas tank was filled and then taken to a local dealer for headlamp alignment check, except in two states where the official state alignment station was employed. The intent was to procure an automobile representative of the late model car population having lamp adjustment in conformance with commercial practice or state requirement. Prior to readings, all windshield and headlamp surfaces were cleaned.

### Car Alignment

In commencing readings at 1500', 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 reticule 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 reticule was sighted on the target. In this manner deviations in headlamp alignment were minimized initially and between readings.

### Areas Measured

Figure

4

As illustrated in Figure 4, the instrument was used to measure sign legend luminances on route shields or arrows, which have ample areas for measurement with the two minute probe at 900, 1200 and 1500 feet. At closer distance 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" square panel of known reflectance was placed on a tripod 30" above 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 1500 and 600 feet, and at night on high and low beams for the seven distances noted. Surround luminancies were taken at 1500 feet and 600 feet both day and night. 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 was 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 1500 and 600 feet to one of 18 categories.

#### Discussion of Results

Figures 5 - 12  
Tables 1, 2 & 3

Nighttime luminance data are shown on Figures 5 through 12 and on Tables 1 and 2 for signs of the shoulder mounted, overhead lighted and overhead unlighted types, by legend and background material. Daytime luminance data are shown in Table 3 for above categories.

Table 4

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 shown in Table 4, with the brightest background material providing the more uniform background. 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) and this fact is also illustrated by the data.

The comparison of overhead unlighted to overhead lighted is revealing, indicating 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 shoulder mounted data indicates the low beam performance to favor 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 1/10 of the legend luminance for the overhead lighted signs and approximately 1/4 to 1/12 for reflective materials depending on the combinations compared. To facilitate rapid detection and identification yet provide an adequate level of contrast with the legend and night surround, a level above approximately 0.2 foot-Lamberts should be given as desirable.

The apparent irregularity of data points for opaque data may be attributed to occasional specular glare arising from headlamps or the proximity of luminaires. The peaking of luminances for reflective materials at the 450-600 foot distances confirms previous laboratory studies cited which 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 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 presentation of the data is shown in Table 1 and 2. Data shown are computed averages; further information on the standard deviations, 95 percent confidence limits and number of readings are given in Appendix D, Tables 1 through 6 and Appendix E.

Daytime surrounds have widely varying luminance and color and much of this is confirmed by Table 5. As indicated by the table, 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 vast majority of signs, this light seems to have little effect on the immediate sign surround, leaving the sign in generally good contrast.

able

6

Table 6 presents the expected recognition distance calculated from the legend, background and surround contrasts according to the formula developed by Forbes, Fry, Joyce and Pain<sup>6</sup> 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 percent 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 1500 feet. 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% of the maximum expected recognition value.

Table

7

The total sign luminance for a lighted or reflectorized overhead is given on Table 7 for various legend and background materials in combination. Values shown are computed for an overhead sign having a typical legend area, from luminance

data derived at 600 feet. 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 headlamps 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 1500 feet 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 at night for high and low beams and for daytime. Sign surround luminance values are also given for day and night. Graphical presentation of the results permits separate comparison of legend as well as background materials in current use. The graphs illustrate the luminance of overhead lighted signs and the availability of similar luminance levels by unlighted signs having several of the currently available retro-reflective 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 attests to the soundness of these original findings. An interesting circumstance of 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 night surround yet provide adequate contrast for letter legibility. Taken together, the three luminance levels

yield the expected recognition distance which 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 greater understanding of the importance of factors contributing to early sign detection, identification as an official traffic device coupled with maximum legibility as these factors relate to materials performance.

#### Acknowledgement

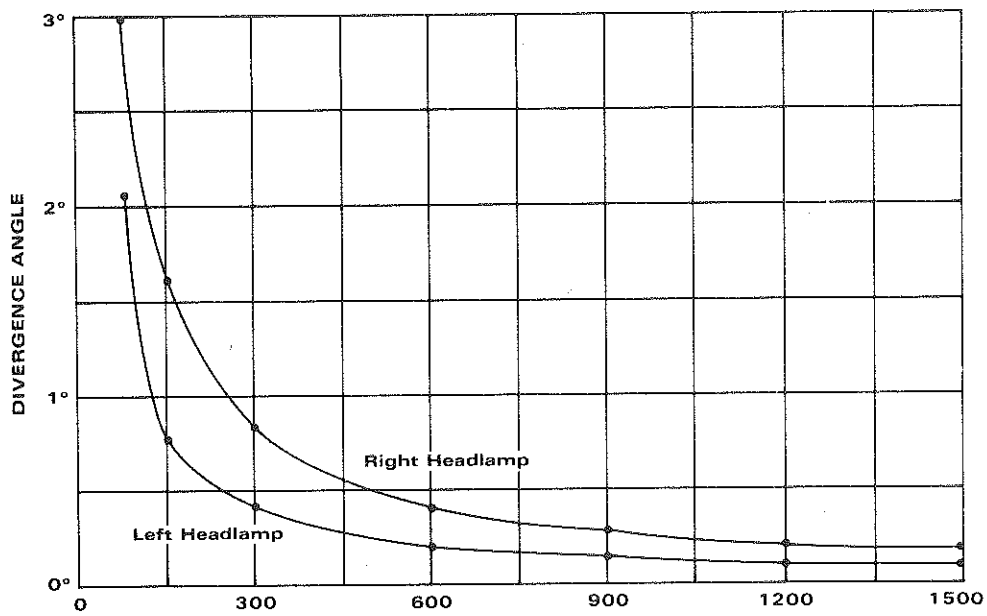
The nearly 14,000 luminance readings and other data collected would not have been possible without the interest and cooperation of the Highway Departments of Arizona, California, Iowa, Minnesota, Tennessee, and the Texas Transportation Institute of Texas A & M University.

The authors appreciation is extended to many individuals without whose assistance this study could not have been made.

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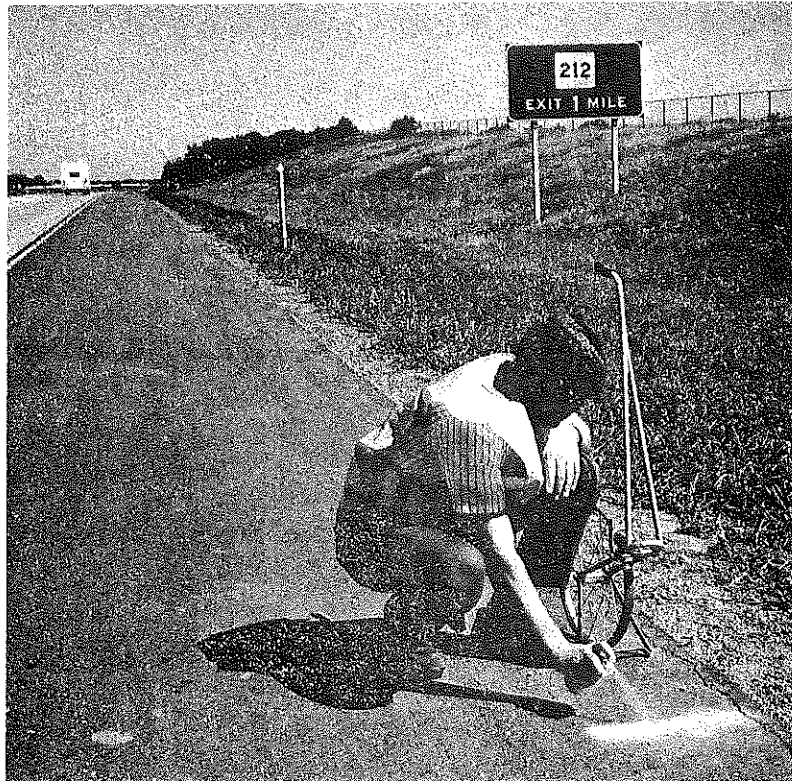


DISTANCE BEYOND HEADLAMPS (Feet)  
 DIVERGENCE ANGLE VS. DISTANCE  
 SHOULDER MOUNTED SIGNS

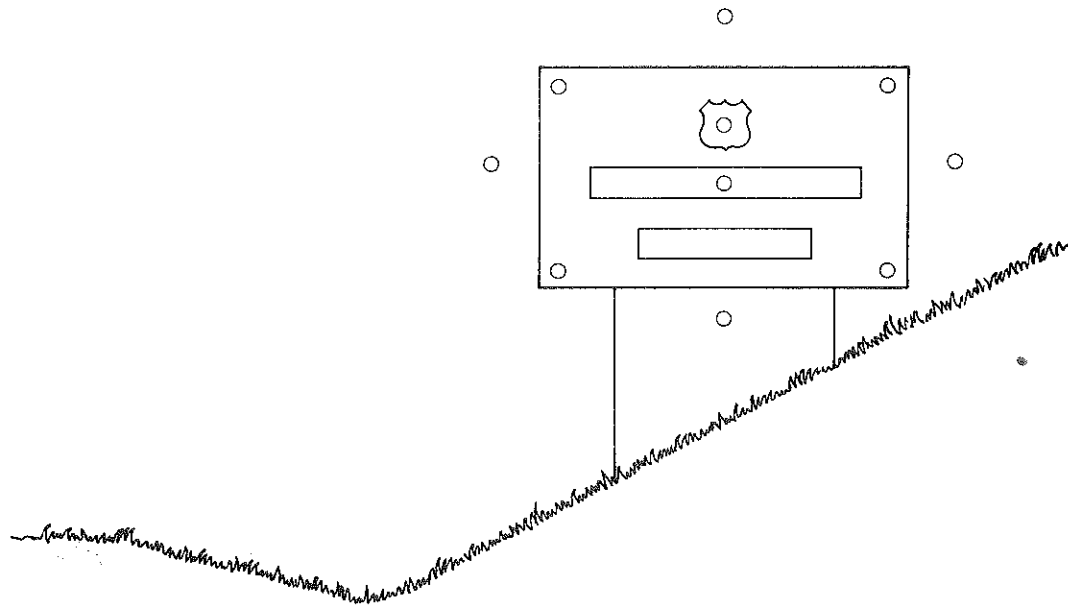
FIGURE 1



FIGURE 2



**FIGURE 3**



**FIGURE 4**

**BRIGHTNESS MEASUREMENT LOCATIONS,  
SHOULDER MOUNTED SIGNS**

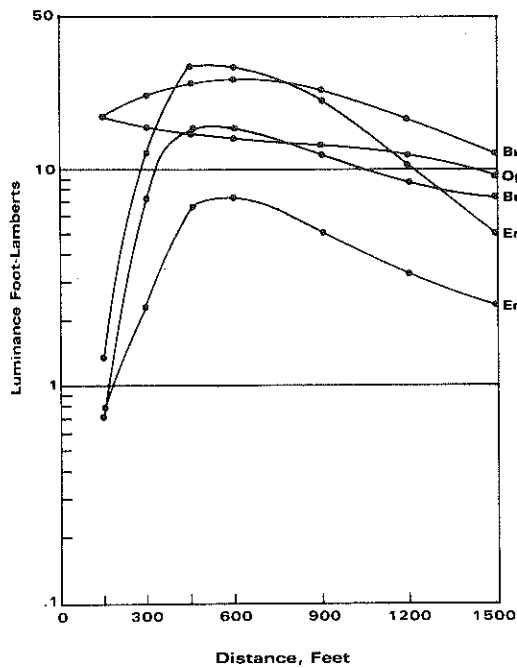


FIGURE 5  
OVERHEAD SIGNS — HIGH BEAMS

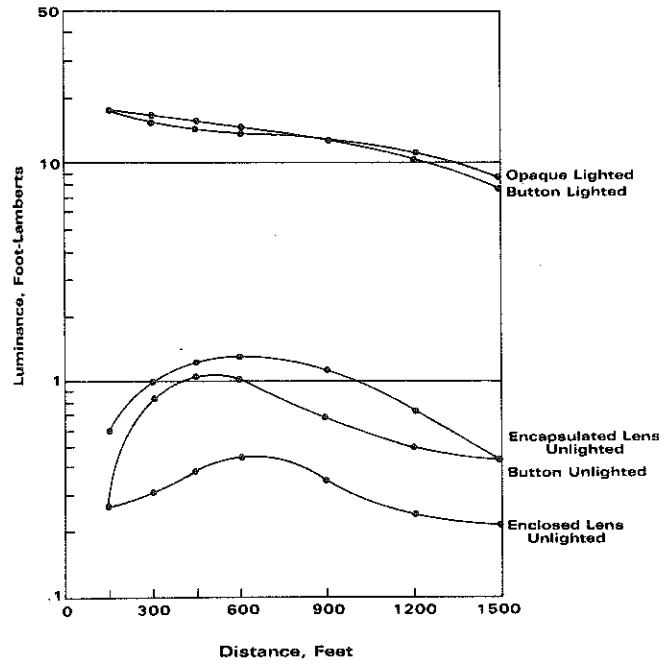


FIGURE 6  
OVERHEAD SIGNS — LOW BEAMS

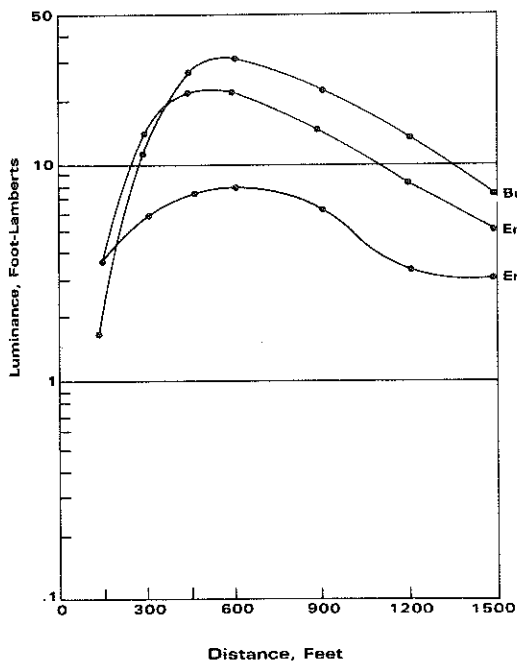


FIGURE 7  
SHOULDER MOUNTED SIGNS — HIGH BEAMS

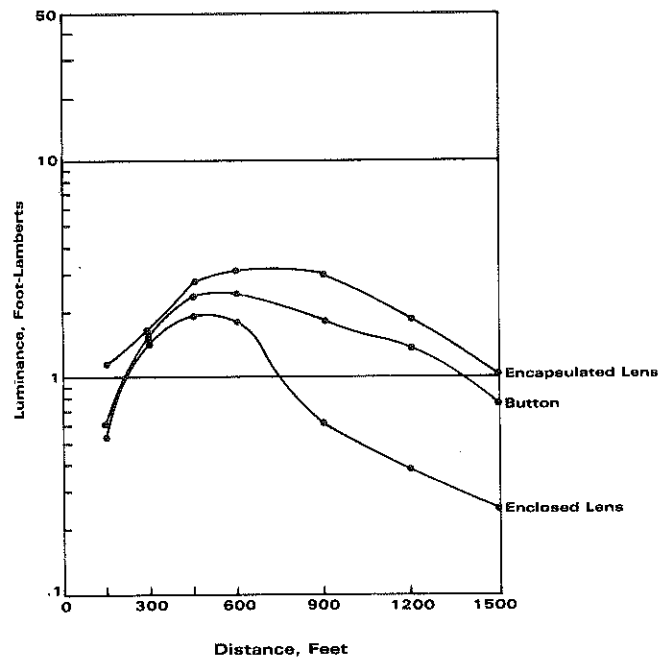


FIGURE 8  
SHOULDER MOUNTED SIGNS — LOW BEAMS

## NIGHTTIME LUMINANCE OF SIGN LEGENDS VS. DISTANCE

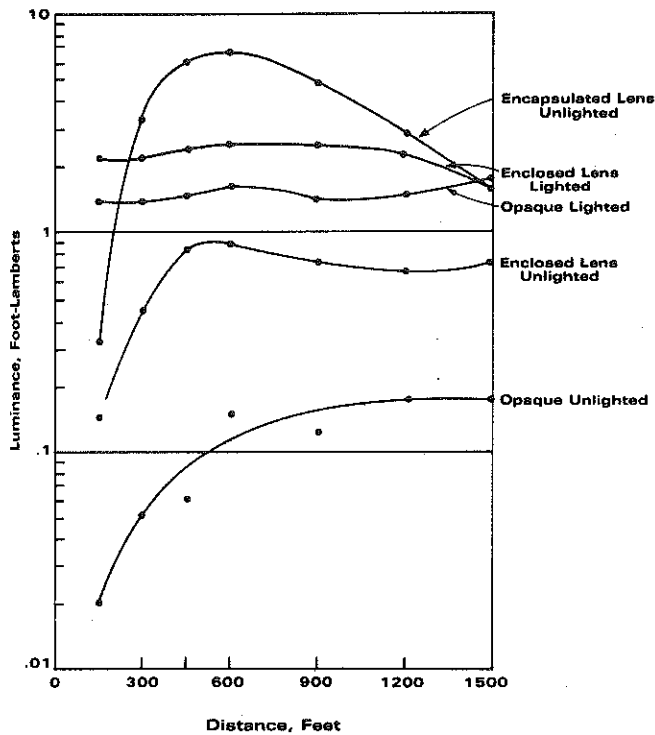


FIGURE 9  
OVERHEAD SIGNS — HIGH BEAMS

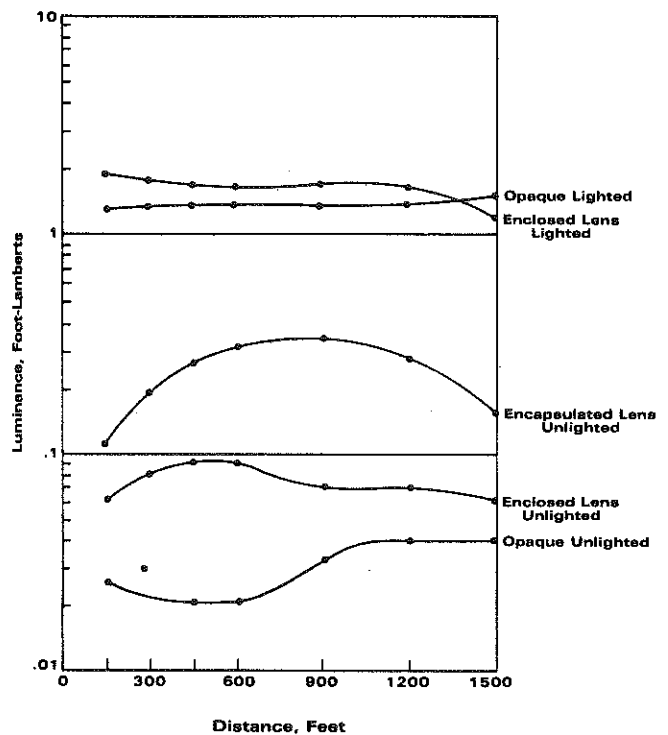


FIGURE 10  
OVERHEAD SIGNS — LOW BEAMS

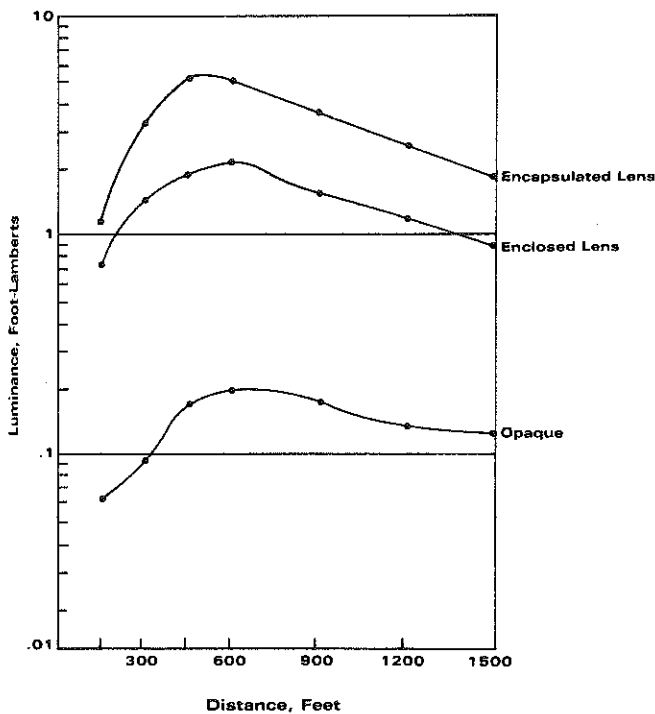


FIGURE 11  
SHOULDER MOUNTED SIGNS — HIGH BEAMS

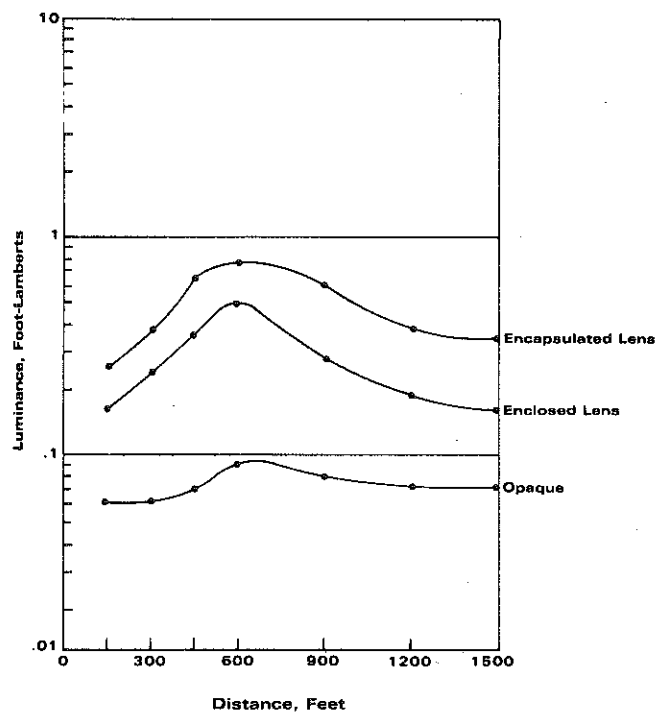


FIGURE 12  
SHOULDER MOUNTED SIGNS — LOW BEAMS

## NIGHTTIME LUMINANCE OF SIGN BACKGROUNDS VS. DISTANCE



Shoulder Mounted Signs Unlighted

LEGEND MATERIALS - LUMINANCE IN FOOT-LAMBERTS						
Distance Feet	Encapsulated Lens		Button		Enclosed Lens	
	High Beam	Low Beam	High Beam	Low Beam	High Beam	Low Beam
1500	5.17	1.07	7.55	.87	3.17	.25
1200	8.64	1.88	13.30	1.40	3.30	.39
900	15.24	3.05	21.61	1.86	6.48	.62
600	21.31	3.02	30.42	2.46	8.00	1.85
450	22.47	2.85	28.37	2.41	7.37	1.92
300	14.52	1.65	11.52	1.57	5.88	1.46
150	3.66	1.16	1.66	.53	3.55	.61

Overhead Lighted Signs

LEGEND MATERIALS - LUMINANCE IN FOOT-LAMBERTS				
Distance Feet	Button		Opaque	
	High Beam	Low Beam	High Beam	Low Beam
1500	11.49	7.97	9.20	8.97
1200	17.56	10.79	11.25	11.17
900	22.68	12.95	12.79	12.60
600	25.11	14.19	14.47	14.37
450	24.98	15.65	14.72	14.62
300	20.63	16.71	15.35	15.29
150	17.20	17.40	17.57	17.57

Overhead Unlighted Signs

LEGEND MATERIALS - LUMINANCE IN FOOT-LAMBERTS						
Distance Feet	Encapsulated Lens		Button		Enclosed Lens	
	High Beam	Low Beam	High Beam	Low Beam	High Beam	Low Beam
1500	4.28	.42	7.02	.43	2.32	.22
1200	10.02	.73	8.40	.50	3.26	.24
900	20.86	1.15	11.27	.70	5.17	.35
600	28.70	1.36	15.13	1.02	7.37	.44
450	29.16	1.19	15.19	1.06	6.92	.38
300	11.82	.73	7.26	.80	2.33	.30
150	1.30	.58	.73	.26	.80	.27

TABLE 1  
NIGHTTIME LUMINANCE OF SIGN LEGEND MATERIALS  
AVERAGE LUMINANCE IN FOOT-LAMBERTS  
1500 TO 150 FEET DISTANCE FOR HIGH AND LOW BEAMS,  
FOR SHOULDER MOUNTED, OVERHEAD LIGHTED AND OVERHEAD UNLIGHTED SIGNS

Shoulder Mounted Signs Unlighted

BACKGROUND MATERIALS - LUMINANCE IN FOOT-LAMBERTS						
Distance Feet	Encapsulated Lens		Enclosed Lens		Opaque	
	High Beam	Low Beam	High Beam	Low Beam	High Beam	Low Beam
1500	1.79	.34	.94	.16	.12	.08
1200	2.49	.38	1.17	.19	.13	.07
900	3.60	.58	1.52	.27	.17	.08
600	4.94	.67	2.15	.33	.19	.08
450	5.10	.62	1.84	.32	.17	.07
300	3.06	.37	1.46	.26	.09	.06
150	1.16	.25	.74	.18	.06	.06

Overhead Lighted Signs

BACKGROUND MATERIALS - LUMINANCE IN FOOT-LAMBERTS				
Distance Feet	Enclosed Lens		Opaque	
	High Beam	Low Beam	High Beam	Low Beam
1500	1.61	1.22	1.73	1.48
1200	2.20	1.65	1.47	1.37
900	2.42	1.68	1.40	1.35
600	2.47	1.70	1.60	1.38
450	2.43	1.74	1.43	1.38
300	2.15	1.78	1.38	1.36
150	2.19	1.90	1.38	1.33

Overhead Unlighted Signs

BACKGROUND MATERIALS - LUMINANCE IN FOOT-LAMBERTS						
Distance Feet	Encapsulated Lens		Enclosed Lens		Opaque	
	High Beam	Low Beam	High Beam	Low Beam	High Beam	Low Beam
1500	1.51	.15	.71	.06	.17	.04
1200	2.76	.27	.66	.07	.17	.04
900	4.64	.33	.74	.07	.12	.04
600	6.60	.30	.94	.09	.15	.02
450	5.83	.26	.85	.09	.06	.02
300	3.26	.19	.44	.08	.05	.03
150	.31	.11	.14	.06	.02	.02

TABLE 2

NIGHTTIME LUMINANCE OF SIGN BACKGROUNDS  
AVERAGE LUMINANCE IN FOOT-LAMBERTS  
1500 TO 150 FEET DISTANCE FOR HIGH AND LOW BEAMS  
FOR SHOULDER MOUNTED, OVERHEAD LIGHTED AND OVERHEAD UNLIGHTED SIGNS

#### SIGN BACKGROUND

	Distance Feet	Luminance Foot-Lamberts	Number of Readings
Encapsulated Lens	1500'	222	22
	600'	167	22
Enclosed Lens	1500'	389	38
	600'	372	38
Opaque	1500'	476	21
	600'	307	21

#### SIGN LEGEND

	Distance Feet	Luminance Foot-Lamberts	Number of Readings
Encapsulated Lens	1500'	331	24
	600'	291	24
Enclosed Lens	1500'	266	10
	600'	325	10
Button	1500'	698	47
	600'	852	47
Opaque	1500'	494	11
	600'	418	11

TABLE 3

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

BACKGROUND MATERIALS - UNIFORMITY RATIO

Distance <u>Feet</u>	Encapsulated Lens		Enclosed Lens		Opaque	
	High <u>Beam</u>	Low <u>Beam</u>	High <u>Beam</u>	Low <u>Beam</u>	High <u>Beam</u>	Low <u>Beam</u>
1500	1.42	1.18	2.37	3.07	2.29	2.35
1200	1.31	1.81	2.08	2.75	2.11	2.51
900	1.61	1.66	2.09	2.65	2.36	2.33
600	1.49	1.78	2.38	3.13	1.80	1.19
450	1.70	1.59	2.63	3.17	2.56	2.63
300	2.68	2.59	2.94	2.97	2.77	2.63
150	-	-	4.27	4.22	3.02	3.11
Averages						
All Distances	1.94	2.07	2.68	3.14	2.41	2.39
Grand Average		2.00		2.91		2.40

TABLE 4

UNIFORMITY RATIO OF OVERHEAD LIGHTED SIGN BACKGROUNDS  
1500 TO 150 FEET DISTANCE FOR HIGH AND LOW BEAMS

SKY COVER

<u>Clear</u>	Luminance Foot-Lamberts	Number of Readings
Snow	2650	3
Sky	1950	150
Green Grass	860	16
Green Trees	700	6
Tan Grass	600	36
Bridge	470	8
<u>Light Overcast</u>	Luminance Foot-Lamberts	Number of Readings
Sky	900	65
Green Trees	455	17
Dark Hill	400	8
Tan Grass	285	23
<u>Dark Overcast</u>	Luminance Foot-Lamberts	Number of Readings
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
<u>Night</u>	Luminance Foot-Lamberts	Number of Readings
All Backgrounds	.02	504

TABLE 5

LUMINANCE OF SIGN SURROUNDS, DAY AND NIGHT  
AVERAGE LUMINANCE IN FOOT-LAMBERTS  
1500 FEET DISTANCE

LEGEND

BACKGROUND	Lighted Opaque	Lighted Button	Reflectorized		
		High Beam 92% Low Beam 95%	Button	Encapsulated Lens	Encapsulated Lens
	Reflectorized	Encapsulated Lens	High Beam 88% Low Beam 76%	High Beam 83% Low Beam 75%	—— ——
		Enclosed Lens	High Beam 94% Low Beam 54%	High Beam 91% Low Beam 57%	High Beam 83% Low Beam 50%
	Unlighted	Opaque	High Beam 63% Low Beam 46%	High Beam 62% Low Beam 46%	High Beam 61% Low Beam 46%

TABLE 6

PERCENT OF MAXIMUM EXPECTED RECOGNITION DISTANCE  
OVERHEAD SIGNS, HIGH AND LOW BEAM

LEGEND

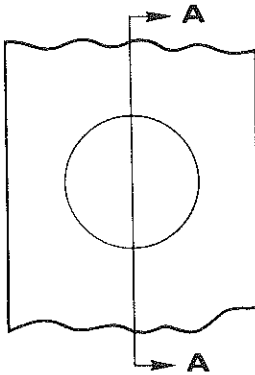
BACKGROUND	Lighted Opaque	Lighted Button	Reflectorized		
		High Beam 2210 cp Low Beam 1345 cp	Button	Encapsulated Lens	Enclosed Lens
	Reflectorized	Encapsulated Lens	High Beam 3008 cp Low Beam 154 cp	High Beam 3735 cp Low Beam 168 cp	—— ——
		Enclosed Lens	High Beam 1172 cp Low Beam 87 cp	High Beam 1920 cp Low Beam 101 cp	High Beam 717 cp Low Beam 54 cp
	Unlighted	Opaque	High Beam 910 cp Low Beam 71 cp	High Beam 1672 cp Low Beam 85 cp	High Beam 472 cp Low Beam 38 cp

TABLE 7

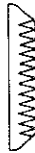
TOTAL LUMINANCE IN CANDELPPOWER  
OVERHEAD SIGN OF 120 SQ. FT. AREA  
FOR VARIOUS LEGEND AND BACKGROUND MATERIALS  
600 FEET — HIGH AND LOW BEAMS

## APPENDIX A

**Button**



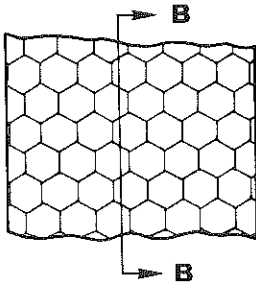
**Specific Luminance**  
Candle power/foot candle/unit area



15.0 cp/in<sup>2</sup>  
for .1° divergence,  
0° incidence

**Section A-A**

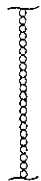
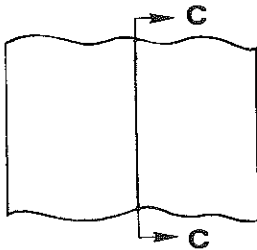
**Encapsulated Lens**



180 cp/ft.<sup>2</sup> (white)  
30 cp/ft.<sup>2</sup> (green)  
for .2° divergence  
-4° incidence

**Section B-B**

**Enclosed Lens**

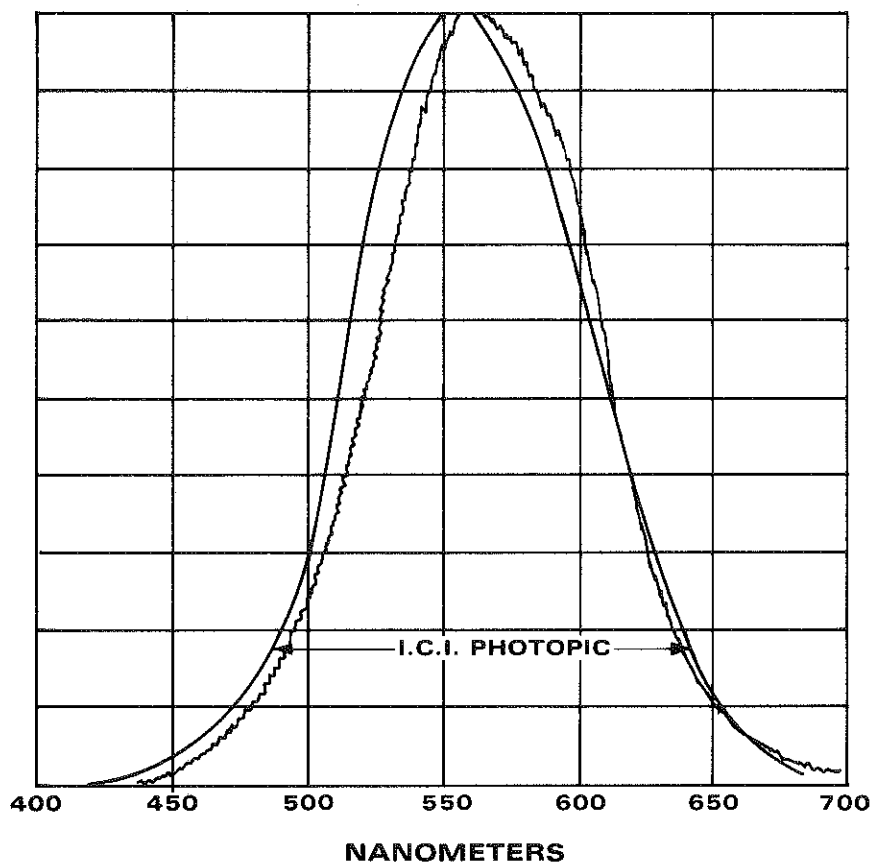


80 cp/ft.<sup>2</sup> (white)  
9 cp/ft.<sup>2</sup> (green)  
for .2° divergence  
-4° incidence

**Section C-C**

## REFLECTIVE SIGNING MATERIALS

## APPENDIX B



**SPECTRAL CHARACTERISTICS OF MODEL 2000, SERIAL NO. 170  
WITH PHOTOPIC CORRECTION FILTER**

**SOURCE: N.B.S. STANDARD OF SPECTRAL IRRADIANCE QM-185 DATE 3/25/68**  
**GAMMA SCIENTIFIC, INCORPORATED**  
**San Diego, California**



APPENDIX C

<u>Year</u>	<u>Make and Model</u>	<u>Number of Vehicles</u>	<u>Windshield Tinted</u>
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 Cruise 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	<u>2</u>	Yes
	Total Vehicles	11	

VEHICLES USED IN STUDY

## APPENDIX D

## BUTTON

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	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 Upper	Lower	Number of Readings	Low Beam Average	Std. Dev.	95% Confi- dence Limits Upper	Lower	Number of Readings
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 A1

NIGHTTIME LUMINANCE OF SIGN LEGEND MATERIALS, OVERHEAD LIGHTED  
 LUMINANCE IN FOOT-LAMBERTS FOR AVERAGE, STANDARD DEVIATION  
 95% CONFIDENCE LIMITS OF THE AVERAGE, AND NUMBER OF READINGS  
 FOR HIGH AND LOW BEAMS 1500 TO 150 FEET

# 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	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 Limits Upper Lower	Number of Readings	Low Beam Average	Std. Dev.	95% Confi- dence Limits Upper 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 A2

NIGHTTIME LUMINANCE OF SIGN LEGEND MATERIALS, OVERHEAD UNLIGHTED  
LUMINANCE IN FOOT-LAMBERTS FOR AVERAGE, STANDARD DEVIATION  
95% CONFIDENCE LIMITS OF THE AVERAGE, AND NUMBER OF READINGS  
FOR HIGH AND LOW BEAMS 1500 TO 150

## 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 A3

NIGHTTIME LUMINANCE OF SIGN LEGEND MATERIALS, SHOULDER MOUNTED  
 LUMINANCE IN FOOT-LAMBERTS FOR AVERAGE, STANDARD DEVIATION  
 95% CONFIDENCE LIMITS OF THE AVERAGE, AND NUMBER OF READINGS  
 FOR HIGH AND LOW BEAMS 1500 TO 150 FEET

## 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	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 Limits Upper	Lower	Number of Readings	Low Beam Average	Std. Dev.	95% Confi- dence Limits Upper	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 A4

NIGHTTIME LUMINANCE OF SIGN BACKGROUND MATERIALS, OVERHEAD LIGHTED  
 LUMINANCE IN FOOT-LAMBERTS FOR AVERAGE, STANDARD DEVIATION  
 95% CONFIDENCE LIMITS OF THE AVERAGE, AND NUMBER OF READINGS  
 FOR HIGH AND LOW BEAMS 1500 TO 150 FEET

## 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	1.51	.72	1.87	1.15	70	.15	.10	.20	.09	70
1200	2.76	1.45	3.39	2.13	92	.27	.20	.36	.18	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 Limits Upper	Lower	Number of Readings	Low Beam Average	Std. Dev.	95% Confi- dence Limits Upper	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 Limits Upper	Lower	Number of Readings	Low Beam Average	Std. Dev.	95% Confi- dence Limits Upper	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 A5

NIGHTTIME LUMINANCE OF SIGN BACKGROUND MATERIALS, OVERHEAD UNLIGHTED  
LUMINANCE IN FOOT-LAMBERTS FOR AVERAGE, STANDARD DEVIATION  
95% CONFIDENCE LIMITS OF THE AVERAGE, AND NUMBER OF READINGS  
FOR HIGH AND LOW BEAMS 1500 TO 150

## 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

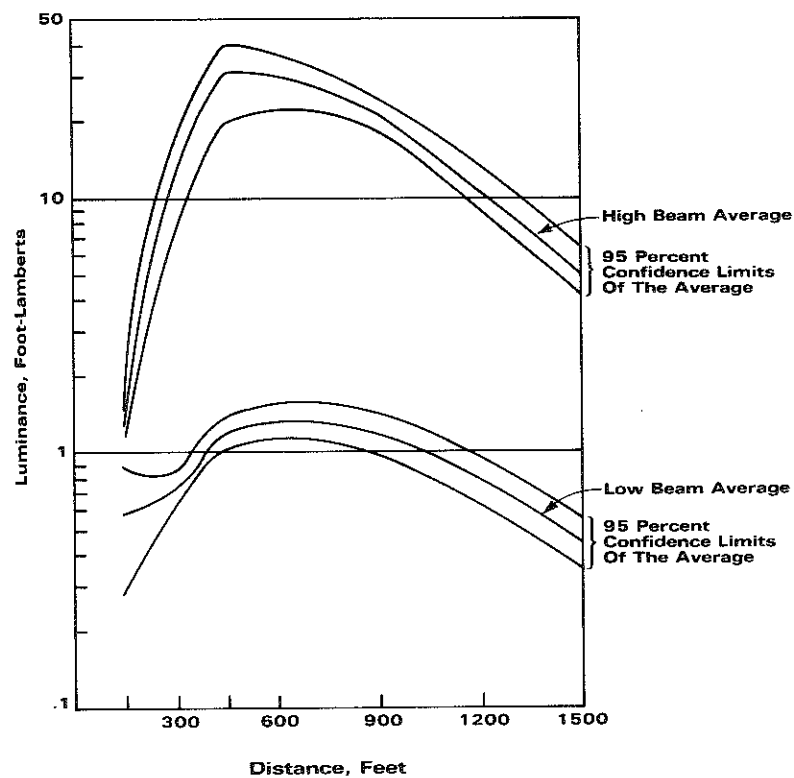
## OPAQUE

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

TABLE A6

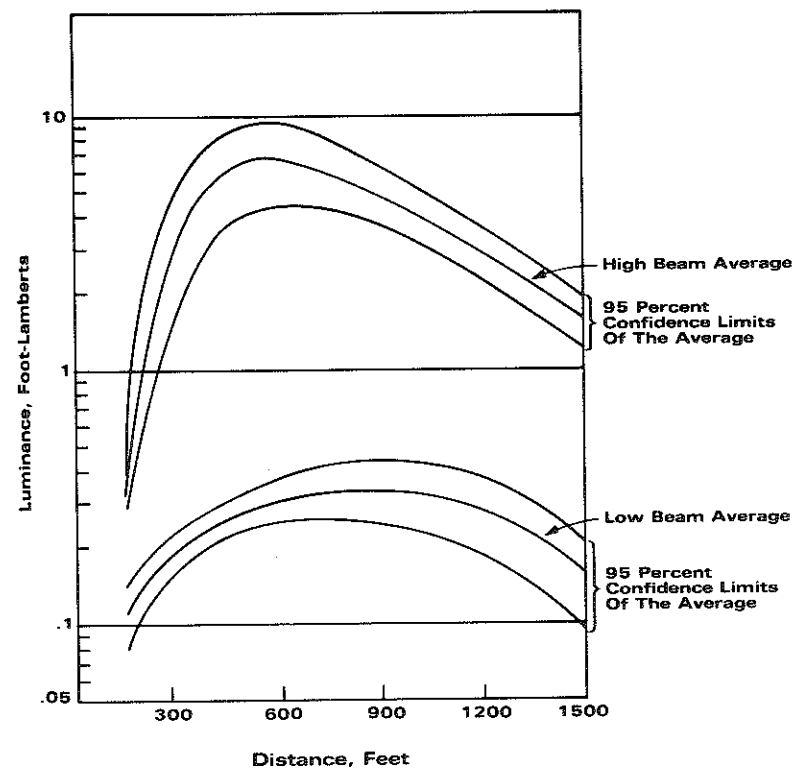
NIGHTTIME LUMINANCE OF SIGN BACKGROUND MATERIALS SHOULDER MOUNTED  
 LUMINANCE IN FOOT-LAMBERTS FOR AVERAGE, STANDARD DEVIATION  
 95% CONFIDENCE LIMITS OF THE AVERAGE, AND NUMBER OF READINGS  
 FOR HIGH AND LOW BEAMS 1500 TO 150 FEET

APPENDIX E1



NIGHTTIME LUMINANCE OF ENCAPSULATED LENS  
SIGN LEGEND AVERAGE, AND 95 PERCENT  
CONFIDENCE LIMITS OF THE AVERAGE,  
UNLIGHTED OVERHEAD SIGNS, HIGH AND LOW BEAM

APPENDIX E2



NIGHTTIME LUMINANCE OF ENCAPSULATED LENS  
SIGN BACKGROUND AVERAGE, AND 95 PERCENT  
CONFIDENCE LIMITS OF THE AVERAGE,  
UNLIGHTED OVERHEAD SIGNS, HIGH AND LOW BEAM



**ATTACHMENT NO. 2**



## LEGIBILITY AND BRIGHTNESS IN SIGN DESIGN

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An important but neglected aspect of sign design is the choice of letter heights to satisfy nighttime legibility requirements. In choosing letter heights, the fundamental relationship of brightness and legibility must be taken into account. Sign brightness is a function of many factors including sign material and position, road alignment, and vehicle and headlight characteristics. A computer program was developed that incorporates these factors and determines sign brightness as a function of road distance. The distance at which the sign must be first legible is used in conjunction with the computed brightness and published empirical data relating brightness to legibility to calculate required letter heights. Minimum letter height requirements for road distances up to 2,000 ft are presented. The cases reported include a straight road, high and low headlight beams, six sign positions, four horizontal alignments, and four vertical alignments. For nighttime legibility, it was found that required letter heights are much larger than the 50-ft-per-in. rule indicates. Because of the widely varying sign brightness found in actual roadway conditions, each sign should be treated individually as a separate design problem.

•IT is evident that, for the near future at least, the conventional highway sign will remain the principal means of transmitting information to the highway user. Increasing demands to satisfy traffic operating problems make it essential to optimize all aspects of sign design. This paper is concerned with an important but neglected aspect of sign design—the choice of letter heights to satisfy night legibility requirements.

In order for a highway sign to fulfill its purpose, its message must be legible under both daytime and nighttime conditions. At night, under typical rural conditions, with no fixed sign lighting, a sign is illuminated only by the car's headlights. Just as for any other object falling within the headlight beam, the luminance or brightness of a highway sign is a function of its position and reflectivity, the road alignment, and the position of the car on the road. In a rural area, sign brightness varies greatly. In an urban situation, where electric power is more readily available, the sign may be internally or externally illuminated and the brightness can be maintained at higher and more uniform levels. However, whether the sign is illuminated by fixed sources or by headlights, the resulting brightness, as seen by the driver, determines the sign's legibility.

Allen et al. (1) studied the relationship between sign luminance and legibility distance (the distance at which a sign can be read for a given letter height, as a function of brightness of the letter) and empirically determined a functional relationship between the two. This important relationship is shown in Figure 1. The curve is an overall average of results for medium ambient illumination without headlight glare and for low ambient illumination with and without headlight glare, for both dark legends on light backgrounds and light legends on dark backgrounds. It should be noted that, in order to obtain legibility equal to or better than 50 ft of legibility per inch of letter height (the commonly accepted design value for daylight operations), a luminance value of more than 5 ft-lamberts is required. If the brightness falls much below 5 ft-lamberts, the night legibility drops

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Sponsored by Committee on Traffic Control Devices and presented at the 50th Annual Meeting.

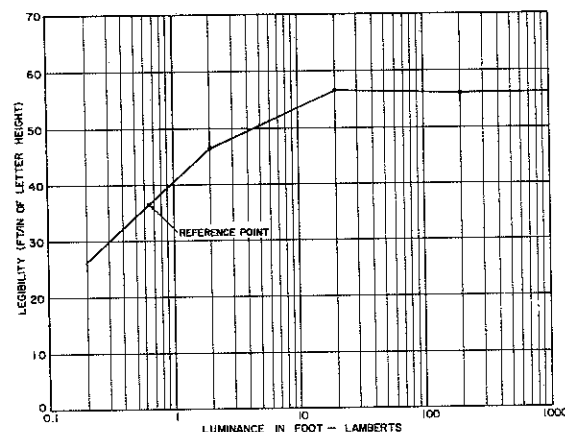


Figure 1. Legibility as a function of luminance.

far below the 50-ft-per-in. value. For many situations the preferred range is from 10 to 20 ft-lamberts. Much higher sign brightnesses are required in areas subject to high ambient illumination (as in an urban area), or where glare sources are present. A complete discussion of these factors is given by Allen et al. (1).

Many signs on our highways have a night brightness much less than 5 ft-lamberts at the point at which their messages are intended to be read. For those signs having low brightness, the commonly used 50-ft-per-in. rule is not valid, and hence many signs may not be legible at the distance assumed by the designer. The Manual for Signing and Pavement Marking of the National System of Interstate and Defense Highways (2) and the Manual on Uniform Traffic Control Devices for Streets and Highways (3) do not account for this brightness-legibility relationship.

Widespread use of retroreflective sign material has resulted in signs that are much brighter than those produced by nonreflectorized surfaces and other diffuse objects in the driver's field of view. These bright signs can result in nighttime performance that, in some cases, approaches that of good daytime conditions. It is very significant to recognize, however, that, as seen by the driver under night roadway conditions, reflective materials in common use today provide a luminance range of from less than 0.1 ft-lambert to more than 100 ft-lamberts. Wide ranges of brightness are due not only to differences in reflective properties of the material itself but primarily to wide ranges in illumination from the headlights and to the geometric relationships between the sign position and the roadway alignment. The relationship of these factors to the brightness of signs can be analytically determined for a wide range of conditions that are likely to occur on an actual roadway.

This paper describes the results of efforts to tie together two fundamental relationships concerning reflectorized signs: the legibility of the signs as a function of brightness and the brightness of the signs as seen by approaching drivers as a function of applicable parameters (sign material, road geometry, vehicle). The results are expressed in terms of minimum required letter heights. The approach to design assumes that the designer will treat legibility at a particular point or road section as a basic factor to be designed for and that letter height selection is one of the primary design decisions to be made. Hence, the basis for the development of a letter height design procedure is established.

The work described herein is a part of that accomplished under NCHRP Project 3-12. The final project report (4) contains a comprehensive account of the relationship of this work to the total information requirements and transmission techniques for highway users.

#### FACTORS AFFECTING SIGN BRIGHTNESS

The major factors involved in determining nighttime brightness at the driver's eye are the sign, the road, and the vehicle.

The sign factor has two subdivisions: (a) material, which establishes photometric properties, and (b) position, which is the location of the sign with respect to the road. The sign may be in the median, overhead in the median lane, overhead in the curb lane, or on the roadside mounted at several possible lateral offsets from the edge of the highway.

The road factor deals with alignment and includes straight roads, horizontal curves with different degrees of curvature and changes in curvature, and vertical curves with different grade changes and grade lengths.

The last factor is the vehicle, which includes the headlight type, high or low beam, and the classification of the vehicle (model of car, truck, etc.) that fixes the locations of the headlights and the driver's eyes. All these factors are given in Table 1.

#### DEVELOPMENT OF COMPUTER PROGRAM

A general analytical method for determining the brightness of reflectorized signs for a variety of sign materials, sign positions, distances, highway alignments, and traffic conditions was first described by Straub and Allen (5). A computational program was written using Fortran IV for the IBM 360/30 computer using similar techniques to determine the brightness of reflectorized signs. The program broadens the scope of the referenced work by including many additional parameters. This program was used to derive the various relationships shown and discussed in this paper.

Sufficient computer runs were made (more than 300 in all), using representative values of the applicable parameters, to demonstrate the applicability of the method and to determine, if possible, the general trend of these relationships; Figure 2 is one example of the results. A field investigation of actual brightness was made, and the results were correlated with the predicted values. A more detailed account of the computer program and its use are given in the project final report (4) and also in a paper by King (6) included in this Record.

TABLE 1  
FACTORS AFFECTING SIGN BRIGHTNESS

Sign	Road
Sign face material (photometric properties)	Vertical curves
Position	Beginning grade ( $g_1$ )
Lateral offset	Final grade ( $g_2$ )
Vertical offset	Total grade change ( $g_1 - g_2$ )
Distance from sign to vehicle	Length of curve (L)
Road	Vehicle
Horizontal alignment	Headlights
Tangent	Number
Horizontal curves	Type
Intersection (deflection) angle ( $\Delta$ )	Arrangement
Degree of curve (D)	Location
Length of curve (L)	Beam use (high or low)
Transition spirals	Driver's eye position
Vertical alignment	
Constant grade	
Level	
Not level	

### DETERMINATION OF REQUIRED LETTER HEIGHT

Given the computed sign brightness versus road distance information for a wide variety of sign, roadway, and vehicle conditions, the next step is to make use of the brightness-legibility relationship to determine the required minimum letter heights.

Figure 3 is one example of the results. It shows the relationship of minimum letter height as a function of the required reading distances from the sign for a straight road and a sign legend made from standard sheeting-type material commonly used on Interstate signs. In applying results to design, it is assumed that only good letter designs are used, such as standard upper and lower case modified Series E (7). It is further assumed that letters are displayed at adequate contrast ratios. The curves in Figure 3 are shown for overhead and roadside signs illuminated by high and low beams.

The basic process for developing this curve is as follows:

1. For a given road distance, find the luminance for a given sign position and beam (from data such as shown in Fig. 2). Example: for a roadside sign, low beams, and a 1,000-ft road distance, read a luminance value of 0.62 ft-lambert ("reference point" on Fig. 2).
2. Using the luminance found in step 1, use Figure 1 to find the corresponding leg-

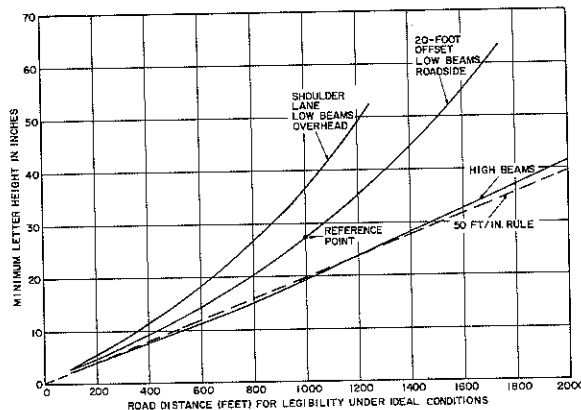


Figure 3. Minimum required letter height as a function of required legibility distances for a straight, level road.

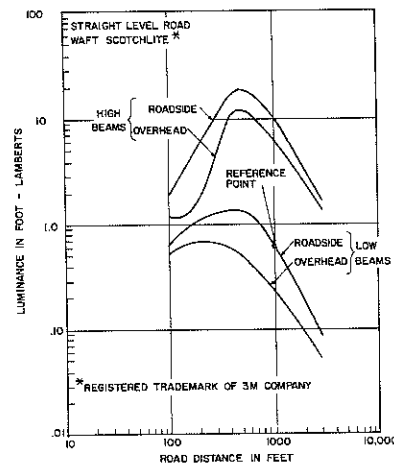


Figure 2. Sign brightness.

ibility factor. Example: for 0.62 ft-lambert, read a legibility factor of 36.5 ft/in. ("reference point" on Fig. 1).

3. Divide the road distance used in step 1 by the legibility factor found in step 2 to find the letter height. Example:  $1000 \div 36.5 = 27.4$  in. The point is plotted in Figure 3 ("reference point"). This is the minimum letter height for the sign message to be legible at 1,000 ft for a car approaching a roadside-mounted sign using low beams.

4. Steps 1, 2, and 3 are repeated as required for other road distances so that a curve can be plotted to show a general relationship for a roadside sign illuminated by low beams. The same basic process, using appropriate data, was used to determine all other curves shown in this paper relating minimum letter height to road distance.

In Figure 3, the curve shown for "roadside" is for legibility at the center of a 10- by 20-ft ground-mounted sign with its left edge 10 ft from the pavement edge and its bottom 7 ft above the pavement. The curve shown for "overhead" is for legibility at the center of a 10-ft high overhead sign mounted with its bottom 17 ft above the pavement over the right-hand lane. For reference and comparative purposes, the commonly used rule of thumb, 50 ft of legibility per inch of letter height, is also plotted in Figure 3. Figure 4 shows the sign positions together with others studied in this project.

The road distance must be specified to apply this technique to a particular problem. By using techniques reported elsewhere (8, 9), an analysis of roadway and expected traffic parameters can be made to determine the distance required for the driver to process the information received from a given highway sign and to perform the required driving maneuvers safely and comfortably before reaching the decision point. This distance determines the position of the last possible point at which the information must be transmitted to an approaching driver. When transformed into the roadway length and added to the previously determined distance, message reading time (a function of sign message length and complexity) determines the position of the first point at which the sign must be legible to the driver. Between these two points is the zone within which the message must be received. From the standpoint of legibility design, the roadway distance from the sign to the first point (the point farther from the sign) is the more critical.

The following example illustrates this new approach to letter height design. Assume that an analysis of traffic maneuvering requirements for a tangent section has indicated that a sign needs to be first legible at a point 800 ft upstream from a proposed sign

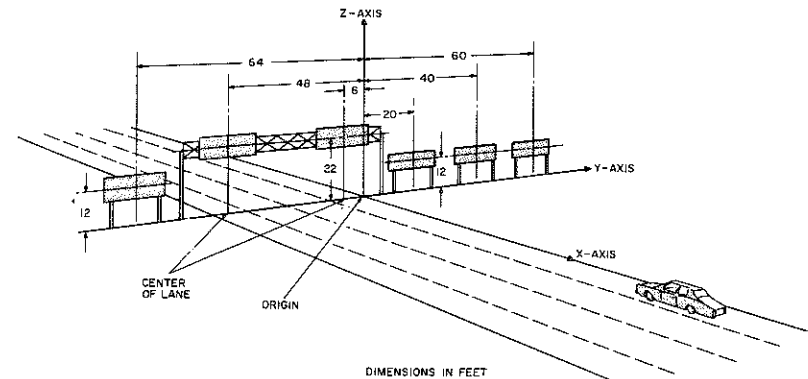


Figure 4. Sign positions.

location. Also assume that low beam use predominates and that the basic design choice being made is between an overhead and a roadside sign position. Referring to Figure 3, it can be seen that, for equal legibility, the minimum letter size for an overhead sign is 27 in. and for the roadside sign is 20 in. In practice, if a nonstandard size happened to be indicated, the designer would consider the next larger standard letter size (7). The choice of which is the better sign position would depend on economic considerations and on other design considerations to be discussed later. It is emphasized here, however, that, from the standpoint of equal legibility, the different sign positions require different letter sizes to allow for the different brightness.

For the preceding example, if a 16-in. letter height were used (based on the 50-ft-per-in. rule), the first point of legibility would be at 540 ft for the overhead sign and 650 ft for the roadside sign instead of the required 800 ft. If this fact were not recognized by the sign designer, this reduced legibility (because of reduced brightness) could lead to serious operating problems.

#### HEAD-LAMP BEAM USE

As can be seen from Figure 3, the curve for high beams closely approximates the 50-ft-per-in. curve shown for reference. Under high-beam illumination, both the overhead and roadside sign positions require letter heights that are nearly equal to each other; hence, only one curve is drawn. Under high-beam illumination, the legibility of the signs closely approximates acceptable daytime performance.

Although vehicles are equipped with both high- and low-beam headlight systems, however, indications are that most vehicles are operated at night using low beams. This is true even for relatively low-volume, rural, Interstate divided-highway alignments. A study in South Dakota (10) reported that 67 percent of all motorists traveling the Interstate study section were using their low beams when first sighted. A later study (11), conducted throughout the United States on both two- and four-lane roads, indicated that for a sample of over 23,000 vehicles observed under open-road conditions less than 25 percent were using high beams.

Therefore, for the purpose of designing reflectorized signs, low-beam operations must be assumed to predominate. One reservation to this statement should be kept in mind. Hare and Hemion (11) stated that "There are marked variations in beam usage habits of drivers from area to area in the United States." Thus, the designer must keep local conditions in mind before deciding on a "design beam."

The additive effects of other vehicles in the traffic stream (as they might increase the brightness of a sign as it would appear to a given driver) was the subject of a special study (4). The total additive effects are surprisingly small (because of the larger divergence angles from the other vehicles' head lamps) and, of course, cannot be counted on to occur during off-peak hours. The net result is that the design condition should be considered as a single vehicle operating on low beams.

#### EFFECT OF SIGN POSITION

The analysis was made at the center of a sign 20 ft wide and 10 ft high, which was faced with material considered as commonly used reflective sheeting. Six sign positions were used in this study (Fig. 4). The 20-ft offset sign is the standard ground-mounted sign. The 40- and 60-ft offset signs represent signs displaced from the highway by 30 and 50 ft respectively. The curb lane overhead sign is the standard, and the median lane overhead sign is mounted over the fourth lane of an eight-lane divided highway, with the bottom of these signs 17 ft above the pavement. The median sign is placed with its right edge 6 ft to the left of the median lane and the bottom of the sign 7 ft above the pavement. The approaching car is in the right-hand lane and the head lamps are on low beam.

Figure 5 shows the minimum required letter height curve for each of the sign positions on a straight, level road. It is noted that the letter height requirements for the 20-, 40-, and 60-ft offset signs are nearly the same, but distinctly greater than the 50-ft-per-in. rule. The median and overhead signs require very large (and impractical)

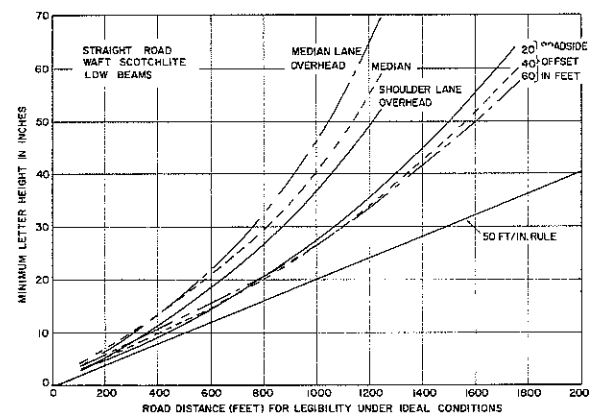


Figure 5. Effect of sign position on letter height—straight, level road.

letter sizes, especially at greater road distances, if reflectorization alone is to provide the necessary brightness.

#### EFFECT OF ALIGNMENT

Figure 6 shows some of the effects of horizontal curvature on the minimum required letter height for a sign offset 30 ft from the edge of the highway pavement (the center is

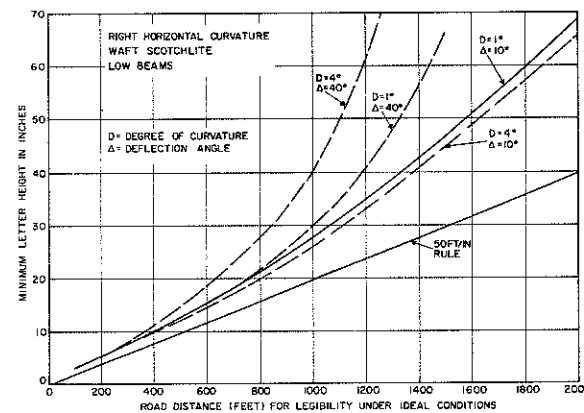


Figure 6. Effect of changes in approach horizontal alignment on letter height for a 30-ft offset sign.

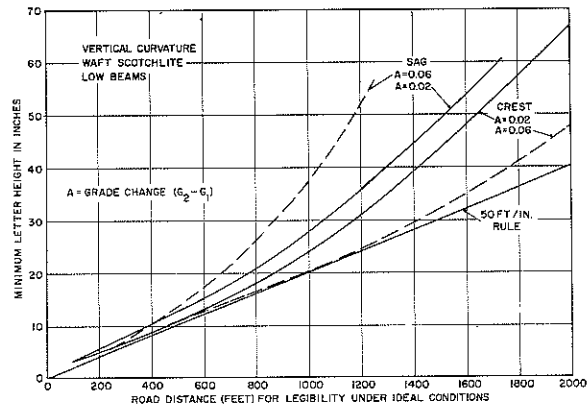


Figure 7. Effect of changes in approach vertical alignment on letter height for a 30-ft offset sign.

40 ft from the edge of the pavement). The plots are for a road curving to the right and show the effect of degree of curvature ( $D$ ) and deflection angle ( $\Delta$ ) as a car using low beams approaches. Although not shown, the graphs for left curvature are similar in shape but show slightly greater letter height requirements.

In all cases larger letter sizes are required than those given by the 50-ft-per-in. rule. The effect is especially pronounced for the longer, sharper curve ( $D = 4$  and  $\Delta = 40$ ); for example, a 40-in. letter height is required for legibility at 1,000-ft road distance, instead of 20 in. as given by the rule.

Figure 7 shows some of the effects of vertical alignment on minimum letter heights. Again the approaching car is using low beams. For these curves, as well as for the horizontal curves, the sign is offset 30 ft from the pavement edge and is located at the end of the road curvature. Figure 7 shows the results of two values of total grade change for both crest and sag curves. In each case, the recommended minimum length of curve for a design speed of 70 mph was used in the calculations (12). The effect of vertical curvature on letter size can be seen from the graph. As the curvature becomes greater, grade change increases and the letter-height requirements for the sag curve are increased. At the same time the letter heights required for a crest curve decrease. The sign at the end of the crest curve with a grade change of 0.06 requires minimum letter heights very nearly following the 50-ft-per-in. rule.

#### DESIGN CONSIDERATIONS

In this paper the relationship between sign brightness and sign legibility has been emphasized. Other major factors, such as the choice of legend and the limits on sign location to satisfy operating conditions, are beyond the scope of this paper. It is obvious that total sign design must take into account many factors in addition to legibility at night. However, attention is focused again on the choices a designer would have in dealing with legibility design.

Several examples have been cited in which larger letter sizes are called for to satisfy night legibility requirements. One choice available to the designer is simply to use the larger sizes needed. Larger letters would require larger sign panels, which in turn yields higher costs. For many situations, the very large sizes are completely impractical to use and other choices become mandatory.

The designer must seek another way to increase sign brightness and hence to decrease the needed size. At problem locations a more efficient (i.e., brighter) reflectorized material might be selected. If a trial sign location is likely to result in low brightness, the designer could seek another location that would serve traffic needs just as well and also provide an adequately bright sign. For example, he could avoid sign locations at the end of sag vertical curves, when possible, and use crests more often.

When reflectorization alone cannot provide the brightness and legibility required, the designer can provide the needed solution by using fixed artificial illumination, either internal or external. The availability of power and maintenance costs may preclude this as a final choice, but if brightness levels can be maintained at sufficient levels artificially (say at 10 to 20 ft-lamberts), the resulting legibility will approach daytime conditions regardless of location problems associated with reflectorized signs. For the example used previously, if sufficient artificial illumination would be provided for the overhead sign, the 16-in. letter height would provide the 800-ft legibility distance needed.

If a single sign location provides questionable night legibility, the designer can consider repeating the sign at more than one location.

These and other choices are available to the designer in considering solutions to providing adequate night legibility. The basic process would be to begin with roadway geometry and traffic operating requirements. The designer would select a trial sign location, determine trial size requirements, check on restraints and adequacies, seek alternative solutions, evaluate economics, etc., in an iterative process. Only then can a solution be found that is acceptable in providing the legibility needed for the operating conditions being designed for.

In very congested areas it may be found that satisfactory solutions using signs alone (whether under daytime or nighttime conditions) cannot be found. In such situations signs can be used extensively, but additional technology will be required to provide supplementary driver aid systems. A complete discussion of driver aid systems is found elsewhere (4).

An important point to stress is that, for the reasonably near future, signs will play an increasingly important role in traffic operations. Because of wide variations in the legibility of signs that are used under nighttime conditions, each sign should be treated as an individual design problem. To be responsive to the actual conditions, the designer must take into account the specifics of alignment, positions, etc., appropriate for each sign.

#### ACUITY AND OTHER LIMITING FACTORS

Of considerable significance is whether the legibility data described by Allen et al. (1), which are the bases of results presented herein, can be applied for drivers with impaired vision. Visual acuity is a function of the angle subtended by the smallest discernible detail. The median driver has a visual acuity of 20/20, which is also the average of the observers used in Allen's study. Therefore, using Allen's results to satisfy legibility requirements implies satisfaction for at least 50 percent of the drivers on the road. If a greater percentage is to be included, drivers with lower visual acuities must be considered. The fifth percentile driver has a visual acuity of 20/70 (13). Because empirical results (like those of Allen) are lacking for drivers with impaired vision, the effect of reduced acuity on legibility distances can only be estimated from a consideration of the geometry of the visual angles. Because small angle tangents vary linearly with angles, a straight-line relationship between acuity and letter height is assumed. On this basis, the 20/70 driver requires letter heights that are 3.5 times those of the median driver. Therefore, for the example used previously, the overhead sign would require letter heights of  $3.5 \times 27$  in. or 94.5 in., and the roadside sign would require letter heights of  $3.5 \times 20$  in. or 70 in. for low-beam illumination. The revised values of letter height should then be considered in the overall sign dimensions, and the computer program must be rerun to verify brightness and in turn letter heights for the new sign in an iterative process until letter height, sign dimension, and brightness agreement is reached. These letter height values, even though extremely large, would still not satisfy

100 percent of the driving population. The matter of visual acuity, of course, also affects vision under daytime conditions. This represents an extremely serious problem for a small segment of the driving population.

In addition to the factors covered in this paper, several others also affect the brightness of reflectorized signs. Some of these are badly aimed headlights, changes in voltage in the lighting circuits, aging of sign materials, and transmissivity (loss of light caused by atmospheric attenuation). These factors were studied under NCHRP Project 3-12 (4), but the results are not included in this paper because of space limitations. In most cases, reduced brightness results in the need for greater letter heights than those indicated by the ideal conditions shown on graphs in this paper.

One final factor should be mentioned in considering the adequacy of signs for nighttime conditions--target value or sign visibility. The driver must have his attention drawn to the sign that he is to read before he can read it; i.e., he must select this particular signal source over all the other signal sources competing for his attention at the particular moment. The lead time required between the last point at which the sign should be detected and the point of beginning legibility cannot be determined unequivocally. It depends on the complexity of the task to which the driver is attending and on the number of competing sources. A qualitative evaluation must be made for every individual location and the proposed sign design checked for adequacy of target value. A paper by Forbes et al. (14) gives a suggested procedure for predicting sign visibility that can be used for this evaluation.

When required nighttime brightness can be defined for target value, the analytical method of determining brightness of reflectorized signs previously described can be used to predict conditions at a specific proposed sign location.

#### CONCLUSION

An analysis of the approach to sign design detailed in this paper clearly indicates that serious deficiencies in nighttime legibility can occur if uniform letter sizes are arbitrarily adhered to or if simplified rules of thumb (such as 50 ft of legibility per inch of letter height) are used universally without regard to specific site conditions and brightness. This is particularly true for reflectorized signs.

Relationships developed in this paper establish a new approach to the design for night legibility. To be responsive to the needs of nighttime legibility, the designer must account for the relationship of sign brightness to legibility, especially for signs of low brightness. The graphs of minimum letter heights presented here show the general requirements that typify modern Interstate road alignments. In general, to account for night legibility, signs must be made larger and/or brighter.

The graphs of minimum letter heights are based on "ideal" conditions (new, clean signs, clear atmosphere, normal vision, and so forth) to account for conditions actually found on the road. Further allowance must be made for such factors as visual acuities less than 20/20 and for diminished sign brightness because of material aging, dirt, dew, and atmospheric attenuation.

As stated in the introduction, the relationships of brightness to legibility used in the development of this paper are based on overall average results for medium and low ambient illumination. Refinements should be developed to account for requirements in areas of high nighttime ambient illumination (for example, urban areas). In general, however, higher sign brightnesses are required in areas of higher ambient illumination and in areas subject to glare.

Because of widely varying brightness conditions, each sign should be treated as a separate design problem.

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**ATTACHMENT NO. 3**



## "BRIGHTER IS BETTER"

H. WOLTMAN

Today we are going to talk about why Reflective Products should be brighter and why, for the last decade, we have done our best to make them brighter. The practical reasons are not always fully understood by our customers, and we are relying heavily on you to help get the message across, that brighter is better.

First of all, many factors affect sign brightness: dirt on windshields, headlamps and sign surfaces, tinted windshields, misaligned headlamps, overloaded cars, low voltage or poor lamp quality, greater clearance distance to signs whether they are overhead or shoulder mounted, and the aging effect on both signs and human eyesight. Traffic speeds have increased roughly a mile an hour a year for the last decade. There are other factors also, but you will note that those factors I have given you are all negative factors. None of them do anything to improve sign brightness and the worst is yet to come.

Most recently we have been advised of the findings of the Southwest Institute that not less than 2/3 of night driving is done on low beams. And, this is even in isolated rural areas of the country. On many highways that they inventory, the percentage changes to 9/10ths that use low beams.

The extensive low beam usage is startling and is the single most serious cause of inadequate sign brightness. Furthermore, the use of low beams has been increasing with increases in traffic volumes. Now, these are the reasons why Engineer Grade is not as effective now as it was five years ago. Having measured many signs, we can attest to the fact that our signs are a fraction of the brightness of signs that are installed by restaurants, oil companies, and motels. These are internally illuminated signs, and they are bright because dollars and cents depend on them for effectiveness. They are effective!

Before we can make comparisons with what is ideal and where we fit in, though, we have to refresh our vocabulary and learn a new term or two. To be honest with you, I had to refresh my memory on these terms too, so don't feel badly about it.

First of all, candlepower is the term used for describing the intensity of a light source, and typically, your car headlights have 25,000 candlepower on low beams and about 70,000 total candlepower on high beams. Foot-candles is the unit used to describe the amount of light that falls on a surface. In our case, the traffic sign is illuminated by headlamps and the amount of light falling on a sign is but several thousandths or several hundredths of a foot-candle of illumination. It is a very small quantity of light when you consider the typical reading distance of a sign because the distance to the sign is squared.

This is then divided into the candlepower output of the headlamps resulting in a very small number (of foot-candles) which is usually less than one. Foot-Lamberts is the brightness of the surface and it is used to describe the amount of light coming from a surface. Luminance is the term used to describe brightness. Now then, let's learn a little about Foot-Lamberts because that is a term we are going to use more often.

The brightness of surfaces that we see in the sunlight, like snow or grass, may vary from 400 to several thousand Foot-Lamberts. I have measured snow with our instruments and found it as bright as 3,000 to 4,000 Foot-Lamberts. Green grass is about 400. In the office, from 25 - 75 Foot-Lamberts is about average for a white piece of paper that you may be reading, with the office illumination. In your home, about 7 - 10 is perhaps about the average and the aggravation point, when you turn the lights on because it seems to be getting a little bit dim to read the newspaper, is about 4 Foot-Lamberts. The so called "white way", which the light companies advertise and which we have in Minneapolis on Hennepin Avenue and Lake Street of closely spaced big fluorescent luminaires develop about 3 Foot-Lamberts on white surfaces. Now then, the street lighting is very much less than this. Mercury vapor street lighting, right under the street lights, may be as high as 1 Foot-Lambert on a white surface and about .01 Foot-Lambert in the mid-block area. Under a full moon, about .01 Foot-Lambert, and under starlight or darker conditions about .003 or less.

Now, how many Foot-Lamberts brightness should a sign have?

The best research on this subject was done by Dr. Terrance Allen of the Virginia Council of Highway Research in 1958. This graph shows relationship between the legibility of the traffic sign and the brightness levels that we have described. He constructed a sign with a number of light bulbs in front of it so that he could vary the intensity of light falling on the white letters that were mounted on a dark background. He adjusted the brightness of these white letters to 0.1, 1.0, 10, and 100 Foot-Lamberts. He had people walk toward the sign and at the distance where they could read the letters on the sign, he calculated the legibility in feet per inch of letter height. (Figure 1)

As shown by Allen's graph, as brightness increases from .1 to 1 Foot-Lambert, the legibility increases quite rapidly. From 1 to 10 Foot-Lamberts, there is an additional increase but it is not in the same proportion. Then, from 10 to 100 Foot-Lamberts, the brightness does not seem to improve and, therefore, we can say the optimum legibility occurs at the top part of the curve at around 10 - 20 Foot-Lamberts. We get 85% or so of the maximum legibility at around 1 to 1½ Foot-Lamberts and on out to about 100 Foot-Lamberts. We could call these ranges on either side of the optimum brightness area that brightness where we get sufficient legibility to produce at least 85% of the maximum possible legibility.

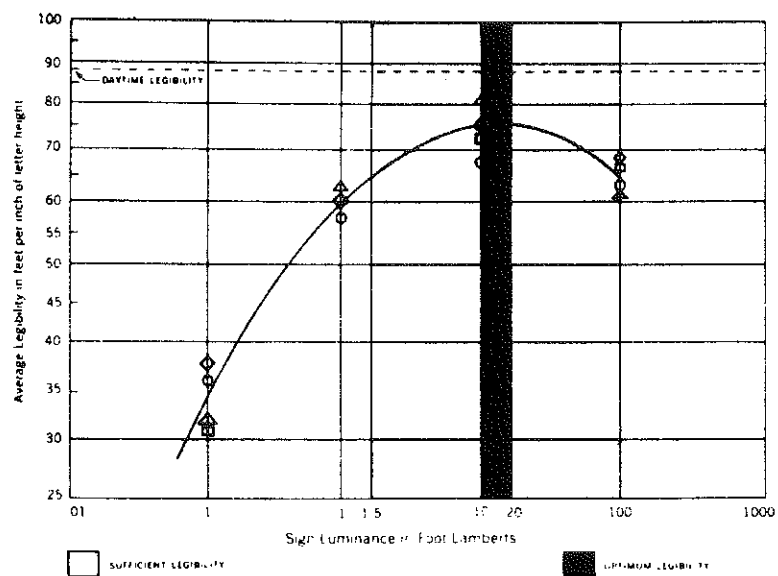


Figure 1. Optimum and satisfactory legibility distances for 6- to 18-in. BPH Series E (Mod.) shown relative to letter luminance. Legibility data from Allen (3).

In another study by Allen at Michigan State University, up to 100 Foot-Lamberts were found to be desirable in bright urban situations and where glare from on-coming traffic may be a problem. But for the rural situations, this is the result.

The question we should now answer is, "How bright are our signs?" We generally respond in terms of number of times brighter than a white paint or in terms of candlepower, or something like that. To know exactly how bright they are to the motorist on the highway, however, is an involved calculation and it is most easily and accurately determined by making measurements on the highway with a telephometer as it was done in our Traffic Control Movie. (Figure 2) With the telephometer, we were able to make brightness measurements of just the letter material on the sign, or just the background of the sign as illustrated in Figure 3. What we found is shown on figures 5 through 8.

The enclosed lens sheeting or Engineer Grade "SCOTCHLITE", Figure 4, does not come up to 1 Foot-Lambert until we get to within 750 feet of the signs and achieves between 1 and 2 Foot-Lamberts. This is for low beams and shoulder mounted guide signs. Encapsulated sheeting - our High Intensity Grade - appears to be the best performing letter of them all, and develops between 3 and 4 Foot-Lamberts at the maximum sign brightness and is within the sufficient level (85%) throughout the approach. What if we switch to high beams?

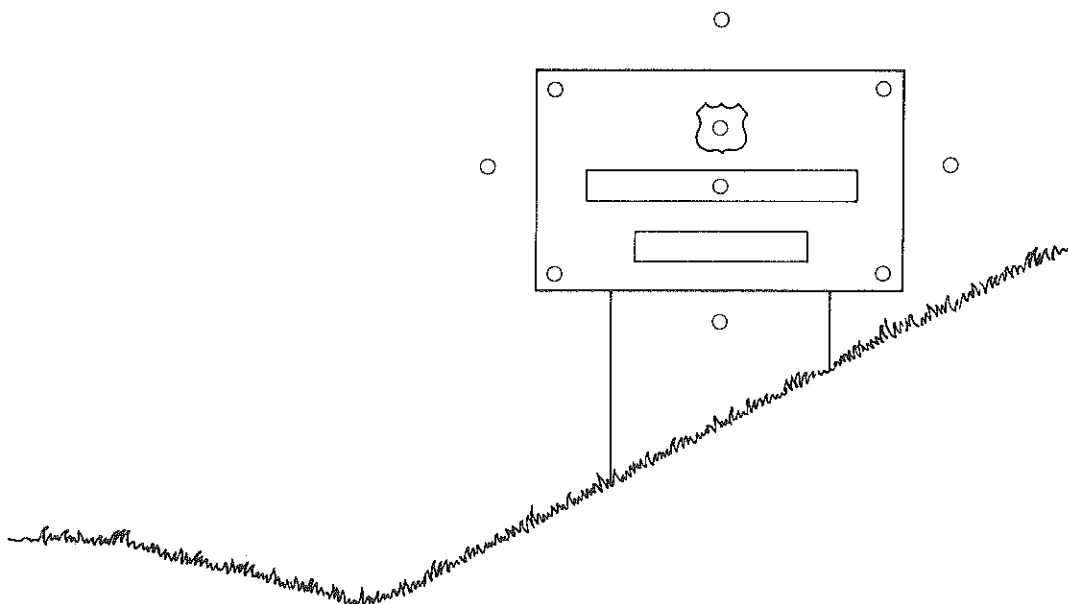


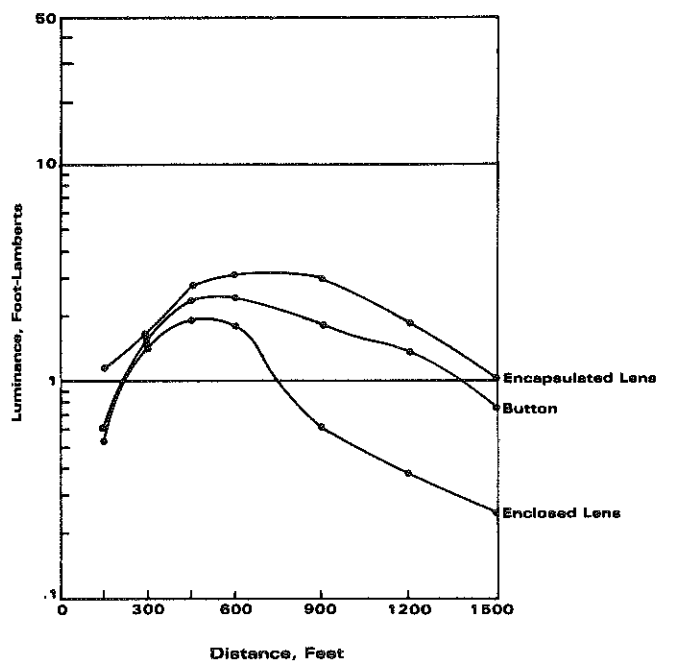
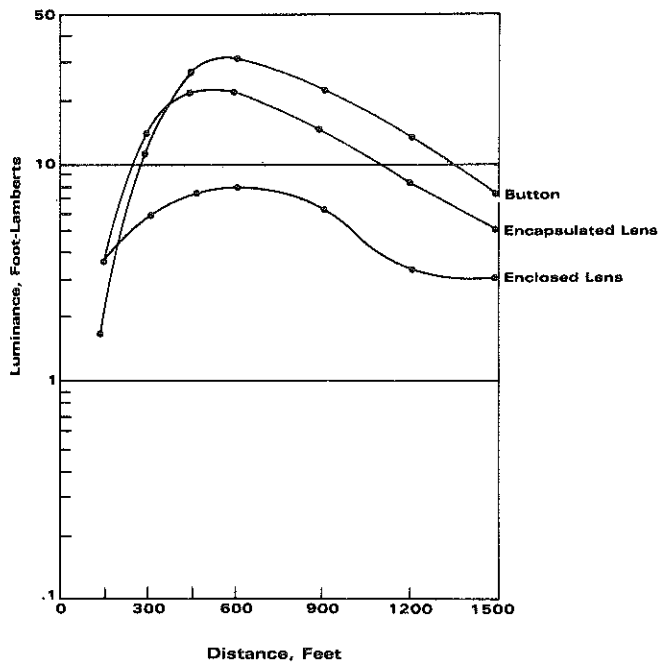
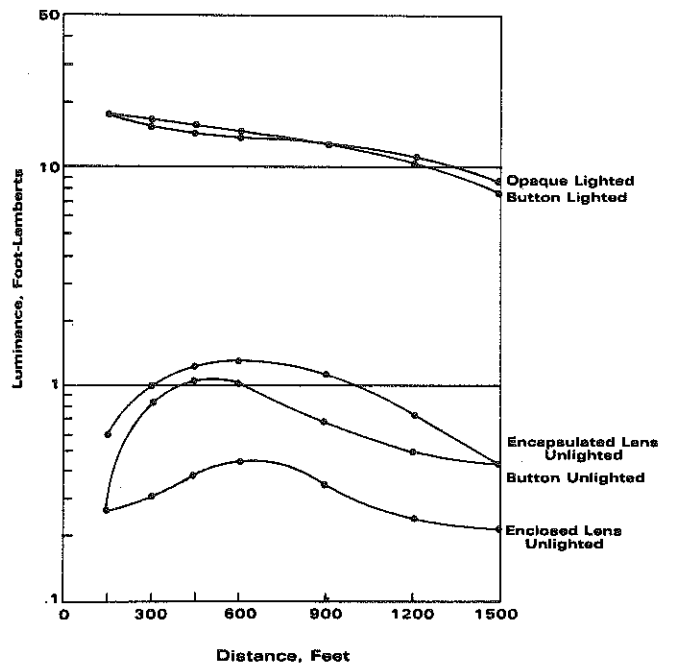
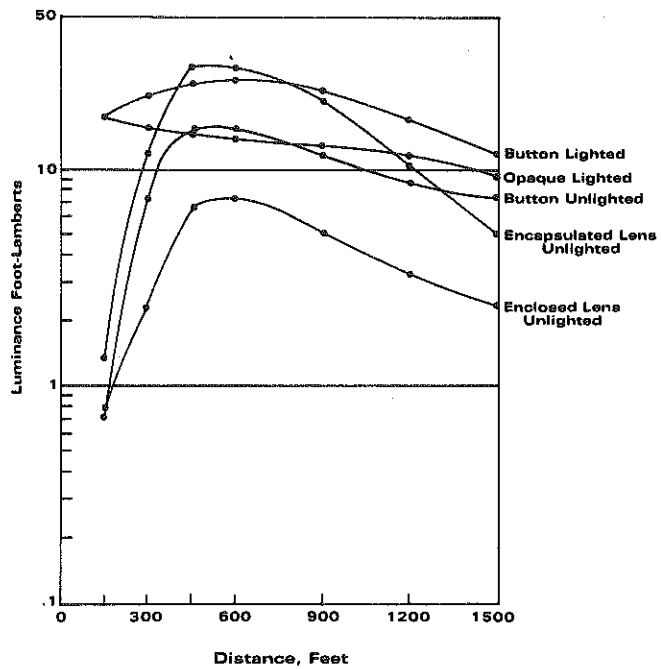


FIGURE 2

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FIGURE 3





## NIGHTTIME LUMINANCE OF SIGN LEGENDS VS. DISTANCE

We see that in Figure 5, where the same signs are examined with high beams. The Engineer Grade sheeting (the enclosed lens) is at the range of 7 to 8 Foot-Lamberts for the reading distances for these signs 900 feet down to 150 feet. The encapsulated lens sheeting goes up into the 10 to 20 range. So, we have very adequate brightness on high beams which I think is something that we have all experienced. But the importance of this whole discussion is the brightness of the sign on low beams.

Let's look at the overhead signs and see how they do. Here the Engineer Grade sheeting on low beams, Figure 6, doesn't provide sufficient brightness for 85% legibility. The button letters and the encapsulated lens sheeting come up to a little over 1 Foot-Lambert brightness. They are in the range of 1.5 Foot-Lamberts brightness for the encapsulated lens sheeting which is fair brightness. We could use more.

We see that the illuminated overheads provide between 10 and 20 Foot-Lamberts brightness. Remember that these reflective overheads are not illuminated, these are simply reflective signs that are in the overhead position so that we can compare the performance of the reflective signs on low beams versus the illuminated signs.

We'll come back to Figure 6 in a minute. Figure 7 is the same series of signs when seen with high beams. On high beams, the performance is quite good. All of the reflective materials provide sufficient brightness for a quite good legibility. Even the Engineer Grade sheeting is in the neighborhood of 7 or 8 Foot-Lamberts brightness on the overhead signs. The best of the materials is the encapsulated lens sheeting which is about 25 to 30 Foot-Lamberts brightness on overhead signs on high beams and using the High Intensity Grade sheeting are quite comparable to the performance that we get compared to the illuminated signs.

Let's return for a moment to Figure 6, the same overheads on low beams. When making measurements, we very often had to wait for traffic to pass because we wanted just the light from our own headlights on the sign. Therefore, we would wait for cars that pulled up behind us to go around and pass and while they were passing, we noticed that the signs were brighter because of the light from their headlights. Nobody ever considers that other cars on the highway contribute useful light to sign brightness that you take advantage of in your own car. So we made some measurements under these circumstances and we found many times we obtained 2 to 5 times greater brightness when other cars were along side of us, behind us, or ahead of us.

So these values all come up substantially under the heavier traffic conditions of many freeways today. This gives rise to our opinion that a number of these overhead installations would operate satisfactorily with our high intensity sheeting despite the fact that much of the traffic would be moving on low beams. Under conditions where the traffic volumes were very low, traffic would be more likely to be using high beams, and would then have the opportunity to switch to high beams to obtain performance equivalent to lighted signs.

We might ask ourselves "How bright our signs are when they are smaller shoulder mounted signs?" The answer is that performance is essentially similar except that maximum brightness occurs closer to the sign at around 200 - 300 feet instead of 500 - 600 feet. The Engineer Grade sheeting comes up into the area of 2 - 3 Foot-Lamberts and High Intensity about 8 - 9 Foot-Lamberts.

What about the colored background of signs? The best information on this is from the study of "Traffic Sign Requirements" that was done at Michigan State University by Dr. Theodore Forbes. In his studies, he has shown that brilliant green color was the best background color for guide signs among the four different shades of green that were tested. For night driving, obviously all guide signs should have reflectorized or illuminated backgrounds. The sign has to be seen against the night sky backgrounds. Otherwise, it is not apt to be seen by the motorist.

Guide signs without reflectorized or illuminated backgrounds need to be 100% larger than signs with reflectorized or illuminated backgrounds to be equally effective at night. You have to make the sign 100% larger if you do not intend to put some kind of material on the sign, reflective sheeting, or illumination, to make it equivalent in performance to a sign which has this ability to stand out from the natural background at night.

When the background is illuminated or reflectorized, not only can it be smaller, as Dr. Forbes points out, but the brighter it is, the better the contrast with the night background and the more effective the sign will be.

Another very authoritative research study that has been done recently, is the "Diagnostic Field Studies" that were conducted by the Texas Transportation Institute at Texas A & M College. This is from page 30 of that report and I would just like to quote what the Diagnostic team found out about sign visibility. "Because automotive headlights do not provide effective illumination, all overhead signs on freeway and arterial systems should be provided with external lighting. In addition, roadside directional signs on the interstate system should be illuminated so that the driver can ascertain the directional message using the low beam of his headlights.

On one study site, however, the use of High Intensity sheeting provided sufficient reflectivity on low beams to eliminate the need for external illumination on both roadside and overhead signs..... The night visibility of the highway visual communications system presents a critical situation. Often the driver uses roadway signs more at night than under daytime conditions. Provisions must be made to insure adequate sign visibility and legibility during periods of darkness."

Fellows, I hope you found some good reasons to believe that the brighter sign is better.

Thanks very much. Have a Good Day!

