LEGIBILITY AND BRIGHTNESS IN SIGN DESIGN

Bernard Adler, AIL, Division of Cutler-Hammer, Inc.; and
Arthur L. Straub, Clarkson College of Technology

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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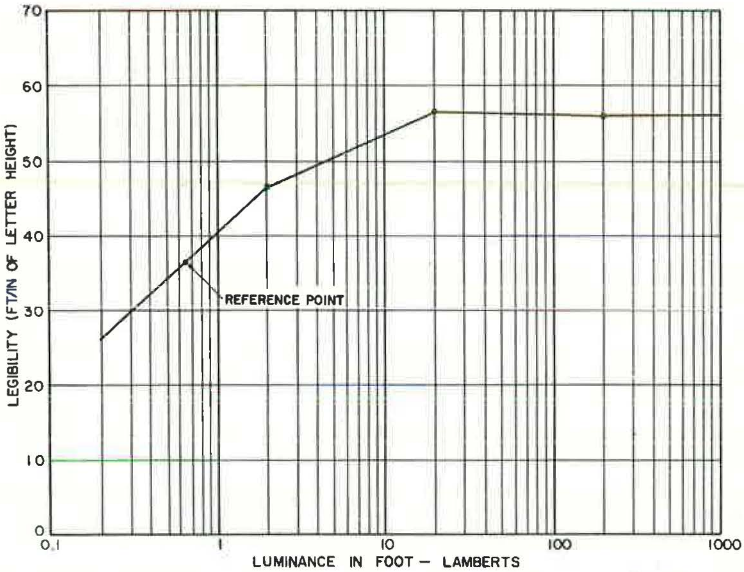

Figure 1. Legibility as a function of luminance.

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

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:

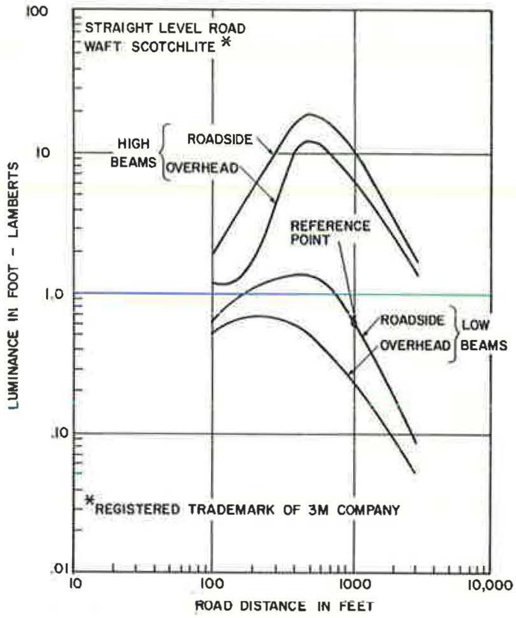

Figure 2. Sign brightness.

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-

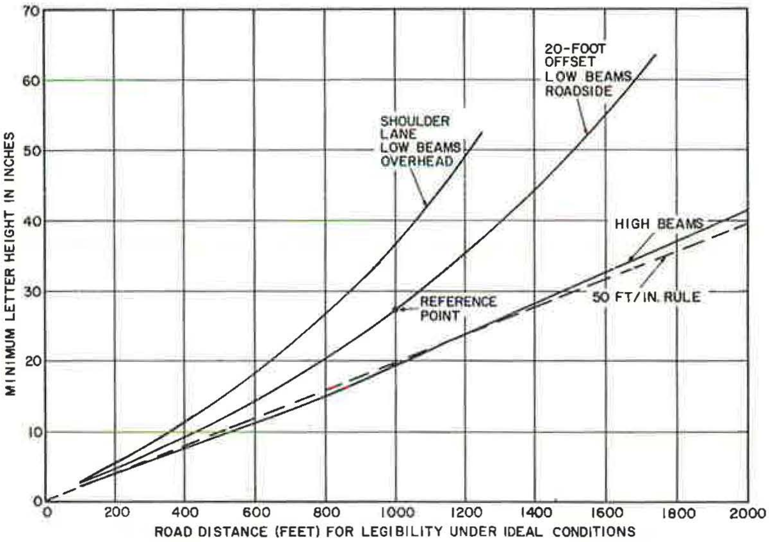

Figure 3. Minimum required letter height as a function of required legibility distances for a straight, level road.

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 ÷ 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

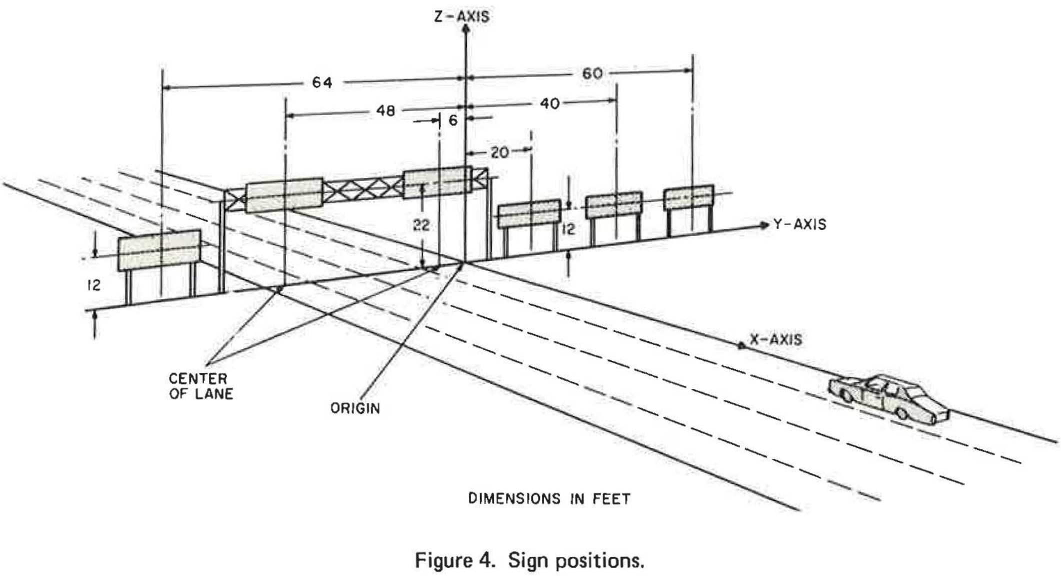

Figure 4. Sign positions.

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)

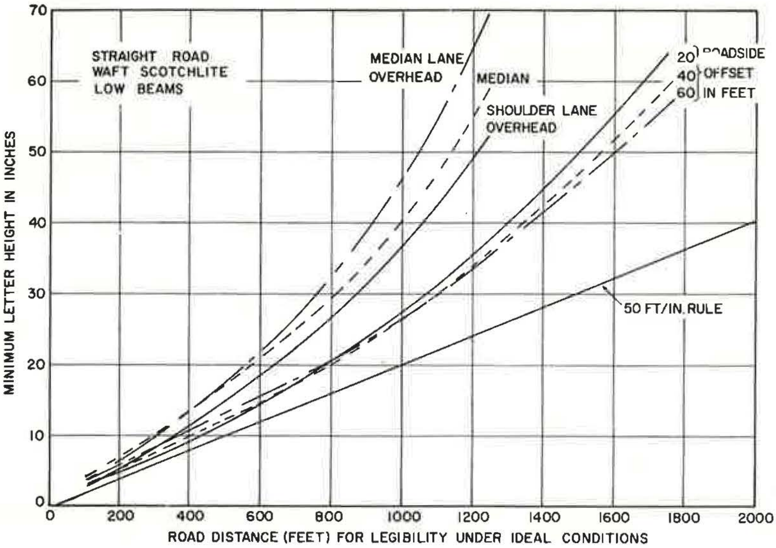

Figure 5. Effect of sign position on letter height—straight, level road.

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

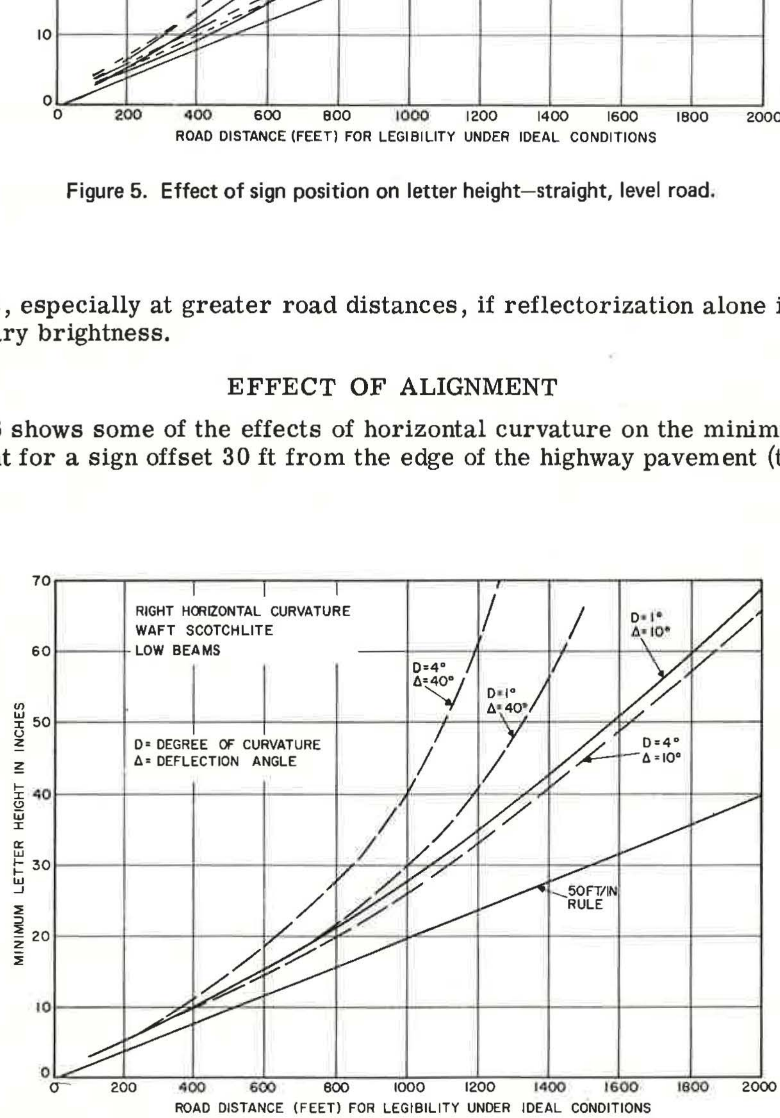

Figure 6. Effect of changes in approach horizontal alignment on letter height for a 30-ft offset sign.

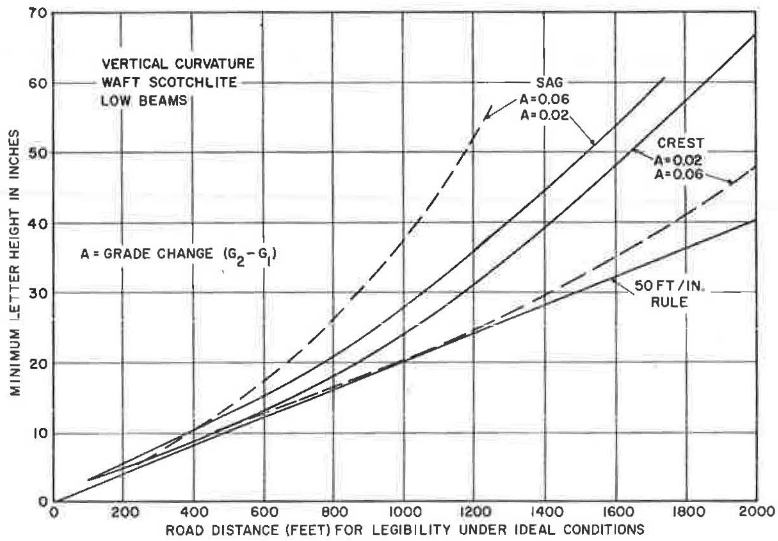

Figure 7. Effect of changes in approach vertical alignment on letter height for a 30-ft offset sign.

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 (Δ) 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 Δ = 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 extensivly, 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 × 27 in. or 94.5 in., and the roadside sign would require letter heights of 3.5 × 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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