Ratings for Visual Benefits of Roadway Lighting

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●THE INCREASING extent to which roadway lighting is being used to improve night automotive transportation is of great social and economic significance. Many people desire, or may be required, to drive after dark. Motorists and truckers involved pay for a large percentage of the over-all multi-billion dollar investment in streets, highways, autos, trucks, and buses. More efficient night operation, higher dividends from the public investment, and more pleasant and attractive night driving conditions result from the use of good roadway lighting.

Seeing is obviously a basic requirement for night driving, as well as day driving. The rapidly increasing recognition and knowledge of the benefits of good roadway lighting may be expressed in terms of the improvement in (a) visual seeing and (b) traffic operations.

As shown in the upper portion of Figure 1, seeing and traffic benefit are interrelated; the traffic benefit is generally contingent upon the seeing benefit provided by the lighting (1 - 12, incl.). Evaluation studies are under way for rating both the traffic and visual benefits. The traffic benefit studies should specify the visual seeing factor effectiveness of the roadway lighting provided.

Seeing Factors

This paper presents computed seeing effectiveness ratings in terms of two of the principal factors—relative visibility and relative visual comfort—shown in the upper portion of Figure 1.

The comparative importance, or weighting, which should be assigned to relative visibility versus relative visual comfort should be decided by evaluation of the effectiveness of each in producing the desired traffic benefit (6, 11, 12, 13). Is the proper visibility-comfort weighting 2 to 8, 8 to 2, or 5 to 5? Some might argue that visibility is primary, comfort secondary. To what extent is this true? Until the lighting is installed, the visibility benefit is not produced or available. If the roadway lighting is pleasant, has a good comfort rating, and makes night driving attractive, it will be installed, backed by motorist enthusiasm and demand. Such lighting should also increase night use and value of the public investment in automotive transportation facilities (2, 3, 4, 6, 7, 11, 12).

RATING TRAFFIC BENEFIT

New traffic benefit ratings for roadway lighting will evolve from current and future studies by engineers, officials, and those engaged in traffic research. Engineering estimates of traffic benefit should be developed now, subject to such future validation as may be essential and practicable.

In addition to accident prevention, traffic benefits include freedom from fear, less reluctance to drive at night, comfort, convenience, and facilitation with higher critical speeds, which result in economic gain due to the value of time saved (6, 7, 8, 9, 13, 14).

New instrumentation developed by the U.S. Bureau of Public Roads is being used to measure night traffic capacity factors such as headways, vehicle formations, speeds, lane use, and availability of passing opportunities with and without good roadway lighting (13). Comprehensive evaluation of the traffic benefit of good roadway lighting is long overdue.

Connecticut Turnpike Studies

Cordiner (15) has said: "There have been important advances in lighting, too. The Connecticut Turnpike, opened this year (1958) with 53 miles of continuous lighting, is a significant step in highway safety. It shows how to obtain safe, efficient use of the highways 24 hr a day, in all kinds of weather."

Traffic capacity studies before and after lighting were conducted on this new turnpike during 1958. Although open for traffic use since January 1958, only a small portion of the 53 miles of continuous lighting, and the intersection lighting, was turned on prior to August 1958 (12, 13).

The U.S. Bureau of Public Roads has cooperated with the Connecticut State Highway, the HRB Committee on Night Visibility, and the Yale Bureau of Highway Traffic in making these studies. New instrumentation developed by the Bureau automatically records the data on tape for analyzing by an IBM 650 Computer. Taragin (16) has reported on the progress of these studies.

It is hoped that these capacity studies will be continued on the lighted and unlighted sections of the Connecticut Turnpike and New York State's 17-mile extension thereof, which will soon be lighted.

Figure 1. Data, emphasis, control, and balance of factors shown in the lower portion of this diagram produce the visual comfort and visibility factors in seeing. These seeing factors and driver alertness produce the improvement in traffic comfort, convenience, and safety essential for efficient night operation of the public investment in automotive transportation facilities. Traffic benefit is usually contingent upon the seeing effectiveness of the roadway lighting provided.

Texas Research on Intersection Illumination

Keese (17) has reported research involving evaluation of both traffic and visual benefits as follows (11, 12, 13):

> A research project on intersection illumination is being conducted by the Texas Transportation Institute for the Texas Highway Department and the U. S. Bureau of Public Roads. The specific objectives of this project are to determine the effects of various types of intersection illumination on traffic performance and safety.
>
> A comprehensive study of an existing intersection during the past year resulted in the following general conclusions:
>
> 1. More research is necessary on highway and intersection illumination.
> 2. Intersection illumination and intersection signing must be coordinated for maximum efficiency.
> 3. Present methods of illumination provide undesirable glares and uneven intensities of light.
> 4. Roadway illumination is a vital feature of highway design and operation. Present illumination design criteria are vague and do not necessarily accomplish the desired results.
> 5. All intersections cannot be illuminated by the same standard design. Each intersection has special visual features and problems that should be carefully considered in the layout and design of the illumination.
> 6. Complexity of variables at any single intersection points up the need for a model study to determine the best illumination design for one or more test intersections.
>
> In light of the foregoing, the present phase of this project is being conducted along the following general lines. A model of an existing intersection has been constructed and miniature light sources are being developed to reproduce field conditions produced by using standard lighting fixtures. This model will be tested for various patterns of illumination to determine the arrangements desired for full-scale study at the test intersection.
>
> The patterns determined by the use of this scale model will be reproduced at the test intersection for actual field study and correlation. Before the intersection is lighted, a comprehensive study will be made utilizing all instruments necessary to measure all traffic behavior and visibility factors. A study of sign lighting will be incorporated in both the model and field investigations.

Highway Safety Study

The comprehensive Highway Safety Study investigation of cause of traffic accidents will doubtless include further indications of the relation between night accidents and poor roadway lighting, or none at all. In the instances where night accidents occur in spite of lighting, its effectiveness should be rated in terms of the visual factors shown in the upper portion of Figure 1 (11, 12, 13).

OTHER TRAFFIC AND VISUAL BENEFIT STUDIES

Other studies of the visual and traffic benefit of roadway lighting should be initiated by interested highway administrators and researchers.

HRB—NRC Research Program

An example is the research program now being considered by the HRB Committee on Night Visibility. This program was prepared by a subcommittee under the chairmanship of O. W. Richards.

Armed Forces—NRC Research Program

The symposium conducted by the Armed Forces—NRC Committee on Vision on The Visual Factors in Automobile Driving, held in November 1957, analyzed the traffic-vision situation and reported the following general conclusions:

1. Although the specific connection has not yet been located, there seems to be no doubt that vision is an all-important factor in vehicle driving. Apparently the right visual factors have not yet been tested, or at least have not yet been correlated with driving ability.
2. Much more vision research is needed along the lines suggested in the preceding comment, and it is still necessary to apply more diligently, to the driving situation, what is already known about vision. Some persons feel that more can be gained by the latter approach than by trying to find some new factors or combinations of factors that might be correlated with the driver's success.
3. Driving situations vary greatly (daytime vs nighttime; two-lane country roads vs four-lane divided expressways; high-density traffic vs low-density traffic, etc.) and the visual requirements vary accordingly. In assessing the role of vision in the driving task, these variations must be taken into account.
4. Negative criteria like accidents are generally unsatisfactory; positive criteria are needed.
5. Studies of visual functions under dynamic situations are sorely needed. All approaches should be employed; that is, laboratory, simulator, and field studies.
6. It is hoped that a reliable measure of driver ability may emerge from groups working on this problem. At present there is no such method of quantifying driver skill or driver ability.
7. The need for closer liaison between the various groups (design engineers, illuminating engineers, safety engineers, vision researchers, etc.) is definitely indicated.
8. Vision research scientists are willing, if not eager, to perform some of the needed research. However, the initiative should come from highway safety people, highway designers and engineers, automobile manufacturers, insurance companies, and the like.
9. Financing should be provided by the primarily interested parties just listed, so as to support the required research program. It was suggested, not entirely in jest, that the required research studies could readily be financed by funds made available by not building a mile or two of the 41,000 miles of superhighway planned under the Interstate Highway System authorized in 1956.
10. A concerted effort should be made to coordinate all factors to make the Interstate Highway System as ideal as possible, to serve as a model for all other high-speed highways.
11. A full-scale study should be made, with the final outcome a handbook of roadway and highway engineering. The signs and illumination of today are 20 to 50 years old.

A continuing working group for developing a suitable research program on visual factors in automobile driving, and to bring the vision research worker and "customer" together for this purpose, has been set up with Dr. K. N. Ogle, Section of Biophysics and Biophysical Research, The Mayo Clinic, Rochester, Minn., as chairman, and Dr. H. A. Knoll, Division of Ophthalmology, Dept. of Surgery, School of Medicine, University of California, Los Angeles, as secretary.

Harvard Medical Research Project

It is expected that visual research studies will receive a suitable percentage of the $809,000 Federal grant for the study of causes of road accidents by the Department of Legal Medicine, Harvard University Medical School. According to a December 6, 1958, release published in the New York Times, this study, sponsored by the National Institutes of Health, is to "complete the scientific picture of the multi-faceted accident problem," and "get at the total situation in which the fatal accident occurs.... These include the driver, the vehicle, the roadway, the traffic, the environment, man-machine relationships—to identify causes..." (18). It also has been pointed out "latent heart ailments and hidden brain injuries could impede vision or slow judgment" (18).

Vision researchers should help determine how much seeing is essential for night driving by the typical or average driver, as well as for those who are psychologically, pathologically, and ophthalmologically handicapped.

VISUAL BENEFIT RATINGS

In visual research much of the work is being done by universities (19 - 25, incl.) under sponsorship of the Illuminating Engineering Research Institute, which is financed

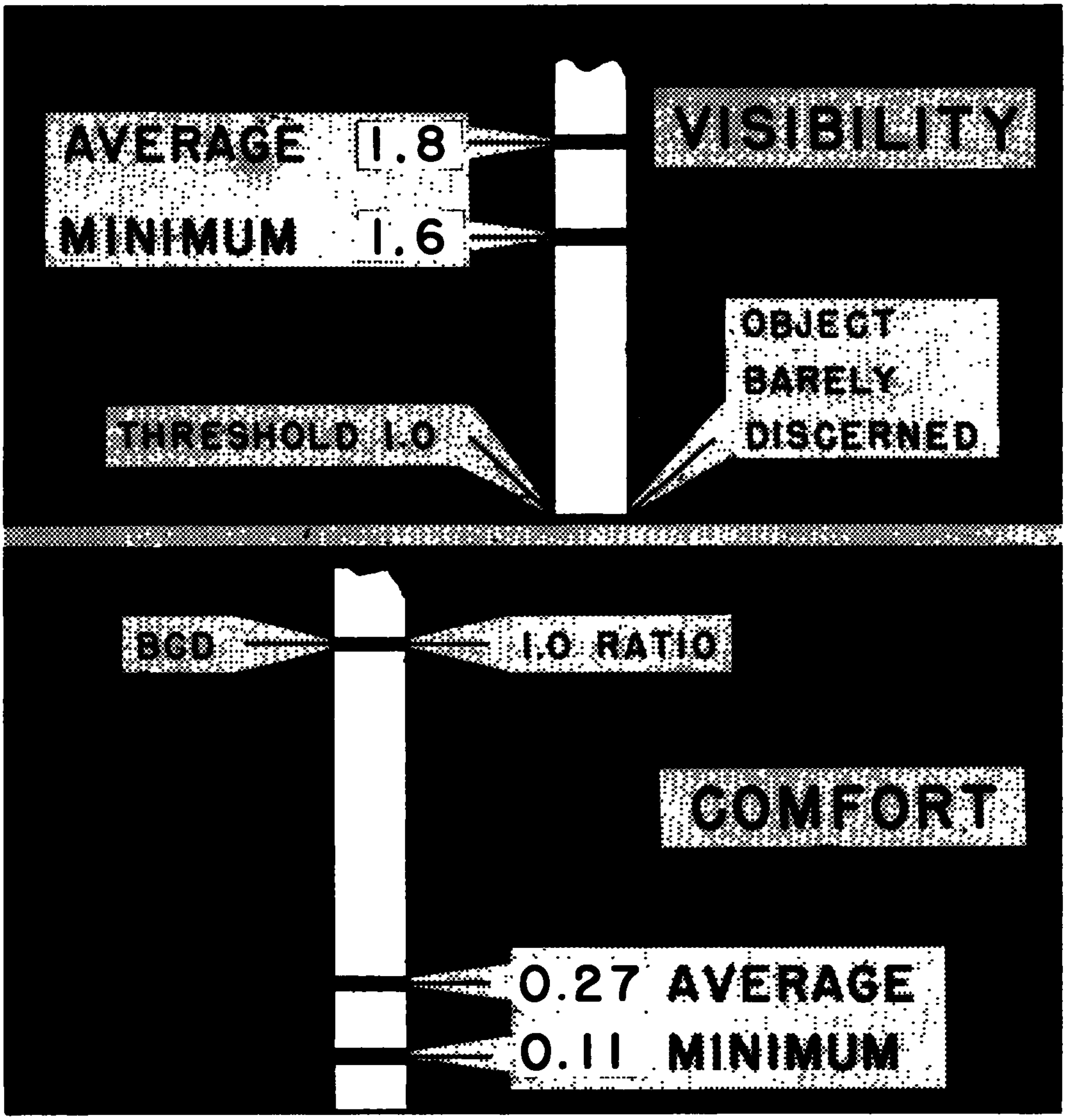


Figure 2. Example of seeing factor ratings for representative roadway lighting systems. Relative visibility ratings (top) may now be accompanied by computed ratings for relative comfort (bottom). The visual comfort rating is relative to the sensation which would be at BCD, the average borderline between comfort and discomfort, for the system of luminaires and the lighted roadway. Analysis of experimental data will indicate the percentage of motorists who would be comfortable with roadway lighting having a rating ratio such as 0.27 or 0.11. The minimum ratings at any position on the traffic-used portion of the roadway are the most significant and logical criteria.

by the Illuminating Engineering Society but administered by a separate board of trustees. Funds are meager and inadequate considering the importance of the work to be done.

Available data are now being used to compute ratings for the visual effectiveness of roadway lighting in terms of relative visual comfort and relative visibility (11, 12). These seeing factors, along with conditions for driver alertness, as shown in the upper portion of Figure 1, are the objectives of the designer's skill in balancing the contributing factors shown in the lower portion of this diagram.

Figure 2 shows the computed visual comfort and visibility ratings for a representative roadway lighting system. Such dual ratings present a significant simplification for everyone, including those who represent the roadway user and desire to know the relative effectiveness of roadway lighting systems.

The relative visual comfort ratings were first presented during the Research Sessions of the 1958 Annual I. E. S. Technical Conference (11).

The readily comprehensible dual ratings may now be concisely presented as either the average for a cycle of numerical variations as a driver moves along the roadway; that is,

Average relative visibility	1.8
Average relative visual comfort	0.27

or, the more significant minimum effectiveness rating at any station or driver position along the representative roadway lines,

Minimum relative visibility	1.6
Minimum relative visual comfort	0.11

BCD Basis for Relative Visual Comfort Ratings

Visual comfort ratings are relative to the motorist-observer visual sensation, which would be at BCD (26, 27), the borderline between comfort and discomfort for the system

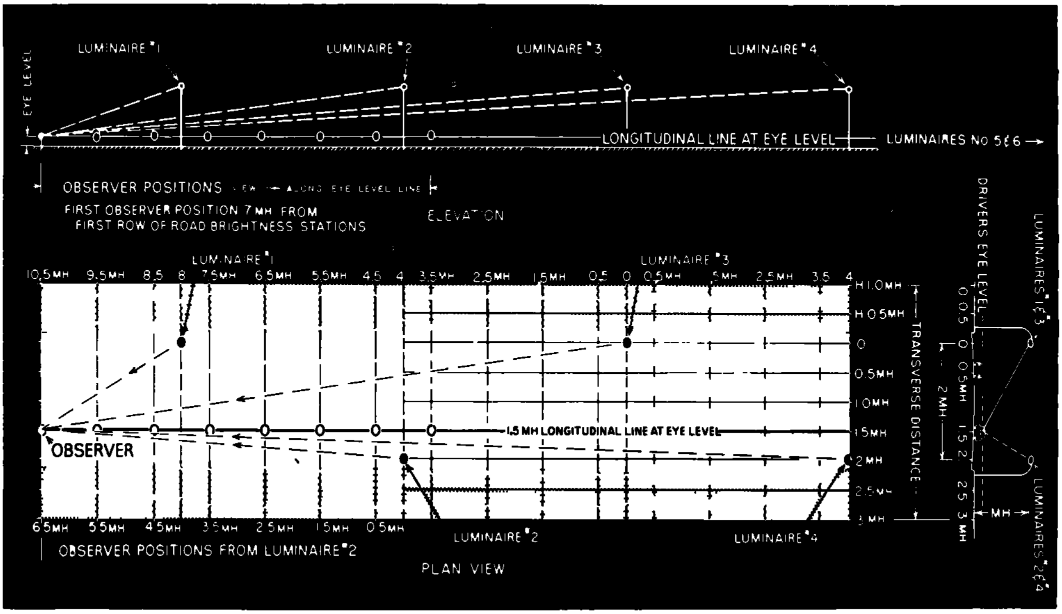


Figure 3. Combined relative comfort and percent loss of relative visibility due to disability veiling brightness is computed for a series of driver-observer positions along the longitudinal eye-level line, also assumed to be the driver's line of sight. This line is 25.7 ft below the luminaire light center. The driver eye-level line path is at transverse distance of 0.5 MH with respect to luminaires on the driver's right such as No. 4, and at 1.5 MH with respect to luminaires on the driver's left such as No. 3. The effect of inclined plane longitudinal eye-level candlepower from several luminaires, as far away as 15 MH, is included in computations.

of luminaires and the lighted roadway. A representative roadway lighting system is shown in Figure 3.

The BCD, designated as 1.0, is based on a geometric average of the observers used in laboratory studies at Case Institute by Putnam and his associates (20, 23). If a sufficient number of observers were uniformly distributed above and below the BCD average, it might be said that 50 percent of the observers would be comfortable driving under lighting having a rating of 1.0. Analysis of experimental data involving a representative number of observers will also indicate the percentage of motorists who would be comfortable driving under roadway lighting having a relative visual comfort rating of 0.27 or 0.11 (11, 12).

By rating roadway lighting in terms of relative visual comfort (11, 12) as shown in Figures 1 and 2, instead of discomfort, several additional advantages are obtained, including:

1. Positive approach to the problem of improving the quality of roadway lighting.
2. An ascending numerical scale whereby improvement is accompanied by a higher number.
3. Relative visual comfort is consistent with one of the principal objectives of motor vehicle transportation; that is, the improvement of all conditions affecting motorists comfort. For example:

    (a) "This construction is for your future comfort and safety. Drive carefully," featured on detour signs erected by the Virginia Department of Highways.
    (b) A statement by Joseph P. Barnett, Assistant Deputy Commissioner, U.S. Bureau of Public Roads: "Intangible benefits are possibly greater use of the highway at night, some increased ease of policing, pleasing appearance, and greater comfort in driving, although many challenge the last benefit."

4. This paper is regarded as the beginning of the provision of computed visual comfort ratings for roadway lighting. Therefore the most useful type of rating may be adopted.

Over-all comfort and driver conditions for night traffic use and movement along roadways include visual comfort. Relative visual comfort ratings for roadway lighting are essential.

Conditions for Computation Example

The example computations described in this paper are based on the following conditions:

1. Available data (2, 4, 7, 9, 11, 12, 13, 19, 20, 28).
2. A representative roadway lighting layout, shown in Figures 3 and 4 with luminaire spacing staggered 120 ft, or 4 MH. Luminaire No. 3 is considered the reference for longitudinal and transverse distance in MH (2, 3, 4, 11, 12, 13).
3. The two longitudinal roadway lines, at transverse distance of 0.5 MH and 1.5 MH, respectively, are assumed to be representative of the traffic-used pavement areas of the typical roadway. The driver eye-level path line is at 1.5 MH (2, 3, 4, 11, 12, 13).
4. Pavement-level brightness stations and driver-observer viewing positions are spaced along the roadway lines at the longitudinal distance of 0.5 MH (15 ft) apart. The pavement brightness stations are reference points. The driver-observer views the pavement brightness stations from a distance of 7 MH. This viewing angle is about 1.2 deg above the pavement surface. At the driver viewing angle the mid-vertical portion of the 1-ft diameter target, or obstacle, at longitudinal distance of 6 MH projects on to approximately line up with the pavement brightness station being viewed at a distance of 7 MH. This 6 MH versus 7 MH longitudinal distance, for obstacle-pavement brightness comparison, approximates field testing conditions (2, 3, 13).
5. Hypothetical luminaire inclined plane candlepower distributions (2, 3, 4) along representative longitudinal roadway lines, at pavement level, also at driver eye-level.

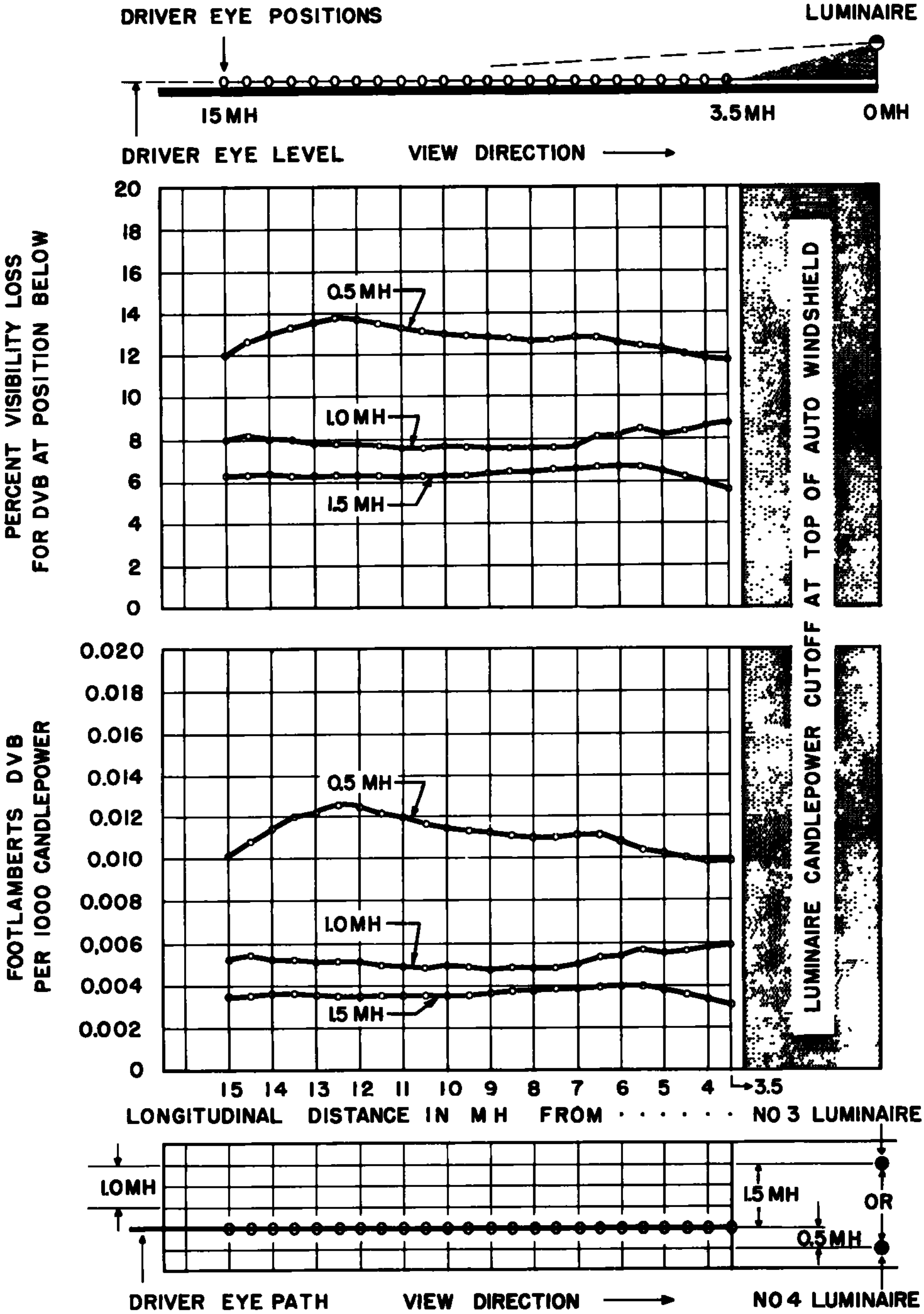


Figure 4. Disability veiling brightness (DVB) produced by 1,000 candlepower from a single luminaire, at a series of driver positions along longitudinal eye-level lines at the indicated distances to the driver's left and right, is shown in lower portion of this diagram. The luminaire is assumed to be cut off from driver view at longitudinal distances less than 3.5 MH. The percent loss in relative visibility shown in the upper portion of diagram is based on the corresponding DVB for 1,000 candlepower. The percent loss is not directly additive, as is shown in Figure 7.

The eye-level is 25.7 ft below luminaire light center, or 4.3 ft above the pavement. Such candlepower data may be estimated from an isocandle diagram (4, 9, 11, 13, 14, 29, 30) or obtained directly from a photometer (30). The data may be tabulated for pavement stations and eye-level positions at 0.5 MH intervals and may also be shown on rectangular or polar distribution diagrams (2, 3, 4).

6. Representative asphalt pavement, traffic-used for 8 years, 8 percent diffuse reflectance (28). Pavement brightness constants are derived from original data (3, 4, 13). Brightness measurement conditions were to ¼ scale (5) that is, 5-in. instead of 20-in. diameter source, 6¼-ft instead of 25-ft mounting height. Computation has converted data to 30-ft mounting height (MH) (4, 13). Luminaire candlepower and pavement brightness constants at longitudinal distances ranging from 10.5 MH on approach side to 8 MH beyond each luminaire, as shown in Figures 5 and 6.

7. Diffuse obstacle target, 8 percent reflectance, 1-ft diameter (4, 13, 28) using luminaire candlepower and obstacle brightness constants up to 10.5 MH beyond the luminaire.

8. At longitudinal distances less than 3.5 MH the light from each luminaire (4) is cut off from driver eye-level positions by the top of auto windshield. (For 1958 cars the average driver eye height was 49.8 in. and the top of auto windshield cutoff is at a vertical angle of 77 deg. For 1955 autos the cutoff was at 76 deg. There is little practical difference. In fact, the 1955 data may represent the average auto on the road.) Luminaire eye-level candlepower, brightness, and DVB constants are used for driver positions at longitudinal distances ranging from 3.5 MH to 15 MH (450 ft) on the approach side of each luminaire, as shown in Figure 7.

9. The projected luminaire source area is assumed to be 100 sq in. when viewed by the driver from position distances such as 15 MH. To be typical of generally used, modern roadway lighting luminaires, the projected area is appropriately and gradually increased to 130 sq in. at 3.5 MH viewing distance (2, 3, 13).

10. The average illumination on the pavement from the luminaire layout shown in Figures 3 and 10 may be about 1.3 footcandle. This is based on an assumed 25,000-lumen lamp (4) and the utilization (Fig. 8) of A.S.A. "Practice for Street and Highway Lighting" (9).

COMPUTING RELATIVE VISUAL COMFORT RATINGS

Relative visual comfort ratings (11, 12) such as those presented in Figure 2 involve comparison ratios of combined computed brightness for a system of luminaires. System ratings in terms of brightness ratios are most easily interpreted and understood. The brightness of the several luminaires comprising the foreground of a roadway lighting system as viewed by the automobile driver may be combined for each of a series of driver viewing positions, as indicated in Figures 3 and 9.

At each driver position $\Sigma \bar{B}$, the combined brightness sensation which the driver would experience from the lighting system luminaires if at BCD (26, 27), may be computed. The $\bar{B}$ brightness of each of the system luminaires is that which would produce the BCD sensation, or the visual sensation at the borderline between comfort and discomfort. $\Sigma \bar{B}$, the combined BCD brightness sensation at each driver position, may then be compared with ΣB, the actual combined brightness of the lighting system luminaires at corresponding driving viewing positions. Thus, the computed relative visual comfort rating is:

$$\text{Computed Ratio at each position} = \frac{\Sigma \bar{B}\text{, the combined brightness of system luminaires which would be at BCD sensation when mounted on the pole brackets with a specified field brightness including that of the pavement (fL)}}{\Sigma B\text{, the combined actual brightness of the system luminaires (fL)}}$$

The computation of both $\Sigma \bar{B}$, the BCD brightness, and ΣB, the actual luminaire brightness for comparison is based on luminaires in position, along the sides of the roadway (Fig. 3), rather than by conversion to the line of sight. Thus, future

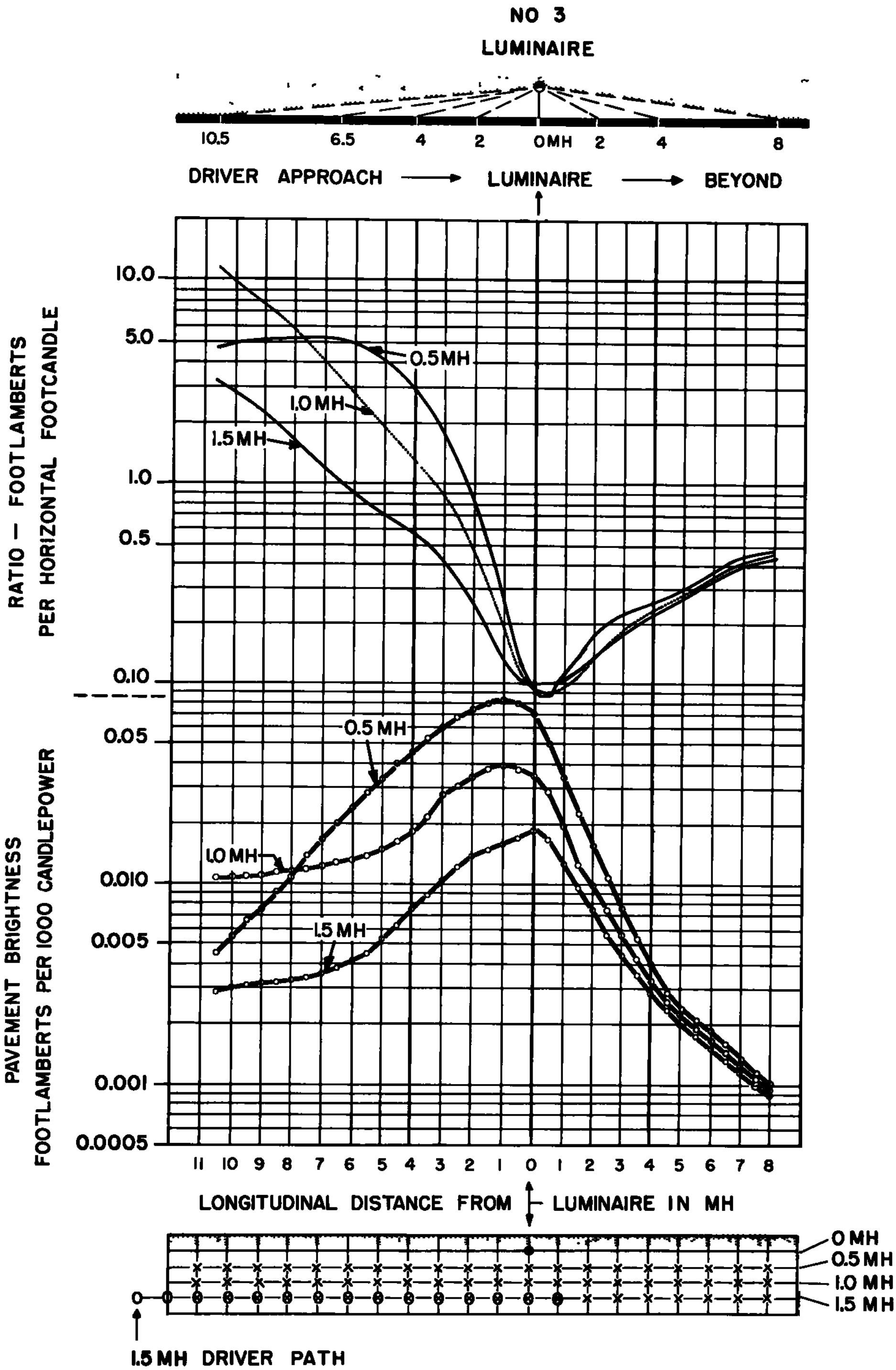


Figure 5. Pavement brightness produced per 1,000 candlepower from a single luminaire at driver's left is shown in lower portion of diagram. Longitudinal distance of driver observation from each pavement brightness station is about 7 MH, or 210 ft. Stations are 0.5 MH (15 ft) apart along the designated longitudinal roadway lines. Data are by Reid-Chanon (25) for traffic-used asphalt pavement. Curves in upper portion of diagram show the ratio of pavement brightness per horizontal footcandle produced by the luminaire at the pavement stations.

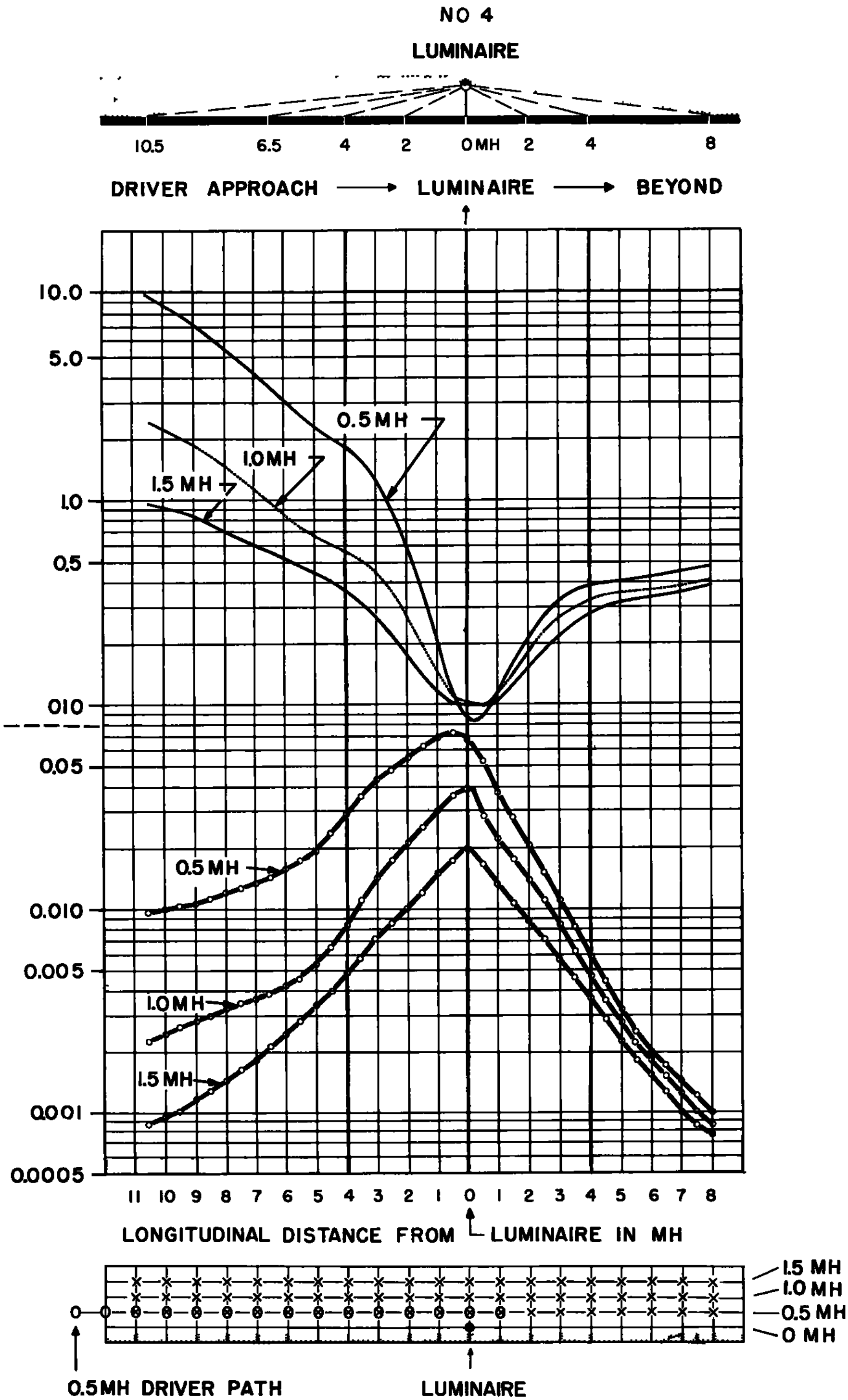


Figure 6. Candlepower from single luminaire on driver's right and at distances greater than 1.0 MH on approach side of luminaire is less effective than candlepower from No. 3 luminaire (Fig. 9) in producing pavement brightness at stations along the 1.0 MH line along center of roadway. With the staggered spacing used for the computation example, pavement brightness along 0.5 MH roadway line in this illustration is combined with that along 1.5 MH roadway line in Figure 5.

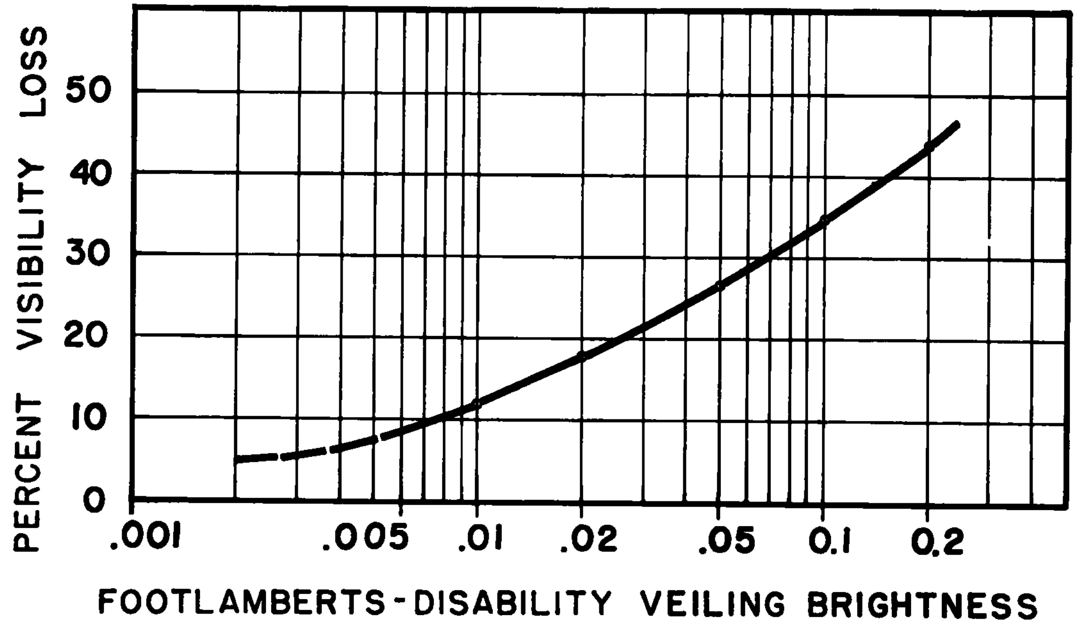


Figure 7. Percent loss in relative visibility increases with increase in disability veiling brightness (DVB) in footlamberts at the driver's eyes. Percent loss applies only to the relative visibility rating above 1.0 threshold. Percent visibility loss includes a Reid-Chanon (28) estimate as to effect of typical fluctuation for drivers traveling 25 to 40 mph.

modifications for improvement of the relative visual comfort ratios of lighting systems may be done directly by decreasing ΣB and B, the actual luminaire source brightness in comparison with $\Sigma \bar{B}$ or $\bar{B}$, the BCD computed for the system luminaires as mounted in position along the roadway.

Actual Luminaire Brightness Major Factor

The actual brightness, B, of each luminaire as viewed by the driver from each longitudinal position distance, is readily computed (11, 12) on the basis of candlepower toward each eye-level position and the projected area of the luminaire source:

$$B = \frac{\text{Luminaire candlepower toward each position}}{\text{Luminaire Source Area in square inches}} \times 452 \text{ (in footlamberts).}$$

The constant (452) converts candles per square inch to footlamberts. The actual luminaire brightness, B, may be reduced by increasing the source area or by diminishing, or cut-off shielding of, the high-angle candlepower toward eye-level driver positions at longitudinal distances from the luminaire greater than 3. 5 MH. At distances less than 3. 5 MH, the luminaire candlepower is usually cut off from driver view mechanically by the top of auto windshield (2, 3, 4, 11, 12, 13).

Exceptions to this principle often occur in residential street lighting where comparatively long (200- to 300-ft) luminaire spacings may be required for economy. To distribute lighting over long spacings the cutoff of luminaire candlepower may be at higher angles corresponding to longitudinal distances greater than 4. 5 MH. Such higher-angle candlepower distributions serve a special purpose. However, they involve

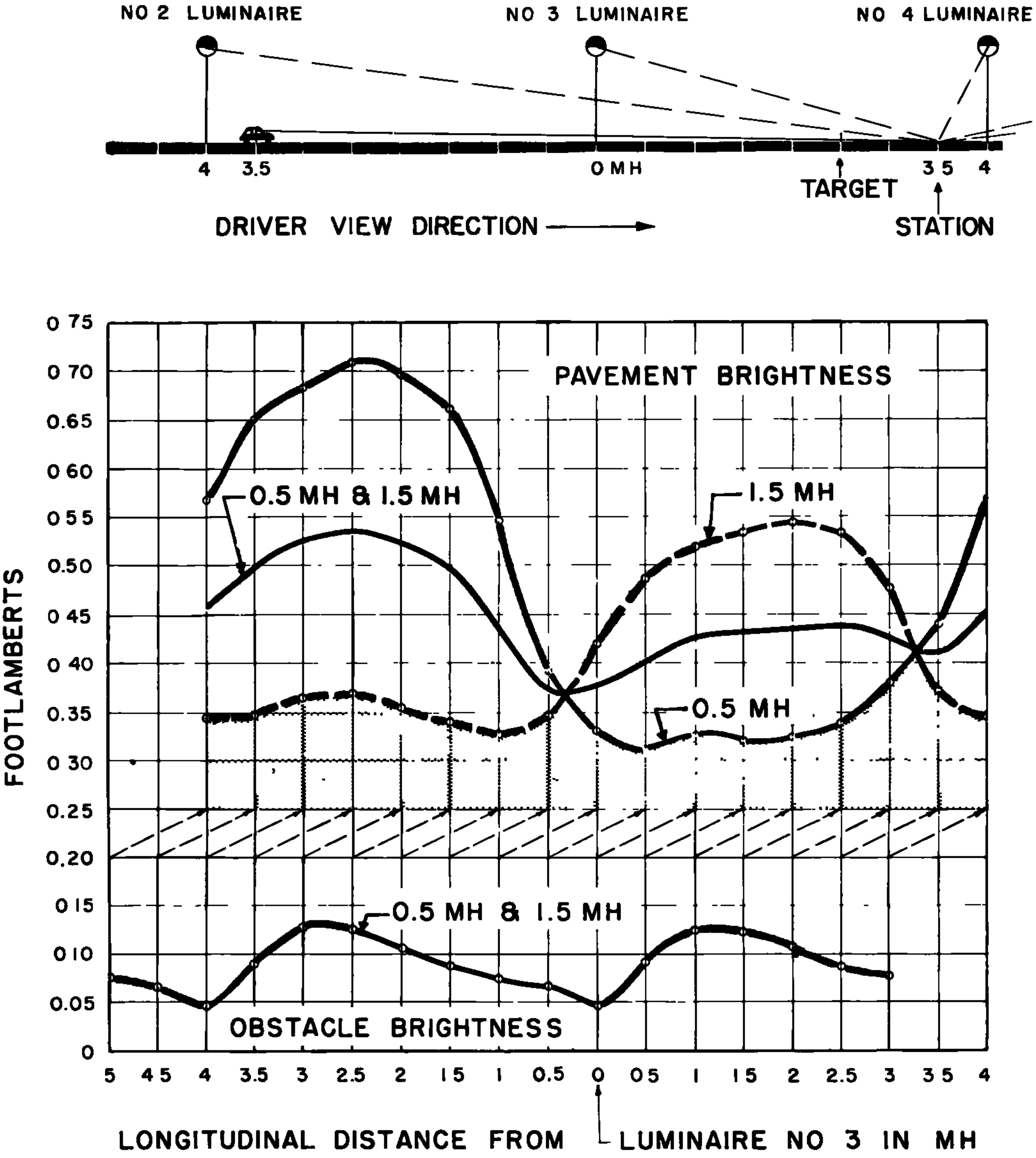


Figure 8. Combined pavement brightness produced by representative roadway lighting system varies at stations along the 0.5 MH or 1.5 MH roadway lines. Pavement brightness curve designated 0.5 MH and 1.5 MH is transverse average of brightness at the two stations at each longitudinal distance. As indicated by shading, minimum pavement brightness alternatively 1.5 MH then 0.5 MH should be most significant. Obstacle brightness is transverse average for stations along 0.5 MH and 1.5 MH roadway lines. For visibility obstacle brightness is correlated with pavement brightness at longitudinal distance 1.0 MH beyond obstacle brightness targets. Reflectance of pavement and of obstacle is the same, 8 percent.

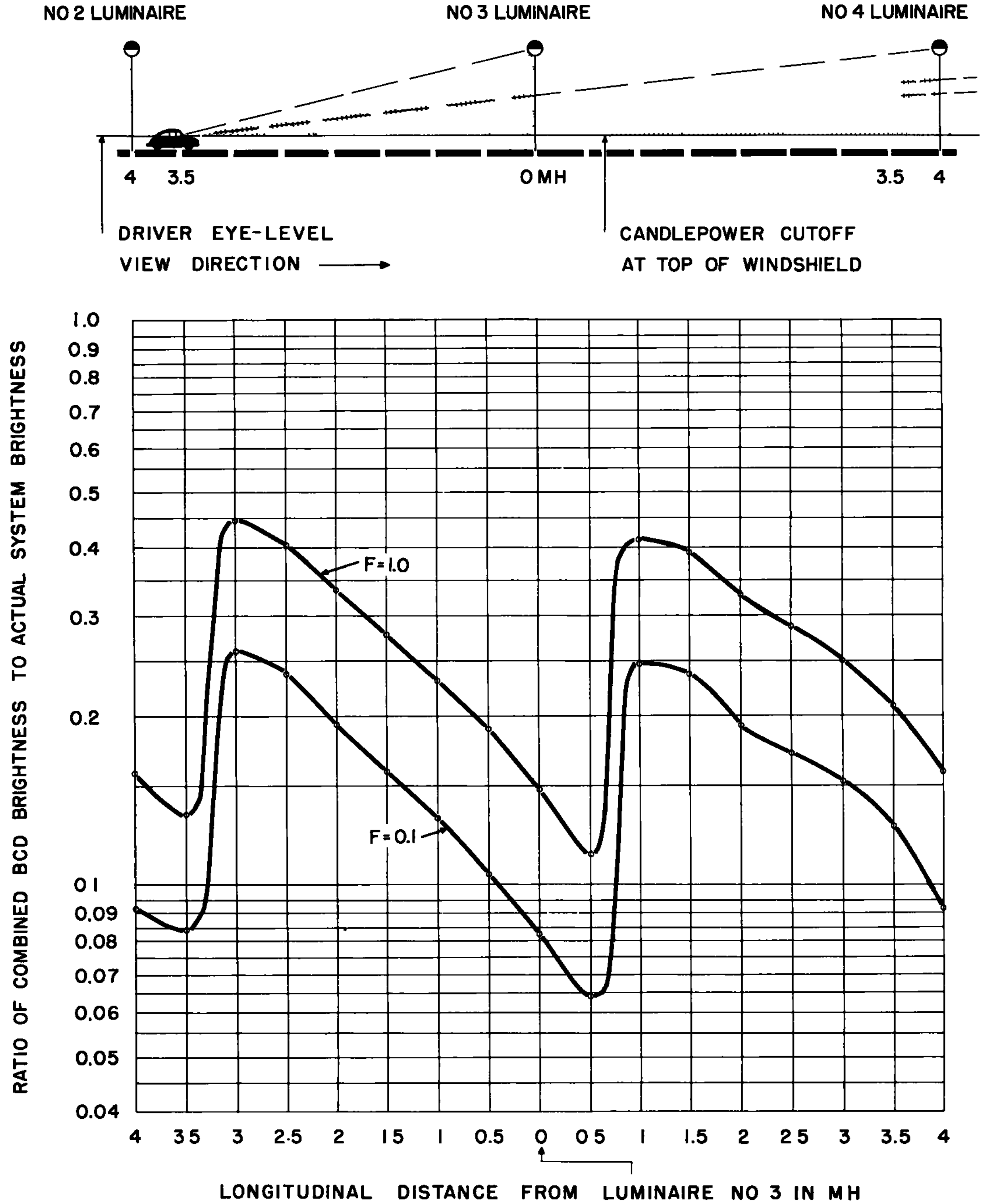


Figure 9. Relative visual comfort ratios vary with motorist position with respect to luminaires along roadway. Control of luminaire candlepower along eye-level line, and top-of-auto-windshield cutoff improve the visual comfort rating. Average and minimum ratings for field brightness (F) = 1.0 footlambert are 0.27 and 0.114, respectively. For F = 0.1 footlambert, average and minimum ratings are 0.16 and 0.064, respectively. As shown, higher average field brightness (F) = 1.0 footlambert, also improves minimum and average visual comfort at any position.

additional loss in visibility due to DVB, as well as a decrease in visual comfort.

ΣB, the combined actual brightness of several luminaires viewed by the driver from each eye-level position, is the direct summation of the brightness, B, of each luminaire in footlamberts. The number of luminaires included for each driver position should be the same as the number used for computation of the combined BCD, or $\Sigma \bar{B}$.

Field Brightness BCD Factor in Relative Visual Comfort

As indicated in Figure 9, the relative visual comfort ratio varies with driver position, also with the field brightness, or the average integrated brightness in the driver's field of view including the brightness of the pavement and objects thereon and near by. Along streets, building front facades and trees are often part of the field brightness. It is expected that in the near future integrating recording instrumentation will be available for measurement of the over-all field brightness for representative roadway lighting systems (21, 22).

Higher $\overline{BCD}$ luminaire brightness, either combined $\Sigma \bar{B}$ or individual luminaire brightness $\bar{B}$ and consequently improved relative visual comfort ratios, result from increasing the driver's field brightness, F. This usually includes higher pavement brightness. For example, the longitudinal average of the relative visual comfort ratios shown in Figure 9 over a cycle of driver positions is 0.27 for F = 1.0 footlambert. When F = 0.1 footlambert, the longitudinal average of ratios over a cycle of driver positions is lowered to 0.16. For F = 1.0 footlambert and F = 0.1 footlambert, the minimum relative visual comfort ratios, 0.114 and 0.064, respectively, are most significant and will probably be used as primary criteria in the future.

The average and minimum ratio ratings shown in Figure 2 are based F = 1.0 footlambert. The maximum and average pavement brightness for the lighting system is computed to be 0.71 and 0.45 footlamberts,. respectively.

Putnam-Case Institute Laboratory Data

The available laboratory (Fig. 10) data by Putnam and Faucett (20) and Putnam and Bower (19, 11) may be used in computing the BCD brightness (26, 27) for each of the system luminaires using the formula:

For F = 1.0 footlambert

$$\bar{B} \text{ or BCD} = P, \text{ Position factor} \times \left(\frac{0.68}{\omega^{0.60}} + 531 \right) \text{ footlamberts}$$

For F = 0.1 footlambert

$$\bar{B} \text{ of BCD} = P, \text{ Position factor} \times \left(\frac{0.43}{\omega^{0.62}} + 124 \right) \text{footlamberts}$$

Luminaire Source Size BCD Factor, ω

The portion of the foregoing formulas in parentheses is $\bar{B}_L$, or the BCD brightness of luminaires if on the horizontal line of sight, computed directly from the Putnam and Faucett (20) studies. However, ω, the size of each luminaire source, is computed for the installed pole bracket location. Expressed in steradians, ω is the visual solid angle subtended at the driver's eye position by the projected luminaire source area.

For an assumed field brightness and position, a somewhat higher $\bar{B}$ would result from decreasing the luminaire size. For example, ω in steradians is 0.00007 for a 130-sq in. luminaire source viewed from a driver position at 0.5 MH transverse and 3.5 MH longitudinal distance. With a field brightness of 1.0 footlambert, $\bar{B}_L$ (the BCD brightness on the line of sight) = 743 footlamberts. $\bar{B}$ in position on the pole bracket at a viewing angle of 16 deg has a BCD brightness of 743 x 1.95 (position factor) or about 1,500 footlamberts.

A smaller luminaire source will have a higher $\bar{B}$. For example, for a 100-sq in. source ω = 0.00005 steradians and $\bar{B}$ = 1,542. However, for the same luminaire candlepower from the smaller source B, the actual luminaire brightness is increased from

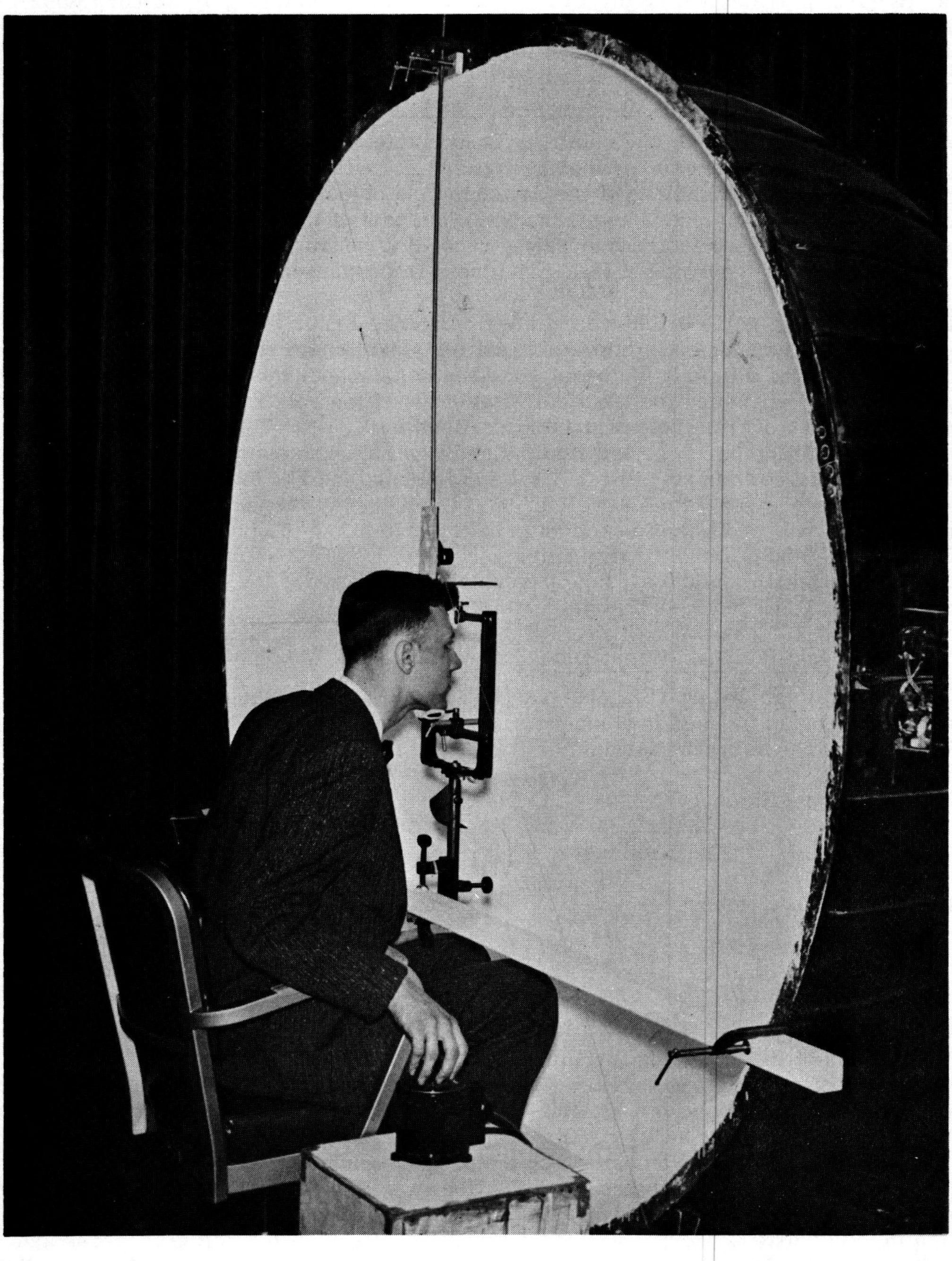


Figure 10. Computed relative visual comfort ratings are based on BCD data provided by laboratory studies over a period of seven years at Case Institute, Cleveland, Ohio. The study determines the BCD brightness on the driver's line of sight for variations of field brightness produced in the hemisphere as well as position factors for roadway lighting luminaire sources at 10, 20, and 30 deg above the line of sight.

34,804 to 45,245 footlamberts. The ratio $\bar{B}/B$ for the single luminaire decreases; that is, from

$$\frac{1,500}{34,804} = 0.042 \text{ to } \frac{1,542}{45,245} = 0.034$$

Thus, the relative visual comfort ratio, $\bar{B}/B$, and consequently $\Sigma\bar{B}/\Sigma B$, decreases with decrease in luminaire size if candlepower remains the same. This clarification should be of general interest. The gain is limited by the mathematical relation expressed in the formula. If, in practice, decreasing the size in steradians is accompanied by an increase in B, the actual luminaire brightness in footlamberts, the ratio $\bar{B}/B$ or $\Sigma\bar{B}/\Sigma B$ may be lowered, with decrease in relative visual comfort.

BCD Luminaire Position Factors

The position factors derived from the recent Putnam and Bower data (19) vary as shown in Figure 11 for the two field brightness conditions, and for each angle θ, the viewing angle between the driver's horizontal line of sight and the luminaire. Angle θ decreases with increase in longitudinal distance of the driver's viewing position with respect to the luminaire. The greater the increase in driver viewing angle, θ, or the farther the luminaire sources are off the line of sight, the greater the increase in position factor and the larger the improvement in BCD brightness $\bar{B}$, or $\bar{B}/B$ ratio, and the relative visual comfort.

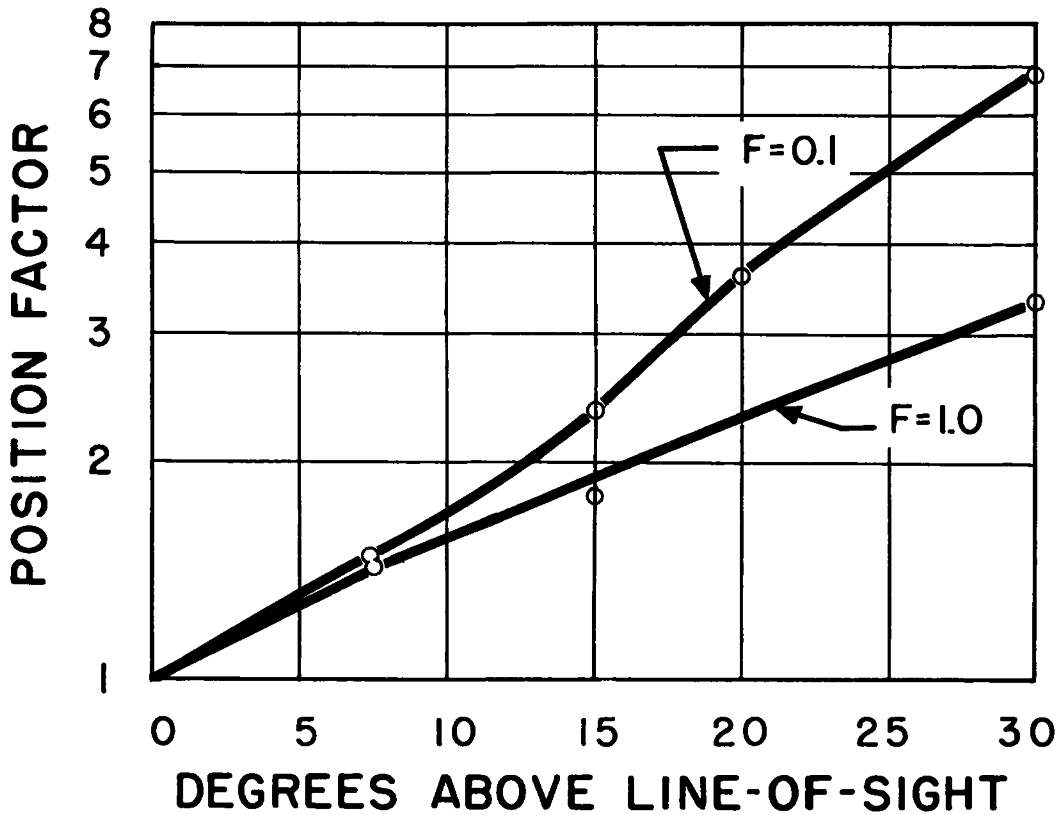


Figure 11. Luminaire position factors, used in computing $\bar{B}$, or the BCD sensation brightness for the system luminaires, are derived from Putnam and Bower 1957 data (19) for field brightness, F = 0.1 footlambert, and F = 1.0 footlambert. $\bar{B}$, or the BCD brightness, of each luminaire size and viewing angle θ, corresponding to the driver position, is computed by multiplying the brightness of a source of the same size which is at BCD on the line of sight by the position factor.

$\bar{B}$, or BCD brightness, of several luminaire sources viewed by the driver are combined by direct addition at each driver position for $\Sigma\bar{B}$. The visual comfort rating for each driver position, as shown in Figure 9, is the ratio $\Sigma\bar{B}/\Sigma B$.

Fluctuation in Brightness and Relative Visual Comfort

The fluctuation in relative visual comfort for a driver traveling along under the roadway lighting system is readily apparent in Figure 9. The space relation of fluctuation valleys or minimum visual comfort is equivalent to the luminaire spacing (4 MH, or 120 ft). This spacing may be readily converted to time interval based on an assumed vehicle speed (2, 3, 4); that is, 2-sec intervals at approximately 40 mph. The dynamic effect of fluctuations is one of the most important of the many factors in relative visual comfort under night driving conditions on which increased data are highly essential.

Correlation with Outdoor Relative Visual Comfort Ratings

The computed minimum comfort rating of 0.114 (Figs. 2 and 9) appears to be consistent with an outdoor test rating of 0.19 for a full-scale roadway lighting system of luminaires equipped with 15,000-lumen filament lamps, as compared with the equivalent at about 25,000 lumens for the hypothetical luminaires used in computations. The 0.19 rating has been derived from outdoor night tests conducted at Hendersonville, N. C., using the new Guth evaluator (31, 32, 11, 12).

The outdoor test relative visual comfort rating of 0.19 is based on a geometric mean of 480 observations, or 48 relative comfort ratios, by 21 observers. The observer position with respect to luminaires was that expected to approximate minimum comfort. Four luminaires spaced 100 ft staggered were used in the outdoor studies. The mirrored brightness of the comparison source of the Guth evaluator shown in Figure 12 is viewed against a concrete pavement background.

During 1959 it is expected to present reports on the outdoor relative visual comfort studies being conducted with the aid of the Guth evaluator. Numerical ratings for the visual comfort quality of roadway lighting are an impelling objective which fully justify such night work.

PERCENT LOSS OF RELATIVE VISIBILITY DUE TO ΣDVB

Another example of the desirability of controlling, shielding, or cutoff of luminaire candlepower from eye-level driver positions of 3.5 MH and more is shown in Figure 13. At each driver eye-level position there is also an appreciable percent loss of relative visibility due to the combined DVB (disability veiling brightness) from the lighting system luminaires. The fluctuation indicated in Figure 13 is significant.

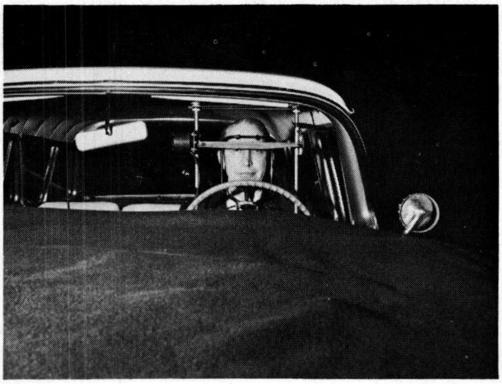
The same (Fig. 3) luminaires, driver positions, distances, and candlepower along the driver's longitudinal eye-level line are involved, as previously used in computing the actual and BCD brightness of luminaires for relative visual comfort ratings.

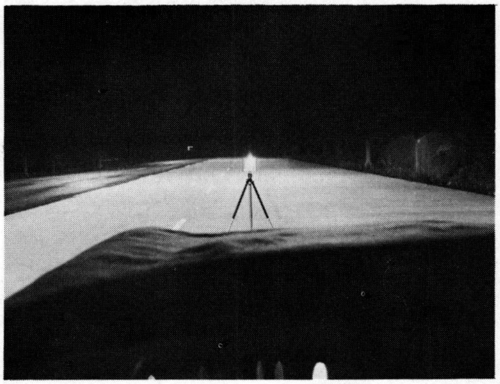
To compute DVB for each luminaire-driver position, constants (13, 11, 12) are now available in terms of DVB per 1,000 candlepower. The constants include driver viewing angle θ and distance from each luminaire in accordance with the formula (2, 3) suggested by the Technical Advisory Committee of IERI. Using constants the formula is simplified to

$$DVB = \frac{\text{Luminaire Eye-level Candlepower}}{1,000} \times \text{DVB constant}$$

The combined ΣDVB for each driver eye-level position from the system luminaires is summed up by direct addition. Then the resultant percent loss in relative visibility for the combined ΣDVB at each driver position is obtained from Figure 7, a curve presenting data estimated by Reid-Chanon (4, 28, 13) studies which included a factor for the increased loss due to fluctuation for drivers traveling at speeds of 25 to 40 mph.

The combined ΣDVB and resultant percent loss in relative visibility produced by the lighting system luminaires at successive driver positions along the representative eye-level line is shown in Figure 13.





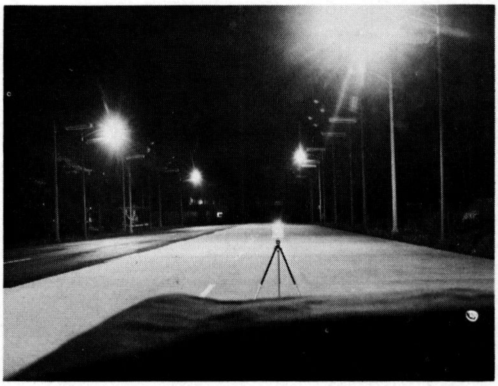


Figure 12. Computed relative visual comfort ratings are consistent with night studies involving more than 400 observations being conducted on outdoor laboratory street at Hendersonville, N.C. using Guth evaluator (31). Upper left photo shows observer in test automobile with evaluator headrest shield in down position for appraisal of BCD brightness. Resultant cutoff of luminaires and observer's field of view is shown in upper right photo. Lower right photo shows driver-observer's view when shield on evaluator headrest is rotated upward to expose observer's eyes to combined brightness of system luminaires. For evaluation of system luminaire brightness, upper left and lower right test conditions are alternated automatically. Observer adjusts brightness of comparison source reflected in a mirror, on line of sight, for an impact sensation judged to be equivalent to combined brightness of luminaires.

The average loss of relative visibility for the computed roadway lighting system is 24 percent based on a longitudinal cycle average of DVB. This 24 percent loss is considerably less (one-half to two-thirds) than the loss which was ascribed to some roadway lighting systems as of 20 years ago. The maximum loss of 35 percent at one position is most significant in plans for future progress.

Figure 4 shows DVB constants for successive driver eye-level line positions at transverse distances of 0.5 MH, 1.0 MH, and 1.5 MH with respect to a single luminaire. The accompanying percent loss of relative visibility in the upper portion of Figure 4 is obtained from Figure 7. Percent loss, which does not increase directly with increase in DVB, is the preferred but not directly additive criterion. As previously pointed out (4) the DVB per 1,000 candlepower and accompanying percent relative visibility loss due thereto, as shown in Figure 4, does not appreciably decrease with increase in driver distance from the luminaire. A glance at this illustration shows the desirability of controlling cutoff of candlepower distribution at high angles toward driver positions at longitudinal distances greater than 3.5 MH.

Integrating instrumentation for measuring and recording the DVB as the driver proceeds along a roadway is under development by Fry (21, 22). There is urgent need for additional data on the reduction in visibility effect of disability veiling brightness including the dynamics of driver movement along a roadway.

COMPUTED RELATIVE VISIBILITY RATINGS

The computed relative visibility ratings and data with respect to visibility factors involve combining the effect of each of several luminaires on a succession of brightness stations along the pavement roadway lines as viewed from related driver positions along a representative roadway (Fig. 14). Thus, some of the variations and fluctuations with driver movement along the roadway are revealed (4, 5, 10, 13, 28, 33).

The combined net relative visibility correlated with the pavement brightness stations

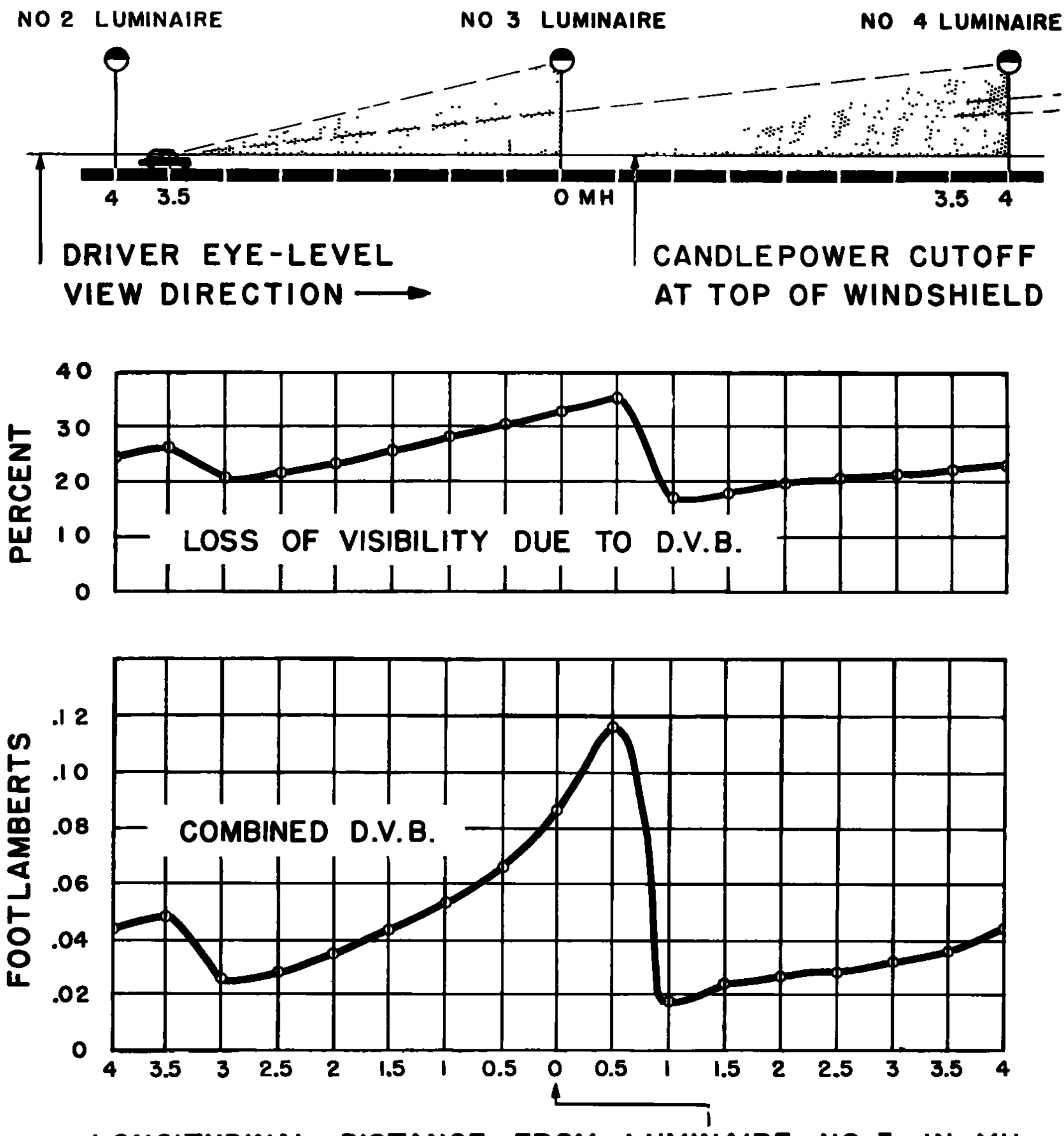


Figure 13. Percent loss in relative visibility due to combined disability veiling brightness, Σ DVB, from lighting system luminaires varies with driver position along roadway due to (a) control of luminaire candlepower, (b) driver viewing angle, (c) distance from each luminaire, and (d) top-of-auto-windshield cutoff. Longitudinal average, Σ DVB, is 0.044 and corresponding average loss in visibility is 24 percent. Largest loss (35 percent) occurs when driver-observer is approaching luminaires on his right, such as No. 4, just prior to top-of-auto-windshield cutoff.

along the 0. 5 MH, also the 1. 5 MH longitudinal roadway lines, is shown in Figure 15, in which the shaded area under the lowest ratings for relative visibility, alternately 1. 5 MH then 0. 5 MH, is significant because it shows the minimum visibility at each successive pavement station along the respective roadway lines. The 1. 6 minimum rating at any position is a proper criterion.

The relative visibility for the 1. 5 MH and 0. 5 MH roadway lines is the transverse average of the relative visibility rating for the two pavement brightness stations at each longitudinal distance. This rating is obtained by transversely averaging the weighted pavement brightness at each longitudinal distance, then applying the driver's loss of relative visibility due to DVB to obtain the net transverse average relative visibility at each longitudinal distance or station.

The computed relative visibility ratings for each station as shown in Figure 15, and the longitudinal average of 0. 5 MH and 1. 5 MH ratings shown in Figure 2, are based on the scale of the currently available Luckiesh-Moss low-range visibility meter used in the visibility studies by Reid and Chanon (28). They defined the threshold as follows:

"A visibility of 1. 0 (as applied to seeing for safety on streets) is defined as bare discernment of a 1-ft obstacle of zero brightness, on a background having a substantially uniform brightness of approximately 0. 01 footlambert, by a stationary observer with normal vision standing 200 ft away at fixed attention with no source of direct glare in the field of view. When an obstacle of this description is so discerned through the Luckiesh-Moss Visibility Meter the reading is unity."

Obviously, a rating of 1. 0 is for all practical purposes a base reference or threshold

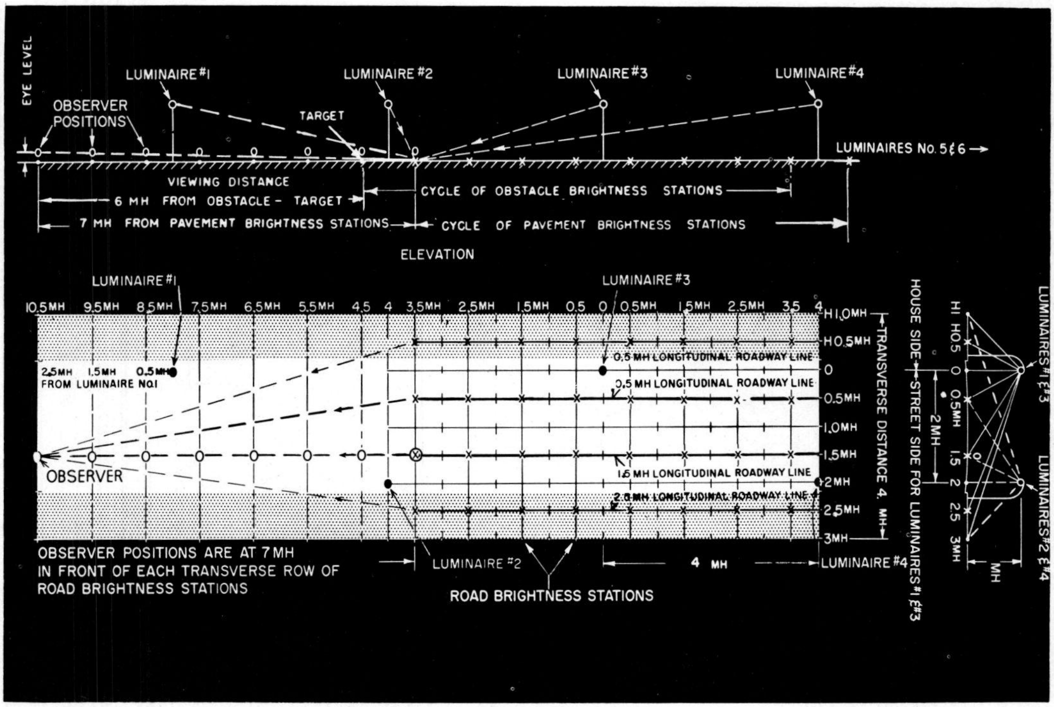


Figure 14. Representative roadway, lighting layout, and conditions for computation of relative visibility, and pavement and obstacle brightness. Driver-observer movement and view-direction is from left to right along 1.5 MH roadway line. Pavement brightness stations and luminaire No. 3 are considered basic reference points. Stations along longitudinal roadway lines at transverse distance of 0.5 MH and 1.5 MH are assumed representative of traffic-used portion of roadway. Targets for obstacle brightness at 4.5 MH longitudinal distance on the approach of luminaire No. 3 are seen in contrast with pavement brightness 1.0 MH beyond target, at 3.5 MH.

to work above. Of interest in this respect are the following excerpts from discussion by Fry (21, 22) referring specifically to the Luckiesh-Moss visibility meter:

"The simplest appraisal of visual tasks is threshold discernment; . . . a level is finally reached at which the task can no longer be identified. This is the . . . level where discernment of a given visual task begins. (This is somewhat like the boiling point of a steam boiler—a 'threshold' of temperature which must be reached before the useful pressure-producing function of the boiler can even begin.) Clearly, threshold is

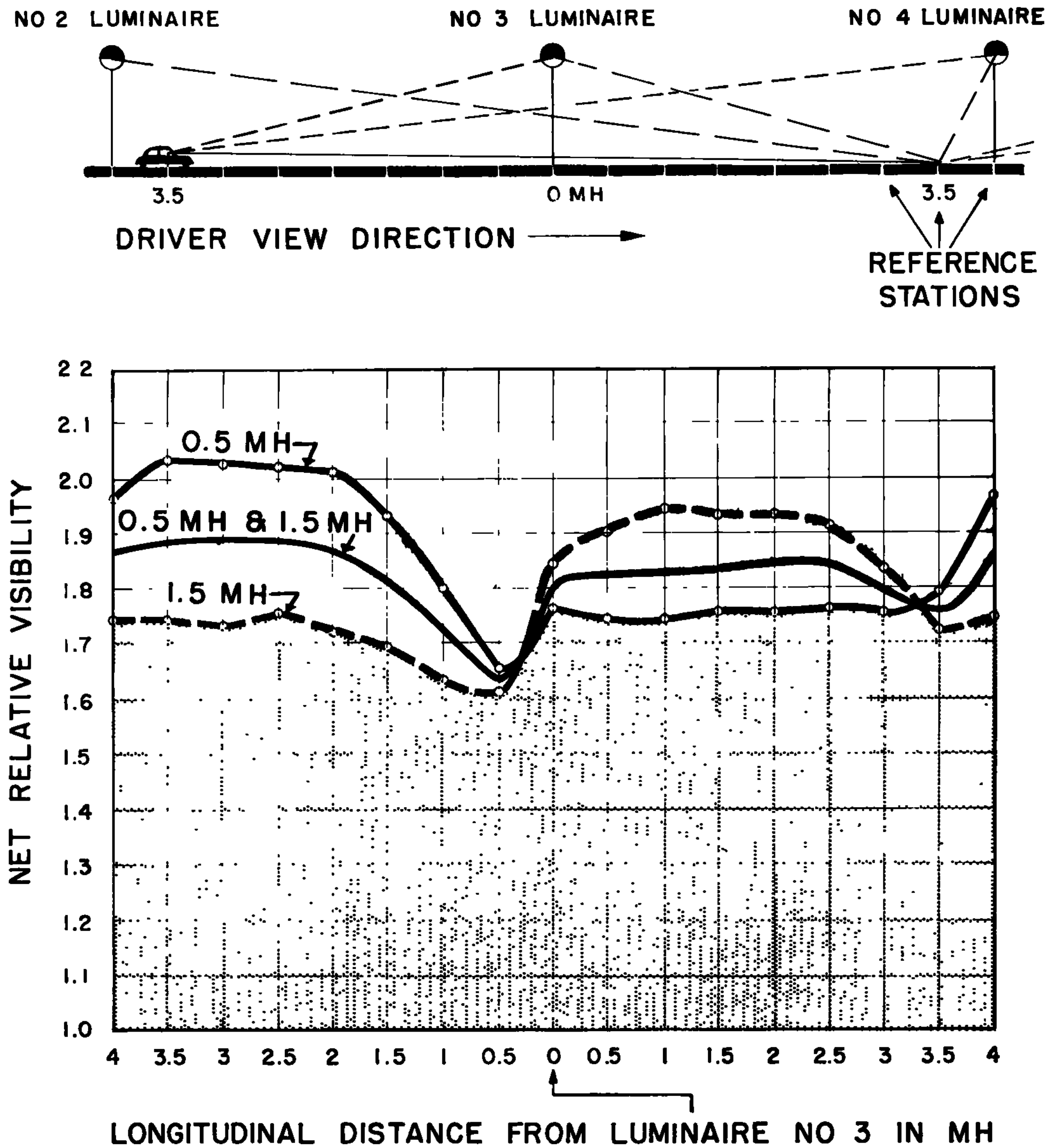


Figure 15. Combined net relative visibility produced along roadway by lighting system varies with longitudinal and transverse location of pavement brightness stations which driver is viewing from a distance of 7 MH. Relative visibility is shown for each roadway line, 1.5 MH or 0.5 MH. Shading shows that significant minimum ratings for each longitudinal distance alternates between 1.5 MH and 0.5 MH roadway lines. Relative visibility designated 0.5 MH and 1.5 MH is computed after obtaining transverse average of combined weighted pavement brightness at each longitudinal distance.

not a desirable or even a minimum working value . . . ."

Blackwell Visibility Rating Relative to That Required for Visual Task

A different approach to the problem of rating or specifying roadway lighting may result from studies now being conducted by Blackwell and associates (25), whose work on roadway lighting is being sponsored by the Illuminating Engineering Research Institute at the request of the IES Committee on Roadway Lighting. He has developed a system for evaluating the requisite brightness for seeing various objects on the roadway when the driver has a time interval of one-fifth second for perception under dynamic moving eye conditions. Under specific lighting and pavement conditions the results of Blackwell's studies might be expressed in terms of requisite footcandles. It is hoped that the results will also be expressed in terms of the relative visibility required for representative night driving conditions.

An instrument called the visual task evaluator (11) has been developed by Blackwell and Pritchard. Using this instrument they are measuring the lighting and brightness really necessary for driver seeing on the roadway at night.

The Blackwell roadway lighting research studies are desirable and essential to knowing how much brightness or visibility is really necessary for quick and certain discernment on the roadway at night. It may be that most roadway lighting provides less visibility than that required. One of Blackwell's first night roadway lighting studies was reported by newspapers (34, 35) and he was quoted as saying that as expected, more and better street illumination is needed to insure maximum safety to drivers and pedestrians; typical city street lighting is not good enough for driver vision and pedestrian safety even at 35 mph; and the road surface is very important, its blackness and shininess being basic factors in seeing objects upon it.

Apparently the brightness contrast for visibility produced by typical roadway lighting systems may be a fraction of that required for the driver's visual task.

The requisite visibility may be that essential for the driver-observer's visual task, based on a specific dynamic condition. In night driving a typical condition may involve high-speed movement of both the target and the observer. Furthermore, part of the driver's attention and sense capacity may be otherwise occupied. The actual dynamics and typical driver conditions should be estimated and included for rating purposes. It is already late to be starting the comprehensive investigation and appraisal of seeing under typical dynamic night driving conditions.

Should Be Provided at Any Traffic-Used Roadway Position

The requisite visibility or brightness should be provided at any traffic-used station or driver position along the roadway. Figure 2 and subsequent illustrations show how relative visual comfort, relative visibility, and factors thereof, vary with station or position along the roadway. It is also obvious that the seeing provided should be the minimum in service at any time with respect to luminaire maintenance or lamp life. Also, factors will be necessary for variations in conditions, such as merging traffic locations and intersections.

Relative Visibility Ratings Also Essential

It is hoped that the requisite level of lighting, brightness, and visibility which evolves from Blackwell's studies may be accompanied by a method for rating the relative visibility effectiveness of other superior or inferior lighting systems. The requisite level may be established as a datum or reference level of visibility. Specific roadway lighting systems will provide visibility effectiveness which is higher or lower relative to the datum or requisite level. Thus, relative-to-requisite ratings would be useful in determining how good or how inadequate the visibility effectiveness of a roadway lighting system may be.

It is hoped that the requisite level of relative visibility which evolves from Blackwell's studies can be correlated with the scale of the Luckiesh-Moss visibility meter, which is relative to threshold or bare discernment.

Other valuable work in the visibility appraisal and measurement of roadway lighting has been done by Finch (24). One of the components used in the Blackwell visual task evaluator was developed by Finch for use in the University of California visibility meter.

Along with new instrumentation for requisite and relative visibility scales under development, correlations are necessary for the effect of the visibility factors such as pavement brightness, obstacle brightness, disability veiling brightness, and fluctuations thereof. Such correlations will facilitate computation of ratings for the effectiveness of roadway lighting and the over-all improvement of night driving conditions.

The visibility efficiency of roadway lighting has been increased appreciably by developmental use of the data and instrumentation available during the past twenty years.

PAVEMENT AND OBSTACLE BRIGHTNESS

Pavement brightness and obstacle brightness are positive factors in roadway lighting visibility or discernment. Figure 8 shows the computed combined brightness (ΣPB and Σ OB) of these factors at successive stations along a representative roadway lighting system.

The pavement brightness at each station produced by the roadway line candlepower from each luminaire is computed using constants (11, 12, 13) per 1,000 candlepower which have been derived from Reid-Chanon data (4, 28). Using these data, the pavement brightness computation per luminaire at each station is simplified:

$$\text{PB (Pavement Brightness)} = \frac{\text{Luminaire Candlepower}}{1,000} \times \frac{\text{Pavement Brightness}}{\text{Constant per 1,000 cp}}$$

The formula for obstacle brightness (13) computation is similar:

$$\text{OB (Obstacle Brightness)} = \frac{\text{Luminaire Candlepower}}{1,000} \times \frac{\text{Obstacle Brightness}}{\text{Constant}}$$

The combined pavement and obstacle brightness (ΣPB and ΣOB) at each station is the summation of the effect of the roadway line candlepower from the several luminaires significantly contributing to brightness at each roadway station. In Figure 8 the combined pavement brightness along the representative 0. 5 MH, also the 1. 5 MH, roadway lines is shown separately. The shaded minimum for these two roadway lines, alternately 1. 5 MH then 0. 5 MH, may be significant.

The 1. 5 MH and 0. 5 MH pavement brightness is the transverse average of the combined pavement brightness at each longitudinal distance along the two roadway lines.

The 0. 5 MH and 1. 5 MH obstacle brightness shown in the lower portion of Figure 8 is the transverse average of the target brightness along the two roadway lines at each longitudinal distance. However, there are no instances in this example where the brightness of the obstacle is as high as that of the pavement. Hence, Figure 8 provides an interesting comparison of the effectiveness of luminaire candlepower in providing pavement brightness versus obstacle brightness.

Compare the 0. 5 MH and 1. 5 MH roadway line pavement brightness with the 0. 5 MH and 1. 5 MH obstacle brightness. The corresponding averages over a longitudinal cycle of stations are 0. 45 footlamberts pavement brightness versus 0. 09 footlamberts obstacle brightness. Both the pavement surface and the target obstacle surface have diffuse reflectance of 8 percent. The pavement brightness for silhouette discernment is higher because of the specularity effectiveness of the pavement in reflecting the incident candlepower projected on it from the luminaires. Also, as will be seen from Figures 5 and 6, the pavement brightness is produced by the candlepower distribution beyond the luminaire as well as that on the driver approach side of the luminaire. The obstacle brightness utilizes only the candlepower distribution beyond the luminaire.

Modern roadway lighting uses special design techniques to produce good seeing with typical traffic-used pavement surfaces (28). Due to advances in luminaire development and use of data which have been available, the pavement and obstacle brightness produced by modern roadway lighting systems is appreciably higher (2. 0 to 2. 5 times) than that obtained from some comparatively inefficient roadway lighting of 20 years ago.

Occasionally in roadway lighting practice there are instances in which the surfaces of an obstacle, such as an automobile, are specular or have high relfectance so that discernment is by glint, reverse silhouette, or surface detail. Such objects provide a safety factor increase in visibility.

Figures 5 and 6 show the comparative pavement brightness effectiveness of longitudinal roadway line candlepower distribution from luminaires located on the driver's left and right, respectively. The pavement brightness constants per 1, 000 candlepower from the luminaire are shown along three roadway lines—0. 5 MH, 1. 0 MH, and 1. 5 MH. The transverse distances are in relation to the luminaire.

Shown in the upper portion of Figures 5 and 6 are the pavement brightness constants per horizontal footcandle. These data are included primarily for information and possible alternative computations. The pavement brightness produced per horizontal footcandle depends on the direction of incident light from each luminaire in relation to a driver-observer viewing position. The result of illumination at each station from each luminaire should be computed separately, then combined.

Nomographs for Computation

Figures 16 and 17 give useful nomographs for determining the gross and net relative

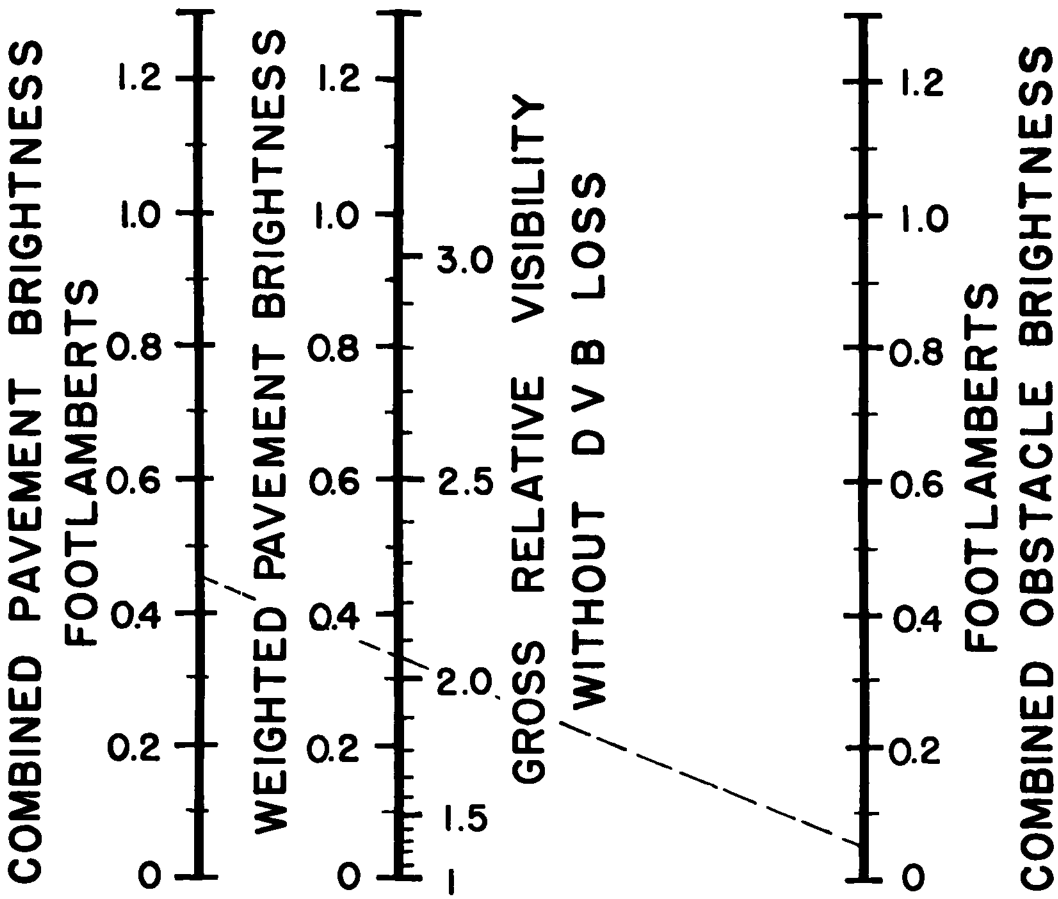


Figure 16. Nomograph for computing gross relative visibility. Combined pavement brightness at a station (left) is connected with combined obstacle brightness 1.0 MH ahead of the pavement brightness station (right) to get weighted pavement brightness and gross relative visibility, without DVB loss. Example is for pavement brightness station on the 0.5 MH roadway line at longitudinal distance 4 MH ahead of luminaire No. 3.

visibility using pavement, obstacle, and DVB brightness data. These illustrations help visualize the combination of factors involved in relative visibility ratings.

Compile Ratings for Other Representative Roadway Lighting Layouts

Relative visual comfort and relative visibility ratings should be computed and compiled for representative layouts of roadway lines, and driver-observer eye position lines with typical luminaire sizes and candlepower distributions. Then, by interpolation, ratings may be estimated for other similar lighting systems being considered for installation. Figure 18 shows example layouts that may be advantageously computed. The top layout shows one-side luminaire spacing, typical for portions of the Interstate Defense Highway System.

When computing ratings the spacing of any layout may be varied as desired. If the spacing is in multiples of 0. 5 MH, the foregoing data, constants, and method are most easily applied; that is, spacings of 90 ft, 105 ft, 120 ft, 150 ft, 195 ft, etc.

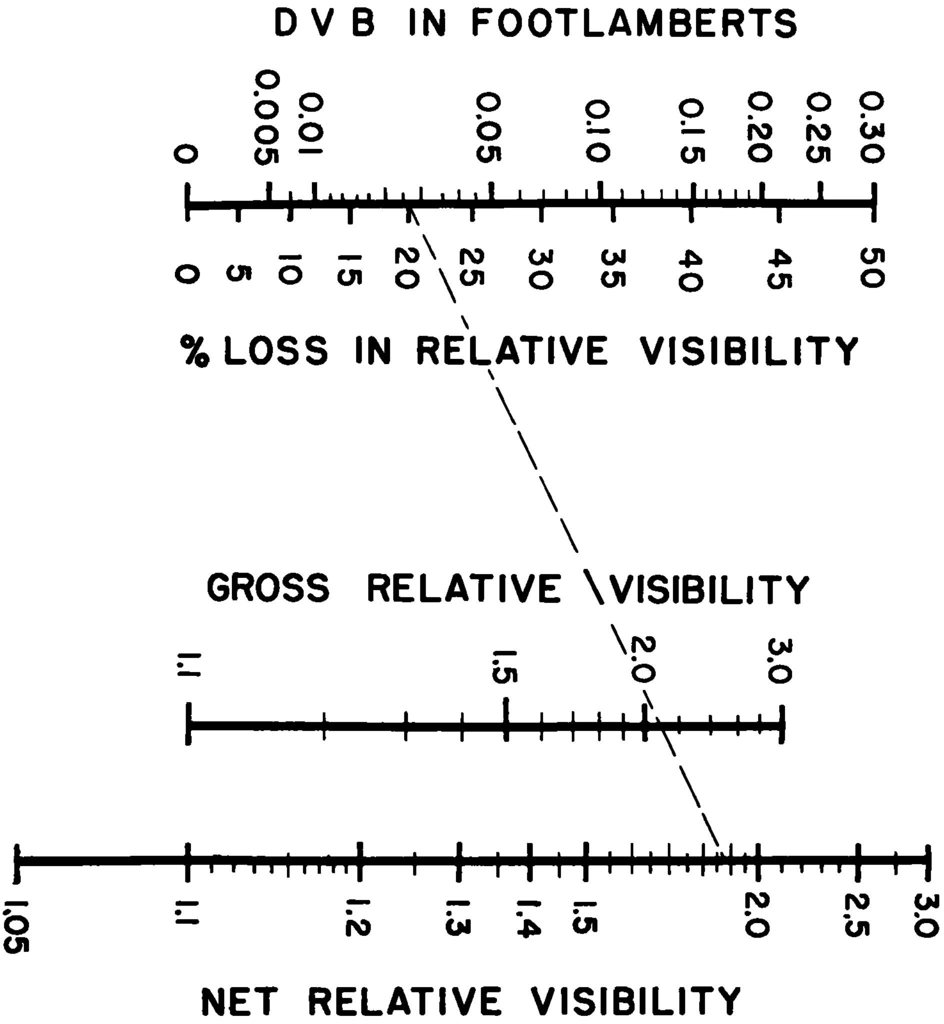


Figure 17. Nomograph for computing net relative visibility. Disability veiling brightness, DVB, and percent loss (left scale) are connected with corresponding gross relative visibility (middle scale) to give net relative visibility (right scale). Net and gross relative visibility are at pavement brightness station described in Figure 16. DVB, and percent loss, are for the driver's viewing position 7 MH ahead of brightness station, or at 3 MH on Figure 13.

ADVANTAGES OF COMPUTED RATINGS

Computation of simplified seeing factor ratings has many advantages including:

1. Prediction of the effectiveness of roadway lighting in readily understandable terms of roadway user benefit.
2. Application and luminaire performance variables may be explored, evaluated, and controlled in design for optimum over-all efficiency.
3. Comprehension of objectives will be improved, complexity reduced, and standardization possibilities revealed.
4. Progress in dynamic visual research under night driving conditions will be encouraged by a method for the use of the laboratory and field data now available and that which will be made available in the future.
5. Time will be conserved. Computation facilitates ratings without the delays, uncertainties, and interferences that may arise in field testing. The use of high-speed computer techniques is obviously feasible and desirable. With example ratings available, other ratings may be estimated by interpolative judgment.

SUMMARY

Better night motor vehicle transportation is an objective which warrants combined use of the best research data and engineering skills.

There has been significant progress in visibility efficiency and relative visual comfort in present-day roadway lighting systems compared with 20 years ago. Development work and data analysis have made this improvement available to designers and the motoring public.

Many more data, accumulated at a greatly accelerated pace, are essential to implement further progress in night motor vehicle transportation. Attention, observations, appraisals, estimates, and evaluations of the night traffic and seeing benefit of roadway lighting by designers and other highway personnel will aid this effort greatly.

Seeing benefit ratings and traffic benefit ratings will indicate how much better good roadway lighting is when compared with poor roadway lighting— or none.

Traffic benefit ratings also will help

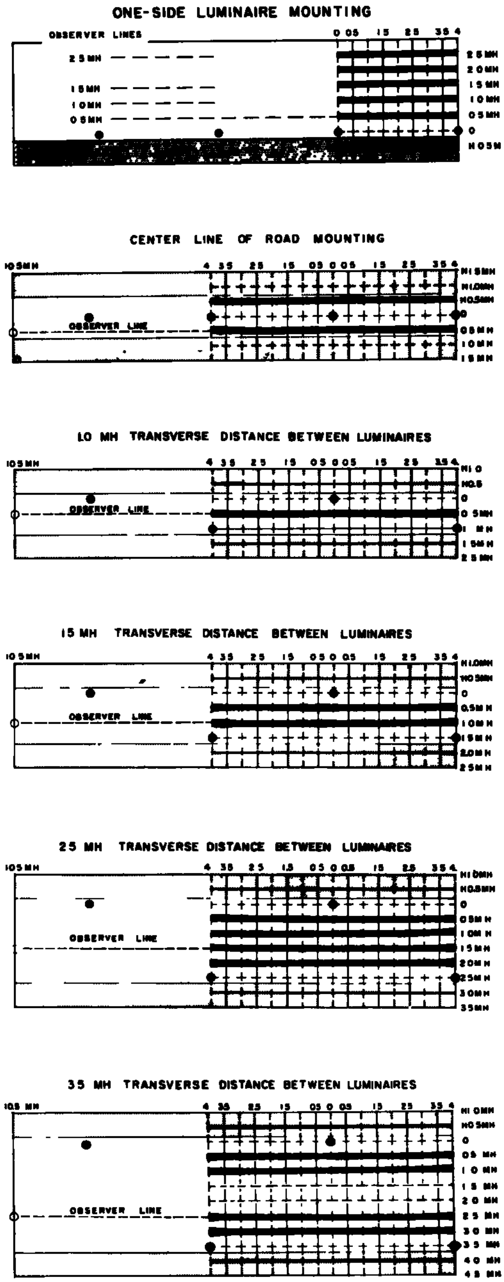


Figure 18. Relative visual comfort and relative visibility ratings should be computed and compiled for representative layouts of roadway lines, and driver-observer eye position lines involving typical luminaire sizes and candlepower distributions. Then, by interpolation, ratings may be estimated for lighting systems being considered for installation. Top layout shows one-side luminaire spacing typical for portions of the Interstate Defense Highway System.

in determining the importance of a good relative visual comfort rating compared with, or accompanied by, a high relative visibility rating.

Better appreciation of roadway lighting effectiveness in producing good seeing will result from numerical ratings in roadway user terms such as "relative visual comfort" and "relative visibility." "Figures of merit" for these seeing factors will also implement attention to the technological details by which seeing will be improved further.

In conclusion, the active interest of many people is required in addition to the small group now working on the evaluation of roadway lighting benefits.

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