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Night Visibility 1959

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Contents

Retinal Sensitivity and Night Visibility

R. H. PECKHAM and WILLIAM M. HART, Eye Research Foundation, Bethesda, Md.

A previous report (HRB Bull. 56, p. 17) indicated a correlation between retinal sensitivity and visibility during night driving. A new method for estimating retinal sensitivity by determining critical flicker frequency has been completed. A large field of view is kept at a constant and high level of brightness, so that retinal adaptation is consistent throughout measurement of sensitivity. A small area within this field alternates above and below the background brightness for a measured contrast, and at levels such that the "average" of the extremes equals the background. The contrast is controlled by a unique beam-splitting device within an optical relay, at any chosen contrast from 0 to 50 percent with respect to background. The frequency of alternation of the two beams is accomplished by a synchronous motor operated by an audio-generator and amplifier, from 30 to 70 cycles per second, at will.

Random order presentation of the stimuli yields data which can be reduced to psychometric estimates of threshold by probit analysis. Subjects chosen from a large ophthalmic practice, ranging from 8 years up to 80 years of age, have been studied.

It has been found that the measure of retinal sensitivity, by means of flicker rate, indicates a superiority in young adults (21-31 yr) of five or more times above the average of the median adult population (32-50 yr). A comparable depression to one-fifth or less in the sensitivity of older adults (51-80 yr) is also demonstrable. This amounts to a superiority of 25 to 1 or better for young vs old adults. Teenagers (8-20 yr) are comparable to the young adult group, but show greater individual variance, depending in part upon immediately preceding out-of-doors activity before their testing.

It is concluded that older drivers (50 yr and more) should be cautioned, and perhaps examined. Elderly drivers should be persuaded not to drive at night, if at all avoidable. Potential protection of elderly retinas by the use of sunglasses or out-of-doors avoidance is suggested. Support of further research is greatly needed, as this degree of retinal dysfunction is a significantly potential cause of accidents due to poor night visibility.

● IN 1952 Peckham (1) reported the effect of sunlight on retinal sensitivity and indicated the night visibility dangers resulting from failure to wear sunglasses at the beach or with out-of-door sports. Those conclusions were based on measurements of a group of beach guards at Atlantic City, and a group of chauffeurs on the desert roads of Arizona (2, 3).

Since that time the observations have been continued, and herein are reported the results of calibrated measurements on a group of 100 subjects in a clinical practice of ophthalmology. These normal subjects ranged from 13 to 80 years of age. Their retinal sensitivity ranged, from the best to the poorest, by more than 500 to 1. The authors have found that "teenagers" and young adults show much greater sensitivity than the middle age group, and that elderly people, even as young as 50 years, show a serious depression of sensitivity. These data, and the methods of obtaining them, are presented because it is believed that they are related to problems of highway safety. The earlier conclusions have been justified, and represent a problem of tremendous and serious implications.

In 1951, Miziak (4) reported that the rate at which a flickering light becomes steady decreases with age. In 1834, Talbot (5) reported that the flicker rate varies with the brightness. The authors' reports (6, 7) have shown that the difference of flicker rate between individual observers can be used as an indication of the sensitivity of the retina. Careful examination of the phenomenon of flicker is required.

Flicker is a purely subjective phenomenon. It refers to the appearance of an alternating light and dark visual stimulus at certain specific rates of alternation. When the visual field, in whole or part, slowly alternates between dark and light, perception will follow the alternation; the dark phase will have the appearance of darkness, and the light phase, the appearance of lightness. As the rate increases, there will develop a tendency for the discreteness of darkness and lightness to disappear, and the perception will assume a more random character; the light appears to "flicker." As the rate of alternation continues to increase, the flickering irregularity seems to fade out until the rate is so rapid that the perception becomes one of "fusion" or smooth coherent lightness.

The appartus is shown in Figure 1. From the subject's side, a large (50 deg) field is illuminated at 300 millilamberts. In the center of this field a small aperture is illuminated from behind, with two alternating beams, one of which is slightly brighter, and the other is equally dimmer, than the background.

Alternation of the beams is accomplished with a perforated disc driven by a synchronous motor whose speed is electronically controlled. The alternation is presented from 20 to 60 cycles (or "flickers") per second in a random order. The contrast of the flicker spot can be set from 50 to 1 percent with respect to the background. The contrast of the flicker amounts to only 5 percent in the experiments reported here. Because the average of the flickering light equals the illumination on the background, the subject maintains constant retinal adaptation.

Since there are no brightness changes in the field, artificial pupils have not been used. It was desired that the eyes be measured as naturally as possible, in order to measure the reaction of the whole visual system.

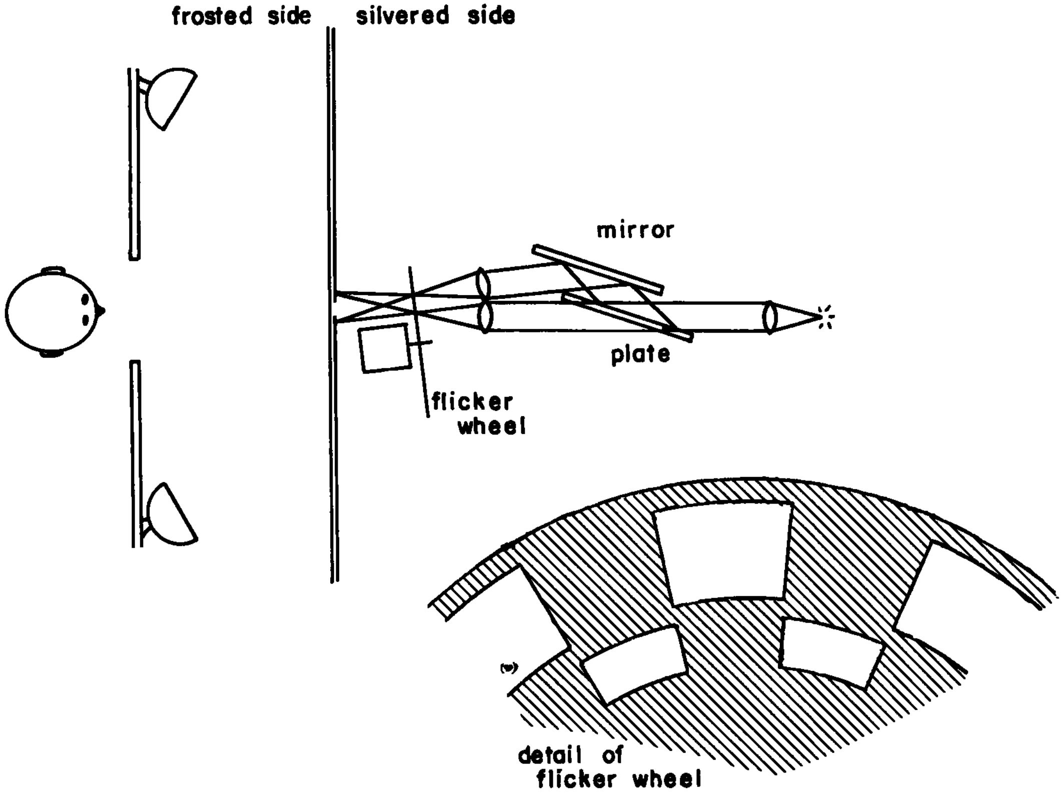

Figure 1. Flicker machine.

The subjects reported on were all normal. When they needed eye glasses to see sharply, these were provided before the tests were made. The problem is not difficult, and the test requires only about 15 min of actual work by the observing subjects. Their job is simple and easy, and it has been possible to measure children of 7 years of age as well as old folks of 80 years.

Only one eye is tested at a time. The other eye is covered with a frosted glass, which allows the light to continue, but prevents sharp vision. This maintains the state of adaptation in the unused eye. The measure of retinal sensitivity is that specific rate at which it is estimated that flicker would be reported one-half the time. This is the "threshold" measurement of the "critical flicker frequency."

The apparatus was originally devised to study certain ophthalmic dysfunctions, but a group of clinical patients whose eyes were normal has been examined to establish a base of performance. The subjects varied from 13 to 80 years of age. The flicker rates reported varied from 25 to 53 cycles per second at the 5 percent contrast and 300 millilamberts here reported.

In a second study, using trained observers only, it was established that the flicker rate could be expected to decrease with decrease in illumination, and that the rate of decrease approximates 7 flickers per second for each logarithmic unit (1/10) of the apparent brightness. This value agrees, for the 5 percent contrast conditions, with the order of that reported earlier of 10 flickers per log unit, for a 100 percent contrast neon flash flicker target (3).

The results of this preliminary survey are given in Figure 2, which shows the distribution of measured threshold flicker rates on 181 normal eyes, of patients between 13 and 80 years, as a whole group.

In a sense, it is as if the same light, comfortable to the normal group, dazzles the highest group, whereas the lowest group can hardly see at all. This is not the actual case, because all of the subjects are always adapted to this same light, but the persons

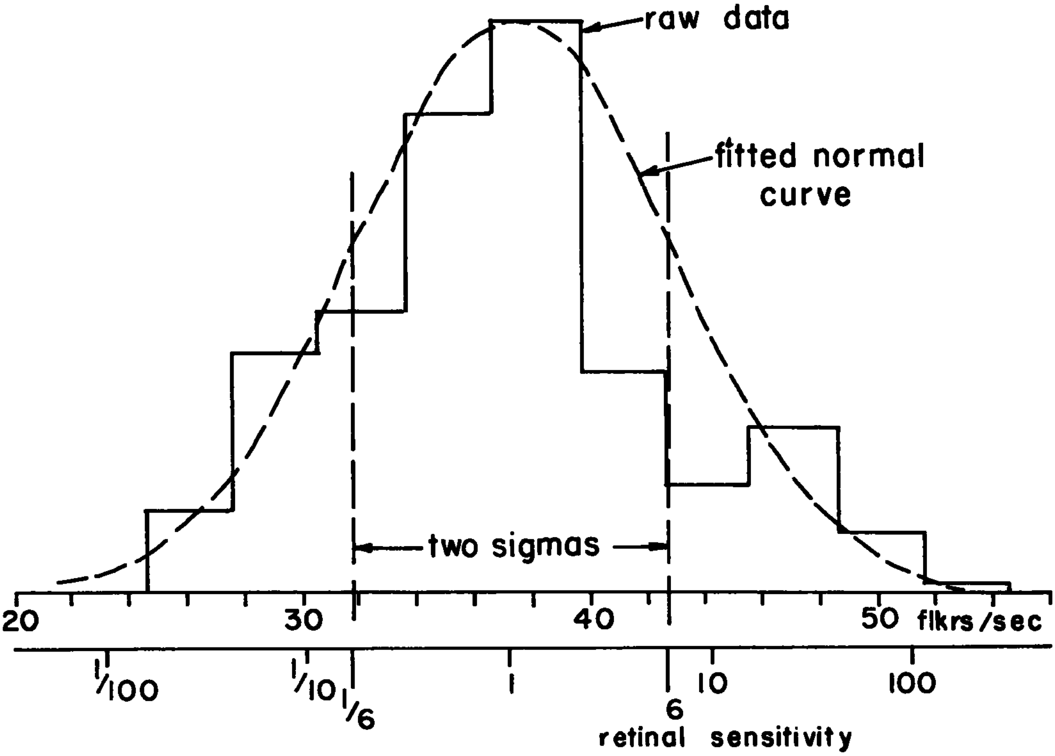

Figure 2. One hundred and eighty-one measurements of retinal sensitivity.

in the highest grade can use it better, and what is sufficient light for the average grade is inadequate for the lowest grade. The extreme grades are the uppermost 15 percent, whose retinal reaction was six times or more as efficient as that of the normal group, and the poorest 15 percent, who behaved as if the light were onle one-sixth as bright as it was.

The data of this Figure 2 include all the subjects reported; that is, all ages. Next, only the extreme data for each age-group are examined separately. These are given in Table 1, in the two youngest age groups, 13 to 19 years, and 20 to 31 years, there were no cases in the poorest grade. There were, however, about one-third in both the younger age groups whose retinal sensitivity was in the highest grade.

TABLE 1

ANALYSIS OF AGE GROUPS, EXTREME CASES
(Values in parentheses represent expected frequencies by chance)

Age (yr)	Lowest Grade, 1 σ Below Average	Highest Grade, 1 σ Above Average	Total Eyes
13-19	0 (5.7)	12 (5.7)	38
20-31	0 (3.6)	7 (3.6)	24
32-50	12 (12.8)	9 (12.8)	85
51-80	19 (5.6)	2 (5.6)	34
All			181

$X^2 = 55.08$
$p = 0.000001$

Between the ages 32 and 50, both extremes are found—lowest and highest. But in the oldest age group, from 51 to 80 years, more than one-half the cases are found in the very poorest grade.

These data are illustrated graphically in Figure 3. The teenagers have remarkably strong response to low contrast flicker stimuli, as do the young adults. In the middle age group a more normal situation is found, with examples of each extreme. In the older age group, however, retinal sensitivity has tremendously diminished.

These data tell a story parallel to that previously reported about the effect of sunlight. The earlier studies included only men in the young adult group. Differences in sensitivity as great as here reported were found in these young men between evening and morning, as a result of sunshine exposure, and their losses were found to be preventable by the use of dark sunglasses (2).

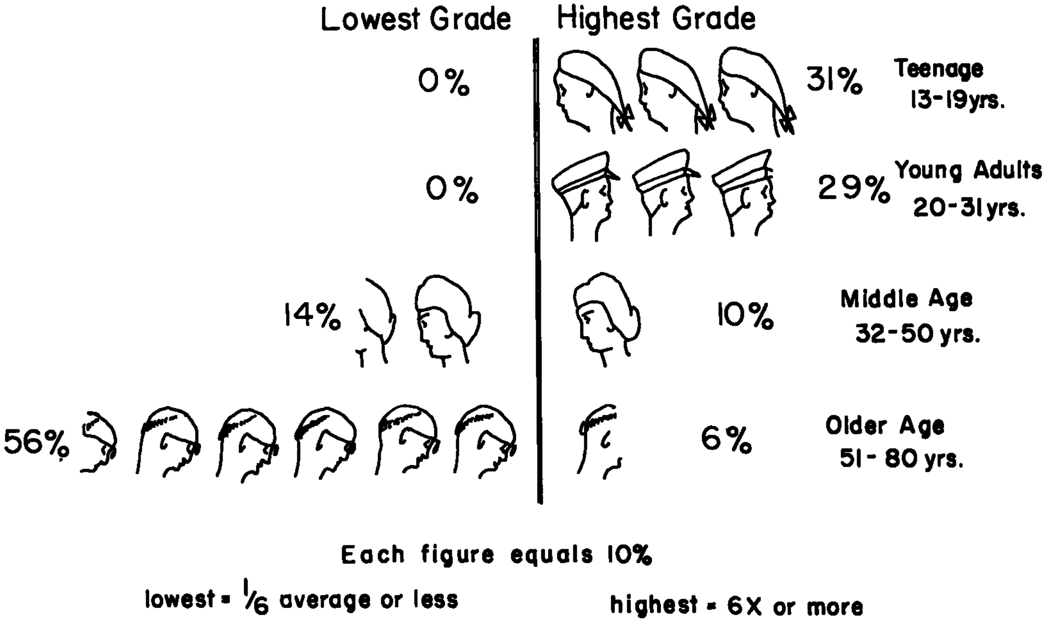

Figure 3. Younger persons show highest retinal sensitivity to low contrast flicker, older persons show retinal depression.

INTERPRETATION OF DATA

It is well known that the eye is a very poor instrument for estimating absolute brightness, although it is an excellent instrument for matching equal brightnesses. Thus, although two observers will agree within a few percent (usually within 2 percent) of the match between a standard and unknown brightness, it has been impossible to ascertain how bright the standard is to either observer.

It is the authors' thesis that the effective brightness of an illuminated field is represented by the ability of the adapted retina and its associated mechanisms to respond to flicker at the brightness in question. When the retinal system is superior, the flicker rate is increased; when the retina is depressed, the flicker rate is depressed. In these experiments, the background is maintained at a level higher than that of the room, and two or three minutes are allowed for adaptation to this higher level (probably a few seconds would suffice). Differences between the determined flicker rates are therefore interpreted as retinal sensitivity; that is, as estimates of the effective brightness of the field.

On the basis that 7 flickers per second represent a brightness difference of one log unit, or ten times, the difference of 5.5 flickers, or standard deviation, represents 0.78 log units. This corresponds to a brightness difference in the effectiveness of illumination of 6 times. Hence, the data in Figure 3 present an interesting picture. Effectively, the illumination of a headlamp beam is 6 times or more as effective for one-third of the teenagers and the young adults, as it is for the median group. And, conversely, the headlamp is one-sixth or less as effective for more than one-half of the eldest group. Between the youngest and oldest extremes there is a range of effective brightness exceeding 36 to 1 for any given level of illumination.

At high daylight illuminations, with high-contrast targets, these differences are not particularly discriminating between the two groups, because visual acuity, as so measured, does not greatly change from about 8 to 300 foot-candles. In the conditions of night driving, however, these retinal differences can easily become disastrous. One need only consider the reduction in effectiveness of one's own headlamps, to one-thirtieth of their present value, to comprehend the effect of the decreased retinal sensitivity for the older as compared to the younger group. Vision of both would be comparable within the small area of maximum illumination, down the road, but the tremendous effect of loss of perimacular vision, to either side of the headlamp beam, is at once evident.

It is not impossible that some remedial cognizance might be taken of these preliminary findings. In the first place, after the not really old age of 50 years drivers should be made aware of the need for extra caution. Older drivers should be persuaded to avoid all night driving, as a matter of survival. Extraordinary visual deficiency, resulting from loss of retinal sensitivity, might be made a basis for a suitable screening test for all drivers above 50 years of age, for example. Also, the estimates of visual benefits from improved lighting conditions and visual aids should not be based on the superior perception of younger observers.

There is adequate information to show that occasionally among younger persons, and not infrequently among the middle age group, temporary retinal depression is quite probable. In fact, the extremes for all groups tend to overlap. This fact is interpreted as evidence that certain conditions of protection, enhancement, and other factors of depression and exposure are effective, and must be discovered, defined, and applied, especially with regard to traffic safety programs. Exposure to sunlight, the longer effects of even mild alcoholic imbibition, potential "tobacco amblyopia", and even systemic dysfunction due to illness, may play a causative role in this condition. The great effect of sunlight exposure was reported in 1952 (2, 3). Middle aged and elderly persons should be taught to use sunglasses for protection during daylight driving, if they anticipate continuing after sunset.

With this discussion in mind, certain specific cases among those here reported can profitably be examined. Two persons of the oldest group, whose ages are 60 and 80 years, show retinal sensitivity within the superior range of the young adults. One of these is a Catholic Mother Superior; the other, a retired Protestant Minister. Both persons live regular and sheltered lives of good regimen, and avoid excess out-of-doors exposure. Among the teenagers a few have been found with greatly depressed retinal sensitivity, for their age, and in particular the poorest performance was found in a boy who was examined within a few minutes after a 2-hr football practice session in bright sunlight.

Certain seasonal changes greatly affect retinal sensitivity and, thereby, traffic safety. In this geographical area, near Washington, D.C., the sun in October was still shining strongly at 5:00 P.M., during the evening rush hour. When civil time was changed from Daylight to Standard, the peak evening traffic changed abruptly from one-half hour before sunset to one-half hour after sunset. Not only do driving habits need to be adjusted for these different conditions, but the fact that the previous days were clear and bright found the retinal sensitivities of the drivers at their poorest. A specific caution was issued at this time through the local newspapers (7) by John W. Childress of the District Division of the American Automobile Association. He pointed out that 75 percent of traffic deaths occur during these evening peak hours, between 4 and 8 P.M. His observation correlates closely with the conclusions herein concerning retinal sensitivity.

Because this paper is a preliminary report of a condition that may be of very serious import to traffic safety as dependent upon night visibility, it is presented with the obvious plea for support of further and more definitive research in this suggestive field.

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Background and Objectives of the U.S. Standard for Colors of Signal Lights

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The U. S. Standard for Colors of Signal Lights embodies an attempt to eliminate some of the inconsistencies between different specifications for signal-light colors now used in the United States on the basis of the recommendations of the International Commission on Illumination. Differences in service conditions justify some of the differences among these specifications, but not all of them. The report also explains the different purposes served by the several parts of the standards and the relationship of basic definitions, limit standards, and procurement specifications.

●THE U. S. STANDARD for the Colors of Signal Lights has four objectives:

1. It is designed to advance international cooperation through bringing the United States into harmony with the recommendations of the International Commission on Illumination.
2. It aims at the elimination of wasteful differentiation.
3. It will accomplish technical improvements in the specifications.
4. It will contribute towards the maximum possible reliability for the recognition of the colors of signal lights.

Background of U. S. Standard

The International Commission on Illumination (CIE) is one of those organizations that have been set up for the dual purpose of coordinating scientific and engineering activities across international boundaries and sharing the results of technical work carried out at the more active centers with localities which can not carry out such work themselves. In the United States the CIE is represented by the U. S. National Committee of the CIE. This committee in turn carries on its work through individuals and committees which specialize in the various aspects of lighting that together comprise the work of the CIE.

At the 1948 plenary session of the International Commission on Illumination, John G. Holmes of Great Britain presented a paper (1) reviewing some of the more important specifications for signal light colors in use in different countries and pointing out the unreasonable variations in these specifications. Since signal lights in different countries are being more and more used by citizens of other countries, there was a strong consensus of those present that the CIE should look into the possibility of bringing more order into the situation. A technical committee was set up by the Commission for this purpose. This committee was comprised of representatives from the interested countries including the United States.

The CIE Committee on Color Specifications for Signal Lights was faced with an urgent assignment because the International Civil Aviation Organization (ICAO) had requested guidance in establishing standards for aeronautical use. As soon as it had been constituted under the chairmanship of Mr. Holmes, the committee proceeded to survey prevailing practices in the use of colors for aviation lights by all the countries which were affiliated with the CIE. These included all the countries which were at that time important in international aviation. On the basis of the reports received from these countries, recommendations were sent to the ICAO in November 1949. The Aerodromes, Air Routes and Ground Aids Division of ICAO (AGA) met that same month and adopted recommendations for standards governing aviation signal colors. These were largely based upon the aviation practices of the U. K. and the U. S.

The CIE committee then proceeded to carry out a more complete study of all signal light color specifications in the cooperating countries. When this had been completed, it prepared its own recommendations for the chromaticity boundaries for signal light colors. These were discussed at the CIE plenary session in 1951, and standard recommendations for chromaticity boundaries were adopted (2). Most of these differed from the ICAO boundaries. These differences resulted from taking into account experience in fields other than aviation and in most cases they were small. In 1952 the AGA Division of ICAO met again and considered the CIE boundaries and adopted nearly all of the over-all boundaries.

In addition to the over-all boundaries the CIE had recommended some more restrictive boundaries for signal lights which were designed to provide more certainly of recognition at the cost of a reduced visual range. These found little interest in the ICAO as they were not sufficiently correlated with specific conditions of use. The CIE 1951 recommendations for restricted boundaries were also unsatisfactory as a basis for bringing specification practices in the United States into a more consistent relationship for the same reason.

In 1955 the CIE again considered its recommendations in the light of experience between meetings and made minor changes in the position of one green and one blue boundary. The yellow-white region was reconsidered, and within an over-all region that was substantially the same as that defined to represent the two colors in 1951, a series of successively more restrictive definitions based upon the conditions of use were recommended. This principle appears to be constructive and it is hoped that restrictive red and green definitions can be developed upon this basis at the 1959 plenary session of the CIE.

International Cooperation

The U.S. National Committee on the Colors of Signal Lights was appointed in 1952 to assist the U.S. representative in preparing for the 1955 meeting and to provide a liaison with those organizations and government agencies which are responsible for the specification and regulation of signal light colors used in this country. It is the responsibility of this committee to introduce the CIE recommendations to the organizations and agencies represented on it. The CIE has, of course, no compulsory authority and whatever actions are taken by American interests will be voluntary ones. Should any case be found in which it would be seriously contrary to follow the CIE recommendations, there would be no expectation to do so. There is however, no reason to anticipate such a situation since the American practices have been carefully considered in the formulation of the CIE recommendations.

Elimination of Waste

To understand the possibilities of eliminating wastes through correlating the different specifications for signal light colors which manufacturers are asked to meet it is necessary to compare the different specifications now in use. To do this for all the colors would be beyond the scope of this paper, but the case for the reds and yellows may be looked at. Since for the types of glass generally used the hue and saturation of these colors vary together, the significant limits of these specifications in a single dimension may be represented. Figure 1 compares the U.S. and international specifications by means of such representation. For this purpose the "y" coordinate in the RUCS system (3) has been used as the best available index of the chromaticity differences to be represented. The extension of the heavy vertical lines across the light horizontal lines indicates changes suggested to eliminate unnecessary differences.

It can not be determined how much, if any, monetary saving can be achieved through making it possible to use the same melts of glass for different types of equipment, but it seems fairly evident that there would be at least some simplications in shop and inspection practices.

Clarity of Specifications

As one studies the specifications now in use it becomes evident that there is considerable confusion between the functions of the definitions stated in terms of the CIE chromaticity coordinates and of the limit glasses. Some specifications, or parts of specifications, read as if the equations were the legal controls on what is acceptable. On the other hand, some of the duplicates of the limit glasses give chromaticities that are outside of these boundaries. Moreover, the limit glasses locate the boundary lines in only a few well separated points, and there is no way of interpolating the boundaries between these points except by spectrophotometric or colorimetric difference measurements neither of which is at present feasible for the inspection of large numbers of pieces of signal ware.

The usual practice, and the universal practice, is to test the ware against duplicates of the limit standards, that is, against carefully measured filters combined with incandescent lamps operated at specified color temperatures. So long as the ware has the same colorant as the limit glasses and differences in chromaticity are due to variations in the thickness of the ware and the concentration of the colorant, the chromaticity limit glasses provide limits that are both practically and theoretically sound. This is because the locus of chromaticities that can be obtained by varying the thickness of ware or the concentration of colorant in ware is a line, and these lines are sufficiently straight that the defining of a single point serves to divide all the chromaticities available with a given

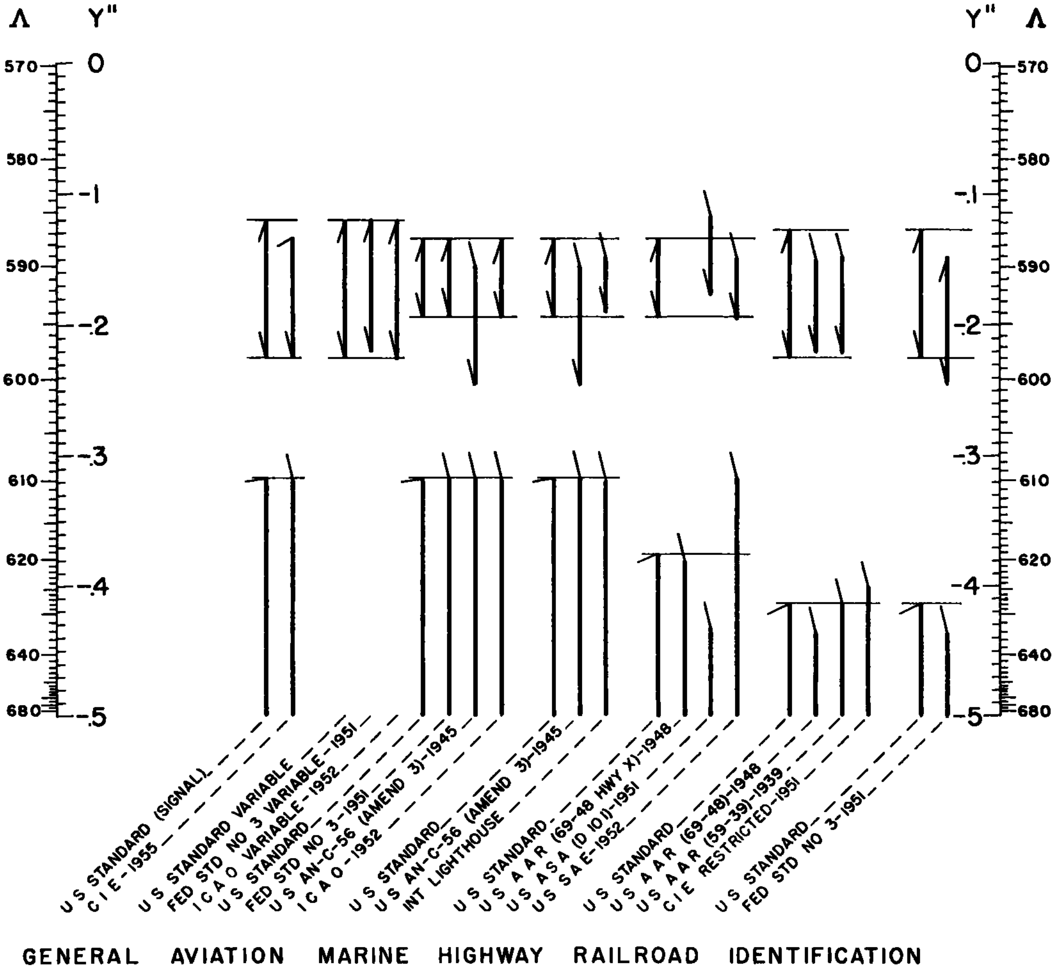

Figure 1. Comparison of limits for red and yellow signal light colors. (U.S. and International specifications R-U-C-S Diagram.)

colorant into two distinguishable classes. The defining of two points defines a specific range of acceptable chromaticities. In practice these conditions have been nearly realized, the ware furnished having chromaticities that are represented by points close to the straight or mildly curving lines which represent the change of chromaticity with the change of concentration of the colorants used in the limit standards, and the inspection is carried out by comparing light transmitted by the ware with light transmitted by the limit standards. Since this practice of purchasing ware on the basis of limit stand-

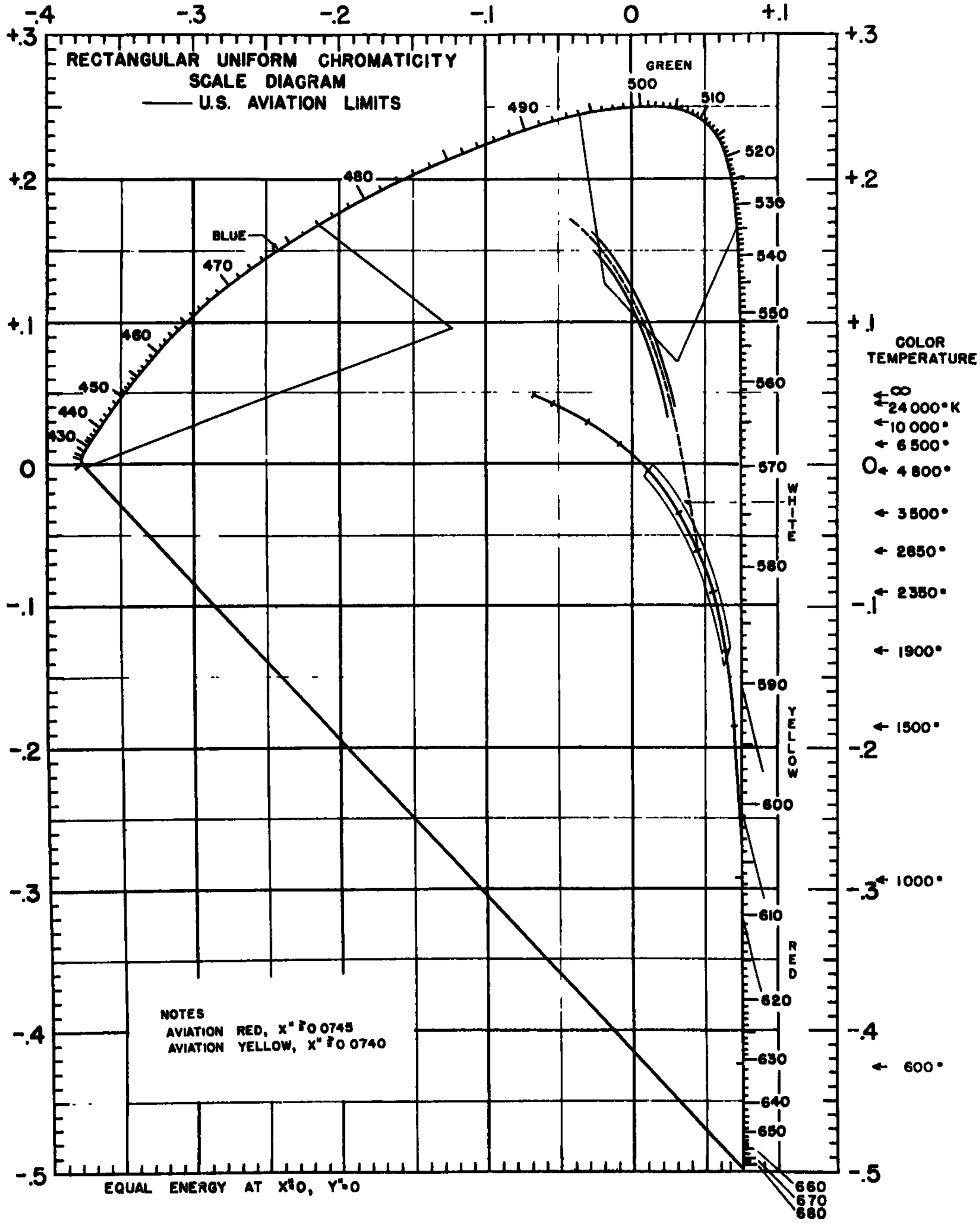

Figure 2.

ards is both well established and theoretically sound, it is desirable that the specifications be clearly based upon it.

It is one of the purposes of the U.S. Standard for Signal Light Colors to facilitate the writing of specifications on the basis of limit standards and at the same time correlate their requirements with the basic chromaticity definitions. This is accomplished by requiring that the ware be made from materials having chromaticity characteristics similar to those of the standard filters. The meaning of this is illustrated in Figure 2 in which the dotted line extending upward from the point representing the chromaticity

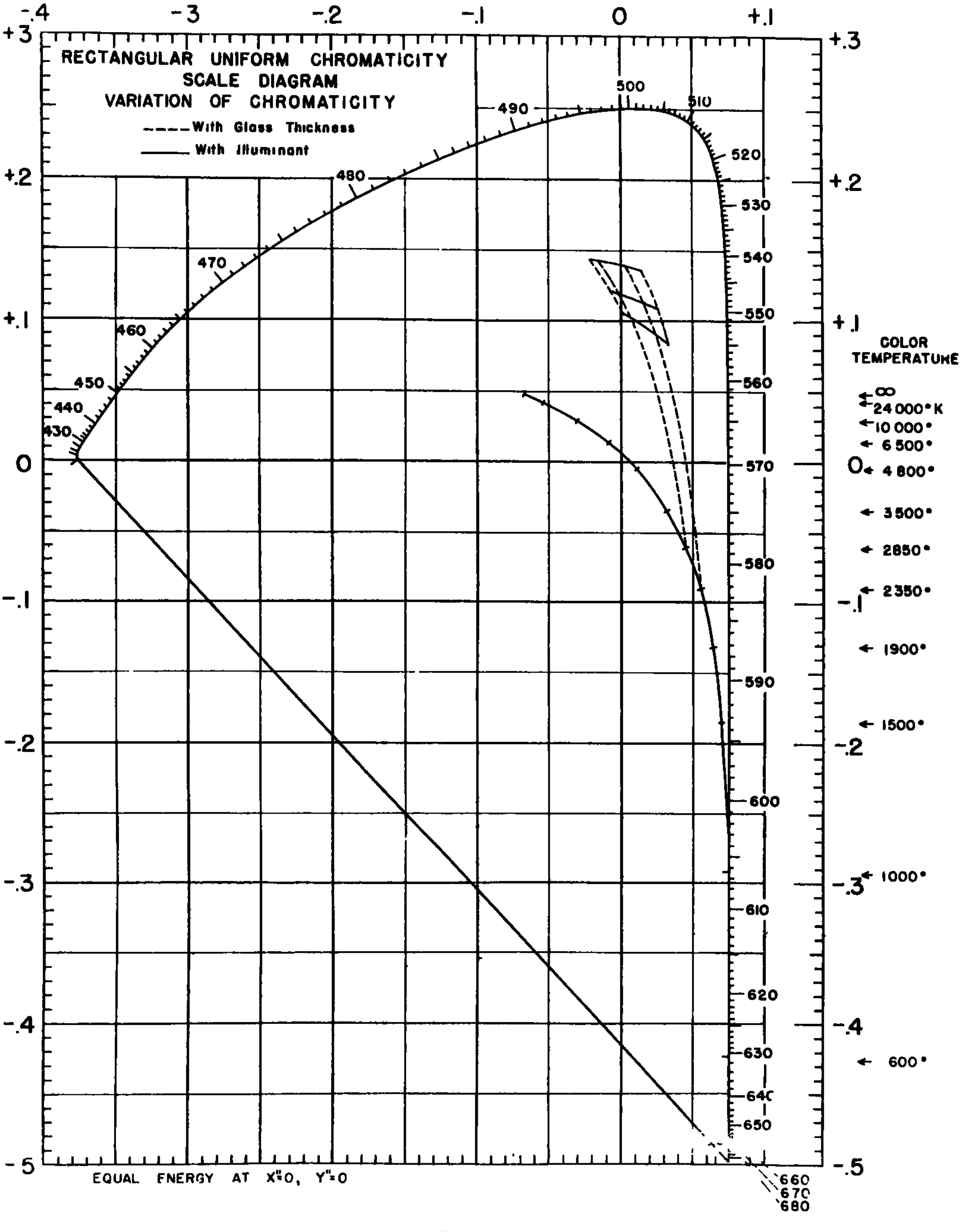

Figure 3.

of an ordinary gas-filled tungsten lamp at 2,854 deg K into the green region of this RUCS diagram represents the chromaticities resulting from the combination of such a lamp with filters of different thicknesses all made from the same type of glass. The curves, one on each side of this dotted line, are the present tolerances for green ware purchased on the basis of this standard.

The adoption of a set of limit filters and the requirement that ware furnished have chromaticity characteristics similar to those of the adopted filters does not limit the chromaticities as seen by the user to those represented by the standard filters with the standard light source. In the case of the green especially, the narrow band of chromaticities defined by these requirements is broadened into a substantial area on the chromaticity diagram by the variations of chromaticity that result from variations in the color temperature of the source of light. Figure 3 illustrates this compound variation. In this figure, as in Figure 2, the dotted lines represent the variations resulting from changes in the thickness or colorant concentration in the ware but in this figure the full lines represent changes in chromaticity caused by variations in the color temperature of the light source.

In the case of red signal lights, the variations in the color temperature of the filament merely result in an extension of the variations allowed by the limit filters. The chromaticities of the yellow, white, and blue signal lights are also extended by the color temperature variations, but with these colors there may also be some broadening of the band of chromaticities of the signals as produced in service.

Nearly all systems of signal lights are affected by these variations in the light source, and it is the responsibility of the specification writer to take them into account and make sure that the over-all variations in chromaticity come within the basic chromaticity definitions.

It has been suggested that photoelectric colorimeters will soon be available and that with them inspections can be carried out with direct reference to the basic definitions without the need for limit filters. This practice would not be sound since it ignores the variations introduced by the differences in the light source. Allowances for these still have to be made, and when the acceptable areas of chromaticity have been reduced to make these allowances, it is probable that there will not be much more area of acceptable chromaticity left in some systems than is allowed under the requirement for similar chromaticity characteristics. On the other hand, basing procurement specifications upon limit standards does not make it impracticable to use photoelectric colorimeters for inspection of the ware furnished under such specificiations. On the contrary, it makes the use of such instruments simpler since the limit standards would serve as necessary calibration standards for such photoelectric colorimeters without which the results at present attainable are not sufficiently precise and dependable for the work.

Reliability of Recognition

The recognition of signal light colors is a matter of education. No one is born with a capacity to catalog colors as red, yellow, green, and blue. Those who are not abnormal in their color vision learn to use the color adjectives according to a general pattern, but the precise limits of what is blue or green differ not only from person to person but even for the same person depending upon the environment and the recent history of the use of his eyes. These effects are even larger for colors seen as signal lights than for the colors of surfaces.

There are nine conditions which affect the probability that a signal light color will be correctly recognized. These are listed in the Report of Secretariat 1.3.3, for Colors of Signal Lights, to the 13th Session of the CIE, 1955 (4) as follows:

1. The number of colors in the system.
2. The normality of the observer's vision.
3. The state of his visual adaptation.
4. The solid angle subtended by the signal at the observer's eye.
5. The illuminance, or the fixed-light equivalent illuminance, at his eye.
6. The luminance of the background.

7. The observer's familiarity with the system of colors.
8. The opportunity to compare colors if such is present.
9. The degree of concentration which the observer can devote to the recognition of the color.

It should be clear from a consideration of these conditions that the separation between the colors is of great importance, and that since many observers will be using the signals of more than one system, it is highly advantageous to have as much uniformity between the different systems as the limitations of their use will permit.

In determining the boundaries for a system of signal-light colors there are four sources of guidance, namely:

1. Basic researches on color perception.
2. Experiments to determine the recognizability of signal-light colors.
3. Experience with the use of lights conforming to known specifications.
4. The practicability of obtaining desired chromaticities with the available colorants.

It is not feasible here to examine any of these in detail. It must suffice to point out that basic researches have contributed to the determination of the direction of boundaries, the results of experiments show that the several colors are centered in favorable parts of the chromaticity diagram, practical limitations dictate the extent of the acceptable color variations, and experience, in some fields at least, although not demonstrating perfection, encourages confidence in the conclusions reached on the basis of research and experiment.

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Proposed Changes in Traffic Signal Color Standards

CHARLES S. MICHALSKI, Citizens Traffic Safety Board of Metropolitan Chicago

● WHILE SPECIFICATIONS for traffic signal glassware have been revised periodically during the past 25 years, there have been virtually no changes in basic chromaticity definitions. In recent years traffic engineers have become increasingly concerned over the variety of shades of reds, yellows, and greens that confront the motorist even on short trips in his own community.

The U.S. National Committee on Colors of Signal Lights, a committee of the International Commission on Illumination, has drafted proposals for standardizing definitions of colors of signal lights used by aviation, highway, marine, and railroad services. At the outset of the committee's deliberations, it was apparent that adjustments are desirable in definitions of colors of highway traffic control signals. The most notable deviation is in the description of the green boundary of the yellow signal.

Under current specifications sponsored by the Institute of Traffic Engineers, much greener yellows are permitted than by other agencies. In fact, the separation permitted between the yellowest green and the greenest yellow is less than separation between the yellowest red and the reddest yellow. Definitions proposed by the U.S. National Committee on Colors of Signal Lights call for a reversal in separations between colors.

The philosophy underlying the USNC spacing between colors is that yellow mistaken for red is safer than yellow mistaken for green. However, there are applications, particularly in flashing signals, where red identified as yellow can lead to disastrous consequences. Hence, it is important that an adequate separation be maintained between yellow and red.

Yellows used by railroads in wayside signals conform with proposed definitions. Use of similar standards in highway traffic control would result in a small, but tolerable, loss in transmittance of six percent.

At the present the American motorist is confronted by signals of three shades of red on the highway: In traffic signals as specified by the Institute of Traffic Engineers, in stop and tail lights of vehicles as specified by the Society of Automotive Engineers, and in railroad crossing flashers as specified by the Association of American Railroads. The railroad crossing signal falls approximately midway between the others in redness and is proposed for adoption for all highway applications.

The minimum required transmittance of the railroad crossing red is approximately 2.7 times the minimum required for highway traffic control red. Under current specifications the minimum transmittance for red traffic control glassware is only 0.047. This means that the amount of light transmitted by a red lens is less than five percent of the light transmitted by a clear lens with similar physical features. In contrast, the minimum required transmittances of green and yellow are 0.200 and 0.440, respectively.

Adoption of the railroad crossing red for highway traffic control purposes will bring about a better alignment in transmittances with little sacrifice in identity.

No changes are proposed for the boundaries of green signals in highway traffic control.

Table 1 is a comparison of boundaries (basic chromaticity definitions) for the red, yellow, and green as proposed by U.S. National Committee with those currently specified by Institute of Traffic Engineers in the CIE coordinate system.

Basic chromaticity definitions as proposed by USNC differ somewhat in form from ITE definitions. The principal reason for differences is the desire on the part of the USNC to reduce to a minimum the number of definitions under which colored signals are purchased and to bring definitions into accord with recommendations of the International Commission on Illumination.

TABLE 1

Color	USNC (Proposed)	ITE (Practice)
Red, intermediate:		
yellow boundary	$Y = 0.310$	$Y = 0.288$
Yellow, restricted:		
red boundary	$Y = 0.400$	$Y = 0.411$
green boundary	$Y = 0.440$	$Y = 0.452$
Green, intermediate:		
yellow boundary	$Y = 0.730(1-X)$	$Y = 0.730-X$
blue boundary	$Y = 0.500-0.500X$	$Y = 0.400$

Surface-Mounted Lights on Roadways for Guidance

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●THE MATERIAL presented in this paper is an outgrowth of developments that have been made in lighting for airports. Recently the Institute of Transportation and Traffic Engineering of the University of California had a research project sponsored by the Bureau of Research and Development of the Federal Aviation Agency to consider the problems of airport runway capacity. In connection with this study, it was necessary to develop a means of delineating an airport runway and a high speed exit taxiway for all weather conditions including daytime, nighttime, and adverse weather. The lighting units that were developed for the FAA have been installed at the McClellan Air Force Base at Sacramento, California and at the San Francisco International Airport. The system may have potential applications to roadways since the basic visual problem of the motor vehicle driver and the pilot is the same.

There are many aspects to the visual perception problem of the motorist. These involve the contrast between adjacent brightness patches, the acuity required to resolve fine detail coupled with the dynamic characteristics of motion, plus a sense of orientation in the spatial field. An analysis reveals that the major information required by a driver is contained in the contour lines that outline the basic elements of the scene. Insofar as the roadway itself is concerned, the basic elements are determined by lineal lines that define the edges of the roadway, the intersections and the turnoffs, the lane lines and the center lines. These basic components are further supplemented by other fine points of perception such as surface detail, color of elements, glossiness of surfaces, and familiar shapes of objects in the field of view. But probably 90 percent or more of the visual information is conveyed to the driver by means of the lineal pattern forming the outline of the basic elements. This idea of contour perception has been used as the basis for establishing a lighting system, using a large number of small light sources spaced on short center distances (approaching the minimum angle of resolution) which will then provide a continuous bright line. The principle of contour perception is recognized in the work of all artists wherein the outline of the scene is drawn first. The details of the texture, shading, color and variations of brightness are used later to bring out the more subtle attributes of the picture. The same principle is used by cartoonists who employ a few simple strokes to convey the basic features of people in caricatures. Similarly, mechanical drawing techniques use the outlines of the parts to provide all of the information needed by an engineer or a technician.

Figure 1 shows the principle of contour perception applied to the runway of an airport. The turnoff for an exit taxiway is shown from a long distance away as well as from a closer position. In either case the scene continues to change from distant to close viewing and provides a continuous supply of information regarding the approaching turnoff. It is desirable to have the lineal effect continuous if the information is to be automatically interpreted.

The Development of a System for Contour Perception

The foregoing has indicated the desirability of a lighting system to develop continuous contours of light along borders and centerlines of roadways. Figure 2 shows a pattern of lights used to define the runway and exit taxiway at McClellan Air Force Base. The edge lights are on relatively large spacings of 50 ft, except in the region of the turnoff where they are spaced at 33 ft. The centerline of the runway has lights on 20-ft centers, whereas the centerline through the turnoff has lights on 10-ft centers. Spacings from 50 to 10 are illustrated in the photograph to show the relative effect of close versus wide spacing to provide the lineal pattern.

The line used to form the contour should have a high contrast with its background.

In order to build up such a high contrast, it is desirable to use direct light sources rather than reflected light. Filament light sources are a logical choice for this design due to their high brightness and simple electric circuitry. If the sources have high brightness, they can be seen against a background which is also relatively high in brightness as in daytime fog. Small filament lamps in the order of 3, 5, or 15 watts are suitable for this purpose since they operate at about the same brightness as higher wattage lamps of greater candle power. The brightness is the flux per unit area per unit solid angle and this is a characteristic of the filament temperature rather than the size. Small light sources can be used to build up a pattern of lights and the light sources can be arranged on close centers so that at near grazing angles (at which they are viewed by a driver), the filament intensities will add together to form a much higher apparent brightness than each single source alone. This effect can be visualized by looking at a ladder lying on the ground ahead. The distance between individual rungs appears foreshortened as the eye position is lowered and the rungs become stacked one on top of the other until the surface looks solid. If filaments are substituted for the rungs of the ladder, the brightness build-up effect can be visualized. This system has several advantages: small sources can be used so that surface mounted fixtures can be designed to protect the sources from wheel impact and yet the complete assembly need not protrude more than a fraction of an inch above the roadway surface. Thus, the fixtures can be rolled over without damage by vehicles. They can be surface mounted on the roadway at nominal installation costs. Furthermore, when small sources are used, there is very little flash-by effect; there is very little flicker in the peripheral field for the units along the edges of the roadway and the glare from each source is negligible. The pattern of lights in depth at constant spacing provides a reliable indicator for speed of travel and develops a good means of judging distances both on the straight-away and when approaching curves, turnoffs, or other important junctions in the roadway.

The lighting unit that was developed to meet the above requirements is a small flat circular disc-shaped fixture that uses either a 3-, 4- or 15-watt 12-volt automotive type light bulb as shown in Figure 3. The bulb selected for this fixture is a tubular shaped bulb used principally in foreign automobiles and is manufactured by a number of European companies. The 3-watt size is quite adequate for roadway use and is preferable because

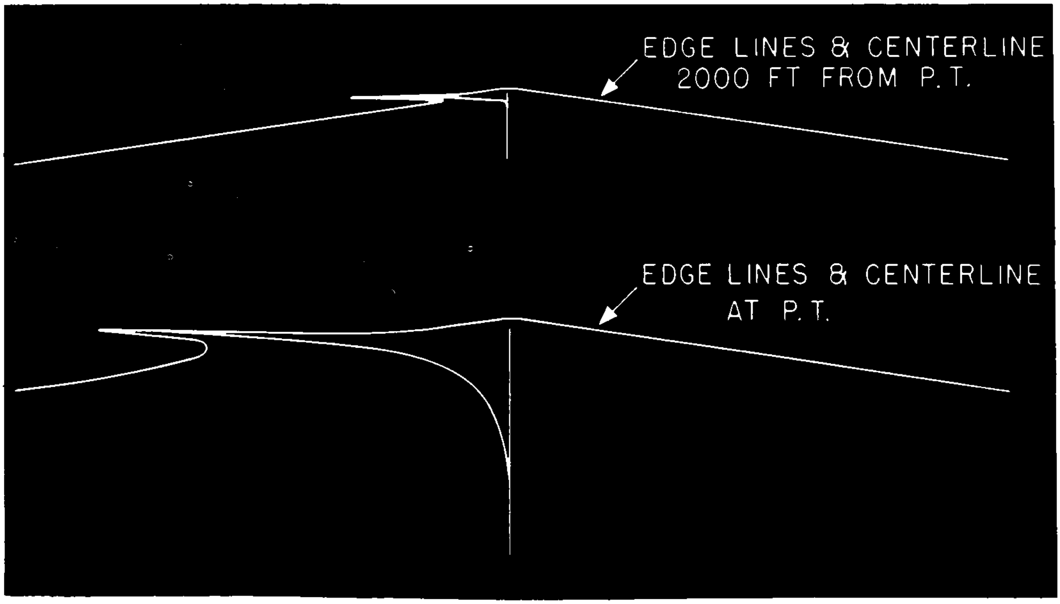
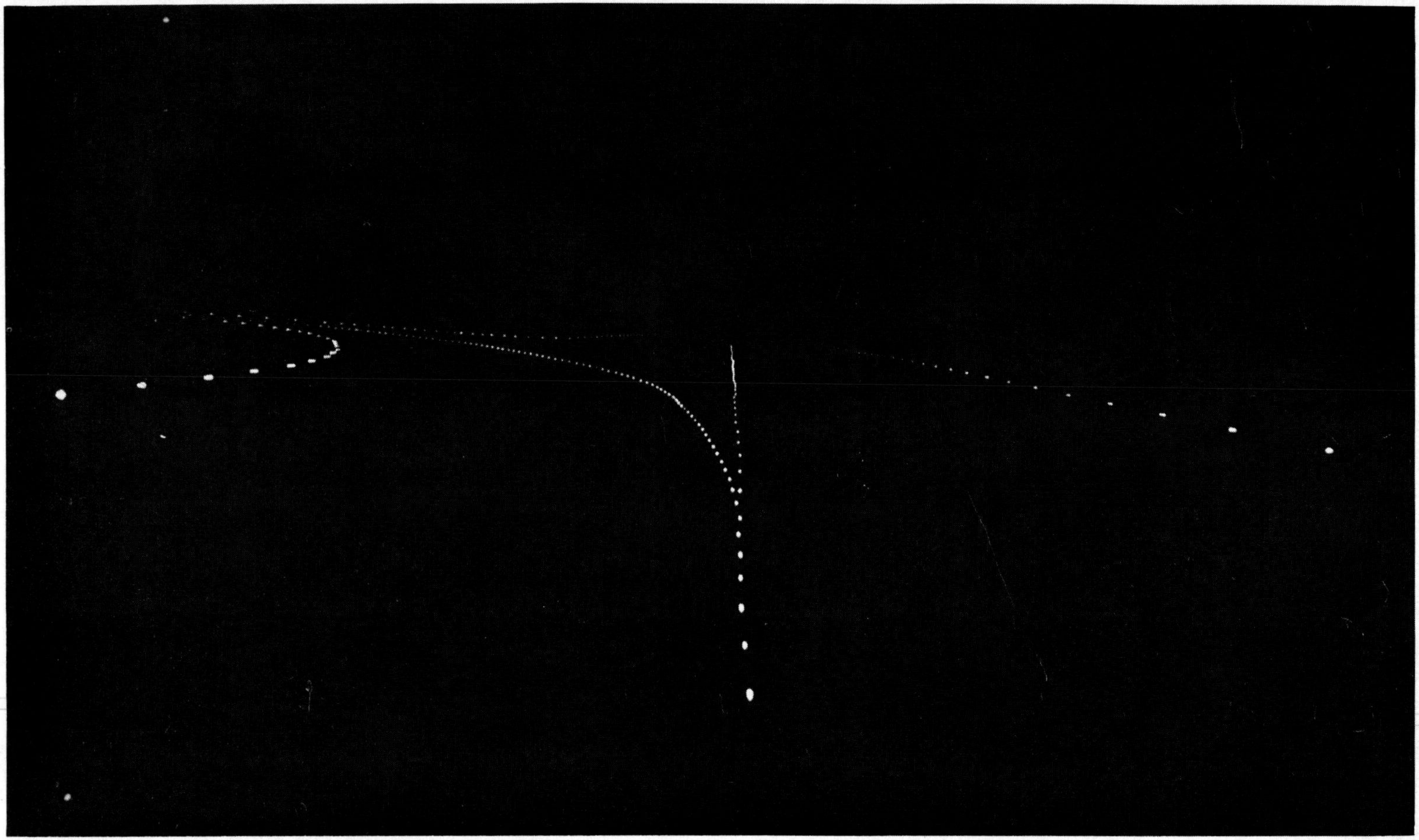


Figure 1. Edge and center contour lines.



Lighting: Edge plus Centerline
Location of Camera: At point of turn
Height of Camera: 13 feet
Bulb: (Edge: 5 watts; 14 volts
(Centerline: 3 watts; 12 volts

Spacing of Lights (feet)				
Edge		Centerline		Across Entrance
Runway	Taxiway	Runway	Taxiway	
50	33	20	10	--

Figure 2.

of its small cross-section. The particular lamp shown in Figure 3 is 7.5 mm in diameter and can be mounted in a unit having a total height above the roadway of only ½ in. The fixture can be run over by automobiles without damage to either the fixture or the car. A noticeable roughness is felt in most cars, particularly at slow speeds. At high speeds the roughness is still apparent but is not intolerable and does not seem to constitute a driving hazard.

The present design is experimental but a number of design features were considered in its development, such as access for bulb maintenance. The top is open so that the bulb can be snapped in or out by hand or with simple tools. Drainage is not a problem since the units are slightly above the roadway surface. The collection of dirt and debris in the throat has not been a problem so far since tire action provides a certain amount of self cleaning. The units have not been tested in conjunction with snow plows or other snow removal equipment. Problems may arise in areas where snow and ice are present, but the heat of the bulb itself is probably sufficient to melt snow or ice in the immediate vicinity of the bulb and in the throat section.

The low operating voltage was selected because of the availability of the low wattage bulbs in the tubular shape. Low voltage has other advantages: It is safe, and ground-lay or surface-lay wires can be used without conduits. Minimum clearances can be used in the fixtures; the exposure of electrical contacts in weather is not a serious problem, and feeder lines can easily be run in from the side supplied by transformers with high voltage primary circuits.

Mounting of Light Units

Several methods of attaching units to the roadway surface are available: With heat treated drive nails; with studs explosively driven into the roadway plus machine screws

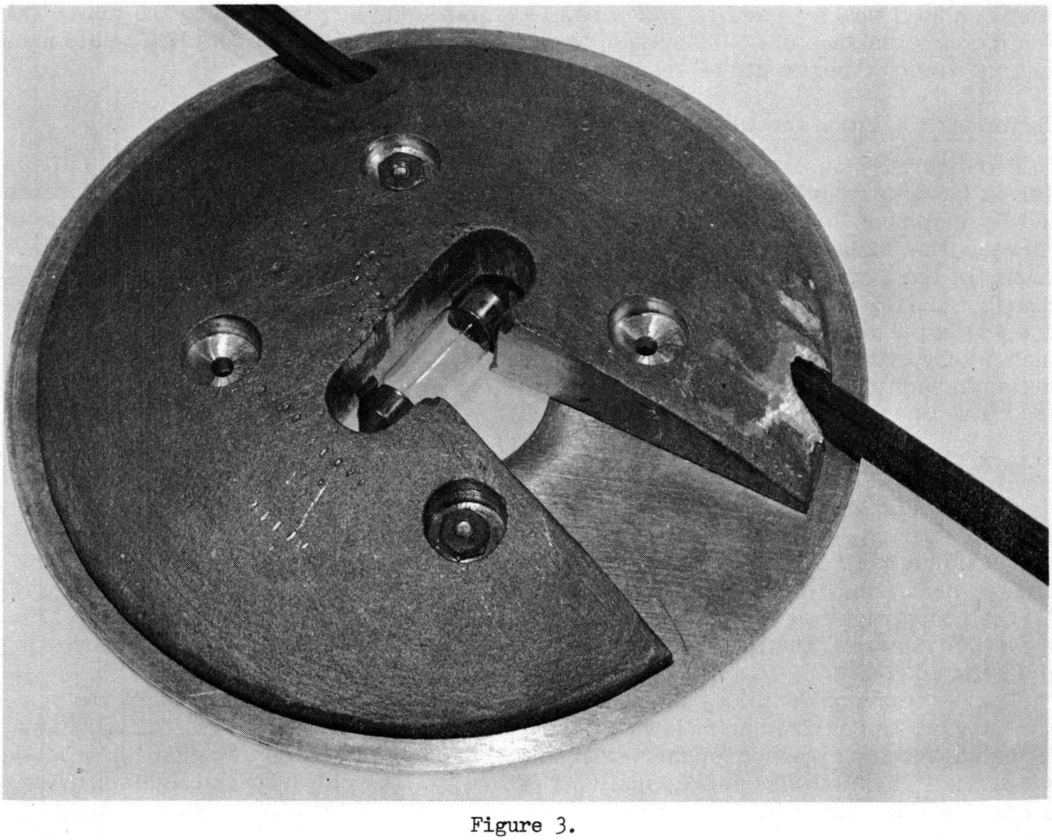


Figure 3.

to fasten the units to the studs; and, with adhesives. All three techniques have been used experimentally. It has been found advantageous to use the adhesive method for experimental purposes. A rubber-base adhesive has proved very satisfactory on both concrete and asphaltic surfaces. The particular material that has been most successful is Stabond No. T161 used with a toluene thinner. The surface must be clean and dry when the adhesive is applied. The adhesive will require several hours to set up firmly. In areas where some of the roadway use will occur prior to complete setting-up, cloth adhesive tape in addition to the bonding material was used. In a permanent installation the adhesive tape would probably not be used.

Power Supply and Service Distribution

The lighting units have been arranged in two basic systems which can be operated independently: a centerline system, and an edge lighting system. At the San Francisco Airport installation the centerline system has additional switching so that the spacing can be changed in order to evaluate its effect on the visual conditions. The supply wire for the 12-volt system was two-conductor No. 14 gage running parallel to the line of fixtures. Each fixture was connected by short pig-tail leads and clip-on connectors. A special terminal was developed to attach to the supply wire so that it was not necessary to strip and splice the wire. A brass U-shaped clip was arranged to go over the outside of the wire. A copper tack was used to pierce through the clip and the stranded wire and was riveted on the opposite side. The 12-volt supply line was connected to the high voltage feeder-line at the side of the runway by means of lateral lines for every 20 lamps. With this arrangement of wiring the voltage gradient along the lights was less than one volt between the maximum and minimum point in the system. This was adequate for uniform brightness. It was determined that a voltage drop of 2 volts along the 12-volt system would have been satisfactory, but that a 3-volt drop along the system gave noticeable brightness variations. For a 2-volt drop along the system and with the lamps on 50 ft spacings and No. 12 wire, 10 lamps could be placed along the line. This would give a distance of 500 ft in both directions from the lateral line which would mean that one transformer would be required per 1,000 ft.

Photometric Data on the Lighting Unit

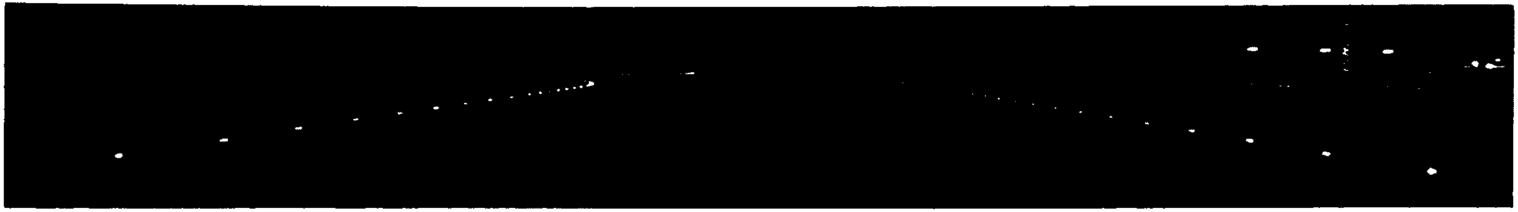
Photometric measurements have been made on the units at the University of California laboratory in Berkeley, California, at the Air Force Wright-Patterson Research and Development Center in Columbus, Ohio and at the CAA Experimental Airport at Indianapolis, Indiana. All of these reports check and indicate that the maximum intensity of the 5-watt light at rated voltage is approximately 7½ candle power and is distributed over a horizontal angle of approximately 20 deg to each side of the centerline and in the vertical direction from the surface (0 deg) up to more than 90 deg. With such a very broad distribution the units appear equal in brightness from all viewing angles including directions considerably off to the side. This permits the unit to be used to delineate curves and edges which may be in the peripheral view of the driver.

Discussion of Results

The work at McClellan Air Force Base permitted a preliminary evaluation of the effect of spacing and brightness of the edge lights and centerline lights. The spacings at McClellan Air Force Base varied from 100 ft on the edge lights down to 10 ft on the taxiway centerline. Some of the patterns of lights are shown in Figures 4, 5, and 6. All the photographs were taken from the eye position of the pilots, approximately 13 ft above the runway. The light bulbs in all of the photographs are 3 and 5 watts operating at 12 and 14 volts.

The reactions of the pilots and observers to the night guidance provided by the system may be summarized as follows: During clear weather all of the various spacings of the edge lights provided guidance that was at least good enough to permit the pilot to negotiate the high-speed turnoff without difficulty. The close-spaced lights provided the best delineation of the boundaries. However, many of the observers and pilots

At Point of Turn



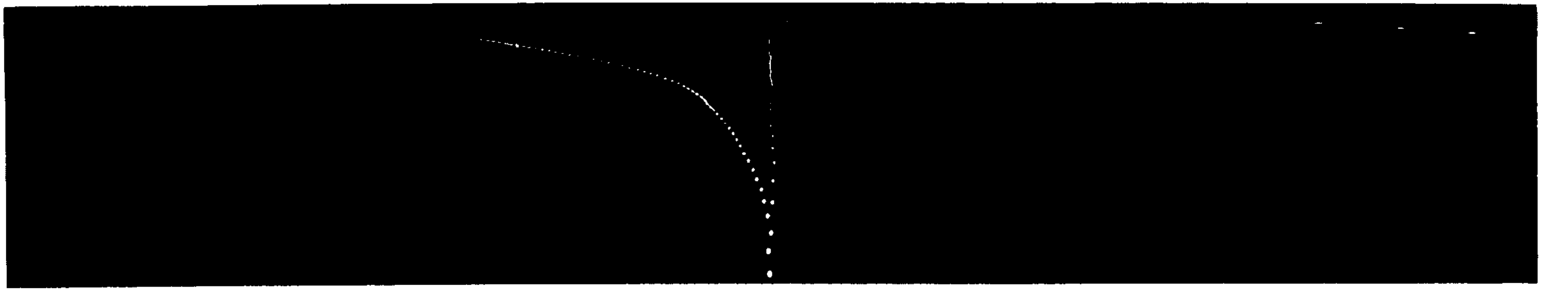
700 ft Ahead of Point of Turn

1500 ft Ahead of Point of Turn

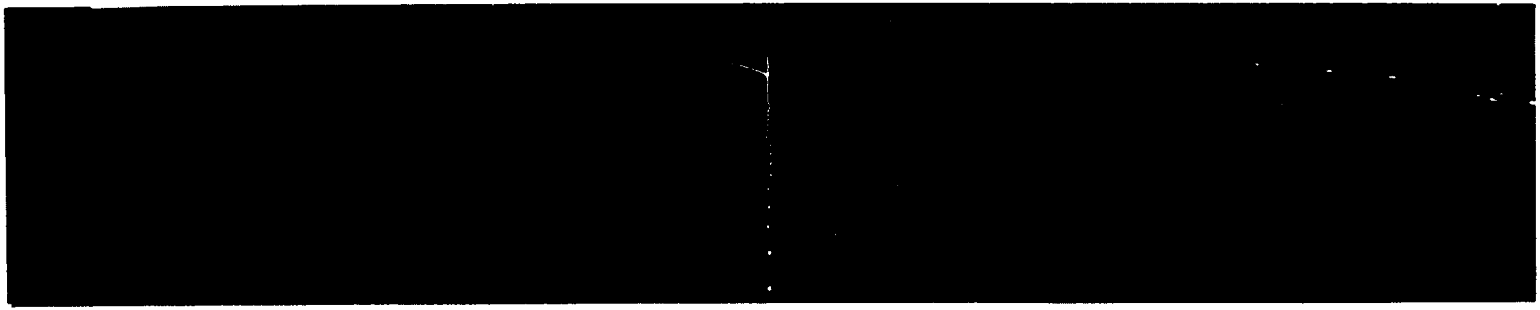
Location of Observer: 13 ft above runway
(Edge: 5W at 14V
Bulb (Centerline:-

Spacing of Lights (ft)				
Edge		Centerline		Throat
Runway	Taxiway	Runway	Taxiway	Runway
50	33	-	-	-

Figure 4. Edge lights only.



At Point of Turn



700 ft Ahead of Point of Turn

1500 ft Ahead of Point of Turn

Location of Observer: 13 ft above runway

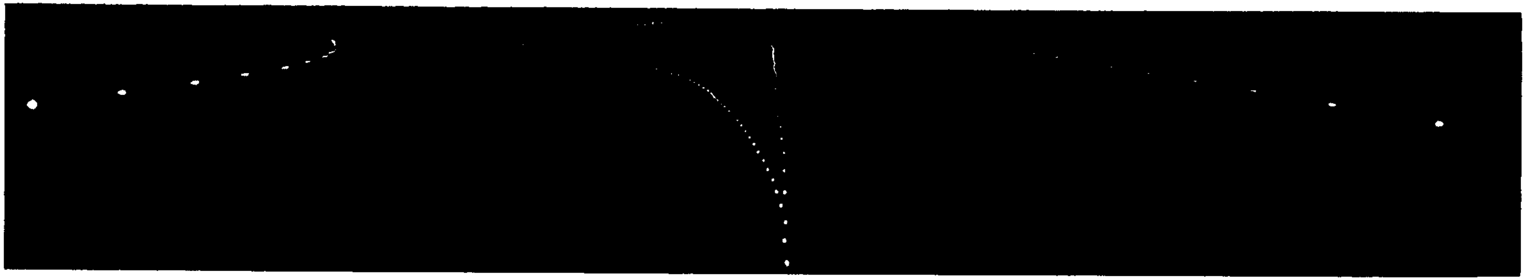
Bulb: (Edge:-

(Centerline: 3W at 12V

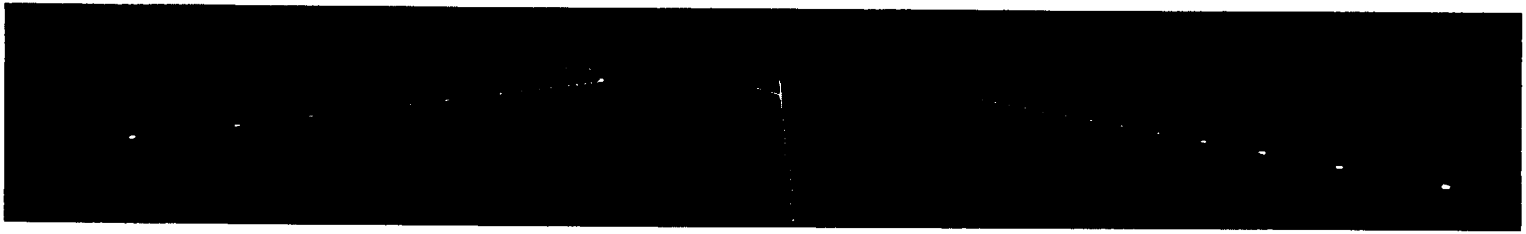
Spacing of Lights (ft)

Edge		Centerline		Throat
Runway	Taxiway	Runway	Taxiway	Runway
-	-	20	10	-

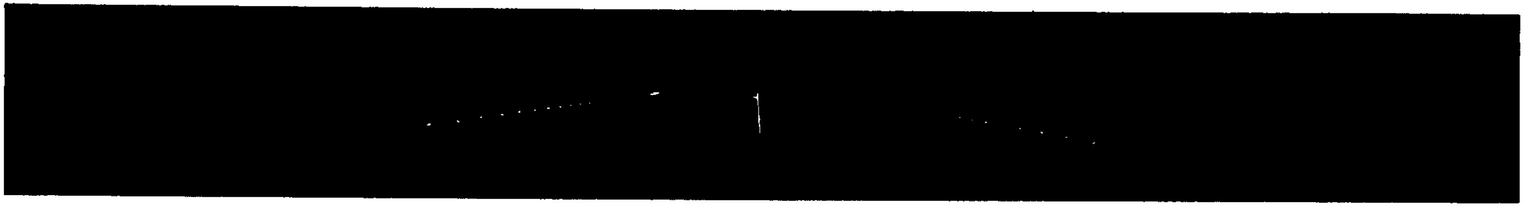
Figure 5. Centerline lights only.



At Point of Turn



700 ft Ahead of Point of Turn



1500 ft Ahead of Point of Turn

Location of Observer: 13 ft above runway
(Edge: 5W at 14V
Bulb: Centerline: 3W at 12V

Spacing of Lights (ft)				
Edge		Centerline		Throat
Runway	Taxiway	Runway	Taxiway	Runway
50	33	20	10	-

Figure 6. Centerline plus edge lights.

stated that the 100-ft spacings on the edges of the runway with closer spacings on the edges of the exit taxiway were satisfactory. Closer spacing was desirable on the far side of the exit taxiway in the region of the junction with the runway. On the basis of these preliminary reactions, the spacings of the lights along the far side of the taxiway were reduced to 3 to 5 ft apart around the nose and 5, 11, and 16½ ft along the remainder of the line extending into the turnoff area. The comments indicated that the guidance provided by the contour type pattern even with fairly wide spacing was so much better than the usual taxiway markings on 200-ft spacings that the turn-off could be made safely with the edge lights only. The point-of-turn was not well defined with edge lights only, but this did not seem to seriously affect the pilot's judgment of the turn-off during the clear weather tests.

With the centerline only the pilot and observer reactions indicated that the system gave a clear and unmistakable path to follow on the runway and clearly indicated the beginning of the turn. The point-of-turn is well defined by the tangent point where the two centerlines meet. With close spacing and the near grazing angles at which these lights are observed the brightness build-up at the point-of-turn due to the ladder effect, is quite apparent. This provides a natural high brightness region upon which the pilot or a motor vehicle operator would automatically concentrate.

In the airport studies the centerline by itself left something to be desired. The observers indicated that, while the path was completely defined, it was important to also know where the edges of the runway were. Thus it seemed that some lack of spacial orientation and uneasiness were felt with the single bright line in a large dark void. For all spacings of the centerline lights up to 100 ft and with either 3- or 5-watt light sources there were no adverse criticisms regarding the flicker or the flash-by effect. With the 5-watt centerline lights operated at 14 volts, the brightness was considered to be too high in clear weather. For normal visibility the brightness at voltages as low as 8½ volts seemed to be more pleasant and quite adequate. Under conditions of adverse weather, fog, etc., it would be desirable to go to the higher voltages.

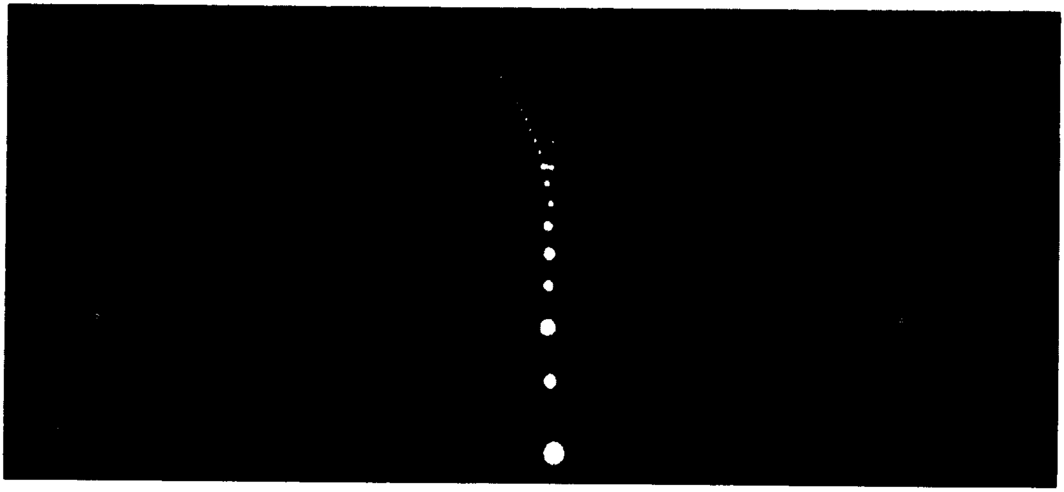
The combinations of centerline plus edge lighting gave the most favorable pilot and observer reactions. This would be expected because of the completeness of the lighting pattern that was developed. It was possible to set up many combinations of spacings and brightness to provide a guidance system using the basic concept of contour perception. The experiments did not attempt to determine the optimum arrangement of lights but were rather to establish the principles upon which a night guidance lighting system could be developed.

It was concluded that the best conditions for night guidance are obtained by drawing full lines of high contrast along the edges and along the centerline of the airport runway and to mark the turnoff point for exit taxiways with a centerline in the taxiway which departs from the runway centerline at the point-of-turn and proceeds through definite break in the edge lighting at the entrance to the turnoff. The edge lighting should develop a completely defined border at the turnoff and the turnoff centerline should extend continuously from the main runway centerline through the exit-taxiway into the turn for a substantial distance. These conclusions which were developed for the airport problem could be applied with very little modification to modern roadways.

On several occasions during the test heavy rain was encountered such that the windshield wipers for the airplanes could not keep the visual field clear. It was noted that the composite system using the centerline plus closely spaced edge lighting was considered to be the best under those adverse weather conditions. On one occasion at McClellan Air Force Base heavy fog was encountered in the early morning hours. The official visibility was reported at 0-0 which may be interpreted as less than 300 ft visual range. The centerline system with lights on 10 ft centers provided rather remarkable guidance under these conditions even though the edge lights became completely obscured. Figure 7 shows the lights in heavy fog.

Fog Chamber Studies

The field work using these lights in adverse weather indicated the desirability of further experimentation. Since fog is rather difficult to control in natural environments,



Pt of Turn Visibility: Less than 300 ft reported at the control tower
4:00 a.m. Sky - dark
3W, 12V centerline
5W, 14V edge

Figure 7. Centerline plus edge lights— heavy fog.

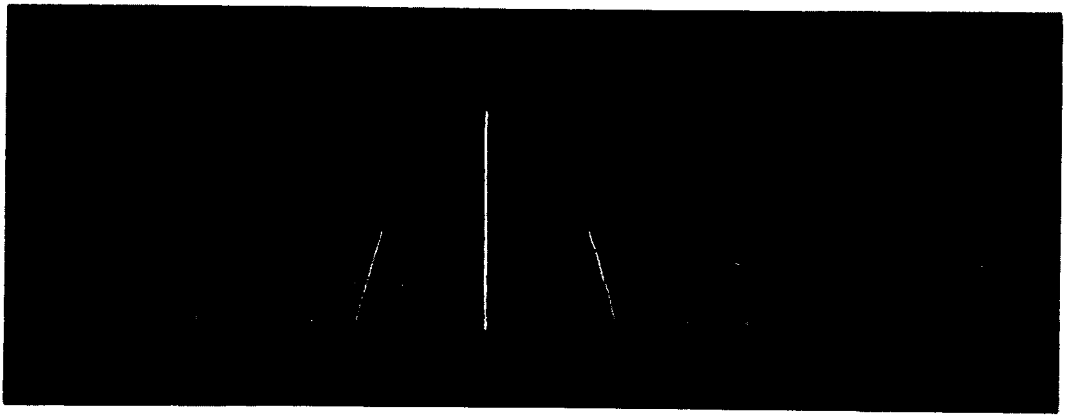


Figure 8. No fog—5 watt lights.

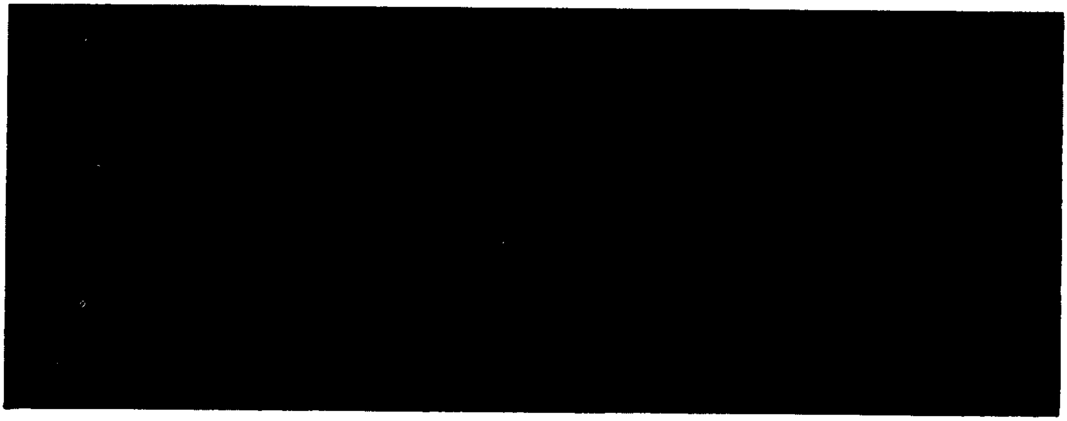


Figure 9. Heavy fog 1 percent transmission to lights at threshold - 5-watt lights.

it was decided to attempt to build an artificial fog chamber so that lighting patterns could be examined under various controlled densities of fog. A suitable chamber approximately 400 ft by 25 ft wide by 25 ft high was obtained on the Berkeley Campus of the University of California under the Edwards Field Stadium. The space was sealed off and a fog generating system installed consisting of special nozzles using air and water under pressure. The details of the fog chamber installation will be described in a later report. Controllable fogs were generated with almost any required density. The lighting pattern to be set up for the San Francisco Airport were set up in the fog chamber as shown in Figures 8 and 9. Various fog densities were used with transmittances of 1 to 100 percent in a 200-ft baseline. The fog chamber studies were used to develop the experimental spacings and patterns of lights to be used operationally at the San Francisco Airport. The San Francisco installation is now largely complete and is in the process of flight evaluation. The spacings at the San Francisco Airport have been decreased to a minimum of 2½ ft between lighting units at the threshold or touch down end of the runway. Provision is made for 15-, 10-, 5- and 3-watt bulb sizes so that the effect of the brightness build-up on close spacings can be studied in low visibility weather. The evaluations are not complete but the preliminary work indicates that the lighting pattern will assist in reducing the weather minimums that are now permitted for the landing of aircraft. If the visual aspects of the pattern prove to be as useful as the preliminary studies indicate, the remaining research that will be required to work out the mounting technique, proper electrical connections, elimination of bulb damage, two-way viewing, and a study of snow removel and dirt collection problems will continue. All of these are important but are secondary to the primary problem of establishing proper visual guidance.

These initial studies suggest that a lineal pattern of lights surface mounted on the pavement may have considerable application possibilities in the highway field. The lights can provide good lineal guidance in almost any weather which is one of the most essential factors in motor vehicle operation.

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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

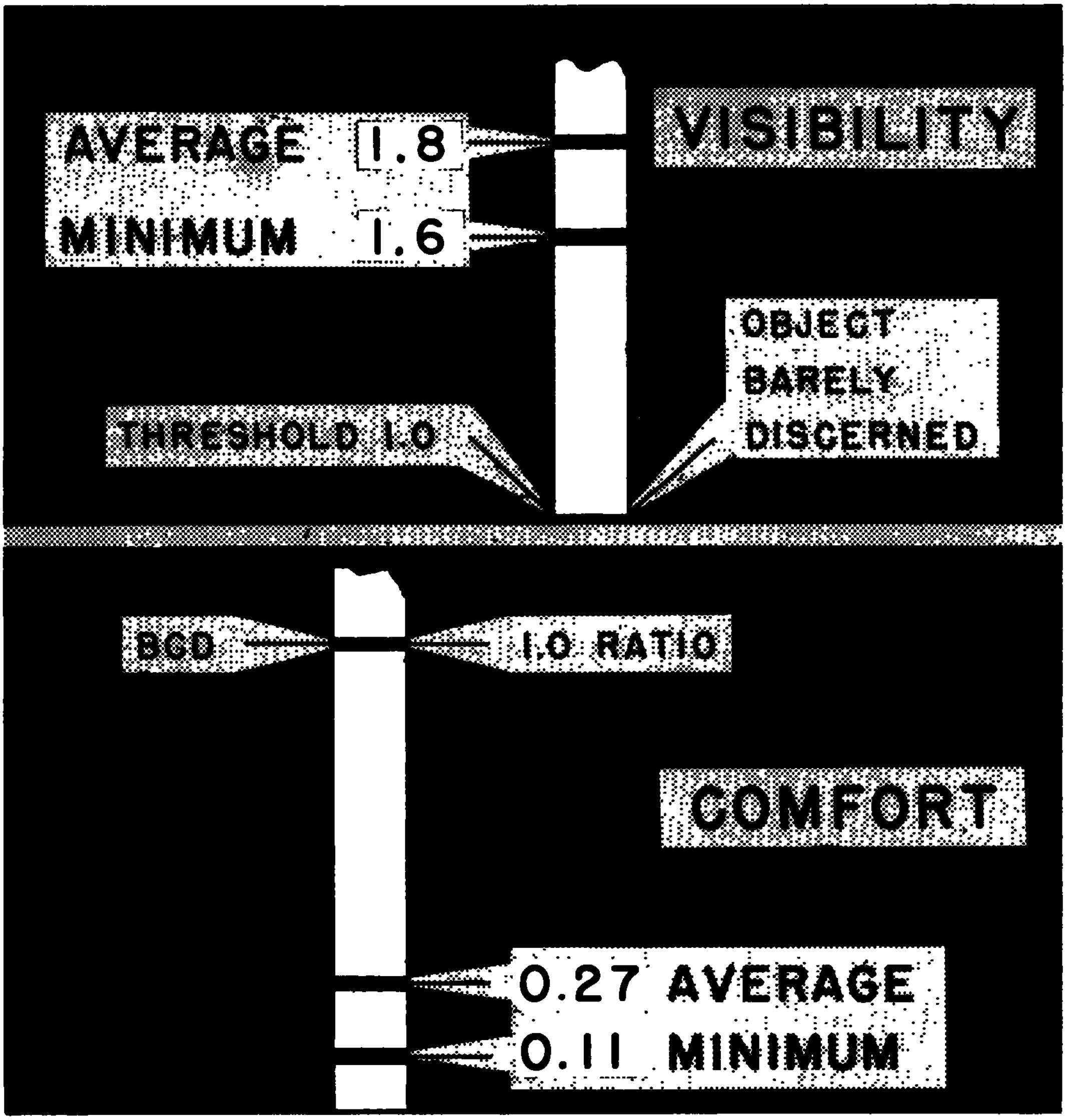


Figure 2. Example of seeing factor ratings for representative roadway lighting systems. Relative visibility ratings (top) may now be accompanied by computed ratings for relative comfort (bottom). The visual comfort rating is relative to the sensation which would be at BCD, the average borderline between 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

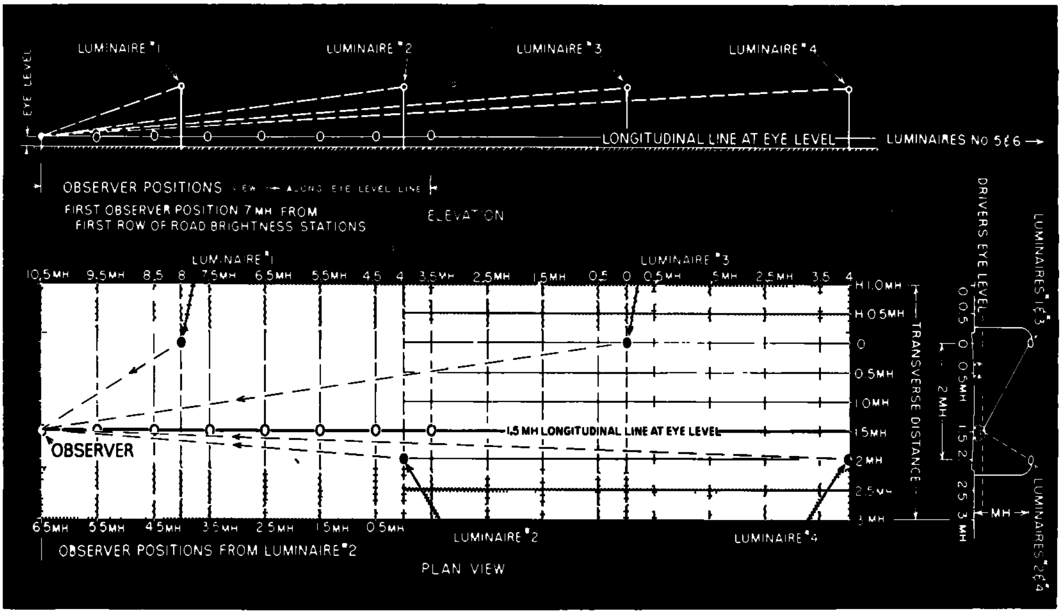


Figure 3. Combined relative comfort and percent loss of relative visibility due to disability veiling brightness is computed for a series of driver-observer positions along the longitudinal eye-level line, also assumed to be the driver's line of sight. This line is 25.7 ft below the luminaire light center. 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.

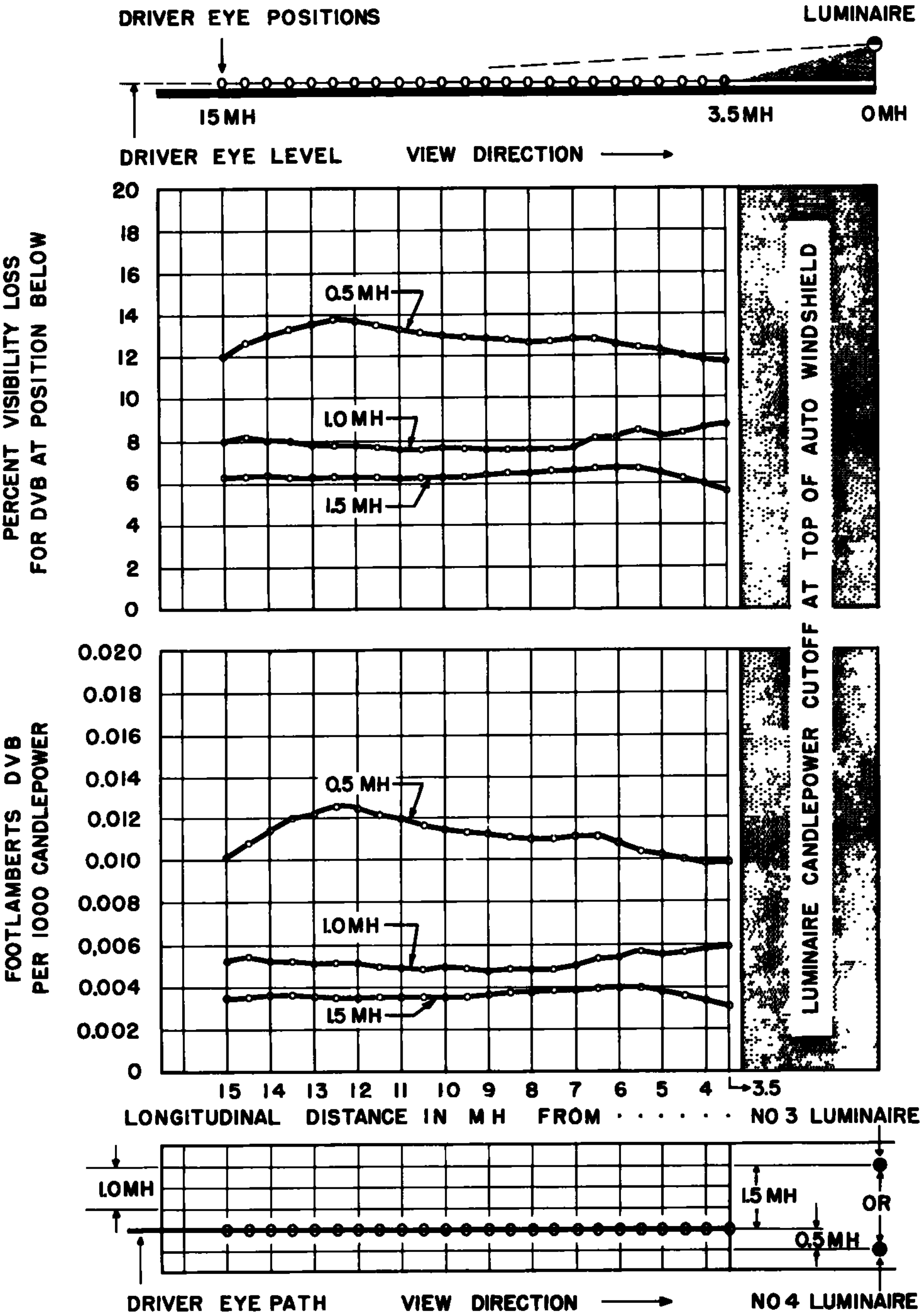


Figure 4. Disability veiling brightness (DVB) produced by 1,000 candlepower from a single luminaire, at a series of driver positions along longitudinal eye-level lines at the indicated distances to the driver's left and right, is shown in lower portion of this diagram. The luminaire is assumed to be 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:

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

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

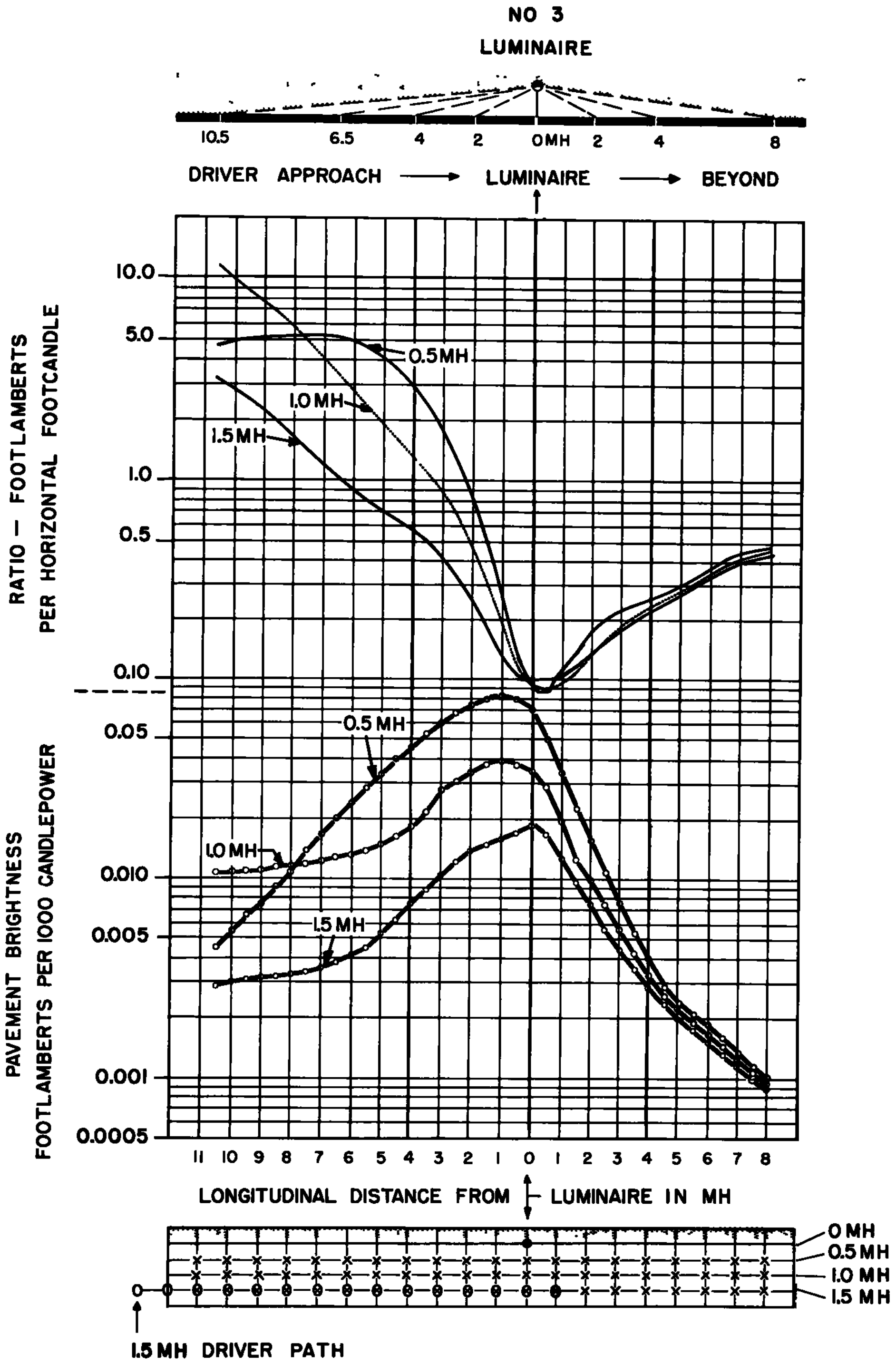


Figure 5. Pavement brightness produced per 1,000 candlepower from a single luminaire at driver's left is shown in lower portion of diagram. Longitudinal distance of driver observation from each pavement brightness station is about 7 MH, or 210 ft. Stations are 0.5 MH (15 ft) apart along the designated 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.

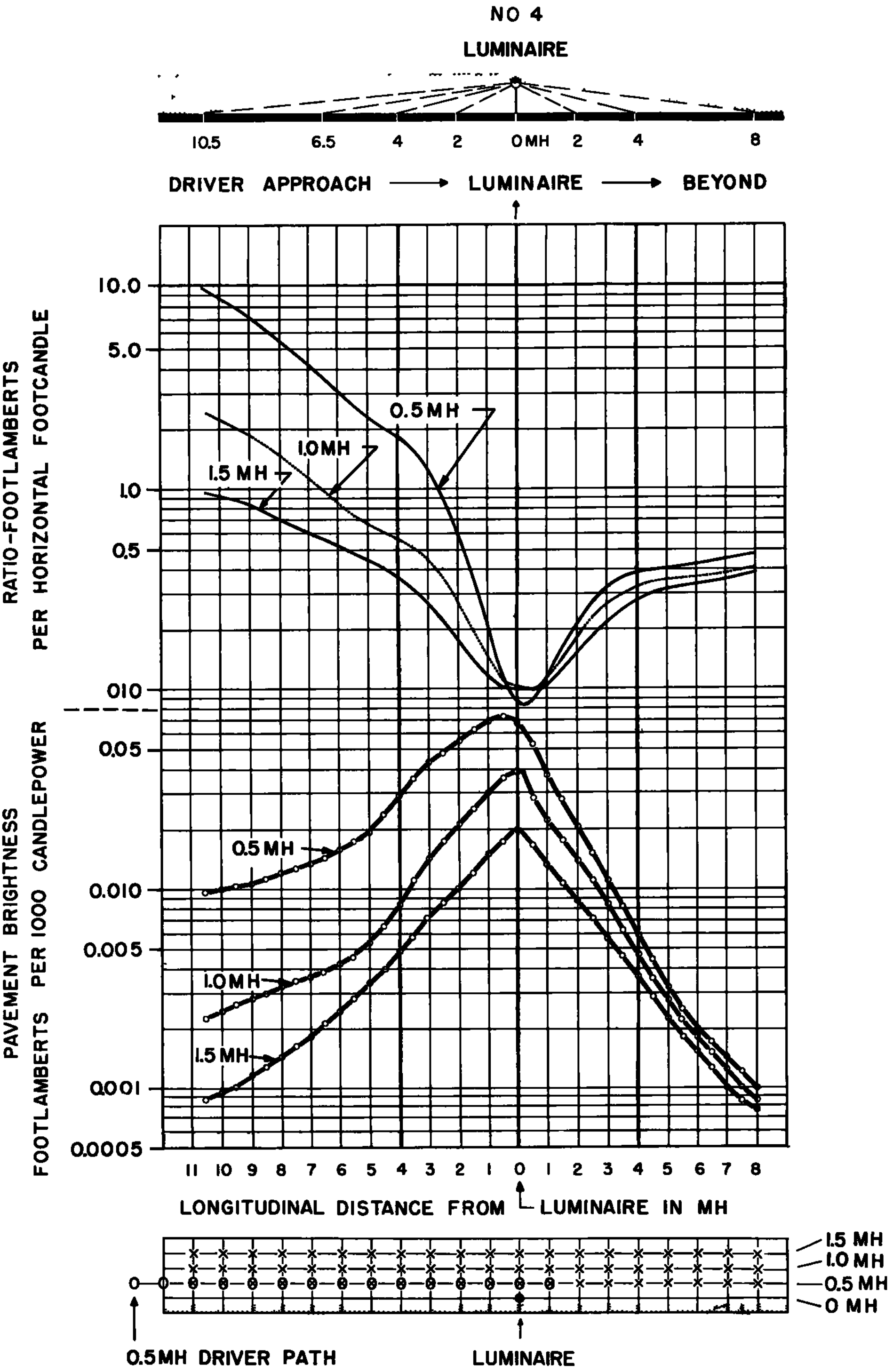


Figure 6. Candlepower from single luminaire on driver's right and at distances greater than 1.0 MH on approach side of luminaire is less effective than candlepower from No. 3 luminaire (Fig. 9) in producing pavement brightness at stations along the 1.0 MH line along center of roadway. With the staggered 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.

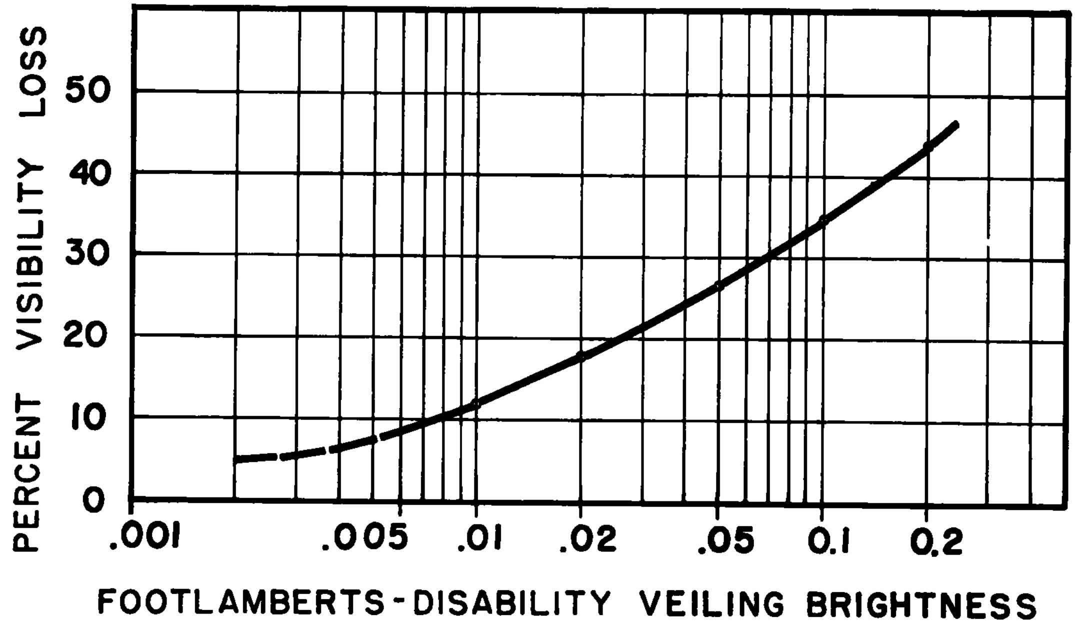


Figure 7. Percent loss in relative visibility increases with increase in disability veiling brightness (DVB) in footlamberts at the driver's eyes. Percent loss applies only to the relative visibility rating above 1.0 threshold. Percent visibility loss includes a Reid-Chanon (28) estimate as to effect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

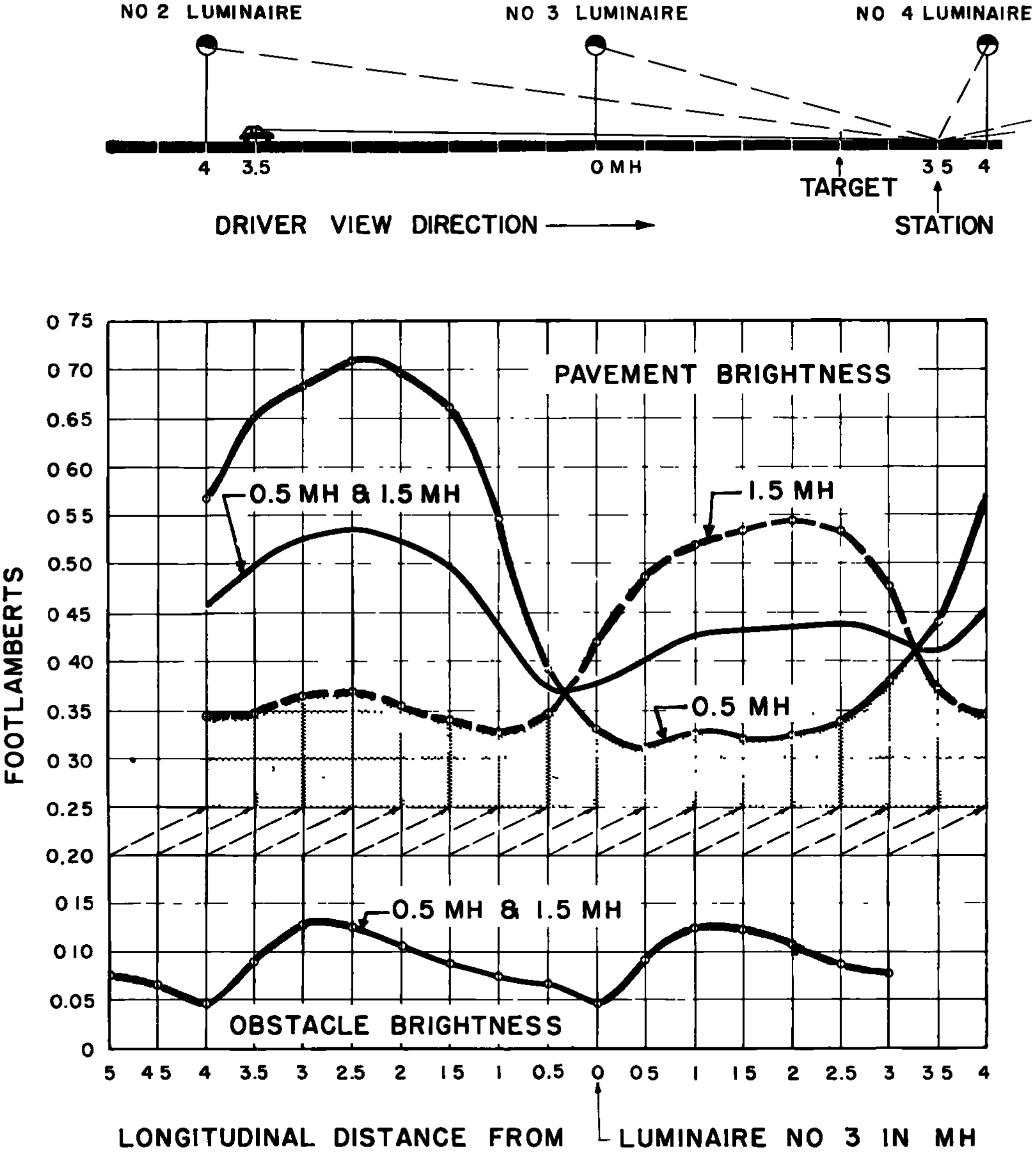


Figure 8. Combined pavement brightness produced by representative roadway lighting system varies at stations along the 0.5 MH or 1.5 MH roadway lines. Pavement brightness curve designated 0.5 MH and 1.5 MH is transverse average of brightness at the two stations at each longitudinal distance. As indicated 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.

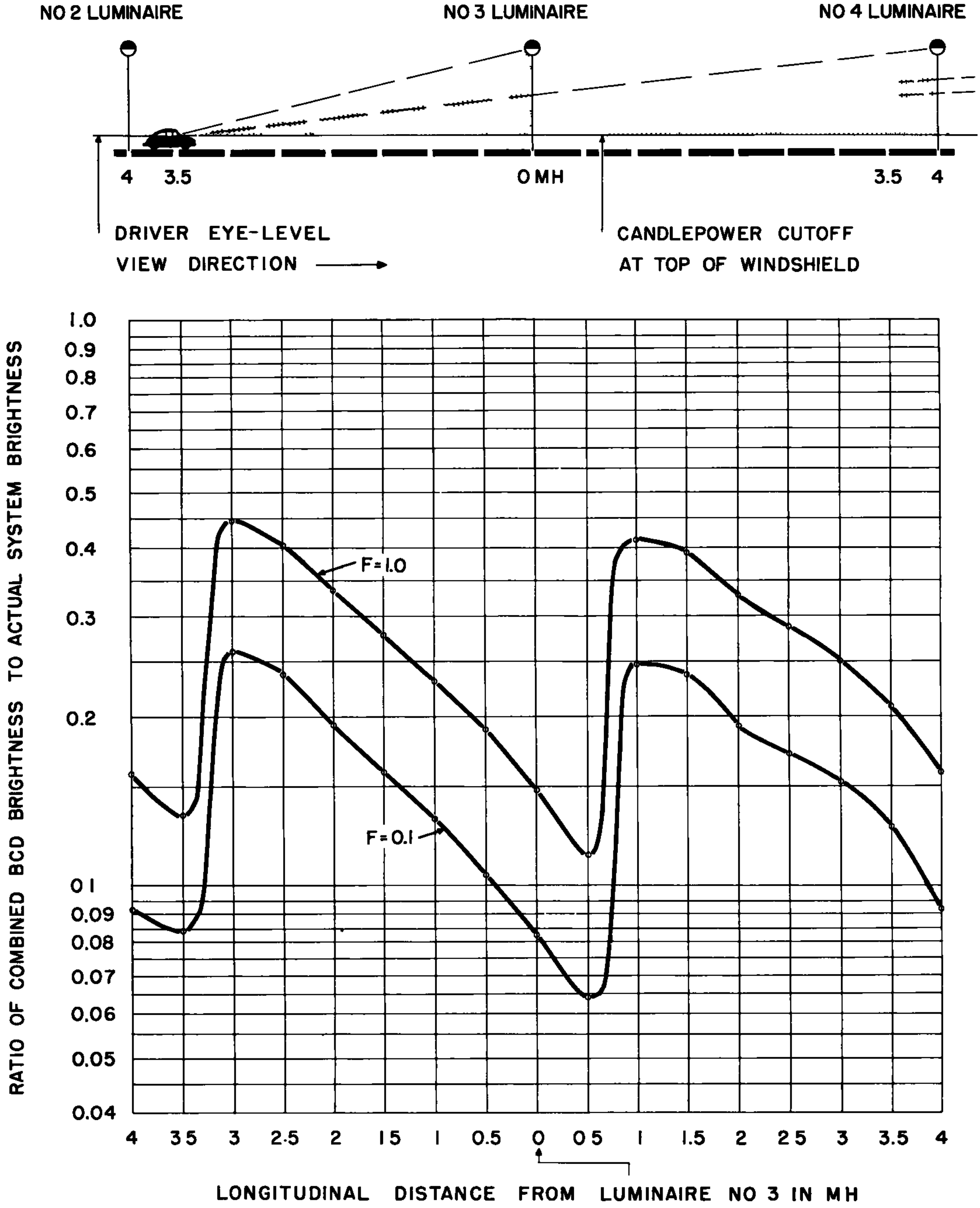


Figure 9. Relative visual comfort ratios vary with motorist position with respect to luminaires along roadway. Control of luminaire candlepower along eye-level line, and top-of-auto-windshield cutoff improve the visual comfort rating. Average and minimum ratings for field brightness (F) = 1.0 footlambert 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 $\overline{\mathrm{BCD}}$ 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

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

For F = 0. 1 footlambert

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

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

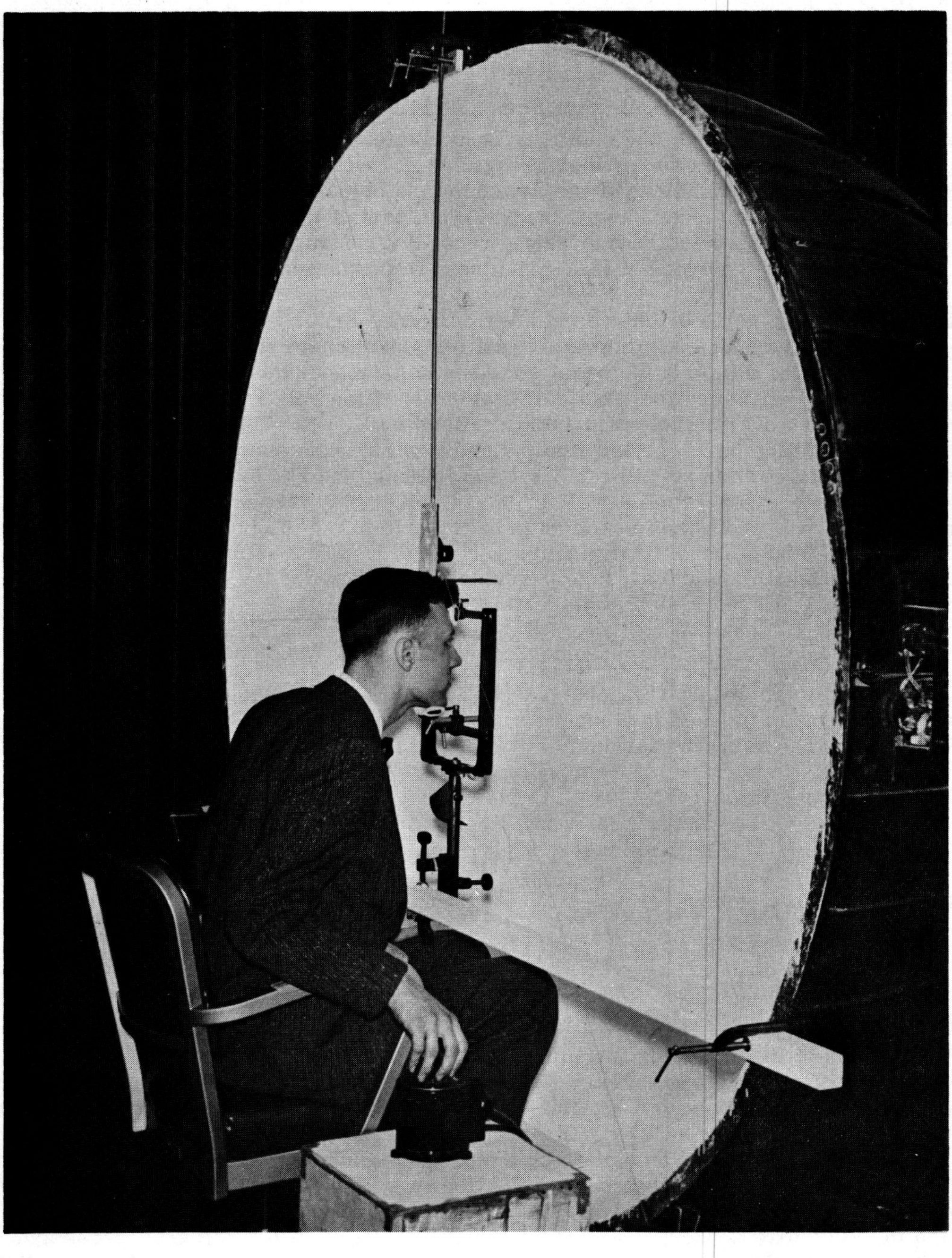


Figure 10. Computed relative visual comfort ratings are based on BCD data provided by laboratory studies over a period of seven years at Case Institute, Cleveland, Ohio. The study determines the BCD brightness on the driver's line of sight for variations of field brightness produced in the hemisphere 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.

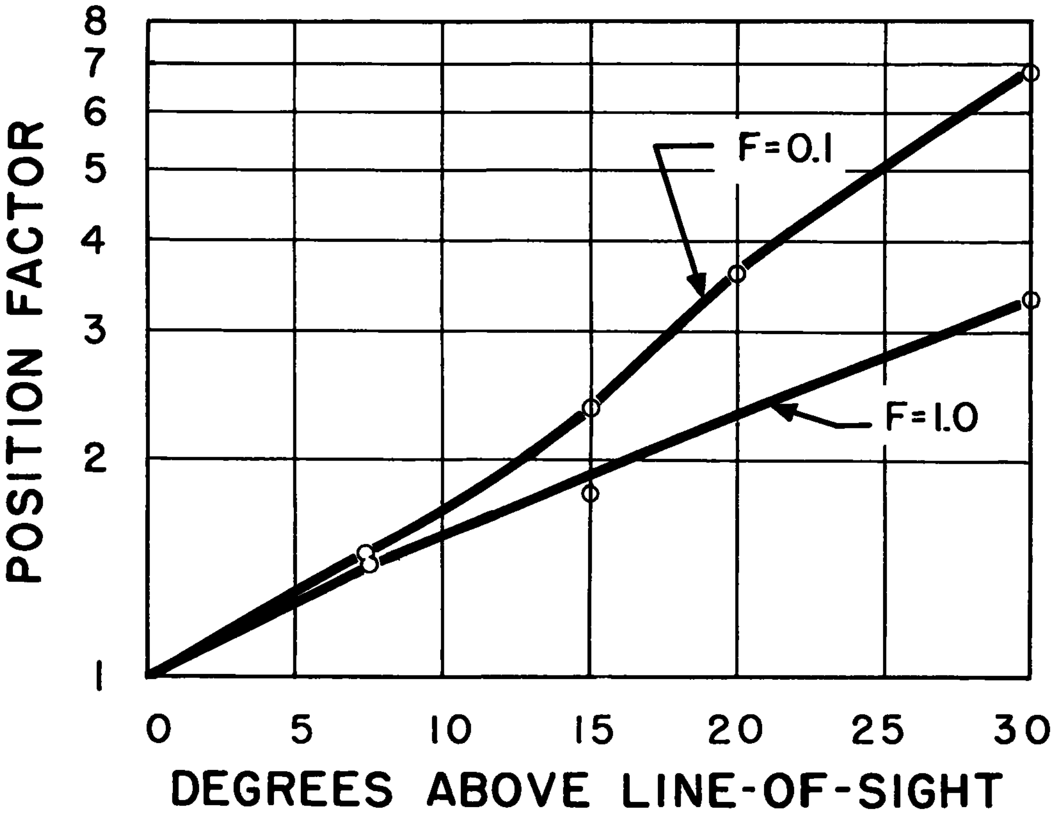


Figure 11. Luminaire position factors, used in computing $\bar{B}$, or the BCD sensation brightness for the system luminaires, are derived from Putnam and Bower 1957 data (19) for field brightness, F = 0.1 footlambert, and F = 1.0 footlambert. $\bar{B}$, or the BCD brightness, of each luminaire size 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.

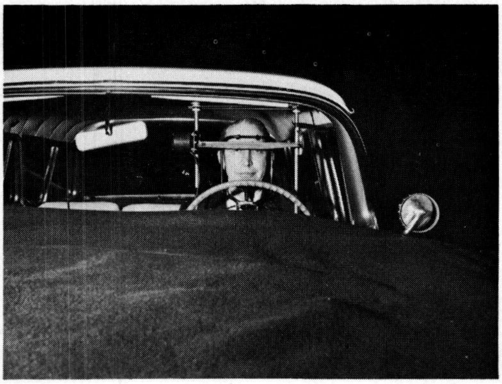
The same (Fig. 3) luminaires, driver positions, distances, and candlepower along the driver's longitudinal eye-level line are involved, as previously used in computing the actual and BCD brightness of luminaires for relative visual comfort ratings.

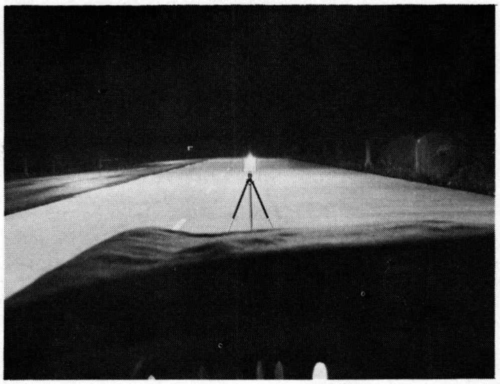
To compute DVB for each luminaire-driver position, constants (13, 11, 12) are now available in terms of DVB per 1,000 candlepower. The constants include driver viewing angle θ and distance from each luminaire in accordance with the formula (2, 3) suggested by the Technical Advisory Committee of IERI.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

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

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.





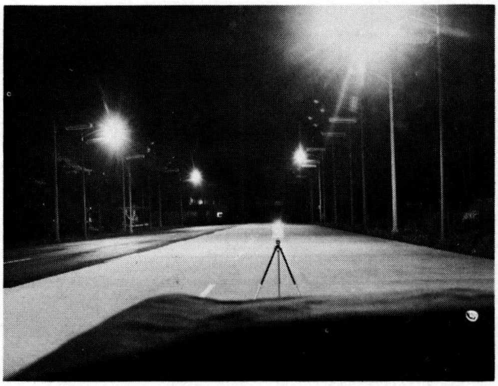


Figure 12. Computed relative visual comfort ratings are consistent with night studies involving more than 400 observations being conducted on outdoor laboratory street at Hendersonville, N.C. using Guth evaluator (31). Upper left photo shows observer in test automobile with evaluator headrest shield 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

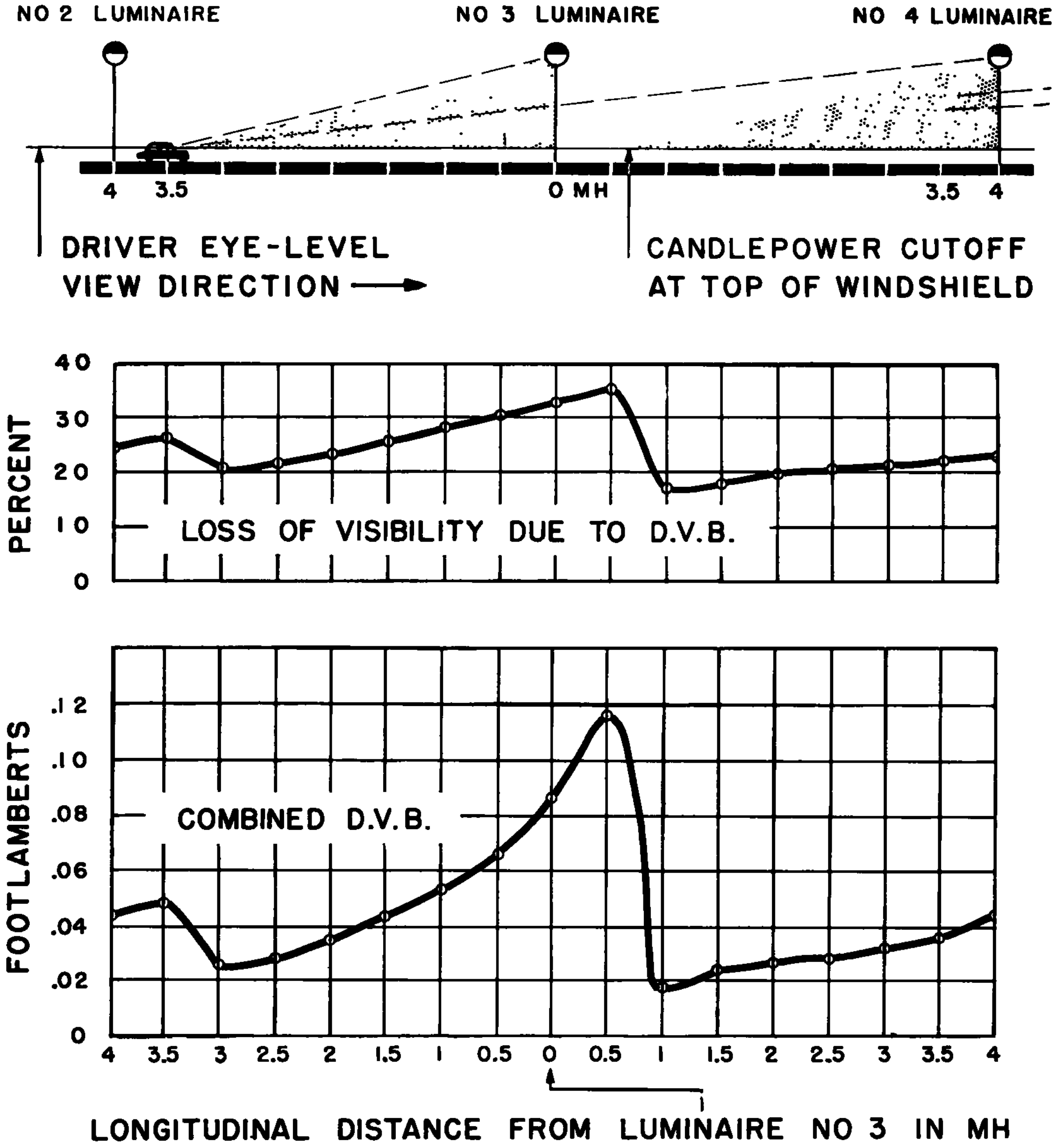


Figure 13. Percent loss in relative visibility due to combined disability veiling brightness, Σ DVB, from lighting system luminaires varies with driver position along roadway due to (a) control of luminaire candlepower, (b) driver viewing angle, (c) distance from each luminaire, and (d) top-of-auto-windshield 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

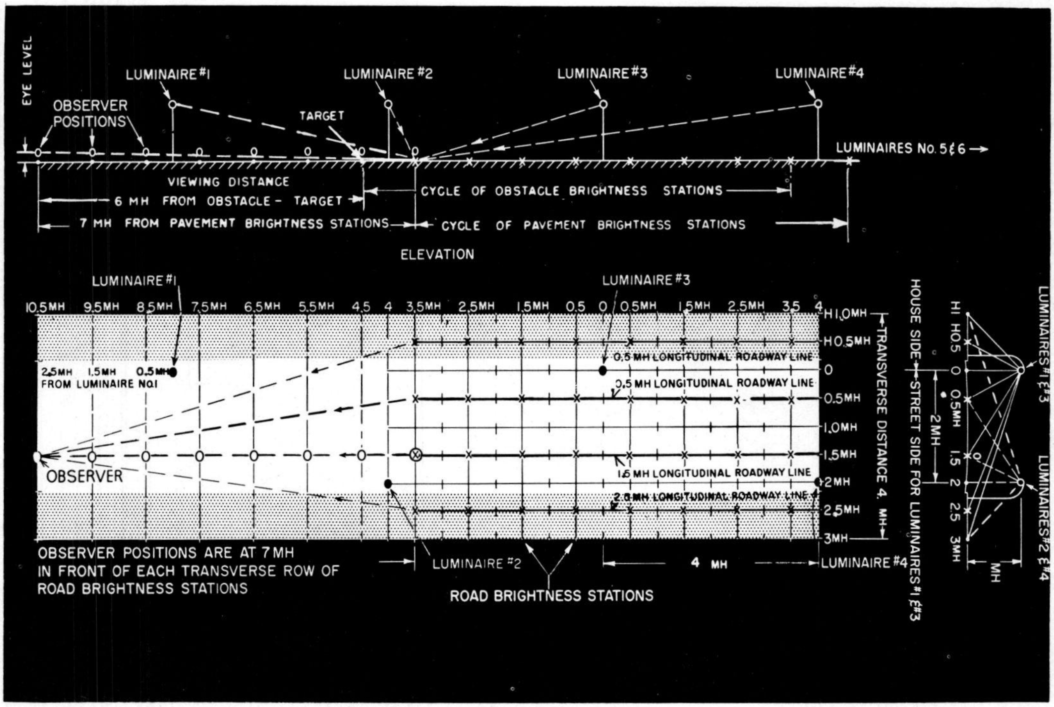


Figure 14. Representative roadway, lighting layout, and conditions for computation of relative visibility, and pavement and obstacle brightness. Driver-observer movement and view-direction is from left to right along 1.5 MH roadway line. Pavement brightness stations and luminaire No. 3 are considered 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

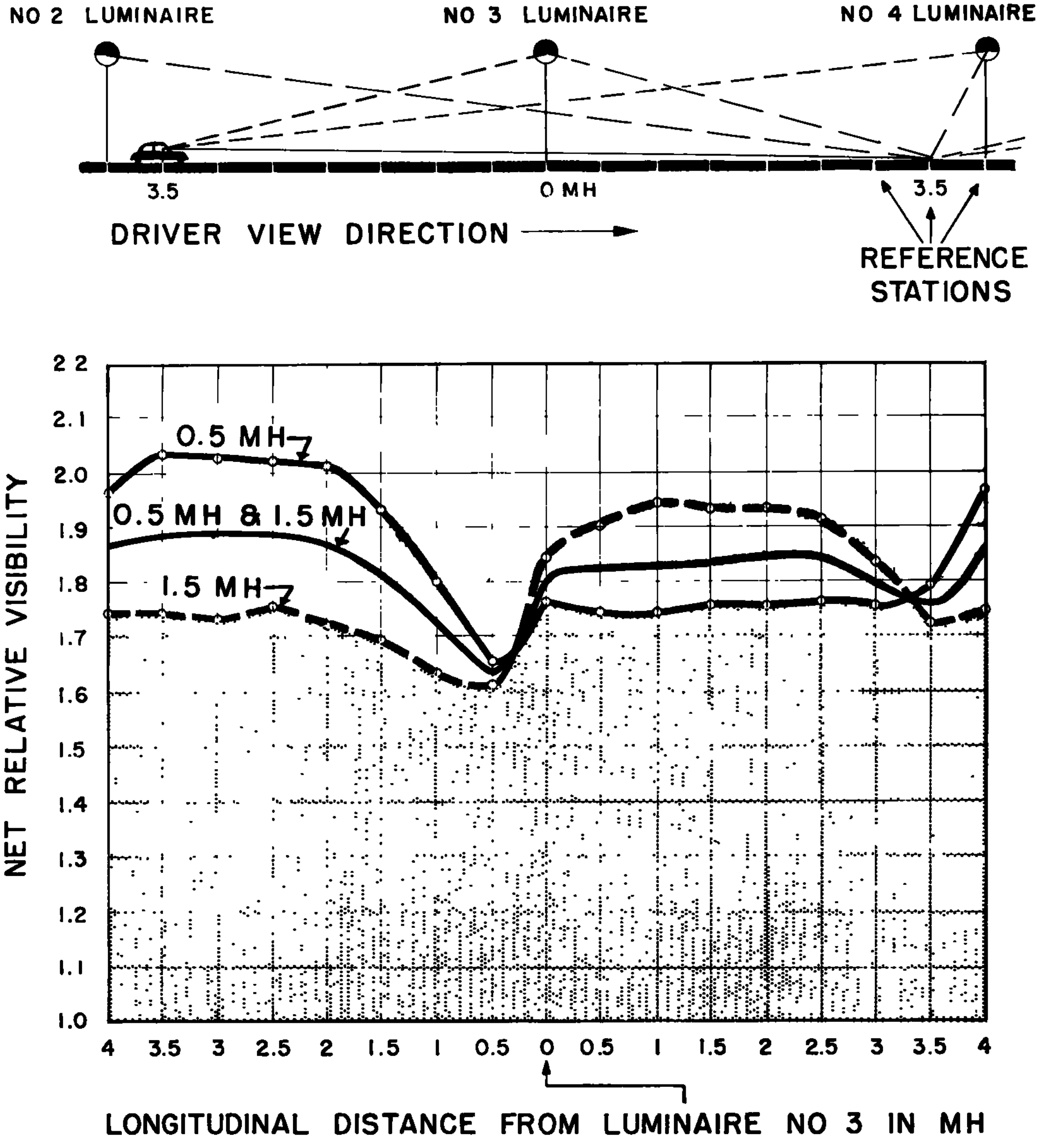


Figure 15. Combined net relative visibility produced along roadway by lighting system varies with longitudinal and transverse location of pavement brightness stations which driver is viewing from a distance of 7 MH. Relative visibility is shown for each roadway line, 1.5 MH or 0.5 MH. Shading shows that 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:

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

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

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

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

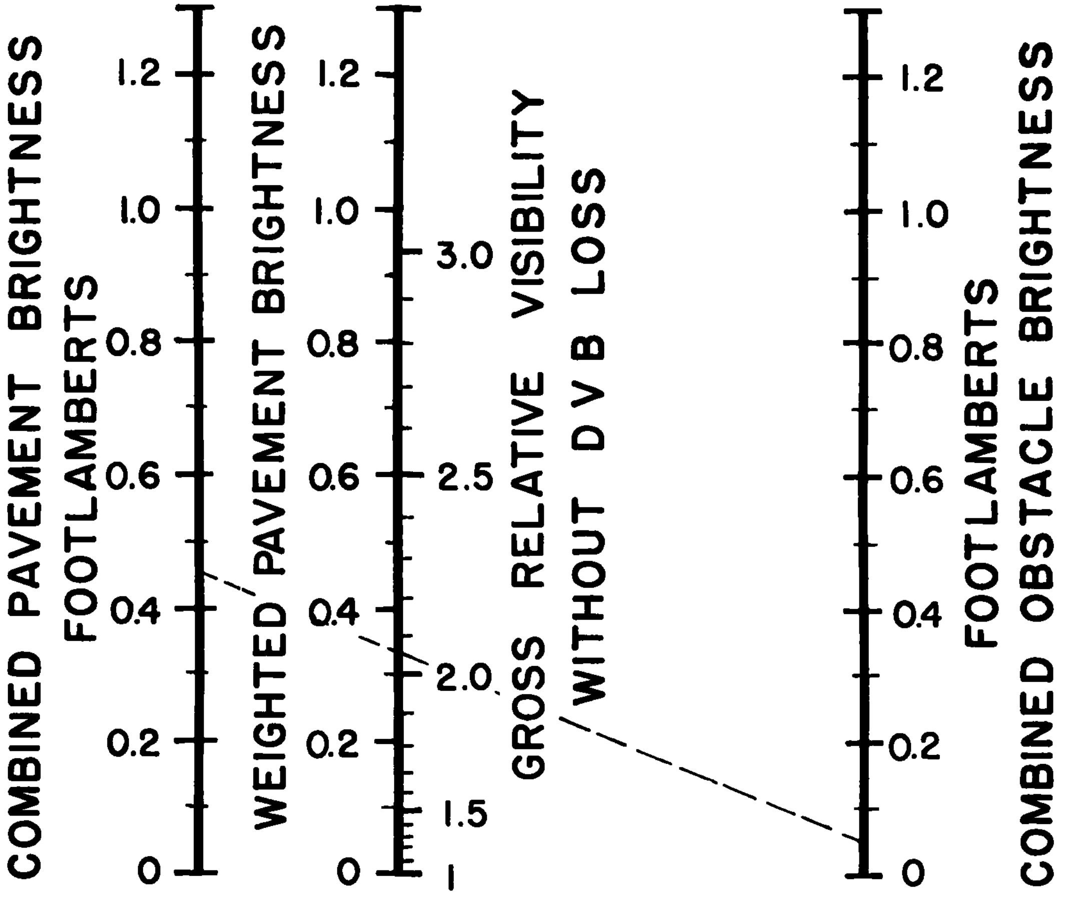


Figure 16. Nomograph for computing gross relative visibility. Combined pavement brightness at a station (left) is connected with combined obstacle brightness 1.0 MH ahead of the pavement brightness station (right) to get weighted pavement brightness and gross relative visibility, without DVB loss. Example 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.

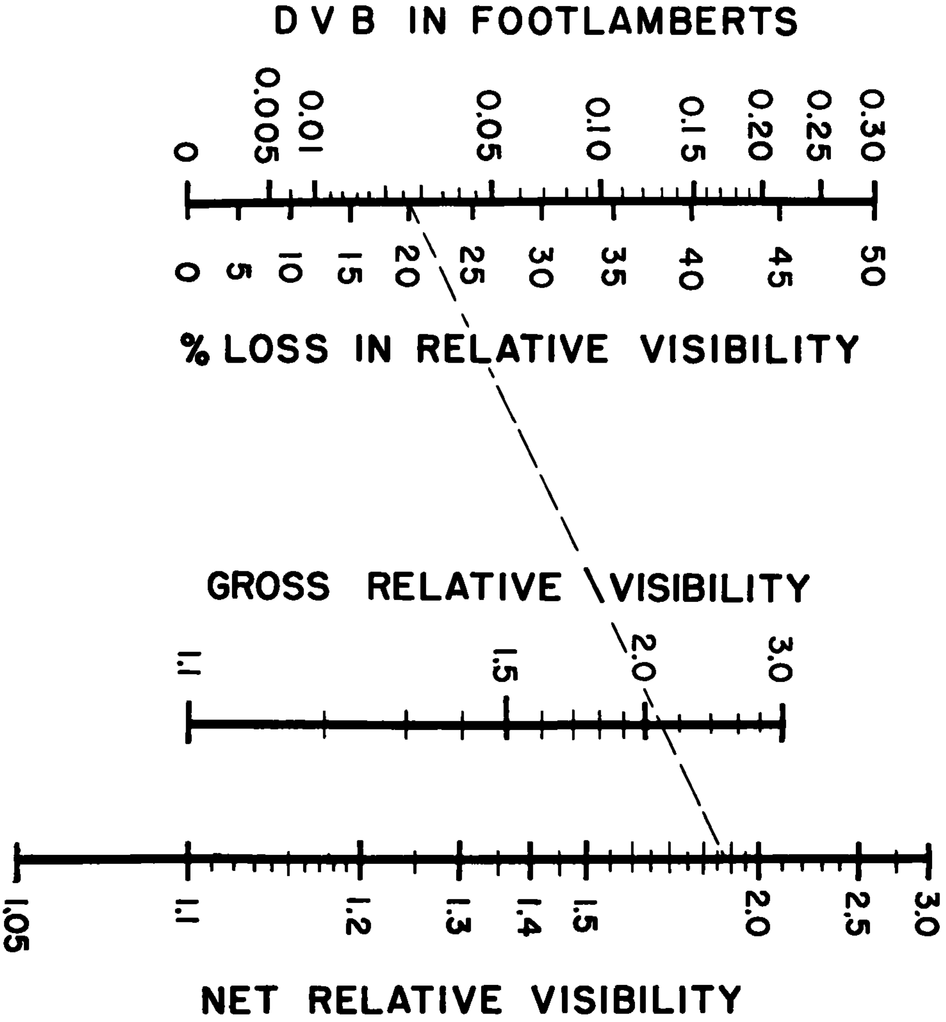


Figure 17. Nomograph for computing net relative visibility. Disability veiling brightness, DVB, and percent loss (left scale) are connected with corresponding gross relative visibility (middle scale) to give net relative visibility (right scale). Net and gross relative visibility are at pavement brightness 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

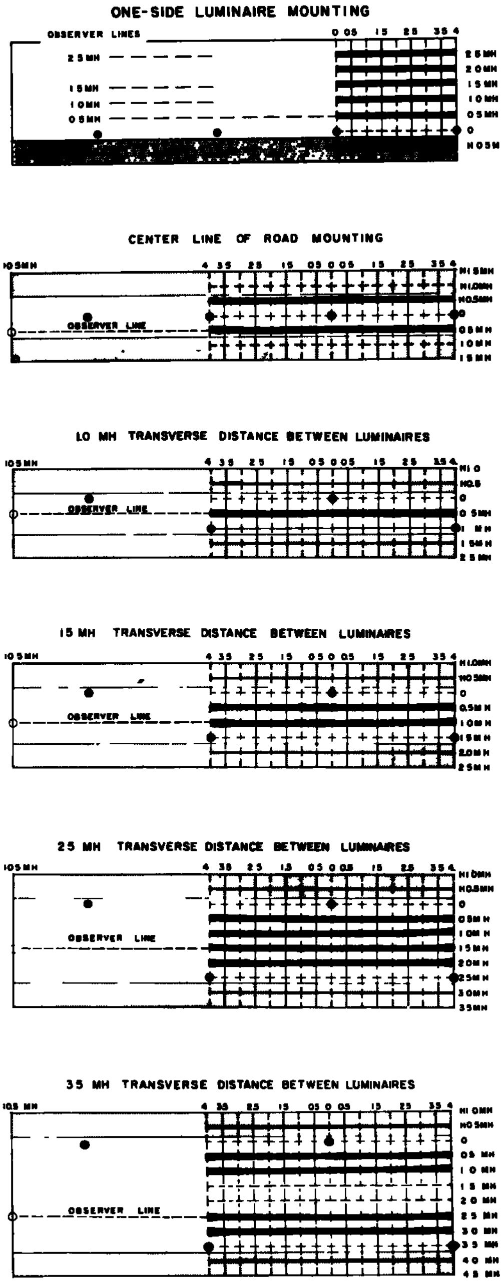


Figure 18. Relative visual comfort and relative visibility ratings should be computed and compiled for representative layouts of roadway lines, and driver-observer eye position lines involving typical luminaire sizes and candlepower distributions. Then, by interpolation, ratings may be estimated for 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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Vision at Levels of Night Road Illumination

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● LEBENSOHN (35) states that "the prime reason for the excess of night accidents is inadequate vision." Visual field defects (including one-eyed drivers), unreliable visual clues, glare, errors in judgments, age, senescence, fatigue, and better testing methods are discussed. Richards analyzes and summarizes the basic problems of night automobile driving (57) and reviews (56) the 1956-57 literature. Windau (65) lists references on motorists' vision. Hirsch (28) considers the night accident problem. The Armed Services Symposium on visual factors in automobile driving brought together people and information, but a last-minute shift in ground rules did not help the organization of the material (6, 9). Night driving received attention. Form discrimination is thoroughly discussed (66) and the NIH symposium is of interest (44) although neither specifically considers night visibility.

The American Standards Association Z7.1 on Illuminating Engineering Nomenclature and Photometric Standards is being revised (31) and the CIE International Lighting Vocabulary is available in English, French, and German (15).

Pirenne Marriott and O'Doherty (49) have measured night vision efficiency. Variation between individuals is considerable. Thresholds for flash area and Landolt C tests are similar, for the same amount of light and training is necessary to find and use the most sensitive part of the retina. Information is available for use at mesoptic levels encountered at the lower levels of night driving.

Blackwell (10) summarizes his 1957 work on rate of seeing, contrast, illuminance and probability of seeing and reports a decrease in the amplitude of accommodation and in accommodation vergence with decreasing illumination. Crouch (17) describes the Blackwell research and includes the new lighting recommendations of the Illuminating Engineering Society. Noting the curve for a 4-min subtence target, a visual capacity of 5 assimilations per second, 99 percent accuracy, and a 15X safety factor, a contrast of about 1.3 is required at 4 ft-L and 170 at 0.03 ft-L. The lack of such contrasts at these levels of illumination, commonly found in night driving, re-emphasizes the difficulty of seeing at night with inadequate light.

Putnam and associates (53, 54) report on discomfort glare at adaptation levels within the night driving range. The information should be useful in planning highway lighting. Adaptation to glare could not be predicted according to Simonson (60) from the continuous decline of light sensitivity under glare and the speed of glare adaptation reveals a considerable range of individual variation. Russel (58) compares the glare from upper and lower beams at various distances from the driver. Differences in visibility of objects are considered. Light road surfaces are better for showing obstacles with dipped (lower) beams. Glare sensitivity increases with age. Case, Davey and Spooner (14) investigated the effect of putting a green light in the car to raise the dark adaptation of the driver. This higher threshold makes resistance to glare easier and recovery from glare is more rapid, but at the higher level one cannot see dim objects as well. With little oncoming traffic lessening the dark adaptation is a handicap. They conclude that it is doubtful whether the gain in ability to resist glare is worthwhile, should that gain in central vision be accomplished by reduction of peripheral sensitivity.

Dynamic visual acuity, measured with a moving test object, seems to have little or no relation to visual acuity measured with a stationary target and considerable research is directed toward the problems of visibility of moving objects. For the high speeds of jet aircraft the eye-body reaction sensitivities are no longer adequate to prevent collision with the distances at which they may be seen (8). Brown (13) reports an upper speed threshold for a line flashed on a screen by a moving disc of about 4 log µL and about 3.3 log minimum visual angle per second. The visual acuity needed to see a checkerboard target at different exposure times from 1/500 to 1 second are given by Zanen and Klaassen-Nenquin (67). Van den Brink's dissertation (11) provides data on retinal summation and the visibility of moving objects. The data are analyzed primarily in terms of their fitting of van der Velden's two quanta theory for vision. He also reports static and dynamic visual acuities to be different.

Ludvigh and Miller (37) have examined dynamic visual acuity with pursuit movements and conclude that the loss in dynamic visual acuity is due to decreased contrast from blurred images. With greater illumination the acuity is better. Another paper (41) indicates that the illumination must be increased appreciably to obtain the same dynamic visual acuity with increasing velocity of movement. Hulbert and others (30) have made an analysis of dynamic visual acuity and its effect on motorists' vision. Two types of studies are reported; one using motion pictures of signs made at a constant speed of 33 mph, and the other using an acuity target moving on a screen. They report that the critical speed which seems to separate static visual acuity from dynamic visual acuity probably lies between movements of 60 deg per second and 120 deg per second, and conclude that there probably is a previous unmeasured aspect of vision underlying dynamic visual acuity that is not correlated with static acuity. These studies show that for night vision at higher speeds, either more lighting, or better and larger signs are required. If this cannot be done driving speeds must be reduced sufficiently to compensate for the difference in dynamic visual acuity.

An alternative is properly lighted signs having better readability. Prince (51) shows that certain reading material can be read 20 percent faster when the spacing of the letters is at a substance of two min and that astigmatism causes less loss of vision for the greater letter spacing. Allen (1) reports that letters with a visibility in daytime of 88 ft per in. can be seen at 34 ft per in. at 0.1 ft-L at night, a loss of over half the distance.

The general problem of the visibility of road markings is discussed by Warner (63). Some of the signs seen on his trip were inadequate and his stress on color contrast with the different colors of soil and surround is important. Colored roads (5) are among recent highway experiments. One county in California has a law limiting colors for signs that may compete with traffic signals and Finch (21) has devised a color meter for the measurement of these colors. It must be remembered that color fails to give information from dim light to darkness and that it may be confusing or misleading for the eight or so percent of humans with deficient color vision. Walls' (6) recommendation that signs use form or shape instead of color to convey information should be followed.

Lorimer (36) points out the advantage of reflectorized license plates to reveal the presence of a car, especially an oncoming car with only one front light. Vertically or horizontally oriented objects are more visible than objects at 60 or 120 deg to the horizontal (45).

The problems and the instruments available for measuring visibility on the roadway at night are discussed by Finch and Palmer (22). Below 30 ft-L Hopkinson (29) found the same relation as did Stevens between brightness and luminance, that is, psychological brightness equals a constant times the luminance (photometric brightness) raised to the 0.3 power. Perceived brightness depends on the amount of light reaching the retina of the eye and the activity of the central nervous system and is the input which triggers the response of the driver. The same road lighting is dimmer for older drivers (7, 33, 40). There is much to be learned on individual variation and this knowledge will likely be the guide for the highway lighting engineers of the future.

The iris of the eye regulates the light reaching the retina and Seitz (59) has measured the ability of the pupil of the eye to dilate with respect to age. Sex and the color of the iris have no effect, but the pupil dilates less as the person becomes older. The maximum width of the pupil was reached in about 2-min of dark adaptation, but the pupil opening varied considerably with individuals. Another study (32) reports no differences in sex or with iris color, but that the mean error of the pupil response to dark adaptation also increases with age. The nature of the reflex of the pupil response is being investigated by Stark and Campbell (61). The small fluctuations in pupil area of about 10 percent probablv do not affect visual acuity. They conclude that there is no need for better control and that this may be an economy in the evolution of organisms.

Lauer (33) believes night vision is sufficiently different from day vision that both photopic and mesoptic vision should be measured with proper equipment for evaluating night driving vision. Fovea-cortex relations are investigated by Dzn (20). Detail in a grating pattern of 5 min of arc or less is detected by the cones in the retina and larger detail by cones and rods or by rods (12). Swartz and Dimmick (62) publish scales for conversion of Snellen to Orthorater scores and vice versa. Otero (48) finds that night myopia remains after breaking the binocular convergence and that this latter is no longer an explanation for the night myopia.

Movements of the eyes affect vision and their relation to the stability of the visual world is discussed by Gregory (25). Electroretinographic studies are summarized by Granit (24). Eye movements and the timing of muscular adjustment are reported by Miller (41). Eye movements must play a part in dynamic visual acuity. (Cf. also, 10).

Intermittent illumination may be helpful under certain conditions and Nachmias (43) has confirmed and extended Sender's conclusions. Collins (16) reports on the variation of flicker fusion and Geratherwol (23) determined that light flashing three times a second and twice as bright as the surround had great conspicuousity.

Improved lighting of roads with polarized, low light is proposed by C.R. Marsh (39) and visibility in fogs is discussed by Pritchard and Blackwell (52).

Weymouth (64) has reported that visual gradients from the fovea out seem to be linear for 20 to 30 deg for a number of visual capacities. Two groups of chauffeurs averaging 23 and 53 years were tested by Baumgartner and Bernard (7) showed that for a Landolt C the average threshold for perception was 32 percent greater and for orientation 34 percent greater for the older than the younger drivers. Decreases in vision with age are summarized by McFarland and Domey (40).

Ogle published a brief review (46) of the present status of knowledge of stereoscopic vision and that the same acuity is found at 0.5 and 10 meters (47). Contrary results of other observers are explained. The problems of stereo image decentration on apparent size have been investigated by Renshaw (55). The dearth of studies of stereoscopic vision at night driving levels is obvious and this would be a possible field for research.

Problems of human dimensions and convenience of automobile and truck driving compartments might well consider some of the dimensions given in Pores' article (50). Comfort is important for good night driving (57).

Discussion continues as to what motorists' vision should be and on licensing problems. Two editorials from The Optician summarize work done in other countries (3, 4). For bus drivers in England, visual acuity must be 6/9, 6/12 without glasses, although 6/12, 6/24 does not disqualify if glasses cannot correct to at least 6/9, 6/12. About 10 percent were rejected for eye defects. They implied that a 6/12, 6/24 minimum is required for uncorrected vision and 6/9, 6/36 with glasses for safe driving. Lebensohn (35) summarizes American requirements in different states. Lauer (34) also surveys various state requirements and he notes that the examinations are getting more and more complicated in form and that the time has come when he believes that the examining procedure should be simplified. Requirements for drivers in motor racing are summarized in an editorial in The Optician (2).

Davey comments about automobiles on viewing a motor show, particularly on the Continental and American cars with windshield curvatures of 7 to 8 diopters and considerable distortion (19). Various features of automobiles which would help or hinder seeing are mentioned.

The problems of prescribing for drivers are discussed by Hardy (27) who favors single vision lenses, although he notes that there are occasions when near vision is required and that bifocals are not necessarily fraught with danger. He does not favor the use of yellow glasses although he states that there is some evidence that weak neutral filters have improved efficiency of driving on long runs without unduly reducing acuity in poor light. Maximum acuity for distance is important and an adequate horizontal field of vision is essential. Special care should be given to fitting comfortable frames with freedom from blind spots. His point is well taken that the best glasses can be nullified when the windshield or glasses are dirty. Crundall (18) discusses the problem of the moving eye and a stationary spectacle lens in terms of the prism powers involved. Lebensohn (35) points out that the Purkinje shift from 555mμ to 510mμ requires about -0.5 diopter and recommends spectacles in night driving be corrected by this amount. Marsh (38) summarizes how vision specialists can help people who must drive at night.

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Factors of Educational Value for Obtaining Safe Night Driving Speeds

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The problem of speed limits is always more or less controversial. First is the matter of convincing the legislator who must attack the problem from the layman's point of view, since he is usually not a professional driver, although he is a law-maker.

After he is convinced, and a law is passed, the drivers on the road must have respect for the regulation in order to secure compliance. In Iowa, night accidents had built up to an alarming extent. There were also many day accidents under the basic speed law. It was felt that a speed law with stipulated limits was desirable but it seemed difficult to set up sufficient proof to support such a speed law for daytime. Consequently it was decided to concentrate on a night speed limit. Factors used in publicizing the need for such a measure and the approach made are discussed. Comparison of 1955-56 with 298 night fatalities, and 1956-57 with 260 fatalities was significant enough and seems to support the reasons for establishing such a law, and the methods used in getting it passed. Analysis of the break-down and factors emphasized are discussed.

● DATA ARE available from various sources to establish a reasonable speed at night for most any locality (1, 2, 3, 4, 5). By integrating these data into a suitable brochure or short paper to be used at public meetings and as a source of guidance to the legislature, the job was accomplished. The various legal associations were enlisted to assist, and a number of public meetings were held to develop sentiment for the measure. Iowa is an average state in most respects and mean values were thought to be satisfactory for most of the elements used.

PERCEPTUAL DISTANCE

By reducing the problem to its simplest terms, that is the relation between the seeing or perceptual distance, not sight distance, and the stopping distance, the approach was made understandable to the layman. First data were presented to show about what distance a driver can see ahead of him at night. Rober's data (4) were used as a base and a table of calculations was made for different intensities of headlights. Since statuatory limitations are set at 75,000 bcp and many lights to not come up to this standard on high beams, no trouble was met in establishing this value for most situations, i.e., a seeing distance at night. Since other factors would mostly tend to limit this to lower values, and since they are mostly well understood by the average driver, they were merely enumerated and some average values presented. No formulation was necessary but in constructing a table a simple product sufficed. Since it may be assumed for safety that most hazards appear on the roadways unexpectedly no allowance was made for this factor. There remained five elements that should be considered. These are:

1. Beam candle power of the headlights.
2. Reflection factor of the object being illuminated, brightness or the amount of light being reflected.
3. Atmospheric conditions through which the beam must pass and the driver must see.
4. Glare effects which are frequently encountered.
5. Visual acuity of the driver which has been found to average around 90 percent

although most states license drivers with 50 percent vision or less. Iowa requires 20/40 vision, while Idaho and some other states specify only 20/70.

Since the base used assumed more or less optimal conditions all the other values for individual cases would tend to lower the distance given in the table by an amount approximately equal to the product of the values. Suppose with a given beam candle power one can see ahead 200 ft to identify an object of a 7 percent reflection factor. With visibility at 90 percent the same object would be seen at 180 ft. A person with acuity of 20/25 or 80 percent would see the object at around 144 ft. Thus a table was used illustrating the perceptual distance for several conditions.

STOPPING DISTANCE

By using the standard formula for stopping distance as,

$$\frac{V^2}{30F \pm 0.3p} + 1.467VT,$$

where V is the speed in miles per hour, f, the coefficient of friction and p, the percent grade as a whole number. Reaction time distance is included in the expression 1.467 VT, where 1.467 is the speed distance ratio, V is the velocity in miles an hour, and a T of .75 second is used as the "agreed upon" time for reaction. Stopping distance was used to include both braking and reaction time distance as stated. A number of stopping distance charts have been published which do not always agree but which approximate the formula $\frac{V^2}{10}$, the latter being on the conservative side on dry pavement surfaces. The longer formula with an insertion of the proper values will give a much closer approximation. The various factors were tabled and explained.

Another table was constructed showing a reasonable stopping distance for the various conditions of traction with a correction for gradient, at several speeds. By matching the perceptual distance with the stopping distance and moving across to the speed column a quick evaluation could be made that seemed to be quite convincing and settled arguments rather quickly. The scheme was used by the courts to settle cases where all the conditions were known. Decisions were upheld by the Iowa Supreme Court in a test case.

The usefulness of such a plan is shown by the reduction in night fatalities from 298 in 1955-56 to 260 in 1956-57. By analysis of variance for the entire year to offset seasonal variations changes, this difference was found significant. By considering the increase in traffic for the second year this was even more significant perhaps than the data showed. Probably this effect was offset by efforts to reduce traffic accidents late in the second year. However, the fatal accidents during daylight hours under the basic speed law seemed to increase slightly for the same period.

SUMMARY

A breakdown of the principal factors in nighttime stopping distance as related to seeing distance was made as an aid to legislators and to the driving public to develop an appreciation of nighttime hazards. Considering the limitations involved, the project seemed an effective educational device for the following reasons:

1. A night speed law of 60 mph maximum was passed although a 50 mph limit was requested by the Commissioner.
2. During the following year nighttime fatal accidents were reduced significantly over the previous year under the basic law.
3. Convictions using the system for violations were upheld by the Supreme Court of Iowa.
4. Scientific data may be effectively used in accident reduction programs.

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