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Bulletin 89

Night Visibility

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Night Visibility

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Contents

A Substitute for Road Tests of Automobile Headlights

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A method of comparing vehicle headlights is described, in which the opinions of drivers are obtained under controlled conditions on a test track. The method is intended both to supplement the usual tests in which the distances at which objects are recognized are determined and to replace road trials, where many conditions are uncontrolled.

Tests with headlamps providing passing beams of four different types are also described. On both wet and dry roads, a pair of new British twin-dipping headlamps was preferred to other lamps tested, although a pair of lamps of a continental make was almost as well liked. Assessments of glare indicated that it was judged to be higher on wet roads than on dry ones, and that a glaring intensity of 400 to 500 candelas from each of the headlamps was easily tolerated on dry roads.

Suggestions are made for further investigations of glare on dry and wet roads.

THE standard experimental method of testing vehicle headlights is that described by Roper and Howard (1) in which a car is driven along a straight track to meet another equipped with similar headlights and the distance at which a test object can be seen is determined. Such tests give a series of distances at which objects are detected in the presence of glare from a similar opposing headlamp. They do not indicate whether the beam gives the driver confidence in his ability to place his vehicle on the road, and to judge this quality in the beam, road tests are often advocated.

The usual way of making road tests of a headlamp is to use the lamp in the ordinary course of driving on the public roads and to form an opinion of its merits without making any measurements. A serious objection to this as a method of test is that it is not fair to judge a lamp by its performance when meeting anything but a similar lamp, and this is not possible on the road. The object of the present paper is to describe a substitute for road tests, carried out on a test track in such a way as to approximate road conditions; the results of a series of comparisons of headlights in the passing condition are also given; and some conclusions are drawn concerning the desirable distribution of light in the beam. No novelty is claimed for these conclusions, which are in general agreement with views put forward by Nelson (2) in 1945.

The method of test described in the paper has recently been used in international comparisons of headlights carried out under the auspices of the International Commission on Illumination.

METHOD OF TEST

The original tests were carried out on part of the concrete perimeter track of London Airport, made available by permission of the Air Ministry Works Directorate. Two lengths of track were used on different occasions, and the dimensions and layout of one of them are shown in Figure 1. It was chosen to provide a reasonable length of straight track and two curves; one curve had a radius of curvature of 300 feet and the other of 400 feet. From previous work it was known that on trunk roads in Buckinghamshire about 99 percent of the curves had radii greater than 400 feet; the curves were therefore more severe than would normally be met on trunk roads near London. The track was level and there was a vertical concrete curb on one side of the track and no curb on the other. The verges were flat and grassy and there were no hedges or trees. Obstacles consisting of rectangles of sacking on wooden

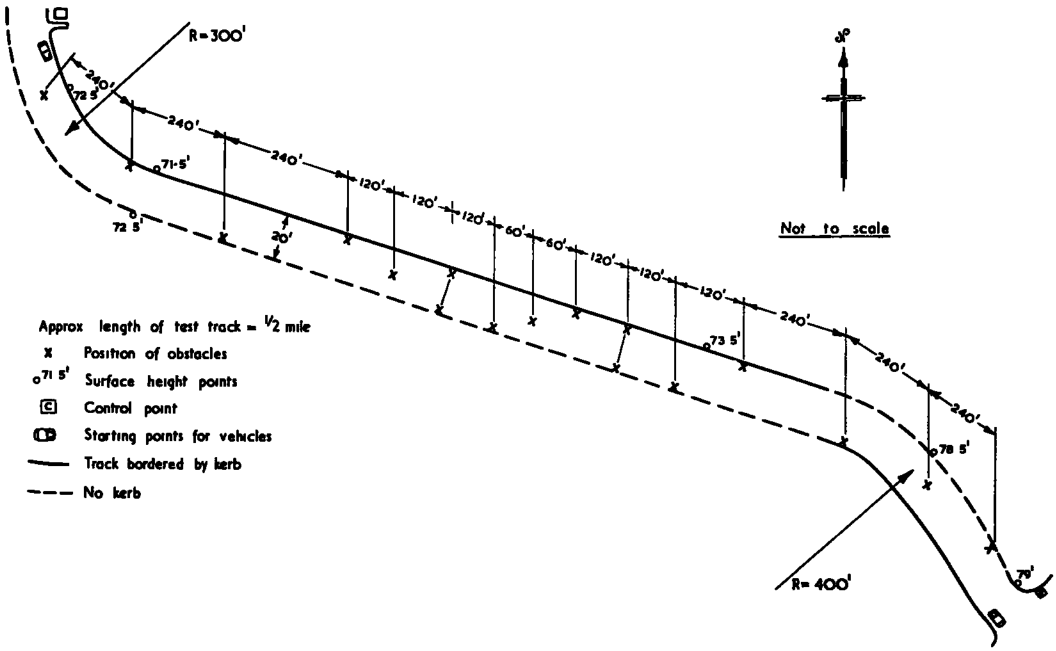

Figure 1. Plan of track used for final tests.

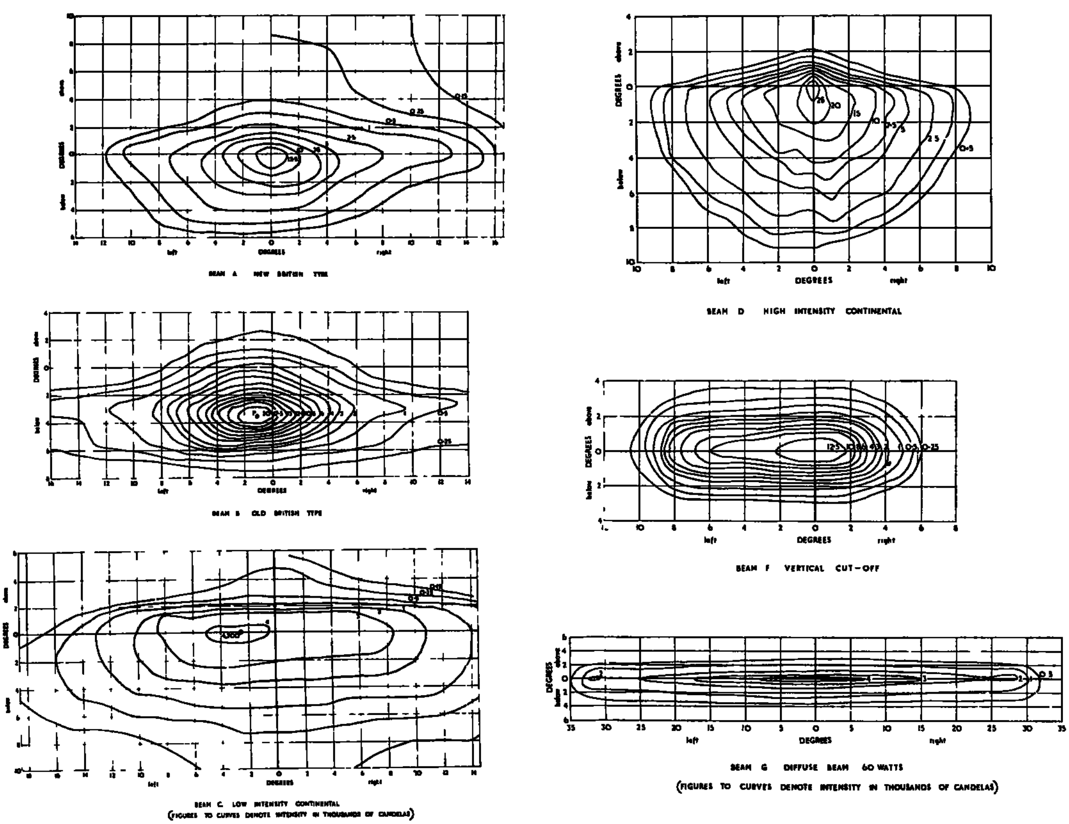

Figure 2. Light distribution curves; left, Beams A, B and C; right, Beams D, F and G.

frames were set up in three lines, one at each side of the road and one in the middle, with the spacings shown in Figure 1. Those placed at the side of the road were 2 feet wide by 4 feet 4 inches high; those centrally placed were 5 feet high but were only 9 inches wide. All had reflectivities, at normal incidence, of about 9 percent.

TABLE 1

PARTICULARS OF BEAMS COMPARED IN THE TESTS

Reference letter	Type	Maximum intensity (candelas)	Adjustment
A	Asymmetric, twin dippers, new British type	13000 (each lamp)	Main Beam ½ deg down (Peak 3 deg down and 3 deg left)
B	Asymmetric, single dippers, old British type	25000	Main beam ½ deg down
C	Symmetrical, twin dippers, continental type	4000 (each lamp)	Cut-off set 1 deg down (Peak 3 deg down and 2 5 deg left)
D	Symmetrical, twin dippers, continental type	28000 (each lamp)	Cut-off set 1 deg down (Peak 2 deg down)
E	Symmetrical, twin dippers, continental type (type D under-run)	11000 (each lamp)	Cut-off set 1 deg down (Peak 2 deg down)
F	Asymmetric, vertical cut-off, single lamp	14000	Peak 2 deg down, cut-off set straight ahead
G	Diffuse beam similar to K 24-watt bulb, single lamp		Peak 3 deg down
H	Diffuse beam, similar to K 36-watt bulb, single lamp		Peak 3 deg down
K	Diffuse beam, 60-watt bulb, single lamp	4000	Peak 3 deg down

Two test cars carried the lamps to be compared, which were arranged so that a change could be made from one lamp to another by turning a switch. Although all lamps were mounted at the same height, it was not practicable to have the alternative lamps in exactly the same lateral positions, but this is unlikely to have affected the results appreciably. The lamps were mounted with their centers 3 feet above the ground.

The observers actually drove the cars during the tests; all but two were unconnected with the planning of the tests and did not know, at any rate for some time, which lamps were being tested.

The test procedure, evolved after preliminary experiment, was for each driver to make eight runs, four as observer and four as driver, using, say, Lamps X and Z, in the order X Z Z X X Z Z X. The driver was told to drive over the course at 30 mph. After eight runs he recorded his preference for either X or Z, both with and without opposing glare. In many of the later tests, he also recorded his estimate of the degree of dazzle for both X and Z, choosing one of the following degrees of glare: none, slight, dazzle, or excessive dazzle. The tests were made on wet and dry surfaces; the wetting was done by means of a water tanker on those nights when there was no rain.

SYSTEMS COMPARED

The comparisons were confined to passing systems, i. e., the dipped headlights or special lamps used when two vehicles meet. The passing beam is probably more important from the point of view of safety than the driving beam; a glare survey (3) carried out by the laboratory in 1947 showed that on British trunk roads the passing system was in use for about four times as long a time as the main driving beam; the conditions of seeing are also more critical when it is in use, since the distances at which objects on the road can be seen are much less in the presence of glare from opposing lamps than when the road is clear.

Excluding systems using polarized light, passing-systems may be divided into four main types: (1) those with a horizontal cutoff, and symmetrical light distribution, as used on the continent of Europe; (2) the asymmetric type with no pronounced horizontal cutoff, as used in the United States and Britain; (3) those with a vertical cutoff, throwing light only on the nearside of the road; and (4) the noncutoff type with a widely diffused beam of low intensity.

The lamps tested comprised examples from each class. Particulars are given in Table 1, and distribution curves are given in Figure 2. In view of the interest at present shown in the relative merits of American and continental types, the main comparison was between examples representing these systems, but a considerable amount of information was also obtained on Items 3 and 4 (above).

It is, of course, also possible to combine the four main types to produce others, but none of these hybrid types has yet been thoroughly tested.

RESULTS AND CONCLUSIONS

Table 2 gives the results of the opinion tests, and Table 3 the judgements of glare. Because of the comparatively small number of observers (a maximum of 12 for any test condition) the differences between lamps are rarely statistically significant.

It will be noted that in Table 3 only two degrees of glare are recorded; this gives a clearer picture of the results than

TABLE 2

COMPARISON OF PASSING BEAMS AGAINST A AS STANDARD

Lamp compared with A (New British Type)	Dry Road				Wet Road			
	Without Glare		With Glare		Without Glare		With Glare	
	Preferred lamp	Score*	Preferred lamp	Score	Preferred lamp	Score	Preferred lamp	Score
B (Old British type)	A	8/11	A	8. 5/11	A	11/12	A	9/12
C (Low intensity continental)	C	7/12	A	6. 5/12	No preference	6/12	A	7/12
D (High intensity continental)	No preference	6/12	A	9/12	D	8/12	A	10/12
E (D under-run)	A	6 5/12	A	8/12	No preference	6/12	A	9/12
F (Vertical cut-off)	A	2/2	A	2/2	No preference	1 2	A	2/2
G (Diffuse beam 24 watt)					A	3/4	A	4/4
H (Diffuse beam 36 watt)	No preference	2/4	A	4/4	No preference	2/4	A	4/4
K (Diffuse beam 60 watt)	K	3/4	A	3/4				

*The score is the number of drivers who voted for the preferred lamp divided by the total number of drivers voting (Half-votes arise from drivers having no preference).

that obtained by including all the four degrees of glare, although in making the observations it is easier to choose from four than from two possible degrees. In future experiments it would be advisable to use the description "negligible dazzle" instead of "no dazzle", since there was always a small amount of glare from the opposing lamp, and drivers found difficulty in deciding when to use the term "no dazzle."

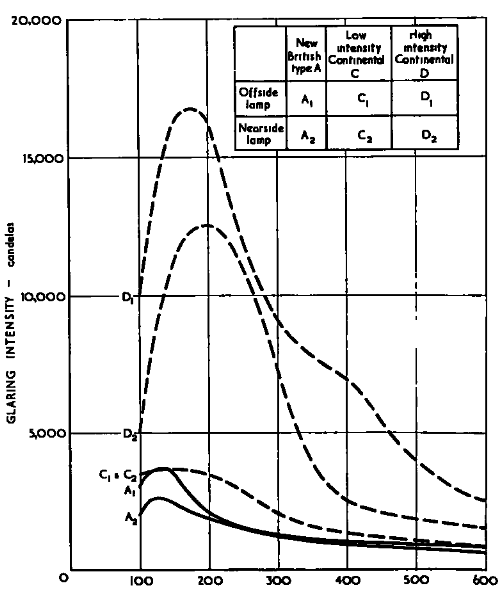

Figure 3. Intensity directed towards the road surface so as to be reflected at the angle for mirror reflection towards the driver.

The distances at which a target, 18 in. high and having a luminance factor of 7 percent, might be expected to be seen have been calculated for the first five beams by a method developed at the Road Research Laboratory (4, 5). The target was assumed to be placed centrally in the path of the car and 10 feet behind the opposing car. The calculated seeing distances are A, 150 feet; B, 170 feet; C, 140 feet; D and E, about 250 feet. The larger calculated distances of D and E depend upon the small central areas of high intensity which were a feature of the particular lamps tested.

The main conclusions from the tables and from the tests as a whole were:

1. The new British twin-lamp passing system, A, was preferred in almost all the trials, and particularly on wet roads, where glare was prevalent. The continental system, C, was judged to be nearly as good under all conditions, and it would not be possible on the basis of these tests, to choose between the two. It may be noted that the peak intensity of A was three times that of C.

2. It is sometimes stated that, when driving with the continental lamps in the dipped position, the sharp horizontal cut-off is quite noticeable, giving the impression of driving into a wall of blackness. No effect of this kind was noticed in these tests and drivers were generally

unable to tell whether they were using a continental beam or the new British beam. None of these continental lamps had a really sharp cutoff, however, and it is possible that the effect may be observed with lamps of other continental makes.

TABLE 3

PERCENTAGE OF DRIVERS WHO GAVE THE ASSESSMENT "DAZZLE" OR 'EXCESSIVE DAZZLE"

	A (New British type)	B (Old British type)	C (Low intensity continental)	D (High intensity continental)	E (D under-run)	G (Diffuse beam 24 watt)	H (Diffuse beam 36 watt)	K (Diffuse beam 60 watt)
Dry	6	27	15	50	8		25	50
Wet	19	33	25	92	50	100	67	

3. System A represents an improvement on the old single-lamp British system, B, particularly as regards glare and comfort in driving on wet roads.

4. The tests with Lamp E, which had a vertical cutoff, confining all the light to the left-hand side of the road, were discontinued because it was impossible to see the test objects in the middle of the road, and on two runs on a wet road, a target was knocked down.

5. The diffuse Systems F, G, and H, which only differed in the wattage of the bulb, gave pleasant driving conditions when no opposing car was present, but were more glaring than System A, particularly on wet roads.

6. With every passing system for which a glare assessment was made, the glare on the wet road was judged to be higher than on the dry road.

The last conclusion is in accordance with common experience and is probably due to two factors: first, the luminance of a wet road surface viewed from the driver's seat due to his own headlamps is several times lower than that of the same road when dry. On this particular road the dry surface was seven times brighter at 40 feet, five times at 60 feet, and three times brighter at 80 feet than the same wet surface. Discomfort glare from a given glare source has been shown by Hopkinson (6) to increase as the brightness of the background decreases. Background brightnesses used by Hopkinson were somewhat higher than those for wet roads, and the conditions differ in other ways, but there is no reason to suppose that the same general trend does not apply. The second factor is the brightness of the streak on the wet road surface, which itself acts as a glare source. The tests furnish some evidence that this second factor is of importance, since there was an indication that the symmetrical beams (C, D and E) were more prone to dazzle on wet roads than the asymmetrical ones. The symmetrical ones have a greater intensity in a direction likely to be reflected from the wet road surface to the eye of the oncoming driver than the asymmetrical, as is shown in Figure 3. (The intensities in this figure are only approximate, since they depend very much on the lateral separation of the vehicles.)

7. Except for the new British type, A, the amount of glare was considerable. For the old British single lamp, B, the proportion of people judging this lamp to be dazzling on dry roads was one in four.

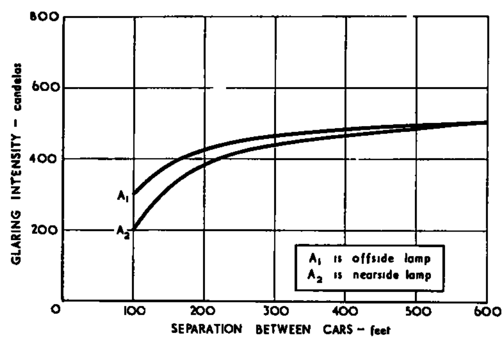

Figure 4. Intensity towards the opposing driver's eye for Beam A (new British type).

8. Some information concerning the intensity considered glaring may be obtained from the tests with Beam A. Eleven out of sixteen drivers classed this beam as giving slight dazzle on dry roads; four thought it gave no dazzle. On dry roads the glaring intensity appears to have been reasonably satisfactory. The variation of glaring intensity for each lamp with distance between the cars is given in Figure 4; this shows that 400 to 500 candelas from each lamp can easily be tolerated.

9. In the course of the tests many beams were compared which are not described in this paper. Among them were some very-narrow beams, and it was observed that the driver's preferences were influenced considerably by the distribution of light in the beam. Broad beams, which lit up the curb and grass verges and the road near the car, were preferred to narrower but otherwise similar beams, possibly because with the broad beams the driver knew his exact

position on the road. In the tests described in this paper, several drivers remarked unfavorably on the restricted width of continental Beam D; on the other hand, continental System C, which has a wide and uniform beam of low peak intensity, was well liked.

A review of the tests as a whole suggests that more investigations might usefully be made of glare on dry and wet roads. The conditions on dry roads present the simpler problem, and it might be possible to carry out laboratory experiments to determine the glaring intensities corresponding to various degrees of dazzle under different conditions of background and target luminance. On wet roads there is the additional complication of the image of the glaring light in the wet road. From other work at the Road Research Laboratory (7, 8), it appears likely that glare is less troublesome on roads with an open-textured surface (large texture depth) than on smooth roads. Not only is there less glare from the bright streak, but the road reflects more light back to the driver so that the beam from the headlight is defined well enough to give the driver confidence. The relation between the luminance coefficients of the surface and beam distribution of the passing system for least glare and best and most comfortable vision require investigation.

ACKNOWLEDGMENT

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Sign Placement to Reduce Dirt Accumulation

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At the present time, it is common practice to erect highway traffic signs low and close to the road; 4 feet above and 8 feet out from the edge of the pavement seems to be the most-common position. This has been considered necessary to keep the signs nearer the hot spot of the headlight beams. But, it puts the signs in a poor spot from a dirt-accumulation point of view.

Extensive tests on the rate of dirt accumulation have been run on test signs over a 19-month period. Splash and spray areas of highways were evaluated. Results indicated there is a sharp reduction of dirt accumulation at 6 feet above and 8 feet out from the edge of the pavement. Moving signs 2 feet out and 2 feet up from the conventional position reduces dirt accumulation to about a third. This is enough so that rains tend to keep the signs clean and reduces the need for maintenance.

The reduction in headlight intensity, because the signs are further from the hot spot, is more than made up for by selecting more-efficient reflecting materials. In addition to having cleaner and more effective signs on the highway, the maintenance engineer is helped because it is easier to plow, mow, and blade highway shoulders with sign posts 2 feet farther out from the edge of the pavement.

● IN the past, traffic signs have been placed low and near the edge of the road in order to get maximum attention value in the brightest spot of the headlight beams.

The "Manual on Uniform Traffic Control Devices for Streets and Highways" (1948 edition) calls for sign placement not less than 2½ feet above the crown of the road for normal rural usage, although some states deviate from this. On the average, however, signs now seem to be positioned approximately 4 feet high and 8 feet from the pavement edge.

Unfortunately, in rural usage, this area, low and near the road, is plagued with heavy dirt accumulation as shown in Figure 1. Dirt accumulation soon causes poor sign performance after erection. Thus, costly maintenance is required if signs are to be kept effective and in keeping with the quality of appearance the motoring public has learned to expect.

This report presents some quantitative data based upon actual highway tests which show how the effect of dirt accumulation can be greatly reduced and even virtually eliminated. Test results indicate this can be accomplished by two steps: (1) Moving signs up to a height 6 feet from the level of the road and 10 feet out. This is 2 feet in each direction from the conventional standard. (2) Selecting more-efficient reflecting materials which, even though they are further from the hot spot of the headlights, reflect as much or more light than the previously used materials placed in the conventional position. This can be accomplished even though the material has reached equilibrium and is being washed by rain as rapidly as it is picking up new dirt.

The installations discussed in this report were made during the winter (February 1952) and records were kept continuously through September 1953. During this 19-month period, sign materials were subjected to the severest of treatments—snow, sleet, slush, sludge, muddy water, heavy rains, and extremes in temperature ranging from -25 F. to +100 F.

Two test installations were selected as being representative of two general types of dirt accumulation that affect traffic signing. The sites for these installations were selected in locations approximately 150 yards apart. This facilitated the taking of data and kept the factors of weather and vehicle count the same.

Panels employed in the tests consisted of metal strips 4 inches wide and 8 feet high, placed on the right shoulder of the highway, at positions 6, 7, 8, 9, 10, 12, and 16 feet from the pavement edge. The surfaces of the panels were covered with a silver, smooth-surfaced, reflective sheeting.

Figure 2 (top) shows the installation which is typical of locations where water

Figure 1. Normal dirt accumulation on typical rural signs 4 feet up and 6 feet from pavement edge.

runs off the roadbed and does not accumulate in large quantities. Signs in this area are subjected to more or less of a fine spray of mud-packed water generated by heavy trucks, buses, semitrailers and high-speed autos. Such locations are typical of our well-drained modern highways and turnpikes. These locations are referred to as "spray" areas.

The other installation, pictured in the bottom view of Figure 2, is after 161 days. It is typical of locations where muddy water collects, stands in puddles, and is thrown by passing vehicles in large drops and quantities against the sign surface to such a degree that the debris-filled water runs freely over the surface of the sign. Such locations are referred to as "splash" areas.

The installations were made on February 15, 1952, on US 61, approximately 3 miles south of the city limits of St. Paul. This section of highway had an average annual daily traffic volume of 5,545 vehicles in 1952. Traffic was almost equally divided between the inbound and outbound lanes.

During the summer of 1949, the "St. Paul-Minneapolis Traffic Study" was conducted. The vehicles traveling this section of road on weekdays were classified as to body type and axle arrangement. The total summer weekday volume was 5,254, of which 4,560 were passenger cars and the remainder trucks and buses. Since this study a new bridge has been opened across the Mississippi River which allows a greater percentage of commercial vehicle traffic on this section of the highway.

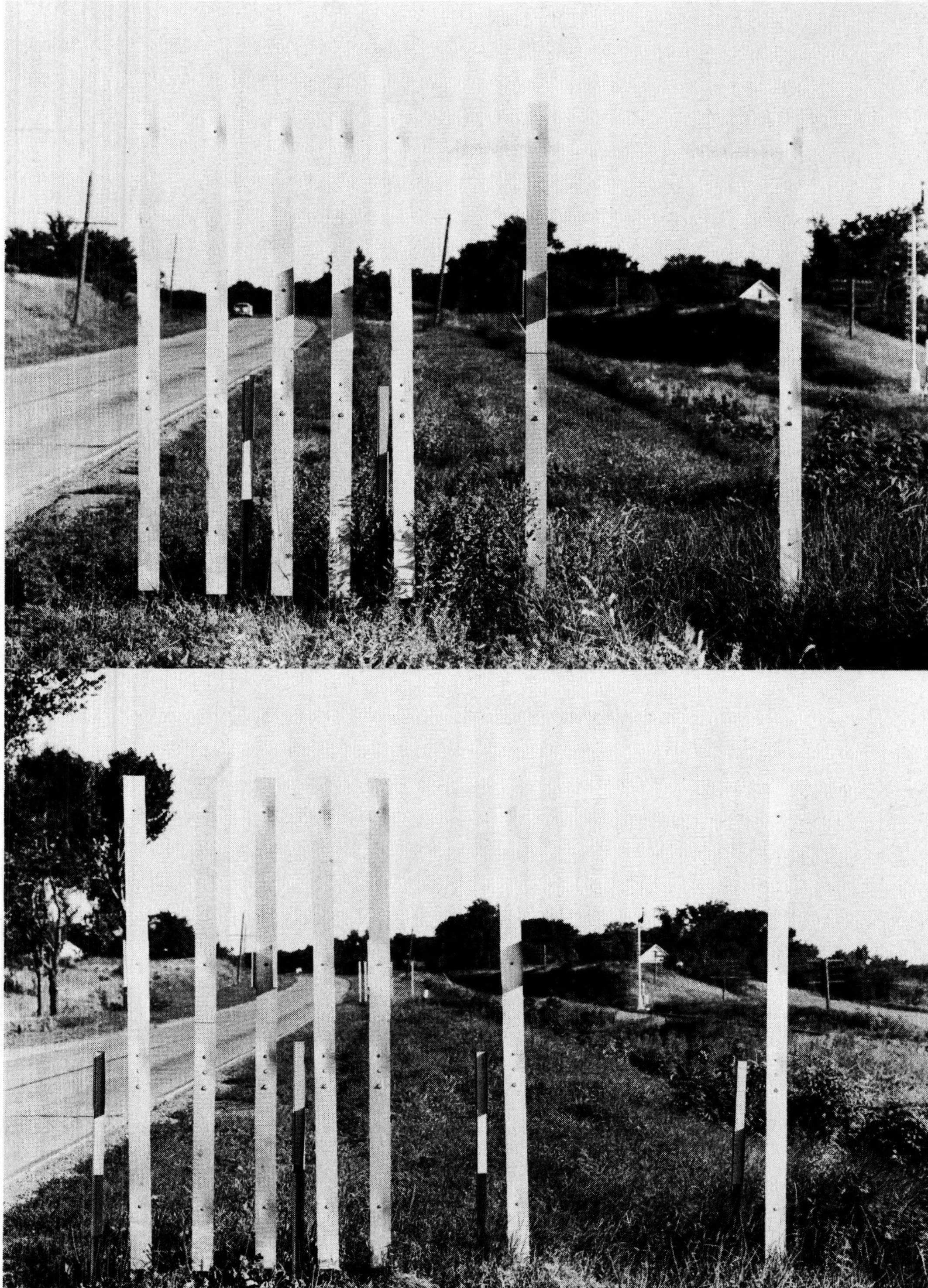


Figure 2. Panel installation at spray (top) and splash (bottom) areas.

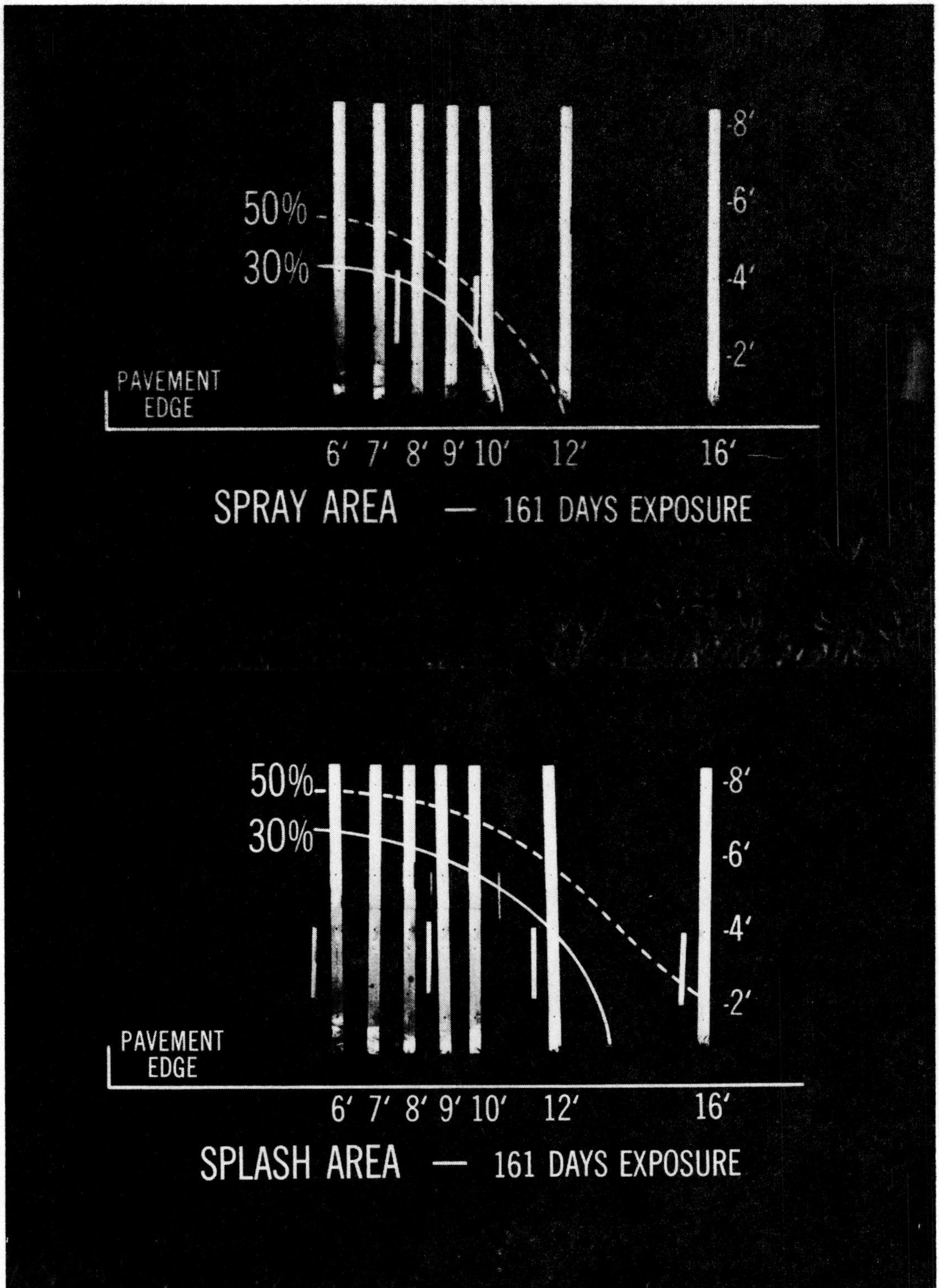
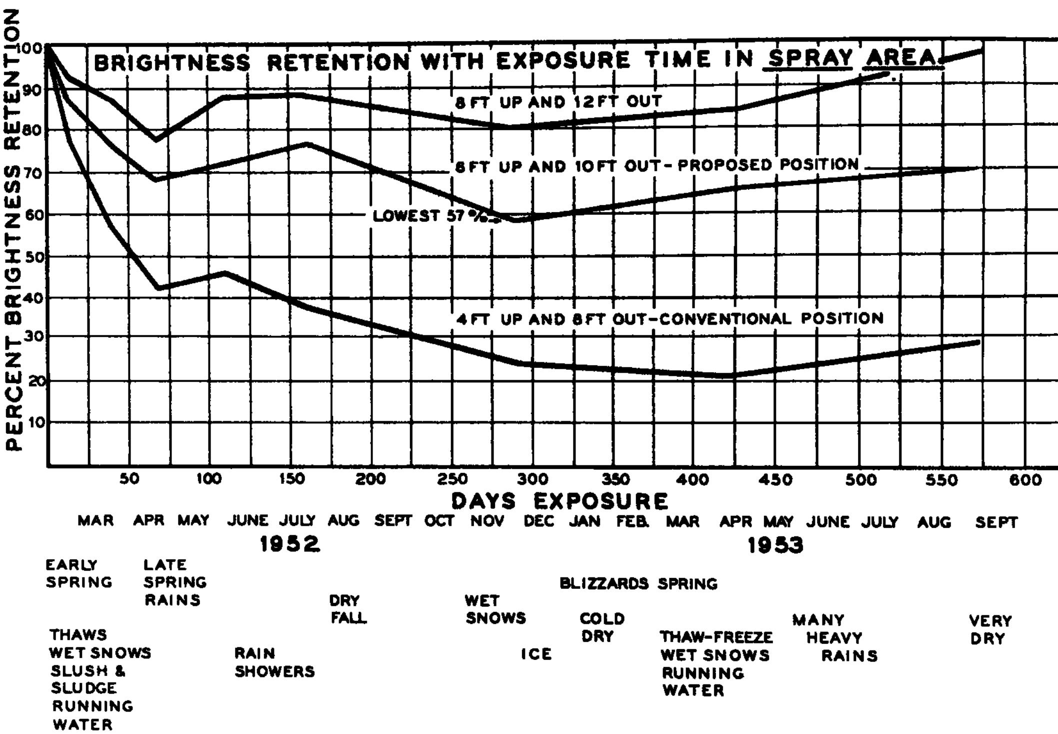


Figure 3. Nighttime appearance of spray (top) and splash (bottom) installations after 161 days, showing superimposed iso-brightness curves of 30-percent and 50-percent brightness retention. Note that weed motion has cleaned the base of the panels.



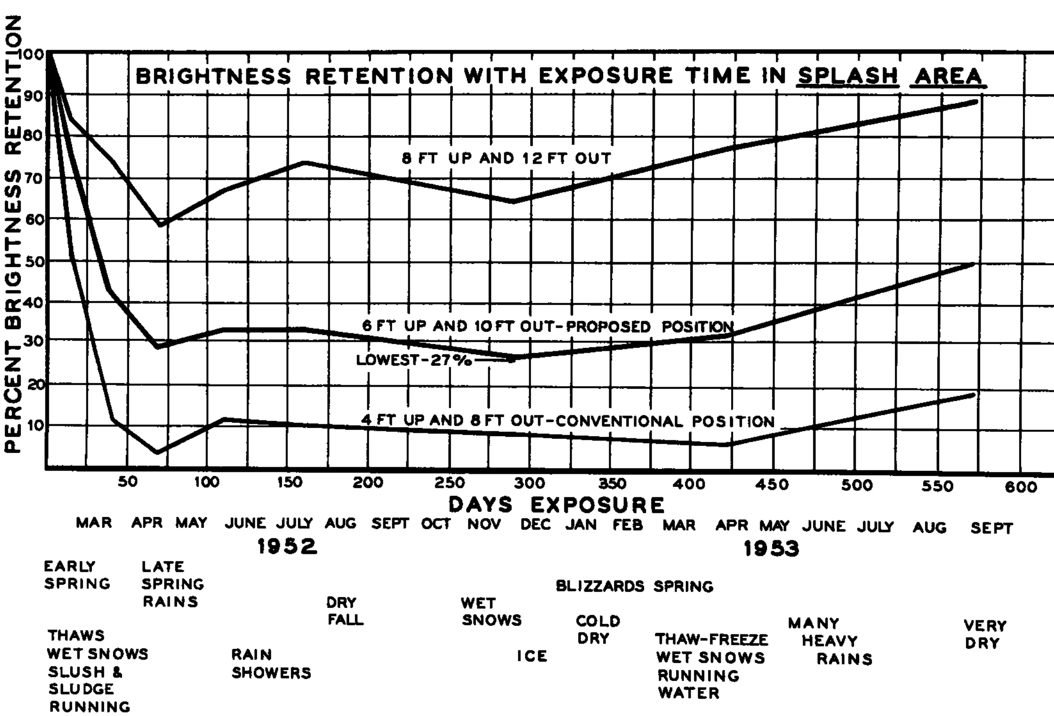


Figure 4. Percent brightness retention at spray (top) and splash (bottom) installations for three positions plotted over 19 consecutive months.

Daytime and nighttime brightness measurements of all test units were recorded before installation. These brightness measurements were repeated at varying intervals, following major changes in weather conditions which, in turn, produced measurable changes on the test panels.

Daytime brightness was measured using a Photovolt Model 610 Diffuse Reflectance Meter. Only nighttime values are shown here because of their importance and greater interest.

Nighttime brightness was measured using a Photovolt Reflector Button Tester which measures reflex reflection. In order to compensate for slight variations in original brightness, the performance of each unit is expressed as percent of the original brightness.

The nighttime appearance of the spray installations after 161 days is shown in Figure 3. The iso-brightness curves, showing zones of equal brightness, have been superimposed upon the photographs. Figure 3 also shows the splash area after 161 days. Because of the sharp demarkation between dirty areas and relatively clean areas, moving a sign just 2 feet out and 2 feet up, to a distance 10 feet from the edge of the road and 6 feet high, tremendously increases its brightness retention. This sharp line of demarkation agrees well with that found in the recent Missouri Study. Moving still farther out and up, to 12 feet out and 8 feet up, reduces the effect of dirt to a still greater degree.

Shown graphically in Figure 4 is the brightness retention for a sign in the conventional position, in the recommended position, and in the extreme position as experienced throughout the 19-month test period. It can be noted that in the spray area, the lowest brightness retention during the test period, at the position 6 feet up and 10 feet out, was 57 percent. During the last 12 months, there was no decrease in brightness. There is approximately a three-to-one difference in the brightness at the position 6 feet up and 10 feet out over the conventional position 4 feet up and 8 feet out. Beyond this point little is gained by positioning signs further out and up.

For the splash area there still exists approximately a three-to-one differential between the brightness in the 6 feet up and

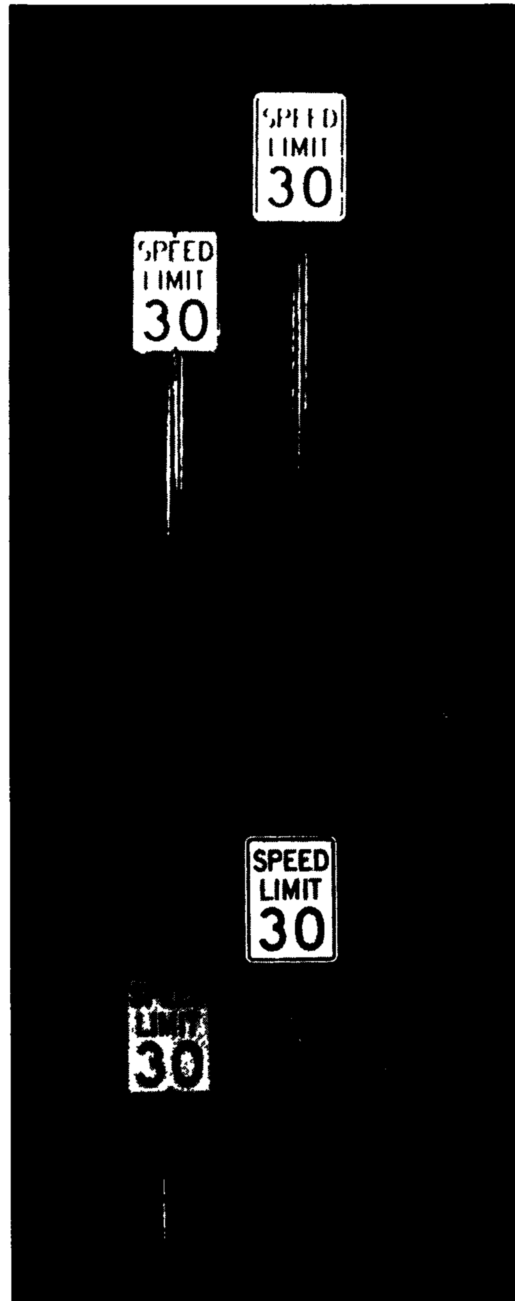


Figure 5. Telephoto pictures of new signs showing old (left signs) and new (right signs) reflective treatments at original and proposed positions, respectively. Illustrates that use of initially brighter material in proposed position (right) overcomes reduced headlight intensity at this position when viewed with auto headlights at 200 ft. with high (top photograph) and low (bottom view) beams.

10 feet out position over the 4 feet up and 8 feet out position. Note that the former had a low of 27 percent brightness retention during the test. While signs in the position 6 feet up and 10 feet out are further removed from the center of the headlight beam, the use of brighter materials on the sign surface provides extra brilliance initially also, thereby overcoming the effect of the reduced incident light as well as the accumulated dirt.

The brightness of two typical 3-sq.-ft. signs, as viewed by an auto at 200 feet has been determined.[1] One sign, 4 feet up and 8 feet out, is reflectorized with a white sheet reflecting material, and the other placed 6 feet up and 10 feet out is reflectorized with a more-efficient material, approximately 4½ times brighter.

In high beams, Figure 5, the first sign will have a brightness of about 9.7 candlepower and the second about 32.0 cp. If the second is reduced in brightness to 57 percent (the minimum for spray area) of its original value, it would return 10.2 cp.; if reduced to 27 percent (the minimum for splash area) it would return 9.0 cp.

For the low beams, Figure 5, the corresponding values are 0.6 cp. for the sign low and near the road, 3.0 cp. for the more-efficient sign 6 feet up and 10 feet out. This value should then be 1.7 cp. at 57 percent original brightness and 0.8 cp. at 27 percent original brightness.

The sign coated with the improved reflecting material after 19 months of exposure in the proposed position without cleaning has become stable brightness-wise. The lowest brilliance reached as a result of dirt collection was 27 percent of the original value. This is equal to, or better than, a new sign 2 feet lower and 2 feet nearer the road, coated with less-efficient reflecting materials and illuminated either by low or high beams of an approaching vehicle.

Other advantages gained by moving signs farther out and higher are very real to the maintenance engineer. Snow removal, mowing, blading, and scraping all become easier and safer with signs in the proposed location.

Cleaner shoulders provide better parking areas and permit the snow to blow off the traveled road. With signs farther from the pavement edge, mutilation and post damage are also decreased. In addition, the higher position of signs helps to reduce damage and defacement of signs by vandals with less likelihood of burial in snow country. On multilane highways the higher signs provide the added advantage of being more visible to passing cars from the inside lanes.

[1]The amount of illumination on the signs was determined from data furnished by a manufacturer of sealed-beam headlamps.

ACKNOWLEDGMENT

We are indebted to the Minnesota Department of Highways, and, in particular, J. E. P. Darrell and C. L. Motl for their assistance in the performance of these tests. This investigation was carried out in conjunction with the State of Minnesota by Homer Rector, physicist, Reflective Products Division.

Discussion

JOHN B. RHODES, Vice President, AGA Division of Elastic Stop Nut Corporation of America — During the last few years there have become available to our traffic engineers new and vastly improved materials with which to reflectorize our street and highway signs and markers. The improvement in the efficiency of these autocollimators has broadened substantially, both horizontally and vertically, the narrow limits within which it was felt that signs had to be erected. Because of the greater latitude thus allowed, we can now place our highway signs farther away from the traffic which they serve. Thus, they not only are further removed from the source of dirt, but also they may be placed so as to serve traffic better, as is the case with signs mounted overhead or with signs whose horizontal dimension has been increased beyond the limits of good signal practice of 10 years ago. This excellent paper considers one of the advantages to be gained from the greater latitude now available in sign placement. I have listened with interest to the discussion it has provoked, and three items in particular seem worthy of further comment.

When the discussion from the floor has been concerned with the relative merits of the two types of reflective sheeting that were used for photometric determinations, the true significance of the research has been ignored. There are a great many surface finishes commonly used on highway signs. For example, there are single-plane signs with porcelain enamel, baked enamel, and reflective sheeting; there are embossed signs with or without prismatic or lens-mirror reflectors; and many others. One surface may or may not accumulate and cling to more encrustations than another, but if comparisons between them are to be drawn, they should be the subject of a special investigation, and not hooked on like a caboose to an investigation of sign placement.

It is evident that any sign that is erected immediately adjacent to a heavily traveled road is likely to become encrusted with the products of spray or splatter, and thus lose legibility. This is as true of non-luminous signs as it is of reflectorized signs, and the loss in effectiveness is just as serious by day when all reflectors are inoperative as it is by night when reflectorization has maximum value. By the same token, a sign will regain some or all of its legibility when the encrustation is eliminated. It is not too important whether it is eliminated by a natural force such as rain or by a human one using soap and water, but it is important if the sign can be located in such a manner as to minimize such encrustations. The authors have shown — and their findings have been substantiated in tests made near St. Louis by the Missouri Highway Department and in others on US 1 at Elizabeth by AGA — that the general practice of positioning signs as close as possible to the theoretical main beam of automobile headlights (at the shoulder of the road 42 inches above the road surface) is fundamentally unsound, and that a sign can be located further from the road and higher above its surface at a net increase in the number of hours in any given period during which the sign has maximum legibility.

Someone has asked whether or not delineation would be affected adversely by a greater horizontal displacement of the delineators in order to avoid the accumulation of dirt. In the case of a sign, the message is the same regardless of the position of the sign. A delineator, on the other hand, being a marker is used not only to indicate alignment, but also to define the safe lateral limits of the highway. This second function is an important one. Hence, AGA has not recommended horizontal displacement beyond the useable surface of the road and its shoulders. To accomplish the same purpose, it has used vertical displacement very effectively. For example, at an important installation on US 1 just south of Washington, when the delineators were mounted at the 42-inch height recommended in the manual, they accumulated so much encrustation of splatter as to be unuseable. When they were raised so that the bottom of the delineator housing was 7 feet above the top of the curb, the difficulty was eliminated without affecting the continuity of the alignment.

The question was asked as to whether or not a sign should be angled either towards or away from the road, practices that are recommended by several of the state maintenance manuals. Fitzpatrick represented that his firm's particular reflective sheeting will function satisfactorily regardless of the fact that the sign might be turned toward, be normal to, or be turned away from the side of the road. Again, it seems to me that the question here is one of sign placement and not one of reflector performance. It is well established that specular reflection can entirely obliterate a sign's message regardless of the surface finish of the sign. Specular reflection, for all practical purposes, can be eliminated by angling the sign away from the road. It is understood that the forthcoming maintenance manual to be published shortly by the Bureau of Public Roads will recommend that this be done in every case except where a manufacturer recommends against such a practice with respect to his particular type of reflectorization. The formula presently used in California and which may be adopted in the federal manual requires the edge of the sign away from the road be moved in the direction of traffic 1 inch for each 10 inches of sign width, i. e. so that the angle of displacement from normal is approximately 6 deg.

In conclusion, may I observe that each year the number of demands for highway maintenance funds increases. At the same time, highway officials are under heavy pressure to reduce expenditures and thus lighten the tax burden. It is in response to such pressures that American industry in general and our own highway reflector industry in particular have by research and development produced materials that require less maintenance, and, as is demonstrated by the paper under consideration, by assiduous researches in the field of product application have demonstrated that by a simple modification in the installation formula the remaining maintenance costs can be decimated. Highway authorities should be quick to avail themselves of these advantages.

J. T. FITZPATRICK, Closure—This paper presents the results of the detailed study of sign placement to reduce dirt accumulation to the end of improving sign performance and reducing maintenance costs simultaneously. It was indicated from the floor that allusions to comparative dirt accumulation of various reflective materials have been made. It was also indicated that comparative performance of reflectors was not germane to this study and, therefore, should be made the subject of a separate investigation.

This report has not compared relative accumulation on various reflective treatments. It is solely concerned with the performance of an improved reflective material at a number of adverse sign positions. The general conclusions of this report apply to all reflective sign treatments: near the traveled way, signs are subject to gross dirt accumulation, and equilibrium over a 19-month period is reached at a substantially low point of reflective brilliance. To overcome this dangerous and objectionable condition, signs should be moved farther up and away from the traveled way. This move serves to reduce dirt accumulation at a sacrifice of some initial brilliance due to reduced incident light. This is of very real concern in any study of sign placement concerned with visibility.

It was reported to those concerned with the reduced intensity of clean signs at the proposed position that this brilliance is equal to that obtained with clean signs produced with older, less-effective treatments at the more-favorable sign location. It has been demonstrated, therefore, that it is now possible to maintain a high level of sign performance at a minimum of maintenance expense.

It has been pointed out from the floor that dirt accumulation is a consideration regardless of finish treatment and is as serious whether viewed by day or night. There is no question that dirt serves to reduce the effectiveness of a sign even in the daytime. The reduction in daytime brilliance was measured, as reported, with a diffuse-reflectance meter.

This report has not attempted to compare the diffuse-reflective with reflex-reflection data. Beyond a reduction in performance with dirt, both day and night, the properties of diffuse versus reflex reflection have little in common. Nighttime performance of all reflectorized signs is materially affected by dirt accumulation, whereas, the same signs may be legible in the daytime. Most of us have seen signs which can be read in the daytime but are almost totally invisible to us at night when the shape, color, and message of the sign are most necessary.

It was also indicated that it was not too important whether signs were washed clean by rain or manually, since signs should be located to avoid initial dirt pickup. We believe this study has shown that sign surfaces consisting of smooth-surfaced reflective sheeting properly positioned minimize initial dirt pickup and tend to become self cleaning within the limits of exposure conditions reported in this data.

The question has come up as to the significance of specular glare to sign positioning. It should be pointed out that specular glare is a function of the sign surface. Some signs are coated with reflective materials which do not and can not provide mirror reflection. With these materials, specular glare is not a consideration. Paint and similarly glossy surfaces not largely retroreflective require more care in sign placement, such as tilt in the vertical or horizontal plane.

This paper reflects the keen interest in the problems of the highway authorities and demonstrates a desire on the part of the sign industry to both improve available materials and the uses to which they may be put.

We are deeply grateful for the opportunity to have presented this report and for the many kind and solicitous remarks.

Effect of Planting in Median Strip on Night-Visibility Distances

EDMUND R. RICKER, New Jersey Turnpike Authority, and
VAL J. ROPER, General Electric Company

● THERE is a general belief that the planting of shrubs in the median strip of divided highways is an effective means of reducing headlight glare; however, there is little reported experience as to desirable types of shrubs, pattern of planting, or relationship to line and grade. Some disadvantages are recognized, particularly as to the creation of a snow fence, the accumulation of papers and trash, and the difficulties of mowing the remaining grass areas in an economical manner. The tests reported were conducted by the New Jersey Turnpike Authority in cooperation with the General Electric Company to evaluate the glare reduction which might be provided by a simple planting along the center of the dividing median.

The width of the median on the New Jersey Turnpike is sufficient to minimize the effects of headlight glare, being 26 feet throughout most of its length. Accident records do not show that glare is a serious contributory cause in night accidents. On the other hand, it is known that many drivers use their low beams from habit when meeting other traffic, and that the low beams are not effective for high-speed driving. While the authority has received some drivers' complaints against the use of high beams, advice from several traffic experts has been that drivers should be encouraged to use high beams because of the increased seeing distance thereby obtained.

Previous tests, as reported before the Illuminating Engineering Society[1] indicate that there is a definite seeing advantage with high beams opposing high beams as against low beams opposing low beams when the traffic lanes are separated by a distance of 21 feet or more. Present studies were initiated to determine the degree to which median plantings might be indicated as a prerequisite to encouraging all drivers to use their high beams.

Several planting patterns were developed by the turnpike engineering staff. Design aims included the use of a minimum number of trees, reasonable ease in mowing grass areas and avoidance of a hedge effect. The design trees were considered to be arbor vitae, 3 feet high when planted, and 4½ feet high and 15 inches in diameter at a point 2 feet 9 inches above the ground after 2 years of growth. The most satisfactory pattern appeared to be that whereby a pair of trees were set 5 feet apart, measured along the centerline of the median, and at an angle such that each tree was offset a foot from the centerline of the median; the trees were thus about 5 feet apart. The pairs of trees were located 24 feet 4 inches on centers, which makes the angular displacement equal between succeeding trees. At approach angles less than 15 deg. this pattern should cut out glare from opposing headlights on a level grade; further growth would improve the effectiveness.

The first test was made on the turnpike itself with cut trees inserted in small holes made with a crowbar. The trees used were scrub cedars and the total length of planted area was 3800 feet. The tests were conducted by comparing the average seeing distance to international standard dummies in the planted area and in an area where no shrubs were planted. Four dummies were placed in each area at successive intervals of 600 feet, 400 feet and 500 feet.

TABLE 1

Observer	Number of Readings with trees	Seeing Distance with trees	Number of Readings without trees	Seeing Distance without trees
		ft		ft.
I	24	418	24	423
II	25	470	24	497
III	28	367	28	357
IV	26	253	28	245
V	27	283	17	216
VI	28	365	28	412
Average, All Observers		359		358

They were five feet off the right lane on the shoulders. Fixed glare cars were parked on the outside shoulder of the opposing roadway so aimed that the high-beam headlamps would strike the test driver's eyes at or near the first dummy. Six observer drivers were tested, each making a minimum of five runs through the test

[1] "Seeing Against Headlamp Glare", Val Roper and G. E. Meese, Illuminating Engineering, March, 1952.

course. The seeing distance to the dummy was measured by having the driver press the horn rim on the vehicle when he first saw the dummy, this action being indicated electrically on a remote recorder geared to the transmission of the test vehicle so as to measure the elapsed distance between this action and the closing of the circuit by an observer riding in the car, who operated a pushbutton when the vehicle passed the dummy. Individual seeing distances ranged from 100 feet to 625 feet. The average seeing distance for the various observers is shown in Table 1.

seeing. This was further brought out by glare measurements which showed 0.0045 to 0.045 footcandles of glare in the planted area as compared to 0.02 to 0.11 footcandles in the unplanted area.

These tests also indicated further practical difficulties in experimentation with median barrier plantings on the turnpike itself. The movement of other vehicles even at low traffic periods provided additional glare which could not be controlled in the tests and it was difficult to find intervals for operating the test vehicle when no other vehicles were going in the same direction

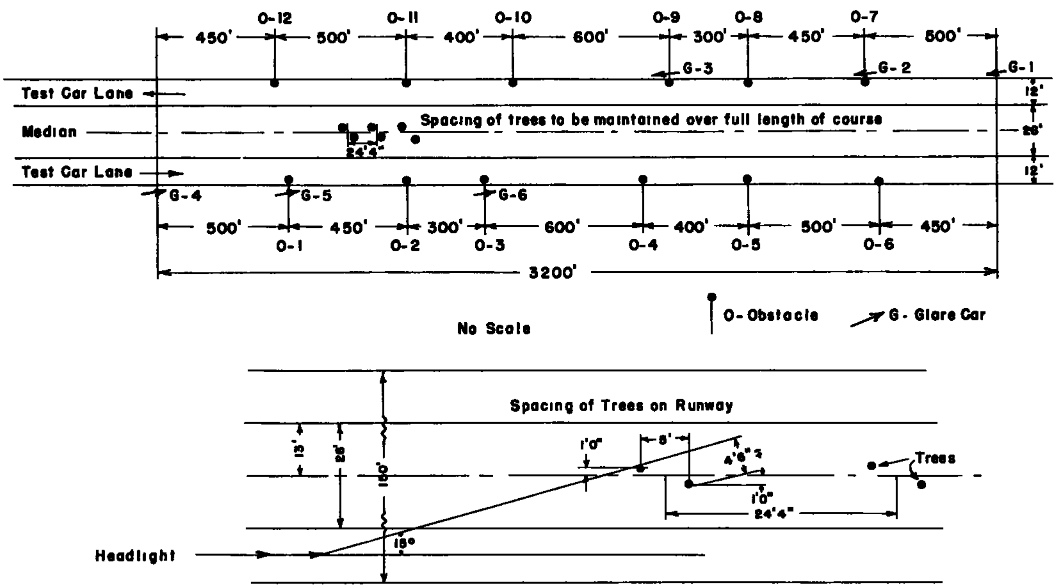


Figure 1.

The indicated results were considered unsatisfactory. Further analysis indicated that the slight curvature of the roadway which included a 12,000-foot-radius curve to the right in the planted area and a 20,000-foot-radius curve to the left in the unplanted area did not make the results comparable. Calculations taking into account the effect of headlight illumination because of the curvature showed that 20,000 candlepower (beam) was directed on the test objects in the planted area compared to 50,000 candlepower in the unplanted area. Although the overall average seeing distance for all six observers was not materially different for the planted and unplanted areas, there was a definite indication that there must have been better glare protection in the planted area, since less light was available for and, hence, adding their headlight illumination on the test objects. It was concluded that further tests should be run under more carefully controlled conditions before any conclusions could be drawn.

The second series of tests were conducted on an unused runway at Newark Airport, used through the courtesy of the Port of New York Authority. Scrub cedar trees were again used to simulate planting, each tree being wedged into a concrete building block and trimmed to a uniform height of 5 feet 6 inches. This Christmas-tree arrangement allowed the pattern to be changed readily and avoided the need for making holes in the runway. The test course was carefully laid out to simulate turnpike conditions of median width.

Two planting patterns were used, one as

TABLE 2

	Observer	Obstacles 1		2		3		4		5		6	
Trees Staggered	A	583		541		547		513		525		556	
Trees in Line	A	586		587		603		535		533		573	
No Trees	A	493		441		505		434		472		468	
Trees Staggered	B	403	0	361	0	321	002	317	078	359	001	387	007
Trees in Line	B	414	0	401	0	374	002	348	017	341	002	385	010
No Trees	B	430	006	432	011	361	019	361	420	308	034	390	086
Trees Staggered	C	415		409		432		380		393		450	
No Trees	C	358		379		408		339		371		370	
Trees Staggered	D	392	0	375	0	371	002	326	068	345	001	359	016
No Trees	D	387	007	332	012	345	021	296	372	300	033	309	119
Trees Staggered	E	498		554		538		565		474		510	
No Trees	E	521		495		499		471		394		432	
Trees Staggered	F	499	0	488	001	499	002	469	034	389	002	443	010
No Trees	F	453	005	441	010	394	018	401	162	368	028	401	101
Trees Staggered	Ave	465	0	455	0	461	002	428	060	414	001	451	011
No Trees	"	440	006	420	011	419	019	384	318	369	032	395	102
Trees Staggered	Ave without Observer B	477	0	473	0	477	002	451	060	425	001	464	011
No Trees	Ave without Observer B	442	006	418	011	430	019	388	318	381	032	396	102

	Observer	Obstacles 7		8		9		10		11		12		Ave	
Trees Staggered	A	499		502		514		551		523		577		536	
Trees in Line	A	536		472		562		549		615		606		563	
No Trees	A	366		382		427		388		401		504		440	
Trees Staggered	B	393	0	316	001	357	001	344	007	320	043	381	025	355	014
Trees in Line	B	386	0	400	001	399	002	366	008	380	025	426	026	386	008
No Trees	B	361	025	297	042	345	060	303	355	292	610	409	315	357	165
Trees Staggered	C	393		366		419		441		460		444		417	
No Trees	C	287		315		342		301		368		371		351	
Trees Staggered	D	341	0	331	001	366	002	360	005	351	048	407	025	360	009
No Trees	D	311	024	255	042	323	059	281	185	327	253	347	190	318	110
Trees Staggered	E	520		487	•	530		542		513		556		524	
No Trees	E	425		410		434		402		400		512		450	
Trees Staggered	F	428	0	419	001	483	002	431	005	466	033	469	035	457	010
No Trees	F	383	022	317	039	383	055	360	189	359	530	479	342	378	125
Trees Staggered	Ave	429	0	404	001	445	002	445	006	439	041	472	031		
No Trees	"	389	024	329	041	376	058	339	243	358	464	437	282		
Trees Staggered	Ave without Observer B	436	0	421	001	462	002	465	066	463	041	491	031		
No Trees	Ave without Observer B	354	024	336	041	382	058	346	243	371	464	443	282		

in the previous test and the other with the trees on the centerline, spaced 12 feet 2 inches apart. The layout of the test course is shown in Figure 1. The test procedure was similar to that previously used, with six observers making a minimum of six runs each on the staggered planting pattern and without any shrubs. The in-line pattern was tested by only two observers, and discarded because of the flicker effect of spilled light between the trees. The results are shown in Table 2.

From those data, it may be seen that there was a great variation between observers. Observer B, who says that he is not troubled by glare, was found to show little improvement with the plantings; it may be that he does not see well at night under any conditions. Observer A, who is greatly troubled by glare, showed the greatest benefit from the plantings: a 28 percent improvement.

The average increase in seeing distance for all obstacles and all observers was 14 percent with the planting of trees. Eliminating Observer B the average increase in seeing distance was 18 percent. On the basis of obstacle location, the average increase in seeing distance with the trees ranged from a low of 6 percent to a high of 31 percent, considering all observers. Leaving out Observer B, the increased seeing distance for the condition of tree planting ranged from a low of 10 percent to a high of 34 percent over the range of obstacle locations. Analyzed on the basis of individual seeing distance and at each obstacle location, the seeing distance with trees as compared to no trees ranged from 93 percent (Observer B at Obstacle 2) to 153 percent (Observer A at Obstacle 11). It therefore appears that as much as 50 percent increased seeing distance can be expected with trees planted as in this trial. Further increased seeing distance can be expected as the trees obtain more foliage, because there was still some glare through the trees.

There is another factor which may be illustrated by traces from the glare recordings: The discomfort or annoyance when driving the expressway without planting as compared to that with planting. The highest recorded value in footcandles at the eye for the condition of the planting was 0.06 footcandles with an average at the 12 obstacle locations of 0.013 footcandles. For the condition of no trees, the highest recording in footcandles at the eye was 0.464, almost eight times the highest value recorded with the trees. The average over the twelve obstacle locations was 0.133 footcandles, or ten times the average with the trees.

What this major reduction in glare would mean in terms of lessened fatigue and annoyance is anybody's guess. The increase in seeing distance for the condition of the trees was substantial: up to 214 feet.

The tests conducted to date have not taken into account problems of line and grade. Further studies are being considered by the turnpike authority in combination with other median problems, and will be reported upon from time to time.

Discussion

NELSON M. WELLS, Director, Landscape Bureau, State of New York, Department of Public Works — My reasons for objecting to plantings in the mall to reduce headlight glare are as follows:

1. Plantings in the 20-foot-wide depressed mall will probably interfere with drainage. Leaving a 5 foot shoulder clearance on each side, two 2½ foot-wide strips of planting would soon interfere with a desirable 5 foot-wide center ditch clearance.
2. Plantings which are high, dense and continuous enough to screen headlights will cause snow to drift on the pavement in narrow mall sections.
3. Plantings would occupy space which may be needed for snow storage.
4. Plantings have been severely broken down by snow piled in malls.
5. Plantings in a mall would interfere with the flow pattern of high speed mowing equipment and usually require considerable hand mowing.
6. Evergreen shrubs or trees would be required for year-around effectiveness. Trees such as pines, spruce and hemlock would soon grow to a size where their heavy trunks would be disastrous to a car out of control. Red Cedars and Arborvitae are not so large growing and would succeed in most soils along the Thruway. A single line hedge of either of these at a height to be immediately effective would cost about $20,000 per mile. Their effectiveness would last 10 or 15 years or until their lower branches were shaded out.
7. Deciduous plants are not as effective and would need frequent pruning to create a dense twig growth for some screening in winter. Two rows of such plants as Hawthorns would cost about $70,000 per mile. Two rows of shrubs would cost about $5,300 per mile but would not be effective for at least 3-4 years. Mixed evergreen and deciduous shrubs and trees on both sides of the ditch would cost about $40,000 to $50,000 per mile. A woven wire fence with Honeysuckle vines would cost about $16,000 per mile and might be effective if used south of Poughkeepsie.
8. Plantings require considerable care for at least two years after planting. Maintenance crews would be needed to start immediately to care for such prominent plantings. The principal maintenance would be hand weeding and watering. Hand weeding several times a year may be required for four years.
9. Maintenance costs would undoubtedly be increased as a result of removing papers, leaves and other debris from such a barrier.
10. The artificiality of a detached hedge in the midst of generally open countryside would impair the natural landscape qualities of the Thruway route.

GENERAL DATA

In the spring of 1947 inquiries on headlight-glare control were addressed to nine leading agencies. Each recommended wide malls as based on their opinions. The Nela Park Engineering Department of General Electric Co., Cleveland, gave the only answer based on tests and they said that unless a screen were continuous the mall should be 200 feet wide on tangents and 2,000 feet wide on curves. The Bureau of Highway Traffic, Yale, assumed a 30-foot mall adequate on tangents and shrubs needed on curves. They called attention to the bad features of tree trunks, drainage, snow drifting and catching debris.

In the fall of 1950 after surveys in nurseries and parks, consultants with the New York State College of Agriculture and the State Botanist, a selection of deciduous shrubs were specially purchased and planted on an 800-foot stretch of a curve on the New York Thruway. The best of these are still ineffective above a height of 3 feet.

Clipped hedges of hawthorns planted in a 6-foot mall on the Henry Hudson Parkway in about 1936 have been successful. They are now effective only for the top 12 inches of their 4-foot height.

Heavy plantings of mixed trees and shrubs were planted in malls on the Merritt Parkway in about 1936. Within 10 years after planting, the evergreen trees had lost their lower branches and other trees and shrubs had to be drastically cut back from encroachment on the pavement.

About three years ago Japanese Holly hedges were planted in the mall on US 1 near the Newark Airport and much publicized at the Highway Research Board. Inspection reveals that this expensive installation has proven ineffective.

In the spring of 1952 a heavy planting of deciduous shrubs mostly 3 to 4 feet high was made at the curves in a 30-foot-wide mall on Route 1841 north of Babylon. Removing weeds has been a costly problem and after two growing seasons the mass is not yet effective against headlight glare.

Oliver Deakin, New Jersey Parkway Engineer, reported in 1952 to the American Society of Landscape Architects as chairman of a committee on Public Roads, Controlled - Access Highways, Parkways: "Committee . . . admits . . . inability as landscape designers to correct headlight—glare conditions on divided highways by planting methods when medians are less than 20 feet wide."

Naturalistic plantings in wide malls are considered successful along various New York State Parkways and I believe it is possible to create a screen with plants in any mall but with numerous complications.

Reflection Characteristics of Pavement Surfaces

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Department of Scientific and Industrial Research, United Kingdom

A practical method of dealing with the reflection characteristics of a pavement surface is described. A reduced range of data, presented in a single family of curves, is found to be sufficient for calculating the luminance (brightness) in the important regions of a street-lighting installation within an accuracy of about 15 percent.

The experimental methods adopted at the Road Research Laboratory to obtain the necessary data are described; measurements are made outdoors on the actual pavement surfaces.

Reflection characteristics for three typical dry British pavement surfaces are presented. In addition, contours of equal luminance in the bright patches obtained on these surfaces under standard conditions are shown in perspective drawing. Standard contours are also given for one of the smoother types of pavement surface formerly employed, and for a fine-textured surface with a high resistance to skidding.

The coarse-textured surface and even the finer sandpaper finishes, which are being adopted as a means of improving the resistance of the pavement to skidding, cut down the reflection of obliquely incident light. This fact may account for the movement away from high-angle-beam lighting towards medium-angle-beam lighting which is evident in Great Britain today.

The effect of texture depth on reflection when the surface is wet is briefly examined.

● ONE of the principal objectives of street and highway lighting is to brighten the pavement surface so that it provides a background against which objects may be seen in silhouette. But the luminance (brightness) produced depends not only on the illumination but also on the reflection characteristics of the surface of the pavement. Although this fact has long been appreciated, the complexity of these characteristics has made it difficult to make full allowance for them in designing luminaires and installations. This paper describes the methods of measuring reflection characteristics that are being used by the Road Research Laboratory of the Department of Scientific and Industrial Research. A practical method for handling such characteristics has been derived: a reduced range of data, presented in a single family of curves, is found to be sufficient for calculating the luminance in the important regions of a street-lighting installation within an accuracy of about 15 percent.

The point of view adopted is that the brightness in a complete installation is built up from the bright patches produced by the individual luminaires, and the reflection data are adapted for easy calculation and appraisal of these patches.

HANDLING REFLECTION CHARACTERISTICS

It is usual to express reflection characteristics in terms of the luminance factor (brightness factor) which is best thought of as the factor by which the illumination on the surface must be multiplied in order to obtain the luminance which it produces. Thus, if B, is the pavement luminance in footlamberts, E, the illumination in lumens per sq. ft. and β is the luminance factor, then

$$B = \beta E$$

The luminance factor, β, is not a constant for a given surface; it varies considerably according to the directions of incidence and reflection. Its value measured under all conditions, yields a large mass of data which, when expressed in the usual angular parameters, is exceedingly tedious to apply. Various simplifications have therefore been sought; the one adopted here is particularly suited to the special conditions which hold in street lighting.

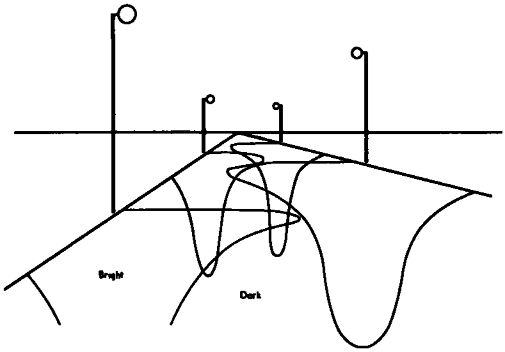
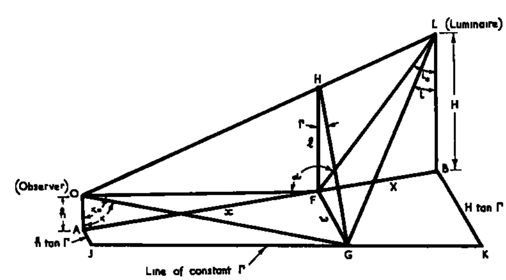


Figure 1. Perspective diagram of bright patches on lighted road.

In a street, each luminaire produces on the surface of the pavement a bright patch which, to the road user, appears more or less T-shaped with a wide head stretching across the street approximately opposite to the luminaire and a tail stretching towards the observer, as in Figure 1. The exact shape depends on the nature of the surface and the light distribution of the luminaire. Whatever the relative position of observer and luminaire, provided that they are not too close together, the patch of light retains a similar appearance, although modified by the changing perspective in which it is viewed. If the luminaire is raised the patch expands more or less in proportion to the mounting height. These uniformities are taken into account in the set of parameters which are adopted. These parameters and the geometry of the reflection are shown in Figure 2: 0 is the observer's eye, L the luminaire, and AB the axis of the bright patch formed on the road surface. In general, we require the luminance factor at a point such as G, which lies off the axis AB. The relative orientation of the incident and reflected light at G, and therefore the luminance factor, is determined by the angles α, Γ, r_0 and the ratio m, where m $(= \frac{H}{h})$ is the ratio of the mounting height of the luminaire to the height of the observer's eyes. These are the parameters chosen for expressing the luminance factor and of these only α and Γ are important.

On the axis of the patch, the luminance factor depends only on r_0 and α. In the street r_0 can vary only from 88 deg., to 90 deg., if the observer is viewing the surface at distances greater than about 150 ft., whereas α can vary widely. It is found experimentally that over this small range of r_0 the luminance factor on the axis depends almost entirely on the value of α. For practical purposes, therefore it is unnecessary to collect data on the variation with r_0. The angle r_0 may be fixed at some suitable value (88 deg. has been adopted), and all measurements made at this angle. For points such as G, which lie off the axis of the patch, it is found that the ratio of the luminance factor at G to that at the point F on the axis depends almost entirely on the value of Γ as long as α remains fixed. The value is not sensitive to changes in m within the commonly accepted limits ($2 < m < 8$), nor to the small changes possible in r_0. Therefore the luminance factor at any point G can be expressed approximately in terms of α and Γ only. These approximate values obtained at the Road Research Laboratory by measurements at r_0 = 88 deg. and m = 3 are denoted by β^* and are plotted as a single family of curves (see Figs. 8, 9, 10). To use these curves in any calculation of the luminance of a street it is only necessary to calculate the appropriate values of α and Γ for the points in question. The formulas used in this calculation are given in Figure 2. Lines, such as FG, across the sheet at right angles to the axis of the patch are lines of constant α. Lines of constant Γ are straight lines such as JGK in Figure 2 where AJ = h tan Γ and BK = H tan Γ. It is therefore convenient to use tan Γ



AO FH and BL are normal to the road surface
AJ, FG and BK are normal to AB the axis of the patch

$$\alpha = O\hat{F}L = \iota_0 + \iota_1 = \tan^{-1}\frac{X}{H} + \tan^{-1}\frac{x}{h}$$

$$\Gamma = F\hat{H}G \ , \quad \tan\Gamma = \frac{\omega}{\ell} = \frac{\omega\,(X + x)}{hX + Hx}$$

Figure 2. Geometry of reflection at point G.

Figure 3. Rolled asphalt with precoated chippings (B.S. 594).

Figure 4. "Non-skid rock asphalt".

Figure 5. Machine-finished concrete.

Figure 6. Compressed rock asphalt.

as the parameter for plotting results instead of Γ. The angle Γ has a special significance in perspective drawings of the patch formed by a luminaire, as is indicated in Figures 11 through 15. Points on the drawing for which Γ is constant lie on a straight line through the light source.

Since measurements are made at r_0 = 88 deg. the error involved in the approximation for β is zero at a point on the axis of the patch 143 feet ahead of an observer whose eyes are 5 feet above the surface (h = 5 feet). It has been stated that a value of 3 was chosen for m. Although this is at the lower end of the important range in the street-lighting problem, the experimental determination of β^* is simplified if m is kept as small as possible. A study of several surfaces has led to the conclusion that the error involved in the use of β^* instead of β is unlikely to exceed about 15 percent within the region 80 feet to 600 feet ahead of a 5-foot observer with values of m ranging from 2 to 8.

The system of approximation described above is a modification of one proposed by Bloch (1) from theoretical considerations. He suggested that a traffic-polished pavement surface scatters light as if it were composed of a multitide of tiny mirrors orientated according to some statistical law. The simplicity of his results depended on an assumption regarding the way in which mirror facets are masked or

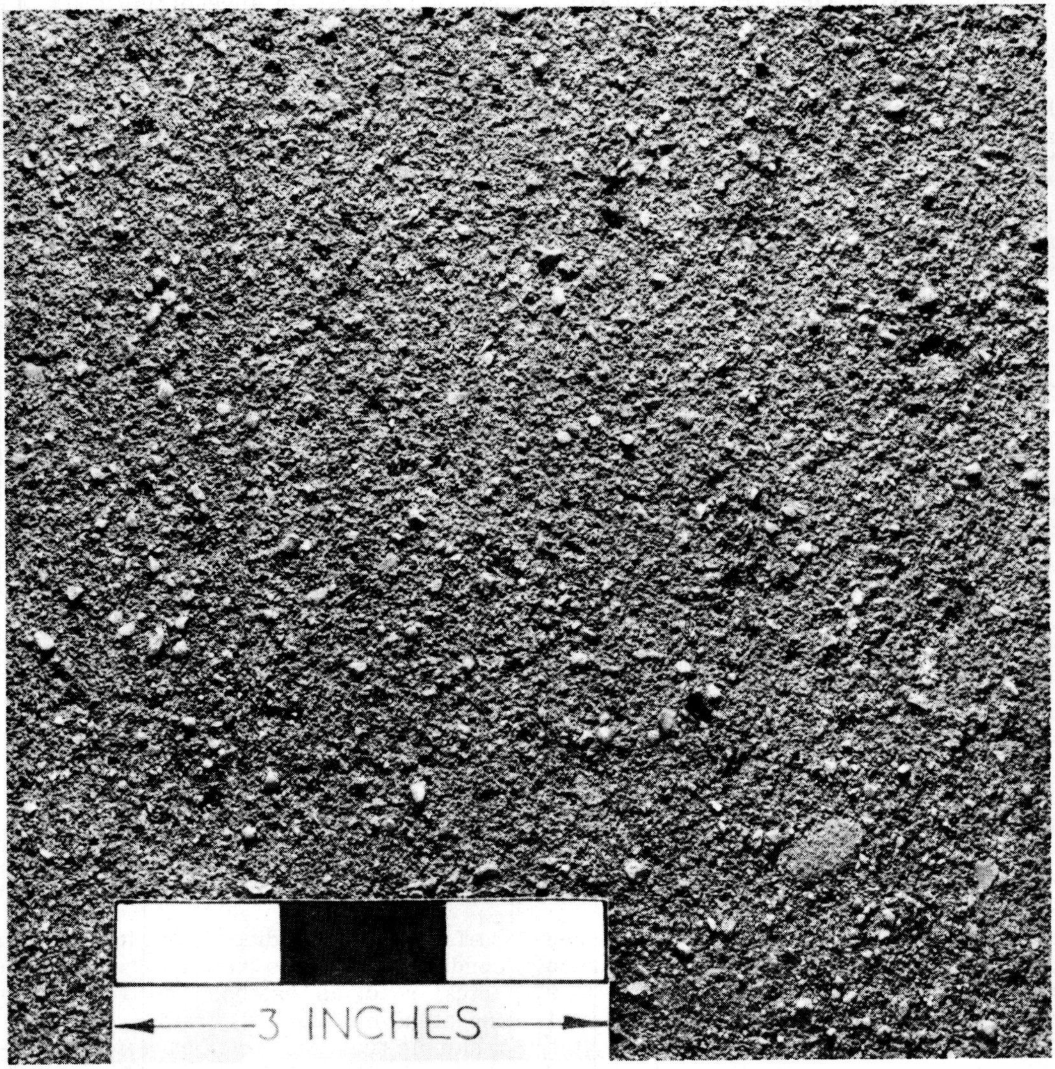


Figure 7. Bituminous sand carpet.

shaded by others. The assumption is not entirely satisfactory and the system outlined above and based on experimental evidence appears to be better. It was Bloch's theoretical treatment, however, which suggested the use of the angles d and Γ as the principal parameters of the brightness factor.

MEASUREMENT OF THE LUMINANCE FACTOR

The experimental arrangement which has been adopted simulates an observer and a luminaire on a reduced scale. The considered) the brightness of the surface may vary so rapidly that the sizes of source, receiver and sample (part of the surface on which an individual measurement is made) must be kept small if the results are to be accurate. But the sample area must not be made so small that it is no longer large compared with the elements of which it is composed. A fuller discussion is given in Appendix A.

As the maximum distance between the light source and receiver is 200 feet on the scale chosen, this experimental arrangement is clearly unsuitable for use indoors. However, in order to ensure that the

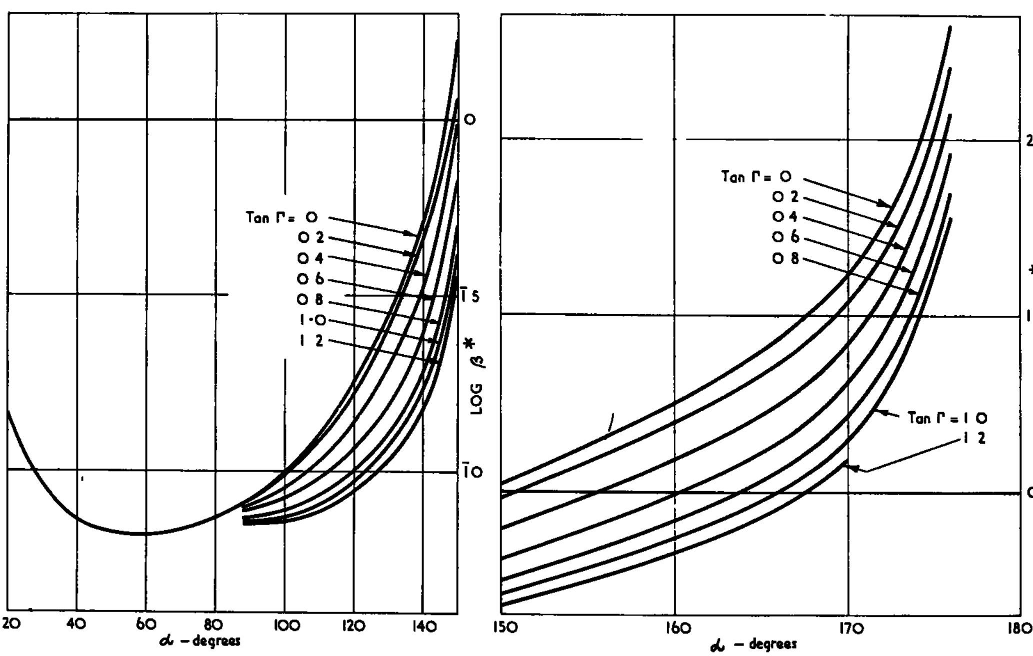


Figure 8. Curves of β^* for a rolled asphalt with precoated chippings - B.S. 594.

procedure is to measure by visual and photographic photometry the luminance along a fixed line transverse to the axis of the road while the light source is set at different distances from the line; the vertical plane containing the receiver and the light source being always parallel to the axis of the road. The scale chosen is such that the fixed dimensions in Figure 2 are h = 1. 75 feet, H = 5. 25 feet, x = 50 feet and r_0 = 88 deg.

The choice of scale is governed by a number of considerations. At the larger values of d (d = 176 deg. is the largest surface being studied is in its working condition, it seems better to work on the actual road, as has been done by certain investigators (2, 3, 4), rather than to cut a sample from the pavement for examination in the laboratory (5, 6). Moreover, a laboratory apparatus, capable of detecting the rapid variation of luminance factor with angle to the same degree of accuracy as can be obtained with the outdoor arrangement, would have to be quite large and elaborate (see Appendix B).

On the scale adopted and with a light source of 300 to 400 candelas, a receiver

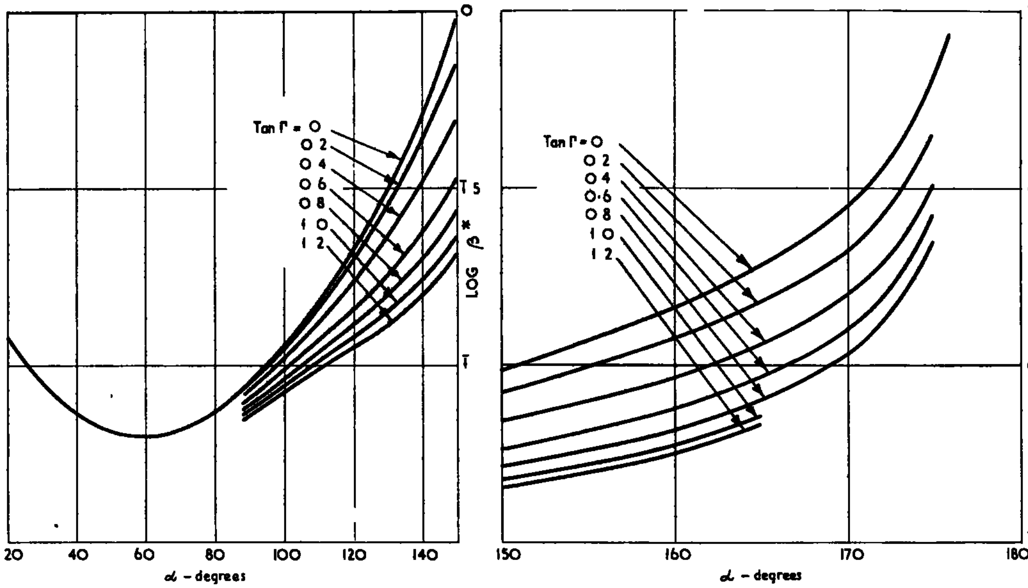


Figure 9. Curves of β^* for a "non-skid rock asphalt".

responding down to 10^{-9} lumens is required. It is difficult to obtain such a high sensitivity and the necessary directional accuracy in a portable photoelectric instrument. It is also difficult to obtain a greater intensity without increasing the source dimensions beyond the permitted limits. It is for these reasons that visual and photographic methods of photometry are at present used.

For values of *d* less than 135 deg. all measurements of β^*, both on and off the axis of the patch, are made with a visual telephotometer. To operate this at a height of 1.75 feet the observer has to sit on the road. The comparison patch in the instrument available covers a portion of the surface 2 inches wide at 50 feet and is U-shaped. At the larger values of *d* only one limb of the patch is used in the matching process.

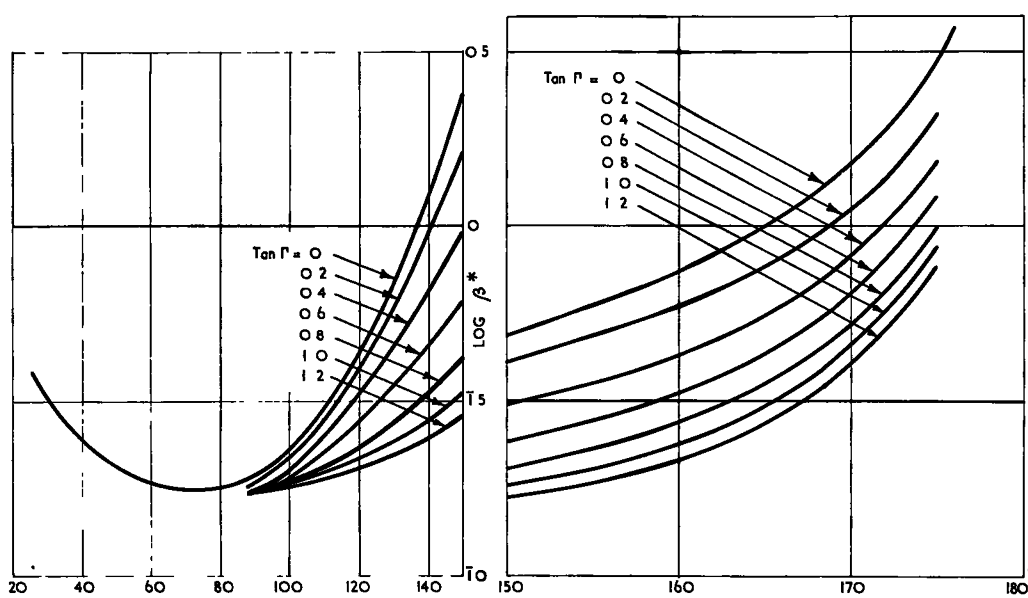


Figure 10. Curves of β^* for a machine finished concrete.

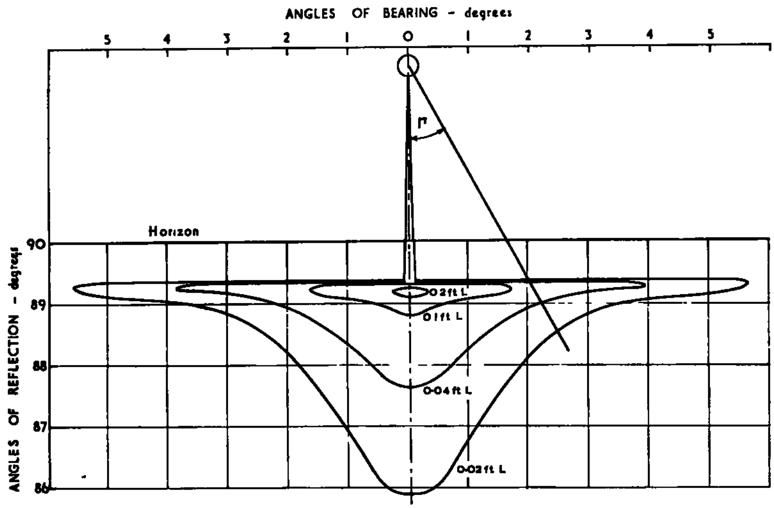


Figure 11. Isoluminance contours in perspective for a rolled asphalt with pre-coated chippings (B.S. 594) under standard conditions listed in Table 1.

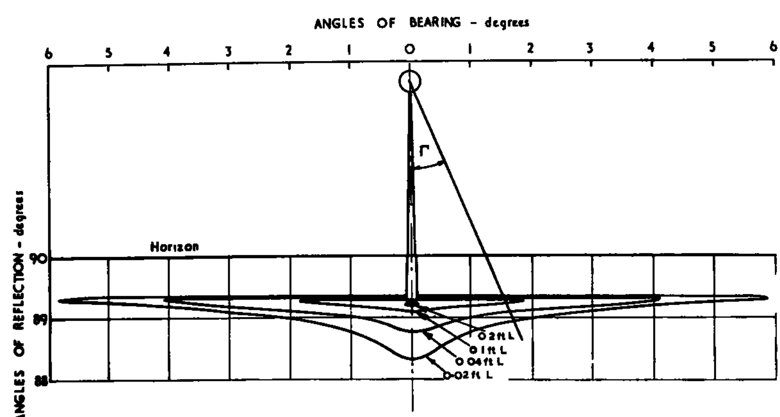


Figure 12. Isoluminance contours for a non skid rock asphalt under standard conditions listed in Table 1.

For values of *d* greater than 135 deg. the fall in luminance factor is so rapid on either side of the axis of the patch that many accurate readings from exactly the same receiver position are required to show its course. Here the photographic method is most convenient. A photograph is made of the patch formed by the test lamp and this is subsequently enlarged to a suitable size and analyzed using a simple photoelectric densitometer. To obtain reasonable accuracy a standard brightness scale is photographed on the same plate. Some notes on the method used are given in Appendix C.

RESULTS

A number of surfaces have now been studied in the manner described, and the results are given for three surfaces typical of present British practice. Photographs of these surfaces, taken by oblique illumination to show up the surface texture, are shown in Figures 3, 4, and 5.

The rolled asphalt with precoated chippings (Fig. 3) is typical of many laid both on city streets and on country roads. The chippings protrude above the asphalt to only a slight extent, and are fairly widely spaced.

The nonskid rock asphalt (Fig. 4) is found only on city streets. Precoated chippings of 1 inch or ¾ inch, spread shoulder to shoulder and rolled in, continue to protrude from the pavement even under heavy traffic.

The machine-finished concrete (Fig. 5) has shallow ridges transverse to the direction of the road and therefore to the direction of the bright patch during the measurement of the luminance factor (the values obtained would probably be different if the experimental arrangement were rotated through 90 deg.).

The β^* curves for these surfaces are shown in Figures 8, 9 and 10.

Whilst curves of β^* are sufficient for research and design purposes they do not present an immediate picture of how the surface is brightened by a street luminaire. It is useful therefore to derive from these curves a perspective drawing showing the bright patch (in the form of a series of contours of equal luminance) formed by a simple type of luminaire under standard conditions. The patches obtained in this way for the three surfaces already considered are given in Figures 11, 12, and 13; the standard conditions being set out in Table 1.

Street luminaires do not usually have a uniform intensity but it is easy to see from this standard patch how the contours of equal brightness would be modified with any given luminaire distribution. Such perspective pictures, worked out for the main types of luminaire in common use, would form a handy addition to the information available to the lighting engineer.

DISCUSSION OF RESULTS

It is interesting to compare the results for the rolled asphalt with precoated chippings with the results published by Waldram in 1934 (2) for a rolled asphalt. The older surface gave a much larger patch than the newer one. Similarly the small patch in Figure 12 for a nonskid rock asphalt may be contrasted with the long patch obtained on a compressed rock asphalt laid in 1929 and still in existence on a London street (standard patch Fig. 14 and photograph Fig. 6). It appears that the efforts to make pavement surfaces non-skid by having a protruding stone aggregate, have seriously reduced their power to reflect light.

Many of the luminaires in use in Great Britain are of the high-angle-beam type (Fig. 16) which emits an appreciable intensity up to the horizontal. On a surface such as the old compressed rock asphalt (Fig. 14) very long patches are produced

TABLE 1

STANDARD CONDITIONS FOR PERSPECTIVE PATCH

Luminaire light distribution:	Uniform intensity of 1,000 candelas
Luminaire mounting height:	25 feet
Height of observer's eyes:	5 feet
Distance of observer from pole:	400 feet
Correct distance for viewing drawing:	16 times height of luminaires

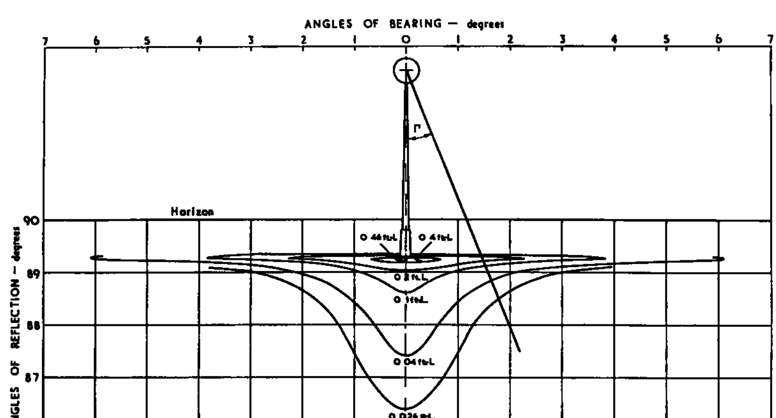


Figure 13. Isoluminance contours in perspective for machine-finished concrete under standard conditions listed in Table 1.

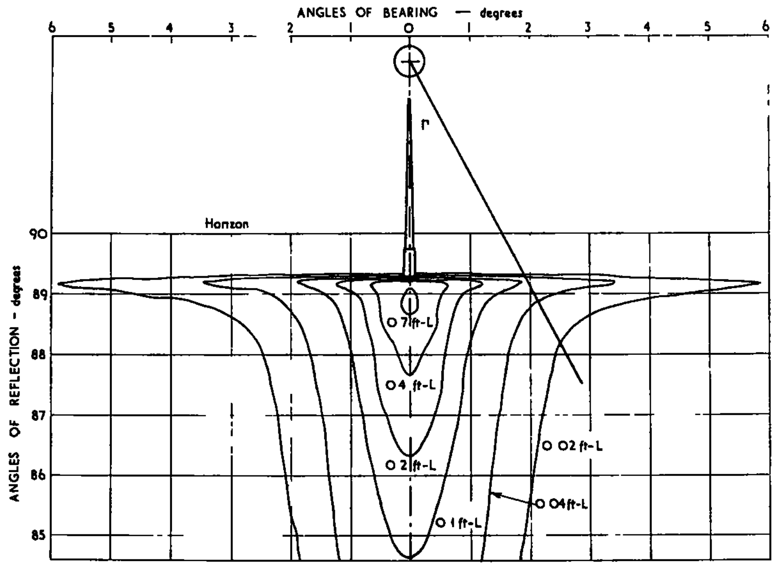


Figure 14. Isoluminance contours in perspective for a compressed rock asphalt under standard conditions listed in Table 1.

which cover most of the pavement as in Figure 1 even with a staggered arrangement of the luminaires and a spacing of up to 150 feet. So high is the surface brightness produced that little discomfort glare is experienced in spite of the high intensities emitted at large angles to the downward vertical. But on modern surfaces of the types studied the patches are much shorter and the general surface brightness insufficient to prevent appreciable discomfort glare. Disability glare may also become serious, rendering the eye less capable of detecting the presence of objects appearing against the darker parts of the surface of dark surroundings.

Thus, high-angle-beam luminaires are not very satisfactory on many present-day pavement surfaces, and there is now a growing preference for the medium-angle-beam luminaire with its maximum intensity at 75 to 78 deg. from the downward vertical and a rapid fall in intensity above this angle (see Fig. 16). To compensate for the shortness of the patch produced, closer spacing of the luminaires is used (about 120 feet on a straight road and less on a curved road). Occasionally cutoff luminaires are employed at a spacing of 90 to 100 feet. These have a peak in-

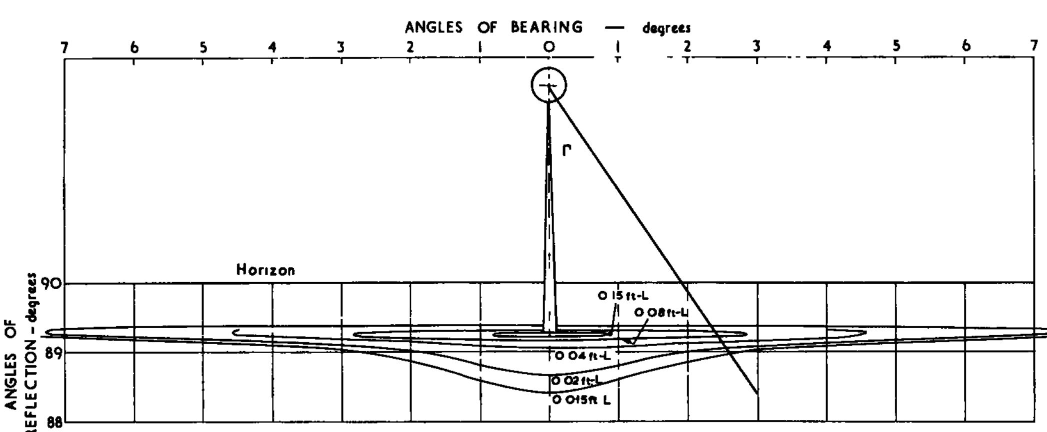


Figure 15. Standard isoluminance contours in perspective for bituminous sand carpet under standard conditions listed in Table 1.

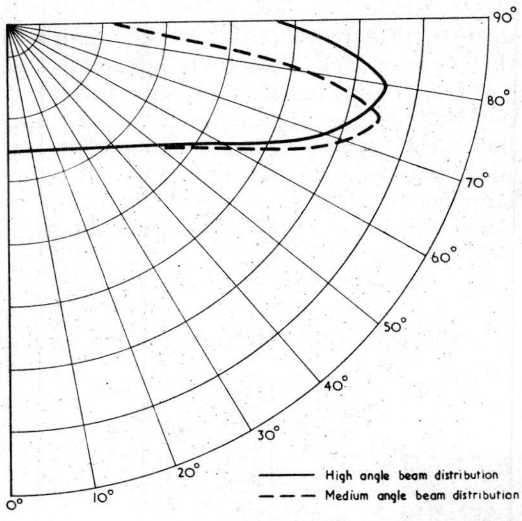


Figure 16. Typical luminaire light distributions in vertical plane through beam maxima.

tensity at about 70 deg. and very low intensities above 80 deg.

The shortness of the patches produced by street luminaires on many present-day pavement surfaces is sometimes said to be due to the coarseness of the surface. But very short patches are also obtained on pavings with a fine-textured surface formed by protruding aggregate patches of small dimensions. (See, for example, the standard patch for a bituminous sand carpet shown in Fig. 15. A photograph of the surface is given in Fig. 7). It is clear therefore that within limits it is the shape of the surface which matters and not the size of its features.

An important question arises from these investigations: does the surface texture required to prevent skidding necessarily prevent the formation of long patches by street luminaires? To prevent skidding it appears that sharp projections are necessary and these tend to destroy the specular reflection of obliquely incident light which makes possible the formation of long patches. Theoretical considerations suggest, therefore, that the answer to the above question may be "yes" and the available experimental evidence points to the same conclusion. For example, of the

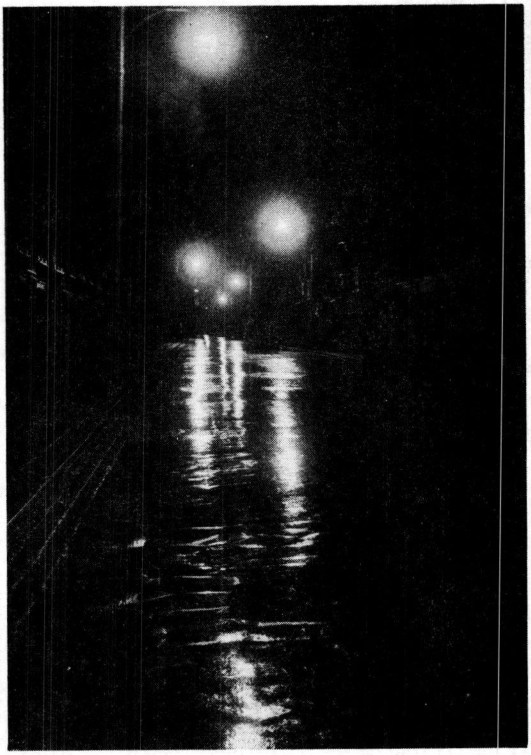


Figure 17. Narrow bright streaks on a wet surface with a small texture depth.

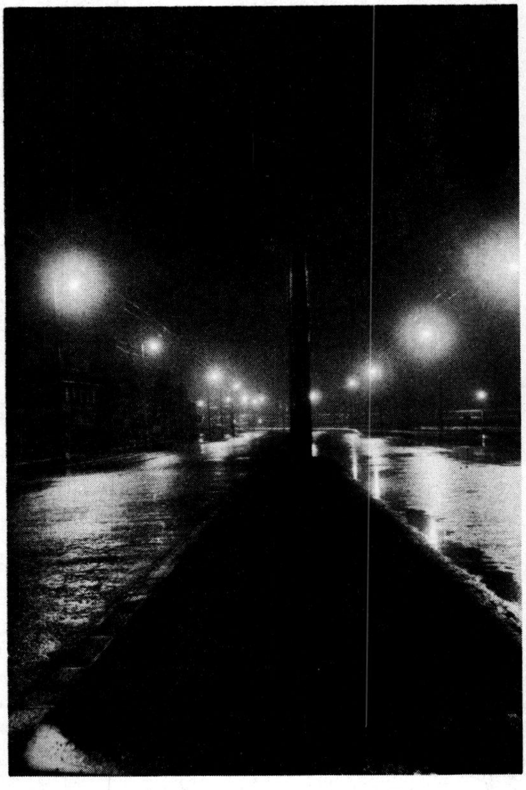


Figure 18. Wide patches on a wet surface with a large texture depth.

surfaces considered in this paper the only really large patch is obtained on the compressed rock asphalt, which is slippery when wet. The shortest patch is obtained on the surface which is most resistant to skidding when wet, fiz., the bitumin-sand carpet.

Because the specular reflection of obliquely incident light has been so much reduced by antiskid methods of pavement construction, the brightness produced by street luminaires now depends more on the diffuse reflectance of the surface than was the case on the smoother surfaces that were formerly used. Diffuse reflection depends on the lightness of color. Experiments are being made to access how much can be achieved by the use of light-colored materials; experience suggests that the benefit should be substantial.

WET-WEATHER REFLECTION

Only reflection from dry surfaces has

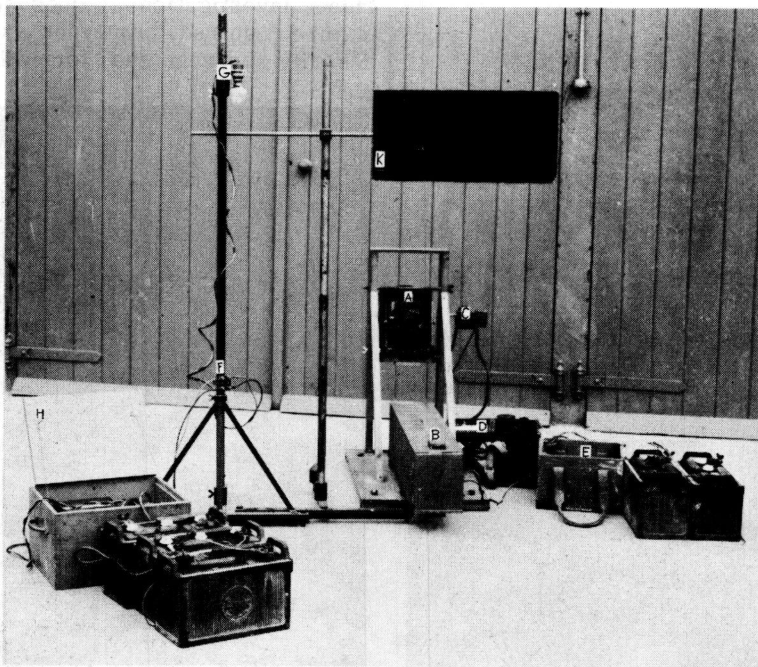


Figure 19. Apparatus used for visual measurements: (A) camera on its stand; (B) calibration box; (C) telephotometer; (D) control unit for telephotometer; (E) control unit for calibration box; (F) lamp stand; (G) lamp; (H) control unit for lamp; (K) screen and stand.

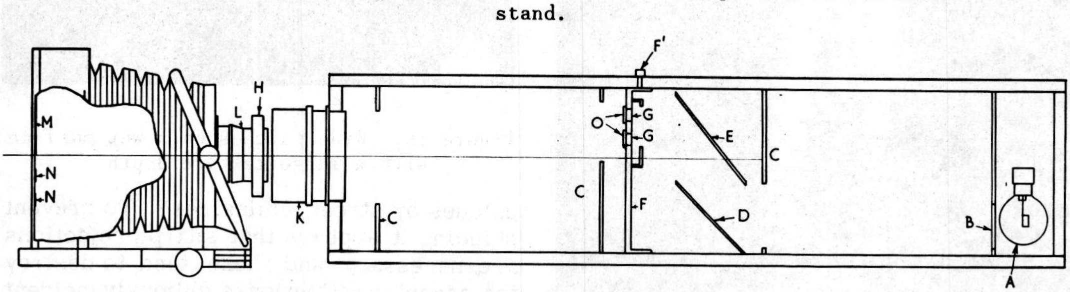


Figure 20. Diagram showing arrangement for calibration exposure: (A) lamp; (B) ground glass screen; (C) screen; (D) plane mirror set at 45 deg.; (E) sand blasted pot opal set at approx. 55 deg.; (F) wedge carrier; (F′) screw to fix position of F; (G) logarithmic wedge screen; (H) shutter; (K) lens - 14 in. focal length; (L) camera lens; (M) mask; (N) image of O; (O) density scales.

been measured so far by the methods outlined above, but useful information has been derived from a subjective appraisal of the appearance of the patches formed on a representative group of bituminous surfaces when wet. It was found that the type of patch formed is closely related to the texture depth of the surface. This quantity is measured by pouring a known volume of fine sand on to the surface and spreading it out into a circular patch so that the valleys are filled in to the level of the peaks. The volume of the sand divided by the area of the sand patch is the texture depth. It is in fact the average thickness of the sand layer.

When the texture depth is small each lantern gives rise to a narrow bright streak, leaving dark areas between the streaks in which objects can be seen only with the greatest difficulty. Sometimes, if the road has bright surroundings, these may be mirrored in the surface and the dark areas eliminated in this way. But where the surroundings are dark, as in Figure 17, the effect may be serious. When the texture depth is large, as in Figure 18, rain has much-less effect on the width of the patches. The texture depth sufficient to give patches of reasonable width during light rain appears to be about 0.013 inches.

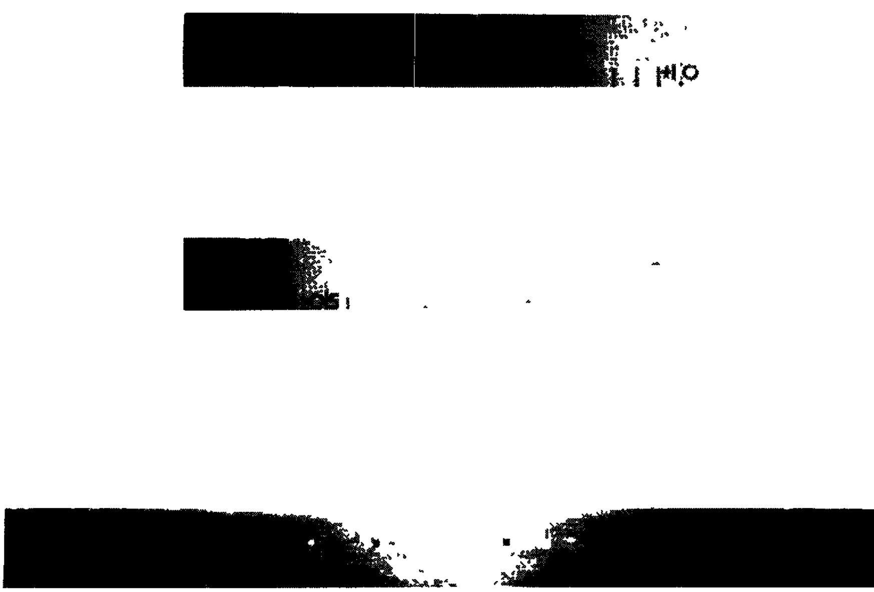


Figure 21. Positive enlargement from negative masked to reduce flare.

ACKNOWLEDGEMENTS

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Appendix A

FACTORS GOVERNING THE DIMENSIONS OF THE EXPERIMENTAL ARRANGEMENT

It is desirable to reduce the size of the experimental arrangement as much as possible in order to limit the area of the road occupied during measurements, the intensity of the light source etc. But since the luminance factor varies rapidly with small angular changes, when d is larger (see Fig. 2) it is necessary to reduce proportionately the sizes of the source, receiver and sample area. The latter requirement sets a limit to the extent of the reduction.

Suppose the value $x = 50$ feet is selected. Then the other fixed dimensions will be: h = 50 cot 88 deg. = 1.75 feet, H = mh = 3 times 1.75 = 5.25 feet. Thus, on a rugged surface with a small source and small receiver, the area of the surface over which the brightness variation is less than 10 percent may be as small as 3 inches wide by 30 inches long when d = 176 deg. Such an area may contain less than 100 aggregate particles which are not necessarily all one kind. Thus, whilst a reasonably representative result might be obtained on such a sample, this would probably not be so if x were further reduced. Moreover, whilst fair accuracy appears to be possible with visual and photographic photometry on this scale, both methods become progressively less accurate with any further reduction.

The value $x = 50$ feet has in fact been selected and the visual and photographic measurements are based on sample areas of the order of those quoted above.

The light source used is a 12-volt, 20-ampere, filament lamp with a diffusing envelope 2.25 inches in diameter, representing a luminaire of about 12 inches on full scale. To represent the pupil of the eye the receiver aperture would have to be about 0.1 inch. The telephotometer and camera used have effective apertures of up to 1 inch, which means that the brightness of a single point on a traffic-polished road surface may vary by about 10 percent over the cone of directions covered by the receiver. But this degree of accuracy is probably quite sufficient.

Appendix B

LABORATORY APPARATUS FOR MEASURING THE LUMINANCE FACTOR

A laboratory apparatus for measuring the luminance factor of pavement samples could be constructed by using a lens to render parallel the light from the source and by mounting the receiver at the focus of another lens. But the incident beam diverges to an extent governed by the size of the source and the focal length of the lens and a receiver of finite area accepts all the light emitted within a certain cone of directions from each point on the sample. Thus, the size of the source and receiver must be restricted to a given fraction of the focal length of the lenses. Working on the same basis as that employed in considering the outdoor arrangement, the size is 0.1 inch for a 50-inch lens. The collimating lens cannot be made very small, since its area determines the area of the sample which can be illuminated, and this must be large compared with the elements of which it is composed. Thus, an apparatus with the required degree of accuracy would be quite large.

For a source of given brightness the collimating lens does not increase the illumination on the sample when the requirements concerning the size of the source are observed but it does shorten the distance between the source and the sample. In practice increased illumination is obtainable since the small source necessary in the laboratory arrangement may be made brighter than the larger source used in the outdoor arrangement, since it may consist entirely of the filament of a lamp.

The receiving lens must have a stop located in the focal plane to limit the light to that arriving in the correct direction. Thus the receiver accepts no more of the reflected light than in the outdoor arrangement when the acceptance angles are identical.

The required receiver sensitivity appears to be about 10^{-7} lumens. Difficulty would be experienced in designing suitable screening to prevent direct light or light reflected from parts of the apparatus from entering the receiver.

Appendix C

APPLICATION OF PHOTOGRAPHIC PHOTOMETRY TO THE MEASUREMENT OF THE LUMINANCE ON THE SURFACE OF A PAVEMENT

The camera is fitted with a mask which may cover either the upper or lower half of the plate. The pavement surface is photographed on the upper half whilst the mask covers the lower half. The position of the mask is then reversed so that a calibrated luminance scale may be photographed on the lower half. The two exposures are made one after the other; the same time of exposure, aperture and focus being used.

A special camera stand (Fig. 19) is used so that when the pavement has been photographed the camera may be lowered in front of a calibration box (Fig. 20) containing a diffusing white surface uniformly illuminated by a battery-fed filament lamp. This surface forms a background to a calibrated neutral wedge screen. An auxiliary lens mounted in the front wall of the box ensures that the wedge is automatically in focus on the photographic plate when the camera is in the lower position.

The negative plates and enlarged positive plates made from them are developed in special tanks, the plates being held firmly against the vertical walls while a plunger rides between them with a small clearance.

The development times are controlled so that the overall contrast is unity (8).

Attention must be given to the uniformity of illumination in the enlarger. Good results can be obtained with a cold cathode lamp, coiled to form a grid and covered by a diffusing screen.

Precautions must be taken to reduce the effect of flare light. The camera lens should be coated and screened from direct light from the light source. The enlarging lens should be coated and all unessential portions of the negative masked. Figure 21 shows an enlargement from a negative. The wedge is in two parts. The markers on the surface of the pavement indicate the line on which the brightness variation is studied and give the scale of distance across it.

The fact that the surface of a pavement consists of a multitude of dark and bright elements necessitates special precautions (8). The camera should be slightly out of focus to photograph the pavement but not enough to render the markers indistinct.

Discussion

D. A. TOENJES, Application Engineering Department, Lamp Division, General Electric Company, Nela Park, Cleveland, Ohio — This paper furthers the basic knowledge of pavement reflection characteristics. Such data are of value in relating the effectiveness of various types of pavement surfaces, to the designs of street and highway lighting equipment and automobile headlighting.

It will be interesting to compare the study outlined in this paper with a somewhat comparable study that is in progress in this country.

Research Project 22 of the Illuminating Engineering Society was originally devoted to the development of equipment suitable for photometric measurements of pavement reflectance. This project was undertaken by J. O. Kraehenbuehl, of the University of Illinois, and has been enlarged to include actual measurements and data on various pavement samples. Associated with this project have been two subcommittees of the I. E. S. Street and Highway Lighting Committee — the Research Subcommittee and a special Task Subcommittee on this Research Project. Details are given in the 1951 I. E. S. paper, "Measurement of Pavement Surface Characteristics" by Professor Kraehenbuehl, published in Illuminating Engineering, May 1952, pages 272-287.

The British study apparently assigns a fixed vertical angle of observation to the observer viewing the road ahead. The study in this country includes a complete range of angles of observation. This is expected to make this study more useful for analysis of floodlighting as well as street lighting and headlighting effects.

The British study depends upon measurements on the actual roadway surface. This has some advantages, in that it is not necessary to remove a section of pavement, and preparations for observation on a particular pavement are not so difficult. However, the study in this country involves laboratory measurements with an actual pavement sample, with the advantages of reproducibility of laboratory results and measurements not limited as to time of observation or flow of traffic.

Also, the laboratory measurements can be made with the sample either dry or wet, and this amount of wetness can be reproducible.

The British study has relied upon visual or photographic techniques of measurement, while the study in this country uses a semi-automatic recording instrument, by which photometry, when once begun in a single pavement sample, can be more rapid and more complete.

Apparently the study described in this paper has been confined to semi-specular reflection from the T-shaped pattern of roadway brightness from a street lighting luminaire. The study in this country includes brightness from other reflected angles, although such angles are admittedly less important in producing the pavement brightness pattern.

Commenting on the conclusions that the author draws from his study, we are inclined to feel that roughness of pavement surface is a help, rather than a hindrance — for, although it lessens the brightness of the T-shaped pattern, it does increase the diffuse reflection outside that pattern. Perhaps this difference in attitude is due partly to the practice, more common in Great Britain, of using street lighting luminaires with relatively high angles of maximum candlepower.

Very likely much information will be gained by a comparison of the results of these two studies.

A. W. CHRISTIE, Closure — The methods described in the paper are designed for the street lighting case and are not intended for problems of vehicle lighting or floodlighting. Further they apply mainly to the region of the pavement surface 80 to 600 feet ahead of the observer, which is of primary importance to vehicle drivers. By so restricting ourselves, all the data necessary for a single surface may be recorded conveniently on a single chart. The method of presentation used by Kraehenbuehl (6) is identical with that employed by Cohu (5) before the war. The data applicable to street lighting are confined to small areas of a number of charts. Indeed it is remarkable how restricted is the region applicable to the road beyond, say, 80 feet. Even for a road 50 feet wide, the relevant region of the sinusiodal web does not exceed 3 percent of the total area. The coordinate system in which the results are expressed makes it difficult to apply them in actual calculations. The data obtained by Cohu appear to have been little used, perhaps for this reason. Already we have used our data for two surfaces, to predict the complete surface luminance patterns which would be obtained with three different types of lighting installation.

It is true that our data are determined at a fixed vertical angle of observation, but in using them it is not assumed that the observer views the road at a fixed angle. A partial correction for variations in this angle is inherent in the method of applying the data. The error involved is negligible at points 150 feet ahead of the observer, and less than 15 percent within the range 80 to 600 feet. If the luminaire intensities are small at high angles the accuracy is even better. The method was adopted after an extensive study of reflection from a number of surfaces and of the existing methods for setting out the results.

Although it is our aim to study the reflection of light incident on the surface at the angles which are most important in producing pavement brightness, this does not mean, as Toenjes thinks, that only semispecular conditions are dealt with. Measurements are made at positions behind and alongside the luminaire. If the standard patches calculated from the data obtained are markedly T-shaped, this is merely an indication of the importance of semispecular reflection on the surfaces concerned. For instance, the mean surface luminance was calculated for a street 45 feet wide, with the surface considered in Figures 8 and 11 and lighted by medium-angle luminaires. The value found was the same as would be obtained with a diffusing surface with a 38-percent reflectance. Yet the luminance factor for light incident vertically on the surface is only about 8 percent. To judge from published data on light distributions and from street-lighting photographs, such conditions are not unknown in the United States.

It was the difficulty of designing a satisfactory laboratory instrument for studying polished road surfaces at the angles appropriate to high-angle lighting which prompted us to use the visual and photographic techniques and to work on actual roads. Suppose that, with Kraehenbuehl's apparatus, a measurement were made on the rolled asphalt with precoated chippings, which we have studied (Fig. 8) at the angles $\Gamma = 0$, $i = i_0 = 70$ deg., and $r = r_0 = 88$ deg. (see Fig. 2). The sample is so large relative to the apparatus that the luminance factor for light reflected from the left- and right-hand edges of the sample would be only about half of that for light reflected from the center of the sample. The effect of this would be to make the luminance factor appear much less variable than it is and this tendency is further accentuated by the employment of a source and a receiver of appreciable dimensions. Yet these angles are well within the range to be studied and the surface is by no means the most specular that is encountered.

There are undoubtedly differences in street practice in the United States and in Britain. In the United States there is a tendency for the main beams of lanterns to be turned in towards the center of the road and for less light to be emitted at high angles, both of which make for a greater dependance on diffuse reflection.

Evaluating Disabling Effects of Approaching Automobile Headlights

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● AS long as the headlights of an approaching automobile are in the field of view of a driver, they will constrict his pupils and produce stray light in his eyes, interfering with his seeing. The constriction of the pupil will reduce the intensity of the useful retinal image and the stray light will produce a veiling brightness which covers the retinal image. The approaching headlights will also produce a marked effect upon the adaptation of the part of the retina on which their images fall, and the stray light in the eye will extend this effect on adaptation to all parts of the retina. After the approaching automobile has passed on by, the observer will still be faced with impaired vision because of the after effects on adaptation and pupil size.

The present paper is concerned primarily with the design of a device which can be used to measure directly the veiling brightness produced in the eye of an observer. The idea is to point the device in the direction in which the observer would be looking and have it measure directly the veiling brightness in the direction of the object looked at. In order to design such a device, it is necessary to know what effect a glare source at a given angle from the primary line of sight will have and how the effects of two or more glare sources add.

One can measure the effect of a glare source at a given angle from the line of sight by using the following procedure. The subject fixates a test object on a dark background and turns on a glare source, and varies the brightness of the test object until it is just visible (Fig. 1). One then turns off the glare source and introduces into the field of view a patch of brightness which covers the test object. The brightness of this patch is varied until the test object is again just visible. One can say then that the superimposed patch of brightness is equivalent to the veiling brightness produced by the glare source, and one can specify the amount of the veiling brightness in terms of the brightness of the equivalent superimposed patch. The effects produced by one or more glare sources can be shown to be strictly additive.

It is difficult to obtain data for small glare angles, and in order to design a meter which will apply to small glare angles as well as large ones, the writer is proposing that values for small angles be obtained by calculating them on the basis of the theory that the effect is mediated by stray light.

Stiles (1) pointed out two fundamental objections to the hypothesis that the effect of a peripheral glare source on foveal vision can be attributed to stray light in the eye: (1) in order to acount for the effect, it was necessary to assume that more light was scattered than was known to be lost in transmission through the media of the eye, and (2) the equation for stray light derived from theory did not conform to the effect produced by a peripheral glare source.

Since Stiles did his study, more-exact information about the transmission of the ocular media has become available and it is known that the transmission of the human eye is lower than that assumed by Stiles.

Furthermore, Stiles assumed as Holladay (2) had done that the scattering by the media of the eye conforms to Rayleigh scattering, which makes the amount of scattering inversely proportional to fourth power of the wavelength. It has been found since then that the effect of a glare source is more or less independent of the wavelength of light (3). This suggests that the scattering particles have a diameter greater than the wave length of light. If this is the case, one can assume a greater preponderance of forward scattering and thus bring the scattering theory into closer agreement with the facts.

It is hardly probable that one can overemphasize the importance of establishing the fact that the effect of a peripheral glare

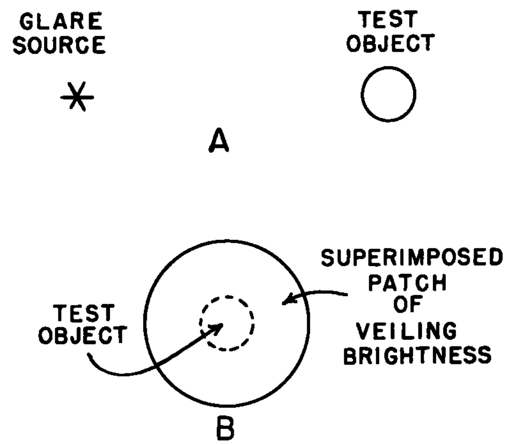

Figure 1. Stimulus patterns used for measuring the veiling brightness produced by a peripheral glare source.

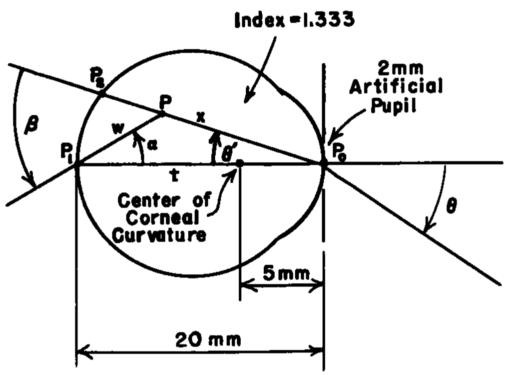

Figure 2. Reduced eye used in computing scattered light in the eye.

source on foveal vision is mediated by stray light. It not only makes it possible to use stray light theory for computing veiling brightness, but it also simplifies the evaluation of the effect of peripheral glare sources on pupil size and adaptation at different parts of the retina. It means that the problem of adaptation can be formulated in terms of pupil size and the adaptation of individual photoreceptors at different parts of the retina.

The facts relating to stray light in the eye may be summarized by noting that stray light may be produced by approaching automobile headlights in several different ways: (1) diffuse transmission through the iris and sclera; (2) flare, produced by multiple reflections at the different refracting surfaces; (3) specular reflection from the front surface of the retina; (4) halation produced by reflection at the pigment epithelium, choroid and sclera; (5) light reflected through the vitreous from one part of the retina to another; (6) fluorescence of the crystalline lens; (7) bioluminescence; and (8) scatter by the media of the eye.

The major source of stray light is scatter by the media and this is true to the extent that the other sources of stray light may be ignored in computing the effects of stray light in the typical observer.

Figure 2 illustrates the geometry involved in computing the scattered light in the eye which is produced by a glare source and which interferes with the visibility of an object which one is looking at. In the figure the glare source is located at an angle, θ, from the object looked at. The object looked at forms an image on the retina at the center of the fovea.

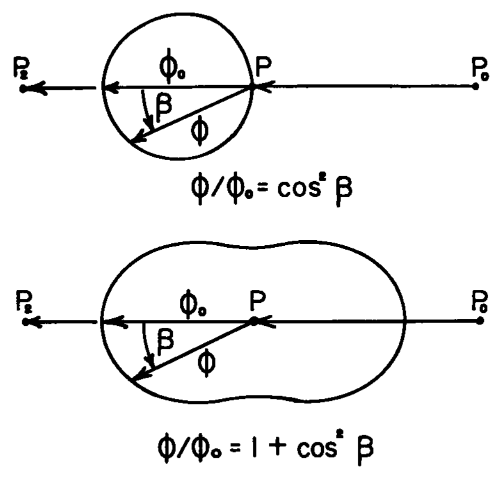

Figure 3. Polar diagrams of scattered light.

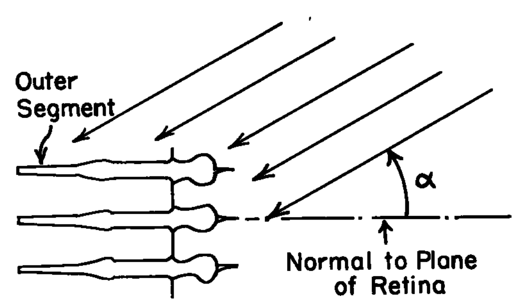

Figure 4. Relation of the angle of incidence to the absorption of light by the photoreceptors.

In order to simplify calculations, it is satisfactory to assume that the eye of a typical observer is equivalent to an eye which has one refracting surface and a single homogeneous medium. It may be further assumed that the pupil of the eye lies in the plane of the cornea. The glare source projects a beam of light through the pupil to a point on the retina. In the calculations about to be described, it has been assumed that the stray light falling on the retina at the fovea is produced by first order scattering at the various points along the beam between the cornea and the retina, and that the stray light produced by flare, reflection at the retina and other sources is negligible. It is assumed further that the amount of scatter is independent of the wavelength.

At any point, P, along the path of the beam, a certain fraction of the flux is scattered in various directions. The lower part of Figure 3 illustrates a polar diagram which shows the relative amounts of light scattered in various directions in the case of Rayleigh scattering. As much light is scattered in a backward direction as in a forward direction. The upper part of Figure 3 is a polar diagram which illustrates the type of scattering which the writer has assumed to exist in his calculations of veiling brightness. This is characterized by a predominance of forward scattering. Scatter at all points along the beam from the cornea to the retina contributes to the stray light falling on the retina at the fovea. The stray light falling on the fovea produces an effect which is equivalent to that produced by a patch of veiling brightness.

In using scatter theory to compute the effect of a peripheral glare source, it has been assumed that the retina is equivalent to a smooth curved surface. The lumens of stray light per unit area falling on such a surface has been computed and compared to the lumens per unit area produced by an external patch of veiling brightness. This comparison implies that the effect of light on photoreceptors is proportional to the cosine of the angle of incidence (cos α).

It is known for example from the Stiles-Crawford effect that this is not always the case. The theory of scattering will have to be modified at this point when the facts are known. Figure 4 illustrates the nature of the problem. The photosensitive substance lines the inside of the outer members of the cones. The problem is further complicated by the extension of processes from the pigment epithelium between the photoreceptors.

As indicated above it is possible to measure the amount of veiling brightness. The straight line designated Equation 13 in Figure 5 represents Stiles data for glare sources located between 1 deg. and 10 deg. from the object looked at. The straight line designated Equation 14 represents Holladay's data for glare angles between $2\frac{1}{2}$ deg. and 25 deg.

The curves designated Equation 12 and Equation 22 are the curves calculated from scatter theory. The curve designated

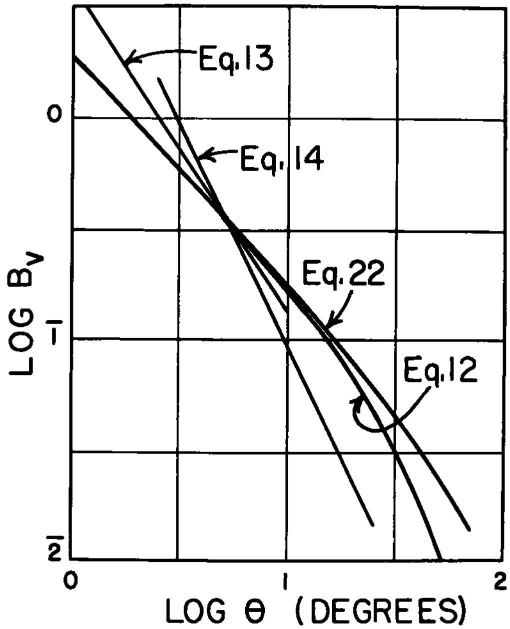

Figure 5. Comparison of theoretical and empirical curves for veiling brightness (B_V) for various glare angles (θ); E = 1 c/m².

Equation 22 is based on Rayleigh scattering and the curve designated Equation 12 is based on the scatter diagram in the upper part of Figure 3, which is characterized by a predominance of forward scattering. Although the fit to the empirical data is better for Equation 12 than for Equation 22, neither is very satisfactory. It should be noted, however, that for small angles for each of the theoretical curves, the veiling brightness is inversely proportional to the glare angle. This would also be true for most any reasonable assumption that one might make about the nature of the scattering.

It would appear that complete agreement cannot be achieved merely by changing the form of the scattering function, or by making a different assumption about how the absorption of light by photoreceptors is affected by the angle of incidence.

It has been assumed that the medium of the eye is uniform from the cornea to the retina. This is only an approximation. It is known that the lens for example has a much higher attenuation coefficient than the aqueous or the bitreous. So far as the lens is concerned the values of both α and β are small for first order scattering and the

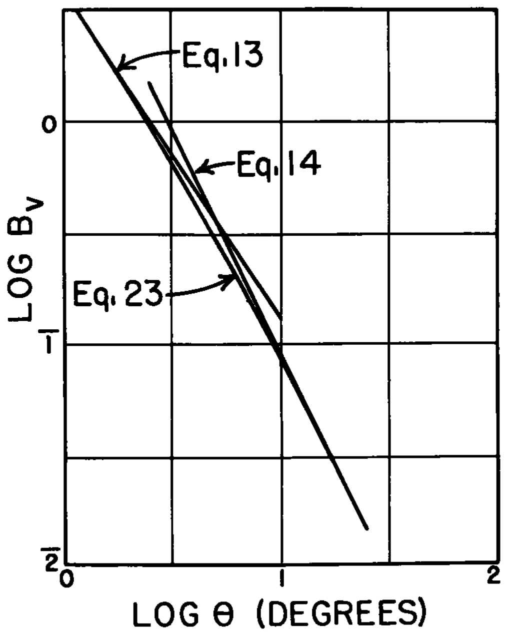

Figure 6. Proposed Equation 23 for computing veiling brightness for various glare angles and its relation to the equations of Stiles (13) and Holladay (14); $E = 1$ c/m².

scattering function determines for the most part the distribution of light on the retina. If the lens alone were considered, it would be necessary to assume an unreasonable amount of forward scatter. Hence all of the media of the eye should be considered with different scattering functions and attenuation coefficients for each. This gives the scattering theory the flexibility it needs to bring it within the range of experimental facts and permits one to make whatever assumption that needs to be made in regard to the effect of angle of incidence upon the light absorbed by a photoreceptor. It seems unnecessary therefore to postulate a mechanism in the retina to help account for the effect of a peripheral glare source on foveal vision, except in the case of glare angles of two degrees or less.

In Figure 6, the curves designated Equations 13 and 14 again represent the empirical data of Stiles and Holladay. The curved line designated Equation 12 represents an approximate fit to both sets of data and at the same time provides for the extrapolation of the data to a zero angle of glare. This curve conforms to the equation,

$$B_V = \frac{8.2\ E}{\theta\ (1.5+\theta)}$$

where B_V is the veiling brightness (candles per square meter), E the illumination (lumens per square meter) in the plane of the pupil which is assumed to be normal to the primary line of sight, and θ is the angular displacement (in degrees) of the glare source from the primary line of sight.

The extrapolation of the data to zero angles of glare is based upon calculations of veiling brightness made from scatter theory and conforms to the proposition that for small angles of glare the veiling brightness is inversely proportional to the glare angle.

It is recommended that this equation be used in calculating the veiling brightness produced by a glare source in a given situation. It is also recommended that this equation be used in the design of a meter for predicting the veiling brightness which must exist for a typical observer in a given situation.

A typical situation is illustrated by two cars passing each other at night when the driver of one car is faced with the necessity of seeing a pedestrian who is located in his path at a slightly greater distance than the approaching automobile. One can compute the brightness of the surface of the highway which forms the background for the pedestrian and the brightness of the pedestrian and the veiling brightness produced by the approaching headlights. With this information, one can determine preciselv how much the contrast of the pedestrian against his background will be affected by the veiling brightness. Furthermore, if the pupil size and the state of adaptation of the photoreceptors in the central portion of the retina were known, the chances of seeing the pedestrian could be predicted.

The devise described above could be used to measure the veiling brightness and it is conceivable that with the addition of continuous recording and computing equipment the state of adaptation at any given part of the retina at any given moment might be determined.

SUMMARY

Evidence has been presented to show that the effect of a peripheral glare source on foveal vision is mediated by stray light.

It is difficult to measure the veiling brightness for small angular displacements of the glare source from the line of sight, but the empirical data can be extrapolated to zero angles of glare by the use of stray light theory.

It is possible therefore to design a device which will measure directly the veiling brightness produced by the headlights of an approaching automobile.

It is also probable that such a device can also be used to determine the state of adaptation of the central region of the retina, at various moments during the approach, and after the approaching automobile has already passed by.

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Visual Detection at Low Luminance through Optical Filters

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● IN recent years, three optical filters have come into rather widespread use for night driving. Two of the filters are offered to the public in the form of "night-driving glasses." The third filter is offered to the public in the form of heat-absorbing windshields. The present paper is primarily concerned with the effect of these optical filters upon visual detection under conditions such as those encountered in night driving. Other implications of the use of optical filters for night driving are discussed to place the detection data in proper perspective.

Tne first section of the paper contains a qualitative analysis of the expected effects of optical filters upon visual performance in night driving. The second section describes a method for quantitative prediction of the effects of optical filters upon visual detection at low luminance. The third section contains a report of experiments in which the effect of the three optical filters upon visual detection at low luminance was investigated. The results of these tests were compared with the predictions made by the method described in the second section. The fourth section discusses implications of the experimental tests and the analyses for highway safety.

I. Qualitative Analysis of Expected Effects of Optical Filter Upon Visual Performance in Night Driving

During the past century, innumerable studies have been made of the relation between visual performance and the quantity of general luminance in the visual field. Large numbers of studies have involved visual detection (sometimes called intensity discrimination or contrast sensitivity). Other large numbers of studies have involved visual acuity. For a summary of some of these studies see Moon and Spencer (1). Lesser numbers of studies have involved other visual capabilities such as flicker and depth discrimination. In most of these studies, the luminance has been uniform over a large portion of the visual field. Studies of all visual capabilities made under conditions of uniform general luminance agree in showing that, at low luminance, a reduction in luminance reduces visual performance appreciably. At high general luminance, a reduction in luminance reduces visual performance either not at all or very little, or it may improve visual performance slightly. The precise amount of change in performance for a given change in general luminance has been shown to depend upon: (1) the general luminance level and (2) the visual capability studied.

Only a little research or clinical attention has been devoted to the relations of visual comfort and general-luminance level. It is generally believed that high levels of general luminance cause visual discomfort, even when the luminance is uniform over a considerable portion of the visual field. It is generally believed that uniform fields of low general luminance do not cause visual discomfort.

There have been a considerable number of studies of visual performance for fields of nonuniform luminance. Most of these studies have involved visual detection or visual acuity. For a summary of these studies, see Moon and Spencer (2). These studies agree in showing that luminance nonuniformity often reduces visual performance. Such losses in visual performance as a function of luminance nonuniformity occur at all levels of general luminance. Unfortunately, systematic studies have not been made to determine the relation between visual performance and level of nonuniform luminance, with a fixed degree of nonuniformity maintained at all luminance levels. As we shall see, such data are directly relevant to the problem of the use of optical filters in night driving.

There have also been a few studies, and much clinical observation, of the visual discomfort produced by nonuniformity of general luminance. Discomfort may be produced at any level of general luminance. Apparently, the higher the general luminance level, the smaller is the percentage luminance nonuniformity required to produce discomfort.

This relation explains the fact that the visual discomfort experienced by most people out of doors in the daytime can be reduced by a reduction in the high level of general luminance. Sunglasses are used for precisely this purpose. It is generally believed that the reduction in general luminance produced by the sunglasses causes little or no decrease in visual performance. This belief is based to only a small extent upon data relating visual performance to the general level of nonuniform luminance. It is based primarily upon the studies relating visual performance to the level of uniform luminance referred to above, which demonstrated little loss in performance when high levels of general luminance are reduced. Extrapolation of this relation to the case of nonuniform luminance is generally accepted. Our knowledge of the photochemical and neural aspects of vision provide bases for understanding why visual performance is relatively independent of general luminance level at high luminance. This independence must occur to a large extent whether or not the field of high luminance is uniform. Such experimental data as there are relating performance and the general level of nonuniform luminance confirm the validity of this extrapolation.

It is easily demonstrated that the visual discomfort produced by luminance nonuniformity at low luminance can also be reduced by reduction in all luminances reaching the eye. For example, the visual discomfort resulting from viewing bright lights at night can be reduced by wearing sunglasses. What will be the effect of general luminance reduction upon visual performance at low levels of nonuniform luminance? There does not appear to be any satisfactory experimental evidence on this point. It would seem reasonable to extrapolate as before and argue that general luminance reduction will have appreciable effects upon visual performance at low levels of nonuniform luminance. The photochemical and neural aspects of vision which produce large changes in visual performance as the level of general luminance is varied at low luminance may be expected to be present whether the luminance is uniform or nonuniform. Such a line of reasoning would suggest that sunglasses not be used to increase visual comfort at low luminance because of appreciable losses to be expected in visual performance. Thus, it is presumably acceptable to wear sunglasses in the daytime to increase visual comfort but not acceptable to do so at night.

These conclusions have apparently been widely accepted for many years. Sunglasses are widely used in daytime visual tasks but have not been often recommended for use in night visual tasks.

Recently, however, several commercial products involving optical filters have been recommended for use in night driving. The most widely advertised filters intended for use at night have been manufactured in the form of so-called night-driving glasses. One of these products involves pale-yellow light filters; the other involves amber light filters. These glasses have been advertised as safety aids for night driving. It has been claimed that the glasses increase visual comfort at night. There is little doubt that optical filters will reduce the visual discomfort caused by viewing bright headlights at night. In addition, however, it has been claimed either that the filters will not reduce visual performance at night or that the filters will actually increase visual performance at night. As noted above, there is reason to believe optical filters will always reduce visual performance at night.

The use of heat-absorbing glass in automobile windshields has become increasingly prevalent in recent years. This glass is primarily intended to reduce solar heating of the automobile interior. In addition to absorbing heat, the glass absorbs visible radiation. It is claimed that the heat-absorbing windshields increase visual comfort in the daytime. As optical filters, they undoubtedly do so just as do sunglasses. By increasing the optical density of the windshields toward the top through use of an auxiliary plastic layer, the windshields are made to reduce luminance nonuniformity in the visual field. In this way, visual comfort is undoubtedly increased even more than would be the case with uniformly dense optical filters, which merely reduce all luminance. The heat-absorbing windshields are clearly acceptable for daytime use, since there is no evidence that filters will reduce visual performance in the daytime. It has also been claimed that heat-absorbing windshields reduce visual discomfort at night. They may be expected to do so, just as will all optical filters. There have also been claims that heat-absorbing windshields either will not reduce visual performance at night or will increase visual performance at night. There is reason to expect that the heat-absorbing windshields, like other optical filters, will reduce visual performance at night.

The claims made for the various optical filters utilize the term "glare". All filters are purported to reduce glare. It is stated in some advertising that glare produces highway accidents and it is implied that since the filters reduce glare, they will reduce highway accidents. It will be well to consider what is meant by the term. The Illuminating Engineering Society (3) differentiates between "disability glare" and "discomfort glare". Each type of glare is produced by nonuniformity of luminance in the visual field. Disability glare is defined as a condition of luminance nonuniformity great enough so that visual performance is reduced. Discomfort glare is defined as a condition of luminance nonuniformity not great enough to produce a measurable reduction in visual performance but one which, nonetheless, produces visual discomfort.

Most experienced drivers are aware that headlights produce disability glare under some conditions. It is common experience that object contrasts near headlights are washed out by a veiling haze, making objects difficult or impossible to see. Disability glare undoubtedly produces highway accidents.

Most drivers will affirm that headlights produce some degree of visual discomfort. Discomfort does not cause highway accidents directly. It can produce accidents indirectly, if discomfort produces a loss in visual performance or a loss in any other aspect of driver performance.

We can now place the claims made by the filter manufacturers in proper perspective. We have stated that there is reason to believe that filters will reduce visual performance at low luminance whether the general luminance is uniform or nonuniform. This means that we do not believe optical filters can reduce disability glare. We agree that optical filters will reduce visual discomfort at low luminance, as well as at high luminance. This means that optical filters can indeed reduce discomfort glare. Unless visual discomfort has an indirect effect upon some aspect of visual performance, however, reduction of visual discomfort will not improve visual performance. Hence, it appears likely that the net effect of using optical filters at night will be a loss in visual performance.

Thus far, we have considered the optical filters only insofar as they reduce general luminance, i.e., we have treated them as neutral filters. The heat-absorbing windshields are substantially neutral over the area used by most drivers. As noted, some of these windshields have a graded density which increases toward the top. This graded density is quite green at the top. Since few drivers view the road through the top of the windshield, however, it will suffice for our purposes to consider the heat-absorbing windshields as essentially neutral filters. As noted, the night-driving glasses are markedly chromatic. We may now consider to what extent the color of these filters introduces additional considerations.

The literature abounds in studies of the relation between the color of light and visual acuity at high general luminance. It must be concluded that the evidence is conflicting as to whether acuity is greater or less with yellow or amber than with white light. It is apparent that one variable taken alone must result in somewhat greater acuity with yellow or amber than with white light. This variable is the chromatic aberration of the eye. Any chromatic filter will reduce chromatic aberration to some extent. Unless other variables are also involved, acuity should increase with any decrease in chromatic aberration. The conflicting experimental literature suggests that variables must be involved when yellow or amber light is compared with white in addition to chromatic aberration. One variable which could work against yellow or amber light is the number of retinal receptors stimulated. Yellow or amber light will not stimulate as many receptors as white light so that the retinal receptive mosaic is coarsened with yellow or amber light, compared with white light. This effect will not necessarily be reflected in the luminous transmission of a filter, since luminosity does not depend critically upon receptor mosaic.

The writer is not aware of evidence that visual acuity at low luminance has been studied systematically with chromatic light. At low luminance, acuity is greatly reduced. Under these conditions, the role of chromatic aberration will be of little significance. Thus, we do not have as much reason to expect the yellow or amber filters to increase acuity at low luminance as at high. The possibility exists, however, that visual acuity may be improved by highly chromatic filters, even at low luminance.

Our discussion of the effect of chromatic filters upon visual acuity is only cursory. The discussion will suffice, however, since it is the writer's opinion that visual acuity is not a particularly critical visual capability for use in night driving. This point of view may be justified in the following way. The night driver must detect certain objects in order to avoid accidents. In particular, he must detect the presence of pedestrians, parked cars, and other obstacles along the roadway. He is not required to recognize or identify details of these roadside obstacles in order to avoid collision with them. If the driver detects them, he will control his vehicle to avoid collision. Of course, the night driver must read signs, but accidents are seldom caused by poor sign-reading. In addition, the night driver must estimate speed and distance, and many accidents result from faulty estimates of these variables. But these estimates are not based upon simple visual acuity. The most important visual capabilities for night driving are therefore believed to be: (1) visual detection, needed to avoid pedestrian and obstacle accidents and (2) visual estimations of speed and distance, needed to avoid collisions with other vehicles.

Studies have apparently not been made of the influence of chromatic filters upon visual detection at low luminance. However, since detection can be shown to depend but little upon image blurring (4), there is no reason to expect a reduction in chromatic aberration to improve detection to any appreciable extent.

Studies have apparently not been made of the influence of chromatic filters upon visual estimates of speed and distance at low luminance. There seems to be no clear reason to expect improvements in these judgments by use of chromatic filters, but evidence on this point is lacking.

It has been suggested in some of the advertising claims that the chromatic filters improve visual performance at night because they reduce the amount of light scattered from the headlights either by the atmosphere or by the fluids within the eyeball. A reduction in scattered light would be expected to increase either visual detection or visual acuity. However, it is difficult to see how this claim can be correct to any appreciable extent. It is true that clear air scatters light selectively, in accordance with Rayleigh's formula. However, clear air scatters very little light over distances such as are involved in night seeing on the highways. When the atmospheric scattering is large, the scattering is essentially achromatic, due to the large particles associated with large amounts of scattering (5). Similarly, the fluids in the eyeball may be expected to scatter selectively in accordance with Rayleigh's formula. As Fry (6) has shown, however, the majority of scattered light within the eyeball is due to large particles which scatter nonselectively.

It thus appears unlikely that the chromaticity of optical filters will introduce effects upon visual detection at low luminance apart from effects due to their luminous transmission. However, the possibility of specifically chromatic effects exists logically until experimental work has been done.

It is claimed in the advertising that the yellow and amber filters are particularly effective in reducing visual discomfort. The writer has compared visual comfort in the laboratory with yellow and amber filters paired with neutral filters of a matched luminous transmission. For these tests, a visual environment was set up to simulate automobile headlights seen at night. The writer confirms that visual discomfort is less with the yellow or amber filters than with matched neutral filters. The explanation for this difference in visual comfort is not apparent.

CONCLUSIONS

The foregoing analysis has indicated that the three optical filters being used in night driving may be expected to reduce visual discomfort due to viewing bright headlights at night but that losses in visual performance are to be expected. Since the reduction of discomfort is a desirable objective in itself, it is essential that quantitative estimates be obtained of the losses in visual performance which are to be expected. A method of obtaining quantitative estimates of the effect of optical filters upon one important aspect of visual performance, visual detection, will be described in the following section.

II. Quantitative Method for Assessing The Influence of Optical Filters upon Visual Detection at Low Luminance

A method has been developed which permits predictions of the influence of optical filters upon visual detection at low luminance. The method is based upon a series of 81,000 visual observations previously reported by the author (7). The method is presumed to be applicable to the evaluation of any optical filter.

The visual-detection data which provide the basis for the method were obtained under conditions which may be described briefly as follows: Observers were seated before an opening in a uniformly lighted cube. A target could be presented, representing a luminance increment to the uniform luminance on the wall of the cube farthest from the observers' eyes. The luminance increment and the target size and duration could be varied. The general luminance of the cube could also be varied. A general view of the cube is given in Figure 1. The observers, cube, and a circular target are apparent. (The windshield placed before the observers was utilized in the experiments to be described in Section III.) Studies were made of the relation between visual detection and general luminance for circular target objects varying in angular size, for each of various target exposure times. Separate studies

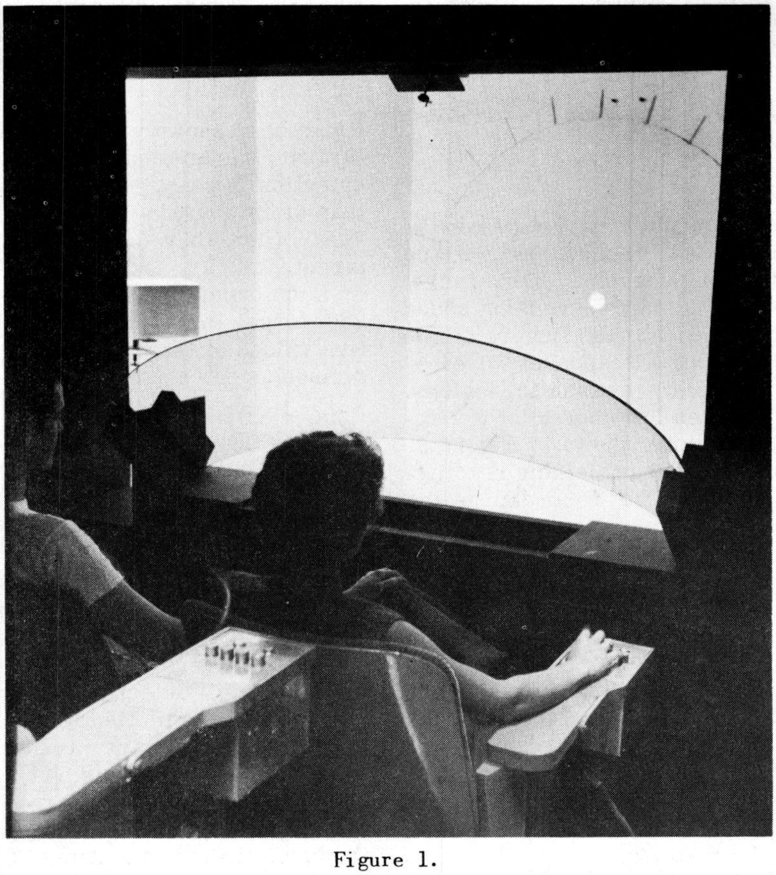

Figure 1.

were made with target durations of $\frac{1}{1000}$, $\frac{1}{300}$, $\frac{1}{100}$, $\frac{1}{30}$, $\frac{1}{10}$, $\frac{1}{3}$, and 1 second. At each target duration, target size was studied within the range from approximately 1 minute to 1 degree of arc. For each target size and each target duration, the influence of general luminance was studied from 100 to 1×10^{-3} foot-lamberts. In all, some 162 experimental sessions were conducted. The targets were presented by transillumination through a plastic screen which made up a portion of the cube wall. The target presentation apparatus is shown in Figure 2.

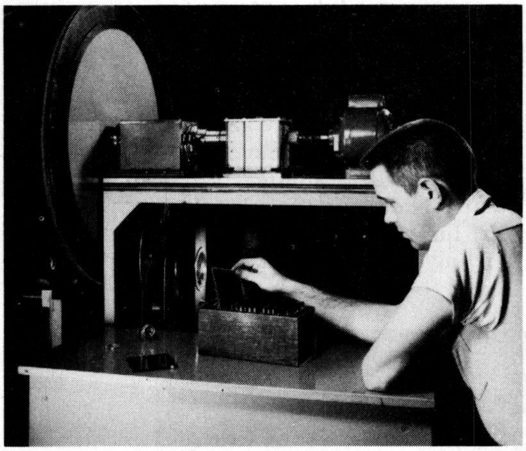

Figure 2.

The entire sequence of target presentations was automatically scheduled by a tape reading-and-timing device. Observers' responses were made by depressing coded buttons, shown beneath the fingers of one observer in Figure 1. Responses were recorded and scored by automatic devices. The apparatus used for control of the experimental sessions is shown in Figure 3. The operator is setting the tape reading-and-timing device. The recorder is the device to the left of the tape reader. The apparatus is described in detail in an earlier publication (8).

The accuracy of visual detection was specified by the probability of detection in a forced-choice situation. In the forced-choice situation, the target appears in one of four temporal intervals and the observer is required to indicate his detection of the target by correctly identifying the temporal interval in which it occurred. The influence of chance successes is eliminated by means of the relation:

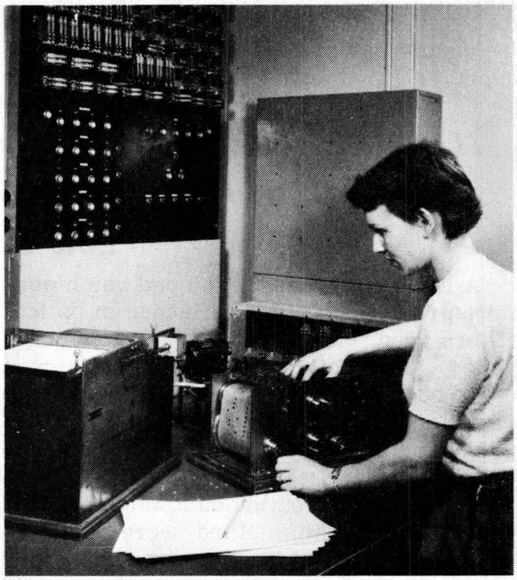

Figure 3.

$$p = \frac{p' - C}{1 - C} \qquad (1)$$

where p = corrected probability of detection,
p' = raw probability of detection,
C = the probability of chance success; in this case 0.25.

It has been shown in an earlier publication (9) that this method of measuring visual detection is more reliable and more valid than simply asking observers to respond "yes" when they detect the presence of a target.

Each experimental session consisted of 250 target presentations, 50 for each of five values of target contrast. Contrast is defined as

$$C = \frac{\Delta B}{B} \qquad (2)$$

where ΔB is the difference in luminance between target and background,
B is the general luminance.

The value of ΔB is taken as positive regardless of the direction of the difference. This procedure is justified by evidence reported elsewhere by the writer (10). The probability of detection, after correction for chance, was plotted against target contrast. A normal ogive was fitted to the data by the probit analysis (11). The target contrast eliciting any desired level of detection probability may be determined from the ogive fitted to the data. The justification for fitting normal ogives to probabilities of visual detection is presented in an earlier paper (12).

In the data to be presented, target contrast values have been presented corresponding to 50-percent-detection probability. Following tradition, the term "threshold" will be used to refer to values of any physical parameter which correspond to 50-percent-detection probability. This low level of performance was selected for precision reasons: The contrast is most-accurately defined at this value of detection probability. Fortunately, the figures may be easily modified to correspond to any other detection probability of interest. It is shown in the earlier paper (7) that multiplication of the target contrasts by a suitable constant corrects the curves to any desired detection probability. For example, multiplying all target contrasts by two corrects the data to correspond to 99-percent-detection probability. Since logarithmic scales of contrast are employed, this type of correction may be made by sliding the log-contrast scale. The form of the relations shown in the various figures does not depend, therefore, upon the detection probability selected.

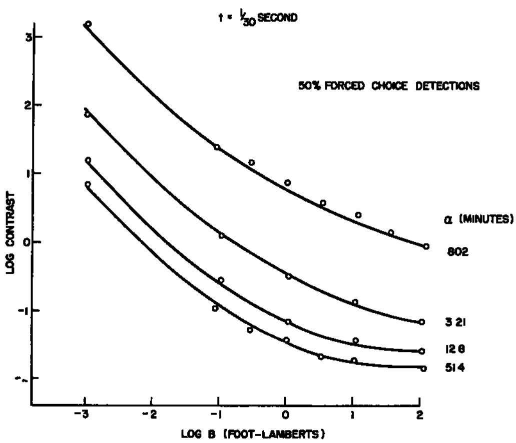

Figure 4.

Figure 4 presents the relation between log contrast and log background luminance for each of four target sizes. The angular subtense of the diameter of the circular targets is represented by the symbol α. These experiments were conducted with a target exposure duration of 1/30 second. This target exposure is considered appropriate for evaluating visual detection in night driving, where only restricted time is available due to the high velocity of the vehicle. Each experimental point is based upon at least 500 observations by two trained observers. The curves refer to a probability of detection of 50 percent. The data refer to "white" light of 2,850 K. for both target and general luminance.

Figure 5 presents interpolations from Figure 4, with log background luminance as the parameter.

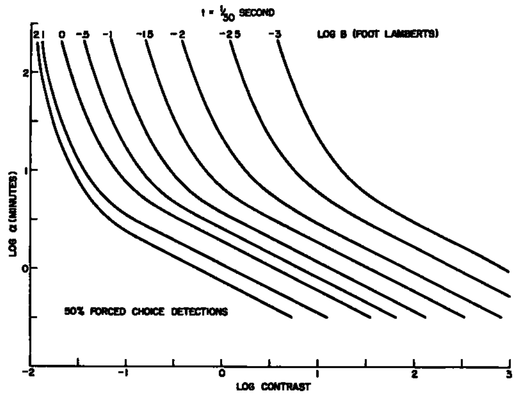

Figure 5.

Figure 6 presents crossinterpolations from Figures 4 and 5. Here we have the relation between log angular subtense (α) and log background luminance, with target contrast as parameter.

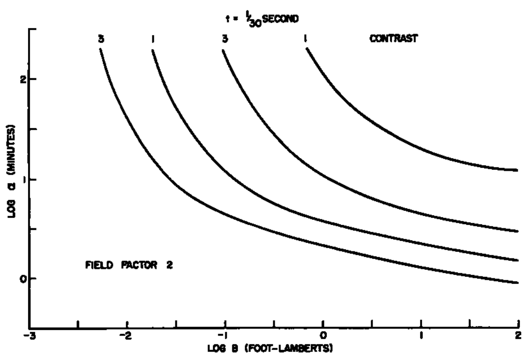

Figure 6.

In constructing these figures, relations between the experimental parameters obtained at target durations different from 1/30 second were employed to insure that the entire body of experimental data exhibited internal consistency. It will be well to note that the quantitative effects of optical filters on visual detection differ but little for data obtained with different target durations. Thus, whether the night driver is considered to have 1/30 second to detect a pedestrian or obstacle, 1/10 second, 1/3 second, or even 1 second will make little difference to the results of the analysis.

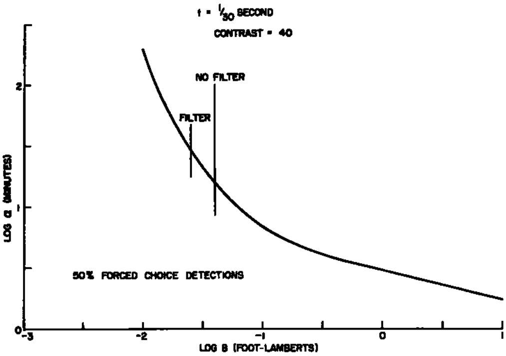

Figure 7.

Figure 7 has been constructed to exhibit the method of evaluating the effect of an optical filter upon visual detection, when the general luminance is uniform. The curve in Figure 7 is an iso-contrast contour, as are the curves exhibited in Figure 6. Now, for a given value of luminance, B, there is one value of threshold α for each iso-contrast contour. Thus, if we know target contrast, C, and luminance, B, we may read the value of threshold α from an iso-contrast contour. The vertical line in Figure 7 labeled "No Filter" cuts the iso-contrast contour at a given value of α, representing the threshold angular subtense of a target for a pair of values of B and C.

Any filter which absorbs light will reduce the value of B, the general luminance. If the filter is clear and unscratched, it will not affect target contrast. (If the filter is not clear and unscratched, the filter will reduce target contrast in addition. In our evaluation we will give the filters the benefit of the doubt and assume that they do not reduce target contrast.) Now, a filter absorbs a fixed percentage of the incident light, regardless of the amount of light. Thus, the effect of a given filter amounts to a fixed decrease in log B, regardless of the value of B. It is apparent from the curves in Figure 7 that such a decrease will always increase threshold α. To ascertain the amount of this increase, from the point on the iso-contrast contour where the vertical line marked "No Filter" cuts, proceed along the contour until you have moved the proper distance along the log B axis to correspond to the filter absorption. Read the value of threshold α corresponding to the reduced B and compare the value of α with that obtained with the original B. The increase in α is the proper measure of the influence of the optical filter upon visual detection.

Our experiments were all conducted at one viewing distance and α was varied by varying the physical size of the target. In the night-driving situation, the target size is fixed and α varies with the distance between the target and the driver. Thus, the practical implication of an increase in α is a decrease in what we shall call the "detection distance," that is, the distance between driver and target when detection first occurs.

One interesting aspect of the effect of optical filters upon visual detection with uniform general luminance is now apparent. The magnitude of the increase in α produced by a given filter is not a fixed quantity but depends upon the physical conditions encountered. From our example in Figure 7, it is apparent that the percentage magnitude of α increase is determined by the slope of the iso-contrast contour over the range of luminance values of interest. It is apparent from the contours in Figure 6 that the extent of α increase resulting from use of an optical filter depends upon the exact values of both B and C. In general, the extent of α increase for a given filter will be greater the smaller the value of B or the larger the value of C.

Let us next develop a means of evaluating the effect of an optical filter when the general luminance is nonuniform. To do so, we must employ information on the influence of nonuniformity upon visual detection. Here we must use data on what has been called "disability glare." These data have been summarized by Moon and Spencer (2).

For simplicity of exposition, we shall hereafter refer to luminance nonuniformities in the usual way as "glare sources." We have avoided use of this term to this point so as not to confuse disability and discomfort glare. In the analysis which follows in this section, however, it will be clear that we refer to disability-glare effects exclusively.

Moon and Spencer showed conclusively that the disabling effect of glare may be evaluated in terms of the concept of a veiling luminance. The physical interpretation of this concept is that light which enters the eye from the glare source does not entirely come to focus on the retina in the image of the glare source. Some of the light is scattered onto other parts of the retina. The glare source thereby adds a veiling luminance, B_V, to both target and general background. The one physical quantity unaffected by B_V is ΔB, the luminance increment of the target.

Expressed in terms of contrast and general luminance, the effects of a glare source are that: (1) target contrast is reduced and (2) general effective luminance is increased. The quantitative relations are as follows:

$$C' = C \cdot \frac{B}{B + B_V} \qquad (3)$$

$$B' = B + B_V$$

where C' = contrast in the presence of glare, (4)
B' = effective luminance in the presence of glare,
B_V = veiling luminance produced by glare.

In order to evaluate the influence of optical filters upon visual detection in the presence of glare sources, we require a method for evaluating the value of B_V produced by a glare source. This may be accomplished by measuring the effect of the presence of glare sources upon the threshold value of α . The procedure may be described as follows: Let us determine the relation between B and α for a fixed value of ΔB, utilizing the data obtained without glare sources. We define ΔB by rewriting equation (2) as

$$\Delta B = B\,C \qquad (2a)$$

Now, to plot values of B and α for fixed Δ B, we select values of B, compute C for the fixed ΔB, and interpolate values of α corresponding to the values of B and C from Figures 4, 5, and 6. The result of such a process is an iso-ΔB contour such as is exhibited in Figure 8. Every point on the iso-ΔB contour defines a pair of values of B and C. In our example, we selected $\Delta B = 0.0161$, for reasons which will become apparent.

The general form of the contour in Figure 8 reflects the fact that glare sources serve to increase threshold α . Consider any one point on the contour. The value of B and the fixed value of ΔB defines a value of C. Now, the addition of a glare source

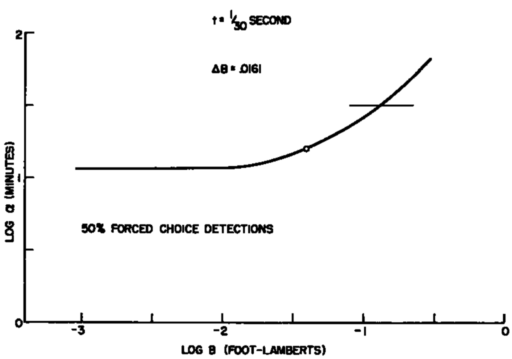

Figure 8.

increases B by the addition of B_V, and incidentally reduces C. However, since Δ B is unaffected by a glare source, we may represent the effects of a glare source by moving along the contour to the right an amount corresponding to B_V. As we move to the right along the contour, threshold α increases. The amount of increase in threshold α reflects the effect of the glare source upon visual detection.

Let us take a concrete example of the effect of a glare source. The open circle on the contour in Figure 8 defines the condition where $C = 0.40$, $B = 0.0402$. These values of C and B represent the point of intersection of the vertical line labeled "No Filter" and the iso-contrast contour in Figure 7. Threshold α for this condition is 11.5 minutes of arc.

Now suppose a glare source is added to the physical conditions of uniform luminance. It is impossible to measure B_V physically in the living eye. We may, however, infer its value from the increase in the value of threshold α produced by the glare source. In our example, suppose the value of threshold α in the presence of a glare source increased from 11.5 minutes to 31.6 minutes. Now, we lay off a horizontal line corresponding to log α , as shown in Figure 8. The intersection of the horizontal line and the iso-ΔB contour defines a value of B', the effective luminance in the presence of the glare source. In our example, $B' = 0.134$ foot-lamberts. Since $B = 0.0402$, $B_V = 0.094$ foot-lamberts. The value of $C' = 0.12$. In the presence of glare, then, B was increased from 0.0402 to 0.134 and C was reduced from 0.40 to 0.12.

The procedure illustrated permits us to specify the values of target contrast and effective general luminance in the presence of glare. With these quantities at hand, we can evaluate the effect of optical filters upon visual detection in the presence of glare. To do so, we construct an iso-contrast contour for the value of C', in our example 0.12. In Figure 9, we have an iso-contrast contour for C' = 0.12, and also the iso-contrast contour for C = 0.40 already presented in Figure 7. The open circles represent the values of B and B' for the values of C and C' respectively. Thus, the arrow joining the two open circles signifies the effect of a glare source in increasing B and reducing C. The net result of these two effects is as shown an increase in the threshold α from 11.5 to 31.6 minutes.

We have already described the process for assessing the effect of an optical filter when no glare is present, in terms of Figure 7. Now that we have described the effect of glare in terms of values of B' and C', precisely the same procedure can be applied. Thus, in Figure 9, the effect of an optical filter in the absence of glare is shown by an increase in α defined along the 0.40-iso-contrast contour. The effect of the same filter in the presence of glare is shown by an increase in α defined along the 0.12-iso-contrast contour.

Figure 9 illustrates a most important point. Starting with the open circle on the 0.40-iso-contrast contour, we note that the use of a filter increases α in the absence of glare. Glare alone increases α as is shown by the open circle on the 0.12-iso-contrast contour. The use of a filter in the presence of glare increases α over and above the increase produced by glare. This Figure presents in a quantitative manner evidence to support the statement

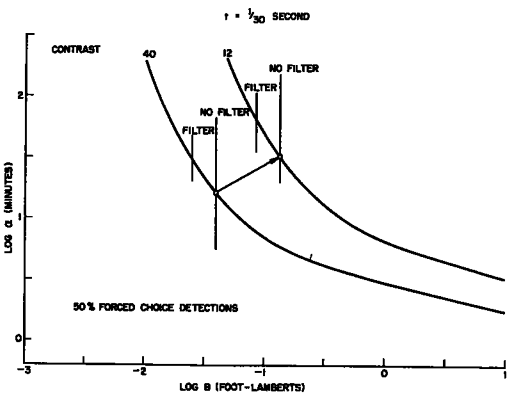

Figure 9.

made in Section I that optical filters would be expected to reduce visual performance in the presence of luminance nonuniformity in the same general way that they reduce performance with uniform luminance.

CONCLUSION

We have developed quantitative methods for evaluating the effects of optical filters upon visual detection in terms of the increase they produce in threshold α. A simple procedure has been described for situations involving uniform luminance. All that is required to assess a given filter is its luminous transmission and a statement of the physical conditions of general luminance (B) and target contrast (C). A more-complex procedure has been described for situations involving nonuniform luminance (glare sources). In this case we need in addition a measure of the increase in threshold α produced by presence of the glare source.

III. Experimental Tests of the Influence of Optical Filters Upon Visual Detection at Low Luminance

Experimental tests have been made of the effects of three optical filters upon visual detection at low luminance. These tests were undertaken primarily to investigate the validity of the quantitative method of predicting the effects of optical filters upon visual detection, described in Section II. The significance of such validation is obvious. If experimental tests show that the analysis is valid, the quantitative method can be used to evaluate filters other than those tested. Such an evaluation method would eliminate the necessity for experimental evaluation of each optical filter which can be produced by one or another manufacturer.

It is to be emphasized that the analysis of Section II ignored the chromaticity of the optical filters, assuming that chromaticity is not highly significant to visual detection at low luminance. If chromaticity were more significant than expected, the predicted effects of filters could err for this reason.

Furthermore, the analysis assumed that glare sources affect visual detection directly only, in a manner quantitatively defined by Equations 3 and 4. We noted in Section I the logical possibility that glare could influence visual detection indirectly. For example, glare could lead to discomfort and discomfort could influence visual detection. If an optical filter reduced discomfort, it could increase detection thereby. Although this indirect effect is logically possible, experimental tests of disability glare fail to exhibit it. However, if indirect effects were present, the analysis would presumably fail for this reason also.

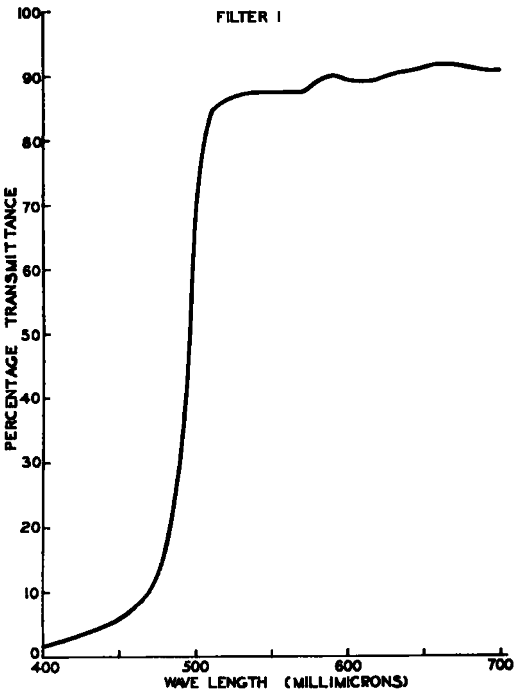

Figure 10.

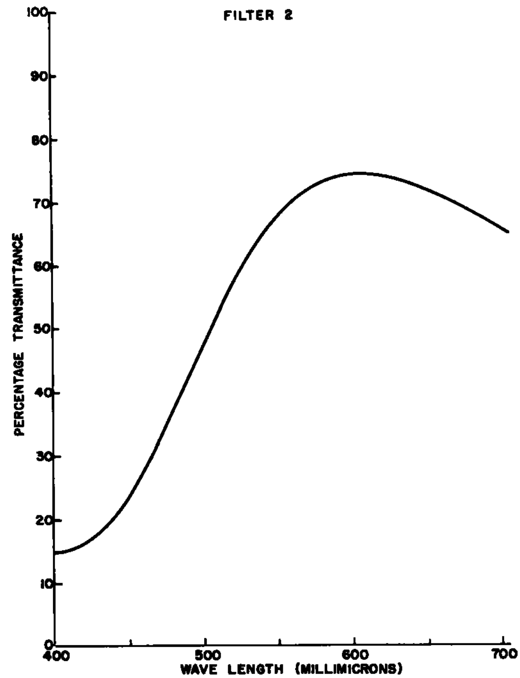

Figure 11.

Tests have been made on three filters. Two of the filters were made up in the form of night-driving glasses. These glasses were purchased from a local optician. The first of these (F1) is a pale yellow filter, the spectrophotometric curve for which appears in Figure 10. The luminous transmittance is 0. 87 for 2, 360 K. energy. The second (F2) is an amber filter, the spectrophotometric curve for which appears in Figure 11. The luminous transmittance is 0. 69 for 2, 360 K. energy. The third filter (F3) was made up in the form of a heat-absorbing windshield. The heat-absorbing windshield and a clear windshield (for comparison purposes) were loaned by the manufacturer. The spectrophotometric curve for the heat-absorbing windshield is presented in Figure 12. The luminous transmittance is 0. 83, compared to a clear windshield, for 2, 360 K. energy.

The basic experimental design involved comparing visual detection with and without the night-driving glasses and between the clear and the heat-absorbing windshield. Every reasonable precaution was taken to insure that the comparisons were without bias and of high precision, since the differences to be evaluated were expected to be small. The obtained results were compared with results predicted on the basis of the method described in Section II.

The basic experimental procedures were similar to those in the earlier published study (7), described briefly in Section II. Certain differences in procedure were adopted which will be described here.

In the present study the variable introduced within each experimental session was not target contrast but was target size. The use of target size as the intersession variable is not feasible under most experimental conditions, since probability of detection does not bear a simple relation to target size. At low luminance, however, the use of target size is reasonably satisfactory. The use of target size as the variable has the advantage that we can evaluate the predictions of α increase with a minimum of experimentation. Detection probability was evaluated as before, using a scale of target size rather than target contrast for the probit analysis, however.

In all cases, the two conditions to be compared were studied together before experiments were begun with other filters. A hundred presentations were made with a given target size, the first 50 with (or without) filters, the second 50 under the opposite condition. Subsequently, 100 more presentations were made with the same target size. The second time, the order of experimental conditions was reversed. Eventually, the procedure was followed for other target sizes. The order of filters versus no filters was random for different target sizes. Consequently, there is no reason to expect any bias due to the temporal order of the experimental conditions.

The observers were required to work for 100 target presentations at a sitting, occupying approximately 40 minutes. The same observers were required to return after a 5-minute rest for two more sessions of 100 presentations each. A third sitting followed a second 5-minute rest. The total time in each session exceeded 2 hours.

A total of 25,500 experimental tests have been made, using six observers. These experiments were conducted in two series. The first series was completed in October 1952. This series consisted of tests of F1 and F2 only. The second series was completed in June 1953. This series consisted of tests of all three filters.

The following special conditions refer to the first series of experiments:

The target was a bright rectangle, whose height was six times its width. (This target was selected to represent the approximate dimensions of a pedestrian.) The target exposure time was 1/30 second. The color temperature of target and background luminance was 2,360 K. Experiments without glare were conducted with the target presented in the center of the large uniformly bright screen shown in Figure 1. In the experiments with glare, the large screen was covered with a black mask except for a central elliptical area intended to simulate the area of the highway illuminated by automobile headlights. The horizontal axis of the lighted ellipse subtended approximately 11 deg. at the eyes of the observers. The vertical axis subtended approximately 2.5 deg. These

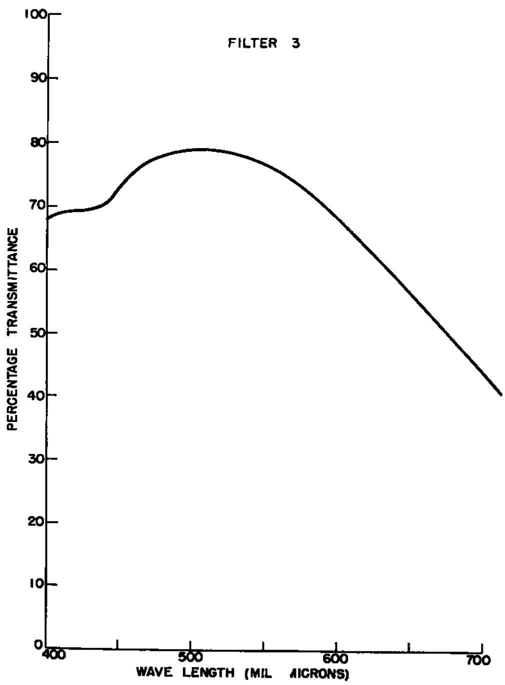

Figure 12.

dimensions were maintained in all tests. The target appeared half way to the right of the center of the elliptical lighted area in all cases. A pair of glare sources was mounted to the left of the target, as viewed by the observers. The separation between the glare sources and the distance from the glare sources to the target was scaled in terms of the target size used. Specifically, the following relations were maintained among the various elements of the visual task with respect to the height of the target, at all times:

Separation between "headlamps" = 0.95. Distance from target center to center of headlamps = 2.83. Thus, the visual display intended to simulate a target and opposing headlamps varied as it would normally vary with distance between the observer and the target. In the experiments with glare, the subjects were able to look away from the glare sources for about 2 of every 12 seconds, the time between observer response and the warning signal for the next presentation.

The following special conditions refer to the second series of experiments:

The target was a bright circle. The target exposure was 1/30 second. The color temperature of target and background

TABLE 1

EXPERIMENT 1

Night-Driving Glasses, F1 (No Glare)

B = .097 C = .27
N = 5800 PR = 1.13

Observers' Initials	R	P
AM	1.00	0.50
LP	1.13	<0.001
HF	1.12	0.008
VL	1.12	0.002
NS	1.13	0.001
AK	1.06	0.12
Average	1.09	

luminance was 2,360 K. Experiments without glare were conducted with the target presented in the center of the large uniformly bright screen referred to above. Experiments with glare were conducted under the same conditions except that one glare source was added at the left of the

TABLE 2

EXPERIMENT 2

Night-Driving Glasses, F2 (No Glare)

B = .099 C = .34
N = 3900 PR = 1.37

Observers' Initials	R	P
AM	1.30	<0.001
LP	1.48	<0.001
HF	1.37	<0.001
VL	1.45	<0.001
Average	1.40	

target at an angular separation of 6 deg. The clear and tinted windshields were mounted in front of the observers as shown in Figure 1. The windshields were intended for use in a 1950 Buick Super automobile. The windshields were carefully mounted with respect to the observer's eyes to

TABLE 3

EXPERIMENT 3

Night-Driving Glasses, F1 (Glare)

B = .525 C = 10
N = 6,000 PR = 1.10

Observers' Initials	R	P
AM	1.11	0.002
LP	1.03	0.21
HF	1.08	0.006
VL	1.01	0.43
NS	1.10	0.007
AK	1.04	0.10
Average	1.06	

maintain the relations which would have occurred in automotive use. Only two observers were used at one time, so that there were no observers positioned to correspond to seats in the rear of an automobile. As in the earlier experiments, the observers were able to look away from the glare source for about 2 of every 12 seconds.

RESULTS

October 1952 Experiments

The experiments conducted in October 1952 involved more experimental data than the later tests. As a consequence, more complete analysis has been made of these data. The observations made by each observer, with and without optical filters, were separately analyzed by the probit analysis. The data are reported in terms of a ratio of α increase, defined as the ratio of the threshold α with glasses to the threshold α without glasses. The ratio of α increase predicted by the method described in Section II is given for

TABLE 4

EXPERIMENT 4

Night-Driving Glasses, F2 (Glare)

B = 0.525 C = 0.10
N = 2,600 PR = 1.31

Observers' Initials	R	P
AM	1.31	<0.001
LP	1.24	<0.001
HF	1.23	<0.001
VL	1.23	<0.001
Average	1.25	

TABLE 5

EXPERIMENT 5

Night-Driving Glasses, F1 (No Glare)

B = .047	C = .41
N = 1,200	PR = 1.16
R = 1.09	P = .25

comparison. The significance of each α increase has been established statistically. The probit analysis of each set of data provides us with a threshold and a standard error of this quantity. Significance of the α increase caused by the optical filter is in each case evaluated by computing a critical ratio from the probit values of threshold α. The quantity P defines the probability of obtaining so large a difference as that obtained by chance alone.

TABLE 6

EXPERIMENT 6

Night-Driving Glasses, F2 (No Glare)

B = 0.047	C = 0.41
N = 1,200	PR = 1.54
R = 1.51	P < 0.001

June 1953 Experiments

The experiments conducted in June 1953 were undertaken primarily to test the heat-absorbing windshield. Tests of the night-driving glasses were conducted to attempt to confirm the results of the 1952 experiments. Four of the original observers were used in the 1953 experiments, whose initials were: AM, LP, NS, and AK. The number of observations made by each observer was insufficient to justify a separate probit analysis. Consequently, the results of all observers were combined and probit analysis was performed on the combined data. Combined data may yield probit standard errors of excessive size, so that significance tests are probably underestimated.

The data for the eight experiments conducted in all are reported in Tables 1 through 8. In the tables reporting the results of these experiments, the symbols will have the following meanings:

B = general luminance (foot-lamberts)
C = target contrast
N = total number of observations
R = ratio of α increase
PR = predicted ratio of α increase
P = probability of chance occurrence of difference this large or larger

We may well begin by evaluating the overall effects of the optical filters investigated. It is to be remembered that values of R, the ratio of α increase in excess of unity represents losses in visual performance. (Implications of these losses for highway safety will be discussed in Section IV.)

First, the average value of the ratio obtained in each of the eight experiments exceeds unity. For F1, the values are 1.09, 1.06, and 1.09. It is to be recalled that this filter has a very high transmission (0.87) and that quite-small ratios were expected. Values for F2 are 1.40, 1.25, and 1.51. Values for F3 are 1.20 and 1.66. All individual values of the ratio exceed unity except one. Observer AM in Experiment 1 with F1 gave an experimental ratio of exactly 1.00.

There is no question but that the average ratios in each experiment except Number 5 represent statistically significant differences. (To estimate significance of the average ratios in the 1952 experiments, we combine the individual measures of significance by the familiar χ^2 pooling techniques. In each of the 1952 experiments we reach better than the 0.001 confidence level.) Since the significance test in Experiment 5 is probably underestimated, the difference obtained may be truly significant. At least, we are justified in concluding that F2 and F3 required significantly increased α under all conditions tested, and F1 required significantly

TABLE 7

EXPERIMENT 7

Heat-Absorbing Windshield, F3 (No Glare)

B = 0.040	C = 0.41
N = 2,400	PR = 1.25
R = 1.20	P < 0.001

TABLE 8

EXPERIMENT 8

Heat-Absorbing Windshield, F3 (Glare)

B = 0.040	C = 0.41
N = 2,400	PR = 1.32
R = 1.66	P = 0.002

increased α under at least two of three conditions tested.

The results of all experiments may be summarized to better compare the predicted and experimentally obtained ratios of α increase.

Experiment	Predicted Ratio	Obtained Ratio
1	1.13	1.09
2	1.37	1.40
3	1.10	1.06
4	1.31	1.25
5	1.16	1.09
6	1.54	1.51
7	1.25	1.20
8	1.32	1.66
Average	1.27	1.28

The agreement between the average predicted and obtained ratios is striking. If we separate all data involving glare from those not involving glare, the following results are obtained:

Condition	Predicted Ratio	Obtained Ratio
Glare	1.24	1.32
No glare	1.30	1.27

These results indicate that, if anything, the obtained α increases are greater than predicted with glare and less than predicted without glare. Since a large value of the ratio of α increase represents a greater loss in visual detection, these data suggest that the filters are, if anything, more deleterious when glare is present than expected. The direction of this difference is opposite to that to be expected if indirect effects of glare were present.

It must be pointed out that there are several suggestive trends in the data. First, in all three tests of F1, less α increase was obtained than predicted. In tests of F2, two of three increases in α are less than predicted. In tests of F3, one of two increases in α is less than predicted. There is, therefore, a suggestion that the yellow and amber filters do not produce as great increases in α as predicted. However, this trend is no more suggestive in the tests with glare than those without glare, so it is probably unreasonable to attribute the trend to the reduction of discomfort glare.

It should be emphasized that all observers reported spontaneously that all filters increased visual comfort during tests with glare. There was no clearcut preference for one or another of the three filters tested. It should also be emphasized that our tests represented conditions of extreme glare. All observers found the tests as unpleasant as any night-driving situation they had ever encountered. They felt that the situation where they had to encounter the glare for about 10 of every 12 seconds represented good simulation of a condition of heavy traffic where glare sources followed one another in unpleasantly rapid succession.

CONCLUSIONS

The results of all experiments seem to validate the predictive method for evaluating optical filters to a satisfactory degree. The author will have little hesitation in using predictions made in this way in lieu of further experimentation of the type reported in this section. The implications of the quantitative analysis and of the experimental data for highway safety will be discussed in the following section.

IV. Night-Driving Implications of the Effects of Optical Filters upon Visual Detection

The quantitative analysis method described in Section II and the experimental tests reported in Section III are expressed in terms of laboratory concepts. It is our intention here to place our analyses and data in terms with more-practical relevance to conditions of night driving. All data discussed heretofore represent thresholds, defined by 50-percent-detection probability. We will now adjust these data to represent detection probabilities more useful for considerations of night-driving problems. Furthermore, the effects of optical filters are expressed in terms of increases in α. We will now re-express these effects in terms of practical highway parameters.

Let us first adjust the threshold data to more-practical probability levels. As was indicated in Section II, we can adjust our data to different levels of detection probability by multiplying all values of threshold contrast by a constant. The constant 2 converts threshold data to 99-percent visual detection. In interpreting this figure, it must be recalled that in our experiments, observers know that targets were going to be presented, and targets were presented frequently. It has been shown (13) that multiplication of threshold contrast by an additional constant of 2 allows for the fact that night drivers do not know when to expect targets and that targets appear infrequently in night driving. We have adjusted the threshold data, accordingly, by multiplying all threshold contrasts by 4. When the data have been treated in this way, they are labeled "Field Factor 2". Iso-contrast contours are presented in Figure 13 representing Factor

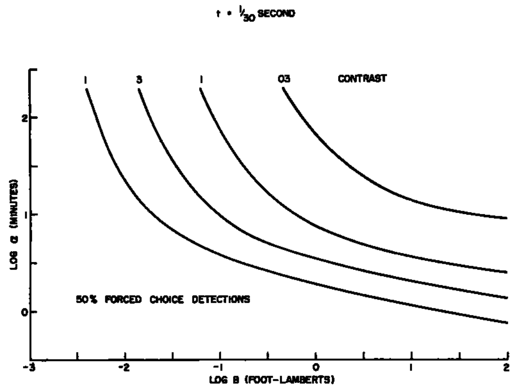

Figure 13.

2. (These are to be compared with iso-contrast contours presented in Figure 6).

Now, let us convert these new data into a useful highway parameter, detection distance. We convert values of α into distances for detection of the international highway test object, a square which is 16 inches on a side. The resulting replot of the data of Figure 13 appears in Figure 14.

We may use these data to compute the losses in detection distance produced by any optical filters. The method should be familiar in principle by now. If we know target contrasts (C) and general luminance (B), we can compute detection distance just as we computed α before. The effect of an optical filter in reducing B can now be assessed in terms of the reduction produced in detection distance. The vertical lines in Figure 14 demonstrate the method. It should be apparent that the quantitative loss in detection distance varies with the conditions of use of the optical filters. The

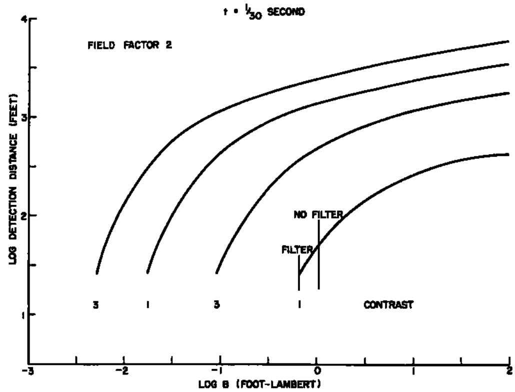

Figure 14.

percentage loss in detection distance corresponds directly, of course, to the reduction in log detection distance. The greatest percentage losses occur where the iso-contrast contours in Figure 14 are steepest. It is apparent from Figure 14 that the iso-contrast lines become steeper as log detection distance decreases.

This means that the percentage loss in detection distance produced by a given filter is greater the shorter the detection distance was without the filter.

When detection distance is already dangerously short, the percentage loss is great, whereas when detection distance is longer the percentage of loss is less. This is an unfortunate state of affairs, and one which was not foreseen until the detection data were examined with this problem in mind.

It will be worthwhile to indicate quantitative losses in detection distance to be expected with each of the three filters of interest here. Only by computing such losses for the same conditions of C and B can we obtain an adequate estimate of the comparative losses to be expected with the three filters. Our experimental tests did not involve the same values of B and C throughout; hence, comparisons among the filters on the basis of these tests can be misleading. In making these computations, the transmissions of the three filters have been evaluated at 3,050 K., the approximate color temperature of automobile headlamps. The appropriate transmission values are: 0. 86 for F1; 0. 68 for F2; and 0. 84 for F3.

To give an idea of the range of losses in detection distance to be expected with each filter, two conditions were selected. The first condition was intended to represent the case where the largest losses would be found. For this purpose, we selected B = 1. 06 foot-lamberts and C = 0. 1. The detection distance without filters was approximately 50 feet. (This condition is represented by the vertical line labeled "No Filter" in Figure 14). For these conditions, F1 reduces detection distance to 79 percent of normal; F2 reduces detection distance to 55 percent of normal; and F3 reduces detection distance to 77 percent of normal.

The second example selected B = 1.06 foot-lamberts, and C = 0.3. Here the detection distance without filters was approximately 500 feet. For these conditions, F1 reduces detection distance to 90 percent of normal; F2 reduces it to 77 percent of normal, and F3 reduces it to 89 percent of normal.

It is to be emphasized that our method of utilizing the data of Figure 14 to compute detection distance losses corresponds to a physical situation in which headlamps are not used by the driver. Thus, the conditions chosen here for calculations represent twilight conditions when the driver has not yet turned on his headlamps.

When headlamps are used, the calculation of detection distance is somewhat more complex. As we have noted, the use of filters at low luminance increases threshold α. Thus, in order to see a given target, the driver must shorten the distance between himself and the target. When headlamps are not used, nothing changes as the driver approaches the target except α. However, when headlamps are used, B changes as the driver approaches the target, in accordance with the inverse-square law of headlamp illumination.

We may represent the entire situation when headlamps are used in the manner shown in Figure 15. The relation between B and detection distance for any viewing situation is represented by a line of slope -½. Thus, one such line represents the situation without a filter. A second such line, displaced with respect to B by the absorption of the filter, represents viewing with an optical filter. The lines displayed in Figure 15 represent an arbitrary assumption of the headlight candlepower and the reflection factor of the target. They will suffice, however, to illustrate the characteristics of the relations which must exist when headlamps are used.

To determine the detection distance without a filter, we select values of B and C where the no-filter line intersects an iso-contrast contour. To determine the loss in detection distance produced by a given filter, we determine the intersection of the filter line with the same iso-contrast contour. The optical filter used in the constructions of Figure 14 and 15 is the same. It is apparent from these figures, that detection distances losses are greatly reduced when the situation of interest involves the use of headlamps.

Calculated losses in visual detection distance have been computed for two conditions involving headlamps, intended to establish the range of losses to be expected. In the first instance, B = 0. 125 foot-lamberts; C = 0. 3. Detection distance without

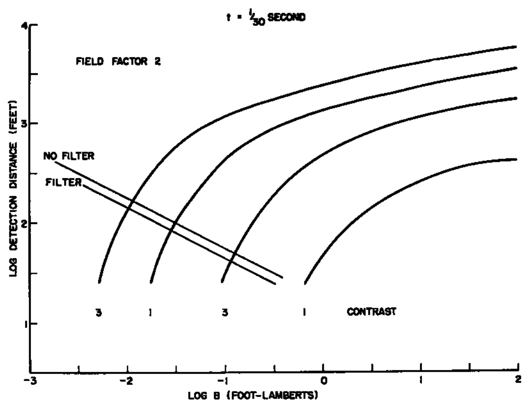

Figure 15.

filters is approximately 50 feet. Under these conditions, F1 reduces detection distance to 94 percent of normal; F2 reduces it to 85 percent of normal; and F3 reduces it to 92 percent of normal. In the second instance, B = 0. 125 foot-lamberts; C = 1. Detection distance without filters is approximately 500 feet. Under these conditions, F1 reduces detection distance to 96 percent of normal; F2 reduces it to 90 percent of normal; F3 reduces it to 95 percent of normal.

There is one further way in which the effect of optical filters can be expressed.

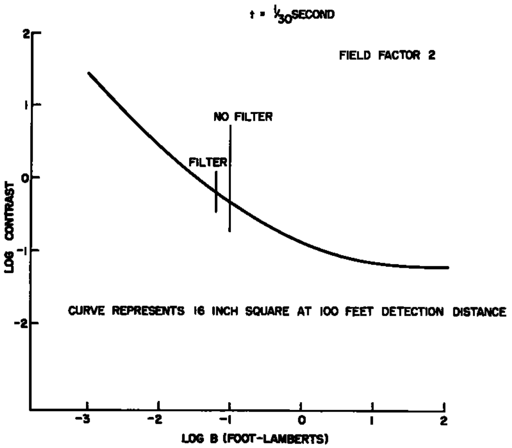

Figure 16.

It is reasonable to assume that there is a minimum detection distance below which detection will be useless in preventing accidents, due to the required stopping distance for the automobile. If we assume such a minimum detection distance, then the effect of optical filters will be to reduce the number of targets which will be detected. Data prepared to represent this case are presented in Figure 16. The curve in this case is an iso-α contour corresponding to the international highway test object viewed at a distance of 100 feet. The value of B is fixed by headlamp illumination at 100 feet and target reflectance. Thus, we may use the iso-α contour to specify how great target contrast must be in order for detection to occur. The intersection of the horizontal line marked no-filter line and the iso-α contour defines the target contrast required when no filter is used. The intersection of the other horizontal line and the iso-α contour defines the target contrast required with the filter. All targets of contrast greater than the contrast required will be detected; all other targets will presumably be struck.

We may specify the percentage increase in the minimum target contrast required when each of the filters is employed. As before, we have analyzed the effect of the filters under two conditions intended to establish the range of effects to be expected. In the first instance, B was taken as .01 foot-lamberts. The minimum target contrast requirement is increased by 16 percent with F1, by 47 percent with F2, and by 19 percent with F3. In the second instance, B was taken as 1 foot-lambert. In this case, the minimum target contrast requirement is increased by 7 percent with F1, 19 percent with F2, and 8 percent with F3. These results are independent of whether or not headlamps are used.

CONCLUSIONS

Threshold data presented in Section II have been converted into a form suitable for use in assessing the highway significance of losses in visual performance at low luminance due to optical filters. Using the percentage reduction in detection distance as a criterion, we find conditions in which detection distance is cut to as little as 79 percent of normal with F1, 55 percent of normal with F2, and 77 percent of normal with F3. Losses as great as this occur under twilight conditions in which headlamps are not used. Conditions can be found under which these percentage losses occur when the detection distance without filters is 100 feet or less. Losses of smaller percentage magnitude occur whenever the use of headlamps is involved.

Losses in visual detection may also be specified in terms of the number of targets not detected at a minimum detection distance. Percentage increases in the minimum required target contrast can be as great as 16 percent for F1, 47 percent for F2, and 19 percent for F3.

The losses in visual detection capability resulting from the use of optical filters at low luminance appear to be sufficiently great so that the use of such filters can scarcely be recommended unless drivers using such filters slow their vehicular speeds accordingly.

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Effect of Wave-Length Contrasts on Discrimination Thresholds under Mesopic Vision

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Various studies have been made of the effect of filters, tinted glasses and windshields as they affect seeing at night. On the average all results have shown a deleterious effect although individual observers sometimes may show a slight improvement. These variations in direction are undoubtedly chance errors as might be expected from any large number of measurements. Lauer investigated the possibility of beneficial effects from certain wave-length bands and obtained negative results. There was a constant increment of nonlinear relationship between increased transmission of light and legibility of letters as measured by the Clason Acuity Meter. More recently, studies by others have supported these earlier findings in greater or lesser degree. In other words, the hypothesis that some types of filters which lower light transmission may increase acuity at night is rejected.

● ASIDE from the fact that a certain level of illumination is necessary for proper seeing, which is axiomatic, there are certain other theoretical considerations which must be taken into account with relation to the problem. At least three of these are noteworthy:

1. Monochromatic or narrow wave band light may sharpen acuity by reducing the amount of chromatic aberration. This is a well-known phenomenon providing the light is of narrow wave-length band which is difficult to obtain under operational conditions.

2. By the same token, monochromatic light has been found to fatigue the eyes differentially. The shorter wave lengths as shown by Ferree and Rand (2) induce greatest fatigue.

3. Wave lengths of similar or contrasting colors may tend to obscure objects of the same or contrasting colors. A well-known method of producing third dimension pictures and cartoons was covering one eye with a red filter and the other with a green. Disparagement of images is created by obscuring one of the projected images on the screen, the red one from one eye and the green one from the other.

The present paper is a controlled study of the third phenomenon noted at one level of transmission, approximately 86 percent. Since clear glass will absorb about 4 percent of light at each surface, the color pigment alone would thus account for but 5 to 6 percent of the total reduction. As such glasses are commonly found in everyday use, it was thought desirable to test the effects at these levels of transmission.

Sixty subjects were submitted to a total of six experimental conditions, two of which were used as controls. The practical question set for solution may be stated as follows: If one uses blue- or yellow-tinted glasses, or windshields, before the eyes when driving at night, will objects of blue or yellow color be less readily seen than when wearing clear glasses? The results showed higher visibility thresholds when using either yellow or blue lenses over the eyes, but no differences could be noted which favor either. The conclusion is that while a slight tint of 5 or 6 percent of density will only mildly affect visibility of the same or contrasting colors, it does differentially reduce seeing efficiency significantly. There is a high correlation between visibility distance and legibility distance, thus confirming the general assumption that better vision aids in picking up the presence of objects, vehicles, or persons on the highway at night.

THE PROBLEM

Red and blue-green glasses are used to obscure corresponding projected color images to produce third-dimension pictures by creating disparagement of the images on the two retinas. It is thus of theoretical and practical interest to know what the effect of tinted glasses or windshields may have on the visibility of specific color in low illumination.

The fundamental hypothesis to be tested experimentally may be stated in the interrogative form as follows: Will tinted lenses of color density of the order of 5 to 6 percent affect the visibility and legibility thresholds differentially for objects of approximately the same wave length under conditions of low mesopic vision?

A corollary hypothesis was similarly tested which may be stated in the interrogative form accordingly: Will lenses of the same described color and density affect the visibility and legibility thresholds differentially for objects of contrasting wave lengths in the visible sprectrum?

Contrasting colors as defined by Pickford (13) quoting Helmholtz, vary in wave length ratios from about 1.19 to 1 to 1.33 to 1. Using this as basis of departure, it was necessary to select lenses and pigmented papers which were as nearly as possible to these ratios.

APPARATUS USED

In order to control conditions, the scotometer described by Stalder (15) was used. This is essentially a dark-tunnel apparatus in which stimuli may be presented on a travelling belt simulating highway conditions. A fixed luminant at one end throws incident light upon the approaching target. As the target approaches, the light intensity increases according to the inverse-square law as is done by an automobile headlight. The rate of approach may be varied from 0 to 60 mph. in scale values, the apparatus being built ½ inch to the foot.

TABLE 1

TRANSMISSION CHARACTERISTICS OF SEPARATE LENS AND LENS COMBINATIONS USED

Lens or lens combinations	Percent of light transmitted	Characteristic wave length[1]
1. Clear plano spectacles	91.12	Regular optical glass
2. Clear plano clipons	92.09	Regular optical glass
3. Blue clipons	86.93	500 mμ
4. Yellow clipons	86.92	560 mμ
5. Plano spectacles and clear clipons	87.88	Regular optical glass
6. Plano spectacles and blue clipons	81.80	500 mμ
7. Plano spectacles and yellow clipons	82.26	560 mμ

[1] Values taken from National Bureau of Standards Circular No. 471, 1948.

Three sets of lens were used, with characteristics as shown in Table 1. Combinations were used to establish controls as indicated.

The planoglasses were used for persons not ordinarily wearing correction. Those wearing glasses merely used the clipons. In this way, any effect of glasses per se was thought to be controlled. Since a few persons do wear a slight tint and there was no easy way to identify the color or density, this was assumed to be negligible.

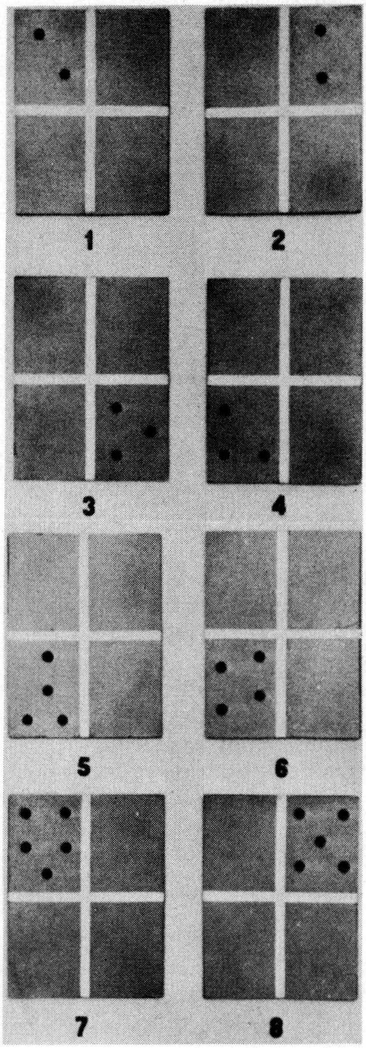

Figure 1. Each of the targets were shown eight times each in random order. The dots are shown in same color here for illustrative purposes. In Response A the quadrant was named. In Response B the number of dots was given.

It would, however, tend to minimize any differences noted for this condition and place findings on the conservative side.

Two colors of paper dots were mounted on targets as shown in Figure 1. In all, 16 of these targets were constructed, each 4 by 5½ inches. The dots were arranged in random order on a background of gray, having a reflectance factor of somewhat less than 50 percent in the visible range.

The dots used were placed in one of the four quadrants, one target having only one color on the gray background. They were made ¼ inch in diameter and were spaced several diameters apart. Specially selected colors of paper were obtained from Munsell as shown in Table 2.

TABLE 2

WAVE LENGTHS AND REFLECTANCE FACTORS FOR COLORED STIMULI AND BACKGROUND USED

	Dominant wave length	Percent reflectance factor
Yellow Munsell paper	573 mμ	74.76
Blue Munsell paper	479 mμ	21.43
		Percent difference in reflectance factors
Gray-yellow differential (Brightness contrast)		30.76
Gray-blue differential (Brightness contrast)		19.07

METHOD AND PROCEDURE

Each prospective subject was examined for visual acuity and those with any marked impairment were not used. Thus visual acuity was controlled to a large extent.

The subject was placed in a semidarkened booth and partly adapted to a level of illumination, approximating night-driving conditions at the wheel, for about 5 minutes. He was then read standard instructions, allowed to ask questions and presented 48 separate observations, eight for each of the six experimental conditions. These conditions are shown in Table 3.

The six conditions were randomized for each subject by a table of random numbers. This was assumed to distribute equally any effects of practice, fatigue or progressive adaptation.

The targets were presented at a scale distance of 600 feet and at a scale velocity of 10 mph. The subject first responded by stating the quadrant in which the dots were located. This was designated as Response A. Secondly, he was asked to respond by giving the number of dots in the quadrant. This is known as Response B. The first index was assumed to indicate the threshold of visibility, while the second that of legibility. Since the latter proved more consistent, it was used as the basis of results of tests for significant differences presented in this paper.

TABLE 3

EXPERIMENTAL CONDITIONS USED

1 Clear lens worn, with blue dots as stimuli
2. Blue lens worn, with blue dots as stimuli
3 Yellow lens worn, with blue dots as stimuli
4. Clear lens worn, with yellow dots as stimuli
5 Blue lens worn, with yellow dots as stimuli
6. Yellow lens worn, with yellow dots as stimuli

RESULTS

The results from 60 subjects using a completely random-block design are shown in Tables 4 and 5.

An analysis of variances for the B responses was made and the results are shown in Table 5.

This analysis of variance shows F value to be significant at the 5-percent level of confidence for color of dots, color of lenses, and for interaction between dots and lenses.

In order to counteract any extraneous effects of the scale, it was thought advisable to make a logarithmic transformation of the raw scores. The mean scores on each condition for each subject were converted to common logarithms. A second analysis of variance was then carried out using the transformed scores. The results from this analysis are given in Table 6.

The F values for color of dots and color of lens again were significant at the 5-percent level, but in this case the interaction was not significant.

T tests were carried out among the means of the several experimental conditions, using the overall means of the

TABLE 4

MEAN DISTANCE SCORES IN SCALE FEET FOR VISIBILITY AND LEGIBILITY THRESHOLDS FOR THE SIX EXPERIMENTAL CONDITIONS

Condition	Response A (Scale feet)	Response B (Scale feet)
1 Clear lens, blue dots	324 05	268 17
2. Blue lens, blue dots	318 44	260.50
3. Yellow lens, blue dots	323.00	260 25
4. Clear lens, yellow dots	377 05	320 30
5 Blue lens, yellow dots	350 66	283 88
6 Yellow lens, yellow dots	365 15	313 42

TABLE 5

ANALYSIS OF VARIANCE OF MEAN DISTANCES FOR LEGIBILITY THRESHOLDS FOR THE SIX EXPERIMENTAL CONDITIONS

Source of variation	Sum of squares	DF	Mean square	F
Between conditions	212,940	5	42,582	19.38*
Color of dots	165,594	1	165,594	75 34*
Color of lens	30,199	2	15,099	6 87*
Interaction	17,147	2	8,574	3 90*
Within conditions	3,266,041	354	9,226	
Subjects	2,617,478	59	44,364	
Error	648,563	295	2,198	
Total	3,478,981	359		

* Significant at the 5-percent level.

transformed scores and the error term obtained from the analysis of variance.

The first four t tests shown in Table 7 are those most pertinent to the hypotheses of the present experiment. Of these, only the mean difference between Condition 4 (planolens, yellow dots) and Condition 5 (blue lens, yellow dots) was significant.

A correlation was computed between overall scores on the scotometer and mean scores for discrimination of the circle breaks on the AAA Night-Vision Meter. A coefficient of -0.089 was obtained. Since the visual acuity measurements of the subjects as obtained on the Sight-Screener were relatively homogeneous, it was not thought necessary to correlate this with scores on the scotometer. The primary object of the visual measurements as a whole was to establish some control on visual acuity by screening out those with vision somewhat below normal.

COMMENT

According to the first hypothesis set up for testing in this experiment, the use of a yellow lens should have made blue dots easier to see, and the use of a blue lens should have made yellow dots easier to see. The mean differences found did not support this supposition. The difference between mean scores in Conditions 1 and 3 was in the reverse of the expected direction, but was not significant. The difference between mean scores for Conditions 4 and 5 was also in the reverse of the expected direction, and this was significant at the 1-percent level.

According to the second hypothesis, a blue lens should have made blue dots more difficult to see and a yellow lens should have made yellow dots more difficult to see. The difference in this case, between Conditions 1 and 2 and between Conditions 4 and 6, were in the expected direction, but neither was significant.

These findings, subject to the limitations of the experiment, indicate that color of a filter in and of itself at the transmission levels used is not a factor in influencing visual discrimination at night, providing that other variables are held constant. The direction of the differences found, for both the A and B responses, however, indicates that any filter which narrows or reduces the amplitude of the wave band and intensity of visible light transmitted will reduce seeing ability. This agrees with the results of previous research. The t tests between means for conditions using a planolens and those using a colored lens revealed only one significant difference, that between Conditions 4 and 5.

Although the results of the t tests are those most pertinent to a test of the hypotheses set up for experimental investigation, some discussion of the F values found from the analysis of variance is in order. The significant F value for color of dots indicate that the yellow dots were easier to see than the blue dots. This was probably due to their greater contrast with the gray background (see Table 2). If blue and yellow papers of identical reflectance factors could have been used, they should have been seen equally well. This, of course, is physically impossible with colored pigments. Likewise, the fact that a background of true neutral gray was not used may have influenced the results. The gray which was used reflected more yellow wave lengths than blue wave lengths, and this fact might have slightly favored the wavelength contrast with the blue dots.

TABLE 6

ANALYSIS OF VARIANCE OF THE MEAN DISTANCE SCORES FOR THE DISCRIMINATION THRESHOLD AFTER A LOGARITHMIC TRANSFORMATION

Source of variation	Sum of squares	DF	Mean square	F
Between conditions	0.51946	5	0 10389	43 93*
Color of dots	0.47905	1	0.47905	197.95*
Color of lens	0.03438	2	0.01719	7.10*
Interaction	0.00603	2	0 00302	1.51
Within conditions	7.64395	354	0.02159	
Subjects	6 93096	59	0.11747	
Error	0 71299	295	0 00242	
Total	8.16341	359		

*Significant at the 5-percent level

The significant F value for color of filters is more difficult to explain. The only significant differences revealed by the t tests were between Conditions 4 and 5 and Conditions 5 and 6. When yellow dots were used as stimuli, the use of blue lenses produced significantly lower scores than when plano or yellow lenses were used. No explanation for this finding can be offered except reduction in visible light on the stimulus.

TABLE 7

T-TESTS BETWEEN MEAN DISTANCE SCORES FOR DISCRIMINATION THRESHOLD FOLLOWING A LOGARITHMIC TRANSFORMATION

Conditions	Mean feet	Difference	t	DF
Clear lens, blue dots Blue lens, blue dots	2.40795 2 39104	01691	1.88	118
Clear lens, blue dots Yellow lens, blue dots	2.40795 2 39113	.01683	1.87	118
Clear lens, yellow dots Blue lens, yellow dots	2 48361 2.45288	.03073	3.42*	118
Clear lens, yellow dots Yellow lens, yellow dots	2 48361 2.47249	.01112	1.24	118
Blue lens, blue dots Yellow lens, blue dots	2 39104 2.39113	.00009	0.01	118
Blue lens, yellow dots Yellow lens, yellow dots	2.45288 2.47249	.01961	2.18**	118

* Significant at the 1-percent level
**Significant at the 5-percent level

The interaction between color of dots and color of lens was not significant when the scores were transformed into logarithmic form, although it was significant at the 5-percent level for the original scores. Examination of the mean scores shows that greater differences from color of lenses occurred when yellow dots were used as stimuli. This may be due to the fact that the yellow dots had higher visibility and were easier to see and thus any differences in lens transmission would produce a greater relative effect. No definite statement on this observation can be made, however, since the interaction for the transformed scores was not significant.

The small negative correlation between overall scores on the scotometer and scores on the AAA Night-Vision Meter indicates that the two devices are not measuring the same thing. The correlation was in the expected direction since low scores on the AAA Night-Vision Meter indicate good performance while high scores resulted from good performance on the scotometer.

CONCLUSIONS

Conclusions drawn from this experiment are subject to the limitations of sample size, the age and sex of the subjects, the type of apparatus used, level of transmission, and other conditions of procedure. These may be stated as follows:

1. Both hypotheses were rejected as stated (a) with two colors of stimuli placed on a gray background of a given brightness contrast, the use of a filter transmitting mostly the wave length complementary to that reflected by the stimuli will not lower the visual discrimination threshold values; (b) with two colors of stimuli placed on a gray background of a given brightness contrast, the use of a filter transmitting mostly the same wave length as that reflected by the stimuli will not raise the visual discrimination threshold values.

2. Results indicated that the use of colored lenses as compared with clear lenses result in reduced visual discrimination under the conditions studied.

3. Visibility and legibility thresholds vary together in direct relationship.

4. Night vision as measured by the AAA Night-Vision Meter is directly but not closely associated with visibility or legibility thresholds for mesopic vision at the levels measured.

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Discussion

D. A. TOENJES, Application Engineering Department, Lamp Division, General Electric Company, Cleveland—The authors have found that visual discrimination is reduced slightly by the use of colored filters. However, at these brightness levels, similarities or differences in the colors themselves of the filters and the test objects did not show any significant effect. These results seem to lead into the question of what might be the effect when two colored filters are used together in viewing a test object. For example, in daytime driving, yellow sunglasses might be used together with a green (heat-absorbing glass) windshield. Are these filters selective enough in their spectral transmission factors that wavelengths passed by one filter would be stopped by the other, with the result that the combined transmission factor would be lower than the product of the two individual factors? Would the proper result have to be found by multiplying the two spectral transmission curves, point by point?

A. R. LAUER, Closure—Toenjes comments are quite apropos. Such filters are actually not highly selective. Since the curves are quite different and the transmission range broad, the theoretical calculations do not hold strictly. Using a yellow clipon and a blue lens or visa versa gives a result somewhat different from the product of the two. The reduction is less than might be predicted.

Signal Lighting for the Movement of Traffic in Fog

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THERE is a distinction between illumination and signal lighting. In the former, of which street lighting is an example, light is directed towards objects to make them visible. In the latter, as in the case of traffic signals, lights are exposed to give information directly.

The utilization of light in fog is principally governed by two basic principles: (1) the attenuation of the light exponentially with the distance it travels, that is, if $\frac{9}{10}$ of the original intensity is scattered and absorbed in the first 100 yards, $\frac{9}{10}$ of the remaining intensity will be similarly lost in the next 100 yards; (2) the visibility of lights and objects depends generally upon the contrast between their brightness and the brightness of their background, the threshold for the necessary contrast being approximately a constant ratio to the background brightness.

These principles give signal lighting an advantage over illumination as a means of controlling traffic in fog. In the case of illumination produced by lights carried on the vehicle, the light has to travel from the vehicle to the object and back to the driver, twice the distance necessary for light from a signal lamp in the same location as the object. This may readily result in a ratio of 1,000 or more times as much intensity being required to produce visibility by means of illumination as would be required for the visibility of signal lights.

Highway lighting, on the other hand, suffers from the disadvantage of losing some of its intensity in reflection at the object seen and from the dazzling effects of the lights themselves. For indicating the position of a vehicle, the signal light has the advantage that it is possible to have a much-higher contrast between the brightness of the light and its fog background than can be obtained with an object. This fact is recognized in the practice of those drivers who are accustomed to light their head lamps in the daytime when driving during periods of low visibility.

The experience of aviation lighting engineers in guiding air traffic through fog was reviewed. This work started in 1934, and it was soon discovered that far more aid could be given pilots in cases where traffic was limited to narrow channels than in cases where traffic was approaching from all directions. As a result, the lighting of runways and the development of approach lights was emphasized. Tests have now established that where high speeds are involved, two rows of lights parallel to the direction of travel are better than a single row on the left, but that a single row in the center is better than either. Tests are still going forward to determine the optimum configuration for the landing operation.

During the course of the aviation work, three devices have been developed which may be useful in connection with solving the highway traffic problem: (1) the fog simulator, which so controls the intensities of lights that the pilot or driver constantly sees only a few lights ahead of him even when operating in clear weather; (2) the kinorama, which simulates the visual appearance of lights as seen by a pilot during the landing operation, the apparent location of the lights corresponding to the manipulation of controls simulating those of an airplane; (3) the transmissometer, which measures the transmission of light through the atmosphere and gives an indication of the density of fog at a desired location, which may be remote from the measuring instrument.

Applying these principles to the highway problem, it seems logical to test centerlines of retroreflective paint on roadways, but because of the visual cutoff of the automobile hoods which would obscure the lines for some distance ahead of the cars, the prevailing practice of using sidelines may prove superior for the relatively slow speeds at which it would be feasible to move highway traffic in fog. A single line of lights on the left may prove superior to either of these by reason of its having a longer visual range than is obtainable with retroreflective paint.

A line of "fixed" signal lights on the left may well provide the necessary directional guidance, but the movement of traffic in fog also requires speed control and the proper spacing of vehicles. Speedometers are unsatisfactory for speed control in fog because with the reduced visibility, attention should be concentrated on the roadway. Subjective estimates are unsatisfactory because a driver's judgment will be distorted by his previous driving at high speeds and by the lack of many of his customary visual cues. For spacing, tail lights are unsatisfactory, since the fog increases the apparent distance to them. Block signals might be used, but as carried out by the railroads, they would not provide the speed regulation desirable.

The speaker suggested the investigation of a new system having a continuously moving signal configuration. The system might consist of fixtures at uniform distances, perhaps 100 feet apart, along the left side of the traffic lane. Each fixture would contain red, green, and yellow lights which would be varied in intensity in such a way that each color would seem to be traveling down the highway following the other at a constant speed. The driver would drive so as to keep slightly behind the green signal. This would place the cars a distance apart equal to three times the distance between the fixtures. It would probably be desirable to reserve a traffic lane on the right as a lane of refuge for any driver who found himself incapable of following the lights, vehicles in this relief lane being limited to very slow speeds such as 10 mph. It might also be desirable to utilize some sort of block signal system to produce an emergency signal in case a car stopped in the speed regulated lane.

Effective Use of Reflectorized Materials on Railroad Boxcars

HAROLD I. STALDER and A. R. LAUER, Iowa State College

● SINCE Koenig (5) it has been recognized in scientific circles that acuity in seeing is a function of the intensity of the stimulus. Luckiesh (8) has identified two primary factors of visibility: (1) luminance or brightness level and (2) brightness-contrast ratio between the object and the background. Hecht (2) has since founded a theory of vision on the differential sensitivity of the receptor elements of the eye, that is, between different rods and different cones.

More recently, Forbes and Holmes (1) have reported that legibility distances of reflectorized highway destination signs decrease when used with a semi-illuminated background. This, of course, would be expected since the brightness-contrast ratio is decreased. Conversely any high-level brightness of the stimulus will increase visibility. It should therefore follow that any object which emphasizes the two factors of seeing enunciated by Luckiesh will be more easily seen at night and will require less impinging light for visibility.

In an earlier study, Lauer and Helwig (6) showed that reflectorizing a stop sign by aluminum or gold paint would materially aid in rendering the sign more-efficient at night. Since that time a great deal of improvement has been made in reflectorized materials and their usage has become very widespread for increasing the effectiveness of signs and markers at night.

The National Safety Council, as early as 1938, recognized the problem of train-car accidents at night. According to figures released at that time, there were 3,089 accidents of motor vehicles at grade crossings in 1938 which resulted in death and injury. Of these, 1,639 occurred in daylight and 1,450 occurred at night. It was estimated that not over a third of all driving in the United States is done at night. Calculated in terms of percent and equating for miles travelled, it is estimated that night accidents constituted 64.3 percent of all such mishaps as against 35.7 percent which occur in daylight, so far as motor-vehicle collisions with trains are concerned. In other words, there is twice as much liklihood of an automobile-train accident occurring at night as in daylight.

From another point of view, the dangers of night driving were even more realistically portrayed. In 1941, Lauer and Silver (7) noted that during daylight only 4 percent of such accidents occurred in which the motor vehicle struck parts of the train behind the locomotive. At night 36 percent of this type of accident happened in such a manner. In 1952 3 percent of cars involved in such accidents struck the train back of the tender in daylight, while 25 percent hit the train at similar points after dark, indicating a short seeing distance. It is thus shown that the danger of an automobile running into the side of a train is eight or nine times greater at night than in daylight. Any defect or condition which shortens the range of accurate vision in low illumination probably increases the liklihood of accidents at night. A correlation of 0.89 between visibility thresholds and legibility thresholds was shown by Stone and Lauer (10).

To indicate the persistence of the problem, in 1952 the National Safety Council reports that 1,348 motor-vehicle drivers were killed in accidents involving collisions with railroad trains. These were about equally divided between urban and rural areas. Sixty-four percent of the accidents involved trains going less than 30 mph. or were standing, and a majority were regular freight, switchyard, and work trains. Forty-eight percent of the fatal accidents reported occurred at night in which drivers ran into the side of the train. In most cases it would be logical to assume that the driver did not see the train in time to prevent the accident. Whatever may be the case, it is obvious that if a driver sees an obstacle in the path of his automobile, in time, he will usually be able to avoid collision.

In addition to deaths there were 3,700 nonfatal injuries of this type, 3,200 of which were in urban areas.

INTRODUCTION

Hoppe (3) made a study designed to obtain certain data relating to a driver's perception of a vehicle being overtaken on the highway at night. Variations in contrast of the lead vehicle were obtained by using panels of different size and reflection characteristics. The following summarization was made from the study: (1) increasing the horizontal visual angle reduced the time for the perception of the direction of relative motion between the vehicles and (2) with a contrast of sufficient magnitude, increasing the horizontal or vertical visual angle reduced the time for perception of the direction of speed differential. Potentially high driving speeds of modern cars greatly emphasize the importance of the time element.

Hoppe and Lauer (4) further established the fact that increased perceptibility would decrease judgment time and errors in the discrimination of relative motion. Anything which gives greater definition of the vehicle ahead increased both speed and accuracy of perception of relative motion, or changing distances, between two vehicles travelling the same direction on the highway.

Experiments were made in the laboratory as well as on the highway using speed differentials up to 10 mph. and the two sets of data showed high agreement. It was therefore concluded that laboratory studies provided a valid approach to the problem. The great economy in time and effort in laboratory tests would not seem to warrant running outside observations. Not only was the expense greater for the latter but there were many hazards involved and it was difficult to control conditions.

Stalder and Lauer (9) studied the effect of pattern distribution on perception of relative motion at low levels of illumination. They found that the pattern distribution of reflectorized material affected the time and difficulty for perception of relative motion. An outline pattern gave better overall results, using a given amount of reflectorized surface, than equal distribution of reflectorized materials spread over the total area in checker-board design.

THE PROBLEM

Three series of experiments were designed to test the efficiency of different types of markings for reflectorizing the side of boxcars. The hypothesis set up for experimental investigation is stated as follows: The addition of limited areas of reflectorized material on the side of boxcars has an effect on the discrimination of lateral motion under conditions of mesopic vision.

A corollary hypothesis may likewise be stated as: The amount and distribution of reflectorized material on the side of boxcars proportionally affects the level of visibility and accuracy of perception of lateral motion.

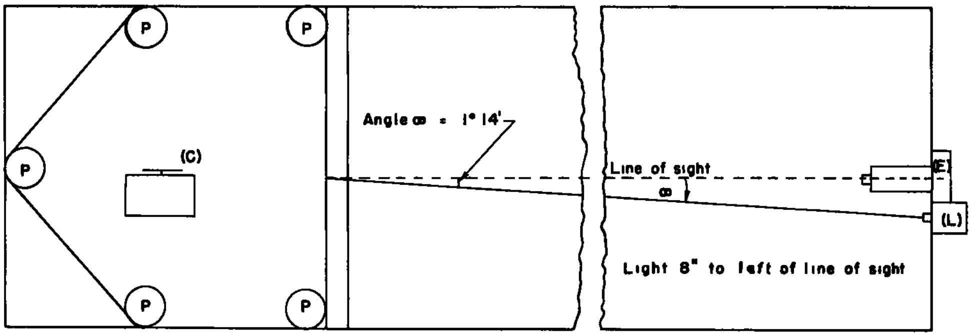
It is hoped that the study may yield data which will provide principles that may aid in providing the most-efficient method of reflectorizing railway boxcars in order to effect the greatest possible protection to the driving public as well as to the railway companies.

The design of the experiment for testing the foregoing hypotheses involved the following assumptions: (1) the data obtained by the experimental conditions used and procedure followed give a valid basis for evaluation; (2) calibrations of lights and lighting of the apparatus and that found under actual conditions of the highway give a fair comparison of light levels needed for threshold measurements; (3) extraneous cues for determining speed and direction of target, e.g., noise, shadows, or reflected light were negligible; (4) rotating the order of presentation of the various stimuli used sufficiently neutralized any systematic errors of practice, fatigue and other possible sources of variance; (5) individual differences of the observers affected all experimental conditions used in a similar way; and (6) all subjects were motivated to give a satisfactory judgment in the experimental situation.

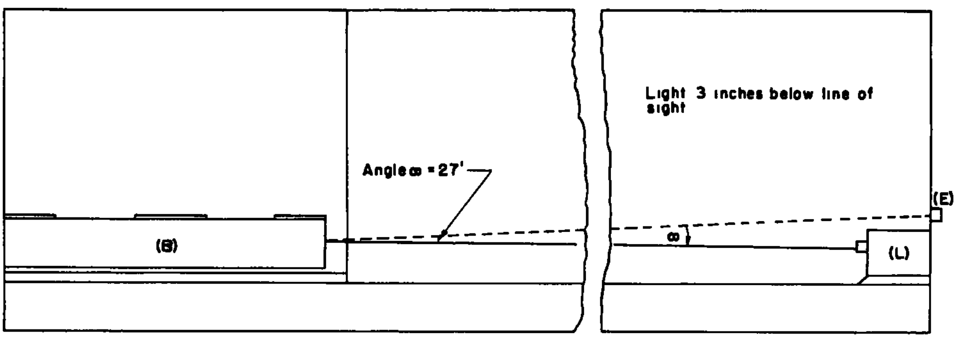
APPARATUS USED

The apparatus used consisted essentially of a dark tunnel approximately 40 feet long and having a carriage (c) mounted at the end opposite the subject. Five flanged pulleys (p) were mounted on the carriage (Figure 1-A) which carry the test belt as it rotates in a vertical position. The belt may be moved in either direction by a reversing switch in order to vary the presentation. Laced to the primary belt is a thin belt on which designs of miniature boxcars are painted. The boxcars (BC) are visible through an aperture (A) mounted on the front of the carriage (C). (See Figure 1-C). The cars (BC) appeared in the opening of the aperture (A) as they move past approximately 29 feet distance from the eye (E) of the observer.

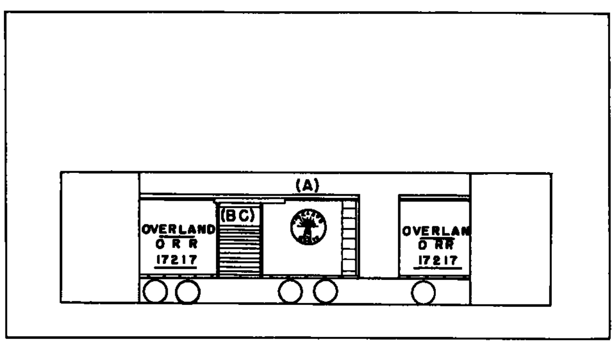
For the first and second series, the luminant (L) was a Ferree-Rand acuity meter used as a projector. An adjustable diaphragm calibrated for the percentage of opening controlled the amount of light as needed. The light source was mounted at the same height and eight inches to the left



A TOP VIEW SHOWING ANGLE BETWEEN LIGHT AND LINE OF VISION IN SERIES TWO



B SIDE VIEW SHOWING ANGLE BETWEEN LIGHT AND ANGLE OF VISION IN SERIES THREE



C CLOSE-UP OF APERTURE OPENING SHOWING SECTIONS OF TRAIN EXPOSED MOVEMENT WAS REVERSED IN RANDOM ORDER

Figure 1. The subject sits at the right with his eye at the scope (E). The two top sketches A and B show the experimental conditions used in Series 2 and Series 3 respectively. The lower sketch C shows the aperture and reproduction of lettering used on the boxcars. It will be noted that the Overland Route mark is several times larger than the small sill markers. The cross-bars below (BC) on the door were quite subdued and were not noticeable as in the drawing.

of the subject's line of vision, subtending an angle of 1 deg. 14 min. This is shown by Figure 1-A.

For Series 3 a Viewmaster Model S-1 projector was used as the luminant (L) with a Variac control. This light source was mounted 3 inches below the line of vision and the subtended angle was 27 min., as shown in Figure 1-B. Illumination levels were calibrated by a Weston Photronic cell with Viscor filter and a portable Leeds and Northrup d'Arsonval galvanometer. Only visible light is measured by this cell.

DESIGN AND METHOD OF PROCEDURE

Three series of experiments using 30, 30, and 25 subjects, respectively, were run. The first series was considered a pilot study and the data are not presented here.

In Series 2 the following experimental conditions were presented to the 30 subjects for a total of 1,260 observations as follows: (1) no reflectorized material on the side of the boxcars; (2) eleven 3/32-inch-square pieces of reflectorized material spaced an inch apart at the lower edge or sill (S) of the car, the equivalent of about 4-inch squares spaced 4 feet apart; (3) same as Series 2 except that the name of the railroad and the number of the car were in reflectorized paint. In Series 3 the same experimental conditions were presented to each of 25 subjects totaling 1,050 observations using a Viewmaster projector for the light source (L) as shown in the middle sketch, Figure 1-B.

In the second and third series each experimental condition was presented to the subject 14 times and the order systematically rotated in an effort to cancel out such factors as practice and fatigue. Reliability of the observations was 0.97. These are estimates computed from the correlation of the odd and even trials using the conventional formula. All subjects were first given a visual acuity test and only those having 70 percent vision (Clason notation) or above were used in the experiment. This is slightly better than 20/30 Snellen acuity.

TABLE 1

COMPARATIVE LEVELS OF ILLUMINATION ON BOXCARS, SERIES 2

Means and standard deviations for the three experimental conditions

Experimental condition	Units of light - mean*	Ratio of light needed with respect to condition 3 as unity	Standard deviation
Condition No. 1	214.00	31.3	62.42
Condition No. 2	175.40	25.7	51.19
Condition No. 3	6 83	1.0	2.53

*Mean score. Score was total of 14 readings for shutter opening on Ferre-Rand acuity meter.

TABLE 2

EVALUATION OF DIFFERENCES FOUND, SERIES 2

Values of t for the mean amount of light necessary to determine the direction of motion between experimental conditions used

Experimental conditions	Value of t
Condition No. 1 Condition No 2	2.62*
Condition No 1 Condition No. 3	18.19**
Condition No 2 Condition No. 3	18.06**

* Significant at the 5-percent level
** Significant at the 1-percent level.

The absolute units were not comparable with Series 3 since a different system of illumination was employed.

Wide differences are here noted between Condition 3 with each of the other two. Thus the fully reflectorized name on the side of the boxcar was far superior to the small, 4-inch diamonds placed along the sill. It is hypothesized that larger concentrations of reflectorized materials, spaced further apart, would be more effective and further experiments are being designed to test this hypothesis.

Because of the physical limitations of placing the luminant so that the angle of impinging light formed with the line of vision would be most critical for the reflectorized material used, the experiment was repeated with 25 subjects for each condition. In this series it was necessary to change the lighting system in order to reduce the angle of viewing. Comparison of the two plans is shown in Sketches A and B of Figure 1.

Since the light units are not comparable in the two series a ratio was used for making direct comparison. The light required for the best Condition 3 was divided into each of the other two. This ratio may be used as a guide to the relative amounts of light needed for discrimination of movement of the train under the three conditions studied.

The results obtained in Series 2 and Series 3 closely parallel with respect to

TABLE 3

COMPARATIVE LEVELS OF ILLUMINATION ON BOXCAR, SERIES 3

Mean and standard deviations for the three experimental conditions

Experimental condition	Units of light - mean*	Ratio of light needed with respect to condition 3 as unity	Standard deviation
Condition No 1	8 33	23.8	2 67
Condition No 2	7.22	20 6	4 29
Condition No 3	35	1 0	12

*Mean score. Score was total of 14 readings for each subject. These are for Series 2 and ratios only are comparable.

ratios as will be noted. Summarized briefly, statistically significant differences were found as follows: (1) In Series 2, measurements the mean level of illumination needed for discrimination of movement in Condition 2 was significantly less than mean illumination required for discrimination of Condition 1 at the two percent level of confidence. (2) For both series the mean illumination for Condition 3 was significantly less than mean illumination level required for Conditions 1 and 2. This was significant at the one percent level of confidence.

TABLE 4

EVALUATION OF DIFFERENCES FOUND, SERIES 3

Values of t for amount of light necessary to determine the direction of motion.

Experimental condition	Value of t
Condition No. 1 Condition No. 2	1 10
Condition No. 1 Condition No. 3	14 87**
Condition No. 2 Condition No 3	8 11**

** Significant at the 1-percent level.

CONCLUSIONS

Subject to the limitations of the experimental procedures, the number of subjects used and other factors which might affect results, the following tentative conclusions may be stated:

1. In general, the hypothesis set forth for experimental testing was confirmed and the use of materials giving greatest brightness-contrast at night significantly decreases: (1) the amount of luminance needed and (2) the difficulty of discriminating movement of boxcars crossing the line of vision at night.

2. The corollary hypothesis that the expanse of reflectorized material has an effect is confirmed. The larger the patches of reflectorized material the lower the level of luminance needed.

3. The extent of the visual angle reflectorized determines effectiveness up to a certain size, but the limits were not determined in this study.

4. It would appear that for a certain area of reflectorized surface of given reflectance characteristics, larger concentrations of reflectorization would be more effective. This study made no attempt to establish optimal values.

APPLICATIONS AND DISCUSSION

Application of the above conclusions to actual highway and driving situations require the basic assumption that the differences found would hold over the wide variation in ranges of distance and illumination which are encountered in driving. Since the experimental conditions show that the materials giving the greatest brightness-contrast and consequent visibility require significantly less illumination for seeing efficiency, there seems to be justification for the assumption.

For comparative purposes only, visibility distances when converted to high-beam headlight intensities are of interest. It is estimated that when using 500 feet as a basis of computation average visibility distance at night under ideal conditions would be approximately: (1) unreflectorized freight train, 425 feet; (2) small reflectorized markers on sill added, 500 feet; (3) fully reflectorized lettering of the type used on the boxcar side, 2,500 feet.[1]

These comparisons are based on relative amounts of light using the inverse-square law. For low headlight beams and conditions of weather giving poor visibility these values would be proportionally lower. The high incidence of automobiles striking the side of trains indicates that many drivers do not see trains at 425 feet.

Since the incident light on the reflectorized materials was not up to the most critical angle, these estimates are conservative and particularly that for Condition 2 as stated. These figures may provide some basis of comparison between the different conditions studied and the

[1] The Overland Route trade mark which was used is more expansive than the small diamonds on the sill.

advantage of the most effective reflectorization.

Further studies need be made of the optimal conditions for size of reflectorized areas, shape of area, spacing distances and height of placement on boxcars for most-effective results.

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