Illumination Requirements for Roadway Visual Tasks

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●BLACKWELL (1) has recently reported a general quantitative method for establishing the illumination levels required for adequate performance of various visual tasks encountered in interior environments. Inasmuch as there are no significant visual factors involved in performing outdoor tasks which are not also involved in performing interior tasks, the general method should be useful in establishing illumination levels for outdoor as well as indoor visual tasks. The present paper reports the establishment of illumination levels required for the performance of typical visual tasks involved in night driving, on the basis of the 1959 method. Of course, there are always special problems involved in the application of any general method in a new connection and in this case, new procedures and instrumentation were required for use of the method with roadway visual tasks. However, the basic assumptions and data used in connection with roadway visual tasks are identical with those used previously in connection with interior tasks.

THE LIGHTING SPECIFICATION METHOD

For the present purpose, a brief summary of the method proposed in 1959 for establishing illumination levels for various visual tasks will suffice.

An extended study was first made of the quantitative performance of normal young observers when presented visual tasks varying in size and contrast at various levels of background or adaptation luminance. In one series, the observers were not required to search and scan for the task, but were presented their tasks under optimal conditions in order to maximize their performance. Visual capacity to perform the tasks was determined for various durations during which the task might be presented. This study revealed the background or adaptation luminance value required to perform a visual task of fixed size and contrast during a fixed exposure time. Data were available for various quantitative levels of performance accuracy.

Study of patterns of eye movements during continuous visual work reveals that the normal eye will pace itself at a rate of about 5 fixational pauses per second. On this basis, it was decided that the visual system would be provided a reasonable level of "visual capacity" if it were enabled to assimilate one item of visual information per fixational pause. The criterion level of visual performance built into the lighting specification system was established as a visual capacity of 5 assimilations per second (APS), at an accuracy level of 99 percent.

Of course, observers must usually search and scan for visual information under far less than optimum conditions. A second series of studies required the observers to perform visual tasks under realistic conditions of search and scanning. Performance data obtained under these conditions were compared with similar data obtained under the optimum conditions studied previously. It was found that allowance could be made for the differences between the realistic dynamic conditions and the optimal conditions by use of a "field factor" of 15, representing that fifteen times more task contrast is required in the one case than in the other. It was assumed that the conditions of the dynamic experiments were reasonably typical of use of the eyes in various actual tasks. Therefore, a factor of 15 was used in adjusting the absolute values of the original data for the purposes of the lighting specification system.

A standard performance curve was then derived for the visual task consisting of a

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bright disc with a 4-min angular diameter, which appeared on a uniform background of lesser luminance. This curve is reproduced as the solid curve in Figure 1. It defines precise values of background luminance required for 4-min standard targets of varying physical contrast to just meet the criterion level of performance capacity and accuracy specified. It is apparent that the lower the task contrast, the higher will the background luminance have to be to maintain the task at the selected performance criterion.

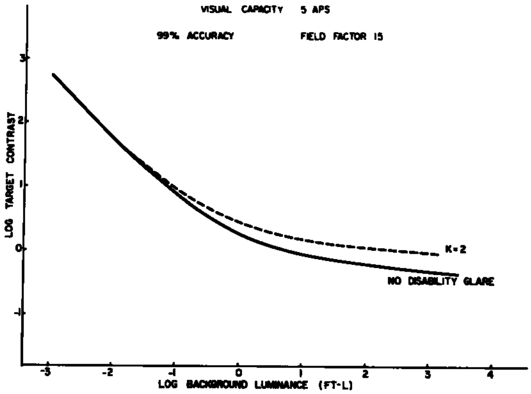

Figure 1. Standard performance data for a 4-min disc target. Solid curve represents no disability glare. Dashed line represents a degree of disability glare as described in the text.

Now, a practical visual task can be rated in difficulty in terms of the specific physical contrast value for the 4-min standard task which makes the two tasks of equal difficulty. Once such an equivalence has been established, the performance curve for the 4-min standard task may be used to establish the precise background luminance needed to maintain the practical task at the performance criterion. Requisite illumination may be computed from the value of required luminance from measurements of the reflectance characteristics of the task. The equation between standard and practical tasks is made in an instrument known as the Visual Task Evaluator (VTE). The device reduces both the standard and practical tasks to near the visibility threshold so that a reasonably precise equivalence can be established. After assessment with the VTE, the difficulty of each practical task may be described fully by a value of "equivalent contrast" for the standard task found to have equal difficulty. Only one value of background luminance and hence one value of illumination can provide the criterion level of visual performance for each practical task.

The original report of the lighting specification method included a statement concerning its use under circumstances in which there is substantial disability glare in the field surrounding the visual task. The basic idea goes back to an earlier paper by Blackwell (2). Blackwell has shown that the disability glare effect can be introduced into visual performance data such as those presented in the solid curve in Figure 1 by constructing curves such as the dashed one shown in the same figure. This curve represents a value of K = 2 in which

$$K = \frac{B + B_V}{B} \tag{1}$$

in which

B = luminance of the task background in the absence of disability glare; and
B_V = total equivalent luminance produced by all sources of disability glare within the field.

It is possible to construct a performance curve for any value of K of interest by geometrical construction in only a few minutes, following the method described (2).

Of the several expressions for B_V extant, the authors prefer the one reported by Fry (3) which may be written

$$B_V = \sum_{i=1}^{n} \frac{10\, E_i}{\theta_i (\theta_i + 1.5)} \tag{2}$$

in which

E_i = illumination produced by a point glare source on the entrance pupil of the eye; and

θ_i = the angle between the point glare source and the line of sight of the eye, measured in degrees. The value of θ_i must always equal or exceed 1 deg.

Of course, it would be possible to compute the value of B_V for the environment of each visual task of interest, but it would hardly be practical. Instead, the authors have developed the idea suggested earlier by Fry (4) that a photoelectric photometer be used in obtaining a value of B_V immediately from the environment surrounding a visual task.

EXPERIMENTAL APPARATUS AND PROCEDURES

In addition to standard items of photometric equipment, three special items of measurement equipment were used. These are shown in Figure 2 in the outdoor site used for measurements at Hendersonville, North Carolina. The large optical device on the right is the VTE. The telescopic device on the tripod to the left is a Pritchard Photoelectric Photometer. What looks like an extra lens near the foremost leg of the tripod is the attachment used to obtain values of B_V by physical measurement.

The Pritchard photometer consists of a telescope and photomultiplier tube, arranged so that the photometer measures the luminance of small distant areas. The attachment for measuring B_V represents a "bug-eye lens" which images a full 180-deg view of the environment in the plane of a photographic absorptive mask. The lens was designed and built by Fry, whereas the authors have prepared the absorptive mask. The mask was designed to weight incoming flux from various portions of the environment in accordance with Eq. 2. An opaque mask obscured the inner 2-deg diameter of the field.

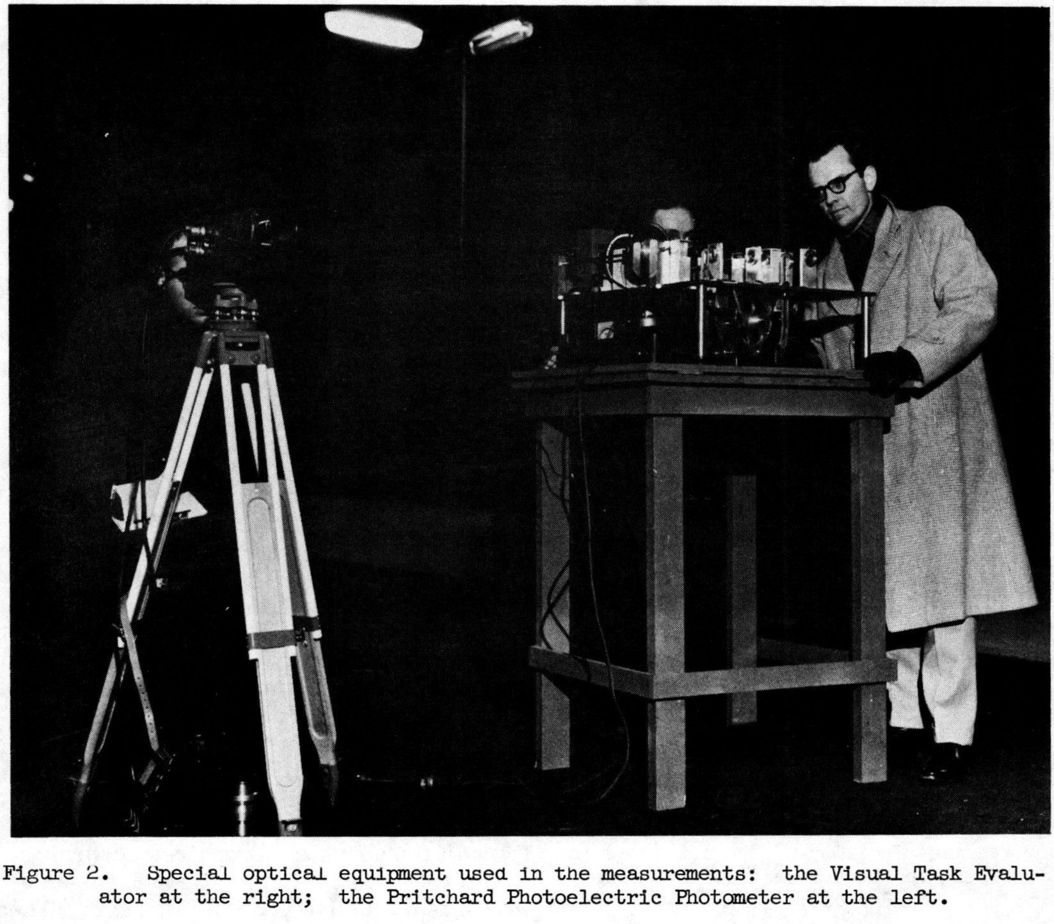

Figure 2. Special optical equipment used in the measurements: the Visual Task Evaluator at the right; the Pritchard Photoelectric Photometer at the left.

Thus, the photometer automatically integrated components of disability glare from all portions of the environment for a particular visual task and gave an experimental value of B_V.

Measurements were made on a special street used for street-lighting research and demonstrations, a daytime view of which is shown in Figure 3. The right half of the roadway was paved with asphalt, the left with concrete. Each pole had fluorescent,

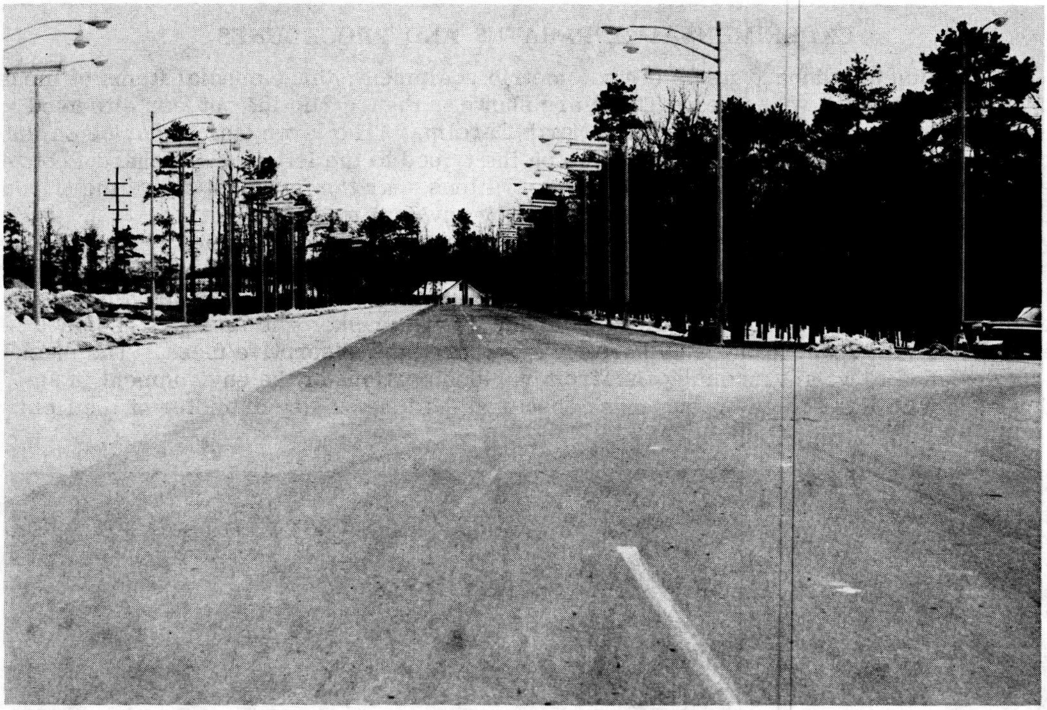

Figure 3. Daytime view of the outdoor testing facility at Hendersonville, North Carolina.

incandescent, and mercury fixtures. The poles used were spaced 200 ft apart on each side of the roadway, in staggered locations. The dimensions of the lanes and the positions of the luminaires with respect to the lanes may be judged from Figure 4. The roadway poles, luminaires, layout and pavement surfaces were intended to represent generally accepted American practice in roadway lighting installation. Further details concerning the installation may be obtained from the Outdoor Lighting Department of the General Electric Company which developed and maintains the installation.

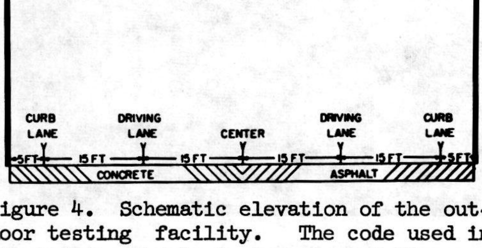

Figure 4. Schematic elevation of the outdoor testing facility. The code used in identifying the luminaires is: F-fluorescent; I-incandescent; and M-mercury.

A variety of realistic targets were used to represent visual tasks of importance to night driving in areas where street-lighting would be used. For example, Figure 5 shows a mannequin located in the center of the concrete roadway, in what is called the driving lane, with the incandescent luminaires in use. The distance between successive luminaires on the left side is 200 ft, with the opposite luminaires occurring at the 100-ft midpoints. The nearest luminaire is on the left side in this case. When the asphalt pavement was used, the arrangement of luminaires was reversed left to right so that in this second case the nearest luminaire was on the right side. For most measurements, there was a total of six luminaires but the arrangement of five shown in the figure was employed in the earliest studies. With an approximately 30-ft mounting height, there were non-uniformities in pavement luminance as may be noted in the figure.

Illumination data for various locations along the roadway is required. These were obtained at 20-ft intervals down the roadway with a Macbeth Illuminometer and standard test plate.

The basic procedure may be described briefly, as follows: A target, such as the mannequin, was set up at a given location on the roadway. The measurement equipment was set up either in a mobile shed or in the back of a closed truck at a known distance from the target. The VTE was used to assess the difficulty of the target exactly as it would appear to a driver proceeding along the roadway. From this assessment, a value of the equivalent contrast of the 4-min standard target was obtained.

The Pritchard photometer was first used to measure the average luminance of an area of the environment containing the target, having a 2-deg diameter. The disability glare attachment was then placed on the Pritchard photometer and a value of B_V was obtained corresponding to the case of an observer viewing the target ahead.

Subsequently, a performance curve (such as the dashed curve in Fig. 1) was constructed for the value of K corresponding to the experimental values of B and B_V. The value of equivalent contrast obtained in the VTE was entered on the ordinate and the

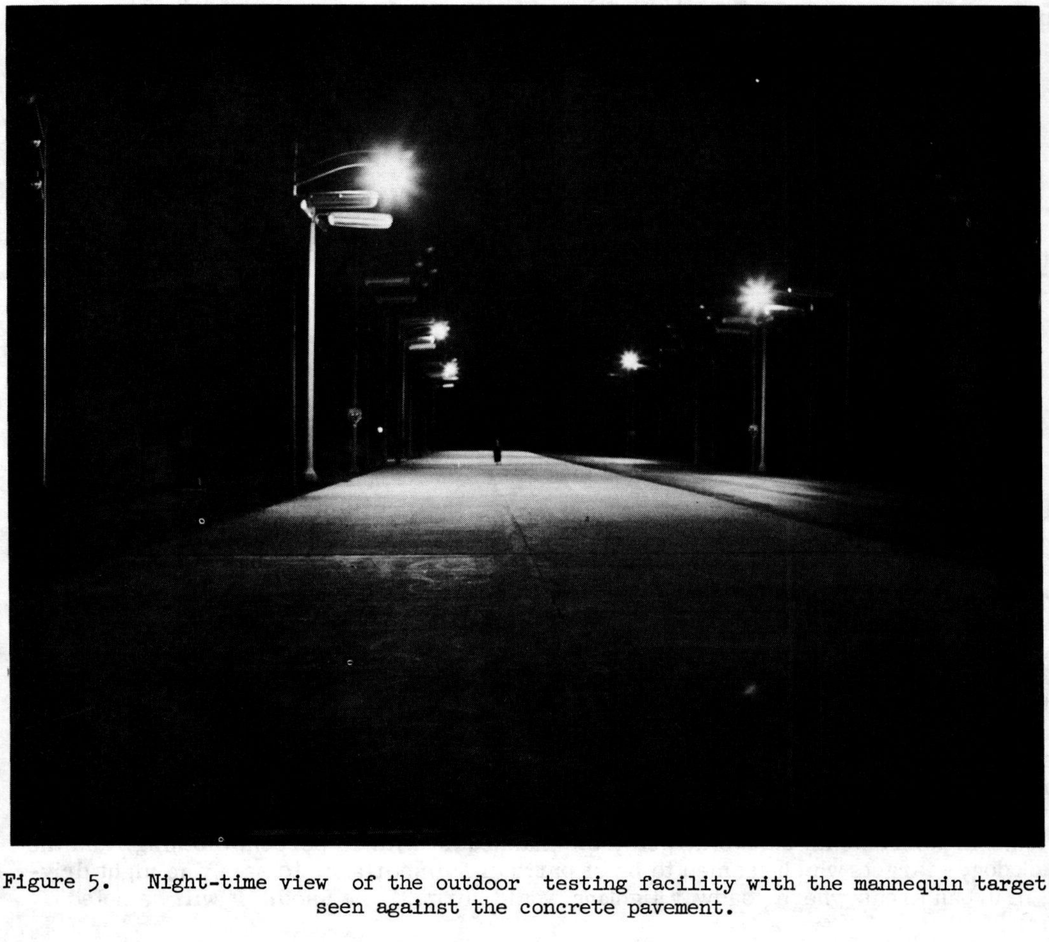

Figure 5. Night-time view of the outdoor testing facility with the mannequin target seen against the concrete pavement.

point of intersection with the appropriate (dashed) performance curve was used to define the precise background luminance level required for adequate performance of the visual task, in the presence of the measured amount of disability glare.

While in the field, measurements were made of the actual illumination falling on a test plate oriented horizontally. The requisite horizontal illumination was obtained from the relation

$$E_r = E_o \frac{B_r}{B_o} \tag{3}$$

in which

E_o = the horizontal illumination actually obtained;
B_r = the luminance required for adequate performance of the task; and
B_o = the average luminance of task and surround actually obtained.

Eq. 3 is actually no more than a method for determining the reflectance of some portions of the pavement for illumination coming from luminaires in a particular position with respect to the target.

EXPERIMENTAL DATA

It was intended that as good a sample as possible of typical roadway visual tasks be investigated. Nine tasks were originally selected for evaluation, in order to obtain some idea of their relative difficulty. Measurements were made on asphalt, with incandescent luminaires. Viewing distances of 180 and 200 ft were used and the results were averaged. The location of the measuring equipment was fixed inasmuch as it was mounted within a wooden shed. The target appeared either 40 or 60 ft beyond the first luminaire on the same side.

Illumination values required for nine different tasks are given in Table 1, in order of task difficulty. It is apparent that the illumination level required for roadway lighting varies enormously depending on whether the task is as large and easy to see as an automobile, or as small and difficult to see as a simulated hole in the pavement. The range of illumination values covers the limits of modern roadway lighting at one extreme and modern interior lighting at the other. These values emphasize the significance of specifying a particular visual task when considering illumination requirements.

TABLE 1

REQUIRED ILLUMINATION LEVELS FOR NINE TASKS[1]

Task Description	Horizontal Illumination (ft-c)
1. Old automobile	0.341
2. Mannequin, with clothing of 60% reflectance	0.358
3. Mannequin, with clothing of 20% reflectance	0.414
4. Yellow cone marker	0.436
5. Toy dog, with light fur	1.52
6. Toy dog, with black fur	1.80
7. Overturned bicycle	10.8
8. Brick obstacle	926.
9. Simulated hole in pavement	>1000.

[1]Asphalt pavement, incandescent luminaires, 180- and 200-ft viewing distances.

After completing these measurements, the authors decided to concentrate their additional measurements on two targets, the mannequin with 20 percent clothing and the black dog,—targets which seemed to be of particular importance to safety in night driving in urban areas where roadway lighting would normally be used. It will be noted from Table 1 that the selections fall near the middle of the original nine tasks in terms of difficulty so that these tasks are by no means extreme.

Because individual roadway installations will vary in the type of luminaire and pavement surface used, the effect of these two variables on the illumination required for adequate visibility of the mannequin and the dog was next studied. These measurements were made at viewing distances of 180 and 200 ft with the same fixed location with respect to the luminaires as before.

Data relating to the effect of luminaire type are given in Table 2. It appears that there is a small difference in the requisite illumination which depends on the luminaire type, with the least illumination being required with incandescent luminaires. On the average, 6 percent more illumination is required for fluorescent and 27 percent more when mercury luminaires are employed. These differences are perhaps not large, but they will be used in analyzing the data to avoid data bias due to luminaire type.

TABLE 2

EFFECT OF LUMINAIRE TYPE ON REQUIRED ILLUMINATION LEVELS[1]

Incandescent	Mercury	Fluorescent
	(a) Mannequin	
0.218	0.432	0.339
0.274	0.498	0.429
0.318	0.654	0.509
0.374	0.852	0.601
0.395	1.31	0.677
0.463	1.48	0.920
0.471	0.871 ft-c	0.579 ft-c
0.472		
0.474		
0.482		
0.598		
1.32		
0.488 ft-c		
	(b) Dog	
0.481	0.517	0.873
0.558	0.636	1.02
0.664	0.692	1.17
0.664	0.875	1.21
0.780	1.83	1.40
1.10	2.96	1.46
1.10	1.25 ft-c	1.19 ft-c
1.10		
1.32		
1.33		
2.16		
2.98		
1.18 ft-c		

[1]Asphalt and concrete pavements, 180- and 200-ft viewing distances. All values are horizontal illumination (foot-candles).

The data relating to the effect of pavement surface are given in Table 3. Here, as expected, the effect of pavement type is different in direction for an object such as the dog which is of lower reflectance than either the asphalt or concrete and an object such as the mannequin which has a reflectance intermediate between that of asphalt and concrete. The dog is easier to see on concrete because it more nearly matches the asphalt in reflectance. There is little difference in the visibility of the mannequin on the two pavements because she differs in reflectance to about the same extent from either asphalt or concrete.

TABLE 3

EFFECT OF PAVEMENT TYPE ON REQUIRED ILLUMINATION LEVELS[1]

Asphalt	Concrete
(a) Mannequin	
0.218	0.274
0.374	0.318
0.395	0.339
0.429	0.463
0.432	0.471
0.472	0.498
0.474	0.509
0.482	0.598
0.601	0.677
0.654	0.852
0.920	1.31
1.48	1.32
0.577 ft-c	0.636 ft-c
Concrete/asphalt factor = 1.10	
(b) Dog	
0.875	0.481
1.02	0.517
1.10	0.558
1.10	0.636
1.10	0.664
1.17	0.664
1.32	0.692
1.40	0.780
1.83	0.873
2.16	1.21
2.96	1.33
2.98	1.46
1.58 ft-c	0.822 ft-c
Concrete/asphalt factor = 0.519	

[1]Incandescent, fluorescent, and mercury luminaires, 180- and 200-ft viewing distances. All values are horizontal illumination (foot-candles).

It was decided to standardize on an asphalt pavement and incandescent luminaires for the next series of measurements. In this series, the viewing distance was fixed at 200 ft, and both the targets and the measuring equipment were moved along the roadway, so that the targets would be viewed under different geometries with respect to the luminaires. The targets were placed at locations 20 ft apart. A total of eleven positions was used, the first and last of which represented the case where the targets were directly under the luminaires. One of the eleven locations corresponded exactly to that used in the earlier studies. Illumination values for each of the eleven locations are given in Table 4, with the values for the location used in the earlier studies starred in each case. It is apparent that by chance a location was selected for the first studies which required the least illumination of any possible location. It is also apparent, as expected, that the location of the targets with respect to the luminaires has a considerable effect upon the illumination requirement. The average values in Table 4 should represent the most reasonable values to use for the selected luminaire and pavement conditions, because there is equal interest in providing adequate visibility for all positions of a pedestrian or dog with respect to the luminaires.

The best over-all illumination value for a 200-ft viewing distance would presumably consist of a composite value for all possible types of luminaires and both types of pavement surface. Such an over-all value may be estimated by using the data contained in Table 4, together with data given in Tables 2 and 3. There is reasonable supposition that the relative values obtained in the earlier studies and given in Tables 2 and 3 can be applied to the data presented in Table 4 to estimate what would have been obtained had all locations of the targets under all luminaires and with both pavements been studied. The average values of Table 4 are first corrected for the bias introduced because the illumination requirement is less for incandescent luminaires than for fluorescent or mercury luminaires. A multiplying factor of 1.11 corrects the values obtained with incandescent luminaires to the values to be expected from equal numbers of the three types of luminaires. A multiplying factor of 1.05 corrects data for the

TABLE 4

REQUIRED ILLUMINATION LEVELS FOR TASKS AT ELEVEN LOCATIONS[1]

Mannequin	Dog
0.415*	0.816
0.534	1.63
0.556	1.65
0.688	1.90
0.726	1.91
0.796	2.25
1.28	2.62
1.82	3.08
2.62	3.10
3.44	3.26
3.60	4.63
1.50 ft-c	2.44 ft-c

[1]Asphalt pavement, incandescent luminaires, 200-ft viewing distance. All values are horizontal illumination (foot-candles).
*Location studied previously.

mannequin obtained with asphalt alone to the average to be expected from equal numbers of concrete and asphalt pavements. A factor of 0.76 corrects data for the dog from asphalt to an average of both types of pavements. The resulting values of requisite illumination are as follows:

Mannequin	1.74 foot-candles
Dog	2.06
Average	1.90

The value of 1.90 foot-candles represents the best estimate of the illumination requirement for the average of the two tasks, when viewed from a 200-ft distance, with equal numbers of each luminaire and pavement condition.

It should be apparent from the foregoing that the illumination requirement varies considerably depending on the luminaire, the pavement, the visual task, and the location of the task with respect to the luminaires. Thus, an average value of 1.90 foot-candles may be difficult to interpret. For this reason, a frequency distribution has been calculated to illustrate the percent of times the mannequin or dog will be adequately visible for various possible illumination values.

A cumulative frequency distribution is presented in Figure 6. It was constructed as follows: Each value in Table 4 represents a task (either mannequin or dog) at some location with respect to the luminaires, there being 22 tasks in all. The factors in Tables 2 and 3 provide a basis for estimating the illumination requirements for each of these tasks for each of the three luminaire and two pavement types. Each value in Table 4 was multiplied by a factor for each luminaire type and another for each pavement type, so that there were considered to be 6 times 22 tasks in all. The distribution curve in Figure 6 represents a cumulative tally of the 132 illumination values obtained in this way. (Inasmuch as the curve is skewed, a 50 percent value is obtained at a value somewhat less than the value of 1.90 obtained previously as the average value.) It is apparent that nearly 6 foot-candles will be necessary in order to provide adequate visibility for all possible instances in which either the mannequin or dog could occur at a 200-ft viewing distance.

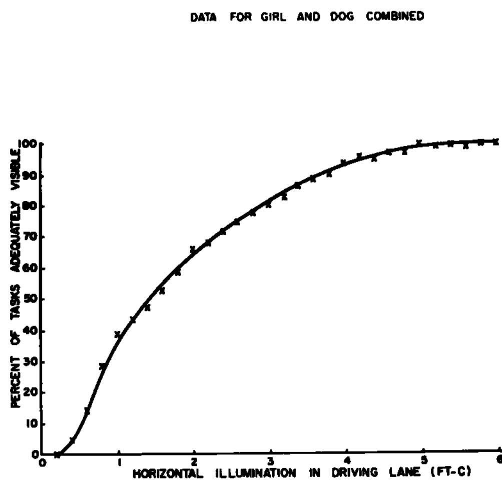

Figure 6. Frequency distribution of percent of times either the mannequin or dog will be adequately visible as a function of illumination level.

Using precisely the same techniques, measurements have also been made at seven viewing distances other than 200 ft, ranging from 180 to 400 ft. Incandescent luminaires and asphalt pavement were again used. All eleven target locations with respect to the luminaires were studied at each distance. The average data are presented in

Figure 7, relative to the average illumination value obtained at a viewing distance of 200 ft. It is evident that the illumination requirement increases as viewing distance increases with a comparatively small change between 180 and 280 ft, but with a very rapid increase as viewing distance increases beyond 280 ft. A value of nearly 5 times as much illumination is required at 300 as at 200 ft, and more than 25 times as much is required at 400 as at 200 ft.

A few measurements have been made in which the targets were placed in the curb lane. Both pavement types were involved, but only incandescent luminaires were used. Viewing distances of both 180 and 200 ft were used. In each case, a curb-lane measurement was always paired with a driving-lane measurement under the same conditions. The data obtained are given in Table 5. It is apparent that nearly three times more illumination is needed when the targets are in

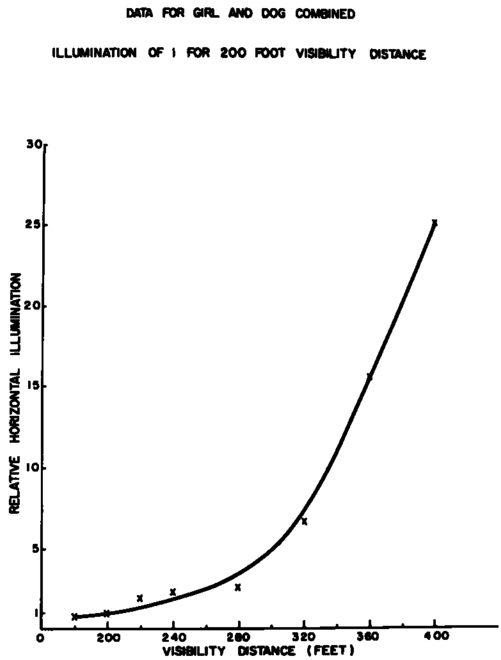

Figure 7. Relation between relative illumination and distance to the targets.

TABLE 5

REQUIRED ILLUMINATION LEVELS FOR TASKS IN CURB AND DRIVING LANES[1]

Curb Lane		Driving Lane
(a) Mannequin		
0.399		0.374
0.498		0.395
1.75		0.472
4.29		1.32
1.74 ft-c		0.640 ft-c
Curb/driving factor = 2.72		
(b) Dog		
0.810		0.664
0.930		0.664
0.985		1.10
2.28		1.32
2.58		1.33
17.6		2.98
4.20 ft-c	Curb/driving factor = 3.14	1.34 ft-c
Average curb/driving factor = 2.93		

[1]Asphalt and concrete pavements, incandescent luminaires, 180- and 200-ft viewing distances. All values are horizontal illumination (foot-candles).

the curb lane than when they are in the driving lane. This result is not due to the fact that illumination is less in the curb lane to begin with, but reflects the fact that the visual task is more difficult due both to confusion introduced by trees and obstacles along the roadway and due to disadvantageous luminance distributions.

SUMMARY AND DISCUSSION

Rather extensive illumination data have been presented for each of two roadway visual tasks; that is, seeing a mannequin and a black dog at various distances down the roadway, with a variety of luminaire types and pavement surfaces. All measurements have been made under an illumination geometry which is representative of generally accepted practice in this country. The data suggest that an average value of 1.90 foot-candles of horizontal illumination is required for adequate visibility of these targets when they appear in the driving lane 200 ft ahead. Nearly three times this much illumination, or nearly 5.7 foot-candles will be required for the same targets to be adequately visible at the same distance when they appear in the curb lane. If the targets must be seen 300 ft ahead in the driving lane, more than 9 foot-candles of illumination will be required and for 400-ft visibility in the driving lane nearly 48 foot-candles will be required. Preliminary measurements indicate that there are more difficult roadway visual tasks than these, which will require even higher levels of illumination.

These data reveal that there are visual tasks in night driving of sufficient difficulty so that interior levels of illumination will be required if these tasks are to be adequately performed. These results should not be surprising because the factors of small size, low contrast, and short viewing time will result in difficult visual tasks whether indoors or outdoors, and high illumination levels simply are required for adequate performance of such tasks. The present data do not suggest that impractical levels of roadway lighting are to be recommended for practical use, but they do provide a basis for evaluating what kinds of gains in visibility and hence improvements in the safety of night driving are to be expected with various increases in roadway illumination.

One caution must be observed in interpreting the present data. It has been shown that the required illumination levels depend importantly on the geometry of illuminating visual tasks. The interpretations of required illumination levels will be absolutely accurate only if these levels are provided with an illumination geometry identical to that studied in the tests. It is manifestly impossible to produce horizontal illumination of 48 foot-candles with the mounting heights and pole spacing involved in the tests although it is possible to approach 5 foot-candles with a similar lighting layout. Inasmuch as the visual task may be more visible with the geometry required to produce higher levels than with the geometry studied, it is unsafe to place even scientific significance on illumination values in this report exceeding 5 foot-candles. It is to be hoped that illumination geometries can be discovered which will provide the desired visibility of the more difficult visual tasks with considerably lower illumination levels than the very high values suggested in this report. Efforts in this direction should be encouraged in every possible way.

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