HIGHWAY RESEARCH BOARD

Bulletin 163

Night Visibility 1957

National Academy of Sciences—

National Research Council

publication 52

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PRESENTED AT THE
Thirty-Sixth Annual Meeting
January 7-11, 1957

1957
Washington, D. C.

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Contents

Assessment of Nighttime Roadway Visibility

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Approximately seven visibility meters have been described in the literature during the last 20 years. The salient features of each of these instruments along with their limitations and applications are briefly discussed. The U. C. Visibility Meter is discussed in detail.

The design equations of the U. C. Visibility Meter are given together with the criteria for a suitable visibility meter. Details of optical parts and calibration are included to show compliance with the design criteria.

The U. C. instrument has been used to evaluate the visibility conditions of two extremes of street lighting, that is, a uniform and an extremely non-uniform roadway brightness pattern. Under each condition a two-dimensional and a three dimensional target was used to gather information. Results of these roadway studies are presented.

These results show a great variation in visibility under the non-uniform roadway brightness pattern and less variation in visibility under the uniform roadway brightness pattern. The peak visibility of the non-uniform condition is only slightly greater than the average visibility level of the uniform condition.

● IT is a well known fact that the curtain of darkness which descends upon the roadway after dusk is responsible for many of the accidents and other hazardous and uncomfortable operating conditions that exist upon our roadways at night. The evaluation of this situation is not simple. This problem has been studied on a continuing basis at the University of California for many years and only recently have we evolved a technique which is believed to assist in answering many of the questions regarding how to make an appraisal of visibility as it actually exists.

It is the purpose of this paper to discuss the various techniques that have been used by others for making visibility measurements and to describe the visibility meter that has been developed under the auspices of the Institute of Transportation and Traffic Engineering at the University of California. Some of the preliminary results obtained in field studies will be presented together with a discussion of these results and a review of their significance.

Review of the Techniques for Visibility Measurement

A review of the literature on the subject of visibility measurement takes us back several years to 1920 when Lloyd A. Jones described a visibility meter which was used primarily to evaluate the visibility of ships at sea and to check on the adequateness of their camouflage as a protective measure from German submarines during World War I (1). Mr. Jones appreciated the problems involved in that visibility is a subjective quantity and as such is difficult, if not impossible, to measure directly. He used an established technique of experimental psychology wherein one applies various physical controls to a device which will make it possible to reduce a subjective quantity to some threshold condition wherein one can make an evaluation that the quantity does or does not exist in the perceptive field. In our case this amounts to whether the object is visible or is not visible.

Such a subjective evaluation can be made by one of four threshold measurements. (1) The object can be reduced in size until it is no longer visible. (2) The object can be exposed for a very short period of time such that it is not visible. (3) The object can be reduced in brightness along with its background until there is not an adequate brightness difference between the object and its background to allow the object to be visible. (4) The ratio of object brightness to background brightness can be reduced without changing either the total brightness of the target area or the brightness of the surround. In this case the contrast between the object and its background is changed to a threshold condition.

In the Jones meter a combination of brightness difference threshold and contrast threshold conditions are applied. The meter itself (see Figure 1) consisted of a veiling brightness source which could be moved either nearer to or farther away from the optical axis thereby increasing or decreasing the brightness of a diffusing glass. A partial mirror is placed in the principal optical path and transmits part of the incident

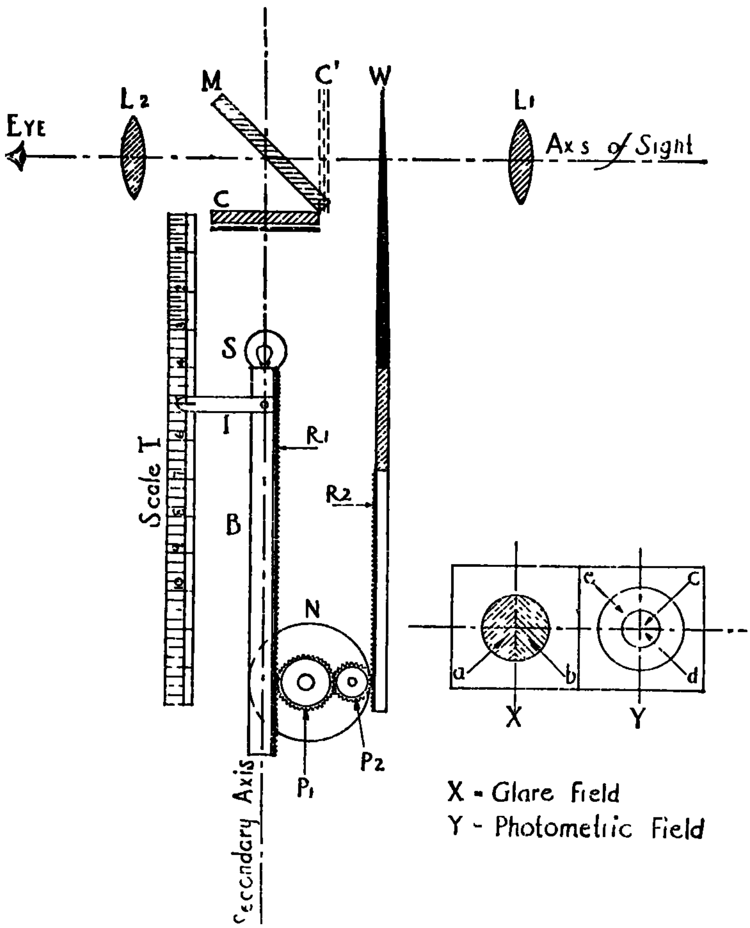


Figure 1. Jones visibility meter.

flux from the object to be viewed and reflects part of the flux from the diffusing glass which acts as a veiling brightness source. A neutral non-diffusing optical wedge was arranged to move across the path of the light from the object. The moving wedge was coupled to the moving light behind the diffusing glass which acts as a veiling brightness source as shown in Figure 1. In this manner the veiling brightness is increased as the brightness of the object and the principal field of view is reduced. This principle as will be shown later under the heading, Design Equations of the Visibility Meter, will accomplish a change in contrast in the field of view such that the object can be reduced to threshold contrast. While the instrument is based on a sound principle it has never received wide-spread use. The reason for this is not known but it would appear that mechanical problems of construction might limit its use and the fact that the overall adaptation level of the eye is changed when the variable transmittance wedge is in-

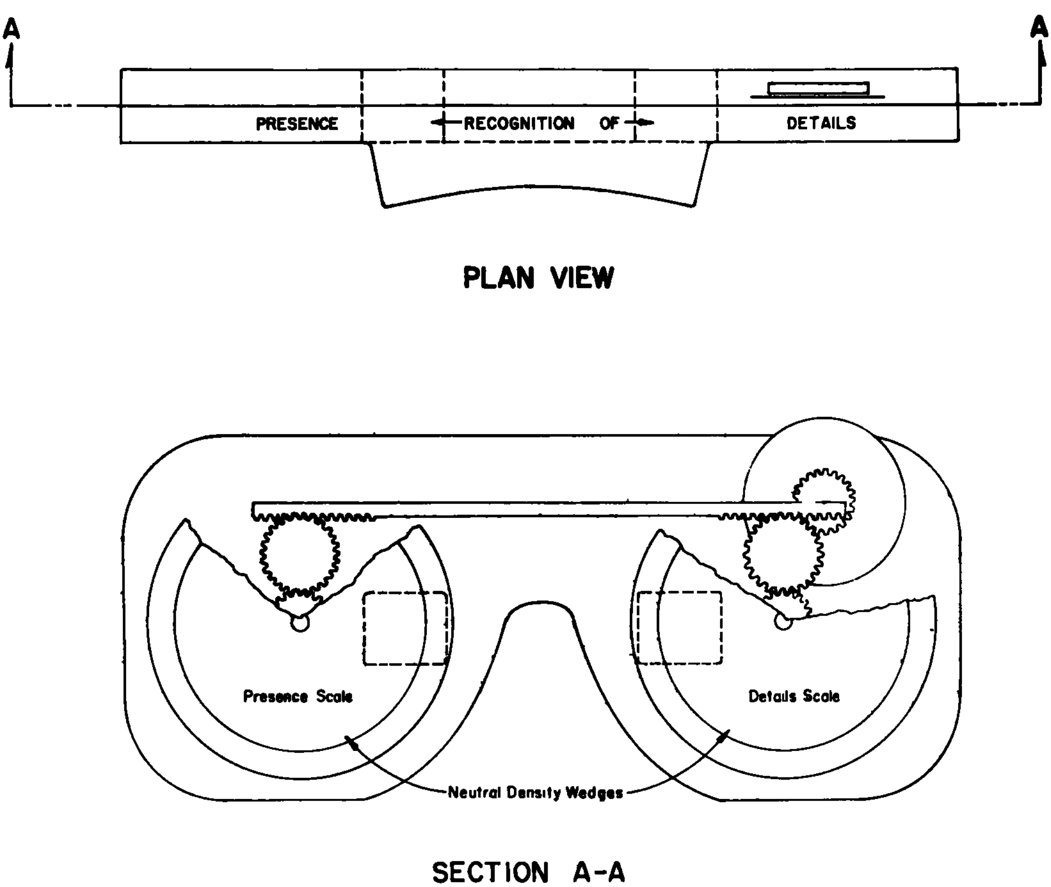


Figure 2. Luckiesh-Moss visibility meter.

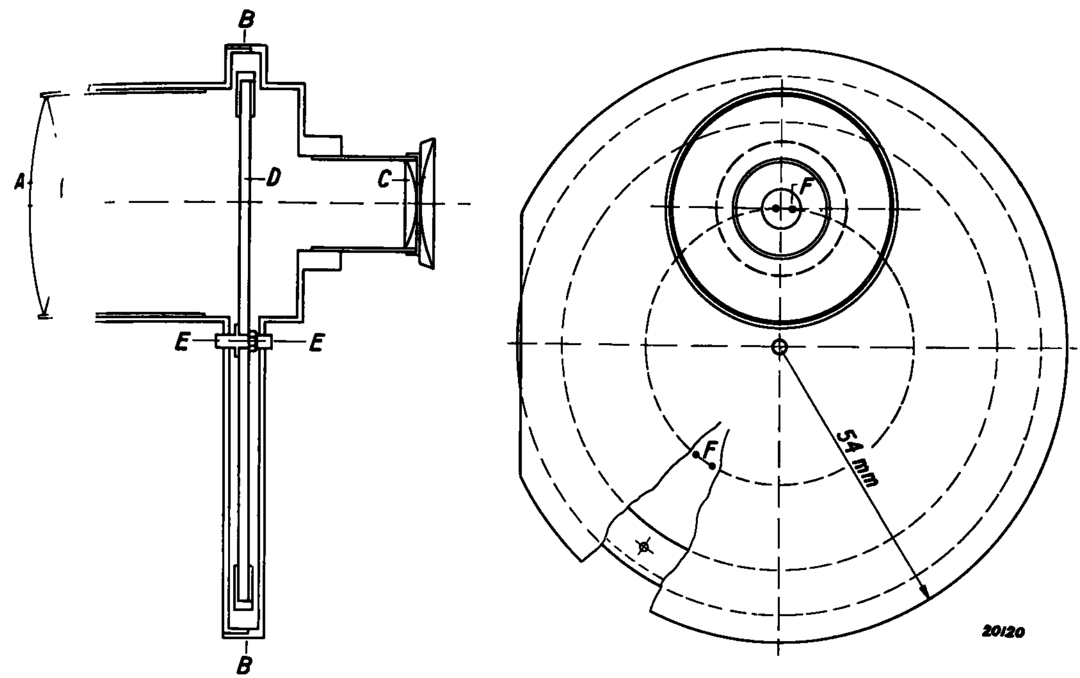
serted in the main optical axis. This would limit its application to high brightness conditions such as the viewing of ships at sea against a daytime sky.

The Luckiesh-Moss Visibility Meter was next in the evaluation of visibility measurements and appeared in about 1935 (2) (see Figure 2). This meter has been described many times and there have been numerous discussions of its application and use as indicated in the reference material (3). The meter consists of two identical circular gradients of varying density, a synchronous driving mechanism and a suitable case. The circular gradients are photographic films prepared as varying density circular wedges. The optical path of the scene viewed by the observer is through the wedges and therefore the light on the observer's side is partly diffused, scattered and absorbed by the wedge. Thus the scattering has the same effect as a veiling brightness source in front of the observer. Rotation of the discs reduces the brightness of the object and its background to threshold conditions by scattering the light from the brighter areas to the less bright areas in the field of view. A calibration scale is arranged around the edge of one of the wedges and is in terms of the relative visibility of a pair of black parallel bars viewed against a uniformly bright white background. The reduction of visibility to threshold conditions by this meter employs the use of a reduction in the brightness difference, the contrast and the visual acuity of the object. The whole field of view is reduced in brightness level and fogged until the predetermined degree of difficulty in seeing is achieved. The setting of the wedge is then read and is used as a measure of a relative visibility.

There are a number of problems in the use of this meter particularly for outdoor viewing at low brightness levels. It has not proven to be an adequate instrument for general use under nighttime roadway conditions.

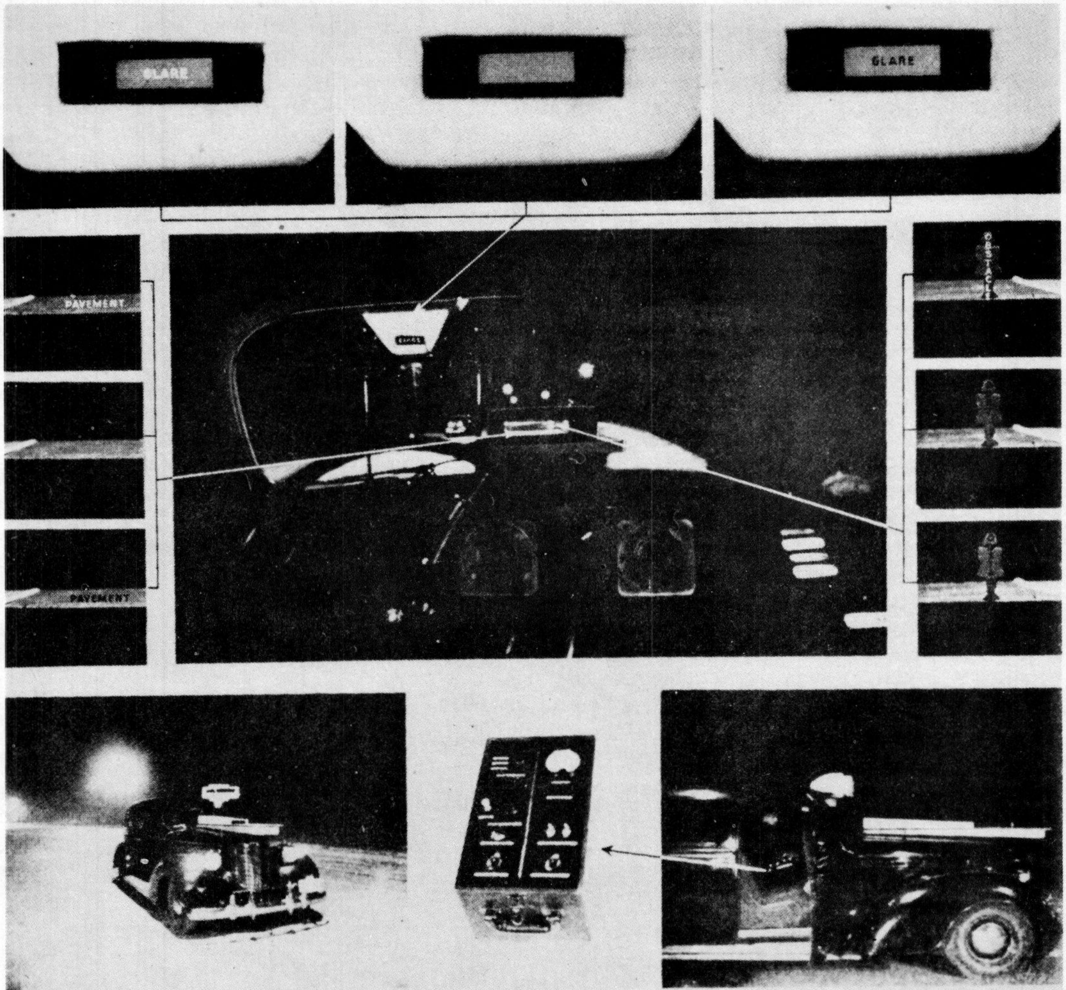
The next reference to visibility measurement is by two men from the Phillips Company in Holland, P. J. Bouma and G. Host, in 1936 (4). The instrument will be referred to as the Phillips Visibility Meter. This meter employs the principle of reduction to the brightness difference threshold. This appears to be the first meter that was specifically designed for street and highway use. Refer to Figure 3 for a line diagram of the instrument. It consists of a 1:1 magnification system and a large disc upon which a series of 50 dots is placed on a circle. The dots are rotated so that they are seen successively in the same position in the center of the optical path and projected upon the roadway, but with varying transmittance. The instrument is aimed at the portion of the roadway to be evaluated and the disc is rotated and a spot is selected which permits the target to be just perceptible against its background. The transmission of the particular spot is then recorded and used as a measure of the relative visibility. The system is ingenious and quite well suited for field measurements in that no external power supply is required. Also the eye remains at a constant adaptation level and the field of view is large enough so that all the principal glare sources are included. Only a small central field of view is varied (approximately ½ minute of arc) and the scene is viewed as it actually appears except for the step-wise variation in the dots which makes the system somewhat indeterminate and difficult to use. This meter would seem to have considerable merit for many field applications, particularly in the daytime where the field brightnesses are high. At night at low brightness levels the application of the brightness difference threshold is not satisfactory.

Following through with the historical development of visibility meters we have noted that in March, 1939, a visibility meter was described in the French periodical, Revue Generale des Routes, and is known as the Duckler Visibility Meter (5). This meter appears to be similar to the Luckiesh-Moss instrument with the exception that a series of variable density glass discs are used in place of the continually varying neutral photographic wedges. Threshold is determined when the object can no longer be seen through a glass of stated absorptive power. The instrument is primarily a brightness



A objective and *C* lens, with which the spots *F* with progressively increasing transmission coefficients are observed against the road surface as background.

Figure 3. Phillips visibility meter.



Operator's view of pavement sample on car hood and of glare integrator above windshield. Top Photometric field of the glare integrator. Left Photometric field of the pavement. Right Photometric field of the obstacle. In each case, the brightness reading in footlamberts is recorded, when the word fades out, by pressing a button which punches the record card in its holder in the control box. Lower Center Control box for photometer circuits. Lower Left and Right Evaluator elements mounted on car.

Figure 4. Reid-Channon street lighting evaluator.

difference threshold meter and does not take into account the degree of contrast between the object and the background against which it is seen. Also, the field of view is small so that the glare effect of street lights is not included. As far as can be determined this instrument has not received popular acceptance.

At about the same time in 1940 a composite instrument known as a Street Lighting Evaluator was developed by Kirk Reid and H. J. Channon (6). This instrument received considerable attention at the time and there have been numerous references to its use in literature (7). Basically the equipment measures three brightnesses and combines these into a single over-all reading. The quantities evaluated are (1) the brightness of the pavement, (2) the brightness of representative obstacles on or near the pavement in question, and (3) the glare effect from sources in the field of view. The equipment consists of three parts as shown in the photograph of Figure 4: (a) a miniature pavement bed is mounted over the hood of the car, (b) a glare integrator is mounted above the operator's eye on the outside of the car, (c) miniature pedestrians or obstacles are placed on the simulated pavement which is on the hood of the car. The texture of the miniature pavement is selected from available materials as being representative of the actual pavement in question and the miniature obstacles are selected as typical of those that might be seen on the roadway. The measurements of brightness are entered on a nomograph supplied with the instrument and, from the three numbers, the relative visibility is determined. The visibility scale is based upon a black obstacle of zero brightness viewed against a uniformly bright background of 0.01 foot-lambert. A number of these instruments were assembled and used throughout the country in the decade from 1940 to 1950. Several technical difficulties occurred in making the evaluation so that at the present time the equipment is not in wide-spread use.

The next visibility meter to make its appearance was one designed by Professor C. L. Cottrell, at Cornell University, based upon the contrast threshold principle. It was first discussed in literature in February, 1951 (8). This instrument was made out of a modified projection gun sight which uses a super-imposed luminous field over a visual target. The super-imposed field is used as a veiling brightness source and covers an area approximately 7 deg in diameter. A sketch of the optics of the instrument is shown in Figure 5. A constant brightness is maintained for the veiling source and varies the brightness of both the object and its background by means of a circular neutral gradient. When the transmission of the gradient is maximum (1.0) the brightness of the total field is the brightness of the veiling glare plus the brightness of the actual field

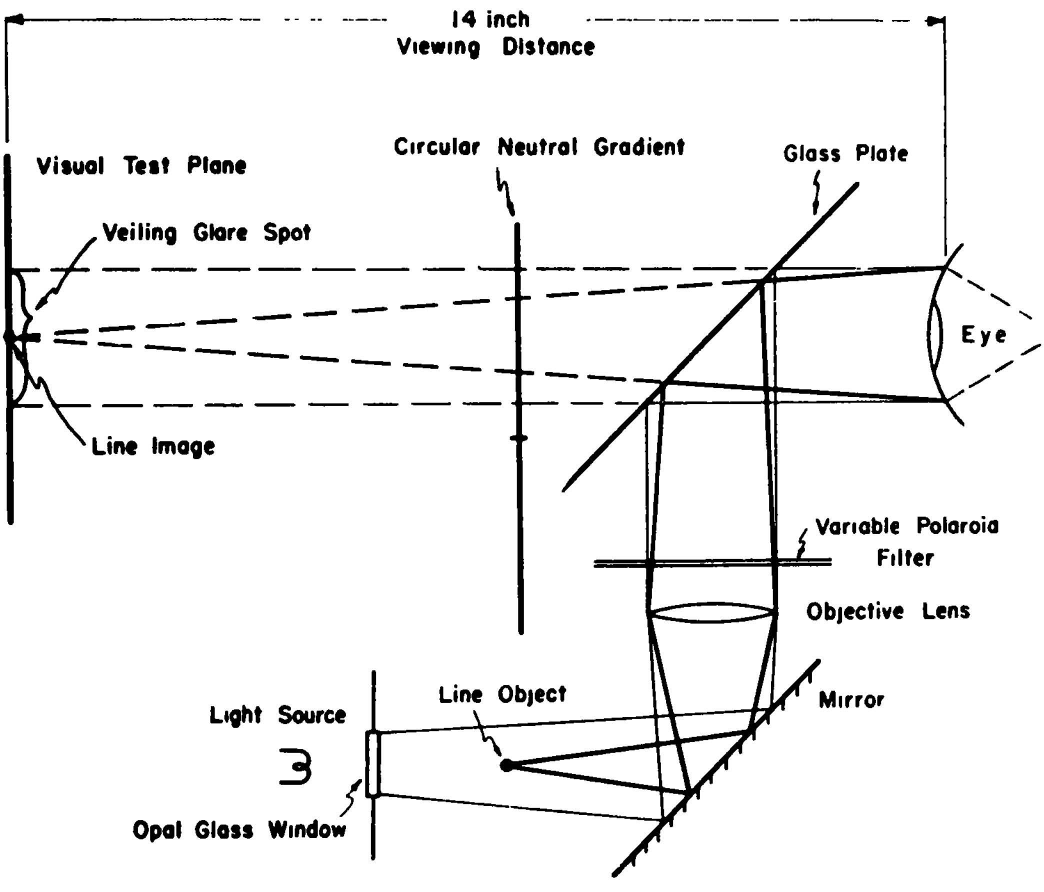


Figure 5. Cottrell visibility meter.

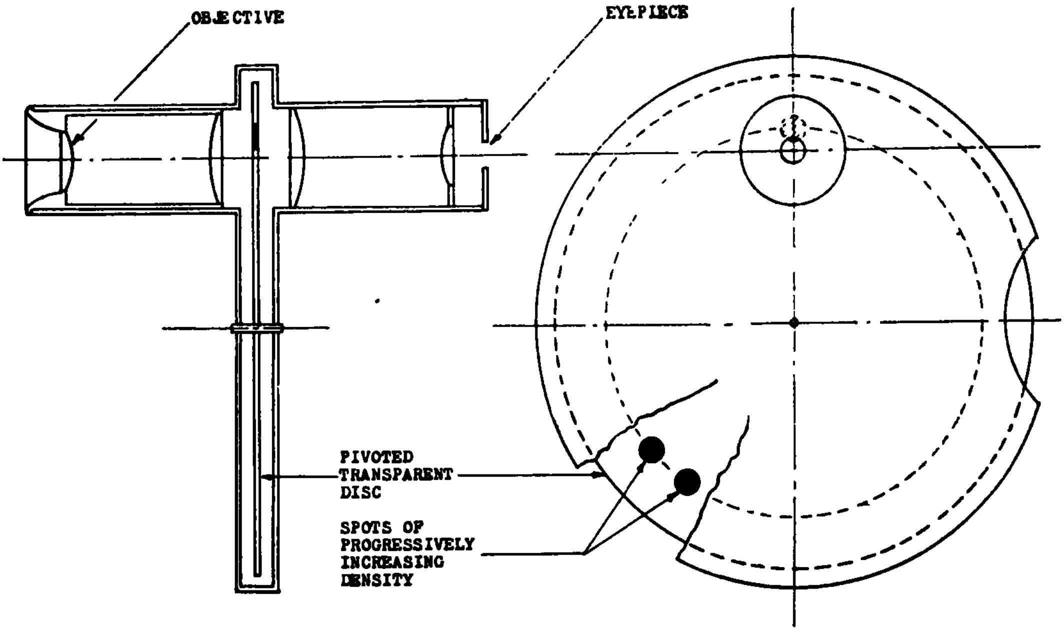
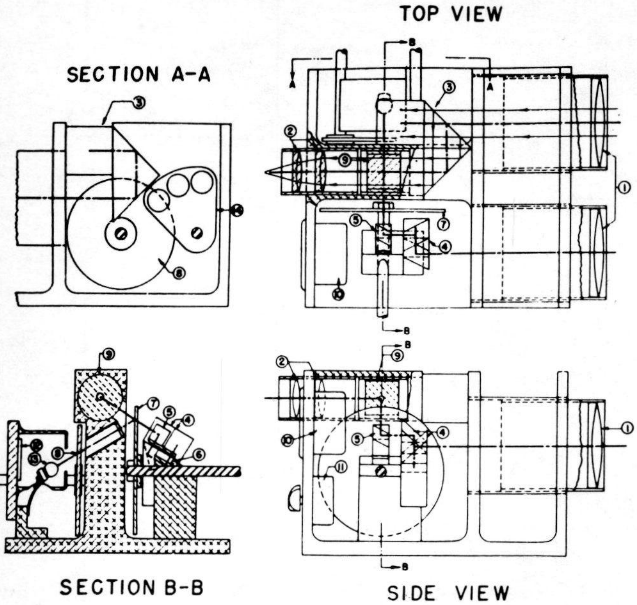


Figure 6. Horton visibility meter.

The equipment is adjusted so that the veiling glare source is equal to the brightness of the field, therefore, under the above conditions the total brightness is twice the brightness of the background. When the gradient is rotated so that the transmission is minimum (0.0), the brightness of the veiling glare source is then equal to the brightness of the background. For any particular visibility measurement, the circular neutral gradient is rotated until the object in question is just perceived at threshold, thus the instrument does measure the contrast threshold under the particular conditions of viewing above described. There are certain limitations, however, which are recognized by the author and those who have used the instrument. The principal limitation being that the adaptation brightness is changed as the neutral density gradient is rotated. Another is that the brightness of the veiling glare source remains constant and therefore the total brightness of the object and its background is continually changing during measurements. At relatively high levels of brightness these changes are not too important and therefore the instrument has proven to be satisfactory under normal daylight and interior lighting conditions. Its use under low-level roadway brightness conditions however may be questioned. To date it has not been used for nighttime roadway work but it may have some application in this field.

A meter very similar to the Phillips Visibility Meter was described by G. A. Horton in 1951 (9). The meter is based upon the brightness-diference threshold principle and consists of a lens system with a 1:1 magnification and a transparent disc in the focal plane of the eyepiece (see Figure 6). A series of transparent circular dots of varying transmittance are arranged around the periphery of the disc and are proportioned to obscure an object at approximately 200 ft ahead of the observer. The disc is rotated until the difference between the object brightness and its background brightness is below the brightness difference threshold. The same comments apply as for the Phillips meter.

After a complete review of the literature in which all of the above instruments were critically examined it became apparent that certain modifications to these instruments and techniques were desirable. Therefore a set of ground rules was developed and an instrument was designed around these specifications. The work was first reported in the literature in September, 1953 (10). Since that time there have been several modifications to the original design and improvements made in the optics so that the equip-



1. **Objective Lens—coated achromat 180 mm focal length.**
2. **Eyepiece Lens—coated achromat 122 mm focal length.**
3. **Binocular Prism 7 x 50.**

4-6. **Right Angle Prism.**

7. **Variable Transmittance Mirror (partial aluminum coating) — visibility index control.**
8. **Variable Density Wedge — background brightness control.**
9. **Object Mirror.**
10. **Ammeter — 100 milliamps.**
11. **Background Brightness Potentiometer.**
12. **Photocell-Round 1-inch dia., A-5.**
13. **Veiling Glare Source — 2.2-volt bulb.**
14. **Color Selector.**

Figure 7. U.C. visibility meter.

ment now approximately complies with all of the ground rules for the design which are listed as follows:

1. The eye adaptation should remain constant at the level of the particular seeing situation.
2. Only a small central portion of the total field should be varied to make the visibility measurement.
3. A change in the contrast of the small central portion of the field should cause no change in the brightness of the remainder of the field while a visual measurement is being made.
4. The total field of view should be large enough so as to include any glare source or sources that may be present.
5. A background brightness measurement should be included as a separate function.
6. Color correction filters should be available so that the reference source within the instrument can be matched in color against the field of view being evaluated.

The instrument to be described in the following paragraphs meets the above requirements and does measure the visibility with a reasonable degree of accuracy. The actual design of the instrument and its machined parts are shown in the working drawings of Figure 7. A list of the optical parts will be found in Figure 7. A plan view of the optical paths of the meter is shown in Figure 7 while the actual instrument is shown in Figure 8. The design equations follow.

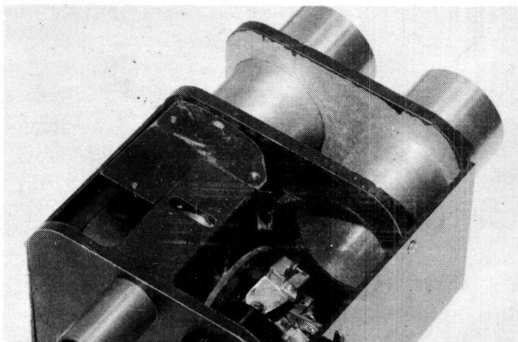


Figure 8. Photograph of U.C. meter.

Design Equations of the Visibility Meter

Definitions:

B_o = object brightness
B_b = background brightness (central portion of field around the object)
B_s = surround brightness (remainder of field)
B_v = veiling brightness
t_m = transmittance of variable density mirror
r_m = reflectance of variable density mirror
C = actual contrast
K = threshold contrast
$t_m + r_m = A$ (a constant - required condition in the design)

At the eye piece of the instrument: The eye sees the apparent brightness of the object, B'_o, the apparent brightness of the background, B'_b, and the brightness of the surround, B_s

$$B_o' = B_o - (1 - t_m)\, B_o + r_m B_v$$

$$B_b' = B_b - (1 - t_m)\, B_b + r_m B_v$$

Threshold conditions will occur when:

$$\frac{B_o' - B_b'}{B_b'} = K$$

So that: $$\frac{(B_o - (1 - t_m)\, B_o + r_m B_v) - (B_b - (1 - t_m)\, B_b + r_m B_v)}{(B_b - (1 - t_m)\, B_b + r_m B_v)} = K$$

If $B_b = B_v$: $$\frac{t_m (B_o - B_b)}{(t_m + r_m)\, B_b} = K = \frac{t_m C}{A}$$

Therefore: Threshold contrast = (t_m) x (a constant) x (actual contrast) which shows "t_m" to be a measure of the threshold contrast for the actual conditions that exist in the field of view. So t_m is a measure of the level of visibility above threshold contrast.

Calibration

The calibration procedure for background brightness measurements was as follows:

1. The reflectance of a piece of matte white blotter paper was measured. The paper was large enough to fill the entire field of the instrument.
2. The blotter paper was illuminated with a standard lamp.
3. The brightness of the blotter paper was then calculated and again checked with a calibrated Luckiesh-Taylor Brightness Meter. Brightness values from 0.01 to 5.0 ft-lamberts were used.
4. The variable density mirror (visibility index dial) was set to the position of maximum reflectance (97 on the dial). The current in the reference source for veiling brightness was then set at a selected value for a color temperature between 2100 deg and 3000 deg K. With these adjustments made the background brightness dial was rotated until a visual match was made between the central portion of the field and the total field.
5. The above was repeated for several values of background brightness (0.01 to 5.0 ft-l) and various currents in the veiling brightness source. The background brightness dial calibration is shown in Figure 9.

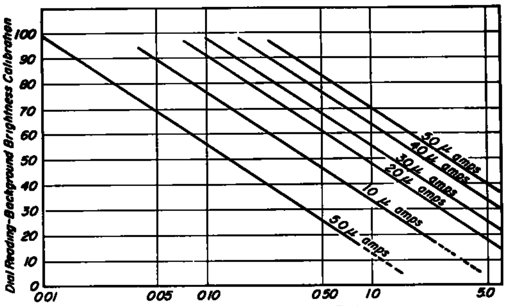


Figure 9. Background brightness dial calibration for visibility meter.

The calibration of the instrument as a threshold contrast meter was as follows on the next page.

1. A series of gray discs 3¼ in. in diameter with diffuse reflectances ranging from 11 percent to 80 percent were made in the laboratory.

2. The discs were placed in the center of a piece of matte white blotter paper which was large enough to fill the total field of the instrument. The field was illuminated with a standard lamp to develop several values of background brightnesses. Observations were made from a distance of approximately 10 ft.

3. The brightnesses of the blotter paper and the discs were calculated and then measured with a Luckiesh-Taylor Brightness Meter.

4. The visibility index dial was set to the position of maximum reflectance of the variable density mirror (97 on the V. I. dial). At this setting the background brightness dial was rotated until a visual match was made with the background brightness.

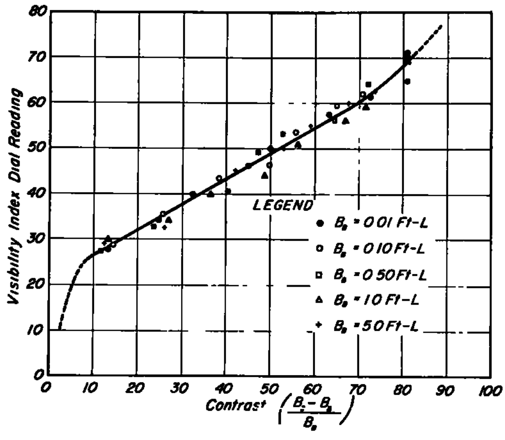


Figure 10. Visibility index dial calibration for visibility meter.

5. The visibility index dial was then rotated until threshold conditions were reached. This is the point at which the gray disc just becomes invisible (or visible). This reading represents the threshold for the particular gray disc and background in use at the time.

6. The above procedure was repeated for several values of contrast using different discs and for several values of background brightness (0. 01 to 5. 0 ft-l).

7. The actual contrast, $C = \frac{B_o - B_b}{B_b}$, was calculated from the brightness values

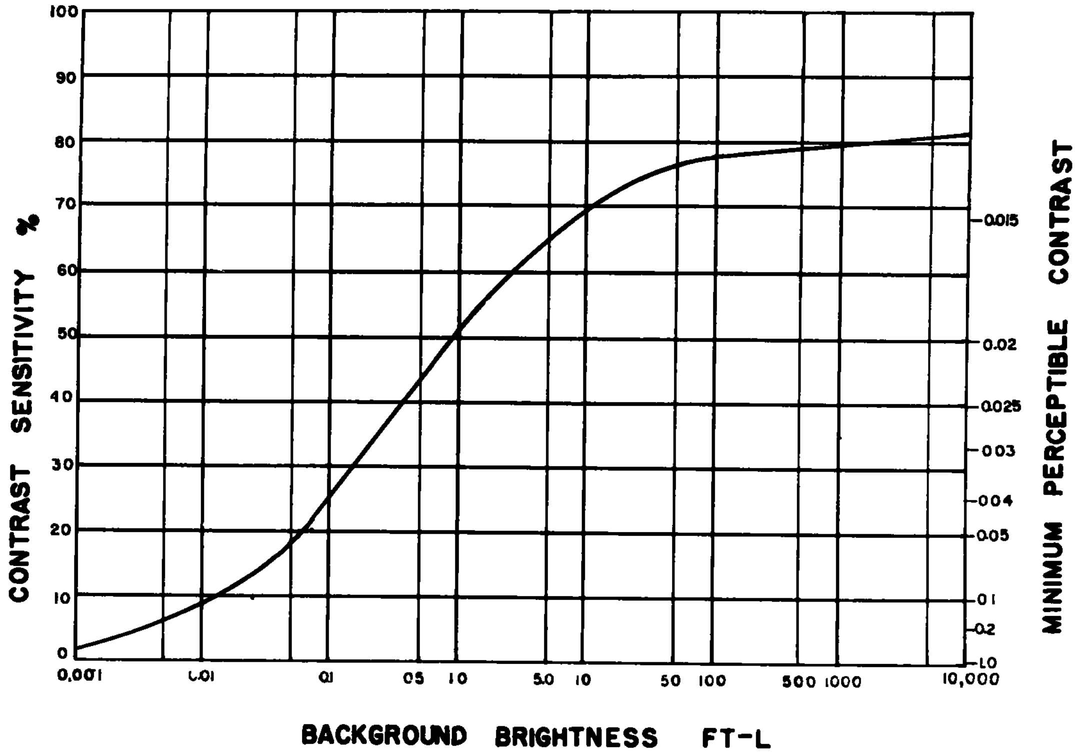


Figure 11. Contrast sensitivity variation.

Figure 12. Outdoor street lighting laboratory-daytime scene.

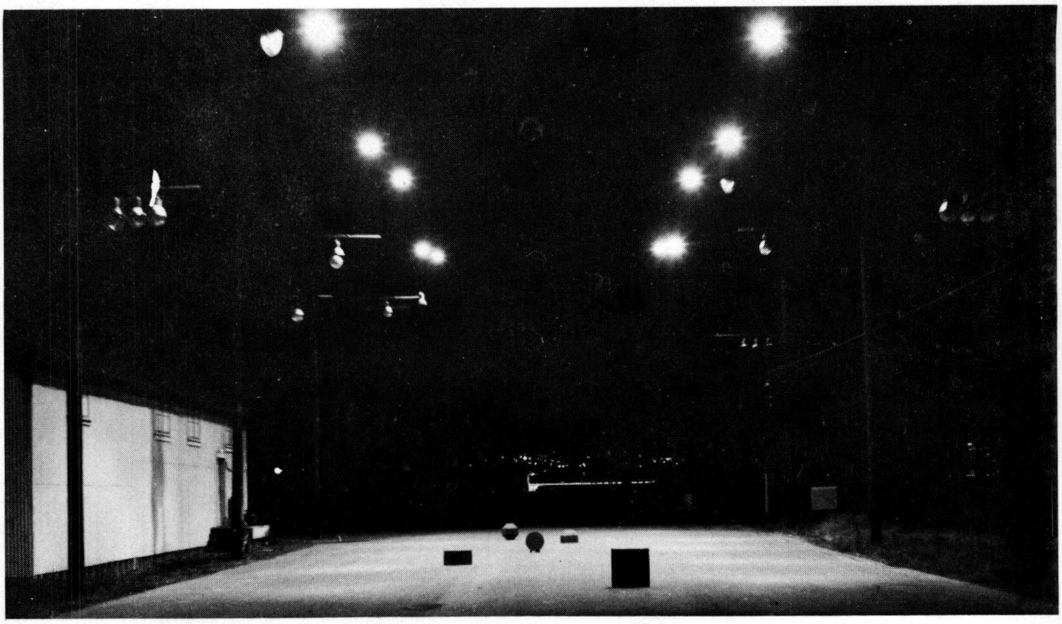


Figure 13. Uniform pattern.

obtained in No. 3. The meter readings for threshold contrast versus the actual contrast were plotted for each background brightness. These data constitute the calibration of the visibility index dial as shown in Figure 10.

It may be observed in the calibration data that the visibility index readings are approximately independent of the background brightness. This fact makes it possible to use a single curve rather than what might have been expected to be a family of curves each having as a parameter the background brightness for the various values of contrast used. From a normal curve of minimum perceptible contrast versus background brightness (Fig. 11) it would be expected that near the lower limit of the calibration curve, viz., 0.01 ft-1, the visibility index would be directly a function of the background brightness. Subsequent calibrations may verify or disprove our present findings which suggest that background brightness is not important in the range of values that we have used.

The Visibility Index

A meter reading on the visibility dial is converted to the visibility index using the calibration curve of Figure 10. The physical significance of the visibility index is this: The object in question has the same visibility as a gray disc with a contrast equal to the visibility index as given by the calibration curve. The disc is assumed to be seen against a uniform background which is at the same average brightness as the scene.

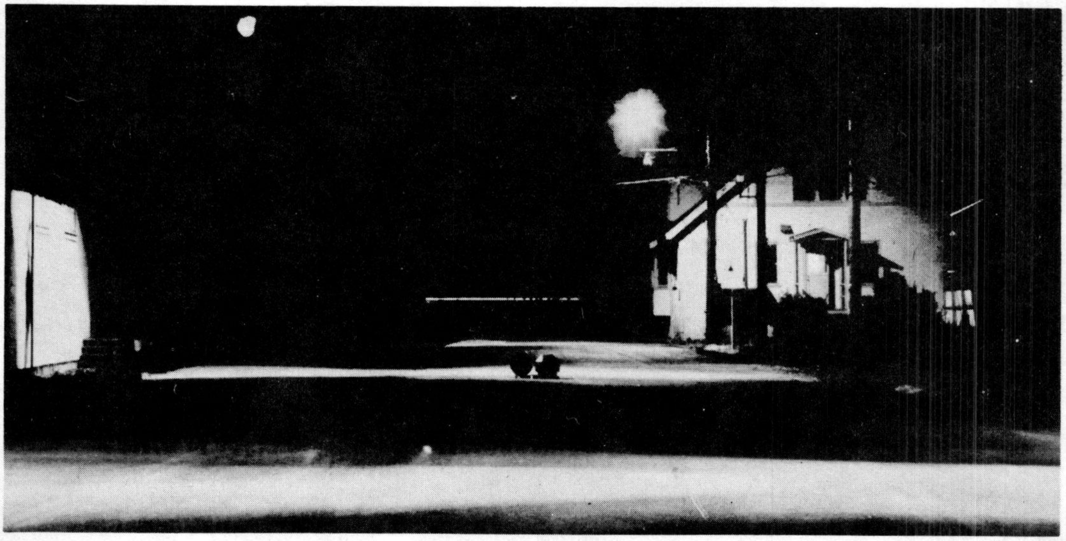


Figure 14a. Non-uniform pattern-targets at 80 feet.

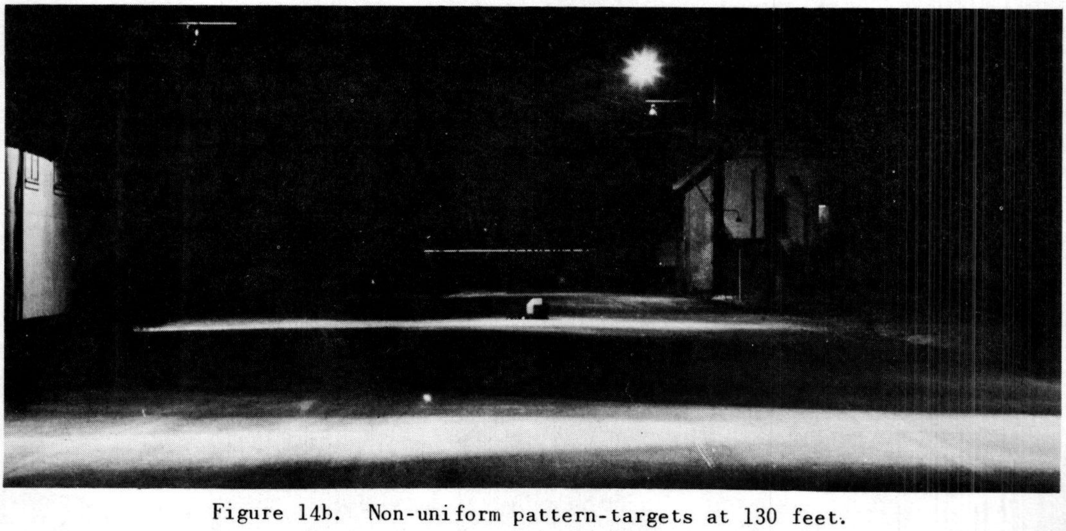


Figure 14b. Non-uniform pattern-targets at 130 feet.

TABLE 1

VISIBILITY MEASUREMENTS USING UNIFORM AND NON-UNIFORM PAVEMENT BRIGHTNESS

(Glare effect of luminaires is excluded—field of instrument did not include the light sources)

Object Position	Uniform Pavement Illumination (1.3: 1 variation)		Non-Uniform Pavement Illumination (19: 1 variation)		Direct or Silhouette Seeing
	Pavement Brightness = 0.20 ft-l Br. Ratio = 4:1 in test area		Pavement Brightness = 0.35 ft-l max. 0.03 ft-l min. Br. Ratio = 12: 1 in test area		
	Type of Object		Type of Object		
	Circular Disc	Octagonal Sec.	Circular Disc	Octagonal Sec.	
	Vis. Index	Vis. Index	Vis. Index	Vis. Index	
	39				Silhouette
At		28.5			Silhouette
70 ft			0		—
				0	
	39				Silhouette
At		31			Silhouette
80 ft			10		1/4 Silhouette
				15	1/4 Silhouette
	39				Silhouette
At		34			Silhouette
90 ft			30		3/4 Silhouette
				32.5	3/4 Silhouette
	39				Silhouette
At		42.5			Silhouette
100 ft			45		Silhouette
				51	Silhouette
	40				Silhouette
At		48			Silhouette
110 ft			45		Silhouette
				51	Silhouette
	43.5				Silhouette
At		43.5			Silhouette
120 ft			41		1/2 Silhouette
				51	1/2 Silhouette
	39				Silhouette
At		40			Silhouette
130 ft			0		—
				44	Direct

The magnitude of the meter reading indicates the visibility above threshold contrast and is called the visibility index. A high visibility index represents good visibility and vice versa.

Preliminary Results

The instrument thus far has been used only for nighttime or low level visibility evaluation. The conditions under which the meter was used have been two different roadway illumination systems. The first system was an experimental uniform illumination (1.3 : 1) system, while the second was an extremely non-uniform illumination distribution system (19 : 1).

A number of visibility measurements were made on several different targets under both systems of illumination. Some of the first reqults of such measurements are shown in Table 1. Photographs of the outdoor street lighting laboratory in the daytime are shown in Figure 12 while the night scenes are shown in Figures 13 and 14.

The results show that the visibility of the circular disc targets remains approximately constant while they are seen against a uniformly bright background developed by closely spaced high mounted luminaires. The visibility index (equivalent contrast) for circular disc targets of 11 percent reflectance is comparatively high. The octagonal section targets showed more variation under the same conditions of illumination due to the directional properties of the lights. This is an important point which needs more attention but will not be discussed here.

While these results are significant, the results of the non-uniform brightness distribution are more spectacular. It can be seen from the results in Table 1 that the circular disc objects completely disappear from view in two positions. Also the visibility index for both objects swing through wide variations. Let us then consider what happens to objects seen on a highway at night. It is subject to the following seeing conditions:

1. The object may be located so as to have sufficient direct illumination to make the object brightness greater than that of its background (positive contrast).
2. The object may be located so as to appear dark against a lighter background (silhouette or negative contrast).
3. The object may be located so that its brightness due to direct illumination is just balanced by the background brightness thereby causing the object to be invisible (at or below threshold contrast).
4. The object may be located so that the direct illumination is very low and its background is dark. Thus, both the object and background brightness are too low to give a contrast above threshold (below threshold contrast).

When the circular disc objects are at 70 or 130 ft on the non-uniform system it can be seen that condition 4 above applies, that is, the brightness of the object is very low and the background is dark causing the object to disappear. When the circular object is in a certain position below the luminaire it can be observed that condition 3 above applies, that is, the object and its background brightness are approximately the same, causing the contrast to go below threshold and the object to disappear. This phenomenon was found to hold true only for the smaller targets having a single plane. The larger objects were usually of sufficient height so as to be in partial negative or positive contrast across alternate dark and light brightness patches at all times.

The results further show that at target locations where the objects have maximum visibility under the non-uniform system, the visibility index is approximately the same as that under the uniform system. In other words, the visibility index does not seem to rise to a significantly higher peak value under the non-uniform system. This would seem to verify many prior suggestions by others that the use of a uniform pavement brightness system has considerable merit. It should be pointed out that the uniform brightness distribution used was approximately constant over the roadway as well as uniform along a longitudinal line so that the visibility of the objects would be approximately the same regardless of position on the roadway.

SUMMARY AND CONCLUSIONS

The principles of operation of a number of designs of visibility meters have been discussed and the limitations of the meters pointed out. A new design for a visibility meter has also been reported which seems to overcome most of the limitations of the previous meters. The details of construction, calibration and use of the instrument are included. It is believed that within the design limitations that are given the meter can be used to obtain reliable visibility evaluations. The meter readings are given in terms of the "visibility index," which is related to the visibility of a circular disc of known contrast.

The results of several field studies using the instrument are reported for two dimensional (circular disc) and three dimensional (octagonal-section) targets when viewed against roadway lighting systems that develop approximately uniform and extremely non-uniform pavement brightnesses. The effect of directional lighting is evident when a three dimensional target is used under either the uniform or the non-uniform system. Much greater variations in visibility were observed under the non-uniform brightness pattern than with the uniform brightness pattern.

In extremes of pavement brightness variation, small targets are much more easily lost in the pattern than larger targets. This is particularly true with two dimensional targets having a single plane. In such cases the target brightness is uniform and it is possible to develop a situation wherein the contrast is below threshold at several positions on a roadway. Some data has been obtained for tall thin targets simulating pedestrians. These preliminary data indicate that for practically all positions on the roadway the target is above the contrast threshold at some point on the target and therefore extremes of visibility do not occur but the average level of visibility is less than that obtained for a smaller target. Also information concerning the variation in visibility over the test area of the roadway is not as evident when such targets are used. Therefore it is believed that for evaluation purposes smaller targets in the order of 12 to 18 in. in principal dimension are more suitable for appraisal purposes than targets simulating pedestrians.

The importance of the roadway brightness pattern in developing nighttime roadway visibility is evident from the preliminary data presented herein. It is apparent that more attention will have to be placed on this aspect of lighting by the engineers who are designing roadway illumination systems.

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Some Night Views of a Highway Lighting Test Installation

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● IN connection with the design of the Connecticut Turnpike, a new expressway from the New York State line at Greenwich, Conn., to the Rhode Island State line at Killingly, Conn., a distance of approximately 129 miles, one of the many problems was night visibility on such a roadway. Everyone recognizes the contribution that street and highway lighting has made toward traffic safety, so progress demands investigation and acknowledgment of the advancements in the art, particularly with regard to expressway lighting.

When Commissioner Newman E. Argraves, of the Connecticut State Highway Department took office, he was faced with a choice of many types of lighting and luminaires for installation on some 53 miles of the western section of the Connecticut Turnpike; for each, the vendors made claims of superiority, especially in the form of better visibility. There is no recognized instrumentation for determining visibility; therefore, the installation of a highway lighting test strip on Route US 1 in the town of Old Lyme, Conn., was authorized for the purpose of measuring by competent comparative observations the relative effectiveness of the various types of highway lighting installed. Details and results of this installation have been given in "A Highway Lighting Test Installation" presented at the National Technical Conference, Illuminating Engineering Society, Boston, Mass., Sept. 17-21, 1956.

It is preferred to call this a report to the Night Visibility Committee, rather than a paper, as a report is a factual outline of what was done, and how it was done. A paper would require drawing definite conclusions from the results, which, in this case, would require further research.

At this point it might be well to outline the conditions under which the pictures were taken and processed. In an attempt to evaluate visibility under the different types of lighting installed on the test strip, a sequence of pictures was taken for each type with the camera placed approximately 50 feet behind the luminaire (Figure 1) for one sequence, and approximately 50 feet in front of the luminaire (Figure 2) for the second sequence. The film was selected so that it had a flat curve in the color spectrogram, and thus had approximately equal sensitivity to blue and green. The exposures were chosen so that they would be beyond the range of the film in both the upper and lower regions. In each sequence men were stationed 200, 300, 400, and 500 ft from the camera. As far as possible, similar clothing was worn for each of the sequences.

After the first group of photographs had been taken, it was noted that there was a variation in pavement brightness background due to curves and grades in the roadway, so the photographs for the conventional mercury and fluorescent installations were taken in the north lane with the camera ahead of the luminaire, and in the south lane with the luminaire ahead of the camera. Under the linear mercury installation all photographs were taken in the north lane and the physical conditions are the same for all the sequences; these can be compared without qualification.

The pictures were taken and processed under the following conditions, using the noted materials:

Camera

1. 4 x 5 Speed Graphic.
2. Graflex Optar f/4.7, 135-mm lens.

Speeds

Shutter speeds for each sequence were 1/25, 1/10, 1/5, 1, 2, 4, and 8 sec. with lens wide open at f/4.7.

Film

1. High-speed panchromatic Ansco Superpan Press.
2. Exposure index, daylight 125.
3. Development, 5 min. in Permadol at 68 F.

Figure 1. Luminaire located about 50 feet in front of camera. (Courtesy of ''Illuminating Engineering'')

Figure 2. Luminaire located about 50 feet behind the camera. (Courtesy of ''Illuminating Engineering'')

Enlargements

1. Omega D-2, 4 x 5, condenser-type enlarger.
2. 8 x 10 Kodabromide F-2, single-weight paper.
3. Exposure, 5 sec. at f/16.
4. Development, $1\frac{1}{2}$ min. in Dektol at 68 F.

Further research might well be undertaken to determine whether the camera can be used as an instrument to measure the acceptability and relative effectiveness of a turnpike lighting installation. In support of this, attention is called to three interesting points developed by the photographic data secured at the test installation and displayed here.

HALATION

A variation is seen in the halation around the luminaires in the first pictures taken with short exposures in the respective sequences, and it is quite possible that this relationship could be a measure of the brightness of the luminaire. It is interesting to note that the measurements taken at the test lighting installation with a Spectra Brightness Spot Meter are similar to the relationship shown in Figures 1 and 2; that is, the 400-watt conventional mercury luminaire registered the highest foot-lambert reading, the 400-watt linear mercury luminaire a lower reading, and the 400-watt fluorescent luminaire the lowest of the three. This relationship is reflected in Figures 1 and 2 in that the pictures taken with the camera 50 ft in front of the luminaire show some halation for the conventional mercury at $\frac{1}{25}$-sec. exposure, the 400-watt linear mercury luminaires reflect this halation effect at $\frac{1}{10}$-sec. exposure, and the fluorescent luminaires show it at $\frac{1}{5}$-sec. exposure.

Recently there have been installed on the test lighting strip five linear mercury low-brightness luminaires with directional unbalanced light distribution and 250-watt EH-1 lamps instead of the 400-watt EH-1 lamps used in the other linear mercury pictures shown. The new units are designed to direct more light toward the vehicle driver and thus favor seeing by silhouette. There has been no opportunity as yet to take instrument readings on this latest installation, but, if the assumption regarding photographic rendition is correct, one would expect to find the brightness of the 250-watt linear mercury luminaire to be very nearly that of the fluorescent unit. This would be based on the fact that the photographs of the 250-watt units show some halation at $\frac{1}{5}$-sec. exposure, which is about the same as that for the 400-watt fluorescent unit. A rough check with the Spectra Brightness Spot Meter shows a reading of 9 candles per square inch for the 250-watt directional linear mercury luminaire, and 7 candles per square inch for the 400-watt fluorescent luminaires.

OBSTACLE RECOGNITION

It is interesting to note that obstacle recognition of the fourth man in line, a distance of about 500 ft, takes place at approximately $\frac{1}{5}$-sec. exposure in all of the picture sequences. This comparison, however, must consider the camera position with relation to the luminaire, because all of the men moved back 100 ft when the camera was placed in front of the luminaire as compared to their positions with the luminaire ahead of the camera. This change of position places the fourth man in a brighter area when the camera is in front of the luminaire.

The photographs indicate that obstacle recognition was about equal under all the luminaires, despite the fact that foot-candles and foot-lamberts varied considerably. It is possible, however, that a comparison on the basis of threshold recognition may not be the complete answer, and the effects of film fogging (which will be mentioned later) may have to be integrated to secure a proper evaluation. Instrumentation on the test strip showed the following average values:

Luminaire	Hor. Fc. Init.	Vert. Fc. Init.	Ft-Lamb.
Conventional mercury, 400 w	2.30	1.82	0.87
Linear mercury, 400 w	1.24	1.20	0.68
Fluorescent, 400 w	1.10	0.87	0.46

On the basis of threshold recognition, Figures 1 and 2 seem to bear out the claims of some vendors that visibility is better under linear-type luminaires of low brightness, particularly with linear light sources such as the fluorescent lamp, which in this instrumentation showed the lowest foot-candle and foot-lambert readings.

FILM FOGGING

It is realized that the mention of glare, because of the many forms that it takes, introduces a controversial subject, but it would be remiss not to call attention to the fact that the photographic sequences show the effects of over-exposure at different time intervals under the various luminaires.

It is to be noted that in the sequences with the luminaire ahead of the camera (Figure 1), definite fogging of the film takes place after 1-sec. exposure under the 400-watt conventional mercury and the 400-watt linear mercury luminaires, after 2-sec. exposure under the 250-watt linear mercury luminaire, and after 4-sec. exposure under the 400-watt fluorescent luminaire. In contrast to this, the picture sequences with the camera ahead of the luminaire (Figure 2) show fogging starting at 4-sec. exposure under the 400-watt conventional mercury, the 400-watt linear mercury, and the 400-watt fluorescent; and at 8-sec. exposure under the 250-watt linear mercury luminaire.

It would be of interest to determine whether densitometer measurement of the film can be corelated with one or more of the different forms of glare when the camera position is properly chosen, due consideration being given to the camera distance from the luminaire, position in the roadway, and target level, and the results compared with an accepted standard reference film.

Photography is a specialized subject and there are many technical details which must be considered. It is realized, also, that the previously mentioned effects are not new to photographers, and, quite possibly, there have been studies made in connection with their application to lighting evaluation. If such references are available, they have not yet come to the author's attention. The key to the problem may lie in sequential exposures of specified lengths, using specified materials processed under given conditions. It would certainly fill a long felt want, from the engineer's point of view, if the adequacy of a lighting installation could be determined by means of photographic comparison with a reference standard.

A Device for Establishing a Safe Stopping Distance at Night

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●THAT a safe driving speed at night should be considerably lower than that in daylight is attested by the fact that on a mileage basis about nine times as many accidents occur during hours of darkness as occur during daylight. Some states have differential day and night speed limits. This is advisable, but in most cases the differential is not great enough. In other states, using the basic speed law, it is extremely difficult to demonstrate before a court, law enforcement personnel, or a public group what is meant by a safe nighttime driving speed.

Considerable research has been done at the Driving Research Laboratory at Iowa State College to assemble useful data on this problem. That the approach is valid is shown by the fact that the Commissioner of Public Safety for Iowa, through the Highway Patrol and the courts of the state, has been able to establish a maximum speed limit, in miles per hour, under the basic statute during hours of darkness. This was upheld by a ruling by the Iowa Supreme Court. The data on which the decision was predicated come from standard information and researches of various experimenters throughout the country. No attempt is made to review the literature here.

While acting as a special instructor for the Iowa Highway Patrol and in presenting the data on safe nighttime driving speeds in court cases, the author hit upon the method of presentation described here. It was first necessary to define each term used in such language as to be understood by the average juryman.

The ruling handed down by the Iowa Supreme Court in its decision in the spring of 1956 upholds the Public Safety Commissioner's contention that any driver traveling at a nighttime speed in excess of 65 mph is presumed to be violating the basic speed limitation statute of being able to stop within the assured clear distance ahead.

APPARATUS USED

When attempting to demonstrate to a jury the various factors to be considered in a safe nighttime driving speed it seems helpful to make a visual demonstration of the principles involved whenever possible. In the instruction of highway patrol officers and recruits, driver education students, and interested public groups, this device has proven very beneficial as a visual aid.

In general the apparatus used is in the nature of an enlarged slide rule, which can be set on an easel and used to explain stopping distances as determined (1) by

$$\text{Stopping distance} = \frac{V^2}{30f + 0.3p} + 1.467\,V\,T \qquad (1)$$

in which

V = speed, in mph;
f = coefficient of friction;
p = percent gradient of road surface expressed as a whole number; and
T = reaction time, in seconds.

Its relationship to perceptual distance at night is based on data developed by Roper and others (2). Their data have been studied and adapted to the slide rule device herein presented.

In the present instance, as shown by Figure 1, perceptual distance, B, is given as 191 feet. This distance represents the number of feet a driver with normal vision would be expected to see an object of at least a 7 percent reflection factor on lamps as found on most modern automobiles. Calculations are made for a speed of 60 mph. The atmospheric conditions are presumed to be clear. Otherwise, corrections can be made.

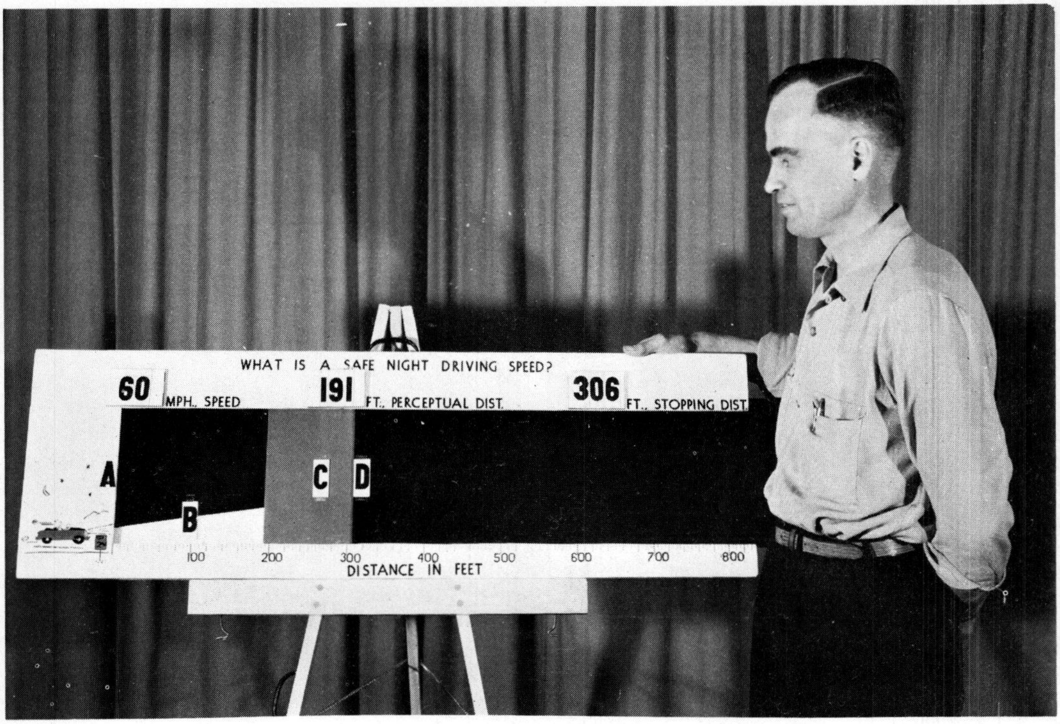

Figure 1. Device for demonstrating method of determining safe night driving speed. Stopping distance must not exceed perceptual distance to stay within safe driving speed range.

The beam candle power of the new quadri-lights is not known, but statutes in Iowa and some other states are patterned after Section 12-226 "Number of Driving Lamps Required or Permitted," of the revised 1954 version of the Uniform Vehicle Code, which permits "not more than a total of four of any such lamps on the front of a vehicle . . . lighted at any one time when upon a highway." However, it is a requirement that the total beam candle power will remain within legal provisions. At least one manufacturer is making the quadri-lights standard equipment; for most others they will be optional on cars delivered in states where they are legal. The apparent assumption is that those states making them illegal, or at least not providing for their use, will not enforce the statute provisions.

A road user with average reaction time and traveling on a dry, level concrete road surface at 60 mph would be able to stop in a minimum of 306 feet. The difference (represented by C in Figure 1) then becomes the danger zone, because stopping distance exceeds the perceptual distance at this speed and under these conditions. Any set of values may be used for demonstration purposes: the principle illustrated is but one example. Both the values for perceptual distance and stopping distance were obtained from formulas and data previously cited.

Point A on the board represents a zero line at which a driver receives the initial warning or stimulus in the process of stopping his vehicle. Space B then becomes the perceptual distance of the driver, with possible corrections made for his visual acuity and the atmospheric conditions as they exist for a given beam headlight candle power. Because older car lights are likely to be deficient in some respects, 40,000 to 50,000 candle power on high beams can be considered to be the average to be expected on the road prior to making the foregoing corrections. However, any strength of beam candle power could be used for calculations, as shown in tables or graph of perceptual distance for varying amounts of light.

The space A to D represents the distance required to stop a vehicle for a given set of conditions. This value takes into consideration the reaction time of the driver, road gradient in percent, and the friction coefficient of the road surface assuming 100 percent brake efficiency.

A safe night driving speed for the driver under the existing conditions can be established. This is represented in miles per hour whereby a stopping distance AD would be equal to or less than distance B. In other words, the C space as illustrated would be completely eliminated when such a speed is maintained, assuming the variables involved remain constant. These values as calculated make no allowance for a safety factor, however. Most engineers would allow a 100 percent margin of safety. This can be taken into consideration by being given judicial notice by the courts, often a necessary detail in court procedures.

The differences, as represented by the danger zone C, are far too prevalent for drivers traveling on the road at night, as is attested by nighttime accidents over those occurring during daylight on a mileage basis. Considering an average of 40,000 beam candle power for the lowermost distribution of light, 100 percent brake efficiency, and other variables as normal, no nighttime road user should exceed 50 mph.

GENERAL SUMMARY

The method used in establishing a safe stopping distance at night and its conversion into miles per hour considering the existing light conditions was devised originally at the request of Iowa's Commissioner of Public Safety for purposes of enforcement of the basic speed limitation type statute. Because no known method of obtaining specific values indicative of a safe and legal nighttime speed for single vehicles was available that was applicable in the enforcement of the "reasonable and proper" aspect of this type of speed law, the present system was devised.

Even though Roper and Howard (2) in their experiment had determined what is being termed here as perceptual distance for various beam candle power values, a method of application was necessary. Certain corrections are necessary in the original values as given to compensate for the conditions as they exist in an actual situation. For example, correction in the perceptual distance of a road user is necessary should his visual acuity be less than normal or atmospheric conditions be other than clear. Stopping distances are determined as previously cited (1), with corrections being applied as they exist at the time and place of apprehension.

While acting as a special instructor of highway patrol personnel the difficulty was encountered of satisfactorily explaining the methods of demonstrating perceptual and stopping distances and how changes in one affected the other. The same problem persisted while serving as an expert witness in litigation and when making talks to public groups. As a result, the visual aid device described was devised. However, no attempt has been made to have the aid admitted into the court records as a method of explanation to a jury. Precedence frequently may nullify the advantage of such a gesture.

The apparatus can be described as one whereby the data from scientific experiments may be reduced to graphic representation in showing to laymen the dangers of excessive night driving speeds. This application of the principle involved has been upheld by a unanimous decision of the Iowa Supreme Court.

ACKNOWLEDGMENTS

The study reported herein was made possible through a grant from the Allstate Insurance Company on driving research, and done under the direction of A. R. Lauer of the Driving Research Laboratory, Iowa State College.

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Discussion

K. A. STONEX, Assistant Director, and P. C. SKEELS, Head, Experimental Engineering Department, General Motors Proving Ground—The profession is indebted to Mr. Swanson for his comments on the controversial subject of what is a proper and safe night driving speed. This subject is a matter of great interest, and while the author's principal objective was the description of a graphic device for demonstrating safe speeds under a variety of conditions, it is felt that a primary contribution is made by bringing this subject into the open in a simple manner.

Mr. Swanson has treated the derivation of what is a safe night driving speed in a much oversimplified form. Although this may be intended merely as an example of the use of the device, the safe maximum stated is at such variance with common experience that the conclusion stimulates thought, and it is hoped that it will stimulate a program to develop a realistic body of evidence.

There is no particular object in dwelling on the points attempted to be shown that the maximum safe night driving speed of 1937 automobiles is 50 mph, that the author has seemingly misinterpreted Roper's data and used numbers referring to the 2 percent reflectance dummy rather than the 7 percent reflectance dummy as stated, or that one can show as convincingly with equally realistic values of coefficient of friction, stopping distance, and visibility distance from Roper's paper, that some higher speed is safe. However, it is appropriate to suggest that there are available more recent data on visibility distance in the Rassweiler-Doane paper in Bulletin 127 of the Highway Research Board, and that there are data on stopping distances in Normann's paper in the Proceedings of the 32nd Annual Meeting of the Highway Research Board which are certainly much more realistic than the calculated distances from the National Safety Council formula of 1937 or earlier.

The issuance of night driving regulations based on computed stopping distances, and the estimates of the visibility provided by 40,000 candle power should be discouraged; these computations can hardly be more accurate than the estimate of how many ducks one can shoot with a 12-gage shot gun and number 4 shot. Roper indicated, in his 1937 paper, that the distribution of the light from the headlights is a matter of primary importance. In the Rassweiler-Doane paper, the contribution of light distribution from more recent headlamps is given in terms of effective night visibility.

Even the data in the Rassweiler-Doane paper need interpretation, in the sense that the observers were instructed not to avail themselves of silhouette seeing, but to make certain that the objects were visible in the direct light of the headlights. Thus, while their data show that the average visibility distance of six observers falls to a minimum of approximately 230 ft at the moment before passing, it must be considered that the test imposed a special restriction where the observers were not availing themselves of silhouette seeing. It should be pointed out further that these tests were conducted with headlamps which are now obsolete; they would show better visibility is they were repeated with headlamps with the improved passing beam, and even a further gain if they were repeated with cars equipped with the four headlamp system. The figure of 50 mph as a safe night driving speed, which Mr. Swanson derived, is hardly representative even of passenger cars of 1937; it should be considered as merely as example of the use of the graphic device and not at all representative of values which should be applied to passenger cars with the current improved headlighting equipment and modern sensitive braking systems.

The author states that "a road user with average reaction time and driving on a dry level concrete surface at 60 mph will be able to stop in a minimum of 306 ft." He does not give the values of the constants, but if a coefficient of friction of 0. 7 is assumed, it appears that he used a reaction time of 2 seconds. This value is very high; the generally accepted figure for perception time plus reaction time to apply brakes is 0. 75 seconds. If stopping distance is computed using a speed of 60 mph, coefficient of friction value of 0. 7, a level road, and 0. 75-second reaction time, the calculated stopping distance would be 238 ft. If this figure is combined with realistic perception distances and the gain obtained with silhouette seeing incorporated, a considerably higher safe night driving speed would be obtained. This brief example should serve to point out the uncertainty of any computations of safe driving speeds, including the writers'.

The determination of a safe maximum night driving speed should take into account the wide variety of night driving conditions. To attempt to regulate speeds on the basis of only the worst possible condition is to invite general disrespect of the regulations and engender formidable enforcement problems. Drivers cooperate in the observance of speed regulations which they consider reasonable, and imposition of regulations which appear to be unduly restrictive is met with widespread non-observance. No regulation at all is better than one generally not observed.

The writers are familiar with the fact that nighttime accidents occur much more frequently than daytime accidents, but they are not convinced that this is necessarily so because nighttime limits are too high. This is a problem requiring more research, and there is no obvious simple solution.

Any regulation should take into account the fact that, on rural highways, traffic volumes are negligible during most of the hours at night and the upper beam is used a large proportion of the time. Under these circumstances, with modern headlighting systems the visibility distance is such that speeds considerably above 50 or 55 mph can be driven with relative safety. During the time and under the conditions of traffic such that the passing beams are used an appreciable part of the time, the driver has the advantage of silhouette seeing provided by the headlamps of approaching traffic, and he has the very considerable advantage of traffic ahead traveling in his direction.

It is common experience that the strain and uncertainty of night driving is eliminated when following a car at a distance of anywhere from a couple of hundred feet up to as far as it can be seen in the distance.

In the attempt to derive an estimate of a safe maximum night driving speed by calculation and oversimplified tests, no one has taken into account the real benefits which are given by silhouette seeing afforded by approaching headlamps and by the taillamps of vehicles ahead proceeding in the same direction, nor have the relative proportions of use of the upper beam and passing beam been considered.

Everyone is familiar with the glow from headlights that indicates the approach of a car over a crest vertical curve or from a side road; this gives more advance notice than a driver has during the day, and these conditions make night driving safer than day driving.

In Michigan, there has been approximately one year of experience with a 55-mph night driving speed on a statewide basis; it is the writers' understanding that the relative safety experience is favorable. On some parts of the rural road system, drivers find that this is faster than they want to drive because of the geometrical design of the road or other conditions; in other locations, this limit is below the safe capacity of the road, and there is a real possibility that the dangers of falling asleep may exceed the possible danger of overdriving the headlights at a higher speed.

There is as yet no clear evidence as to what constitutes a maximum safe night driving speed and so far no one has demonstrated a technique which will yield such data.

C. O. SWANSON, Closure—It was the primary purpose of this paper to describe a device of slide-rule type which could be used with any data to establish a safe stopping distance at night. Data from the National Safety Council (1956 Edition of "Accident Facts") on day and night accidents show at least three times as many fatalities at night. There seems no doubt but that a greater margin of safety should be allowed for stopping distance under nighttime conditions.

It is the author's impression that the discussers are arguing primarily for higher speeds rather than for a simplification of the paper under discussion. By using the least conservative set of constants it is possible to do this, but the author's purpose was to take a reasonable set of values which are realistic. Many cars on the road are of prewar type and no increase in headlight illumination standards has been accepted in Iowa.

It is agreed that the probelm is complex and no simple solution can be given which will fit all conditions. Likewise, drivers differ markedly and some states require only 20/70 vision for a driver's license. This fact emphasizes the need for conservative estimates with respect to a safe nighttime stopping distance.

Messrs. Stonex and Skeels have misinterpreted the data in referring to a stopping distance of 306 feet at 60 mph. A coefficient of friction of 0.5 was assumed, which is well below that given by authorities for a rolling speed.

It is further agreed that more experimental work should be done on the problem, preferably by research agencies unbiased with respect to the outcome.

Visibility of Reflectorized License Plates

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Studies by the National Safety Council have established that peril to life and vehicle trebles after sunset, primarily as a result of reduced visibility. Low illumination, contrast extremes, atmospheric conditions, and attendant driver reaction at day's end contribute a host of physical and sensible limitations.

Other statistics show that rear-end collisions are the largest single factor in rural motor vehicle accidents. In spite of very considerable and progressive efforts of the automobile industry and enforcement agencies, unlighted, over-aged, damaged, or improperly maintained or equipped vehicles are a continuing hazard to the motorist and a constant challenge to safety leaders. The reflectorized license plate offers a universal opportunity and practical enforcement device for maintenance of minimum protection.

This paper presents data to establish typical visibility distances of unlighted vehicles, both with and without reflectorized license plates, relative to safe stopping distances. Visibility and performance limitations imposed by rain, mist, snow and glare have been considered in establishing performance criteria, because 25 percent of all accidents occur under such conditions. Observations indicate that a completed plate capable of reflecting 5 c. p. per incident foot-candle provides the minimum brilliance for requisite warning in typical situations. Practical considerations include ease of cleaning, damage resistance, and effective performance although bent or mutilated.

The experience of several states has shown that such reflectorized license plates have aided enforcement agencies. Legibility distance from the rear is markedly improved and the front license plate of lighted vehicles is both visible and legible to the motorist approaching from the opposite direction. This feature assures positive delineation of "one-eyed" vehicles and location of parked cars prevalent in residential areas.

●PERIL to life on streets and highways trebles after sunset according to published reports of the National Safety Council. Three times the number of deaths per 100,000,000 vehicle-miles driven occur after dark, and nearly three-fourths of these fatalities occur to occupants of motor vehicles in rural areas.

Notwithstanding the effect of increased vehicle occupancy on night fatality rates, surveys in three states have shown that more than one-third of all night traffic accidents were directly related to lack of visibility. Reduced visibility is more indirect, but no less a factor in a high proportion of the balance. Senses dulled by alcohol, fatigue, and poor eyesight are not only more commonly encountered at night, but also are most significant at this time of contrast extremes—from almost total absence to irritating glare. As reported by the National Safety Council and defined by Delaware, more than one-third of all drivers involved in fatal accidents in Delaware over a three-year period "had been drinking." Reduced contrast sensitivity and increased reaction time of the drinking or fatigued driver undoubtedly contribute to the number of rear-end collisions, the most prevalent motor vehicle accident type as reported by the National Safety Council.

The problem of rear-end collisions as related to night visibility has been fully recognized by industry and safety authorities for years. The automobile industry has improved headlighting on several occasions. It has adopted two taillights, lighted rear plates, turn signals, improved fusing, higher voltages, indicating circuitry, larger and more effective taillights, and reflectors. Both mandatory and voluntary forms of vehicle inspection have been adopted to real advantage in a number of states and locales. Yet, following the voluntary national safety check held in May 1955, the parti-

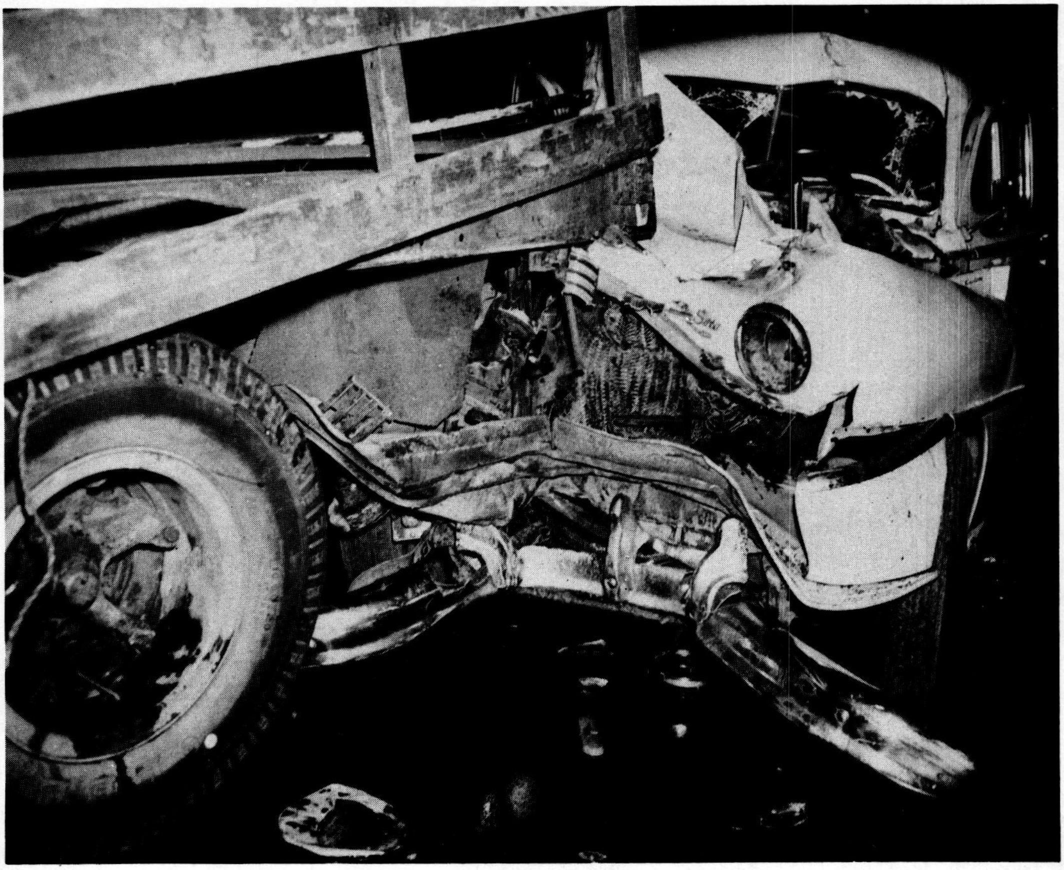

Figure 1. Typical rear end collision.

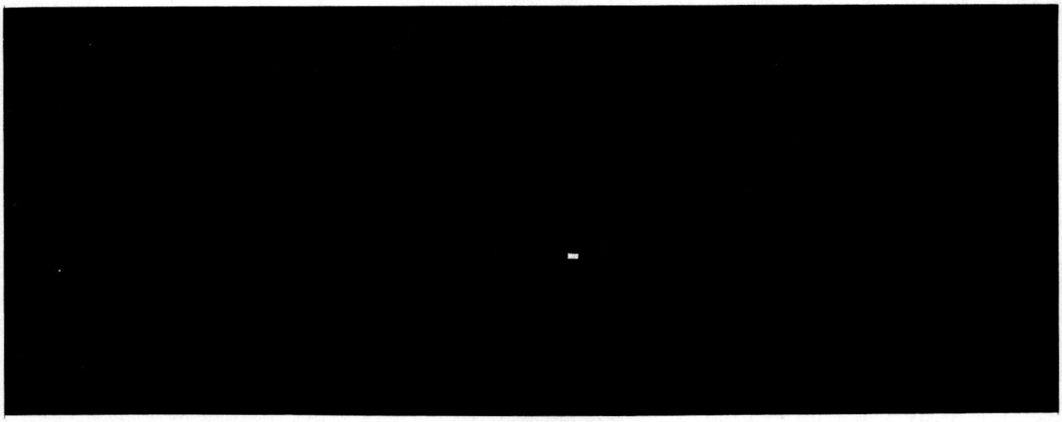

Figure 2. Comparison of painted and reflectorized plates on two vehicles viewed from 200 ft.

cipating organizations reported that rear lights accounted for 26.6 percent of all defects. In spite of very considerable and progressive efforts of the automobile industry and enforcement agencies, over-aged, damaged, neglected, or improperly equipped vehicles are a continuing hazard to the motorist and a constant challenge to safety leaders.

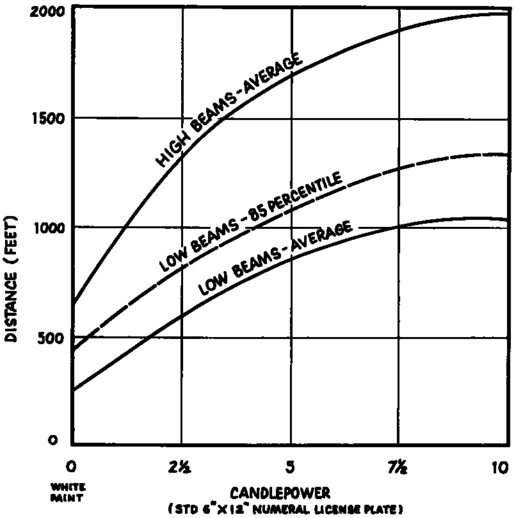

Figure 3. Average detection distance of painted and reflectorized license plates of varying brilliance, viewed with high and low beams.

Reflectorized license plates have been adopted in recent years by a number of states as a safety measure designed to reduce the threat of vehicles otherwise inadequately protected. These damage-resistant registration plates protect against collision in the case of lighting failures, damage to conventional plastic or glass taillight-reflector assemblies, or combination reflector assemblies inoperative as a result of dust and dirt collection on the rear surface. Routine maintenance and cleaning has all too frequently been shown not to include disassembly and cleaning of these units. On the other hand, simple washing normally restores reflective plate performance. Thus, because registration is required of every vehicle on a public road and because registration plates are issued by the state at regular intervals, the reflectorized license plate offers the first universal opportunity and practical enforcement device for maintenance of minimum protection.

A series of observations have shown that unlighted, dark-colored vehicles with damaged or ineffectual rear reflectors are first visible from 400 ft to the overtaking motorist using high beams. This distance is reduced to a mere 150 ft with low beams. Painted, clean white license plates viewed with low beams increase this distance to 250 ft; vehicles equipped with reflectorized plates are visible up to 1,000 ft (Figure 2).

Figure 3 shows the relative visibility of painted and reflectorized license plates of varying brilliance, viewed with high and low beams. Under ideal viewing conditions it is evident that marked increases in visibility are possible with reflectorized license plates. Completed 6- by 12-in. license plates with a reflective brilliance of 10 c.p. per incident foot-candle, measured in accordance with photometric procedures of the Society of Automotive Engineers, at 0 deg. divergence, may be seen an average of two-fifths of a mile on high beams. The level of reflective brilliance required is dependent on visibility demands of the motorist, in turn dependent on his physical requirements, vehicle limitations, and driving conditions. Minimum visibility requirements, therefore, under most driving conditions must be equal to or greater than total stopping distance.

A number of studies of vehicle braking and stopping distances have been published in recent years. A particularly comprehensive study was presented by Normann (5). Although this study was primarily concerned with vehicle braking distance on a dry concrete surface, measurement of driver reaction times and distances were made. Because the drivers were aware approximately when the stop was to be made, these reaction times, averaging ¾ sec. (Figure 4), were considered absolute minimums and more in the nature of a byproduct of braking distance tests.

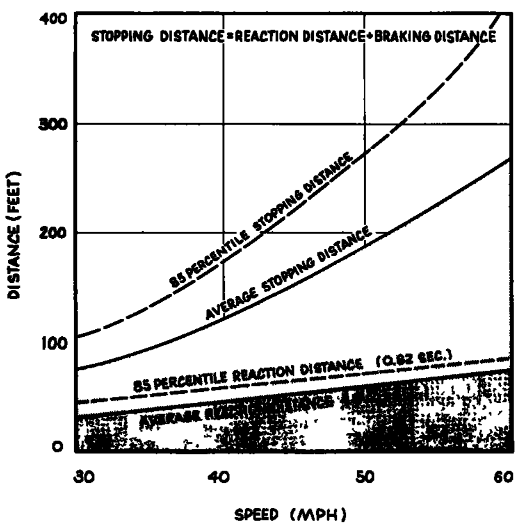

Figure 4. Average reaction and braking distances (from Ref. 5).

To be realistic, reaction times must consider the total elapsed time from the instant of hazard detection by the unwary motorist until application of brakes. Because recognition and discrimination of relative motion is required at threshold visibility levels, it is logical to employ allowances for reaction time based on studies of perception of relative motion at such illumination levels. Stalder and Lauer have presented such a study (6).

This report showed mean perception time before reaching a judgment to be 1½ sec. for two reflectorized target forms at overtaking speeds in excess of 30 mph. This interval was found to be true regardless of whether high beams were used or whether low beams and low opposing lights were employed. Under these conditions a third target form consisting of a point source of illumination resulted in mean perception times in excess of 2 seconds. From the manner of test it can be assumed that perception time included reaction time, although the observer's voice actuated the timing mechanism rather than his right foot the brake.

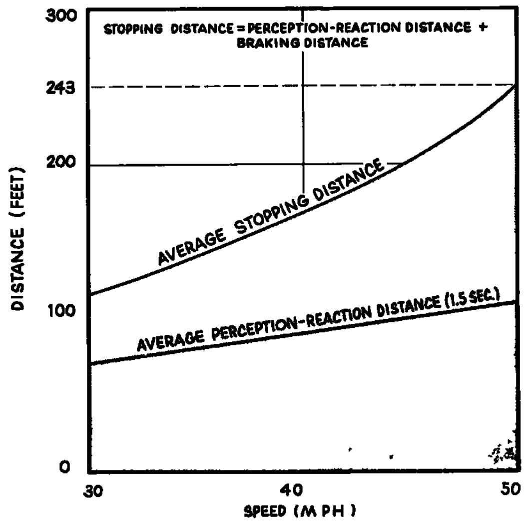

Figure 5. Mean perception and braking distance.

In Figure 5, speed is plotted against mean perception and braking distance calculated from Stalder and Lauer's 1½-second minimum perception-judgment time with Normann's average braking distance superimposed. It is apparent from these data that 243-ft visibility is the minimum requirement for the average motorist and vehicle at 50 mph if a rear-end collision with a stationary vehicle is to be avoided. This minimum visibility must be assured in the most common, adverse circumstances, which in themselves do not demand significant speed reduction.

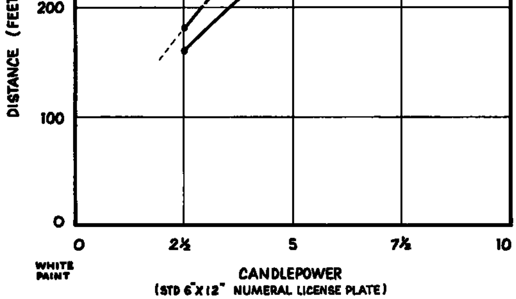

Figure 6. Average detection distance of an unlighted vehicle protected by reflectorized license plates of varying brightness and viewed with low beams and low opposing lights.

OPPOSING HEADLIGHTS

The problem of visibility in the face of opposing headlights has been regarded by a number of agencies and investigators as common enough to require the establishment of standards of performance based on these conditions. Correspondingly, the same visibility tests were conducted of standard over-all reflectorized license plates varying from 2½ to 10 c.p. per incident foot-candle. These were attached to an unlighted vehicle and viewed with low beams. Maximum veiling effects were observed when the vehicle approaching in the left lane was located at any point 30 ft beyond the target vehicle to 100 ft ahead. Tests were conducted with vehicles stopped opposite one another separated by a conventional 4 to 5 ft. The average of a number of observers and viewing vehicles is illustrated in Figure 6, from which it can be determined that completed plates capable of reflecting 5 c.p. per incident foot-candle, on the average

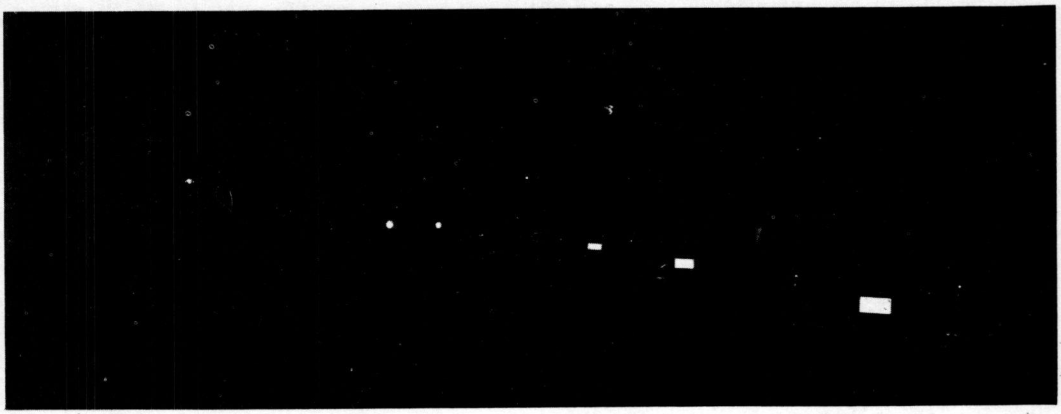

Figure 7. Reflective license plates provide effective delineation of parked cars.

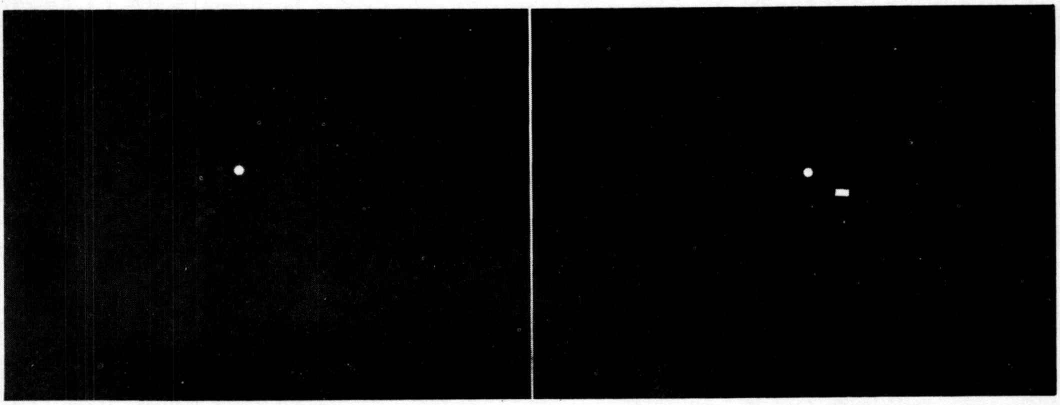

Figure 8. Photograph from 200 ft illustrates the benefit of reflectorized front plates in providing delineation of approaching one-eyed vehicles.

and under these conditions, provide the minimum brilliance for requisite warning at 50 mph.

OTHER REQUIREMENTS

More typical requirements necessarily include need for rain performance. The National Safety Council has pointed out that one out of every four accidents occurred under conditions which reduce visibility (such as haze, mist, smoke, rain, hail, dust, snow, or combinations of these). The same tests conducted on a misty night revealed that average visibility of the 5-c. p. plate dropped to 100 ft, the minimum requirement at speeds appropriate to these conditions, 25 mph or less. However, such marginal visibility does not provide more than marginal safety.

The physical condition of the road surface is another factor that may increase the basic requirements for braking distance. Braking distance is increased up to ten times on glare ice as compared to dry concrete, up to five times on packed snow or gravel. Wet pavements, dependent on composition, can increase this distance as much as glare ice. Thus, a stopping distance requirement of 243 ft for 50 mph on dry concrete must be recognized as a point of departure rather than absolute. This is not the "safe" stopping distance, but rather the absolute minimum for the average motorist in ideal weather conditions.

Correspondingly, these became basic considerations when the State of Minnesota adopted reflectorized license plates. To provide a more adequate margin of safety, required candle power was doubled and performance was required at all times relatively unaffected by rain. Each Minnesota license plate initially provided at least 10 c.p. per incident foot-candle. After one year of use and before cleaning, rear plates have retained an average of two-thirds the required brilliance, even after a series of recent snowfalls and thaws. This value increased to 85 percent of the original requirement after normal washing.

Practical considerations demand reflective materials for license plates which may be simply cleaned with materials and methods normally used to clean automobile finishes. Effective and enduring performance as a safety device is required even though plates may be damaged, bent, or mutilated in normal use. It is equally essential to require that such treated plates provide adequate indication when a vehicle, disabled or otherwise, is positioned at an angle to the roadway or oncoming traffic.

Among the common motoring situations in which reflective license plates have been shown to operate effectively are delineation of parked cars (Figure 7) prevalent in residential areas; warning of damaged, stalled, or parked and unlighted cars and trucks in the road, as well as on shoulders of rural roads; supplementary warning for motorists approaching from the rear at higher relative speed; and effective protection in case of taillight failure unknown to the motorist. It has been particularly well recognized that reflective front plates assure positive delineation of approaching "one-eyed" vehicles by indicating the relative position of the vehicle on the road.

Where adequate contrast and brilliance have been provided, law enforcement, especially in apprehension of stolen vehicles, has been greatly aided by permitting enforcement officers to read registration numbers nearly as easily at night as during the day. Reflectorized license plates have been demonstrated to increase night legibility distance by 50 percent. In fact, the front license plate, normally obscured by the opposing headlights of an approaching vehicle, is legible for the first time. Because enforcement officers are able to read the registration numbers of vehicles approaching in the opposite direction, the number of plates checked is greatly increased. This, of course, is also to the advantage of the average motorist in increasing apprehension and recovery of stolen vehicles, as well as deterring the traffic violator.

At a time when traffic accidents are increasing at an alarming rate, any responsible program of accident prevention must include full consideration of every enforcement technique and safety contribution. Because each state requires vehicle registration and periodically renews license plates, a universal opportunity is provided to adopt a particularly effective safety and enforcement device through license plate reflectorization.

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