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Night Visibility

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Contents

Vision at Levels of Night Road Illumination

*VI. Literature 1960**

OSCAR W. RICHARDS, American Optical Company, Research Center, Southbridge, Mass.

•MANY STUDIES of vision were produced in 1959. Some articles on night vision and others of interest to the committee are reviewed. As it is impossible to examine all of the literature, omission of any paper merely reflects the limitations of a single reviewer.

The translation (64) of Jayle's Night Vision (63) is welcome. The translators have condensed the original monograph, omitted most of its bibliography and added some recent material. References, other than general sources, are not cited for much of the added material and some of it needs revision. Lauer (74) has summarized the contributions from the many years of work of the Driving Laboratory at Iowa State College. The visual needs of driving form a chapter. May the second edition have another chapter on night driving vision!

An issue of the Journal of the American Optometric Association is devoted to the visual problems of automobile driving (1, 3, 33, 69, 104, 115, 127). A colloquium on driver licensing was held at the University of Michigan (2, 46, 11, 116). Barr and McEwen (15) provide a world list of periodicals concerned with vision. General bibliographic sources are available (11, 32a, 107), and Hopkins has reviewed literature on peripheral vision (59). Brindley (24) organizes much useful information on retinal physiology and discusses proper experimentation on seeing. Arden (12) reviews some spatial and temporal aspects of retinal organization and Lombard (78) reviews seeing at low luminances. Examination of 1,000 age 18-22 men in Great Britain reveals that 80 percent had normal vision without glasses, and the amounts and kinds of defects found are listed by Sorsby (9, 117).

Research needed on night driving vision is listed (1). Richards (104) discusses the basic problems of night driving which derive from insufficient light for adequate seeing, and some means for alleviating the difficulties. Driver performance and deficiencies are discussed by Forbes (45, 46) and by Darrell and Dunnette (36). Platt (98) proposes research based on his previous traffic analyses. This should be extended to include night driving.

Questions as to the usefulness of, and the optimum kind of visual training for auto drivers, increase in frequency (104, 116). As seeing is a learned function, what should the night driver look for? What does he need to see? How should he look (optimum scanning, rate time, pattern)? What distortions prevent or reduce seeing? Are general technics practical, or are the innate personal search patterns better than random patterns? The considerable information now available on visual search and detection opens another source of aid toward night driving seeing problems and points the way to further research (20, 27, 89).

Night searching should be done by moving the eyes in a circle with short jumps of 12 to 20 deg always focusing off center according to Tuxbury (124), and Dayle (35) found that few subjects used the superior step-wise approach in searching for faults.

Scleral reflections are used by Smith and Warter (114) to record and measure tracking movements of the eyes. Tracking errors increase with visual noise, which raises an interesting question of noise on dynamic seeing in night driving (62). Methods for recording the direction of seeing are described (65, 110, 142). Their use in analysis of the seeing task of automobile driving should be profitable research.

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Blackwell and Kristofferson (20) give a neural formulation of the effects of target size and shape on visual detection and V. Bekesy (16) proposes a neural unit concept consisting of an area of sensation surrounded by an area of inhibition for both skin and eye and relates the unit to the Mach bands. Stereoplotting has been done at luminances similar to night driving and improves with illumination (140).

Illumination and Glare

Measurements by Blackwell (21) indicate a need for some 1.9 (0.7 - 2.8) ft-c horizontal illumination to see a black dog, or a mannequin with 20 percent reflecting clothes, in the driving lane at 200 ft and 5.7 ft-c in the curb lane at 200 ft, based on his field factor for 99 percent seeing. Such lighting is rare and may not be practical for all roads. Nevertheless, the way is pointed toward improved analysis of the geometry of seeing and better lighting. Brightness scaling is practical (93, 119) and illuminating engineers should consider brightness as well as luminance in their professional work. The design and performance of battery-operated flashing warning lights are described (61).

Rex (100) summarizes advances in highway lighting and he and Franklin (101, 102) discuss discomfort from glare. Spencer and Peek (118) compare relative visibility with low and high mounted luminaires in clear and foggy weather. A preliminary report on glare from large sources promises useful information (60). Autocorrelation is another technic for night vision study used by Logan and Burger (77) by comparing the amount of information in pairs of pictures made with different lighting. The efficiency of seeing is not seriously reduced by changes in brightness ratios of one to three (Boynton, 6). Wolf (131) reports an increased sensitivity to glare about age 40 and that between ages 5 and 15 and 75 and 85 increases of fiftyfold to seventyfold in brightness are required to see against glare. Examination of aphakic and cataractous patients indicates that the vision is reduced from opacities of the ocular media and entoptic light scatter. Investigation of glare from white and yellow light gave inconclusive results, although the yellow was thought to spare the blue cones (41). The Holland Tunnel transitional lighting is described (49). Taragin and Rudy (123) discuss traffic operation as related to illumination and delineation and Fitzpatrick (44) the advantages of fluorescent, colored materials for coordinating signs and pavement treatments for motor traffic guidance.

Dark Adaptation

Wulfeck (135) reports the contrast sensitivity threshold (DL) and the absolute threshold (RL) equally sensitive measures of the effects of different pre-exposures on dark adaptation and visual sensitivity. Similar measurements are needed on the peripheral retina at night driving luminances. Variations of 0.3 to 0.5 log unit threshold value are reported by Wolf (133). The effects of pre-exposure on dark adaptation are analyzed (53-55), and of clear and tinted windshields (86). The association between retinal sensitivity and glare is reported (95). Recovery time from looking directly into an arc va varies from 7 to 10 sec at a 100 ft-c/sec to 55-60 ft-c/sec exposure (87).

Mandelbaum and Nelson (83), using saturation matches, found rod sensation predominant at levels above cone threshold and equality between rod and cone sensation at a thousand times cone threshold. At one log unit above cone threshold (7.2 $\mu\mu$L) rods contributed 4 times as much brightness as cones for violet, 8 times for red, 16 times for green light. Wald (125) uses a two-filter method to determine the mixed role of rod and cone function in dark adaptation. Rod participation at photopic intensities may explain some of the problems of night driving seeing at low photopic and upper mesoptic levels.

The information capacity of the human eye at low luminances is examined by Benarie (17). Acuity of a dark-adapted eye was not less when the other eye was exposed to 100 ft-L, although at exposures shorter than 3 sec gave some interaction. Under the two conditions, the targets looked different suggesting that sensitivity may not be the same as acuity (81).

A night visibility meter with a standard light and attenuator was patented by Vos (136). A night vision sensitivity tester developed at New London is reported reliable and to reveal marked differences in visual sensitivity. The best man was six times better in terms of the visual angle seen 50 percent of the time, and could see at 10 miles with almost 1/7 of the light needed by the poorest man (71, 122). Scotopic sensitivity of people varies (Sweeney and Kenney, 121) with a seasonal exposure to radiation, being best in winter and early spring and poorest in summer.

Acuity and Contrast

Brierly (23) reviews some of the general information on acuity. Better vision at 15 deg from fixation was obtained with some blurring of the retinal image than with the sharpest image (66). Luckiesh-Moss visibility measurements and Blackwell's VTE measurements are convertible according to Eastman and Guth (40). The discussion indicated that Blackwell was not in agreement.

Sloan's test letters (112) have average legibility equal to corresponding Landolt rings, increase in size by a tenth log unit per line, are available from 20/200 to greater than 20/20. Spectral energy thresholds for acuity resolution are measured (27). Television characters of 10 min vertical visual angle on the screen have essentially maximum visibility (109). Black on white was more visible than white on black. Breneman (22) provides a graph of increased luminance required for 50 percent seeing on motion picture screens of varying brightness, and a test method for judging the quality of projected images (73). Some of the brightnesses fall within levels found in night driving. Prince's final report on letter legibility and subnormal vision is available (94).

Ronchi (108) reports that correcting chromatic aberration helps seeing at low retinal contrast, but not when resolution is complicated by border defects. Van den Brink and Bouman's (28) plot of spherical aberration of the unadapted eye shows variation from 0.9 to 1.8 diopters. Acuity varies with luminance and distance because of these inhomogeneities of the lens exposed by the pupil. Variations in the power of the lens and in acuity were measured by Arnulf et al. (13) in an investigation on tolerances for spectacle lenses; also the microfluctuations of accommodation (141).

Variations of visual acuity with pupil size measured by Campbell and Gregory (32) suggest that the natural pupil size for a given illumination adjusts the eye to optimum acuity. The average pupil area was found to vary with the interest value of the visual stimulus (57) which adds another complexity to the problem of the control of the pupil and another means for varying the illumination on the retina.

Zoli (137) has compiled a bibliography on night myopia. Perception in empty space myopia is described by ten Doesschate (38). This myopia is different from night myopia and an empty field rarely occurs in nonblackout night driving. Pitts (79) measurements of the transmission of the bovine eye show a slow decrease in transmission from about 600 mμ to 450 mμ and an increasing reduction for shorter wavelength radiation.

Contrast effects are important in night vision and an integration of night vision needs involves contrast adaptivity and inhibition (4), border gradients (128), blurring of moving edges (19), Mach bands (16, 151), etc. (70, 134). Contrast thresholds were measured by Ogle (92) in the fovea for increasing amounts of blurred image. An image in white light out of focus by one diopter increased the threshold about ten times. The threshold increases as the second power of the out-of-focus imagery. This work supports and explains the reviewer's experience that correction of night myopia reduces the person's sensitivity to glare and the improved night vision reported from even small changes in spectacle power.

Interest in the visibility of fine lines continues. Nachmias (91) found no evidence to link the nonuniformity of directional eye movement during fixation with the variation of the visibility of differently oriented fine lines. Fender and Mayne (43) used fine wires as a visibility test with fluctuating lights and conclude: "Thus if the illumination is to be flickered to facilitate the performance of a visual task, the frequency of intermittence must be 'tuned' to the subject with some care."

Another report on dynamic visual acuity from the University of California finds little correlation between it and static visual acuity or critical flicker fusion (30). The least detectable difference in speed measured in terms of visual angle degrees per second at the eye is a linear function of speed from 0.1 to 20 deg visual angle per second; therefore, drivers react to relative velocity rather than to relative speed (25, 26, 29).

Bhatia (18) expresses the maximum angular velocity of eye movements as a function of perceived size and distance to the target, emphasizing the importance of distance. McColgin (84) finds the absolute threshold for perception of rotary motion increases with distance from the fovea and the resulting isograms plot as ellipses. Vertical motion is perceived better than horizontal motion, and velocity is more important than area in influencing the threshold. His results were confirmed when the head is rotated 90 deg. Keesey (68) found from the study of involuntary eye movements that acuity increased with exposure from 0.02 to 0.2 sec and concluded "...that acuity is mainly based on the discrimination of the spatial pattern of retinal illumination, regardless of any temporal changes of intensity pattern on the receptor cells."

Changes in speed to and from 60 mph in a fluid drive transmission automobile gave the impression of change in distance, size, or both to subjects looking at a fixed target in the car. The target seems to approach on acceleration and recede on deceleration (49).

The impression of movement obtained from momentary stimulation of the peripheral retina by a stationary light is explained by White (130) as due to the two retinal images which are separated with slightly different subjective onset times. The retinal images are from the stimulus and the catoptric image of the second order which is focused at the retina of an emmetropic eye.

Binocular Vision

The similarities of fluctuation of the accommodation of the two eyes of the subject indicate central nervous origin according to Campbell (31). The fluctuations are appreciably smaller with a fixed convergence angle. Convergence control of the eyes is maintained by the vergence components of the drifts and saccades (42). Krauskopf and associates (72) found that the monocular response functions determine the occurrence, magnitude and direction of the saccades for each eye during binocular fixation as well as monocular fixations and correct for the slow drifts. The eye most off target triggered the saccades of both eyes and the vergence is corrected by a smaller saccade of the other eye. There are more saccades in binocular than monocular fixations and this is expected because the drift in each eye is independent. Eye movements and nervous control of the accommodation convergence relation are discussed by Morris (90). Fused images are brought to corresponding retinal areas within 2 min of arc (139).

Using two special ophthalmoscopes to see and regulate the disparity of the retinal images, Pickwell (97) found retinal image slip from a lag, in the change of vergence in the eyes, behind the rotation of the target and the retinal images. These observations suggest another kind of incoordination that could play a role in triggering an accident in poor light.

Mandelbaum (82) reports that a screen at 14 to 25 in. from the eye prevented seeing letters at 85 yd by preempting accommodation and suggests that "possibly the appearance of imperfection, dirtiness, and other blemishes on the windshield of the cars and airplanes interfere more with the perception of distant objects, under certain conditions, than by their mere interposition."

Color

Decreasing the illumination by a sixth gives normal subjects some idea of the reduced clarity of color as would be seen by those with a mild deficiency (126). To keep discrimination errors below 1 percent, Gustafson (52) shows that the contrast must be at least 75 percent. Changes in the photochromatic interval with dark adaptation are reported by Lie (76) and Luria and Schwartz (80) are measuring preadaptation effects from colored light. Baglien (14) mentions among other factors of vision that yellow is first identified and seen most clearly. On the contrary with poor light, yellow turns gray and is less visible than other colors (105). Another paper states: (10) "...yellow tinted lenses are a particular handicap to colour-deficient drivers." A more thorough test of tinted windshields by Wolf et al. (132) confirms the fact that seeing is reduced proportionately to the loss of light from absorption by tinted windshields and McFarland et al. (86) show that this loss is of greater consequence for the older driver. Brightness can be scaled with both white and colored stimuli (Olney, 93).

Color vision is reviewed by Hurvich and Jameson (62a). Schroeder (111a) explains color vision based on three different sensitive regions on one cone receptor in the retina. Boynton's (21a) theory involves three types of photopigments among five kinds of cones, opponent color processes to the lateral geniculate body, and coding in terms of the four psychologically unique colors from there to the cerebral cortex, to quantify color vision and explain color vision deficiencies. Vos (138) explains why some people see blue in front of red, and others red in front of blue.

Age

Hirsch and Wick (58) bring together much of the information on the adverse changes in seeing with advancing age. Walton and Kaplan (127) discuss the driving-seeing problems of senior citizens. Domey et al. (39) have analyzed their information on the age changes of dark adaptation and offer a mathematical equation for senescence in terms of dark adaptation. Tinted windshields are no help to the aged driver (86) and Wolf (131) shows that a marked increase in illumination is required to see against glare after about 40 years of age.

Driving and License Problems

Most methods of communication between drivers are visual according to Davey (37). Peletier (96) discusses the importance of vision in driving, the responsibility of the ophthalmologist, and what should be tested and evaluated in eye examination of motorists. A similar article is directed to optometrists (5).

The proper testing of drivers and the inadequacy of the British acuity test of ability to read a motor license at 25 yd is discussed (37). The comprehensive studies on the design and visibility of American license plates should be helpful (56, 67). Wilkie (129) reports that of more than 1,000 people with driving licenses from a 4,400 British practice, 45.5 percent could read a license plate at 25 yd without glasses, 47.1 percent with glasses, and 7.5 percent did not have glasses and could not read the plate. Deficiencies by age groups are given. Properly lighted targets are recommended. Sorsby (117) gives vision statistics for young men.

Another British contribution (47) discusses the importance of small uncorrected visual errors, fatigue, and their role in causing driving accidents. Riley (106) mentioned that "thousands of people needlessly wear sunglasses for driving because they mask symptoms of certain eye disorders which would require treatment," which is wrong because it lets the disorder go unchecked.

Motor licensing practices are discussed (7, 69, 111) and Crinigen (33, 34) reports on the requirements of the various states.

Accident prone drivers are more distractable and have poor eye-hand coordination according to Smeed (113). Allgaier (2) recommends giving night driving tests to night accident repeaters. Faults of driver behavior are listed by Sheehe (111) who also states that 80 percent of the human failure is due to driver error and that more than 75 percent of accidents occur in familiar country within 50 mi of the driver's home.

Alpern (3) states the advantages and disadvantages of contact lenses. Wearers of these should carry a card stating they use the lenses so that the lenses will not be left on the cornea for several days in case of an accident. Danger can arise from displacement of the lenses on the eye from wind in open-top cars, from turning the head too far in backing, from increased tears, and from a foreign body getting behind the contact lens (requires removal of the lens). Occasionally a contact lens will slide off the cornea for no apparent reason. Sensitivity to light is increased with contact lenses. Discomfort from allergies and colds can be a problem for contact lens wearers. When contact lenses are needed, the driving license should be marked with the restriction, as with spectacles. A check by removing the lenses need not be required as with proper lighting the contact lens can be seen on the eye.

King (70) discusses how to measure seeing from within an automobile, its importance, when it can be responsible for accidents, and some desirable limits for the restrictions of driver's vision by the shape of the vehicle. Stonex (120) reviews vehicle dimensions, McFarland and Domey (85) human factors and evaluate 1957 models, and Lee (75) discusses driver eye height and design features of automobiles. The technics available to discover and record where a person looks (65, 110, 142) should be used to obtain information on actual seeing from the driver's seat so that the car design will least restrict seeing at night.

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Vision at Levels of Night Road Illumination

VII. Literature 1961

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•SOME CONTRIBUTIONS from the current literature on vision have been selected for their interest to the HRB Night Visibility Committee (86). No person can find or read all the literature, and omissions reflect the limitations of a single reviewer. Snydacker (97) reviews some 377 papers on vision, and the reports of the Armed Forces Vision Research Committee are summarized for 1957-60 (56). Danielson (31) discusses the visual aptitudes of motorists, the Fourth American Optometric Association Motorist's Vision meeting is reported briefly (8), and Schmidt (89) presents a detailed analysis of seeing at night driving luminances, methods for testing dark adaptation, and the desiderata for a suitable test. The problems of aging are brought together by Marsh (69). LeGrand (65) has a small volume on seeing for those reading French. Ogle (77) provides the optics needed for eye care, and Weale (109) presents recent knowledge about vision from a modern viewpoint.

The limits of vision seem determined by the minimum number of light quanta that can stimulate the retina and by the upper safety limit of the tissues (83, 110). Screening testing of motorists visual abilities is now underway in England (6) and Davey (34) describes the League of Safe Drivers which requires annual retests of driving abilities. Driving simulators are discussed by Fox (46, 47) and Hulburt and Wojcik (59).

ILLUMINATION, GLARE AND DARK ADAPTATION

DeBoer (17) calls attention to the advantages of sodium lamps (100 l/W) for lighting highways where color is unimportant. Sodium lighting gives better distance visibility than mercury or incandescent lamps. Mercury lighting of 4/3 that of sodium appeared equally bright, and for equal visibility mercury should have 154 percent of the sodium lighting. DeBoer (18), from measurements indoors and outdoors, concludes that road surfaces should be at least 0.6 ft-L for safety and comfort in dense traffic.

An elementary symposium of illumination is reported (42). Cleveland and Keese (25) summarize their experience with intersection lighting in Texas, and Huber (58) reports on reflectorized color coding of a Minnesota interchange. The advantages of surface-mounted and low side lights during fogs are described by Finch (45) and Spencer (98). Luminance measurements of roads are discussed by DeBoer (18) and Rex (85). Nagel and Troccoli (75) describe a light meter for reflex reflective materials. Dawson and DuPre (36) describe vision and techniques of measurement at low luminance levels, and the standardization of measuring methods for scotopic and mesoptic seeing.

Rex (85) reviews means for rating glare and comfort factors. Wolf (117) reports an increase in sensitivity to glare with increasing age, especially after age 40. Some of the effects of speed, road elevation, and curvature on glare have been measured by Fries and Ross (48) for use in the design of glare protection by a median divider between lanes.

The glare problem and dark adaptation while driving in street traffic is discussed from an ophthalmologist's viewpoint by Gramberg-Danielsen (51 through 54). He points out that although the external luminances at the site of an accident can be measured, the state of dark adaptation of the driver is not obtainable. Glare recovery, according to Salvi and Venturi (88), is more rapid in individuals with dark-colored irides, although after yellow light, recovery is better for individuals with blue irides. Recovery after red glare was not related to the color of the iris.

Reducing the pupil area with pilocarpine lessens illumination on the retina, raises the luminance threshold at mesoptic levels by some 20 percent, and reduces the peripheral fields by 6.5°. Thus Jayle et al.(60) reemphasize the importance of knowing the the actual amount of light on the retina. Older people have smaller pupils and some drugs in common usage alter pupil size (93, 96). Lowenstein and Loewenfeld (67) find that dim light from smaller pupils alters the functional condition of the Westphal-Edinger nucleus within the brain and consider adaptation involving the central nervous system.

Recent work questions the duplicity theory of dark adaptation, and Weale (111) shows that there is little threshold difference between rods and cones (see also 86).

Domey (38) and Domey and McFarland (39) indicate that after 3 min preadaptation to 1,600 mL, 10 min of measurement at intervals of 1 min permits accurate prediction of the ultimate level of dark adaptation, which could be useful as a screening test. Boardman (16) reports that 300 ft-c of red light have about the same effect as 3 to 10 ft-c of tungsten light on preadaptation changes. Alpern and David (3, 7) show that lessened illuminance on a test chart is associated with an approach of the far point (night myopia), recession of the nearpoint (night presbyopia) and the reduced effectiveness of a given stimulus to evoke an accomodative response.

SEEING WHILE IN MOTION

Dynamic visual acuity is being investigated actively. Feldhaus (44) summarizes some of the earlier literature in an attempt to explain motion seeing problems.

Berg and Hulbert (22) find dynamic visual acuity unpredictable from measurements of static visual acuity and not related to flicker fusion or lateral phoria. Females gave better performance than males. Brown (19) compares thresholds from several studies expressing speed in terms of the visual angle (ω) subtended at the eye by a moving stimulus. The threshold increases in direct proportion for nonsuperimposed stimuli from 0.1° to 20° per sec ($\Delta\omega = k\omega$). Difference of $\Delta\omega$ for adjacent and for separate stimuli are used by Brown (20) to interpret tracking behavior.

An enclosed area pattern on the back of the preceeding car reveals motion of that car better than the same area painted with stripes. Motion towards is seen easier than motion away from an observer, probably due to the increasing brightness. These suggestions of Potter (84) may be helpful toward lessening rear-end collisions.

A series of papers by Crawford (29) is of interest. A decrement in visual performance begins when the motion is about 75° per sec, although much individual variation was found. Crawford confirmed the third power relation of the velocity previously reported by Ludwig and Miller. The seeing pursuit of a fast-moving object usually occurred in two stages or saccades. Latent periods averaged 200 msec. Over one-half the observers showed a second saccade eye movement when the velocity was over 50° per sec. The typical response to a moving target involved a latent period and intersaccadic interval followed by a steady state. The timing of the various phases depended on the rates of movement of the target. Subjects with high capacity for seeing detail in moving targets have greater extrafoveal acuity then those with less ability. Fixation errors of 1° to 2° of arc in position and 1.5° to 6.5° of arc per sec do not interfere with perceptual ability when the detail of the object to be perceived is of the order 1 to 3 min of arc. Simultaneous errors of position and velocity severely reduce visual acuity. Corrective eye movements that take time are necessary with greater errors. Because the equipment was not adapted to present vertical target movements, measurements were made with the subject turned horizontally (30). The results show changes in apparent movement and location of the horizontal when the visual and perceptual are disparate. A fixed head position could not be used in the study of eye movement because the head not only rotates about the horizontal axis in large pursuit movements but inclines in the vertical plane. Eye and head movements, when both are used, are analysed. With rapid movement the eyes look beyond the position of the head. These brief references indicate something of the scope of Crawford's useful investigations.

Miller and Ludwig (73) found that the apparent speed of an object in an empty field is dependent on the square of the real velocity, its duration, and size, from measurements of when a moving object was seen to have stopped moving. The time delay in the perception is more than the latent period of the response.

SEEING TIME LIMITATIONS

In actual life, much seeing must be done within a limited time. Sperling (99) reports that more information seems to be taken into the system during brief visual exposures than is reportable, and Averbach and Coriell (11) find visual read-in to be rapid, read-out slower, and erasure local. The information in storage was estimated to vary from 37 to 54 bits. Storage times varied from 250 to 300 msec and maximum performance from detecting and reporting was 250 msec. Information is becoming available toward knowing how much information can be utilized by motorists confronted by a choice of routes and how much time must be provided to insure orderly traffic movement.

Visual detection or discrimination is being investigated by Ments (70) through signal-noise considerations. Siegel and Crain (94) report stimulus effectiveness from color, size, shape, and distribution. Blackwell and Bixel (15) describe preliminary work on instrumentation for varying contrast and lighting on target and background for the analysis of the role of contrast rendition in seeing. How the detectable target size and shape may be limited by the organization of the nervous system is also being analyzed (63).

Luminance around a test area influences the seeing in the test area by the amount and distribution of the surrounding light. Inducers evenly spaced around the test site make it harder to see than when they are grouped along one side of the test area. Surrounding sources are more effective in raising the threshold for peripheral than for foveal vision (Kaplan and Ripps, 62).

Involuntary eye movements were examined by Shortess and Krauskopf (92) at short exposures (0.02 to 1 sec) by means of stereoscopic acuity thresholds for normal and image-stabilized eyes. Their results are reported as being consistent with static but not with dynamic theories of acuity.

Roger (87) reports the design of an eye movement camera, and Sunkes and Pazera (101) state that measurements of the eye movements of helicopter pilots were used in designing the windshield. A similar study with automobiles would be desirable.

The oscillations, flicks, and saccades of eye movements have been described many times. Howarth and Gibbins (57) emphasized these by the statement that one sees by means of the sequence of short exposures lasting from $1/10$ to $1/2$ sec; during these, the image drifts up to 60 min arc across the retina with a high frequency tremor of 20 sec visual angle. Clowes (26) believes that these movements, together with the known physiology of vision, account for contrast discrimination. Bryngdahl (21) applying linear filter theory analysis to vision finds a relationship between theory and the actual eye movements, which suggests that the eye movements give vision greater ability than predicted from the form and function of the eye. Thomas (102) describes how to observe the saccadic movements of one's own eyes with the aid of a cathode ray tube.

ACUITY, CONTRAST, ACCOMMODATION AND FIELDS

Visual acuity measurements using the optokinetic nystagmus correlates 0.92 with subjective tests on a Snellen chart according to Voipio (105), and Schumann (90) discusses this as an objective method for testing acuity. Walton (108) has published refractive errors found in 1,000 patients. With decreased illumination and small viewing angles, shape fluctuates more rapidly, according to Contincelli (27). Conscious effort can reduce the fluctuating shape. Peters (82) shows the relations between visual acuity and refractive errors for several age groups by ingenious graphs. British practice for improved legibility of scales is summarized by Maddock (71).

Uhlaner (104) describes a night vision test combining visual accuity detail in brightness contrast sensitivity for use at moonlight levels. A useful relationship is reported between vision measured at moonlight and at starlight levels of luminance. Morris (74) has devised a size-contrast test having two panels with circular targets decreasing in both area and contrast by factors of two. The test is also useful for testing vision through instruments and testing television fidelity. It also supplies a vision efficiency index.

On visual contrast, Dreyer (41) has decided from further experiments that contrast thresholds for brighter than background are independent of the area of the background; likewise, for negative contrast stimuli. The similarity of the two kinds of stimuli suggest that the simultaneous contrast phenomena may be considered to be a result of an indirect adaptation process. Another paper (40) shows that a dark frame around the test area aids seeing fine detail darker than the background, but not fine detail brighter than the background. Simon (95) discusses the problems of determining contrast visually and within instruments.

Ogle (78, 79, 80) gives a formula relating contrast thresholds for small bright disc targets seen against a white background, pupil size, and the blurredness from out-of-focus imagery. Measurements were obtained for both fovea and periphery of the retina. Thresholds increase with out-of-focus blurring of the retinal image, more so for small (0.6-min) than for larger (20-min) targets. For discs smaller than 3 to 4 min the effective image size approaches a minimal limit of about 6 min of arc. His results "imply that the size of minimal effective retinal image is determined more by dioptric factors than by quasi-independent retinal areas within which summation of luminous energy is supposed to occur" (78). Fry (49) warns against spurious resolution from out-of-focus images.

Logan and Berger (66) use autocorrelation methods to study degraded contrast and loss of information. The discussion of the paper revealed skepticism, difficulties, and the possibility of another method for the analysis of vision. Stevens (100) proposes repealing Fechner's Law and discusses the contrast seen with gray on a white surround.

Allen (2) describes an improved infrared optometer and reports a maximum accommodative change of about 5.8D per sec. Reading from his graphs accommodation starts after a latent period of about ½ sec and lasts about 0.3 sec; relaxation was slightly longer. Accommodation was steadier at distance. Fluctuations of about 3 cycles per sec were seen in the records for accommodation at near. Luria's (68) work on accommodation is interesting although at lower luminances than those of civilian night driving.

Empty field myopia, Doesschoate (39) points out, is different from night myopia and is not likely to appear when driving at night. Gramberg-Danielson (53) recommends wearing a correction for night myopia when helpful during night driving.

Visual fields and their relation to motor vehicle driving are surveyed by Kite and King (64). The first part describes the problem and gives some data; the second part should be useful when it becomes available. Davey (32), and Godfrey and Dickins (55) discuss the motorcyclist's limited fields of view from different kinds of goggles. A recent report shows that the 1960 American cars offer 310° of fair vision at the driver's eye level, which is an increase of 15 percent in the decade (10). The change in the fields of view with pupil constriction mentioned earlier may also play a role in night driving (60).

COLOR VISION

Judd (61) proposes a five-attribute system for describing visual appearance. Wilmer (115) discusses the unique problems of seeing blue, and Birch and Wright (13) discuss normal and deficient color vision.

Birmingham, England (9) is reported to be experimenting with colored roads, using green, red and white mixes. They also propose to make the beltways brown in color. It will be interesting to see whether the color-deficient persons can tell the difference between the red, green, and brown after the roads become dirty. From a study of driver responses to amber traffic signals, Olson and Rothery (81) recommend a constant amber phase of about 5.5 sec as practical for a wide range of speed zones, with variation when needed to allow for extra wide cross-streets. Color discriminations for yellow and red were reported to be reduced considerably in workers on diesel engine trains after 12 hr of work (103). An examination of color-deficient individuals in Germany showed that there was little evidence that the present traffic lights were hazardous. The main difficulty is the shortening of the red end of the spectrum for protans. It is suggested that the only satisfactory solution of the problem would be to use an equal area shape rather than a color for the signal (52).

Thresholds were measured in the periphery of the retina for 2.6 min arc-subtence red, green, and white signals. The thresholds for red were above those for white and the thresholds for white were slightly greater than for green (72) Bishop and Crook (14) report that for targets of greater luminance than the backgrounds about 9 hues, 3 luminance levels, and 2 purity levels are useful for operational coding, providing no more than 30 of the possible combinations are included in the set. Under optimal conditions the maximum size of an identifiable set is 60 when trained observers are used.

Crain and Siegel (28) using 0.32° targets of red, yellow, orange, and blue fluorescent colors and matching nonfluorescent paints found that the ordinary paints were seen at lower thresholds than the fluorescents, but that the color thresholds were lower for the fluorescent colors. Tachistoscopic thresholds were determined for shape, color, perimeter, area, and organization of pattern for ordinary and fluorescent paints. Dichromatic stimuli were more effective than a single color, squarish were more effective than rectangular stimuli, and increasing the area of the stimulus increased effectiveness only until an optimal size was reached.

Refractive errors, Wienke (114) discovered, are related to the red/green ratio which matches yellow (Raleigh equation), and myopes use more green and hyperopes more red to match yellow than do emetropes. This was not due to the size differences in the images (113).

REGULATION AND BEHAVIOR

A detailed discussion of licensing problems by Algea (1) shows a need for basic information on the integration of the driver, vehicle, and highway. Davey (33) summarizes the visual tasks of road users. The lessened fatigue and easier seeing with proper spectacles, when such are needed, are emphasized (4, 5, 33).

Speed limits are effective only if they do not frustrate the driver, because a frustrated driver is believed to cruise at the maximum speed allowable and needs frequent control by looking at the speedometer which takes his view away from the road for periods as long as 3 sec, according to calculations of Gramberg-Danielsen (51). Feinberg (43) reports on measurements made of 115 transport drivers in the 1940's. Fewer nearsighted drivers appear to enter this occupation. Of 24 subjects tested before and after a day's driving, no differences were found by the use of several tests.

An evaluation of the records of amateur sports car drivers in Great Britain failed to disclose any relation between ocular status, driving performance, and accident rate (12).

Chalfant's (23) summary of part of the California survey shows that professional drivers, chauffeurs and traveling salesmen, and labor or semiskilled workers comprise a greater proportion of the problem drivers than other occupational classes. Negligent drivers, as a group, averaged or exceeded the mileage of the ordinary driver. Sherman (91) also discusses the problem of accident-prone drivers and points out that they are, in general, ordinary normal individuals but ones that do not have good seeing habits. He believes that a proper training in the use of the eyes during driving (such as the Smith system) would improve driving, greatly reduce the accident record, and then make possible separating the real accident-prone from the negligent.

Nathan (76) briefly reviews some aspects of visual fatigue. No reliable criteria were found, although he does give suggestions for further experimentation. Chastain (24) reports from a practical test on 6 subjects that 0.10 percent blood alcohol definitely decreases driving ability. Westheimer and Rashbass (112) found that barbiturates interfere with the vergence and tracking movements of the eyes and Wilson (116) reports that prolonged chloroquine treatment caused irreversible damage to the retina. Both Shulman (93) and Sloan (96) summarize some of the effects of drugs on vision Some tranquilizers tend to blur vision. Other drugs affect pupil size and those that constrict the pupil could reduce night seeing. Adaptation and central nervous system correlation can be distributed by various drugs. The ophthalmologists should determine to what extent the usual dosages of commonly used drugs impair night driving ability of motorists.

Complex noise above 90 db did not cause any loss of visual acuity, fields, or the physical component of the stereoscopic sense, but did disturb perception and the nocturnal morphoscopic sensibility. The color vision disturbances were toward protanomaly (50).

DRIVING TASK ANALYSIS

In England an effort is under-way to find out what the seeing tasks of driving involve (Davey, 35; Waldram, 106, 107). In the earlier studies a voice recorder was installed within the automobile and the running comment of the driver was recorded; shortly thereafter, motion pictures also were made. Motion pictures were also projected before a subject with a television system showing where the subject looked at the picture.

The eye sees with quick fixations of ¼ to ½ sec. Hard to identify subjects are watched longer and some situations (such as a bicycle) take undue time with many fixations. Peripheral vision is used when the car being passed was not looked at. Blurred vision on the near side appeared to be sufficient, but offside the unexpected attracted the viewer's attention. At corners the eye tended to look ahead of the picture, in much the same way as was reported by Crawford for dynamic viewing.

Without traffic the eyes fixated a little opposite and a few hundred feet ahead. Steering was mainly by the centerline and the curbs were seen casually.

With medium traffic there was much use of peripheral vision, motion changes were noted, familiar patterns were reacted to, and fixation occurred when in doubt or when the unusual pattern appeared. Therefore, low illumination makes undue demands for fixation. When following, the eyes tended to concentrate on the car ahead.

In dense traffic the British experimenters show the problems of trying to respond to several orders of elements rather than one at a time.

Night driving illumination is less; the bright sky and color clues are gone. Color is stated not seen at night even when the lighting is adequate. Driving with dense goggles reducing the seeing in overcast daylight to night levels was less good than ordinary driving at night with the car lights. The lighting from the auto was adequate under good weather conditions, but Waldram shows a need for additional fixed lighting for adverse conditions.

Much information, as noted in this and previous reviews, is becoming available. The experienced driver is reported to pay attention to a closing situation. Waldram and Davey's analysis shows many similarities to the Smith-Sherman driving rules and supports Sherman's (91) often-repeated comment that improper use of the eyes results in automobile accidents. Applying modern means of showing where the observer looks (86, 87, 101) and analysis like Davey and Waldram are doing should form a basis both for better driver training and for removing the accident repeater from the highways.

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Flicker Fusion, Dark Adaptation and Age as Predictors of Night Vision

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Dark adaptation and critical flicker fusion thresholds for 60 subjects ranging in age from 16 through 89 were obtained. A methodical analysis of the statistical interrelationship among dark adaptation thresholds and critical flicker fusion thresholds as function of surround, light/dark ratio, and age were systematically examined. The prediction of dark adaptation threshold at the 40th minute was significantly increased by certain critical flicker fusion data.

•THE THRESHOLD of dark adaptation and the rate at which it is achieved are two inexorably related phenomena underlying perception as a function of low levels of luminance. Although photopic thresholds are quickly restored by the presence of high light levels, scotopic sensitivity develops much more slowly. For example, it requires approximately 30 min to achieve 98 percent dark adaptation, but only a few seconds to return to photopic thresholds provided the retina is not "bleached." Thus, tasks that depend on rapid dark adaptation may exceed the capacity of the visual mechanism to adapt. This means that the respondent is more or less handicapped when required to perform precise tasks where luminance varies rapidly, intermittently, and irregularly over a wide range of intensity. It is well known that these are the characteristics of nighttime, especially in urban and highway environments.

The prediction of dark adaptation thresholds has infrequently been attempted, although it is known to vary as a function of several important conditions such as age, vitamin A deficiency, variations in light frequency, intensity and duration of pre-adaptation light conditions, and post-adaptation stimuli. The function, however, is unusually stable and, on occasion, is used as a clinical research tool, alone with the measurement of critical flicker fusion; but for purposes of prediction, few if any standards have been developed. As a consequence the clinical psychologist, physiologist, and physician have had no usable referent distributions available to assist them in locating any given individual in a population. It is suggested that a frame of reference would be useful for both clinical and experimental reasons.

Therefore, two sets of data (one of dark adaptation thresholds and one of critical flicker fusion thresholds) have been statistically examined to determine whether such data would be potentially useful for developing methods of predicting DA and CFF thresholds for individuals. The author's first exploration was published in the American Journal of Ophthalmology (1). In this experiment there were 240 male subjects ranging in age from 16 through 89 years. It was shown that, by combining DA thresholds obtained at 60-sec intervals from minute 2 through minute 9 with the ages of subjects in a multiple correlation technique, the DA threshold at the 40th minute was easily predicted by the obtained multiple R of 0.91. This is an unusually high value. The statistical properties of this sample indicated that it would be highly suitable for representing the larger population from which it was drawn, thus providing a functional frame of reference for

TABLE 1

CRITICAL FLICKER FUSION AND DARK ADAPTATION MEANS AND STANDARD DEVIATIONS FOR 64 SUBJECTS

Variable	Mean	Standard Deviation
Age(1)	53.0156	16.0317
Low surround LDR:		
2	36.5801	3.4418
3	38.7910	3.4760
4	40.3066	3.3718
5	40.9980	2.9825
6	40.4238	2.8202
7	39.8027	2.7283
8	35.1855	2.6919
9	27.2891	3.3418
10	19.5195	3.1805
11	10.5371	2.4997
High surround LDR:		
12	38.9336	3.4403
13	40.8016	3.3673
14	42.1875	3.3881
15	43.2676	3.0487
16	42.7246	2.7419
17	42.0586	2.7841
18	37.2246	2.6567
19	29.2266	3.5438
20	20.0781	3.8449
21	9.2793	2.2090
Dark adapt. threshold:		
22	6.8059	0.3283
23	6.4916	0.4683
24	6.2775	0.5486
25	6.1498	0.5950
26	5.9194	0.6133
27	5.6423	0.6321
28	5.4036	0.6727
29	5.1328	0.7133
30	4.7981	0.7533
31	4.5109	0.7674
32	4.2695	0.7825
33	4.0486	0.7693
34	3.8119	0.7534
35	3.6458	0.7419
36	3.5166	0.7024
37	3.4212	0.6670
38	3.3444	0.6550
39	3.3089	0.6527
40	3.3048	0.6529
41	3.3041	0.6509

TABLE 2

MULTIPLE CORRELATION (R) OF AGE, 20 CFF VARIABLE, AND 20 DARK ADAPTATION VARIABLES WITH THE 40th MINUTE DARK ADAPTATION THRESHOLD, THE CRITERION N = 64

Variable	df_1	Multiple R	SE(est)	F-Ratio	$1-R^2$	R^2	df_2
Age(1)		0.6899	0.4750	56.30	0.5241	0.4759	62
Low surround LDR:							
2/98	2	0.7161	0.4580	32.11	0.4872	0.5128	61
5/95	3	0.7213	0.4546	21.69	0.4797	0.5203	60
10/90	4	0.7406	0.4411	17.92	0.4515	0.5485	59
25/75	5	0.7452	0.4378	14.48	0.4447	0.5553	58
40/60	6	0.7453	0.4378	11.87	0.4446	0.5554	57
50/50	7	0.7459	0.4374	10.04	0.4436	0.5564	56
75/25	8	0.7766	0.4138	10.45	0.3969	0.6031	55
90/10	9	0.7892	0.4034	9.91	0.3771	0.6229	54
95/5	10	0.7915	0.4015	8.89	0.3735	0.6265	53
98/2	11	0.7920	0.4012	7.95	0.3728	0.6272	52
High surround LDR:							
2/98	12	0.7987	0.3955	7.49	0.3621	0.6379	51
5/95	13	0.7991	0.3953	6.79	0.3615	0.6385	50
10/90	14	0.7991	0.3953	6.18	0.3615	0.6385	49
25/75	15	0.8037	0.3914	5.84	0.3541	0.6459	48
40/60	16	0.8039	0.3913	5.37	0.3538	0.6462	47
50/50	17	0.8043	0.3910	4.96	0.3531	0.6469	46
75/25	18	0.8050	0.3905	4.60	0.3520	0.6480	45
90/10	19	0.8100	0.3860	4.42	0.3439	0.6561	44
95/5	20	0.8133	0.3832	4.20	0.3386	0.6614	43
98/2	21	0.8133	0.3832	3.91	0.3385	0.6615	42
Dark adapt. threshold at minute:							
2	22	0.8357	0.3600	4.38	0.2987	0.7013	41
3	23	0.8445	0.3529	4.33	0.2868	0.7132	40
4	24	0.8501	0.3472	4.23	0.2774	0.7226	39
5	25	0.8629	0.3333	4.43	0.2554	0.7446	38
6	26	0.8922	0.2979	5.56	0.2039	0.7961	37
7	27	0.8952	0.2941	5.38	0.1986	0.8014	36
8	28	0.9085	0.2759	5.91	0.1746	0.8254	35
9	29	0.9217	0.2562	6.62	0.1505	0.8495	34
10	30	0.9354	0.2336	7.70	0.1250	0.8750	33
12	31	0.9420	0.2218	8.14	0.1126	0.8874	32
14	32	0.9440	0.2181	7.94	0.1088	0.8912	31
16	33	0.9456	0.2152	7.69	0.1058	0.8942	30
19	34	0.9576	0.1908	9.41	0.0831	0.9169	29
22	35	0.9739	0.1504	14.72	0.0516	0.9484	28
25[a]	36						
28[a]	37						
31[a]	38						
34[a]	39						
37[a]	40						
40[b]	41						

[a]25 - 37 not used because R is so high.
[b]To be predicted.

clinicians. A second study (2) of CFF as a function of age, two surround levels, and ten light/dark ratios suggested that these variables were intercorrelated. However, inasmuch as CFF is also used to test visual thresholds and measure elements of vision different from those measured by dark adaptation, the question has arisen as to relationship between the two phenomena. Therefore, data obtained from 64 subjects common to an extensive age study of CFF and the aforementioned dark adaptation study were examined.

The 64 subjects common to both studies were distributed in age from 21 through 88 years. Critical flicker fusion data were taken under two different surround levels using ten different light/dark ratios ranging from 98/2 to 2/98. Thus, there were twenty different CFF observations for each subject. There were also twenty dark adaptation thresholds obtained for each subject. Because the subject's age was known, 41 variables in all were available for analysis (see table 1 for variable means and SD's).

The 40th minute of dark adaptation was again chosen as the datum to be predicted. Then, an extensive 41-variable, multiple correlation was computed. Table 2 shows the order in which the variables were entered in the equation, the corresponding multiple R values, the associated, $SE_{(est)}$, F ratios, $1-R^2$ values, R^2, and the degrees of freedom at each level for n_1 and n_2.

The results show that age alone accounted for the greatest portion of the variance by far, inasmuch as R for the 40th minute and age alone was 0.70. The standard error of estimate was exceedingly small, and the F ratio extremely high, thus giving assurance that this R was highly significant. However, 0.70 is not sufficient for individual prediction of high accuracy. The next twenty variables, in successive order, were the twenty light/dark ratios under their respective high and low surround conditions. In all, they increase the R value from 0.70 to 0.8133. The LD ratios under low surround conditions account for nearly all of the increase. However, this reflected the effect of the order in which the variables were entered into the equation. Had the order been reversed, then the high surround data would have accounted for approximately the same degree of increase in R.

The ten dark adaptation thresholds were then introduced in order of time beginning with variable 22 in Table 1. The multiple R continued to rise. By using only the 7 values obtained during minutes 2 through 8 of the dark adaptation process, R was increased to 0.91. This magnitude is sufficient to allow predicting individual dark adaptation thresholds. The standard error of estimate for R = 0.91 was 0.26, which was very small. The 6.62 F ratio was large, thus assuring the significance of the correlation. The 6.62 F ratio, the $1-R^2$ value 0.17, and R^2 (0.82) show that R (0.91) was reliable for this sample and for the population from which the sample was drawn.

Not all the dark adaptation thresholds were used in the multiple regression equation. It was felt that, because R had risen to 0.97 with the 35th of 40 predictor variables, no further computations were necessary inasmuch as the obtained values accounted for nearly all the variance.

CONCLUSION

Combining critical flicker fusion observations and dark adaptation thresholds obtained from representative age samples yields data of such validity and reliability as to make prediction of individual performance possible to a highly accurate degree. Thus, developing statistical standards representative of the population would enhance the clinical usage of both these measures for experimental and diagnostic purposes.

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Effects of Age on Peripheral Vision

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Changes in visual sensitivity with age at photopic, mesopic and scotopic luminance levels have been found in studies on visual acuity, dark adaptation, and flicker. It also has been shown that sensitivity to glare increases with age. Approximately at the age of 40 years the pace of change is accelerated. This can be shown equally well for the dark adaptation, flicker, and glare data. Most studies thus far have been restricted to tests in the central visual field. Information on visual performance in the peripheral visual field is obtained by studies on dynamic visual acuity and flicker perimetry. Perimetric fields obtained by the flicker method in individuals between the ages of 6 and 93 years under various experimental conditions are presented, and the effects of alertness, training, and experience are discussed.

•IT IS WELL KNOWN that the efficiency of vital mechanisms of the body declines with age. Vision is no exception. In early youth, for instance, it is very easy to accommodate for objects at a short distance from the eyes, whereas above the age of 45 or 50 years accommodation needs assistance by reading glasses.

The range of dark adaptation becomes gradually smaller with age. Though in the young, adaptation can increase sensitivity in excess to 1:100, 000, it may be reduced to 1:1, 000 in advanced age. In the aged, therefore, scotopic sensitivity may be only 1/100 of the sensitivity found in young individuals (1, 2, 3).

The sensitivity to glare becomes progressively greater with age. Though young individuals can easily discern details in the vicinity of a glare source, older individuals encounter considerable difficulties. For both these visual functions a change in sensitivity is particularly noticeable at the age of 40 years. Changes in the transmissiveness of the ocular media and increase of scatter of light at that age are probably contributing factors (4, 5, 6).

Studies on responses to flicker in the central retina have shown that critical flicker frequencies decrease with advancing age. It appears however that for flicker perception a decisive change occurs rather at the age of 60 than at 40 (7, 8).

This relationship between sensitivity and age was found in direct vision. For moving objects or for an individual moving in a vehicle, peripheral vision becomes of considerable importance. It seemed of interest, therefore, to study flicker responses of the peripheral retina especially in relation to age.

For studies of this type, a flicker perimeter is used. This instrument incorporates an adjustable chair with head and chin rest mounted on a crossbar between the side arms so that the eye level of an observer can be adjusted in relation to the center of the perimeter which has an object distance of 1 m. The object is a Sylvania glow modulator tube activated by a Grayson stadler flicker apparatus. The light source has only a very small diameter in front of which a short focus lens is used to illuminate evenly a translucent screen yielding a round flicker field of 2° angular subtense. By means of diaphragms, as well as color and neutral filters inserted in front of the screen, size, brightness, and color of the testfield can be varied. The flicker light is mounted in a tubular enclosure with the circular field at one end and held by an arm originating above the head of the observer. This arm moves through any desired arc to cover a hemispherical surface with 1-m radius. A second equally suspended arm bears a fixation point in relation to which the flicker field is adjustable. The positions of testfield and fixation point are read from scales at the base of the arms. Thus, flicker fields can be put accurately in any special relation to the fixation mark while the observer's eye remains fixed at the center of the hemispherical arrangement (Fig. 1).

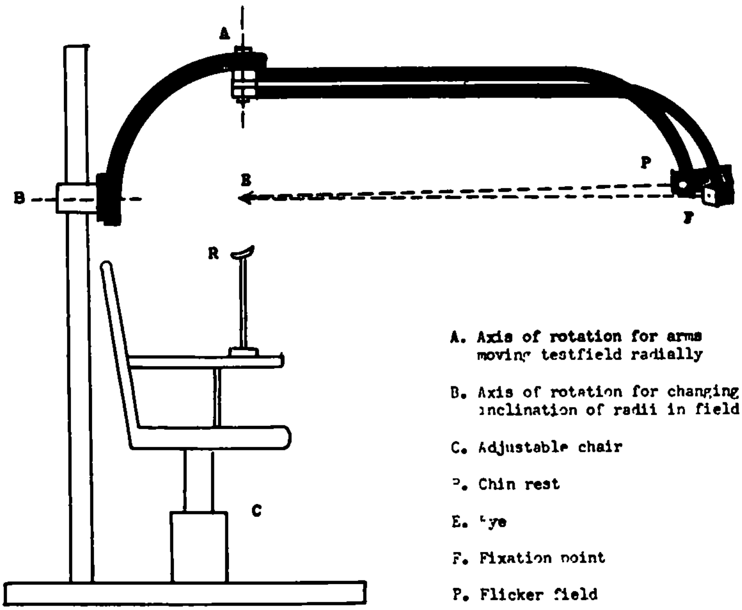

Figure 1. Diagram of flicker perimeter.

The controlling device for the light source permits changes in luminance, in light time fraction from 2:98 to 98:2 in each flicker cycle and in frequency from 150 to ½ cps. The light is bluish-white and presents no difficulties to perception in the periphery. In the experiments described here only the full brightness of the source (30 footlamberts) and a light time/dark time ratio of 1:1 was used.

The test room is dimly illuminated. One eye is occluded; the seeing eye fixates the red fixation point while the flicker field is positioned at any desired angle and distance. The size and luminance of the testfield are so chosen that the target is easily noticeable in any position. During tests, flicker frequency is gradually reduced from complete fusion to the point when the observer indicates that he sees flicker. This is the critical flicker frequency (CFF) to be determined. The CFF value in cycles per second is read from a scale on the flicker apparatus. The frequency is immediately raised again to a level above fusion to avoid undue fatigue by the flickering light, and after a short interval the critical frequency is determined for a second time. Usually first and second readings are in close agreement. If, however, a difference greater than 2 cps is found, additional readings are taken, and the mean is taken as the CFF value for that point of the visual field. Tests are made along the horizontal and vertical meridians and along the diagonals as far out as CFF values are obtainable. A complete flicker field includes as many as 70 CFF values. Usually, however, the number is smaller on account of the physical limitations presented by the structure of the face, when eyebrows, cheek bones, and nose obscure vision in certain directions.

Figure 2 shows a perimetric field chart with the CFF values for a 13-year-old. At the center, CFF is 51 cps. Similar high values are found to 50° and in the far periphery frequencies of one-half the central values are found. The distribution of CFF

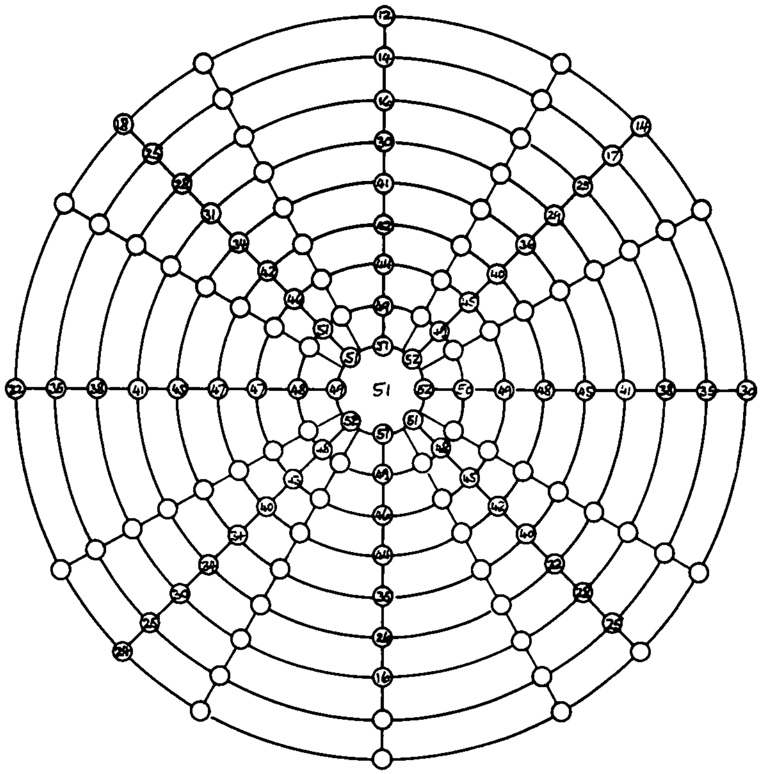

Figure 2. Flicker field (right eye) of a 13-year-old. White light; light time/dark time ratio 1:1.

is rather regular, and deviations from it may be used for diagnostic purposes, as sudden abrupt changes in CFF values are indicative of retinal lesions. Unfortunately, however, the usefulness of flicker perimetry as a diagnostic tool suffers because critical frequencies are not a series of absolute numerical values but depend on age. It is therefore necessary in relating changes in CFF to pathological conditions to correlate them to the flicker values normal for a given age (9).

Changes in flicker fields are particularly noticeable in advanced age. The results of a study of flicker fields in a group of 107 Spanish American War veterans between 73 and 94 years of age are shown in Figure 3 in which the CFF values along the eight principal radii of the visual field are given. These are plotted for five age groups, each covering a span of five years (10).

At the center of the visual field, a maximum flicker frequency of 32 cps is found for the youngest group, and 27 cps for the oldest. The CFF values drop systematically with age so that for each retinal position along the eight radii they become progressively smaller yielding in the far periphery values below 10 cps. If CFF values shown for an adolescent in Figure 2 were assumed to represent a normal flicker field, the values obtained with the veterans would seem abnormally low. But inasmuch as within the 25-year span represented by the veterans a systematic decline in CFF is noticeable, one may assume that the decreasing CFF values are typical for high age.

To obtain flicker data covering the entire span of human life it was necessary to extend the study of normal flicker fields to all age levels. For this purpose, individuals were used who visited the out-patient department of the Massachusetts Eye and Ear Infirmary and who according to their clinical records had no pathological conditions. The data are adequate to show the general trend of CFF in relation to age, but the results should be regarded as preliminary, because unequal numbers of individuals were used

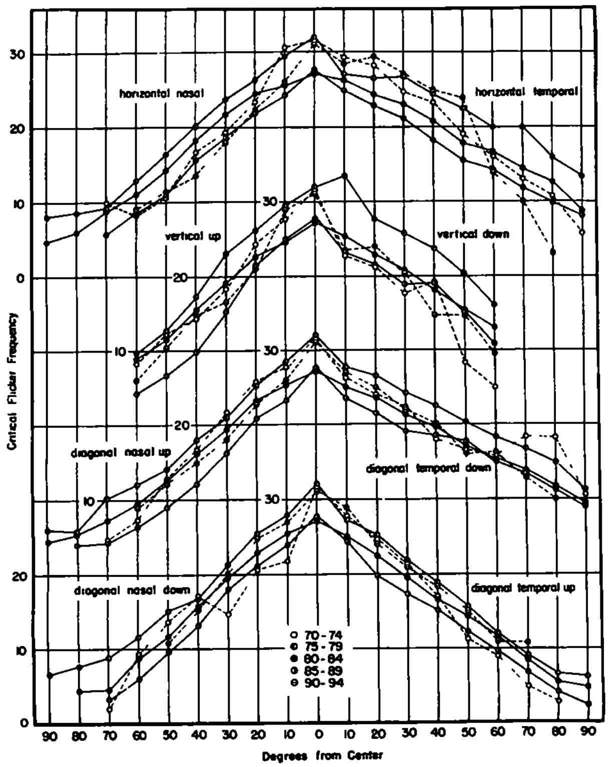

Figure 3. Data obtained from 107 individuals between 72 and 94 years of age. CFF values plotted for five age ranges of 5 years each against retinal position on 8 radii. Frequencies higher at center, declining steadily toward periphery.

in the various age groups (3-22). The same is true for the Veterans' data (2-64). Among the individuals below 75 years picked from the clinics those between 30 and 55 years are much less readily available than those younger or older. The numbers must therefore be suplemented before a complete analysis of the data can be carried out.

Figure 4 shows the results of flicker tests along the horizontal meridian of individuals between 5 and 75 years in groups of 10 years. They may be compared with the curves of the horizontal meridian in Figure 3. The top curve of the set in Figure 3 overlaps with the bottom curve of Figure 4 and represents a continuation of the age range from 5 to 95.

The curves of Figure 4 show for all age groups the highest frequency values at the center. Center values above 40 are found up to age 35, and slightly lower than 40 up to age 65. For young individuals CFF remains above or near 40 cps as far as 30° from center, and frequencies above 30 cps occur as far as 70° in the temporal field, and as far as 50° in the nasal field. As age progresses, the CFF values become smaller at all points but the drop is more pronounced in the far periphery and especially in the nasal field.

Figure 5 is a combination of the data presented in Figures 3 and 4 by plotting for various angular distances the CFF values against age. Each curve represents the changes in CFF with age for points located 0°, 20°, 40°, 60°, and 80° from center along the horizontal meridian in the nasal and temporal fields and along the vertical meridian above and below fixation. All curves show that at each point of the visual field CFF varies with age. From childhood, CFF rises to maximum values between 20 and 30 years, then drops to a lower level which is maintained until age 60. Above 60 years CFF declines faster, reducing flicker perception considerably, especially in the far peripheral field.

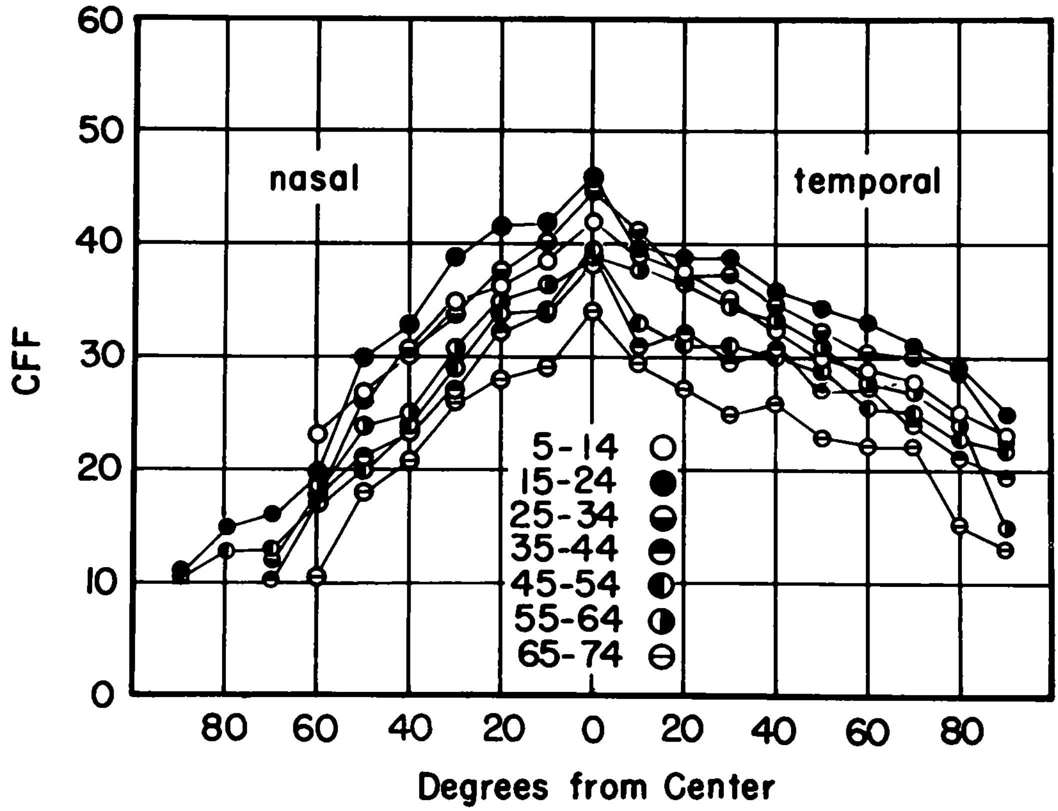

Figure 4. Data obtained from individuals between 5 and 75 years of age. CFF values for horizontal meridian of visual field given for seven age ranges of 10 years each. For each age, frequencies higher at center, declining toward periphery. At every retinal point, CFF becomes smaller with age.

The data presented unquestionably show an interdependence of mean CFF and mean age for a given group of individuals. There is, however, a great deal of variability between individuals, a fact that should be emphasized. In some cases a CFF level that lies considerably below normal is found throughout a rather limited visual field, and it appears as if CFF depended not only on the receptive power of the retina but also on the mental alertness of the individual under study. A well-motivated child of 10 years or less may show a flicker field with frequencies between 40 and 50 cps up to 60° from center in all directions, and beyond 60° a slow decline up to angles where it becomes physically impossible for rays from the flicker light to enter the pupil. Equally high values may be found in a 50- to 60-year-old professional man or woman who is mentally alert and has experience in visual observation. In contrast to this, a much younger person may give central CFF values that are as low as those of the Veterans and who will not respond to flicker with certainty when the field is presented 40° to 50° in the temporal field. For further study it might perhaps be of interest to correlate low CFF's with other psychological tests and perhaps the occupations of subjects.

In the peripheral retina, visual acuity becomes progressively poorer. When acuity in direct vision is 20/20, it is only 20/40 at 5° and only 20/80 at 10° from center. The perception of details in the peripheral visual field is therefore very difficult as compared with the center of the retina. When visual acuity is studied while test objects are in motion (dynamic visual acuity), it is found that acuity deteriorates rapidly with the increase of the angular velocity of a test object. The correlation between static and dynamic acuity is low. Even in individuals with 20/20 vision or better, it cannot be predicted how they will respond to objects in motion. Static visual acuity increases with luminance until a maximum is reached; dynamic acuity, however, requires 20 times more light until a significant effect is noticeable (11, 12, 13).

In flicker recognition the perception of detail is not necessary. For this reason peripheral sensitivity can be studied advantageously by the flicker method. Where acuity would have become immeasurably low in the periphery, good responses to flicker are still obtained.

In flicker perimetry the CFF values obtained for all ages decrease progressively as one moves out in the peripheral field. Moreover, frequencies for each retina point become smaller as a function of age. This means that for older individuals frequencies that would be seen as definitely flickering by a younger individual would appear fused and as a stationary stimulus possibly not noticeable at all.

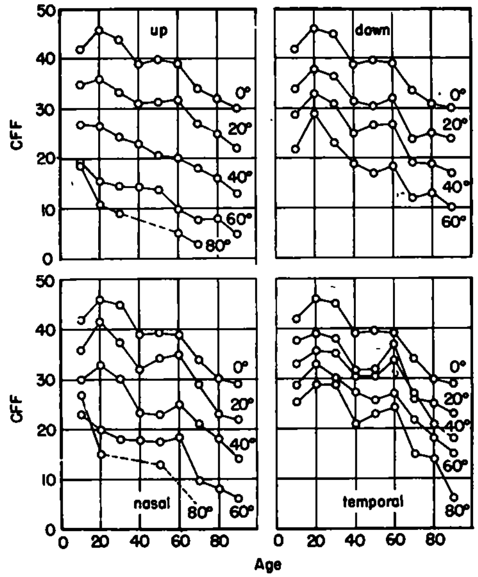

Figure 5. Relationship between CFF and age at center of retina and 20°, 40°, 60°, and 80° from center on four principal radii of visual field. At each retinal location, CFF highest between 20 and 30 years, then remaining relatively steady up to 60 years. After 60 years, a faster decline in CFF noticeable.

In a moving vehicle peripheral visual perception is of great importance. Probably at all times information gathered by the peripheral retina is used subconsciously and utilized for road safety. With increasing velocities of travel and density of vehicles on the road, peripheral visual perception might be even more important than is attributed to it. In view of the fact that the driving population over 55 or 60 years is steadily increasing, the changes in peripheral visual perception with age as indicated by the study to responses to flicker should be taken into consideration in the presentation of visual information that must be assimilated by drivers of all ages (14, 15).

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A Modification of the Bio-Photometer for Alterocular Fixation Control

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• ONE FACTOR to be controlled in dark adaptation testing is that of fixation so that the region of the retina under investigation is known and constant. This is rather easily controlled during the bleaching phase, but in the test phase the subject is tempted to deviate from the conventional red fixation light to search the area in which the test object is anticipated. This may not be a serious detraction for a trained subject, but it is very disconcerting to both the naive subject and the conscientious test operator.

The present report, preliminary to a more comprehensive study in progress, describes an attempt to modify the Bio-photometer model D-145, an instrument manufactured by the Frober-Faybor Co. of Cleveland, Ohio, (1) to provide for the testing of one eye while its orientation is controlled by the fixation of the other eye. This technique is referred to as alterocular fixation control.

APPARATUS

To control the orientation of the line of sight of the nonfixating eye, which is undergoing the test while the other eye is fixating, it is necessary to hold accommodative convergence constant and to provide a compensatory correction for the relative deviation of the two eyes under dissociation. Both of these conditions are provided for by the combination of a prism and a pair of lenses just inside of the viewing apertures. The instrument, as seen from the subject's side, is shown in Figure 1. The schematic plan of the instrument is shown in Figure 2.

The accommodative convergence is held steady by means of a convex lens (Fig. 2, L_2) mounted in front of the fixating eye (O. S.) to place the image of the fixated red light at a distance of 1 m. Similarly, a convex lens (Fig. 2, L_1) is mounted in front of the test eye (O. D.) to place the image of the test plane at a distance of 1 m. This distance is assumed a suitable accommodative stimulus for all of the subjects in the group, in the sense that an object at this distance can be held in reasonably steady focus.

The compensatory correction for the relative deviation of the two eyes is provided for by the lateral and vertical moveability of the red fixation light (Fig. 2, B) in combination with an 8^{Δ} base-out prism mounted in front of the fixating eye.

Another modification consists of a small opaque annulus (Fig. 2, A), with outside diameter of 15 mm and inside diameter of 6 mm, on the transilluminated bleaching field (Fig. 2, M) to provide a fixation target for the test eye during the bleaching

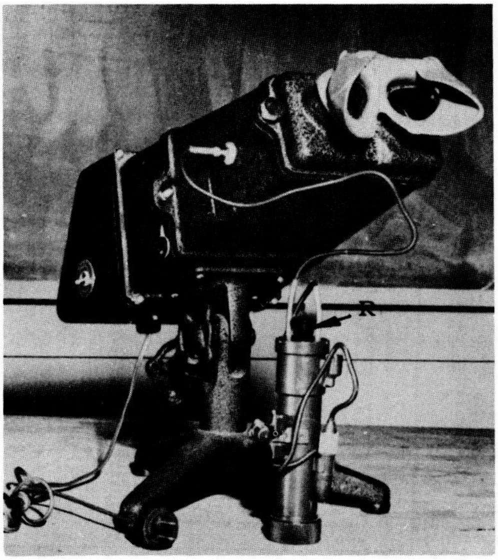

Figure 1. The Model D-145 Bio-photometer with modifications.

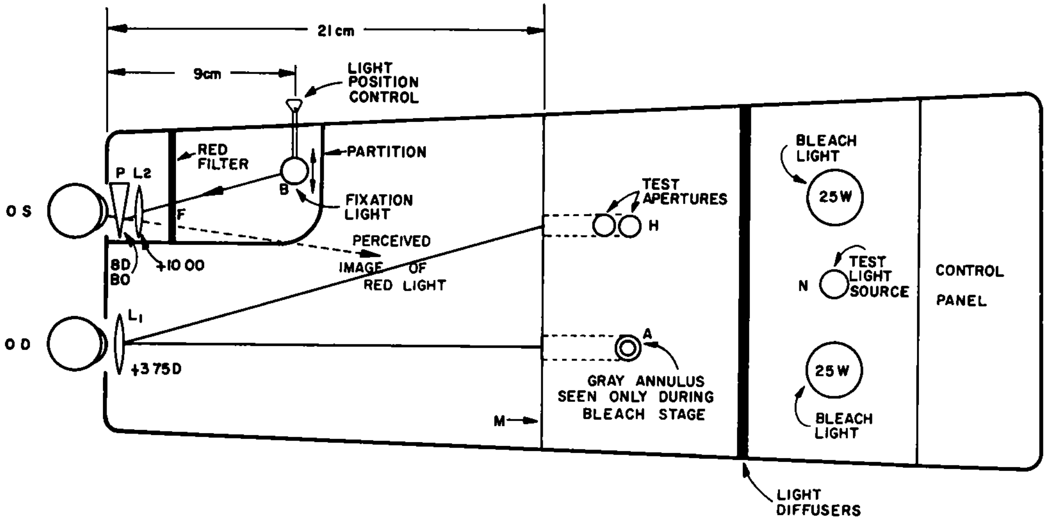

Figure 2. Schematic diagram of the modified Bio-photometer.

phase. This annulus also serves as a fiducial mark for adjusting the position of the red fixation light in front of the other eye until the light appears to lie inside the annulus.

The only other functional modification of the Bio-photometer is that of reducing the luminance of the two brightest spots in the original quincunx target by the overlaying of translucent papers to reduce transmittance. This modification reduces their luminance 7½ times, but they are still brighter than the other three spots. The latter three spots serve no purpose except, rarely, to call attention to negligence on the part of the subject.

Inasmuch as the instrument is to be described in full detail elsewhere (2), only a few functional features need to be pointed out here with reference to Figure 2. The test plane M has two components. One is an opaque rectangular plate with the five quincunx target apertures. Only the two identified as H are employed in the test These apertures, 4 mm in diameter and separated by an edge to edge distance of 28 mm, are located one above the other and are equally luminous. The centers of these two apertures are located 17 mm to the left of center. The other component consists of the translucent bleaching surface that comes into full view when the opaque plate is flipped down, out of position. The opaque, gray-appearing annulus A is located to the right of center so that the total bleaching area centers around a point about 12^0 nasal to the line of sight of the test eye (O. D.). Because the left eye fixation is pre-adjusted to make the red light appear in the annulus, the alterocular fixation of the red light by the left eye is presumed to maintain the line of sight of the right eye in the same position during the subsequent testing. The resulting angle between the line of sight of the right eye and the direction of the test apertures, therefore, approximates 16^0.

PROCEDURE

For the purposes of this preliminary study each subject was kept in a completely dark room for 10 min. Then the bleach lights were turned on and adjusted to give 250 millilamberts, and the subject was instructed to fixate the annulus, which was visible to his right eye. During the bleaching, the position of the red light was adjusted until the subject reported seeing it inside the annulus. The bleaching phase was continued for a total of 3 min. At the same time that the bleach lights were turned off, the quincunx target plate was flipped into position and the faint light, N, was turned on to illuminate the test apertures, H. At the end of the first and each succeeding minute the subject was instructed to report the first appearance of the two test spots, H, as the intensity of the test light source was gradually increased. As soon as their appearance was reported, the intensity of the test light was noted and immediately reduced to a value well below the threshold. The noted intensity at the moment of visibility was recorded in rheostat scale units. From time to time, the intensity of the red fixation light was reduced to make it comfortably visible to the subject without seeming unncessarily bright.

RESULTS AND OBSERVATIONS

Figure 3 shows a sample of seven successive runs on one subject, numbered in the order in which they were obtained, and successively displaced 20 rheostat units each to separate them on the vertical scale or ordinate.

Altogether 16 pairs of runs on a corresponding number of subjects were made on the modified Bio-photometer. For the purpose of determining the relative reliability of the test at the first, second, and subsequent minutes, the coefficients of correlation of the raw data for each minute and the coefficients of rank correlation of the ranked data for each minute were computed. The trends of these correlation coefficients are shown in Figure 4. The coefficients are positive throughout the range of the 10 min investigated and appear to reach a maximum at about the sixth minute.

What seemed to be a very important incidental observation was that all of the subjects reported the judgments very easy to make. There was virtually complete absence of any temptation to drift away from the fixation light to explore the region in which the test spots were anticipated. The several subjects who had previously submitted to tests on the unmodified Bio-photometer gave substantial testimony to the reduced conflict of attention on the modified instrument.

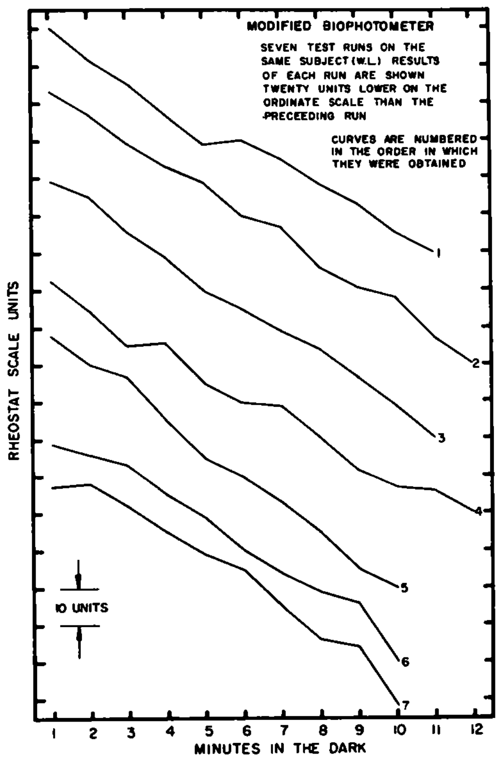

Figure 3. Results of seven test runs on one subject. Each successive run of data is successively displaced 10 rheostat units downward to facilitate complete separation for comparison purposes.

SUMMARY

A Bio-photometer was modified to measure the dark adaptation of one eye while its orientation was controlled by the fixation of the other eye. Preliminary

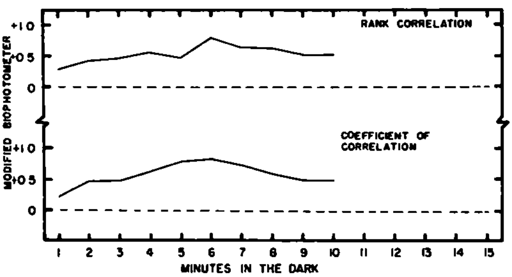

Figure 4. Test-retest correlation coefficients at each of 10 consecutive minutes on 16 pairs of runs on a corresponding number of subjects presumed to be normal. The lower curve represents the standard coefficients of correlation computed from the rheostat scale values. The upper curve represents the rank correlation coefficients computed from the relative ranks of each rheostat scale value at each minute.

testing over a 10-min range on a small sample of subjects suggests that relatively good reliability is attainable, and that the test-retest reliability reaches a maximum at about the sixth minute following the end of the bleach period. Reports of the subjects indicate that the visibility judgments are remarkably easier to make by this technique.

ACKNOWLEDGMENTS

This study was undertaken as a part of the research in night vision for driving, supported by a grant from the American Optometric Foundation.

REFERENCES

1. The instrument manufacturer and address as given in the article were taken from the Bio-photometer nameplate. The accompanying instruction manual was entitled "Vision, Light and Dark Adaptation." Bio-Medical Instrument Company, Newbury, Ohio, no date (circa 1942). In some of the manufacturer's literature the address was given as Chagrin Falls, Ohio.
2. Lyle, W.M., Master's thesis in preparation, Indiana Univ., Bloomington (1962).

Traffic Operations and Driver Performance As Related to Various Conditions of Nighttime Visibility

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During the summer months of 1959 the Traffic and Planning Division of the Minnesota Highway Department and a manufacturer of highway sign materials conducted a joint field study of an experimental reflectorized color guidance system installed in the cloverleaf interchange at the intersection of US 61 and Minn 36. This is a report of the experimental results of traffic surveys and driver interviews made for the study. A description of the reflectorized system is included.

• A STUDY PROGRAM designed to evaluate the use of reflectorized materials for information and guidance through a major highway interchange was undertaken over a seven-week period during the summer of 1959 at the intersection of US 61 and Minn 36. The reflectorized treatment, described fully by Fitzpatrick (1), consisted of the use of colored, reflectorized material combined to distinguish clearly the significant features of an interchange. Signs, pavement markings and delineators were used for the system.

Yellow, consistent with its note of caution, was used to indicate on-ramp and acceleration lanes. The pavement of the acceleration lanes is treated with yellow reflective material paralleled by yellow delineators along the entering ramp and acceleration lane. Yellow delineators also parallel the right-hand edge of the through highway preceding merging zones.

Devices and markings indicative of the exit areas, including deceleration lanes, used blue as the identifying color. The traveled roadway surface of deceleration lanes and exit ramps are treated with blue reflective material and paralleled by blue delineators. Guide signs, appropriate to the particular exit, also use blue reflective material.

An existing pavement lighting installation permitted the study of various combinations of day and night visibility conditions. Five nighttime visibility conditions and two daytime visibility conditions were evaluated for this study. The conditions and dates of the tests are given in Table 1.

Because of the desire to keep the total test period to a minimum, the time between changes in the different conditions was limited to 3- or 4-day weekends. This requirement was in direct conflict with the desire to give drivers more time to adjust to the changing conditions. The only publicity informed the public that the lights at the interchange were to be turned off for a period of five to six weeks so that the Highway Department might conduct a series of tests on new devices for nighttime traffic operations.

Study Site

The intersection of US 61 and Minn 36 is a four-leg, cloverleaf interchange (Fig. 1) immediately north of St. Paul, Minn. Observations were made on the off-ramp from US 61 northbound to Minn 36 eastbound and the on-ramp from Minn 36 eastbound to US 61 northbound. US 61 at the study site has a four-lane portland cement concrete pavement with a median divider. Speed limits on US 61 were 60 mph during the daytime and 50 mph at nighttime. No speed limits were posted for ramp traffic, but

TABLE 1

Condition	Date	Description
I. Night lights on	June 8-12	Intersection operated as before test period. Lighting consisted of mercury vapor luminaires at approximately 200 ft spacing and designed to provide an average illumination on the pavement of 0.6 to 0.8 footcandles. Only interchange was lighted, US 61 and Minn 36 were unlighted.
II. Lights off	June 16-18	No special treatment added and lighting turned off. Existing signs remained unchanged.
III. Interstate delineation—lights off	June 22-26	Lights remained off; delineators placed according to (2). (Standards modified to correct for radii of curves at interchange.)
IV. Full reflective treatment—lights off	July 13-16	Lights remained off, blue and amber delineators and blue and yellow reflective pavement paint added. Blue delineators and reflective paint represented exit ramps. Blue reflective signs replaced green reflective signs at nose of exit ramps. Yellow reflective pavement paint and amber delineators placed at entrance ramps.
V. Full reflective treatment—lights on	July 20-22	Same as Condition IV except lights turned on as in Condition I.
VI. Daytime before treatment	July 12-18	No changes made in signs, delineators, or pavement markings. Same as Conditions I and II except lights not required.
VII. Daytime after treatment	July 9-14	Signs, delineators, and reflective pavement markings arranged as in Conditions IV and V.

yield-right-of-way signs were posted at points where ramp traffic entered through lanes.

Speed change lanes for the off-ramp and the on-ramp are of limited design, but a 10-ft bituminous concrete shoulder immediately adjacent to the through lanes on US 61 was available to road users at the two ramps. Both ramps had bituminous concrete pavements, 22 ft wide with 8-ft bituminous concrete shoulders. Geometric details of the two ramps are shown in Figures 2 and 3. In the following discussion the off-ramp is referred to as Ramp A and the on-ramp as Ramp B.

Collection of Traffic Data

Placement to the nearest 1 ft and travel time to the nearest 0.05 sec were measured at eight segmented metal strips located as shown in Figures 2 and 3. For Ramp A, tapes 1 and 2 detected both through traffic and ramp traffic, whereas the remaining tapes detected ramp traffic only. For Ramp B, tapes 1 through 6 detected ramp traffic only. Tape 7 detected both ramp and through traffic and tape 8 detected through traffic only.

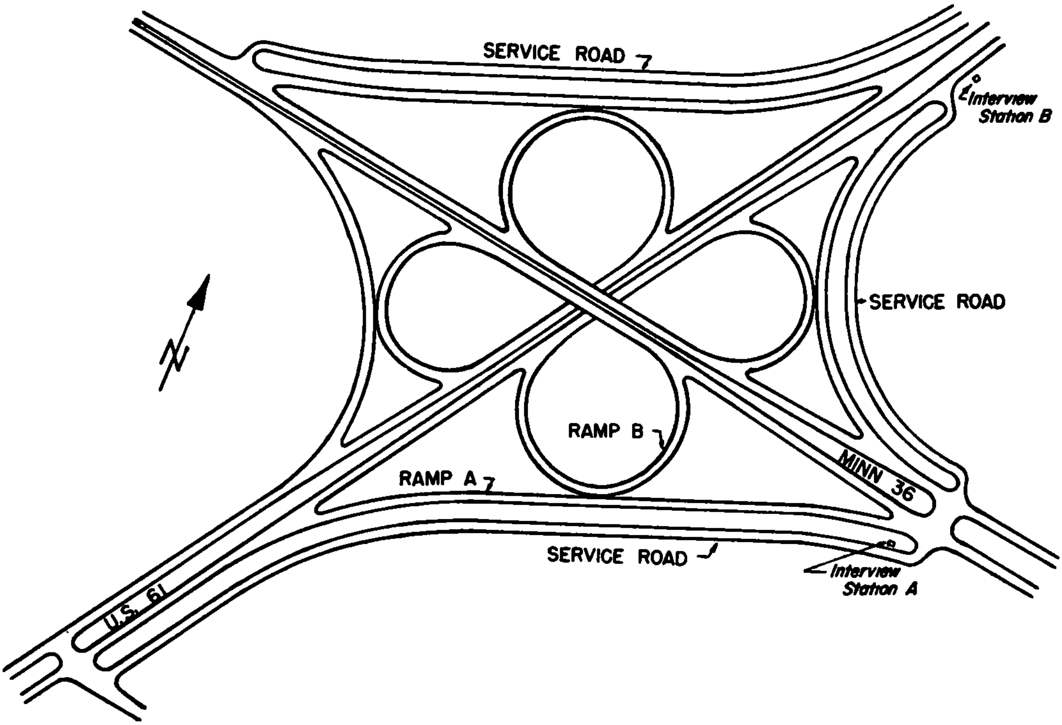

Figure 1. Test site—US 61 and Minn 36.

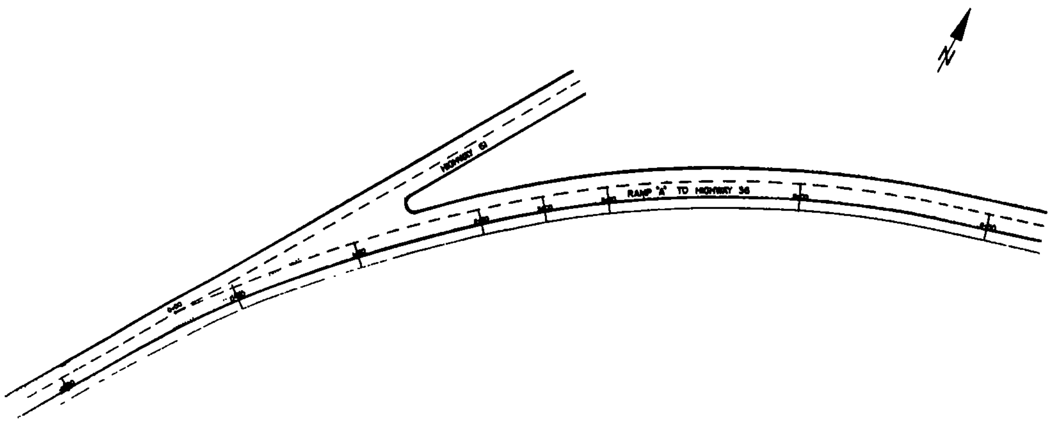

Figure 2. Ramp A.

All night studies were conducted between the hours of 9:30 PM and 12:00 midnight, daytime studies between 3:00 PM and 5:00 PM. All measurements were made on dry pavement with no abnormal weather conditions.

Results of speed and placement observations, at each tape and for each of the test conditions, are given in Table 2 for Ramp A and in Table 3 for Ramp B.

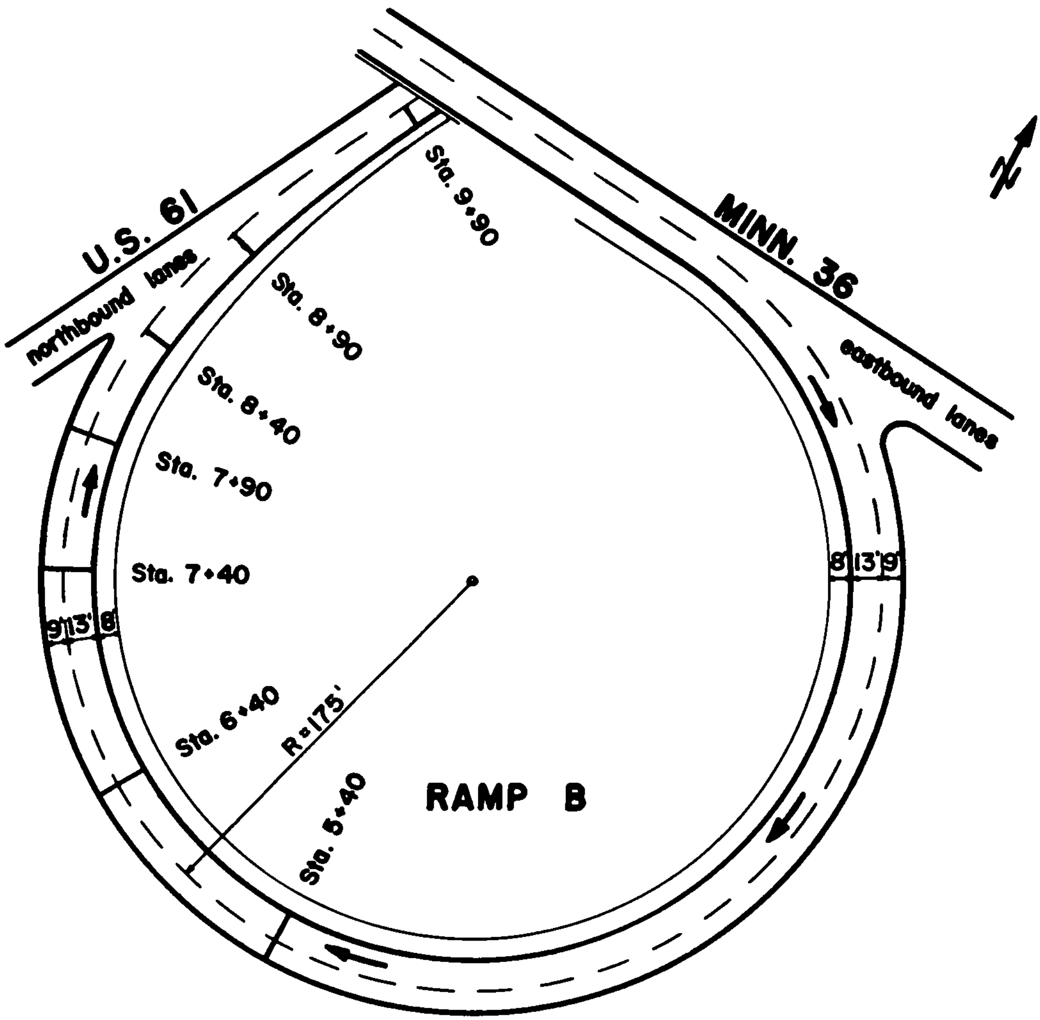

Figure 3. Ramp B.

ANALYSIS OF RESULTS

Ramp A

Velocities of Through Vehicles.—Velocities of through vehicles in the speed trap (1-2) are shown in Figure 4. Mean daytime velocities during the midafternoon hours (48.33 mph) are significantly higher than nighttime velocities (43.38 mph). The difference in speed limit at this site (60 mph daytime, 50 mph nighttime) tends to confuse the effect of visibility on the observed velocities.

The nighttime velocity for through vehicles during Condition I is significantly greater than all other nighttime through velocities. With the exception of Condition I, the type of treatment on the ramp does not appear to have a great effect on the nighttime velocity of through vehicles as they enter the interchange area.

Velocities of Through Vehicles vs Velocity of Ramp Vehicles.—A comparison of velocities of through vehicles against the velocity of ramp vehicles at the same speed trap (tapes 1-2) and of ramp vehicles at the next speed trap (tapes 2-3) is also shown in Figure 4. Vehicles in speed trap 2-3 are partially in the through lane and the dif-

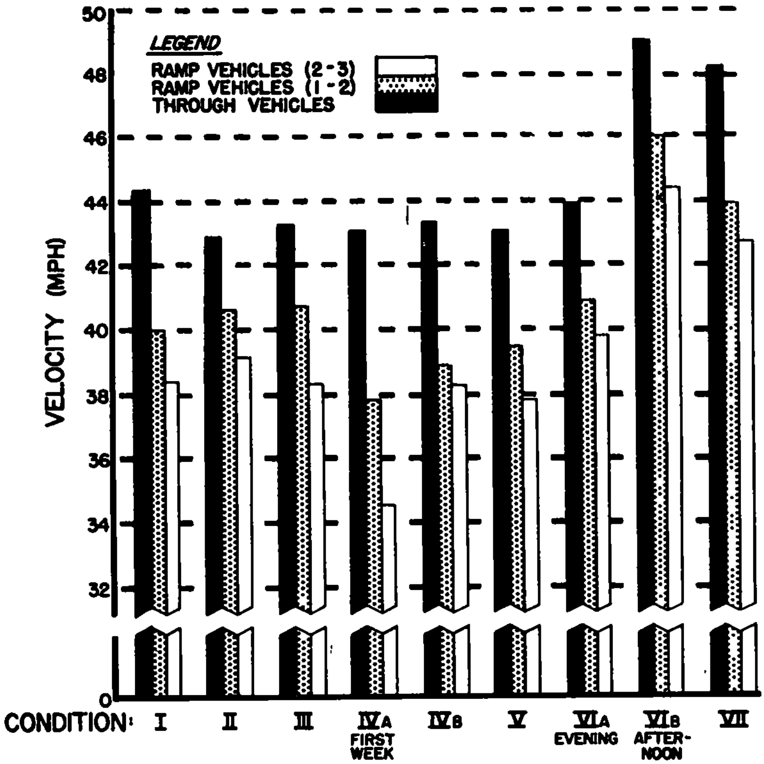

Figure 4. Ramp A velocities.

TABLE 2

SUMMARY OF DATA, RAMP A

Trap	Property	Condition I	Condition II	Condition III	IV 1st Week	IV 2nd Week	V	VI Even-ing	VI After-noon	VII
Through veh (1-2)	Mean velocity (mph)	44 32	42 87	43 30	43 07	43 36	43 05	43 93	49 03	48 18
	Variance (mph)	39 86	42 08	44 18	43 26	44 64	43 48	71 76	55 02	57 80
	Sample size (veh)	433	347	238	111	545	610	240	412	1246
Ramp veh (1-2)	Mean velocity (mph)	39 51	40 62	40 69	37 88	38 90	39 49	40 88	45 91	43 95
	Variance (mph)	39 86	26 86	48 83	48 72	46 78	40 61	54 91	47 49	44 29
	Sample size (veh)	140	127	143	64	157	150	50	173	261
(2-3)	Mean velocity (mph)	38 39	39 17	38 36	34 58	38 33	37 88	39 81	44 41	42 73
	Variance (mph)	40 40	32 99	32 68	39 03	40 54	34 35	38 00	42 63	55 46
	Sample size (veh)	159	131	150	87	158	148	49	175	262
(3-4)	Mean velocity (mph)	39 39	39 49	39 09	37 38	38 39	39 03	40 71	44 56	42 85
	Variance (mph)	34 40	28 38	35 62	40 15	41 56	33 87	27 08	42 44	46 34
	Sample size (veh)	160	131	149	83	157	147	49	177	258
(5-6)	Mean velocity (mph)	40 14	40 67	39 46	37 51	38 52	38 17	41 40	44 63	42 03
	Variance (mph)	46 49	44 06	41 52	62. 27	41 01	35 28	44 77	56 15	59 19
	Sample size (veh)	161	134	150	84	152	146	49	176	252
(6-7)	Mean velocity (mph)	39 14	39 80	38 93	36 99	38 80	39 46	40 11	43 30	42 85
	Variance (mph)	34. 22	29 01	33 64	43 99	42 89	40 43	28 77	35 25	38 44
	Sample size (veh)	161	132	150	85	151	146	49	175	252
(7-8)	Mean velocity (mph)	39 54	39 86	39 09	35 86	38 09	37 93	40 50	43 73	41 86
	Variance (mph)	32 73	31 92	37 73	42 30	41 85	34 91	34 84	40 11	39 29
	Sample size (veh)	159	129	152	88	153	145	49	173	255
Median placement (ft)										
Tape 1		4. 5	4 5	4 5	5 0	4 0	4 5	--	3 5	4 0
Tape 2		2 0	2 0	1 5	2 5	0 0	0 0	--	0 5	-1 0
Tape 3		2 5	3 0	2 0	2 5	2 0	2 0	--	1 0	0 0
Tape 4		2 0	2 5	1 0	2 0	1 5	0 5	--	1 5	-1 0
Tape 5		0 0	1 5	1 0	1 0	1 5	0 5	--	0 0	-1 0
Tape 6		0 0	2 0	1 0	1 5	2 0	1 5	--	1 5	0 5
Tape 7		2 0	4 0	3 0	3 0	2 5	2 0	--	3 5	1 5
Tape 8		2 5	4 5	3 5	4 0	3 0	2 5	--	4.0	2 5

TABLE 3

SUMMARY OF DATA, RAMP B

Trap	Property	Condition I	II	III	IV	V	VI	VII
Through veh	Mean velocity (mph)	41.54	43.27	43.65	42.32	42.13	45.19	46.22
	Variance (mph)	34.72	40.65	40.54	46.18	34.21	43.29	51.97
	Sample size (veh)	305	293	572	538	284	754	514
Ramp veh (1-2)	Mean velocity (mph)	22.96	23.76	23.88	22.99	22.39	22.43	23.49
	Variance (mph)	9.16	8.41	20.68	9.14	11.54	11.93	17.61
	Sample size (veh)	192	167	332	383	241	556	383
(2-3)	Mean velocity (mph)	21.94	23.21	22.73	22.39	21.07	20.94	22.35
	Variance (mph)	10.61	16.87	12.50	11.15	14.71	14.02	20.51
	Sample size (veh)	192	156	329	381	241	557	384
(3-4)	Mean velocity (mph)	20.31	20.04	21.22	20.91	19.29	18.22	19.86
	Variance (mph)	28.32	23.49	22.51	23.41	25.86	31.60	23.86
	Sample size (veh)	192	159	331	390	243	564	378
(4-5)	Mean velocity (mph)	21.21	19.14	20.45	18.44	17.10	16.32	18.17
	Variance (mph)	71.70	61.94	51.69	52.23	60.53	57.73	38.80
	Sample size (veh)	182	152	307	357	230	535	359
(5-6)	Mean velocity (mph)	20.86	19.84	21.75	20.82	19.30	18.96	20.19
	Variance (mph)	33.32	59.04	49.08	54.52	45.14	48.75	45.16
	Sample size (veh)	170	132	281	349	228	528	357
(6-7)	Mean velocity (mph)	24.41	25.41	25.91	26.69	24.75	24.14	25.87
	Variance (mph)	18.92	25.57	34.35	39.40	27.23	28.64	27.66
	Sample size (veh)	169	128	298	354	223	517	352
Median placement (ft):								
Tape 1		2.0	2.5	3.0	0.5	0.5	1.0	-0.5
Tape 2		2.5	3.5	3.0	1.5	0.5	2.5	0.5
Tape 3		3.0	3.5	4.0	1.5	0.5	3.0	1.0
Tape 4		3.0	5.0	4.5	1.5	1.5	3.5	1.0
Tape 5		3.0	4.0	4.0	1.5	1.0	2.5	1.0
Tape 6		4.5	4.5	5.5	3.0	2.5	4.0	2.5

TABLE 4

VELOCITY DIFFERENCES FOR THROUGH VS RAMP VEHICLES

Through vs Ramp Vehicle Trap	Velocity Difference (mph) for Conditions I	II	III	IV 1st Week	IV 2nd Week	V	VI Evening	VI Afternoon	VII
(2-3)	5.93	3.70	4.94	8.49	5.03	5.17	4.62	4.12	5.45
(1-2)	4.40	2.25	2.61	5.19	4.46	3.56	3.05	3.12	4.23

ference in average speed between through vehicles and ramp vehicles at this point ranges from 8.49 to 3.70 mph. A summary of differences is given in Table 4.

During daylight hours, when visibility is presumably ideal, the speed differential between through vehicles and ramp vehicles ranges from 4.12 to 5.45 mph. These speed differentials, day and night, indicate that the geometry of the exit ramp permits ramp vehicles to operate at a speed that minimizes interference with through vehicles.

The difference in velocities between through vehicles and ramp vehicles at the first speed trap on US 61 may give some measure of the advance warning given ramp vehicles by the intersection treatment. The differences are also given in Table 4. Daytime differences before treatment (Condition IV) are consistent at about 3 mph. Drivers are aware of the ramp and make only slight adjustments for the change in speed.

At night, with a minimum of lighting or guides (Conditions II and III) existing traffic did not slow down in anticipation of the ramp. It is not possible to say whether this reflects greater confidence on the part of the driver or less advance knowledge of the point of exit. But inasmuch as these differences are even less than those found under the best conditions of visibility (Conditions VI and VII), the evidence indicates that with no lights, or with Interstate delineation only, drivers are not anticipating the ramp exit.

The maximum speed difference occurs during the first week of full treatment (Condition IV). Drivers approaching the ramp are well aware of the all-blue surface treatment. This effect is also present in the daytime as evidenced by the speed difference of 4.23 mph after full treatment as compared to a difference of 3.12 mph before treatment.

With one week of familiarization the speed difference for night, full treated (Condition IV), changed from 5.19 to 4.46 mph, indicating that drivers were going through a learning process. Further familiarization plus the lights (Condition V) resulted in a further decrease in speed differences.

Although the velocity differences between through and ramp vehicles at the first speed trap do not give clear-cut patterns, it appears that two conclusions may be made:

1. Minimum night visibility guides (Conditions II and III) give less advance knowledge of the precise location of the ramp exit, as evidenced by a minimum velocity difference between ramp and through vehicles.
2. Drivers require a learning period and change their method of operation as time goes on after the introduction of a new and different night guidance system.

Velocity Profiles of Ramp Vehicles.—When velocities at each of the speed traps are shown in Figure 5, daytime velocities are greater than nighttime velocities at all points. All conditions show a pattern of deceleration in passing from trap (1-2) to trap (2-3).

The influence of the treatment on mean velocities is again evident. The lowest observed mean velocities at all stations occurred during the first week of full reflective treatment (Condition IV). Maximum nighttime velocities at all stations occurred with the lights off. During the second week of full treatment, drivers had made adjustments and tended to drive at velocities that approached those under the other conditions. The decrease in velocity with reflective treatment is also evident in the daytime studies.

Before paint was applied, drivers tended to maintain or slightly increase their velocity between the final two speed traps. In all instances, after reflective treatment had been applied, vehicles decelerated when leaving the painted section. Speed trap (6-7) was at the end of the treated section, speed trap (7-8) was beyond the treated section. Drivers faced with an abrupt change in surface treatment reacted by slowing down. (The delineation was continuous over the length of the ramp.)

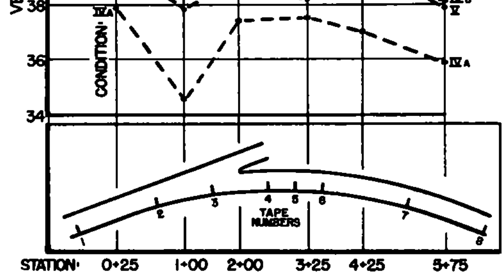

Figure 5. Ramp A velocity profile.

Analysis of Variance of Velocity Data.—An analysis of variance was made to evaluate the differences in velocity and to furnish more information on the reasons for these differences.

Separate analyses were made for the day and night studies. The first week of full treatment (Condition IV) was not included in the analysis inasmuch as it was apparent by inspection that the observed velocities were of different character than the remaining velocities. The daylight evening velocities were not analyzed with the midafternoon velocities for the same reason.

The design for the nighttime analysis of variance is given in Table 5.

TABLE 5

DESIGN FOR NIGHTTIME ANALYSIS OF VARIANCE

Hour	Condition									
	I		II		III		IV		V	
	1st Night	2nd Night	1st Night	2nd Night	1st Night	2nd Night	1st Night	2nd Night	1st Night	2nd Night
1st	X	X	X	X	X	X	X	X	X	X
2nd	X	X	X	X	X	X	X	X	X	X

Five different conditions were observed. Each condition was observed on two different weekday nights, generally not on consecutive evenings. Two hours of data were collected for each night. The following questions were asked and tested:

1. Are the speeds significantly different for each of the five treatment conditions?
2. Is there any difference in speeds between the early part of the week and the latter part of the week? (1st day vs 2nd day)
3. Are the speeds in the early night hours (approximately 9:45 to 11:00 PM) significantly different from speeds observed at a later hour of the night? (1st hour vs 2nd hour)
4. Are the speeds for the ten different days significantly different? (days) This item, difference between the ten nights, would presumably be significant if the treatment differences were significant. On the other hand, the night-to-night differences may or may not be different if the treatment differences are not significant.

The analysis of variance test given in Table 5 was applied to the following speed observations:

Through vehicles

Trap 1 - 4 (ramp)
Trap 5 - 8 (ramp)
Trap 1 - 2 (ramp)
Trap 2 - 3 (ramp)
Trap 3 - 4 (ramp)
Trap 5 - 6 (ramp)
Trap 6 - 7 (ramp)
Trap 7 - 8 (ramp)

The same analysis of variance design was used for the daytime speeds, except that no comparison was made between the first and second days. The first day vs second day comparison was not made because the elimination of the daytime-evening observations reduced the before daytime study (Condition V) to only one day of observation.

The results of the analysis of variance are given in Table 6.

TABLE 6

RESULTS OF ANALYSIS OF VARIANCE[a]

Source of Difference	Night				Day		
	Treatment Conditions	1st Hr vs 2nd Hr c	Days	1st Day vs 2nd Day	Treatment Conditions	1st Hr vs 2nd Hr	Days
Through vehicles	0.025[b]	0.001[c]	0.001[c]	0.05[b]	0.040[b]	0.500	0.150
Trap 1-4	0.200	0.150	0.50[b]$_{b}$	0.02[b]	0.003[b]	0.800	0.001[c]
Trap 5-8	0.450	0.180	0.020[b]	0.15$_{b}$	0.020[b]	0.800	0.040[b]
Trap 1-2	0.080	0.120	0.030[b]	0.02[b]	0.003[b]	0.900	0.002[c]
Trap 2-3	0.500$_{c}$	0.650	0.200	0.20	0.20[b]	0.800	0.002[c]
Trap 3-4	0.500[c]	0.250	0.080$_{c}$	0.07	0.010[c]	0.400	0.004[c]
Trap 5-6	0.004[c]	0.600	0.003[c]	0.08$_{b}$	0.001[c]	0.600	0.003[c]
Trap 6-7	0.600$_{b}$	0.800	0.090$_{c}$	0.02[b]	0.450$_{b}$	0.800	0.080$_{c}$
Trap 7-8	0.020[b]	0.100	0.022[c]	0.15	0.004[b]	0.600	0.004[c]

[a]Numerical entries give probability of getting velocity differences under any condition by chance alone.
[b]Velocity differences that might occur by chance alone less than 1 time in 20.
[c]Velocity differences that might occur by chance alone less than 1 time in 100.

During the daytime studies there was no real difference between the first and second hour observations. The difference between treatments and days are significant at nearly all points.

The nighttime velocity analysis is less consistent. There appears to be no justification for assuming that velocities during the two study hours at night were not the same on any given night (except for through vehicles). There is no logical explanation for this significant difference by hours for the through vehicles when a like difference does not occur for ramp vehicles.

The analysis of variance indicates that the different treatments have a significant effect on speeds only for through vehicles, and ramp vehicles between tapes 5 - 6 and 7 - 8. The significance of the speed differences between 7 - 8 is explained by the driver reaction to the end of the color pavement. There is no logical explanation to the speed difference between 5 and 6. The significant difference in speed between through vehicles for the treatment conditions is brought about by the higher speeds of the vehicles during Condition I. This may be a function of the chronology of the experiment as well as the visibility conditions, inasmuch as during Condition I drivers were unaware of a testing program, though in subsequent tests drivers were aware of some program.

Although the analysis of variance does not indicate a statistically significant difference in treatments, there are several factors that influence the test for analysis of variance. Figure 5 shows that velocities for Condition II (no lights) are consistently higher at all stations during nighttime observations. Although the analysis of variance test did not establish a statistically significant difference, it is most improbable that the speeds during the Condition II study (lights off) could exceed speeds during all other conditions at all six speed traps simply by chance. (The actual probability is $1/5^6$ = 1/15, 625.)

The extreme variation in observed speeds between drivers also influences the results of the analysis of variance. The observed standard deviation at night is about 6.5 mph, which means that the range of speed between the 15 percentile and 85 percentile is approximately 13.0 mph. This rather large difference between drivers tends to obscure any real difference between the other factors being tested; i.e., days, first hour vs 2nd hour, treatments, etc. If differences do exist, this difficulty of extreme variation can be overcome by increasing the sample size. The necessity of limiting the over-all study period and the relatively low volumes at night made it extremely difficult to obtain a larger sample than observed in this study. The higher daytime volumes permitted larger sample sizes to be taken without increasing the sampling rate or time.

The speed differences between the first day and second day of the test were not anticipated. However, at three of the nighttime speed traps there is an indication that such a difference may exist. The first day-second day difference has little influence on the results of the test for differences between treatments but does give some indication that in an experiment of this type the time of the week should be a control factor.

In almost all speed traps, the night-to-night speed differences are significant. These speed differences are a function of two principal causes: (a) any differences caused by the type of treatment on drivers' speeds at night, and (b) differences in the way drivers behave from day to day. Drivers do not react in the same way on different days even when all apparent differences in the highway, weather, etc., have been eliminated. It appears that this variation is even greater than the effect of the treatment used on the highway and does mask some of the observed differences.

Vehicle Placement. —Figure 6 shows the median placement of the right rear wheel of vehicles relative to the right-hand edge of the pavement, shown to the nearest ½ ft. Placement stations 1 and 2 are located on the through pavement, the right-hand edge being the edge of the concrete. Positions 3 through 8 are on the off-ramp with the edge of the traveled portion being separated from the paved shoulder by a white reflectorized shoulder stripe. The nighttime situation with lights is taken as the standard of comparison.

Vehicle placements for daytime before-and-after reflectorized treatment and for nighttime with the lights on (Condition I) are shown in the upper section of Figure 6.

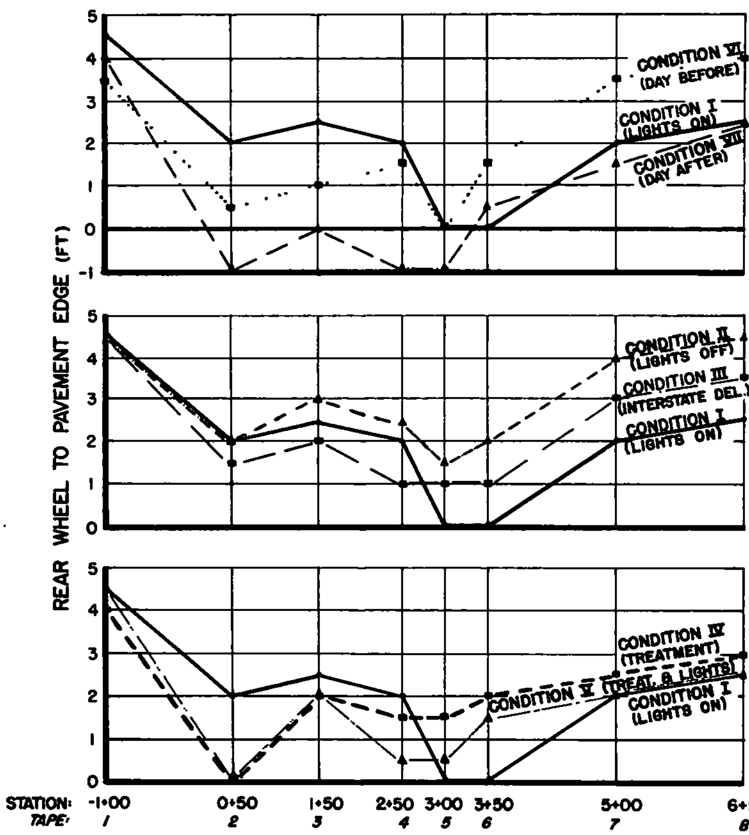

Figure 6. Ramp A vehicle placement.

The most notable difference between the three conditions occurs at stations 2, 3 and 4, when the effect of the treatment in daylight is to cause the vehicles to use the shoulder as a transition lane to the ramp. (The geometry of Ramp A is such that the most gradual approach to the ramp is one that approaches the shoulder of the pavement at stations 2 and 3.) At night with lights, vehicles remained 2 ft away from the shoulder, following a more abrupt path to the ramp; in daytime before treatment, the path is midway between the other paths shown.

At nighttime with minimum guides (Conditions II and III), vehicles used nearly the same path as with the lights on as shown in the second section of Figure 6. Drivers took a median position at least 1 ft away from the shoulder at all stations.

Finally the effect of the addition of the reflectorized treatment both with and without lights is shown in the lower section of Figure 6. In moving from the through lane to the ramp at station 2, the vehicles again use more of the shoulder as a transition lane, as was the case for daytime with pavement treatment. Beyond the nose of the ramp the paths cross and are then parallel to the vehicular paths observed with lights only.

In all instances in which reflectorized treatment was used (Conditions IV, V, and VII), vehicles tended to use more of the shoulder lane parallel to US 61 in decelerating and approaching the off-ramp. This is consistent with the observations for speed, in which instances, reflectorized treatment conditions apparently caused ramp drivers to approach with a lesser velocity than for other conditions. During the daytime with reflectorized treatment, when drivers were aware of the material on the edge of the shoulder, they did use portions of the shoulder in preference to driving on the brightly colored pavement In no other instance was the median placement position beyond the edge of the pavement.

Ramp B

Velocity Analysis. —The purpose and geometry of Ramp B precludes a complete analysis of velocities as made for Ramp A. The absence of an acceleration lane, the

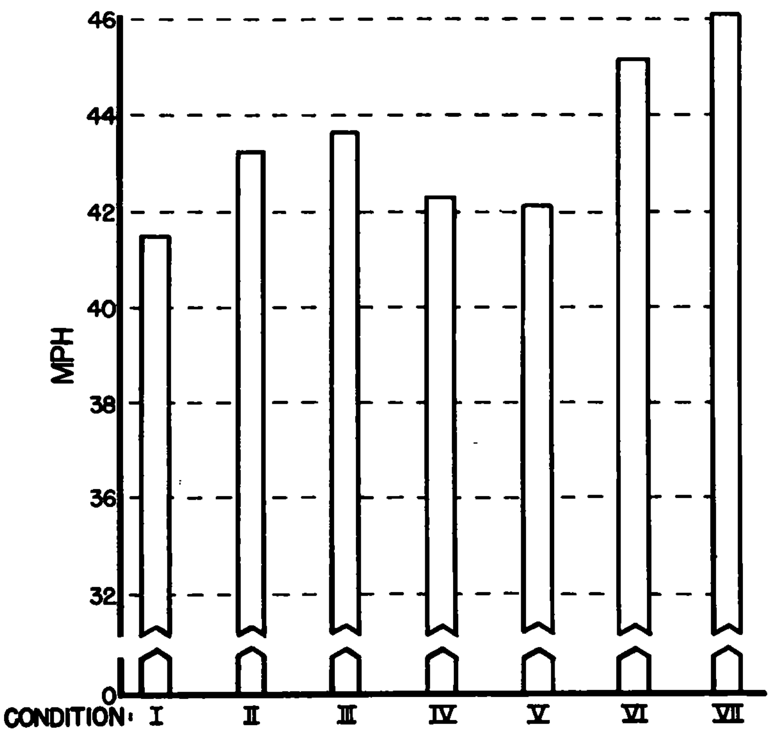

Figure 7. Ramp B over-all velocity.

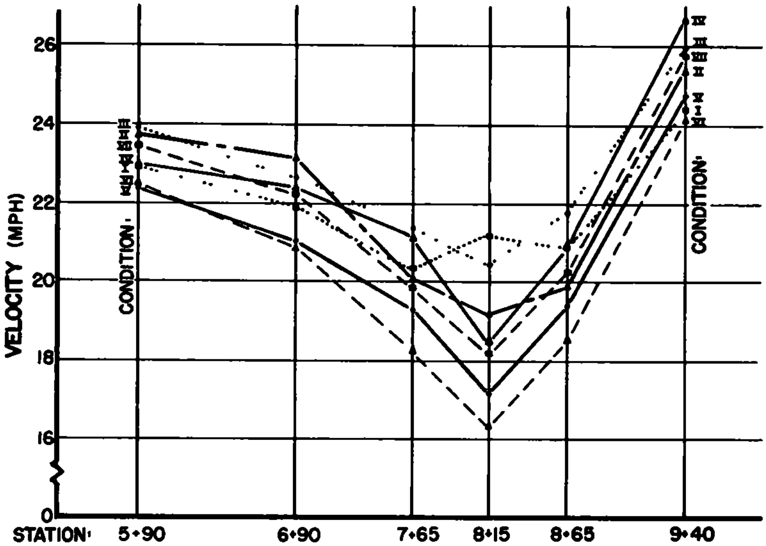

Figure 8. Ramp B velocity profile.

presence or absence of vehicles on US 61, a greater volume on Ramp B, and the restrictive geometry of the ramp limited the free choice of speed by the majority of vehicle drivers, so that visibility conditions are considered to have a lesser effect than that in the analysis of Ramp A. The following data are presented to give an indication of the type and nature of operation at Ramp B.

Velocities of Through Vehicles. —Velocities of through vehicles on US 61 in the lane immediately adjacent to Ramp B are shown in Figure 7. The average of all nighttime velocities was 42.70 mph and for daytime the average was 45.61 mph; in both instances less than the equivalent measurement made before the entrance to Ramp A. Through vehicles at this point were influenced by the presence of ramp vehicles and by deceleration of some through vehicles preparing to turn at the next exit ramp immediately beyond the end of the speed trap.

Maximum nighttime velocities occurred during the condition of poor visibility (i.e., no light) and with Interstate delineation only. During the daytime the maximum through speed occurred after treatment.

Velocity Profiles of Ramp Vehicles. —Velocity profiles for Ramp B are shown in Figure 8. Daytime velocities are no greater than those observed at nighttime, again reflecting the influence of the volume on velocity patterns at this ramp.

Vehicles enter the test area at a speed of about 23 mph and decelerate to about 18.5 mph at a point 100 ft before entering the through lane. From this point onward, the average vehicles accelerate quickly, entering the through lane at a grand average velocity of 25.5 mph; about 15 to 20 mph slower than the through vehicles in the same lane.

Vehicle Placements. —Median vehicle placements for Ramp B are shown in Figure 9. Placements again refer to the right rear wheel and are referenced to the paved shoulder edge which is differentiated from the true pavement edge on the ramp by means of a reflectorized shoulder edge marking. Station 7 is on the highway and the vehicle positions at this point are influenced by traffic on US 61. Station 8 is beyond the point at which ramp vehicles would cross it and is applicable to through vehicles only. The discussion applies only to placement stations 1 through 6 which are on the circular portion of the ramp.

The condition for daytime before, daytime after, and lights on is shown in the upper section of Figure 9. For lights on and daytime before treatment, the paths are very nearly parallel. After the painted treatment in the daylight, when the paved shoulder is visible to the driver, the driver path is shifted 2 ft towards the inside the circle, the average driver using only the first 7 ft of a 22-ft wide pavement.

Vehicle placements for Conditions I, II, and III are compared in the middle section of Figure 9. The effect of turning the lights off is to cause the drivers to move from ½ to 1 ft or more further on to the pavement and stay away from the shoulder to a greater degree than with the light on. There is little difference between the light-off condition and the addition of Interstate delineator.

The effect of reflectorized treatment during Conditions IV and V is shown in the lower portion of Figure 9. Again, the effect of treatment only (Condition IV) and treatment plus light (Condition V) is to move the vehicles closer to the shoulder, much as existed for the daytime, after reflectorized treatment.

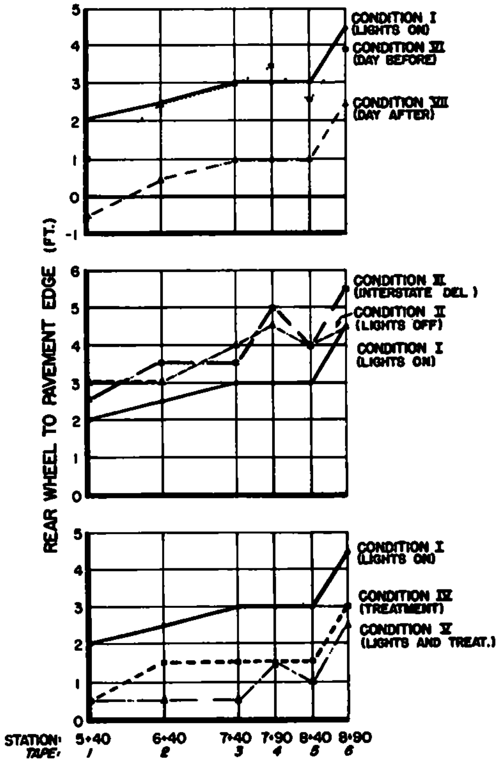

Figure 9. Ramp B vehicle placement.

SUMMARY

The summary of results is as follows:

1. Except for lights on, the type of treatment used at the intersection had relatively little effect on nighttime velocities of through vehicles as they approached the interchange at a point 300 ft before the nose of the first exit ramp. Absolute volume levels of through and merging vehicles influenced the velocities between Ramps A and B. Daytime through velocities were less after treatment than before.

2. Greatest differences in nighttime velocities between through vehicles and off-ramp vehicles before their exit (taken as indicative of early recognition of the exit situation) occurred with lights only, reflective treatment only, and reflective treatment plus lights. Minimum speed differences at the off-ramp occurred with lights off and Interstate delineation treatment.

3. Daytime velocity differences between through vehicles and off-ramp vehicles were greater than at nighttime with no lights and with Interstate delineation only.

4. Minimum off-ramp velocities occurred during the first week of reflective treatment. Maximum nighttime off-ramp velocities occurred with minimum treatment—no lights. Daytime off-ramp velocities were consistently greater than nighttime velocities; daytime before reflective treatment greater than after reflective treatment. Off-ramp velocities tended to increase with time as drivers adjusted to the reflectorized treatment.

5. Off-ramp vehicles tended to decelerate when passing from reflectorized pavement to nonreflectorized pavement. This pattern occurred during daylight, with reflective treatment at night, and with reflective treatment plus lights. The deceleration took place even though the blue and yellow reflectorized delineators were extended over the length of the ramp.

6. Velocities at Ramp B are influenced by volumes of ramp traffic and through traffic, the higher velocities on the ramp occurring at night with low volume. Daytime Ramp B velocities are lower, largely because of the influence of the greater volume rates during the day.

7. In all conditions of reflectorized treatment, daytime, nighttime treatment only, and treatment plus lights, drivers used more of the shoulder lane parallel to US 61 in

decelerating and entering the off-ramp. Minimum use of the shoulder for transition to the off-ramp occurred with lights on, lights off, and Interstate delineation. During daytime after treatment, drivers tended to use the shoulder of the ramp proper for a greater distance than any other treatment condition.

8. At Ramp B, vehicle placements for lights on and daylight are nearly identical. With poorer levels of visibility, lights off and Interstate delineation, drivers move closer to the center of the ramp away from the shoulder. With treatment, day, night, and treatment plus lights, drivers tend to move away from the center of the ramp, using the extreme right-hand edge of the pavement.

CONCLUSIONS

The conclusions drawn from the analysis of the data are based on studies made with minimum periods for driver familiarization between phases of the study. Although further time for adjustment by the drivers to the different treatments may have influenced the results, the basic measurements are taken to be typical of the influence of the different treatments on driver patterns.

The most evident influence of the integrated reflectorized treatment occurred at the exit ramp. Both velocity differences and use of the paved shoulder as a transition to the off-ramp indicated that the system gave drivers knowledge of the exit location which was equal to that in daytime or with the lights on. The combined use of lights and reflective treatment did not show a substantial change in the use of the exit ramp when compared with lights only or reflective treatment only.

There is evidence that full width painting of the on-ramp in particular caused drivers to encroach on the shoulder. Whether drivers would follow this pattern with less substantial shoulders than are present at this site is not evident from the data. Also, the abrupt ending of the blue pavement at the off-ramp caused drivers to slow down when leaving the blue pavement. More gradual transitions for the start of the yellow on-ramp paint and the end of the blue off-ramp paint will probably diminish these last two effects. It is also possible that broad stripes of reflectorized pavement will accomplish the same results as obtained with full width reflectorized pavement.

Finally, further test installations at different interchanges will be required to substantiate the findings of this particular study and its applicability to other conditions of design and traffic. Even more important is the need for improved measures of driver performance and evaluation of highway improvements. This study has compared stream flow characteristics, day and night, for different treatment conditions one against the other. No absolute figure of merit is available. There is a real need to develop better measures than those used here, many of which only indirectly get at the needed answers.

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Requisite Luminance Characteristics For Reflective Signs

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Signing on urban and rural roadways exhibits a complex of sign positions and ambient illumination levels suggesting need for determining optimum characteristics for retro-reflective materials under these conditions. Other studies have evaluated available reflective materials for individual effectiveness. This study is designed to establish reflective characteristics required for any installation and suggests a brightness range for typical sign environments.

Ideally, consistent luminance would be maintained through approach distances for all sign positions. Iso-illuminance and iso-divergence data indicate varying illuminance and retro-reflective efficiency throughout the approach. However, inverse relationship at generally useful distances indicates little modification of the classic divergence curve is necessary for materials considered.

Ambient illumination of sign surfaces commonly ranges from 0.4 foot-candles in illuminated areas to less than 0.1 in rural locales. Current reflective materials provide good high beam performance and adequate low beam performance where ambient illumination incident on the sign surface does not exceed 0.4 foot-candles. In excess of 0.4 foot-candles, stream traffic provides additional useful luminance. Sufficiency values for sign luminance are presented for dark and illuminated locales.

• IT IS generally acknowledged that sign performance is dependent on attention value and legibility. Forbes (1) has reported that these are functions of target and priority value, pure and glance legibility, respectively. Each factor is related directly to contrast—the sign with surround, providing attention value; letters with background, for legibility.

Literally, contrast is the result of apparent differences in brightness and color alone, and a subjective experience given to extreme variation at night. Excessive stimuli from glare sources (such as opposing headlights and luminaires, colored tail lamps, and electric advertising) contrast with the generally inadequate luminance for effective nighttime perception elsewhere in the highway scene. In the absence of minimal luminance of conventional sign surfaces at night, the Manual of Uniform Traffic Control Devices (2) prescribes the reflectorization or illumination of essential traffic signs.

Most studies of reflective treatments have been largely confined to a comparison of the performance of available materials in a dark environment at one or two sign positions. Yet marked differences are experienced in field brightness and headlight illumination with varying sign location and position. Ranging from total darkness to brilliant illumination, these conditions seem to impose widely different luminance demands on signs and legends for optimum contrast prompting investigation of the characteristics required for desirable retro-reflective performance in a number of common situations.

Consideration of night traffic sign environments suggests three representative conditions: (a) dark rural, (b) illuminated suburban, and (c) bright urban. Each is a qualitative expression of ambient illumination and invites separate consideration of contrast needed for maximum attention value and legibility. Unfortunately, techniques for the quantitative determination of field brightness and attention value are still largely unsuitable for field use. Accordingly, this study is limited to the evaluation of luminance needs and consequent necessary reflective performance for satisfactory sign legibility in the several environments.

LEGIBILITY AND REFLECTION

Legibility Criteria

Legibility criteria are generally employed in the assessment of luminance for optimum performance. The luminance desirable for dark conditions has been reported by Allen (3) for letter sizes from 8 through 18 in. Under the test conditions maximum legibility for the modified BPR Series E illuminated letters on dark backgrounds occurred at approximately 10 to 20 ft-Lamberts (ft-L) (see Fig. 1).

It is apparent that a satisfactory confidence level results within a range of letter luminances from 1.5 to 100 ft-L. The reduction in legibility distance at 100 ft-L has been attributed to halation or "overglow." At 1 ft-L, legibility is reduced to approximately 80 percent of maximum; 0.1 ft-L is shown to yield 45 percent of maximum.

Despite the relatively large luminance span from 1.5 to 100 ft-L, the corresponding legibility is shown to range from 63 to 74 ft per in. of letter height. A similar study performed by the authors led to legibility distances essentially consistent with those reported by Allen. Slight differences are attributable to variations in test conditions.

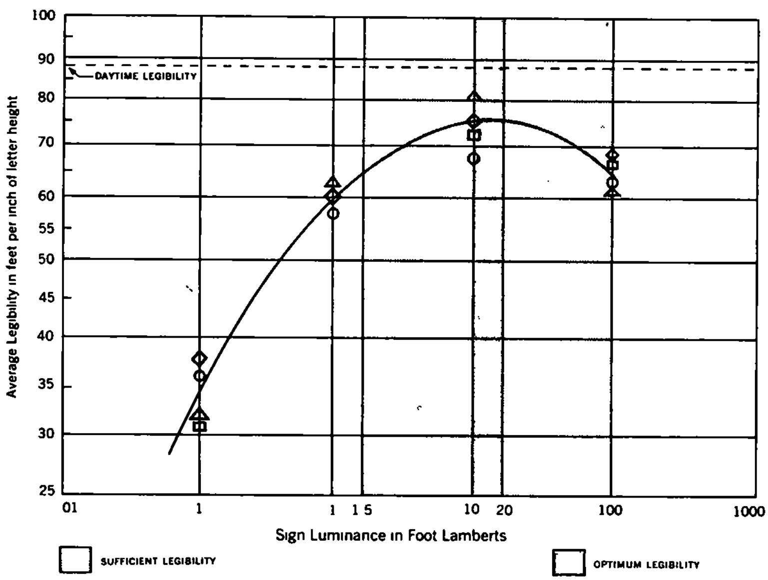

Figure 1. Optimum and satisfactory legibility distances for 8- to 18-in. BPR Series E (Mod.) shown relative to letter luminance. Legibility data from Allen (3).

Reflective Characteristics

The luminance attained by reflective treatments is dependent on their specific luminance, illuminance, angular position relative to the vehicle (incidence), and the angle subtended at the sign by the motorist and his headlights (divergence). With the exception of specific luminance, each is affected by sign position and distance. The influence of the independent variables—sign position, distance, and specific luminance—must be determined from an analysis of the highway scene.

Derivation of Luminance Data.—Sign placement was found to exist in a vertical field of approximately 2,000 sq ft. This is represented graphically by a plane extending 55 ft from the right edge of the lane of travel, 24 ft to the left and 28 ft above the lane. For reference, the right headlamp assembly is positioned 2 ft to the left of the road edge. Standard traffic signs—overhead, edge, median, and shoulder mounted—fall within the field boundaries (see Fig. 2).

Conventional traffic and Interstate signs employ letters varying in height from approximately 3 to 24 in. with corresponding legibility varying from less than 100 ft to more than 1,000 ft. For the purpose of this study, the limits of visual observation were 75 and 1,200 ft. Luminance calculations were also made for intermediate distances of 150, 300, 450, 600, and 900 ft (see Fig. 3).

Headlamp Illumination.—Varying headlamp intensity throughout the sign field necessitated a plot of illumination for each headlight assembly for high and low beams. To establish headlamp distribution for the seven distances, appropriate areas of iso-candle charts for the dual headlamp system were photographically enlarged and plotted for each distance. Illuminance values were calculated by application of the inverse square law. Illuminance for a typical information sign is shown in Figure 3. Headlamp illumination was found to vary from a minimum on low beams of 0.001 ft-candle to a maximum on high beams of 7 ft-candles.

Divergence Fields.—Retro-reflective materials exhibit varying efficiency expressed in terms of specific luminance with respect to the divergence angle (Fig. 4). Specific luminance has been defined as foot-Lamberts luminance per incident foot-candle and is determined photometrically at specified divergence angles with a 1,000-watt tungsten light source and a photronic cell chromatically corrected for the spectral response of the human eye.

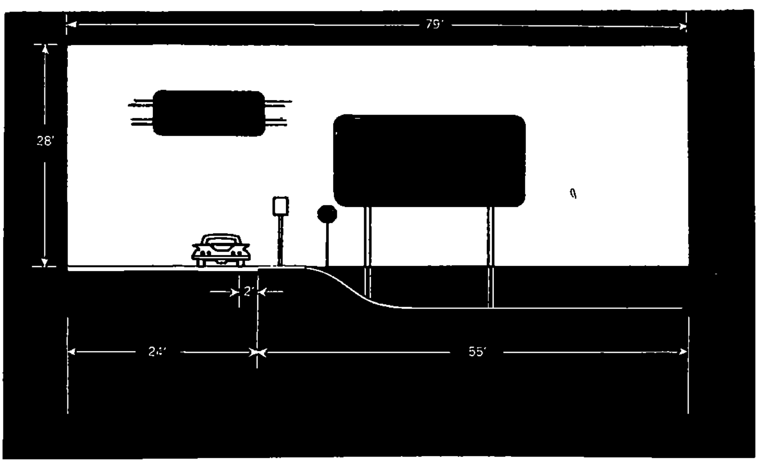

Figure 2. Sign field showing relative position of typical roadway, vehicle, and traffic signs.

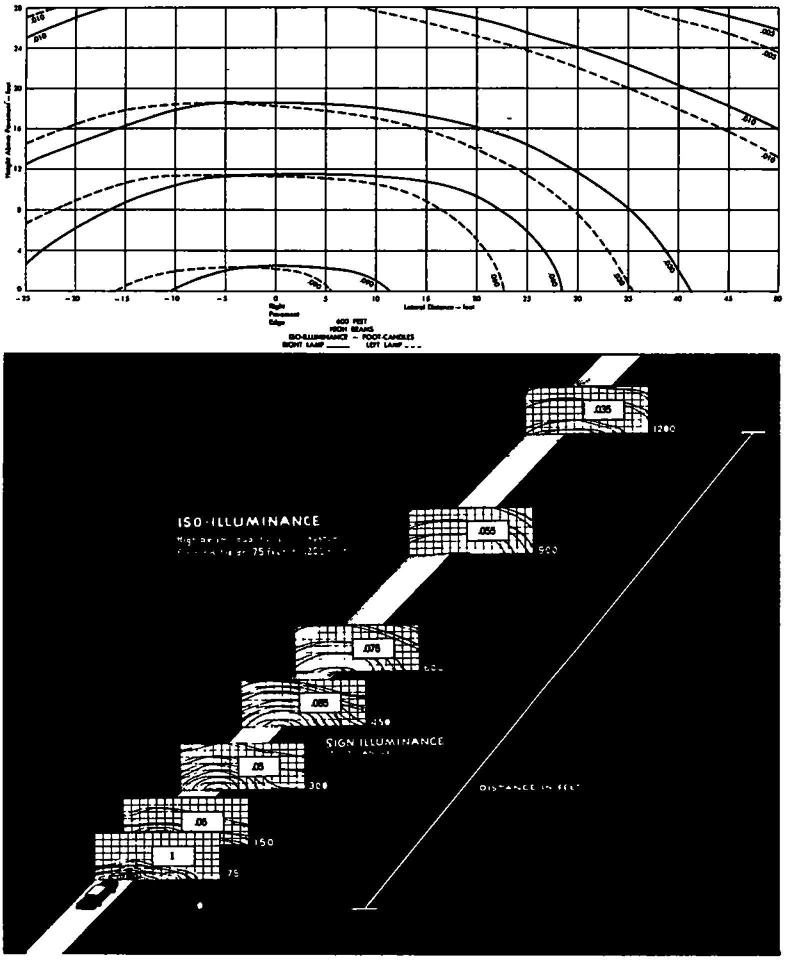

Figure 3. Distribution of high beam illumination for seven distances indicating illuminance values for typical information sign.

The divergence angle is the angle subtended by incident light from the source and the reflected light beam at the observer. The trigonometric expression for this angle is

$$\cos \theta = \frac{a^2 + b^2 - c^2}{2ab}$$

in which

θ = divergence angle;
a = headlamp-to-sign distance;
b = eye-to-sign distance; and
c = eye-to-headlamp distance.

To determine the divergence angle appropriate for each headlamp, average figures were obtained from measurements of a number of late model automobiles (1958-61).

Distance between headlamps	5.1 ft
Height of headlamps from road	2.5 ft
Eye height above road	4.1 ft

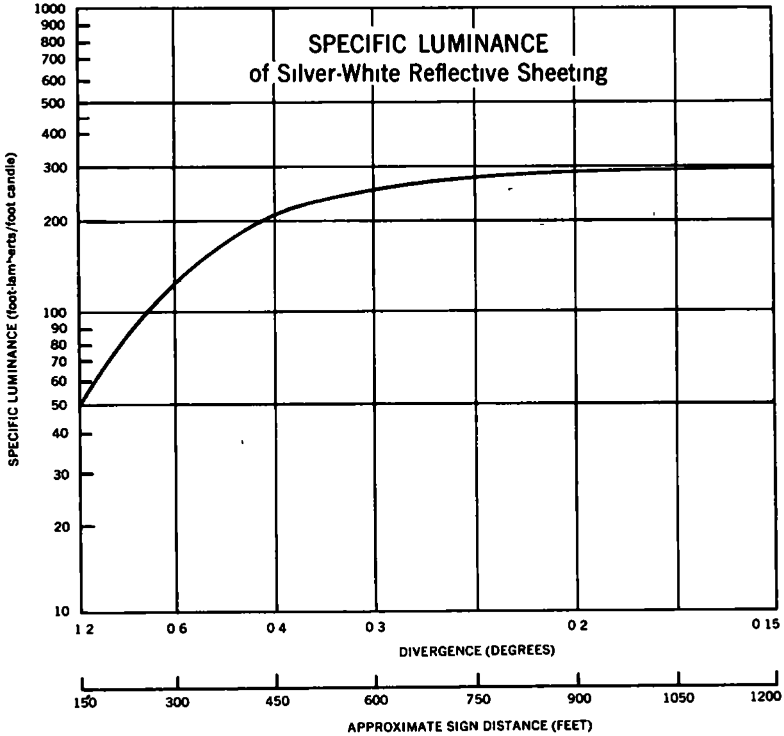

Figure 4. Specific luminance for silver-white reflective sheeting relative to divergence angle and corresponding average distance.

Lateral distance, line of sight to left headlamp	1.05 ft
Horizontal distance from eyes to headlamps	7.5 ft

The resulting expression was programed for computer calculation. Values for 136 divergence angles per headlamp assembly were obtained for the seven sign fields (4). The data reveal that the value of the divergence angle varies from right to left lamp by a factor ranging from 2x to 4x. Inasmuch as each headlamp assembly supplies a factorially different part of the total illumination, right and left lamp assemblies and related divergence angle must be independently considered.

Sign Luminance. —Sign luminance is determined by reference to the graphical data which provide illumination and divergence for each headlamp. The sign luminance for each lamp assembly is the product of the specific luminance and illuminance at the sign. The sum of the products for each headlamp assembly is the apparent sign luminance to the driver in foot-Lamberts.

The resultant luminance is shown in Figure 5 for several typical sign positions based on the performance of retro-reflective sheeting employed on traffic signs. From 100 to 1,200 ft, high beams provide a 2 ½ to 1 ratio between minimum and maximum luminance with an average value of 20 ft-L. Large panels of silver-white reflective materials exhibiting specific luminance characteristics shown in Figure 4 were used to confirm calculated luminance values. Measurements made with a Luckiesh-Taylor brightness meter at representative positions, and distances were found to agree with the calculations.

Ideally, the luminance curve would be flat, affording uniform brightness at all distances, a characteristic of daylight illumination. Fortunately, changing distance ex-

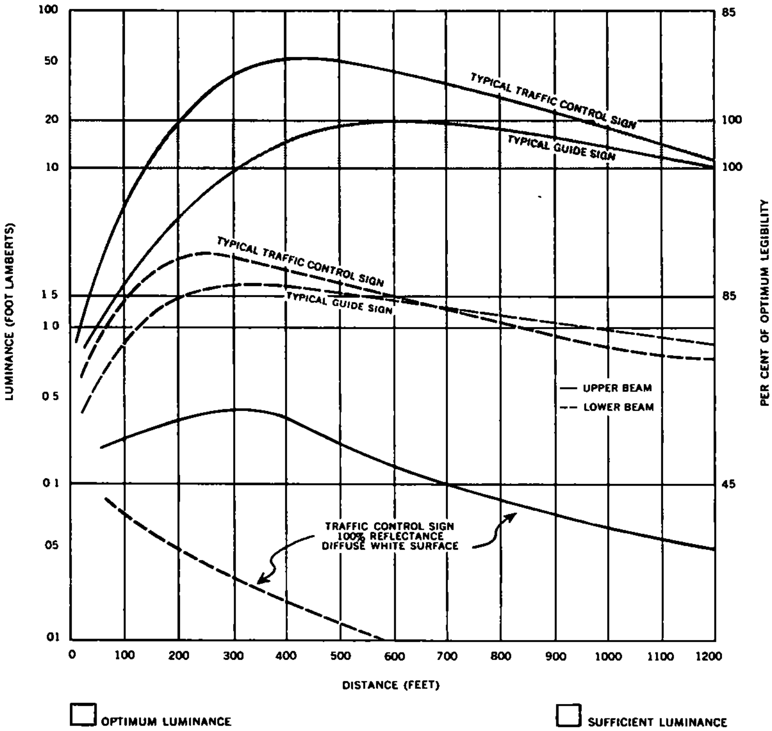

Figure 5. Reflective sign luminance for distances from 75 to 1,200 ft for high and low beams. Optimum and sufficient ranges provide 100 and 85 percent of maximum legibility distance for the modified alphabets, 8 to 18 in. Luminance of perfectly diffusing white surface shown for comparison.

hibits an inherent dichotomy in the optical performance of retro-reflective systems as illustrated by the related but contradictory effects of changing headlamp intensities and divergence angles on sign approach.

At great distance, headlamp illumination is understandably low. Concurrently, divergence angles are small, contributing to high efficiency (Fig. 4) and compensating for generally low illuminance. With decreased distance, exponential increases in headlamp illumination largely offset corresponding reductions in efficiency at the higher divergence angles.

The combined result of these changes is illustrated by the luminance values shown in Figure 5. The degree of compensation offered by these conflicting effects is seen to provide a maximum luminance variation of 2 ½ to 1 within generally useful distances. This compares with the 4 to 1 ratio considered suitable for roadway illumination.

It is possible to design a divergence curve for reflective materials which would yield uniform luminance throughout the approach. This function will cross the present divergence curve at 0.2° and 0.85°, corresponding to approximately 900 and 200 ft, respectively. Between these distances, present materials are in excess of most brightness requirements.

Ambient Illumination. —A number of previous studies have suggested that sign legibility is related to the degree of ambient illumination provided by the environment. To establish prevailing luminance levels, measurements were made of a diffusing white surface exhibiting 90 percent reflectance with a Luckiesh-Taylor brightness meter. In each case this standard reference surface was held normal to traffic flow in representative sign positions.

With good-sized reference panels this instrument permits determination of a wide range of luminance at distances of a few feet to over 200 ft. Because data from this meter are related to the operator's experience, a 9-ft-L standard source was employed to confirm observer accuracy. Numerous measurements in several illuminated locales were averaged to determine the levels of incident illumination. Review of the data suggested the three categories under which performance tests should be conducted.

DARK RURAL

Within this range, illumination was found to be negligible. Light levels incident on sign surfaces in this category vary from minimal to 0.1 ft-L. Legibility studies by Allen, previously reviewed, fit these data. Reflective sheeting luminance of 10 to 20 ft-L, as shown in Figure 5, provides 100 percent legibility with the 85 percent level occurring at 1.5 and 100 ft-L. Calculated luminance, confirmed by measurements with the brightness meter, indicates that reflective sheeting luminance provides in excess of 1.5 ft-L at distances from 150 to 650 ft with low beams. High beams provide 3 to 50 ft-L of reflective sheeting luminance at distances ranging from 100 to 1,200 ft.

ILLUMINATED SUBURBAN

Light levels incident on sign surfaces in this category vary from 0.1 to 0.4 ft-L. Road illumination with attendant glare sources increases prevailing light levels. The disabling effect of glare sources on vision has been determined by Fry (5). Bright glare sources subtending narrow angles with the object viewed were shown to impart a marked veiling influence rapidly diminishing with angular increases. The substantial difference in height between luminaires and typical shoulder mounted signs may provide the necessary angular displacement.

To determine the prevailing illumination and its effect on legibility where highway lighting is used, a number of illuminated interchanges and their approaches were mea-

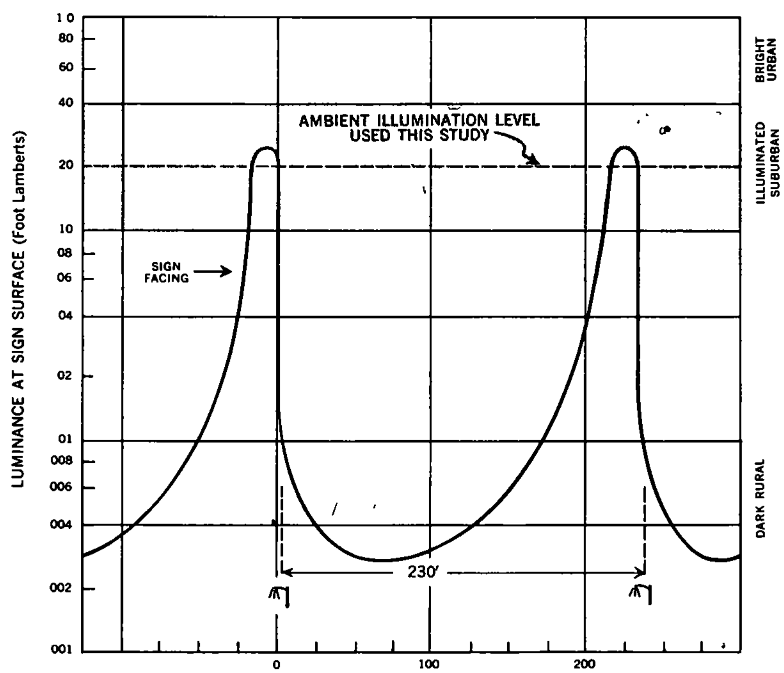

Figure 6. Luminance exhibited by 90 percent reflectance vertical sign surface relative to luminaire location shown for guide sign position. Illumination provided by mercury vapor luminaires (20,000 lumen, H-33 1CD at 30-ft mounting height).

sured along sections of Interstate highway employing mercury vapor luminaires (20,000 lumens, H-33 1CD) at 30-ft mounting height. Light incident on the sign surface was found to vary extensively with luminaire placement as shown (see Fig. 6).

In illuminated suburban areas the typical night view comprises a series of mercury vapor luminaires, interchanges with their extensive illumination, suburban residences, and occasional electric signs. The data illustrate that luminance of a perfectly diffusing white surface in this environment is often less than 0.1 ft-L. Individual signs in illuminated suburban areas with ambient illumination in this lower range properly belong in the dark rural category.

Test at 0.2-ft-L Illumination

A legibility test was conducted on a section of roadway with illumination provided by luminaires on 190-ft spacing at 30-ft mounting height. The legibility of 12-in. letters was evaluated on a straight, level section of roadway 1,200 ft in length. The essentially linear relationship between legibility distance and letter height has been established by Allen (3) and others. This condition holds where consistent letter luminance prevails whether provided by daylight, illumination, or reflective materials. Under these conditions of ambient illumination a test of 12-in. letters, the size predominantly in use, could thus be expected to reveal the measure of change produced in legibility distance for every letter size.

Test Signs.—Letters tested were standard Bureau of Public Roads 12-in. Interstate upper case, with a stroke width 0.2 times the letter height, spaced according to BPR recommendations. The reflective material used for letters exhibited specific luminance characteristics similar to those shown in Figure 4. A front illuminated sign with white letters was also used having nine independently controlled fluorescent lamps to vary illuminance.

Signs were mounted at a height of 14 ft from the pavement to the bottom edge and 16 ft from the left edge of the sign to the right pavement edge. Luminaire alignment and sign placement were representative of highway practice. Signs were located with respect to adjacent luminaires to obtain 0.2-ft-L luminance, within the range of 0.1 to 0.4 ft-L observed in typical installations.

Legends.—Two legends, GOAL and LOAN, were used for each condition. The legends contain straight and curved letters, the letters G and N more difficult to resolve; O and L, least difficult. Legibility distances for both legends were averaged to obtain the legibility distance for each condition.

Observers.—Forty-five male observers were used ranging in age from 20 to 62 years with an average age of 34. Observers were asked to discriminate individual letters before recording distances. Observations were made from ten cars. No headlamp checks or adjustments were made because legibility results were averaged and should yield data more representative of actual road viewing conditions.

Design of Experiment.—Each observer viewed the illuminated sign and reflective materials with high and low beams in dark and illuminated conditions, permitting correlation with results of Allen's legibility studies in dark field conditions.

Results

Average legibility distances for reflectorized 12-in. letters for different conditions of illumination (see Fig. 7) are given in Table 1.

The nearly identical results under conditions of moderate illumination and total darkness indicate that the effect of highway luminaires on legibility is negligible with either low or high beams as shown in Figure 7. Legibility differences slightly favor the 0.2 ft-L ambient condition indicating that legibility does not deteriorate but, in fact, marginally improves in changing the dark condition to illuminated suburban. Luminance requirements for the dark condition, therefore, do not require change for optimum legibility in most illuminated locales.

Higher traffic volumes associated with illuminated highways discourage the use of high beams, correspondingly reducing sign luminance and legibility. Despite generally satisfactory performance at lower luminance levels, current practice frequently involves the use of larger signs and letters on such roadways, providng substantially increased absolute legibility distance. An increase from 10- to 12-in. size yields a 20 percent improvement in legibility as shown by Allen (3).

TABLE 1

AVERAGE LEGIBILITY DISTANCES

Sign	Head-lamp Beam	Distance from Luminaire (ft-L)	Avg. Legibility Distance				
			Light (ft)	Dark (ft)	Diff. (%)	Light (ft/in. letter height)	Dark (ft/in. letter height)
With white reflective letters	High	0.2	798	780	+2.4	66.5[a]	65.0
	Low	0.2	705	684	+2.8	58.5[a]	57.0
Front illus. with white letters on black	Low	15	802			66.8[b]	

[a]0.2 ft-L ambient incident to sign surface.
[b]15 ft-L.

Although roadway illumination up to 0.4 ft L in no way reduces sign legibility, associated higher traffic volumes and roadway design contribute to more general use of low beams. The separation of roadways or the employment of glare screens would markedly improve night visibility by permitting general use of the high beams.

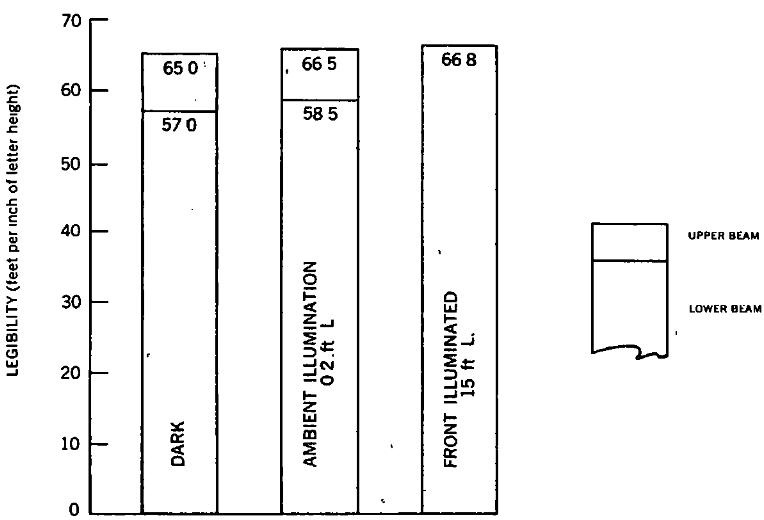

Figure 7. Average legibility distances for 12-in. reflective letters in dark-rural and illuminated-suburban conditions (0.2 ft-L) with upper and lower beams. Legibility data for front illuminated letters in illuminated suburban condition exhibiting 15 ft-L is shown for comparison.

BRIGHT URBAN

Light levels incident on sign surfaces in this category range from 0.4 to approximately 4.0 ft-L. Urban street lighting studied consisted of 33-ft M.H. 6-tube fluorescent fixtures (G.E. Type 606) at 45-ft spacing, producing an average of 4 ft-candles on the pavement surface. Results of measurements of white test panels, in such brightly illuminated locales, vary from 0.4 to 4.0 ft-L dependent on luminaire proximity.

The determination of desirable luminance levels for maximum contrast and legibility in this environment led to measurement of signs selected on the basis of their comparative visibility. Prominently visible signs exhibit luminances from 75 to 125 ft-L. Though it has not been established that signs with lower luminance are less legible, they are less visible unless of large size.

The substantial traffic volumes usually associated with this type of roadway frequently involve the presence of closely preceding and following vehicles supplying additional headlight luminance at useful divergence angles. In effect, stream traffic was found to increase sign luminance factorially, from two to six times for a combination of two vehicles, with additional benefits for more than two.

CONCLUSIONS

Graphical data are presented that describe the effects of changing divergence and headlamp illuminance within the sign field. Coupled with knowledge of specific luminance, this data permits reliable calculation of reflective traffic sign luminance. Calculation and field measurements indicate normal shoulder-mounted reflective signs provide luminances of 1.5 to 3 ft-L with low beams, and 10 to 50 ft-L with high beams at generally useful legibility distances. Field measurements of the effects of no light to moderate illumination in rural and suburban surrounds disclose that ambient luminance on signs can range from the negligible to 0.4 ft-L.

In these environments, sign luminance of 10 to 20 ft-L provides optimum brightness for maximum legibility. Luminance provided by low beams results in 85 percent of the maximum legibility figure. The results of measurements in standard highway lighting conditions show improvement in reflective sign legibility compared to the dark condition, notwithstanding presence of luminaires and associated glare. The luminance of existing reflective materials provides adequate brightness for good legibility of most information and traffic control signs in rural and illuminated suburban environments.

Surrounds of greatly varying brightness require assessment of the contrast afforded by sign luminance, color, and shape. An investigation by Finch and Howard (6) of the detection of traffic signal lights against a background of electric advertising signs suggests the manner and merit of such a study. Further research should be particularly directed toward a generally useful quantitative test of attention value.

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Visual Data on Roadway Lighting

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This paper presents additional data on seeing factor effectiveness ratings for roadway lighting. Such ratings provide an essential basis for highway engineering evaluation of traffic, economic, and human benefits.

Field measurements for different roadway lighting systems are continuing, are significant, and should be reported for the guidance of highway engineers interested in improving night motor vehicle transportation.

Preliminary tests show that about twice as much pavement brightness is required for equivalent L-M visibility when the target is dynamic (0.1- to 0.2-sec exposure) instead of static. This is based on ratings by eight observers.

Measurements made with the new Blackwell portable visual task evaluator are reported and compared with those obtained with the Finch visibility meter. Experience gained at Hendersonville using the first prototype model of this meter retarded measurements earlier this year. More extensive data are now available and are presented.

•MORE GENERAL USE of available visual data in prescribing roadway lighting is one of the greatest opportunities in the improvement of night motor vehicle transportation in the United States. Urgency is involved because the livelihood, general welfare, and economic progress of millions of citizens is dependent on efficient after-dark movement of people and goods. When data are not interpreted and used to meet challenges such as the Highway Safety Study (7) progress is retarded.

The Illuminating Engineering Society has an obligation to provide a recommended practice for American roadway lighting based on the available visual research data which its leading members know about and have sponsored.

There is a need for extending the improvement of night motor vehicle transportation. One is obliged to consider statements such as:

> The U.S.A. is lagging behind British and Continental European practice in the use of high quality roadway lighting.... Poor lighting may as well be omitted.

These comments by R. J. Smeed, Deputy Director of the British Road Research Laboratory, were supplemented by similar remarks from other leading European road engineers at the World Traffic Engineering Conference, held in Washington in August 1961.

Americans visiting Europe bring back similar reports of progress abroad in providing the quantity and quality of roadway lighting appropriate for progress in night transportation. European progress is based on implementing and using visual data to benefit the public (see Appendix B).

Those who attended the World Traffic Engineering Conference, anyone who reads the literature featuring world-wide traffic engineering and the illuminating engineering use of available visual data and roadway lighting is likely to get the impression that

European highway engineers are more interested than American engineers in night visibility and in efficient night motor vehicle transportation.

The United States is producing the most efficient roadway lighting luminaires providing a high degree of seeing effectiveness. This effectiveness can be measured (8, 17), computed (14, 18, 24), and hence predicted in terms of visual data such as relative visibility, relative visual comfort, and pavement brightness. Also through industry interest and invention, the cost of providing this seeing effectiveness, or even light lumens or foot-candles on the roadway has gone steadily downward—it is 20 percent less than in 1940.

There is no question that to meet the needs in the United States it is necessary to (a) implement and use available knowledge, (b) provide appropriate visual effectiveness, and (c) continue to increase public value to increase use.

IMPLEMENTATION AND USE OF AVAILABLE KNOWLEDGE

Visual data and requirements (1) have already been presented extensively in technical reports and made generally available for study and action during 1961, 1960, 1959, and earlier. A report by Fletcher Platt (4) presenting studies by Bruce Greenshields of the University of Michigan emphasizes that visual is the driver's most important sensory process. This fact applies to night as well as daytime driving. Additional study should be devoted to night transportation which produces sizeable Federal and State motor fuel tax revenue and increases the value of automobiles and roads.

In H. R. Blackwell's report (1) on "Illumination Requirements for Roadway Visual Tasks," (1), foot-candle illumination recommendations based on visual data were reported as the result of studies of roadway lighting. Included is a figure of slightly more than 2.4 ft-c for the medium reflectiveness asphalt pavement (his Table IV) and 1.2 ft-c for the high reflectiveness concrete pavement, based on a concrete vs asphalt factor of about 0.5 (his Table III).

Table 1 compares the recommendations by Blackwell (Col. C) with the 1940 recommended practice (Col. A) and the present-day 1953 ASA practice (5, 26) (Col. B) recommendations for high reflectiveness pavement surfaces.

TABLE 1

COMPARISON OF RECOMMENDED PRACTICES FOR HIGH REFLECTIVENESS LIGHT CONCRETE OR LIGHT FINISHED ASPHALT ROADWAYS[a]

Roadway[b]	Recommended Practice (avg. ft-c)		
	I.E.S. 1940	A.S.A. 1953[c]	Blackwell 1960
	(A)	(B)	(C)
Expressway and freeway:			
Continuous urban	1.2	0.6	1.2 - 2.4[d]
Continuous rural	0.8	0.6	1.2 - 2.4[d]
Interchange urban	2.4	1.2	
Interchange rural	1.6	1.2	
Other:			
Major	0.8	0.75 - 1.0[d]	1.2 - 2.4[d]
Collector	0.6	0.6 - 0.8[d]	1.2 - 2.4[d]
Local or minor	0.4	0.45 - 0.6[d]	1.2 - 2.4[d]

[a]Reflectance 20 percent or more, except where noted.
[b]Urban intermediate area classification.
[c]In use January 1962.
[d]Medium reflectiveness pavement surface, such as 10 percent reflectance.

Blackwell's foot-candle recommendations based on visual data are about double the illumination (Col. B) currently recommended by the 1953 ASA practice, still in use January 1962. This statement applies to roadways other than expressways or freeways in areas classified as urban intermediate.

For continuous expressways and freeways, Blackwell's recommendations are two to four times that shown in present-day ASA practice, depending on the reflectiveness of the pavement surface being lighted. The comparative foot-candles are based on the brightness obtained on high reflectiveness light concrete or light finished asphalt pavements.

Blackwell and other vision researchers point out that the foot-candles that he finds required should not by any exaggeration be considered optimum. Optimum for roadway lighting may be higher than the illumination levels specified for interiors.

For lighted limited access highways 1953 ASA practice for street and highway lighting is 0.6 ft-c. This figure can also be derived from the 0.8 ft-c shown in the 1953 practice Table IV modified by the footnote factor for high reflectance pavement.

Column A in Table 1 shows that 21 years ago the Illuminating Engineering Society recommended practice for foot-candles on urban intermediate area streets was about the same as ASA practice, January 1962. Moreover, for express freeways and viaducts carrying what was then considered to be heavy to very heavy traffic the 1940 I.E.S. recommendation was 0.8 to 1.2 ft-c. This highway lighting recommendation ranges from one-third more, to twice that recommended by ASA practice in 1962.

Blackwell's recommendations (1) in Column C are for the dog visual task. This target is quite similar in size and in visibility measurements to the 1-ft diameter 8 percent reflectance disc used in several other roadway lighting studies (8) in the U.S. The lighting system on which the foot-candles are based includes modern, semicutoff-controlled, filament lamp luminaires spaced 100 ft staggered. The layout and measurements are shown in Figures 4 and 6 of (8).

In addition, Blackwell reported his roadway lighting studies to the 1960 Research Symposium sponsored by the Illuminating Engineering Research Institute (2), the 1959 I.E.S. Annual Technical Conference, the I.E.S. Committee on Roadway Lighting, and in mid-June 1961 to a group including Ohio State Highway Engineers as well as David Solomon and W. P. Walker of the U.S. Bureau of Public Roads.

Blackwell, commenting on a paper he is now preparing on roadway lighting in which he includes pavement brightness and relative visibility data, said:

> It is my firm intention to include the pavement luminance data in the paper which I will submit to "Illuminating Engineering." In addition, I will include the supra-threshold factors and other items of data analysis which you have heard me present from time to time.

His comments (1) regarding optimum foot-candles for roadway lighting include:

> 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. Such 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.

Also, as he states to HRB in describing "The Lighting Specification Method"

> A factor of 15 was used in adjusting the absolute values of the original data for the purposes of the lighting specification system.

The over-all factor of 15 is the same as that used by Blackwell in prescribing lighting levels for interior tasks.

Blackwell has pointed out that other I. E. S. committees are using his data. According to C. L. Crouch, I. E. S. Technical Director:

> The following I.E.S. Committees used the results of the Blackwell studies as a basis for their recommendations following the leadership of the R.Q.Q. Committee Report No. 1: Handbook; Industrial; Institutions; Merchandising; Offices; Progress; Recommendations for Quality and Quantity; Residence; School; and Sports and Recreational Areas (Interior).

However, the author feels that these interior activities do not involve a range of human capability factors that are as critical as those existing in the drivers on the highways at night.

Blackwell's moderate factor of 15 according to a study of his papers and presentations (1, 2, 3) multiplies two factors; i. e., 2. 5 times 6. Quoting in small part from one of his papers (3):

> [Pertaining to 2.5 multiplier]...we may wonder to what extent common sense seeing is equivalent to laboratory observing at an accuracy level of 99 percent. It would seem reasonable to suppose that the contrast threshold for common sense seeing would be still higher than the laboratory threshold even for 99 percent accuracy. It is, therefore, undoubtedly conservative to use a contrast multiplier of 2.5 to take account of the criterion difference between common sense seeing and laboratory performance with the forced choice method.

This 2. 5 factor is evidence that Blackwell's recommended foot-candles for roadway lighting may be low. There are many differences between trained normal young laboratory observers and the average daytime driver. With an awareness of human factors of drivers, 2. 5 is a very small safety factor for the wide range in night driver capability, especially in the light of fatigue, drugs, intoxication, distractions, etc., as well as vision, and 6,000,000 drivers 65 years of age or older.

When all factors are considered, Blackwell's required foot-candles seem low in the margin of protective seeing afforded the typical night motorist. However, his foot-candles are based on extensive visual data instead of personal opinion.

Platt writes in his paper (4):

> Also as a result of transient factors (fatigue, illness, drugs, alcohol) one person's ability-to-observe changes to a marked degree from time to time.

Actually, in night drivers there appears to be a large and critical range of variations in vision, distractions, perception and response, psychomotor functions, performance and skills, attitude, reaction time, and aging—typical of night drivers.

A discussion by Marsh (10) points up many of these factors, including that an estimated 6,000,000 drivers are 65 years of age and over.

A 100 to 1 estimated variation in driver capability was voiced at the National Conference on Driving Simulation March 1961 (11). James L. Malfetti of Columbia University pointed out that

> Roadhouses and suburban cocktail parties are generally accessible only by automobile. People will continue to drink and drive. The real effect of this activity is not really known. We must provide for this.

In reviewing Blackwell's (3) interior multiplier of 6, apparently, this part of the overall factor 1. 5 combines elements for consideration including

> Threshold measurements were made both with and without advance warning as to the moment of presentation of the target. It

> was found that the threshold contrast was 1.4 times higher when the observers were not given advance warning that a target was to be presented.
> ...With two locations each separated from the line of sight by three degrees or more, the threshold contrast was 1.31 times higher when the observer was not given advance knowledge of the target location...

The field task simulator (3) was also used by Blackwell to provide the interior search and scanning that he mentions in his HRB paper. Fifty moving targets of variable brightness were set up in the laboratory to rotate before the eyes of laboratory-trained observers at controlled rates of speed.

> ...On the average of 6.0 times as much contrast was needed in the Simulator as in the laboratory experiment...In this case, the informational content is considered to be 2.5 items per second...
> ...These data suggest that the overall field factor required to compensate for all the many differences existing between laboratory conditions and those of the Simulator varies between 6.0 and 7.25....The factor of 6, or 7.25, can be understood as due to a factor of perhaps 4.0 to provide a receptive psychological factors such as lack of knowledge as to when and where the target objects would appear.
> ....Section I[3] has the desirability of insuring that information assimilation can occur within a single fixational pause. To insure this level of performance we must provide a level of visual capacity sufficient to permit assimilation of at least five items of information per second...Selection of this level is surely conservative since it provides the capacity to assimilate only a single item of information per fixational pause...

Referring to Mr. Platt's paper (4):

> It is assumed that fundamental actions are taken by the driver only on decisions based upon focused observations. Experiments have demonstrated that the number of observations that a person can make is limited by time. Therefore the faster a vehicle is moving, the fewer observations can be made per mile traveled... There is a finite limitation (although it may vary) on the number of discrete events that can be observed at a given time. Finite limitations for observations in each important sense modality are estimates as follows: Seeing - 16/second.

For night drivers, 1/16-sec seeing will require much more light than Blackwell's foot-candle recommendations. Thus, in only one small detail, this confirms the fact that laboratory factors for dynamics may be submarginal for actual night driving conditions.

DOUBLE PAVEMENT BRIGHTNESS AND DYNAMIC VISIBILITY

As would be expected, split-second dynamic instead of static targets require twice as much pavement brightness and, consequently, foot-candles to produce equivalent visibility from similar lighting systems. This has been reaffirmed during the past few months under the full-scale roadway lighting conditions at Hendersonville, N. C.

Heretofore, a static target (8, 14, 18, 19, 20) has been used for the relative visibility rating of roadway lighting systems. The target is a 1-ft diameter, 8 percent reflectance disc, normal to the driver's line of sight and at a viewing distance of 180 ft. Visibility measurements on this basis have been reported using both the Luckiesh-Moss and Simmons-Finch meters.

A 1/6-sec exposure instead of steady, static exposure of a 1-ft diameter target at a known location only 200 ft in front of the observer requires twice as much pavement brightness. The 1/6-sec target exposure was interrupted for 4-sec intervals. No search or scan was involved. The observer's eyes were fixated at a known location, waiting with plenty of time allowed for the target to appear and reappear at fixed intervals. Dynamic target measurements with the Luckiesh-Moss visibility meter were followed by equally deliberate and attentive static target measurements.

Figure 1 shows the target used for this simulation of target dynamics. The split-second dynamic target exposure is automated so that the disc rotates through a 90° arc, from a position where it is parallel to the driver's line of sight (as shown at the left of Fig. 1) to the customary position normal to line of sight (shown at the right of the illustration), and then back to the position parallel to view.

The 1/6-sec time exposure includes the time of partial exposure indicated at the mid-portion of this figure. The target then remains parallel to the observer's line of sight for 4 sec. For the comparative static measurements the same target is used steadily exposed (as shown at the right of Fig. 1).

Obviously, during these outdoor tests, the observer (driver) is stationary, at fixed attention, rather than in motion traveling along a roadway. There is no discrimination between objects, no unexpected visual tasks, none of the other customary night motorist problems of attention, preoccupation, psychomotor skill, physiological, or pathological condition. This is merely one attempt, one step, toward simulation of the actual pursuit movement and avoidance maneuvers and other conditions experienced under actual night driving.

Also, in support of Blackwell's studies is the report by de Boer (12) involving field and laboratory tests to determine the pavement brightness required which is equivalent to 2 to 2.8 ft-c under certain simulated and actual driving conditions. The resulting Netherlands practice is discussed later.

Waldram of Great Britain joins de Boer in acknowledging the fact (14) that traffic deviations and situations must be seen and interpreted with split-second rapidity.

Blackwell explains (3) in further support of his over-all factor of 15:

> ...For the present it seems wise to base our standard performance curve upon a level of visual capacity which is surely the minimum required for all visual tasks...It was decided that a field factor of 15 would be recommended for use at the present time. ...Thus selection of a field factor of 15 must be considered a conservative estimate on the basis of our present knowledge.

Here, Blackwell uses the word conservative in the sense of low and moderate. After making a weighed average of two pavement surfaces and several lighting systems:

> The resulting values of requisite illumination are as follows: Dog 2.06 footcandles. Average Dog and Mannequin 1.9 footcandles. ...It is apparent that nearly 6 footcandles 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 foot viewing distance.

A succinct quote from "Light for Safety on Streets and Highways": "The outside is a little tougher than the inside."

Two- to 3-ft-c illumination for a roadway lighting system cannot be considered overly protective from the standpoint of seeing safety factors provided for the night motorist.

Another factor is weather condition. It has been estimated that in the U.S. the pavements may be wet 15 percent of the time. The motorist welcomes the aid of roadway lighting most enthusiastically during wet, icy, or snow conditions.

PROVIDING APPROPRIATE VISUAL EFFECTIVENESS

During dry weather conditions twice as much light (foot-candles) is required on medium reflectiveness asphalt pavement to produce the pavement brightness equivalent

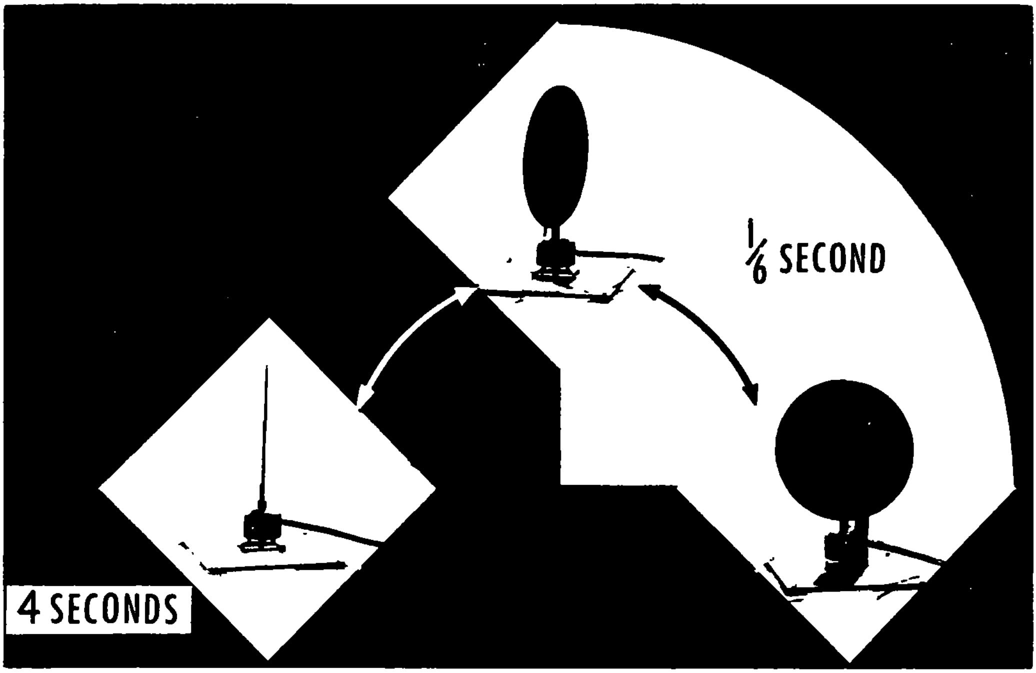

Figure 1. Exposure target (1/6-sec) used in simulation of some driving dynamics studies at Hendersonville, N.C.

to that obtained on high reflectiveness pavement surfaces. Pavement brightness is one of the principal factors in visibility.

Table 2 shows (2) Blackwell's conclusion as result of his Hendersonville studies (1) on the 100-ft staggered spaced lighting system and 5-year-old pavements. Table III, p. 124 (1), shows a concrete/asphalt factor of 0.519 in comparative foot-candles required. This pertains to the dog static target (similar to the 8 percent reflectance disc), which is revealed by negative contrast with the brighter background of pavement.

TABLE 2

RELATIVE INCREASE IN AVERAGE FOOT-CANDLE ILLUMINATION REQUIRED TO PRODUCE EQUIVALENT PAVEMENT BRIGHTNESS FOR DRIVERS' CONTRAST (VISIBILITY) OF TYPICAL DISC OR DOG TARGET

Lighting System[a]	Pavement Reflectiveness[b] (ft-L)		Approx. Increase in Illumination Req'd. from Same System
	Medium (Asphalt)	High (Concrete)	
15,000-L filament 100-ft staggered spacing	0.18	0.35	2:1
Blackwell 1960 recommendation	--	--	2:1
20,000-L mercury, 100-ft one-side spacing	0.46	0.72	1.5:1

[a]With semicutoff control.
[b]Roadway lighting systems (light distribution and geometry are the same).

As also shown in Table 2, the ratings from Figure 6 (8) showed that the average measured pavement brightness for the staggered lighting system used by Blackwell is 2 to 1 higher on the concrete pavement.

For the 100-ft one-side spaced mercury luminaire lighting system shown in Figure 12 (8) the ratio of pavement brightness measurements is approximately 1.5 to 1. The semicutoff luminaire light distributions are similar for both the filament (staggered) and mercury (one-side) lighting systems.

To assure equivalent pavement brightness for contrast visibility the foot-candles for medium reflectiveness pavement surface should be increased 50 to 100 percent over that required for high reflectiveness pavement depending on the system geometry. Also, the Luckiesh-Moss relative visibility ratings (8) are interesting in contrast.

Table 1 is based on high reflectiveness pavement surface (20 percent or more reflectance). For medium reflectiveness surfaces of the order of 10 percent, the 1953 ASA practice footnote under Table IV suggests a one-third increase, a factor of 1.33 to 1. It also suggests that for pavement having low reflectance of the order of 3 percent pavement the previous Table 1 foot-candles should be doubled by a factor of 2 to 1, or 100 percent.

As low as 4 percent reflectance has been measured on new asphalt pavements. The Hendersonville asphalt pavement is medium reflectiveness, of the order of 10 percent. The ASA practice factors appear to be low for future use.

As stated in 1961 (8),

> It is well known that the reflection characteristics of asphalt pavement can be made favorable by top surface treatment such as rolling-on a white or light gray aggregate. Also aging and traffic use may favorably affect the specular pavement reflection characteristics for raodway lighting.

An example is a section of Gratiot Avenue at Detroit shown in Figure 2 which has been recently described by Young and Wall of the Detroit Public Lighting Commission:

Figure 2. Gratiot Avenue, Detroit, Mich., mercury lighting; average illumination, 2 ft-c.

> We attribute this high ratio to the good directional reflectance of this particular kind of pavement consisting of worn asphalt with a light-colored, well-worn aggregate rolled into the surface.

The ratios referred to by Young are foot-Lamberts per foot-candle. For pavement brightness along the center of the curb lane from observer stations along the center of the same lane and directly in line with the luminaires, the Pritchard meter with 1° aperture measures the average pavement brightness at about 2 ft-L. However, transversely, across the pavement, the minimum brightness is about 0.7 ft-L when the observer-meter positions remained in the curb lane. This is consistent with the relative pavement brightness per 1,000 candlepower data shown in Figures 5 and 6 (14), also in Appendix B (8).

The calculated foot-candles, average about 2.0 for this 95-ft opposite spaced, 20,500-lumen mercury lighting system. The measured foot-candles are appreciably lower, bringing out the present-day instrumentation progress situation in which measurement of roadway lighting foot-candles is apparently less accurate than measurements of pavement brightness (foot-lamberts).

An abbreviated numerical tabulation of available pavement brightness visual data is shown in Appendix A. Specularity produces brightness along the 0 and 0.5 M.H. (driver-observer path) which is appreciably higher than that along the 1.0 M.H. and 1.5 M.H. L.R.L. (longitudinal roadway lines).

EUROPEAN PROGRESS

Continental European engineers are adopting recommendations (13, 20) based on their available visual data. Data have helped them provide the type of roadway lighting which they, and apparently the British, believe to be more adequate and higher quality than ours. For example, in May 1959, the Netherlands Commission on Public Lighting adopted the recommendations that are compared with ASA practice in Table 3.

Use of the Netherlands recommendation has provided twice as much illumination on urban intermediate area streets and three to four times as much light on continuous urban or rural highways as compared with that specified by ASA practice. Likewise, according to latest reports, Germany provides 1.5 ft-c, France provides 2 to 3 ft-c, and Belgium 1.5 to 2.0 ft-c. This relatively good lighting is appreciated by, and is popular with, the European night-driving public.

Additional evidence of progress abroad is the fact that they are not only using visual data as a basis for their foot-candles, but several countries are actually omitting foot-candles and recommend installing lighting on the basis of its pavement brightness, which is a visual factor; for example, Belgium, 0.45 ft-L; and Netherlands, 0.6 ft-L.

These visual criteria simplify recommendations. Factors for pavement reflectiveness (such as Table 2) are no longer necessary, and the seeing effectiveness of their roadway lighting is assured because they are also specifying cutoff luminaire candlepower distributions such as were described in previous papers (8, 9, 12, 14).

To obtain the Netherlands foot-candle equivalency given in Table 3, there is the following statement on page 5 of the Netherlands recommendations (13):

> ...The above-mentioned luminance of 2 cd/m^2....(0.6 footlambert brightness)...corresponds, for lighting installations and road surfaces such as those customary in this country (see Appendix C), to an average illumination of 20 to 30 lux (2.0 to 2.8 foot-candles) on the road surface, approximately....The above-mentioned level must be maintained in normal operation, taking into account dirt collected on the fittings and the deterioration of the luminous flux from the light sources, on roads where the greatest density of motorized traffic can be expected...

The European countries are placing their best lighting on their highways where speeds are high. In contrast are certain tendencies in the U.S. Good lighting on the highways is in the best balanced interest of night motor vehicle transportation.

TABLE 3

1952 U.S. STANDARDS VS 1959 CONTINENTAL EUROPEAN RECOMMENDED PRACTICE FOR HIGH REFLECTIVENESS LIGHT CONCRETE OR LIGHT FINISHED ASPHALT PAVEMENT[a]

Roadway[b]	Recommended Practice		
	A.S.A. 1953[c] (avg. ft-c)	Netherlands 1959	
		Equiv. Illumin.[d] (avg. ft-c)	Pavement Brightness Actually Specified (ft-L)
Expressway and freeway:			
Continuous urban	0.6	(2.0) - (2.8)[e]	0.6
Continuous rural	0.6	(2.0) - (2.8)[e]	0.6
Interchange urban	1.2		
Interchange rural	1.2		
Other:			
Major	0.75	(2.0)	0.6
Collector	0.6	(1.5)	0.45
Local or minor	0.45	(1.0)	0.3

[a]Reflectance 20 percent or more.
[b]Urban intermediate area classification.
[c]In use January 1962.
[d]Not specified, but in accordance with suppositions in text of their recommendations as to possible equivalency on favorable light reflectiveness pavements in Netherlands.
[e]Medium reflectiveness (asphalt).

At the Washington, D.C., World Traffic Engineering Conference, Granville Berry, City Engineer of Coventry, England, said:

> In U.S.A., and to some extent Great Britain, the benefits of installing good roadway lighting are being largely overlooked. We can no longer afford to do this. Lighting should not be an afterthought.

Charles Prisk (7) of the U.S. Bureau of Public Roads said this is a challenging comment. Granville's formal report (22) states:

> While excellent work is being done in relighting some of their cities...the general standard of lighting on the American road system lags behind that in Britain...In Philadelphia...a ten year relighting program is due to be completed in 1964 which includes some very excellent installations designed to higher levels of lighting than laid down in the American Standard Practice for Roadway Lighting (now under revision).

The Principles of ASA state:

> American Standards are sometimes adopted by a governmental agency or other organizations for mandatory applications.

In preparing its recommended practice, I.E.S. should study, implement, and use the reports on visual needs for night driving by American researchers as well as those of European laboratories. Also to be considered is the highway safety study (7), reports by the Michigan State Highway Traffic Center (24), the Texas Transportation Institute (25) as well as the Ohio State Institute for Research in Vision (1, 2, 3).

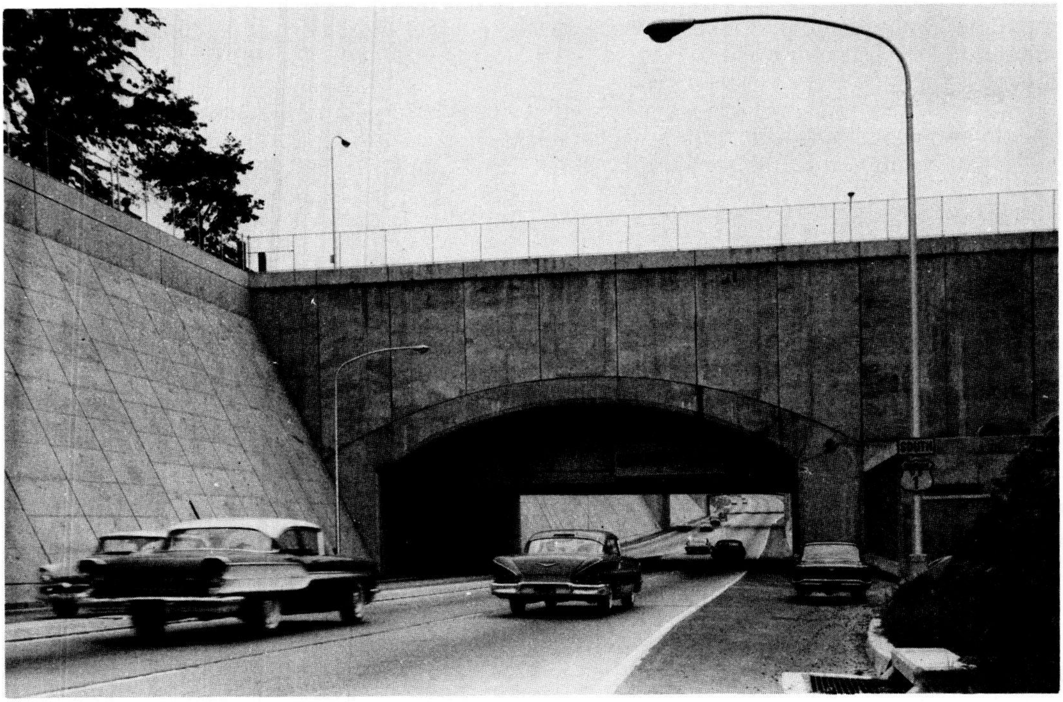

Figure 3. Kingston, N.Y., Intersection entry to New York Thruway arterial spur; illumination at intersection, 3 to 4 ft-c; approaches, 3 ft-c.

I. E. S. should also consider the fact that in many instances American roadways are lighted with several times as much foot-candle illumination as that specified by the 1953 standard practice. This has evolved from the fact that there has been great progress in the development and production of luminaires and light sources that are highly efficient in providing good night seeing conditions. One example is the 3- to 4-ft-c illumination of the intersection entry of the New York Thruway Arterial spur at Kingston, N. Y., shown in Figure 3.

INCREASING PUBLIC VALUE TO INCREASE USE

When roadway lighting having higher public value in seeing factor effectiveness is provided, it merits the confidence, enthusiasm, and support of the public. Use of such lighting is continuing to increase in the U. S. Another reason for this progress is improved economics. The cost of putting light on the street has gone steadily downward for the past 20 years.

The evidence and trends make it clear that the public is getting greater value than ever before in street lighting service. Over the past two decades, advancements in vapor light source efficiency and life have made sizeable contributions to cost reduction. Furthermore, the life of mercury vapor lamps is many times that of filament. Mercury lamps have a rated life of three years compared to six months for incandescent. One relamping trip of six trips appreciably changes the relamping and maintenance expense figures.

FUTURE LAMPS

In preparing recommended practice, consideration should be given to the announcements of double-light-output-per-watt lamps for roadway lighting. These lamps may be available and in use before publication and distribution of a new practice. The resulting increase in light output should be recommended for use to improve seeing for night motor vehicle transportation. Also, control of candlepower distribution and luminaire brightness (8, 9, 12, 13, 14, 15, 17, 18, 19, 20, 24, 25) should be considered.

More than ever before, there are a large number of people who realize that one should be prescribing visibility so substantial—and visual comfort which is more reasonable—for the public welfare, benefit, and enthusiasm.

CONCLUSION

American highway, traffic, and illuminating engineers are just as interested in night transportation as are the European engineers. The economics of night seeing from roadway lighting per dollar cost have been and will continue to be significantly improved. Visual data available should be studied, thoroughly considered, and used. It is hoped that this study and presentation of data and motivations on roadway lighting will aid others to take appropriate action.

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Appendix A

REPRESENTATIVE PAVEMENT[1] BRIGHTNESS[2] AS VIEWED BY DRIVER APPROACHING LUMINAIRE ALONG THE 0.5 MH LRL VIEWING PAVEMENT AT DISTANCE OF 200 FT WITH LUMINAIRE ALONG 0 MH LRL[3]

Long. Dist. (MH)	Brightness Along LRL (ft-L)			
	0 MH	0.5 MH	1.0 MH	1.5 MH
1.5	0.0069	0.621	0.025	0.012
2.5	0.0053	0.049	0.017	0.0087
3.5	0.004	0.036	0.011	0.0058
4.5	0.0029	0.023	0.0065	0.004

[1] Surface is 8 percent diffuse reflectance traffic-worn asphalt.
[2] In foot-Lamberts per 1,000 cp.
[3] An abbreviation of data shown in Figs. 5 and 6 (14), Fig. 6(9), and Appendix B (8).

Appendix B

AUTHOR'S NOTES ON ROADWAY LIGHTING HIGHLIGHTS, WORLD TRAFFIC ENGINEERING CONFERENCE, WASHINGTON, D.C. AUGUST 24-26, 1961

R. J. Smeed, Deputy Director, Road Research Laboratory, Great Britain, stated that the U.S. may lead the world in traffic engineering features other than roadway lighting, but it is lagging behind British and Continental European practice in the use of high-quality roadway lighting. Further he said we are much better off when streets are lighted well; i.e., poor lighting may as well be omitted. The night accident rate should be far less than day rate. Why is the reverse existing? The high night rate would be less likely if roadways were properly lighted. The street lighting in U.S. is not as good as that in some portions of Europe.

C. H. Rex was recognized for the following discussion comment to direct attention of the 400 delegates to an activity in which U.S. may at least be abreast of European technology.

Digital computer ratings for the relative seeing factor effectiveness of roadway lighting (relative visual comfort and relative visibility) will be made available Fall,

1961. The method of evaluation and comparison of predicted vs measured visual ratings have been presented previously in the reports of papers presented at sessions of the HRB Annual Meeting. These reports include other valuable information on traffic engineering.

Granville Berry of Coventry, England, said that in U.S., and to some extent in his own country, the benefits of installing good roadway lighting are being largely overlooked. We can no longer afford to do this. Lighting should not be an afterthought. Charles Prisk of the U.S. Bureau of Public Roads said this is a challenging comment.

P. Lefevre, Chief, Roads and Bridge Engineer, Belgium Ministry of Public Works, said the standard of highway illumination has increased considerably during the past three years and on highways outside urban areas is now ranging from 10 to 15 lux (1.0 to 1.4 ft-c). (December 1961 "Light and Lighting" L. Gaymard 2 to 3 ft-c)

Belgium has a comprehensive program of lighting all intersections where accident rate is 12 per year. Also they are installing lighting systems on all roads carrying over 10,000 vehicles per 24-hr day. They expect to light 700 km of highway during the next five years. The lighting they have installed has paid for itself in accident prevention alone. Additional benefits are shifts in some traffic to night hours, and when lighted, the people enjoy the freedom of convenient night travel. These extra benefits may top everything else. (December 1961 "Light and Lighting" A. Boereboom 1.5 cd per sq m = 0.45 ft-L)

G. Botsch, France, said everyone agrees lighting does reduce accidents. In dealing with financial matters, there are some who believe that the grading of priority for various measures may involve philosophers and psychologists as well as traffic engineers.

A. Berti, Director General Autostrada Serrovalle, Milan, Italy, called for better lighting techniques and recommendations on lighting of tunnels as well as roadway intersections.

R. Riekenbert, Germany, said that it is their common practice to light highway intersections.

Henry Barnes, Baltimore, and General Reporter W.T.E.C. Electronics Session, said good roadway lighting is very important on highways and streets. In Baltimore getting rid of 8,000 gas lights has helped appreciably reduce fatal night accidents. Comment during first afternoon session: "If ignorance is bliss, we certainly have nothing to worry about."

In opening the World Traffic Engineering Conference on August 24th, Secretary of Commerce Luther H. Hodges said that 56 percent of motor vehicle traffic is generated by social and recreational activities of the motorists.

> ...But I would like to conclude by urging you to give particular attention here and in all of your planning to the opportunities for greater research. New Knowledge, developed within a framework of earnest international cooperation, is the sound basis for progress in any technical field. It is especially essential in a discipline whose answers to our traffic problems will have far reaching consequences for the economic and social patterns of the future...

Roger Coquand, Director of Highways, France, general report:

> ....But it goes without saying that all research on the geometric character of roads, on signs, the lighting and marking of roadways, the roughness of surface, highway lighting, and the improvement of winter servicing are of the greatest concern in safety....

Charles Noble, Consulting Engineering, Princeton, N.J., general report referring to contribution by J. R. Dorfwirth, Vienna, Austria.

> ...The view that speed change lanes should have a different color than the main freeway pavement is widely held. However, unless the visibility and rideability of the lanes are of equal or superior quality to the main freeway pavement the motorist will shun the lanes. He will seek out what looks and rides best...

Referring to contribution by George A. Hill, District Engineer, California Division of Highways:

> ...The Author sets forth such excellent guiding principles for interchange designers that they bear repeating. His eight golden rules are as follows:
>
> ...4. Adequate warning of impending on and off movements must be provided.
>
> ...8. Maximum day and night visibility to interchange areas of decision should be provided.
>
> Above all, let us get away from the minimums in providing motor traffic facilities. It is too much to ask the traveller to risk his life on minimums. Drivers usually drive by maximums. Often they cannot adjust to minimum designs. The driver needs and is entitled to a factor of safety equally as much as the piece of steel you will put into your next bridge.
>
> Let us think and act somewhat in the spirit of the great architect, Burnham, who said, "Make no little plans for they have no power to stir men's minds."

P. Lefevre, Chief Engineer-Director of Roads and Bridges, Ministry of Public Works and Reconstruction, Belgium:

> ...In order to remove the effect of the geometric or physical design Features of the various lit or unlit stretches of road, the ratio of nighttime accidents to daytime accidents was calculated. On roads with average-to-poor lighting, all other things being equal, the night rates were 1.40 to 1.49 times higher than the day rates. On unlit roads this figure was 1.45, almost the same, in fact, as in the previous category. On very well lit roads, the coefficient varied between 1.17 and 1.25. Thus the possible reduction in nighttime accidents would be in the order of 20 percent were the roads to be consistently well lit...

The Italian Ministry of Transport called attention to twelve scientific research subjects. Street lighting is No. 9 on their list.

H. J. H. Starks, F. Garwood, G. O. Jefficoate, and R. J. Smeed, Great Britain on ... street lighting and accidents:

> The influence of street lighting on accidents has been studied by comparing the accident frequencies occurring on 64 lengths of road before and after the introduction of better lighting.
>
> The Laboratory studies may be summed up as follows:
>
> 1. Good modern street lighting reduced the average frequency of injury accidents in darkness by 30 percent.
> 2. There was strong evidence that the reduction in pedestrian accidents was greater than the reduction in other types of injury accidents.
> 3. There were no significant differences between the accident reductions for fluorescent, mercury, and sodium lighting.
> 4. The total savings in accident costs on the 64 lengths were more than sufficient to pay for the increases in the capital and running costs of the improved lighting installations...

Quote from "Lighting Conferences." Light and Lighting, p. 245 (Aug. 1961), Andre Boereboom, Belgium, Chairman of the C.I.E. (International) Roadway Lighting Committee said:

> the papers and discussions on street lighting had been most valuable and he emphasized the great responsibility that rested on the shoulders of lighting engineers in all countries to produce the best possible street lighting.

An Instrument for Assessment of Visibility Under Highway Lighting Conditions

A. E. SIMMONS, Division of Highway Transportation, State of California

There is currently no generally accepted objective method for the determination of visibility of objects in highway traffic lanes at night under highway lighting conditions. Visibility appraisal methods are generally subjective in nature, with wide variance among observers.

This paper provides an analysis of the problem of visibility assessment under highway lighting conditions and evaluates many of the factors that could provide an index to visual performance under these conditions. The findings of this investigation have resulted in a mathematical analysis of visual assessment and permit the establishment of visibility criteria for highway lighting.

The instrument described provides an objective determination of relative visibility. The device consists of a dual monocular system with suitable optical wedges arranged to reduce a 2^0 central portion of the roadway area under observation to a contrast threshold, while maintaining a constant eye adaptation, thus providing a relative index of visibility. The visibility index is calibrated in terms of the contrast between an object of fixed size and its background.

The findings of this investigation provide rational design criteria for highway lighting, enable the prediction of the visual performance of a highway lighting design, and provide an objective visual appraisal method for the comparative evaluation of visibility of existing highway lighting systems.

•CURRENT METHODS for the assessment of visibility under highway lighting conditions are substantially subjective in nature with wide variations in interpretation among individual observers.

In a previous paper (1) by the author a report was made on the development of an instrument for the evaluation of night visibility on highways. Using this instrument, observations were made under actual traffic conditions with moving vehicles as objects. Visibility determinations were made at several distinctively different lighting installations using sodium, mercury, and incandescent light sources, with and without the presence of glare. The meter readings showed significant difference among highway lighting systems and between the visibility values on the same system with and without glare sources present. Though successful in principle, this meter had several limitations due to the lack of a visibility index reference and the complexity of the neutral density wedge system.

This research effort resolves the problems of the earlier instrumentation and develops a rational engineering design criterion for highway lighting. Instrument calibration has been provided that enables the comparison of performance of existing highway lighting installations in terms of known contrast conditions.

Inherently, visibility is subjective in nature, and as such, it defies measurement directly. Therefore, it is necessary to develop indexes that can be correlated with visibility in order to quantify the term objectively.

For this research the contrast threshold method has been selected, as in the earlier study, as the most representative phenomenon to measure for highway lighting conditions at night. This is the basis for the method that has been developed in this research project for the assessment of visibility under highway lighting conditions.

FACTORS AFFECTING VISIBILITY UNDER HIGHWAY LIGHTING CONDITIONS

Discernment Methods

There are many factors affecting visibility under highway lighting conditions. In addition to the effects of the physical factors on seeing conditions, visibility is affected by the mental, psychological, and physiological condition of the observer.

The most important physical factors that directly influence night visibility on highways are the following:

1. The contrast between the object and its immediate background.

$$C_t = \frac{B_o - B_b}{B_b}$$

in which

C_t = target or object contrast;

B_o = object brightness; and

B_b = background brightness.

2. The brightness of the object.
3. The size and shape of the object and its identifying detail.
4. The brightness of immediate background of the object (within a 2° to 5° angle).
5. The brightness patterns of the surround within the principal visual field (60° total visual angle).
6. The ratio of brightnesses within the principal visual field.
7. Motion of object and observer.
8. Time available for seeing.
9. Glare from any light source in the visual field.
10. Relative positions of the observer, the object and the luminaires.

Under actual field conditions, the contrast between the object and its immediate background is determined by the difference between the brightness of the object and the brightness of the pavement or immediate background as seen by the vehicle operator.

Brightness Influence

Where the brightness of the object is less than the brightness of the background, discernment is by silhouette, or negative contrast. Contrast as used in this report is defined as the ratio of the difference in brightness of the background and the object to the background brightness, or

$$C_t = \frac{B_o - B_b}{B_b}$$

Thus defined the contrast can vary from -1.0 under silhouette conditions to +00 under direct object lighting conditions.

Where the brightness of the object is more than that of the background, discernment is by reverse silhouette (positive contrast). Under high levels of object brightness (over 1.0 ft-L) discernment will be by surface detail similar to daylight conditions, and the object will be recognized by variations in brightness or color over its own surface with or without general contrast with the background.

The brightness of the object is determined by its reflectance factors and its relative location with respect to the light sources, the intensity of the light sources, and the relative location of the observer.

The brightness of the immediate background of the object is determined by the relative position of the observer and the object with respect to the light sources, the intensities of the light sources, and the reflectance characteristics of the background surface (highway pavement).

The ratio of the brightnesses within the principal visual field is the ratio of the maximum brightness to the minimum brightness of the background surface (highway pavement) as viewed by the vehicle operator.

The size, shape, and identifying detail of an object are important factors in night visibility. The size and shape of a pedestrian or animal may establish its identity even under silhouette lighting conditions. The surface detail or glint from specular reflections from a polished surface of an automobile help to establish its identity.

Under highway operating conditions the observer or vehicle driver is usually in motion while typical objects such as pedestrians may be moving or motionless.

Studies by Finch (2) and others have shown that the time available for recognition of an object is an important factor. As vehicle speed increases, the time requirement for night visibility decreases. The lower the levels of illumination, the longer are the time factor requirements. As the range of brightness in the driver's field of view increases, requiring light adaptation of the eyes, time factor requirements are involved to a greater degree.

The highway visual scene usually involves relatively large objects (6 min of arc or larger) which must be recognized with certainty in a short period of time (0.2 to 0.02 sec) at relatively low adaptation levels (1.0 to 0.005 ft-L).

INSTRUMENTATION

Design Considerations

Based on the experience obtained in a study reported in a previous paper (1), a careful re-analysis was made of the requirements of a relative visibility assessment method for highway lighting conditions.

It was considered essential to have the amount of light entering the eye during the threshold determination approximately the same as the amount of light entering the eye when the full view of the scene is under observation in order to maintain the eye adaptation constant and the pattern of brightness the same during the assessment procedure.

To obtain the highest degree of eye sensitivity during the threshold determination, the image of the portion of the scene used for reduction to threshold should be concentrated on the foveal area of the retina. This portion of the eye, which provides photopic vision, occupies a 1° to 2° visual field.

During a contrast threshold determination the average brightness of the field of view should remain constant to maintain a constant contrast value between the measurement area and its background.

The medium used to reduce the brightness of the measurement area should be made of a material that would not scatter the light rays from the object and its background.

So that the visibility index number could be readily interpreted in terms of known visibility conditions, some standardized relationships should be used for reference values.

The complete scene as viewed by the motorist should be in the field of view during the assessment determination. This would include the pavement and shoulder area in front of the vehicle and the luminaires as normally seen from the driver's position in the vehicle.

In addition to a relative visibility index determination it is desirable to obtain actual brightness values of the object and its background so that a complete comparative analysis of the visibility could be made of different lighting systems using different lighting levels (brightness levels).

The basic design principle of an instrument should be that a measure of visibility is obtained when a small portion of the scene as viewed through the instrument is reduced to the contrast threshold, while maintaining constant eye adaptation.

Summarizing these requirements, the ideal visual assessment instrument for highway lighting conditions should include the following features:

1. The eye adaptation should remain constant at the actual roadway brightness level while using the instrument.
2. Only a small central area approximately 1^0 to 2^0 in total visual angle should be changed in contrast while making a visibility measurement. The remaining area should be unaffected insofar as brightness pattern and glare sources are concerned.
3. The change in the measurement area should cause only a change in contrast without changing the average brightness and without scattering the light rays from the object and its background.
4. The visibility index as read on the meter scale used should be related to standardized target contrasts and a simple calibration procedure.
5. The total visual field should be approximately symmetrical and should include about 60^0 total visual angle. A field somewhat larger is desirable if it could be achieved without compromising the optical system.
6. A reference value for the average background brightness and object brightness should be available in the instrument.
7. The instrument should be small, portable, and self-contained (battery powered).

The design of the instrument to meet the above requirements is shown in Figure 1. It consists of a dual monocular system with objective lenses (1) and image erecting lenses (2) so arranged that the field of view as seen through the eye piece (3) shows in an outer annular ring the normal view of the scene through the upper monocular. The central portion of the field of view, as seen through the lower monocular, has projected on it a variable veiling brightness source V. The variable neutral wedge W reduces the central portion of the scene to contrast threshold by the dual action of the reduced brightness of the scene and the added brightness of the veiling source. The principal visual field is unaffected, the average brightness of the central field remains approximately constant, and the contrast may be reduced to threshold.

The operation of this instrument is as follows (Fig. 1):

1. Adjust neutral wedge W for full visibility of scene (maximum transmittance) then focus on scene. Inasmuch as most highway lighting observations are at least 100 ft distant, the focus adjustment need only be checked periodically.

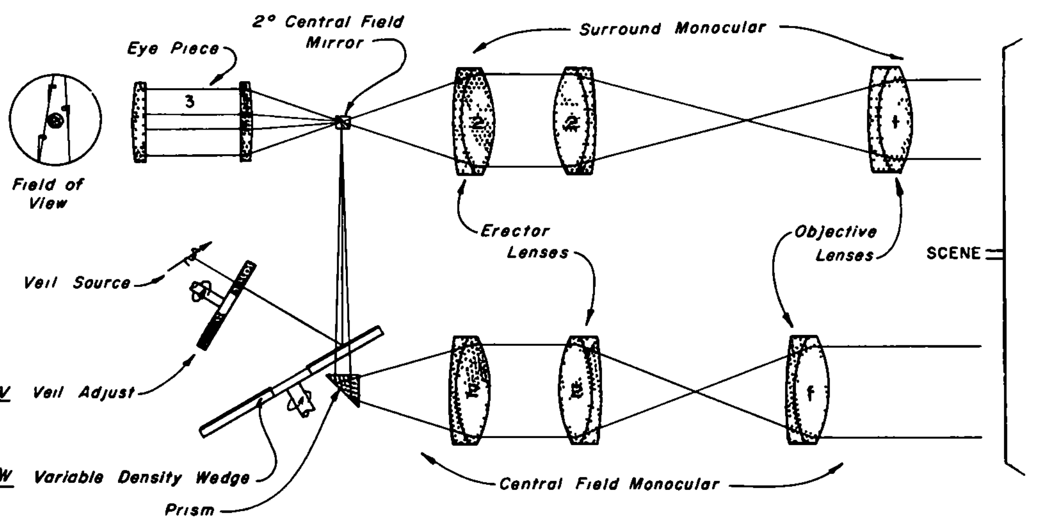

Figure 1. Visibility meter, lenses and wedge system.

2. Adjust neutral wedge W for full visibility of veiling source V (minimum transmittance, approximate).

3. Adjust veiling source V to match the average brightness of the surround around the central spot. Read the average brightness from the calibration chart.

4. Rotate neutral wedge W until threshold is reached in the central area, then read the dial setting on the wedge. The dial setting is termed the Visibility Index (VI).

Figures 2 and 3 show views of the completed instrument. Figure 4 shows the scene as viewed through the meter. This view is a daytime picture to facilitate the photography. Under actual operation on a lighted highway, the central field always remains at the same brightness as the average brightness of the surround.

Neutral Density Wedge W

The variable neutral density wedge W is the key element in the function of the meter. It reduces the central portion of the scene to contrast threshold by the dual action of

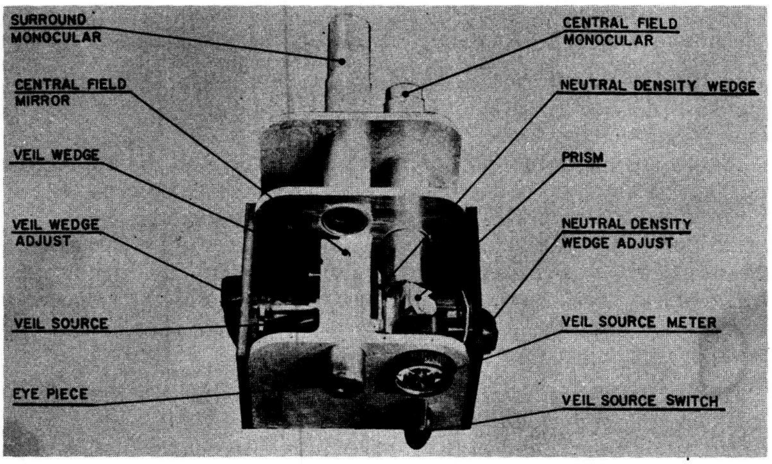

Figure 2. Visibility meter.

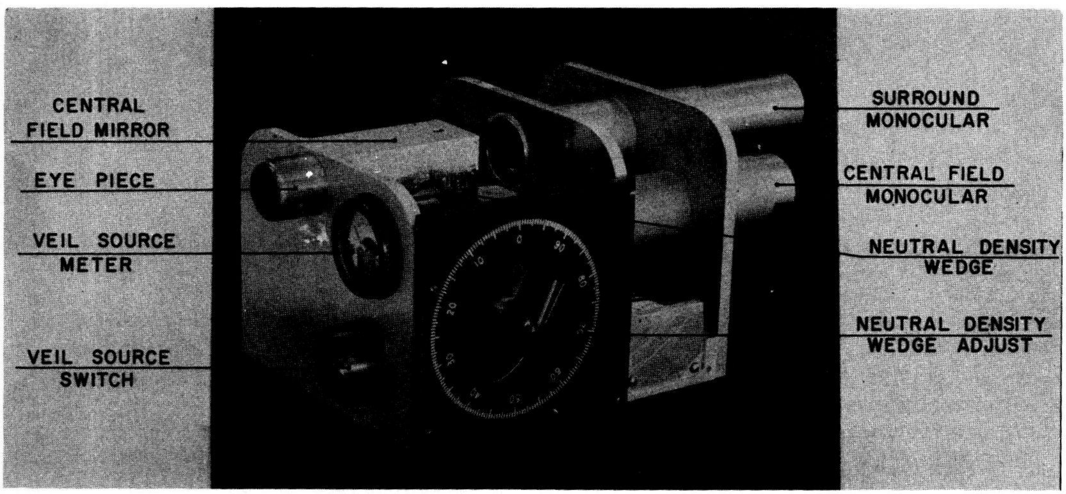

Figure 3. Visibility meter.

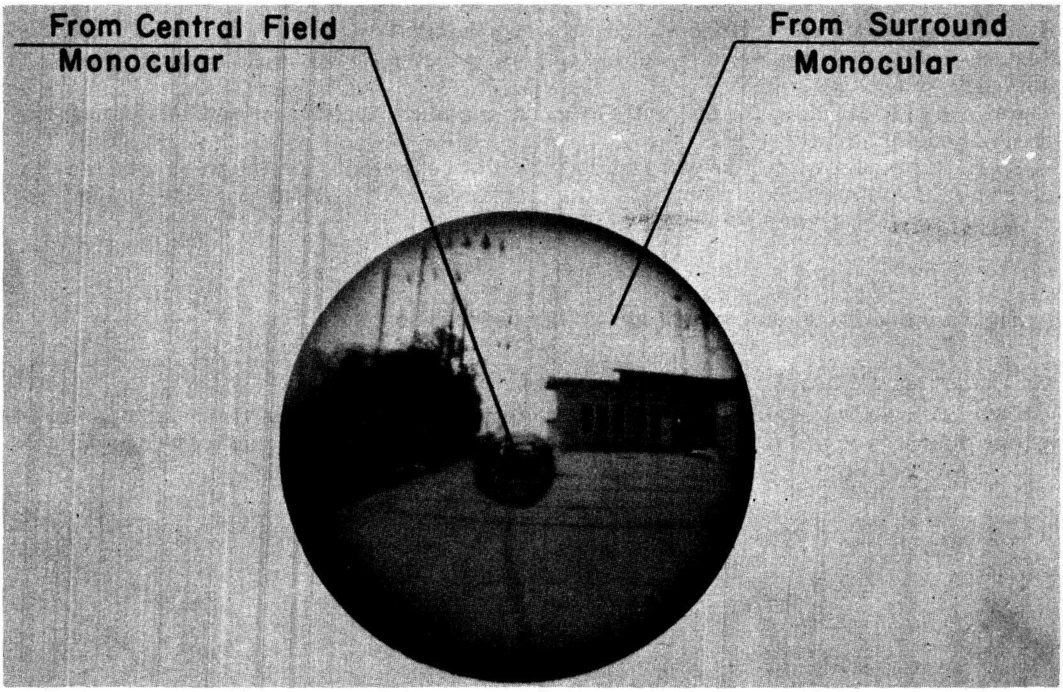

Figure 4. View through instrument.

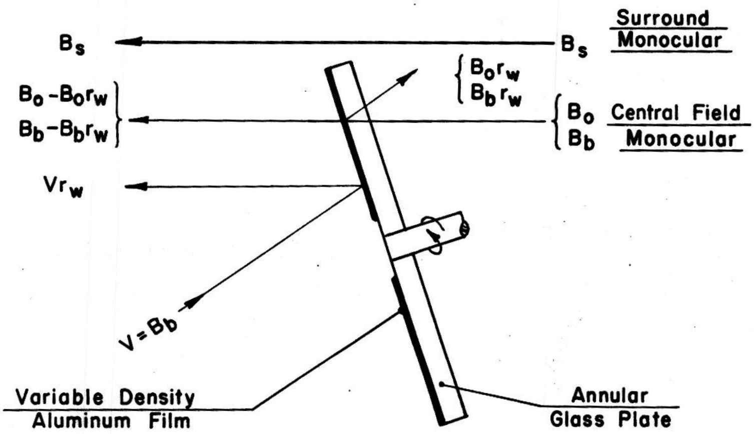

Figure 5. Wedge functions.

the reduced brightness of the scene and the added brightness of the veiling source.

The wedge consists of an annular optically flat glass ring with a variable density layer of metallic aluminum evaporated on its surface over 350° of arc. The wedge transmittance varies from 1.0 to 0.01 (approximately).

Figure 5 shows the relationships among the variables at the wedge.

The sum of the wedge reflection factor, transmittance factor, and absorption loss through the plate is unity, or

$$t_w + r_w + \text{absorption loss} = 1$$

The actual wedge density as used in the instrument can be considered as composed of the actual wedge reflectance factor r_w', and the absorption loss, or $t_w = 1 - (r'_w + \text{absorption loss})$, or where t_w = wedge transmittance, $t_w = 1 - r_w$, in which $r_w = r'_w + \text{ab. loss}$, or $t_w + r_w = 1$.

Veiling light is added to the central field to maintain constant brightness during the threshold determination.

By initial adjustment, the veil light V which is reflected from the wedge surface to the central field mirror is matched to the brightness of the scene by proper adjustment of the veil source control; therefore,

$$V = B_b$$

Figure 6 shows the instrument set up for observation.

Calibration of Visibility Meter

Two calibrations are required for the meter: (a) calibration of the brightness of the veiling source wedge, and (b) calibration of the variable neutral density wedge W.

Figure 6. Visibility meter set up for observations.

The veiling source wedge is calibrated by observing a matte white surface through the meter, for a range of brightness values from 0.01 to 5.0 ft-L for various color temperatures of the reference lamp. The veil wedge is adjusted to match the brightness of the central field mirror to the brightness of the white matte surface for a series of veil lamp current values.

Figure 7 shows the calibration curves for the veiling source wedge.

The calibration of the visibility index (VI) scale for the meter has been related to the visibility of a target with known contrast conditions. A series of disks 3 ¼ in. in diameter, painted a matte neutral gray color with a range of reflectance values from 11.0 to 60.0 percent, were placed on a white matte uniformly illuminated surface. The disks were observed through the meter from a distance of 10 ft and the VI wedge was adjusted until the disks were at contrast threshold for a series of brightness values from 0.01 to 5.0 ft-L on the white matte surface. Under these conditions the disks present a visual size of 1^{0} 33 min. The VI calibration curves are shown in Figure 8. Therefore, a VI wedge setting at threshold becomes an index of visibility for an equivalent object with a known contrast and a fixed visual size.

Mathematical Relationships at Contrast Threshold

The operation principles of the visibility meter are expressed mathematically as follows (see Fig. 5):

initial target contrast is

$$C_t = \frac{B_o - B_b}{B_b} \tag{1}$$

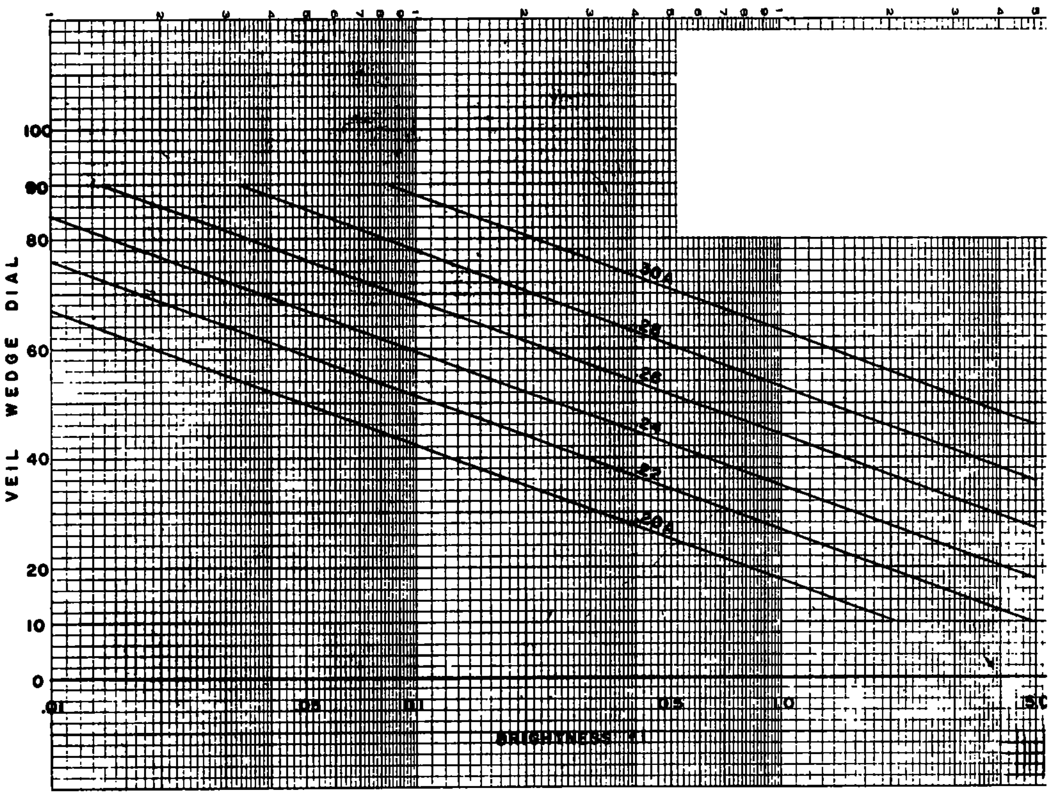

Figure 7. Meter veil calibration, No. 14 lamp 2.5-V blue bead 0.30A.

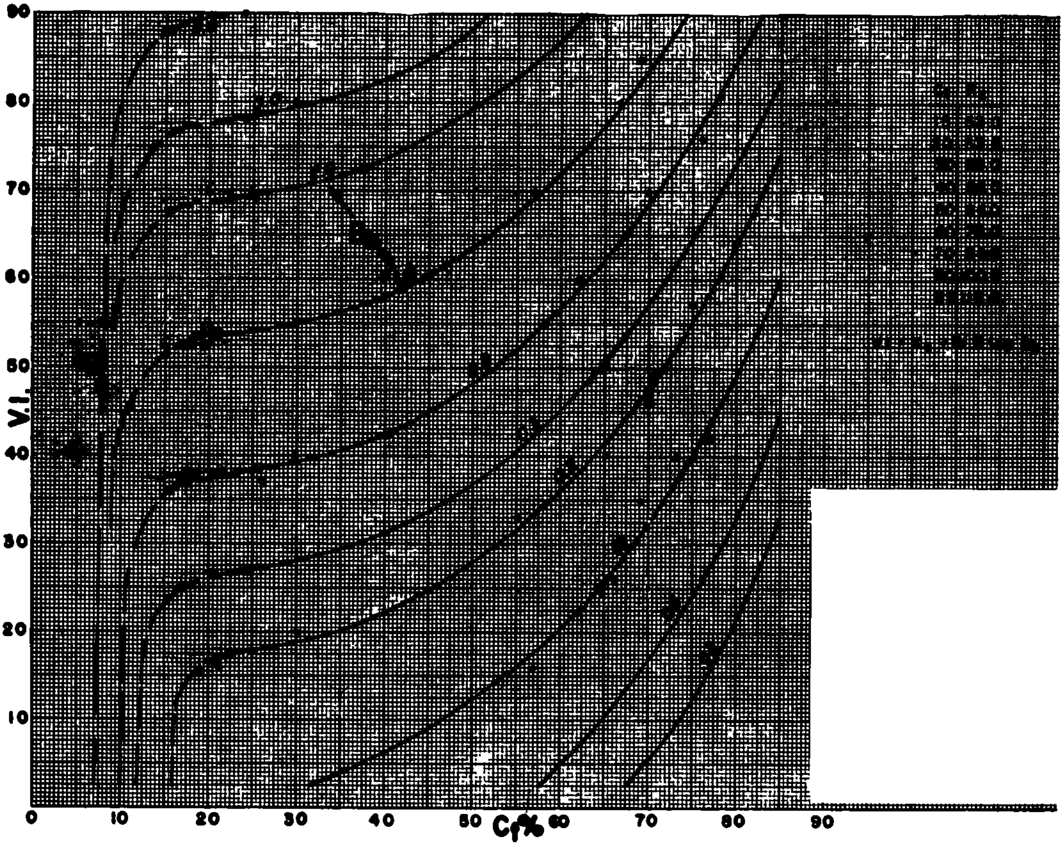

Figure 8. Highway lighting visibility meter calibration curve (VI vs C_t wedge A, veil lamp No. 14, visual target size 1°33'.

Sighting through the eyepiece the meter is adjusted to threshold for the central field. This operation subtracts

$$B_o \cdot r_w \text{ from } B_o \text{ and } B_b \cdot r_w \text{ from } B_b,$$

and adds

$$V_{r_w} \text{ from veil source V to } B_b \text{ and } B_o$$

As explained in the discussion of the wedge W functions,

$$t_w + r_w = 1 \text{ (approx.)} \tag{2}$$

Therefore,

$$r_w = (1 - t_w) \tag{3}$$

Then, at threshold as seen thru the eye piece the new contrast is obtained by substituting these values in Eq. 1.

$$C_o = \frac{\left[B_o - (B_o \cdot r_w) + r_w V\right] - \left[B_b - (B_b \cdot r_w) + r_w V\right]}{B_b - (B_b \cdot r_w) + r_w V}$$

Substituting terms of Eq. 3,

$$C_o = \frac{\left[B_o - B_o(1 - t_w) + r_w{}^V\right] - \left[B_b - B_b(1 - t_w) + r_w{}^V\right]}{B_b - B_b(1 - t_w) + r_w{}^V}$$

$$C_o = \frac{B_o - B_o + B_o t_w + r_w{}^V - B_b + B_b - B_b t_w - r_w{}^V}{B_b - B_b + B_b t_w + r_w{}^V}$$

By initial adjustment of the meter

$$V = B_b \tag{4}$$

Substituting B_b for V from Eq. 4

$$C_o = \frac{B_o - B_o + B_o t_w + r_w B_b - B_b + B_b - B_b t_w - r_w B_b}{B_b - B_b + B_b t_w + r_w B_b}$$

Collecting terms,

$$C_o = \frac{t_w(B_o - B_b)}{B_b(t_w + r_w)}$$

Because $(t_w + r_w) = 1$ from Eq. 2,

$$C_o = \frac{t_w(B_o - B_b)}{B_b}$$

$$C_o = t_w \cdot \frac{B_o - B_b}{B_b}$$

Because $C_t = \frac{B_o - B_b}{B_b}$ from Eq. 1,

$$C_o = t_w \cdot C_t$$

Thus the contrast threshold, which is a constant at a given adaptation level, is the product of the wedge transmittance and the actual target contrast. Therefore, the transmittance of the wedge is a measure of the contrast threshold, consequently an index of visibility.

The wedge scale is numbered from 0 to 100 with 0 corresponding to a wedge transmittance of 1-absorption losses, and 100 corresponding to a wedge transmittance of 0.01. The wedge scale numbers of 0 to 100 indicate the visibility index (VI).

A VI of 0 indicates that the contrast between the target and its background is at or below the minimum contrast that can be detected by the eye, or essentially zero visibility. Thus, a low visibility index number (high t_w) will indicate a low initial target contrast, consequently a low degree of visibility, although while a high visibility index number (low t_w) will indicate a high initial target contrast; therefore, a high degree of visibility.

The amount of veiling brightness required to reduce the object to threshold is dependent on the average background brightness (see curves in Fig. 7).

Consequently, when the meter is used under actual highway lighting conditions the visibility index determinations are related to actual known contrast conditions, corresponding to the calibration objects and their backgrounds.

VISIBILITY ASSESSMENT ANALYSIS

Mathematical Considerations

If the calibration curve data shown in Figure 8 are replotted holding C_t constant, a family of curves of VI vs B_b is obtained as shown in Figure 9. The coordinates are semi-logarithmic and all the curves are straight lines.

Under these conditions it is evident that for this meter the general relation among the variables is

$$VI = K_c + A \log B_b$$

From experimental data shown in Figure 8,

When $C_t = 40$ and $B_b = 1$, $VI = 58.0$. Therefore,

$$58.0 = K_c + A \log 1$$

$$K_c = 58.0$$

When $C_t = 40$ and $VI = 6.5$, $B_b = .10$. Therefore,

$$6.5 = 58.0 + A \log .10$$

$$6.5 = 58.0 - A$$

$$A = 51.5$$

The general formula is then

$$VI = K_c + 51.5 \log B_b$$

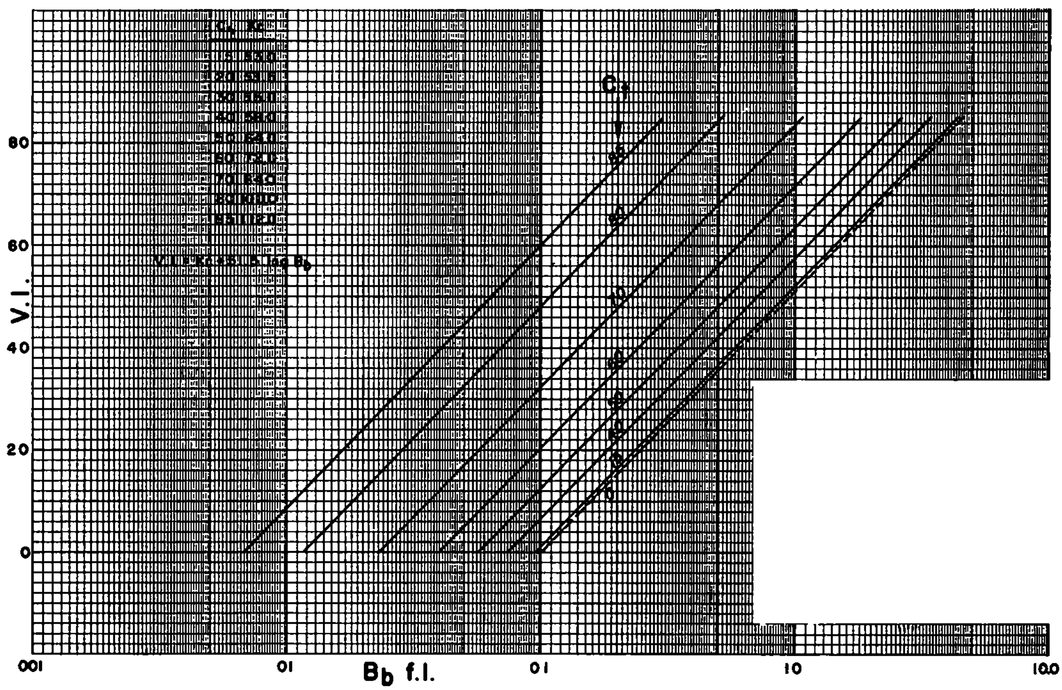

Figure 9. Highway lighting visibility meter calibration curve (VI vs B_b) wedge A, veil lamp No. 14, visual target size 1°33'.

The empirical value of K_c for each value for Ct is given in the following table and shown plotted in Figure 10.

C_t	K_c	C_t	K_c
0	51.5	50	64.0
15	53.0	60	72.0
20	53.5	70	84.0
30	55.0	80	100.0
40	58.0	85	112

These constants, of course, are dependent on the physical characteristics of the neutral density wedge W, and are applicable only to the instrument developed in this project.

Visibility Index

From the mathematical relationship established for this meter,

$$VI = K_c + 51.5 \log B_b$$

it is evident that for a given initial target contrast the visibility index, or degree of visibility as determined by the instrument, will vary as the log of the background

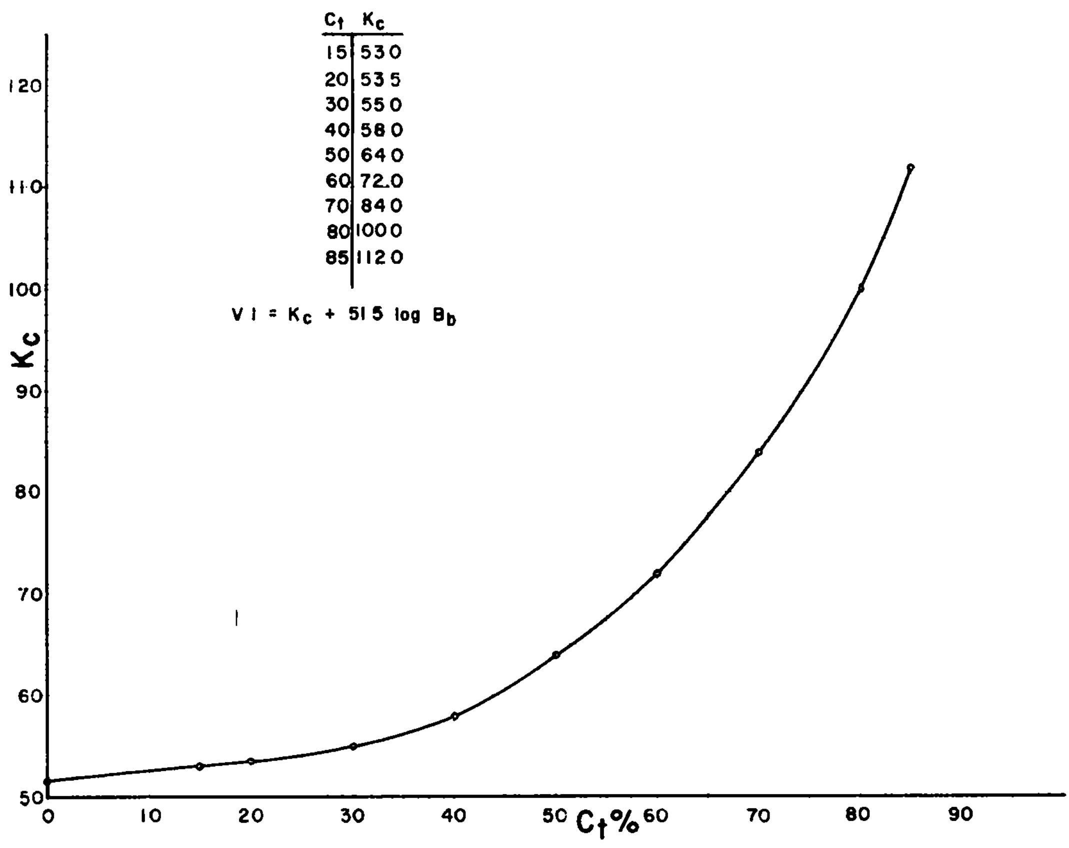

Figure 10. Highway lighting visibility meter (K_c vs C_t).

brightness. This is shown in Figure 9 and is confirmed by the typical visual performance curve in which visual acuity or contrast sensitivity will vary approximately as the log of the background brightness for the range of brightness covered by this instrument.

For any fixed VI (fixed degree of visibility) the background brightness must increase logarithmically as the target contrast decreases.

For example (Fig. 9), an object with a contrast of 85 percent with a background brightness of 0.04 ft-L would have the same degree of visibility (VI = 40) as the same object with a contrast of 40 percent against a background of 0.46 ft-L.

Using the general formula, the values of VI have been calculated for representative values of C_t and B_b. These calculations are given in Table 1. The actually observed calibration points shown as dots in Figure 8 are very close to the calculated points of the curves.

Borderline Between Adequate and Inadequate Visibility (BAIV)

The visibility index of 0 is established at the maximum wedge transmittance (near 90 percent). When threshold conditions occur at this setting, it indicates that the target in the central field of view is at threshold or essentially zero visibility or borderline between adequate and inadequate visibility, as seen by the normal eye thru the instrument. Figure 11 shows this zero visibility relationship as defined by the developed equation for the instrument in which

$$VI = K_c - 51.5 \log B_b = 0$$

and is a plot of object contrast vs background brightness when VI = 0. The curve is shown extrapolated to zero contrast which is not possible, but the implication is that below 0.10-ft-L background brightness all low contrast roadway objects will be at or below the threshold for detection. High contrast objects of 80 percent or more will be at

TABLE 1

CALCULATED V.I. FOR EACH VALUE OF K_c WHERE:

$$V.I. = K_c + 51.5 \log B_b$$

VISUAL CONTRAST

$$C_t = \frac{B_o - B_b}{B_b}$$

B_b = BACKGROUND BRIGHTNESS
B_o = OBJECT BRIGHTNESS

		VISIBILITY INDEX, V I (NO'S IN TABLE)										
C_t	K_c \ B_b	01	.03	.05	.1	.2	.3	.5	1.0	2.0	3.0	5.0
15	53.0					170	26 0	37 5	53 0	68 5	77.5	89.0
20	53.5					17.5	26.5	38.0	53.5	69.0	78.0	89.5
30	55.0					19.0	28 0	39.5	55 0	70.5	79.5	
40	58.0				6 5	22.0	31.0	42.5	58.0	73.5	82.5	
50	640				12 5	28.0	370	48.5	64.0	79 5	88 5	
60	72.0			5.0	20 5	360	450	56.5	72.0	87.5		
70	84.0		5.5	170	32.5	48.0	570	68.5	84 0			
80	100.0		21.5	33.0	48.5	64.0	73.0	84.5				
85	112.0	9.0	33.5	45.0	60 5							

contrast threshold, or zero visibility when the background brightness is in the order of 0.01 ft-L.

It is evident that the area to the left of the curve will be a region of inadequate visibility and the area to the right of the curve will be a region of adequate visibility.

The low limit of object contrast calibration by the meter is 20 percent. Therefore, the area to the left of the curve and below 20 percent object contrast will be a region of inadequate visibility due to insufficient contrast. The area to the left of the curve above 20 percent object contrast will be a region of inadequate visibility due to insufficient background brightness. This curve has been termed the BAIV curve, the borderline between adequate and inadequate objective visibility under highway lighting conditions.

The BAIV relationship is considered one of the significant developments of this research because it provides an objective appraisal standard for visibility under highway lighting conditions.

It is proposed that all highway lighting situations should fall within the region of adequate visibility.

HIGHWAY LIGHTING DESIGN

Current Practice

Current recommended practice for highway lighting design in the United States has been sponsored by the Illuminating Engineering Society and approved by the American Standards Association (3). This authority states that "the objective of street and highway lighting is to provide adequate pavement brightness with good uniformity and appropriate illumination of adjacent areas, together with reasonable freedom from glare." Therefore, the importance of pavement brightness is recognized. However, no specific consideration is given to this factor in the recommended design practice, which consists essentially of a specification of average horizontal foot-candles on the pavement, determined by the ratio of luminaire output to pavement area between luminaire standards.

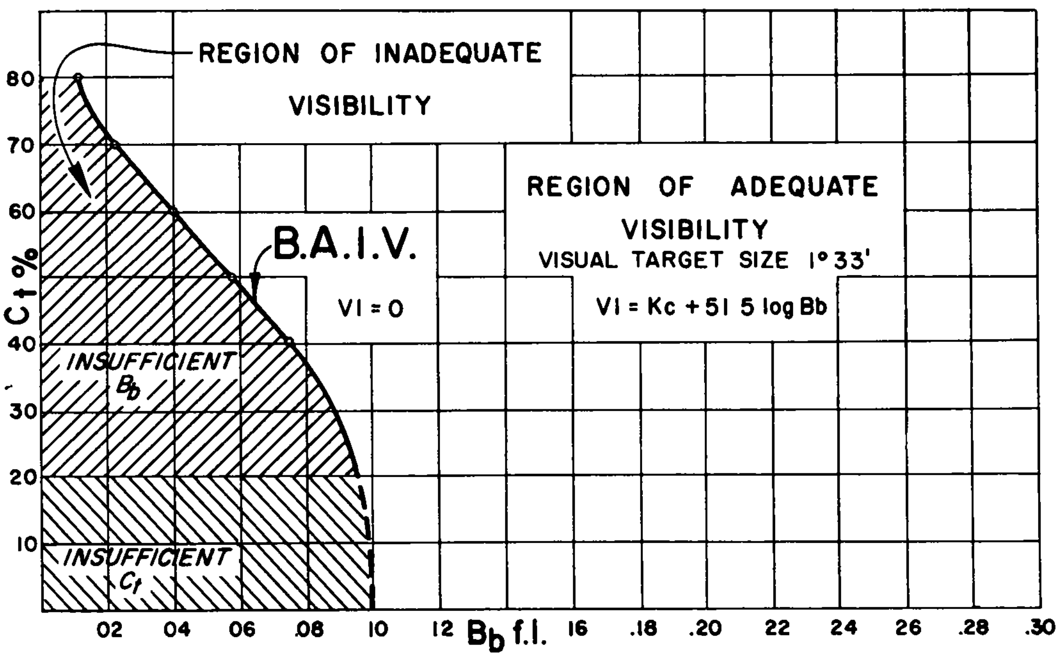

Figure 11. Highway lighting borderline between adequate and inadequate visibility.

It is well known among illumination engineers that the pavement brightness patterns as seen by the motorist depend on the reflectance characteristics of the pavement and the relative positions of the observer, the object, and the light sources. There is no information currently available that will permit a determination of observed brightness on the pavement from an illumination specification of average horizontal foot-candles on the pavement. Therefore, it is evident that the present design practice does not support the recognized objective of good highway lighting, "to provide adequate pavement brightness with good uniformity."

Design Criteria

Visual Approach.—In a study of design standards for highway lighting the first consideration should be the actual visual elements that are apparent to the observer. The observer will see

1. The road surface and boundaries as patterns of brightness.
2. Luminaires as small concentrated bright areas.
3. Obstacles as a form or shape with some range of brightness values.

The actual lumen output of the luminaires or the average or actual foot-candle intensity on the roadway is not apparent to the observer. The entire scene as viewed by the motorist is composed of variations in brightnesses. The principal visible features are the pavement and object brightness which indicate whether the way is clear or obstructed, and the brightness of the luminaire which constitutes a source of disability and discomfort glare.

This concept goes beyond the current recommended design practice which considers only an average horizontal foot-candle illumination value on the pavement.

BAIV Criterion.—In the instrument calibration procedure described earlier a determination was made of visibility conditions at contrast threshold, termed the borderline between adequate and inadequate visibility of objects under highway lighting conditions. This BAIV relationship (shown in Fig. 11) is a plot of C_t vs B_b when VI = 0, or as expressed by the formula derived for VI,

$$\text{BAIV} = \text{VI} = K_c + 51.5 \log B_b = 0$$

Under these conditions visibility is at contrast threshold or the borderline between adequate and inadequate visibility.

Figure 12 shows a typical critical contrast curve in relation to the BAIV curve. This critical contrast curve is by Blackwell (4) with 1/10-sec response and 60-min target size, with a field factor of 1.0.

Blackwell (4) describes the field factor (FF) as the necessary increase in critical contrast values to meet actual visual conditions.

The inherent losses in the instrument due to the lense and wedge system result in the BAIV curve. Therefore, the BAIV curve can be considered a practical critical curve for highway lighting conditions with a built-in field factor ranging from 3 to 5, based on the Blackwell critical contrast data.

In this particular instrument the low limit of threshold calibration was a 20 percent contrast object, within the brightness range of 0.01 to 5.0 ft-L.

To extend the BAIV curve beyond the limits of an object contrast of 20 percent, the BAIV curve has been extrapolated by using the Blackwell (4) critical contrast values with a field factor of 5.0 for the background brightness range from 0.10 to 5.0 ft-L. This results in the BAIV (with FF) curve shown in Figure 12, with the field factor ranging from 3 to 5.

On the basis of this BAIV (with FF) curve the field factor varies from a value of 5.0 for the high brightness range of the meter to a value of 3.0 for the low brightness range of the meter.

In Figure 13, the visibility meter calibration curve, the BAIV (with FF) relationship is shown. The BAIV curve for essentially zero visibility occurs when VI is essentially zero for target contrasts and background brightness less than 85 percent and 0.008 ft-L,

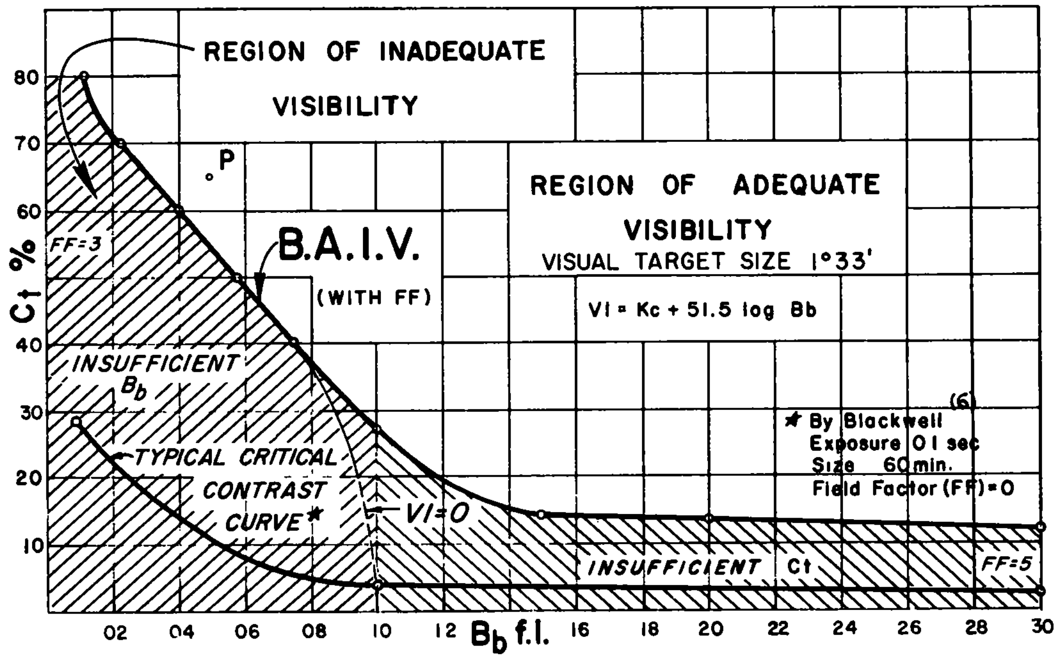

Figure 12. Highway lighting borderline between adequate and inadequate visibility.

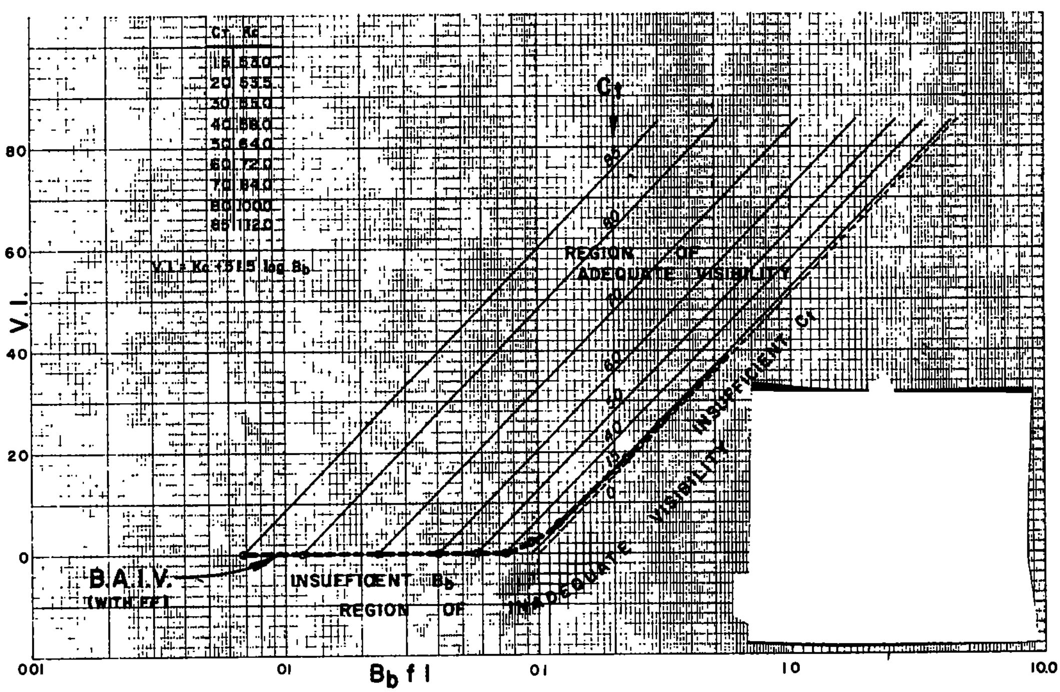

Figure 13. Highway lighting visibility meter calibration curve (VI vs B_b) wedge A, veil lamp No. 14, visual target size 1°33'.

and more than 40 percent and 0.06 ft-L. At higher background brightness levels (above 0.06 ft-L) the minimum acceptable value of VI to be above the BAIV level increases to a number greater than zero.

The region of adequate visibility conditions (that is, sufficient object contrast and background brightness) is above the BAIV curve. The region of inadequate visibility due to insufficient background brightness is below the BAIV curve for values of B_b less than 0.10 ft-L. The region of inadequate visibility conditions due to insufficient object contrast is below the BAIV curve for values of B_b more than 0.10 ft-L. Therefore, a minimum background or pavement brightness of 0.10 ft-L would assure the visibility of an object of a low contrast value.

Design Standard

The establishment of BAIV curve provides an objective design standard for visibility under highway lighting conditions; namely, to assure that an object with minimum contrast will be visible under all highway lighting conditions. The minimum background pavement brightness should not be less than 0.10 ft-L.

This criterion is based on conditions of uniform background brightness and the absence of glare. Should either of these conditions not be present other criteria would obtain.

This same conclusion has been reached by Dunbar (5), who has stated "that when the pavement brightness in any region reaches a value of 0.1 ft-L, a further increase in brightness will not materially alter the revealing power in that region. When the lowest brightness of the background exceeds 0.1 ft-L the revealing power of the installations as a whole will become independent of the brightness."

DeBoer (6) has reached a similar conclusion when he determined that "the roadway brightness should not be less than 0.15 ft-L for minimum contrast objects to be visible under highway lighting conditions."

Silhouette Lighting

It is well known at low levels of pavement brightness (below 0.10 ft-L) objects are seen in silhouette with relatively high contrast characteristics.

Under these conditions the obstacle will usually have a contrast in excess of 50 percent. From the BAIV curve a target contrast in excess of 50 percent will require a background brightness of at least 0.05 ft-L to be visible (see Fig. 12).

Thus, considering C_t and B_b at point P in Figure 12, this point would represent an object with 65 percent contrast and a background brightness of 0.05 ft-L. Inasmuch as point P is to the right of the BAIV curve, it is in the region of adequate visibility.

This suggests the possibility of providing adequate visibility more economically for roadways using very low levels of uniform roadway brightness.

Current highway lighting practice recommends illumination levels of 0.2 to 2.0 average horizontal ft-c per sq ft of roadway surface. Under typical highway conditions, using conventional luminaires this practice has resulted in pavement brightness in the range of 0.1 to 2.0×10^{-3} cd per sq in. (0.05 to 1.0 ft-L).

Based on the minimum requirements of 0.05 ft-L as previously established, it is evident that current practice provides up to 20 times the illumination values necessary for adequate illumination.

Adequate visibility with the use of such a low level of illumination is contingent on the absence of glare sources in the field of view and a uniform brightness level over the roadway surface.

COMPARISON WITH OTHER INVESTIGATIONS

A review of the literature shows that there are two earlier investigations that are directly comparable with the findings developed in this research. These two investigations undertook to evaluate visually visibility conditions on lighted roadways. These were observations of lighting conditions by groups of observers and were entirely subjective in nature.

Field Studies

Dunbar (5) made field observations of an 18-in. diameter plane target from an automobile traveling at 30 mph under a series of roadway lighting conditions. He concluded that the ratio of pavement brightness to object brightness to be perceptible under highway lighting conditions should not be less than 1.5 for objects seen darker than their backgrounds.

DeBoer (6) has carried out a similar investigation with visual observations of an 11-in. square plane target from a distance of 300 to 700 ft. He concluded that the ratio of pavement brightness to object brightness under silhouette condition should not be less than 1.7.

The results of these two investigators are compared with the findings in Figure 14. The higher B_b/B_o ratios for the BAIV curve for a background brightness less than 0.06 ft-L can be attributed to the larger visual target size used in the instrument calibration procedure under ideal static laboratory conditions, whereas the lower BAIV curve for background brightness more than 0.06 ft-L results from the higher sensitivity of the visibility meter for low contrast objects.

Considering that both Dunbar and deBoer made subjective observation under actual highway lighting conditions in the field, the agreement with this investigation is considered quite good, and does support the validity of the assessment procedure and design criteria developed in this research.

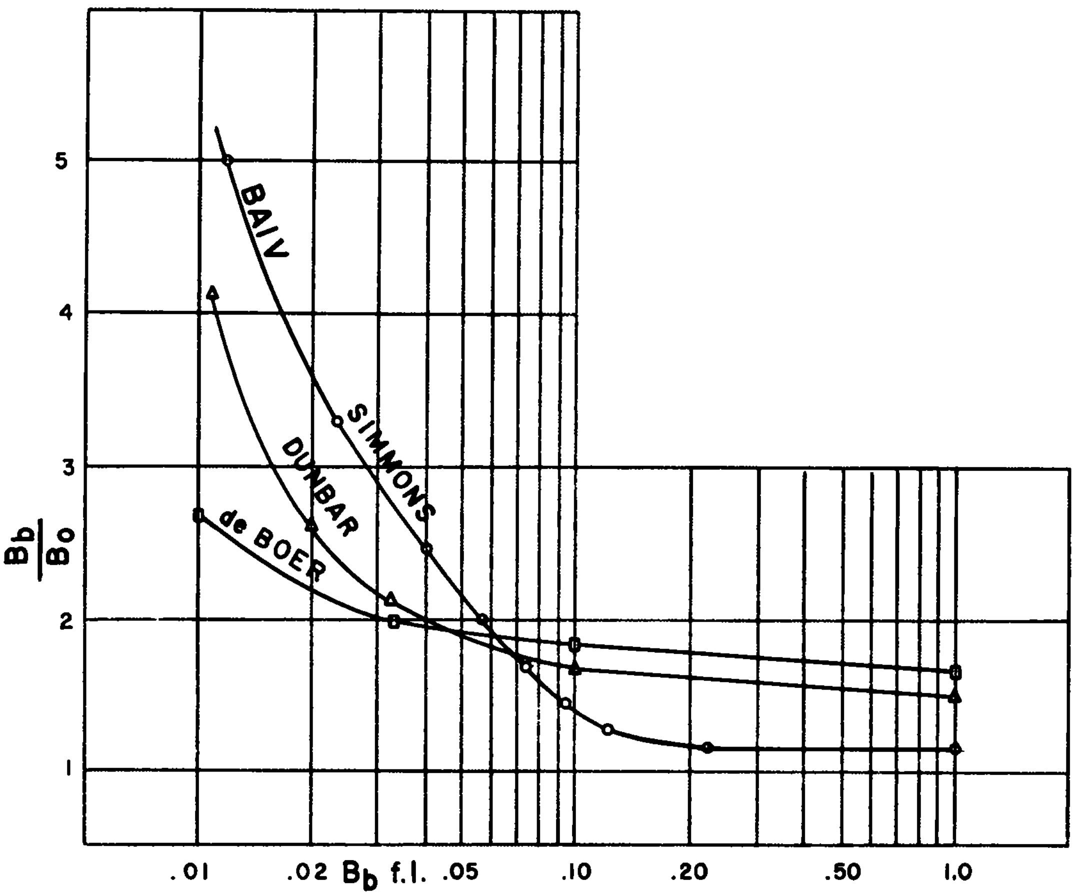

Figure 14. Highway lighting, smallest ratio of road brightness to objective brightness perceptible under highway lighting conditions.

Referring to Figure 14, the smallest ratio of pavement brightness to object brightness observed with the visibility meter developed in this research is 1.2 and indicates the maximum sensitivity of the instrument.

SUMMARY

This research project has been an attempt to develop instrumentation and an objective appraisal method for the determination of relative visibility under highway lighting conditions. An investigation has been made of the physical factors influencing visibility under highway lighting conditions and has related these factors to the objective determination of visibility of objects on the roadway at night.

Instrumentation, incorporating an unbiased objective appraisal of visual conditions on a lighted roadway at night, has been developed.

The instrument calibration technique provides an index to visibility related to actual contrast conditions between an object and its background. This calibration technique has been termed the visibility index (VI).

A mathematical analysis has been made of the instrument calibration data relating the visibility index to object contrast and background brightness. The establishment of this mathematical relationship between the contrast of an object and its background brightness has enabled the determination of a highway lighting design criterion. This design criterion has been termed the borderline between adequate and inadequate visibility (BAIV).

The BAIV relationship established by this research has been compared with subjective visual appraisal methods and found to be in substantial agreement.

The finding of this research should help lead the way toward more effective and economical highway lighting designs.

ACKNOWLEDGMENTS

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Glare Screen for Divided Highways

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To make use of the full sight distances provided by modern highways, motorists must use their high-beam headlights when traveling at night. Because of the objectionable glare to oncoming motorists, some form of screening is desired and often is required.

Several forms of glare screen are in use today. These include plantings of shrubbery, wood or metal fences placed parallel to the centerline of the highway, and intermittent fences of wood or metal placed in a louvered pattern, or placed at 90° to the centerline of the highway.

Each type has advantages and disadvantages, but the screen found most satisfactory is a line of expanded metal mesh, erected in the median strip, parallel to the centerline of the highway. Because of the manufacturing process involved in making expanded metal mesh, the manufactured screen has a twist in the strands of the diamonds which will block out light normal to the surface of the strands. Although the view through the fence is impeded at small angles with relation to the centerline of the highway, the fence becomes transparent at angles greater than about 20°. At angles greater than 20°, the glare from opposing headlamps is not considered objectionable during nighttime driving. During the daytime, the fence does not interrupt the general viewing by passengers traveling in the automobiles.

Width of median strip, height of headlamps, and height of drivers' eyes all play a part in locating the required upper and lower edges of screen. To provide complete protection from glare, the upper edge of the screen should be 7 ft 2 in. above a line connecting the inner edges of the roadway. If consideration is given to the fact that heavy trucks ordinarily occupy the slow lanes of highways, the top edge of the screen can be reduced to a height of 5 ft 8 in., and be effective in preventing glare in about 95 percent of the meetings of opposing vehicles. The lower edge of the screen should be mounted 1 ft 9 in. from a line connecting the inner edges of the roadway.

On tangent lines, the cut-off angle of the screen should be about 20°. An expanded mesh having a dimension of 1 ½ in. center to center of diamond with a ¼ in. strand width will have such a cut-off angle. On curved roadways, the cut-off angle of the screen must be increased by an amount which varies with the roadway width and the curvature. A screen having a dimension of ¾ in. center to center of bridges and a 3/16 in. strand width will satisfy the requirements of curves having a radius of 1,000 ft.

Because of the manufacturing limits of expanded metal mesh, variations from these dimensions result in glare that is objectionable to a varying degree depending on the susceptibility of the driver.

•HIGHWAYS on the Primary and Interstate Highway System are designed for speeds of 50 to 70 mph. According to current AASHO specifications, corresponding minimum stopping sight distances for these design speeds will vary from 350 to 600 ft. To take advantage of these design speeds during nighttime driving, it is necessary to use high beams of headlights. This can cause objectionable glare to drivers of opposing vehicles, and, depending on the median width, may result in a sight distance so small that a definite safety hazard results.

The State of Idaho Department of Highways has conducted tests (1) in which seven different drivers drove a standard, late-model American-made automobile down a test track towards the opposing glare of the high beams of a stationary automobile's headlights. The stationary automobile was located in the opposing lane across the median strip. The run was made ten times with median widths varying from 10 to 100 ft in 10-ft intervals. An object was placed in the path of the moving vehicle and opposite the stationary vehicle, but far enough back so that the stationary vehicle's lights would not reflect on the obstacle.

There were two men in the test auto. The driver stated when he could see the obstacle, while the other man dropped a marker at that point. The driver made several runs, starting with the 10-ft median, then the 20-ft median, and so on, until there was no glare, or until he could clearly observe the obstacle with his headlights alone.

The calculated statistical average of sight distances for the seven drivers tested gave the following results:

Median Width (ft)	Distance from Object (ft)
10	184
20	262
30	335
40	389
50	416
60	457

There was no glare after the 60-ft median width.

The average sight distances for the seven drivers tested are compared with the minimum safe stopping sight distances required by AASHO:

Design Speed (mph)	Minimum Sight Distance (ft)
30	200
40	275
50	350
60	475
70	600

To take full advantage of minimum highway sight distances during the nighttime driving, the following are necessary:

1. A highway with a 10-ft median width should have a maximum design speed of 30 mph.
2. A highway with a design speed of 50 mph requires a median width of between 30 and 40 ft.
3. A highway with a design speed of 60 mph or greater requires a median in excess of 60 ft.

It is immediately recognized that median widths of this magnitude are often not possible because of the expense of land acquisition and highway construction. It is also recognized that in urban areas where there normally are narrow median strips limiting maximum speeds on a multilane divided highway to 30 mph is an impractical restriction.

Thus, to prevent intolerable glare for drivers of approaching vehicles, it becomes necessary to provide some device that will prevent glare and permit motorists to take full advantage of highway sight distances.

Types of Screening in Use

Plantings of large dense shrubbery provide a very suitable glare screen and have the added advantage of providing some degree of cushioning for vehicles tending to cross into the opposing lane of traffic. However, there are several disadvantages to shrubbery, chief among which is the fact that it takes several years for the plantings to grow sufficiently to provide glare protection.

Fences may be used in either of two ways. The fence may run continuously along the median strip and may be made of material that is either opaque or semi-opaque. It may also be made of short sections of opaque material erected across the median strip either in a louvered pattern or at 90° to the centerline of the highway. To be effective, a fence erected in the latter manner should have a spacing between lines of fence equal to about three times the length of intermittent fencing.

Expanded metal mesh is considered to provide the attributes required of a glare screen material, because it provides an opaque appearance up to about a 20° angle to the plane of the fence, but allows an unobstructed view through the fence when viewed normally. Because of the manufacturing process involved, the strands are given a twist that prevents view through the fence when viewed obliquely. This feature of expanded mesh is desirable because it allows automobile passengers a relatively unimpeded view of the surrounding countryside and also permits police surveillance of the opposite traffic lane.

Requirements for a Glare Screen

To be effective, a glare screen should shut out all glare from opposing headlights up to an angle of about 20° in relation to the centerline of highway. Beyond that angle, glare is usually not objectionable, and, therefore, the fence should allow the passengers of automobiles to see through the fence, if possible.

Because of the relationship of opposing automobiles on horizontal curves, the fence should shut out glare for angles greater than 20°. It will be seen that glare screens on horizontal curves of radius of 1,000 ft should cut off light up to about 25°.

The screen should be low enough to prevent light from the lowest sports car from shining underneath it into the eyes of an opposing driver. By the same token, it should be high enough to prevent lights from the large trucks from shining over the fence and into the eyes of a driver of an opposing truck or bus.

Variations in roadway width, median width, and roadway curvature all play a part in establishing the elevation of the upper and lower edges of the screen and the required cut-off angle.

Vertical Position of Screen with Respect to Roadway

The upper and lower edges of the screen are set by consideration of height of headlamps, height of opposing driver's eyes, and change in elevation of pavement across the roadway.

If a six-lane divided highway having a 5-ft median strip is considered and it is assumed that the nearside headlamp of an approaching car is 4 ft 6 in. from the outside lane edge and that the eye position of an approaching driver is 3 ft 3 in. from the inside lane edge, the vertical position of the glare screen can be fixed.

A sports car traveling in the slow lane of a six-lane divided highway would have its headlights about 2 ft above the pavement corresponding to 1 ft 9 in. to the lower edge of the lamp. When this car approaches another sports car in the opposite slow lane, the other driver's eye height can be as low as 3 ft. This situation will establish the criteria for fixing the lower edge of the screen. It is also necessary to consider the drainage slope of the roadway because the elevation of automobile headlights will be reduced as the car changes its position with respect to the median. For purposes of discussion the roadway slopes are considered 1 in 48 from the edge of the median strip (Fig. 1). Therefore, for this roadway cross-section the lower edge of the glare screen should be 1.80 ft above a line connecting the inner edges of the roadway. The lower and upper edge of the screen is always taken in relation to an imaginary line

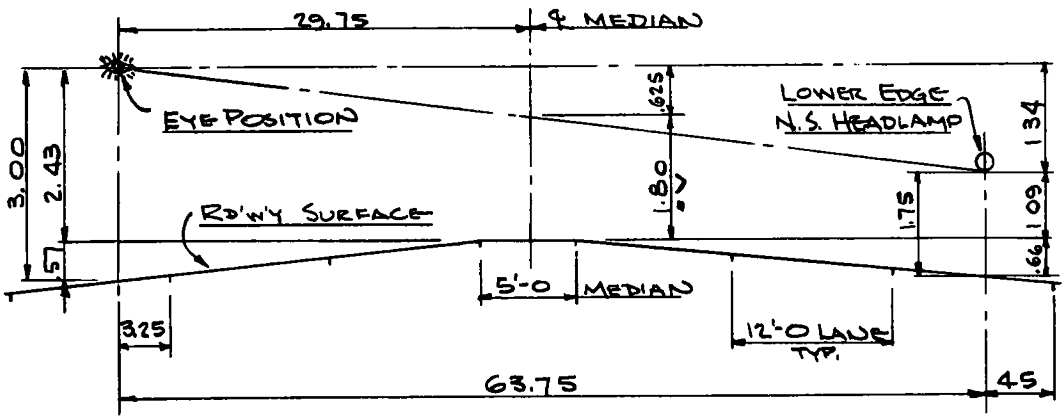

Figure 1.

$$v = 2.43 - (1.34/63.75)(29.75)$$
$$v = 1.80$$

connecting the inner edges of the road and is not measured from the elevation of the median strip.

In establishing the height of the upper edge of the screen, the extreme case will be that of a driver of a large truck traveling in the fast lane meeting lamps of another large truck occupying the opposite slow lane. Taking the upper mounting height for headlamps on modern trucks at 3 ft 6 in. corresponding to a height of 3 ft 9 in. measured to the top of the lamp face, and the eyes of the opposing driver at 8 ft, have the criteria to fix the upper edge of the screen are obtained (Fig. 2). Therefore, the upper edge of the screen should be 7.23 ft above a line connecting the inner edges of the roadway.

A large truck will ordinarily occupy the slow lane throughout most of its journey. Therefore, it is wise to consider what effect this fact will have on the over-all height of the screen. Again, considering the same roadway cross-section and the same two trucks, except that both trucks occupy their respective slow lanes, the top of the screen will be fixed by the relationship shown in Figure 3. Therefore, the upper edge of the screen should be 5.40 ft above a line connecting the inner edges of the roadway.

The figures are intended to show the method of arriving at the upper and lower edges of the screen and the limiting dimensions will, of course, vary with change in roadway cross-section. Manufacturers of expanded mesh normally produce most economically in even foot increments, and a 48-in. wide sheet of expanded metal erected 1 ft 9 in. from a line connecting the innermost edges of the roadway will have its upper edge 5 ft 9 in. above the same line. It is thought that screens of this height will provide glare protection in a sufficient number of cases to warrant the economics provided.

Fixing the upper and lower edges of the screen by the previously discussed method is valid for roadways with a straight grade on tangent. In the instance of vehicles approaching in a trough or at the brow of a hill, the screen should be lowered or raised according to the degree of vertical curvature. Experience has shown that the glare experienced from opposing headlights in a trough is relatively unobjectionable, compared to the glare from headlights approaching on a brow of a hill.

Expanded Metal Glare Screen for Roadways with Horizontal Curvature

To provide the same order of glare protection on curves as on straight sections of roadway, the cut-off angle of the screen must be increased by an amount that varies with the width of the roadway and the radius of curvature of the bend; for example, Figure 4.

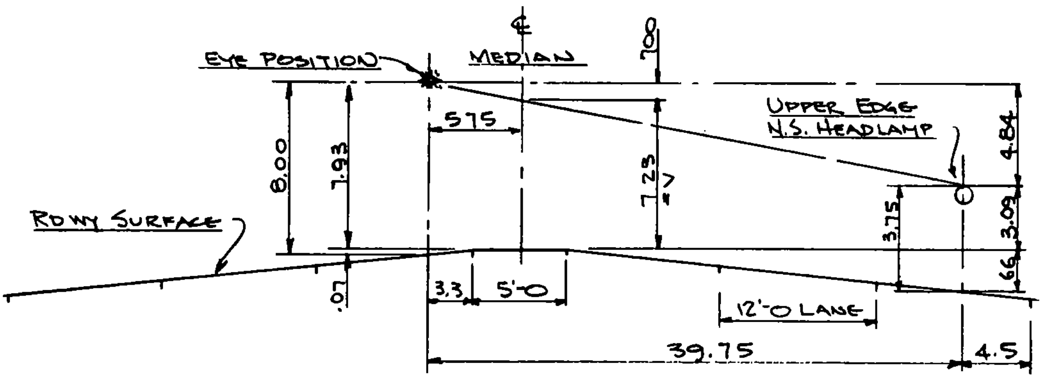

Figure 2.

$v = 7.93 - (4.84/39.75)(5.75)$
$v = 7.23$

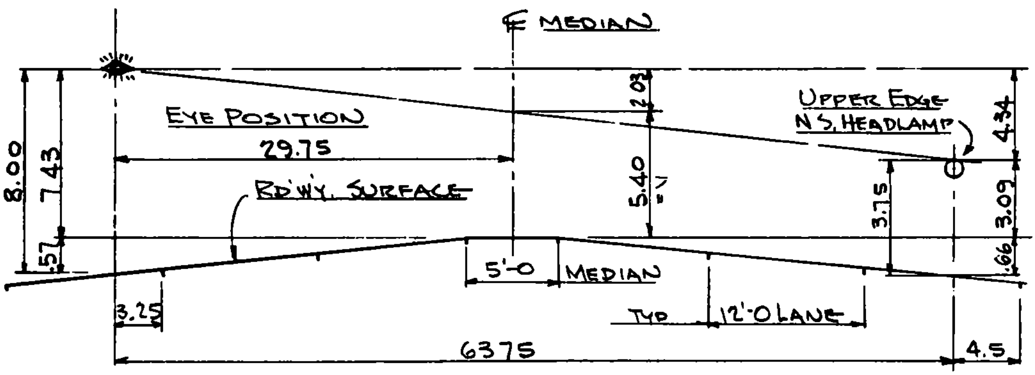

Figure 3.

$v = 7.43 - (4.34/63.75)(29.75)$
$v = 5.40$

To consider a specific example, it can be assumed that

radius = 1,000 ft;
b = width of roadway + ½ median strip = 38.5 ft;
$\alpha = 20^\circ$;
s = source;

and the required minimum cut-off angle is

$$\theta = \cos^{-1}\left(\frac{R-b}{R}\cos\alpha\right)$$
$$= \cos^{-1}\left(\frac{961.5}{1,000}\cos 20^\circ\right)$$
$$= \cos^{-1}(0.9035)$$
$$= 25^\circ \text{ 20 min.}$$

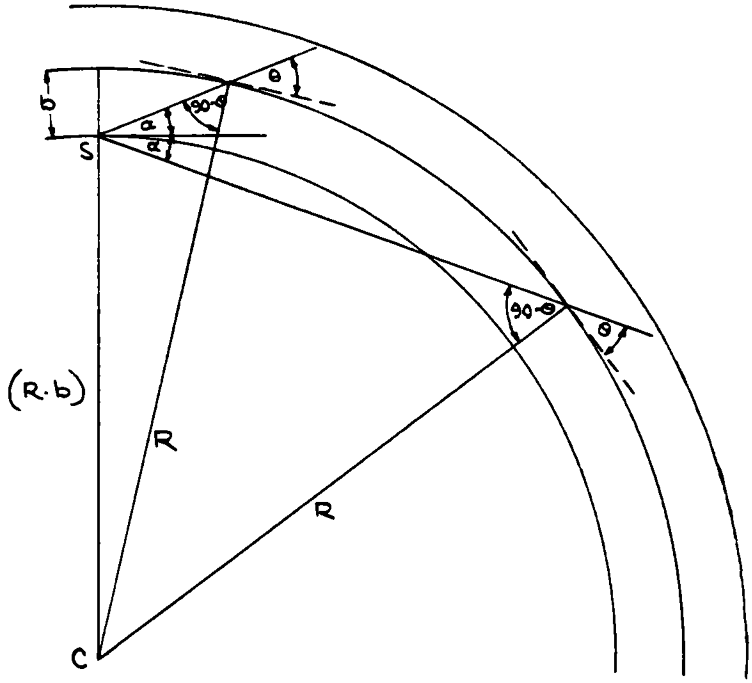

Figure 4.

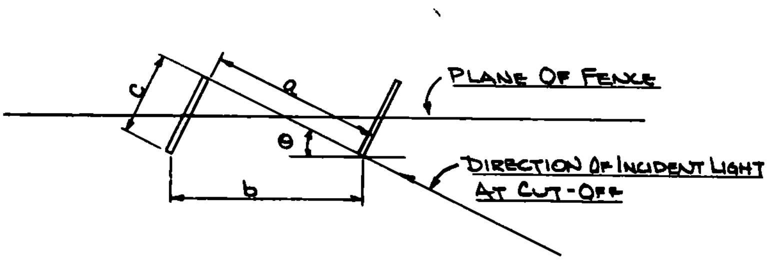

Figure 5.

Whence $c^2 = a^2 + b^2 - 2\,ab\cos\theta$ and $\cos\theta = a^2 + b^2 - c^2/2\,ab$

In this computation the angle α is ½ the angle of the headlight beam. It becomes apparent that given equal roadway plus ½ median widths, the required cut-off angle of the screen will decrease as the radius increases until it reaches the 20^0 angle required on a straight roadway.

Dimensions of Expanded Metal Mesh

During the manufacturing process of making expanded metal, the material is slit by cutting dies and then pushed, the result being that the strands have a twist. The ability to prevent headlight glare from passing through the mesh is a function of angle of twist, strand width, and distance between adjacent strands. A section through the short dimensions of expanded metal mesh would appear as shown in Figure 5.

A sample of expanded mesh was measured at several locations and was found to have the following dimensions:

$$c = 0.500 \quad b = 1.375 \quad a = 1.125$$

Therefore,

$$\cos\theta = \frac{1.125^2 + 1.375^2 - 0.500^2}{2 \times 1.125 \times 1.375}$$

$$\theta = 19^\circ \text{ 05 min.}$$

The nominal dimensions of this particular mesh are 1.500 × 4.000 center-to-center bridges × 0.250 strand width. From the cut-off angle afforded, it would appear that this particular mesh is satisfactory for use on tangents.

Another example of expanded mesh was measured at several locations and was found to have the following dimensions:

$$c = 0.375 \quad b = 0.937 \quad a = 0.781$$

Therefore,

$$\cos\theta = \frac{0.937^2 + 0.781^2 - 0.375^2}{2 \times 0.937 \times 0.781}$$

$$\theta = 22^\circ \text{ 40 min.}$$

The nominal dimensions for this particular mesh are 0.750 × 2.00 center-to-center bridges × 0.188 strand width. From the cut-off angle afforded, it would appear that this particular mesh is suitable for radii of slightly over 1,000 ft.

REFERENCE

1. "Headlight Glare vs Median Width." State of Idaho Department of Highways, Boise (Dec. 1957).

U.S. Standard for the Color of Signal Lights

F. C. BRECKENRIDGE, U. S. Bureau of Standards, Washington, D. C.

• THE COORDINATION draft of the U. S. Standard for the Colors of Signal Lights has been completed and is now being reproduced. It will be mailed to all members of the U. S. National Committee on the Colors of Signal Lights sometime during January 1962. This draft is composed of six sections, each of which has been approved by the Committee at one of its meetings. It is now being circulated to the members of the Committee so that they can present it to their sponsoring organizations for final adoption. The present plan is to publish the standard as a National Bureau of Standards handbook.

The Standard has three purposes: (a) to bring U. S. specifications for signal light colors into agreement with the recommendations of the International Commission on Illumination; (b) to eliminate meaningless differences among the specifications issued by different organizations in this country; and (c) to set up a technically sound basis on which relatively brief procurement specifications can be based.

The application of the standard to the various types of signal lights seen on the highway affords a good illustration of what the standard is intended to accomplish. There are at present three specifications that control the colors of most of the red signal lights used on the highways, and each of these specifications calls for a different color. The specification covering the red lights used in urban traffic signals is sponsored by the Institute of Traffic Engineers, but it is based on the requirements of the railroads for red lights for use as wayside and train signals. These lights are a deep red designed for use under relatively difficult conditions where the utmost certainty of correct recognition is paramount. The red lights used on highways at railroad crossings, however, are governed by a specification which is the responsibility of the Association of American Railroads. This specification does not require as deep a red as that now being used on most urban traffic signals. The most commonly seen red lights on highways are those of the intervehicular signals carried by the automobiles and trucks. The specifications for these lights are sponsored by the Society of Automotive Engineers and are based on the requirements for aviation red lights. The aviation specification was designed to provide for signals that could be seen at a maximum distance under conditions which make the recognition of the color secondary to the observation of the light itself. Presumably this specification was used as a basis for the automotive red lights because at the time when it was applied to intervehicular use the electrical power available on vehicles was much more limited than it is at present. The standard recommends the adoption of an intermediate red for all three of these highway applications. This recommendation has already been adopted for use in the 12-in. traffic lights that are being installed on open highways and appears to be giving good satisfaction for that use. (Subsequent to the presentation of this report the S. A. E. Lighting Committee has appointed a subcommittee to consider the adoption of the U. S. Standard for intervehicular signals.)

Another example of a slight change that might be brought about as a result of adopting the standard is the specification of the Institute of Traffic Engineers for yellow lights for use in highway traffic signals. This specification as presently written would permit the use of lights that are paler than those allowed under the recommendations of the International Commission on Illumination. The range of yellow colors permitted by this specification, however, appears somewhat larger than is necessary. The standard would recommend a deeper yellow as a pale-limit for this type of signal but would not recommend any redder red-limit for them. The actual effect on the lights in service might not be as large as might be thought from a comparison of the chromaticity definitions in the two specifications. Under the standard, more attention would be given to the color temperature of the light source used with the filter. It is the practice of most traffic signal departments to use lamps of very long life for traffic signal purposes. These lamps have a redder light source than that used for testing the filters. Consequently, the lights as actually shown on the highways probably seldom reach the pale-limit yellow allowed by the specification. The change recommended in this case might turn out to be rather a case of setting the records straight than one of changing the actual colors in service. In any case, inasmuch as the recommendation of the standard does not permit the use of redder yellow lights than are presently acceptable, no risk of confusion could arise from the adoption of the standard for the control of traffic signal yellow.

Engineers and highway officials who would find the U. S. Standard of assistance in connection with their work may obtain copies by writing to the National Bureau of Standards, Washington 25, D. C. Such requests should be sent to the Photometry and Colorimetry Section.

Lenses for Night Driving

WENDELL E. BRYAN, American Optometric Association, Denver, Colo.

•VARIOUS experiments with lenses have been used in night driving. Many of these lenses have been developed in the past and have been categorized as gimmicks. It was the author's desire to try to develop a scientifically sound lens for use in night driving that would not encompass any tint directly over the pupil, but would cause a shadow effect to fall across the pupil to eliminate the oncoming glare of headlights when driving at night on the highway. It is the author's purpose to consider the principle of the lens rather than the exact tint established for research purposes.

The "Nite-Site" lens consists of a calobar green slab-off on a white lens. These lenses must be fitted on prescription so that the line of demarcation between the white and the green falls 3 mm to the left side of the night pupil. The pupil area measurements are taken in dim illumination for accuracy. When the driver looks straight ahead while driving on the highway at night a shadow is cast across the pupil, eliminating peripheral retinal shock. As already observed, patient indoctrination is very important when fitting this lens. At no time is the driver to turn his head to any great degree to eliminate the glare of the oncoming light, but rather to look straight ahead and the lens will take care of the oncoming glare on the highway. The lens, however, is not designed for use in driving in the city at night because of the conflicting light coming from the right side.

Any refractionist can prescribe the lens and any optical laboratory can make it up to his prescription. There are no patents to be concerned—this is merely an attempt to solve part of the night driving problem, particularly for commercial drivers.

This lens has been researched for five years and there are over 200 of the author's patients wearing this lens with a great deal of satisfaction. These people consist mostly of commercial drivers, members of the Colorado State Patrol, members of the Denver Police Department, and several of the driver examiners of the State of Colorado.

The truck and bus drivers have reported the effectiveness of the lens in eliminating glare from their outside rear-view mirror coming from the headlights of cars to the rear of their vehicles. Also, many truck drivers and State patrol members have been impressed with the lens because it eliminates the peripheral scattering of light reflected from snow flakes when driving in a snow storm. The general acceptance of the lens on the individuals fitted has been encouraging.

Future plans for research of this lens will be to incorporate a mirrored surface into the lens in place of the tint and see if this relieves the objection to the tinted portion as far as the Night Visibility Committee members are concerned.

To summarize, this lens appears the best answer in lens construction and in principle.

Roadway Delineation with Curb Marker Lights

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• ROADWAY delineation has received considerable attention in recent years. Two earlier papers by the author (1, 2) have described a system of small, surface-mounted lights designed to develop lineal patterns of high brightness and contrast for night use and in conditions of inclement weather such as rain or fog. Suggestions were made in those papers regarding the use of marker lights on roadways to mark traffic lanes, division points, turn-on lanes, turn-off ramps, and other points of potential conflict. This paper is a report of one actual installation by the City of Oakland, Calif., where this concept of lighting has been applied to a section of winding road frequently enshrouded in fog

Early in 1961, the author received a request from John A. Morin, Assistant City Manager, City of Oakland, Calif., to attend a conference on the visibility problems of motorists using a section of Skyline Boulevard along the ridge of hills in East Oakland. This roadway is frequently covered by dense fog that inhibits traffic flow and makes vehicle operation very hazardous. The roadway is aligned to the winding contour of the hills, and the alignment will probably remain essentially as is in the future, although improvements may be made as funds become available. One section of the road is now being repaved with an asphaltic-concrete surface, concrete curbs, and other features in accordance with present design requirements.

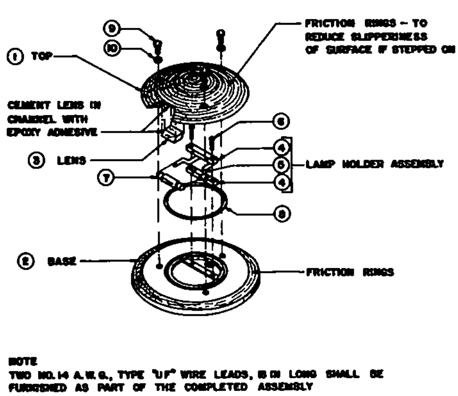
A preliminary study of the visibility problems of motorists using this stretch of roadway indicated that the guidance aspect was of primary importance. A decision was made to install a 3,500-ft section of lighting that would have guidance as its basic objective. The design and installation of the system was assigned to J. E. Austin, Superintendent, Electrical Department, and H. W. Carmack, Assistant Superintendent, Electrical Department, City of Oakland. The author consulted with them and reviewed the state of the art as it applied at the time, particularly the centerline lighting systems developed for airport use. These men then proceeded with the layout and fixture design for the specific installation on Skyline Boulevard.

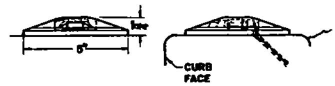
Several features of the lighting units received special attention in addition to the photometric considerations: (a) the design was to be tamperproof, because the units were to be in a residential neighborhood with children playing in the vicinity; (b) the units were to present a minimum cross-section above the mounting surface so that pedestrians would not trip or slip on the structures; (c) maintenance should be simple and not often required; and (d) costs should be kept to a minimum.

The developed design is shown in Figure 1. The assembled unit is 5 in. O.D. by ¾ in. high. It is arranged to be cemented with an epoxy resin adhesive directly to the top of the curb along each side of the roadway. The particular road is arranged for one-way traffic, so the units are unidirectional and face toward on-coming vehicles.

The layout of the roadway is shown in Figure 2. The test section is a portion of Skyline Boulevard between Bal Moral and Redwood Road in Oakland. The units are mounted on the top of the concrete curb along each side of the two-lane section. The spacing is uniform at 30 ft between units, except at the intersections where gaps are left in the lineal patterns. It is intended that fixed overhead street lights will be installed at the intersections and that these will develop the needed visual information. The overhead street lights were not in service at the time this article was written.

The electrical service, connections, and switching provisions are also shown in Figure 2. The system is arranged for multiple operation from 240-volt mains. The 200 VA transformers are of watertight, rubber-covered construction with 10- and





PARTS LIST

PC. NO.	ITEM & DESCRIPTION	REQ'D*
1	TOP, CAST BRASS	1
2	BASE, CAST BRASS	1
	EPOXY ADHESIVE (TYPE TO SUIT)	A.R.
3	LENS, CLEAR ACRYLIC PLASTIC	1
4	LAMP HOLDER BLOCK, VULANIZED FIBER	2
5	LAMP HOLDER TERMINAL, PHOSPHOR BRONZE	2
6	#4-40 x 1/2" LONG MACHINE SCREW, SUPERTANIUM	2
7	LAMP, 12 V, 5 W. - TUBULAR TYPE, 1 1/2" LONG	1
8	PARKONE-O-RING, 2 2/8" I.D. x 1/8" NOM DIA., NEOPRENE, CAT. NO. 0430-8	1
8A	WIRE LEAD, #14 A.W.G., TYPE "UF", SINGLE COND., 18" LONG	2
9	#8-32 x 3/8" SPANNER HD (SECURITY) SCREW, STAINLESS STEEL	3
10	#8 SIZE LOCKWASHER, SUPERTANIUM	3

*MATERIAL FOR ONE COMPLETE ASSEMBLY

Figure 1. Curb marker light.

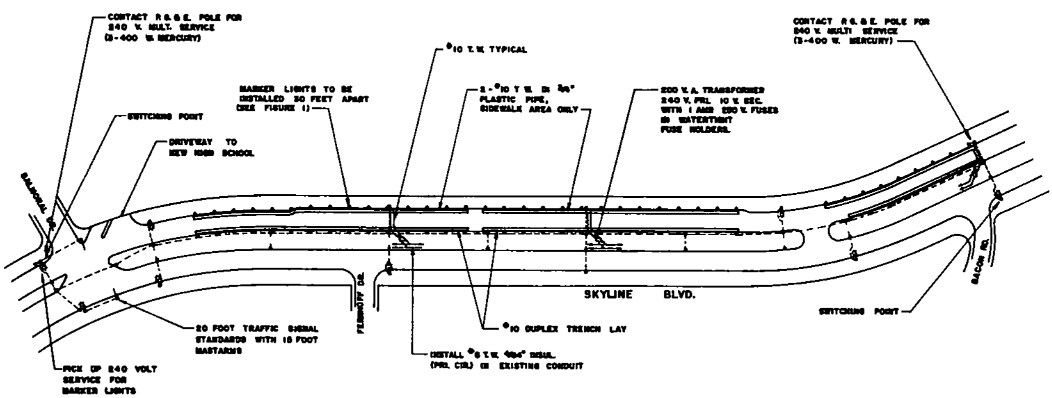


Figure 2. Street lighting system, Skyline Boulevard.

12-volt secondary taps to supply the 12-volt, 5-W bulbs used in the fixtures. The connections are now made to the 10-volt tap which supplies 8 to 9 volts at the lamp terminals. The wiring is in plastic conduits located alongside the curbing. Connections to each fixture are made through a ½-in. drilled hole in the concrete curb under the base of each fixture. The wires are spliced in a junction box that is cast in the concrete and the pigtails are fed through the ½-in. drilled hole to the fixture. All wires are completely concealed in the final assembly. For relamping, the top cover is removed and the exposed lamp and terminals can be serviced. The system is completely safe for use by any of the maintenance people, because the terminals are only at 8 to 12 volts, depending on the load and transformer taps.

An open view of the fixture is shown in Figure 3. The simplicity of the design is one of the favorable attributes. The material housing is brass to avoid corrosion or surface-finishing problems. Spanner-type screw heads are used to secure the cover to make vandalism more difficult. A heavy window is sealed in the top piece to keep curiosity seekers from poking sticks and other objects inside. The complete unit is watertight and has drainage in all directions to make it at least partially self-cleaning.

The installation on Skyline Boulevard was partially completed at the time of this presentation. Approximately one-half of the units are now operable. The type of roadway and general terrain are shown in Figure 4. The nighttime views of the same scenes are shown in Figure 5.

A short discussion of the installation can be offered at this time, although it is too early to evaluate operating experience.

The cost estimates prepared by the City of Oakland show the following items:

177 curb marker lights	$1,150.00
Wire, transformers, and other material	1,605.00
City labor force	2,000.00
Engineering and inspection	300.00
	$5,055.00

This is for approximately ½ mi of roadway, or about 5,000 lineal ft of lights (2 lines, one on each curb). An approximate cost figure is about $1.00 per lineal ft per line.

This is a trial installation using custom-made lighting units and untried construction methods. It would, therefore, be expected that these costs would be higher than future costs, using production units and improved installation techniques.

The 30-ft spacing seems to be reasonable for the straight sections, but 20 to 25 ft was recommended on the basis of earlier experience in airport lighting. The curved sections should have closer-spaced units in order to maintain the lineal continuity. It is desirable to keep the visual angle between units to less than 0.2°. This criterion would require that the lateral separation between units should not be more than 1.75 ft on a line at right angle to the direction of viewing for lights 500 ft ahead. Even for fairly large radius curves, this would require longitudinal spacings of 10 ft or less. It has been determined that for aircraft operation on high-speed turn-offs from runways, the spacings should be not more than 10 ft (3). At the intersections, offsets, and points of discontinuity, it is recommended that the spacings should be less than 10 ft in order to clearly mark the change in direction and outline the discontinuity in the pattern.

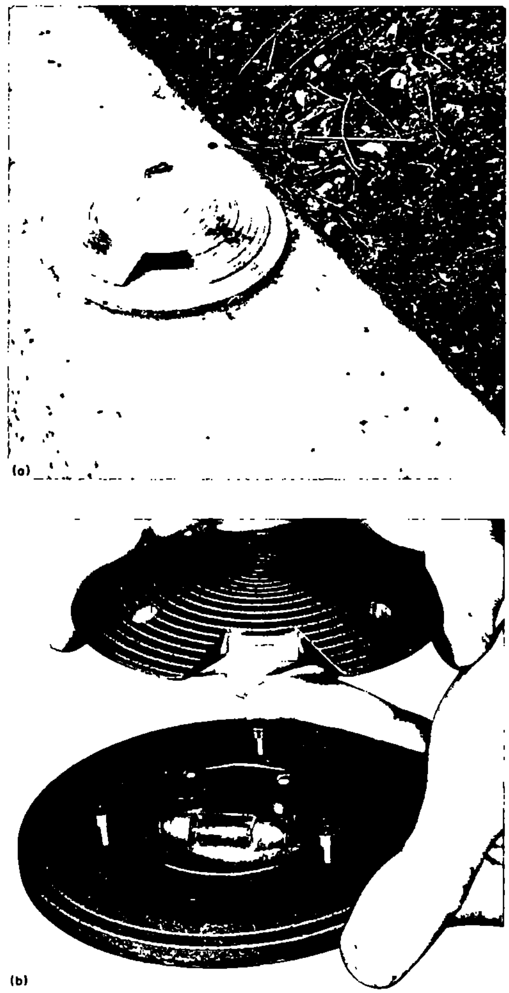


Figure 3. Close-up views of marker light: (a) complete fixture mounted on curb; and (b) open view showing lamp and terminals.

Some compromise in spacing will always be necessary in real situations where cost must be weighed against theoretical considerations. So, as a guide for future designs, the following spacings are suggested:

Along tangents	20 to 30 ft
Around long radius curves (3,000- to 5,000-ft radius)	10 to 15 ft
Around sharp curves (500- to 1,500-ft radius)	8 to 10 ft
At points of discontinuity	3 to 8 ft

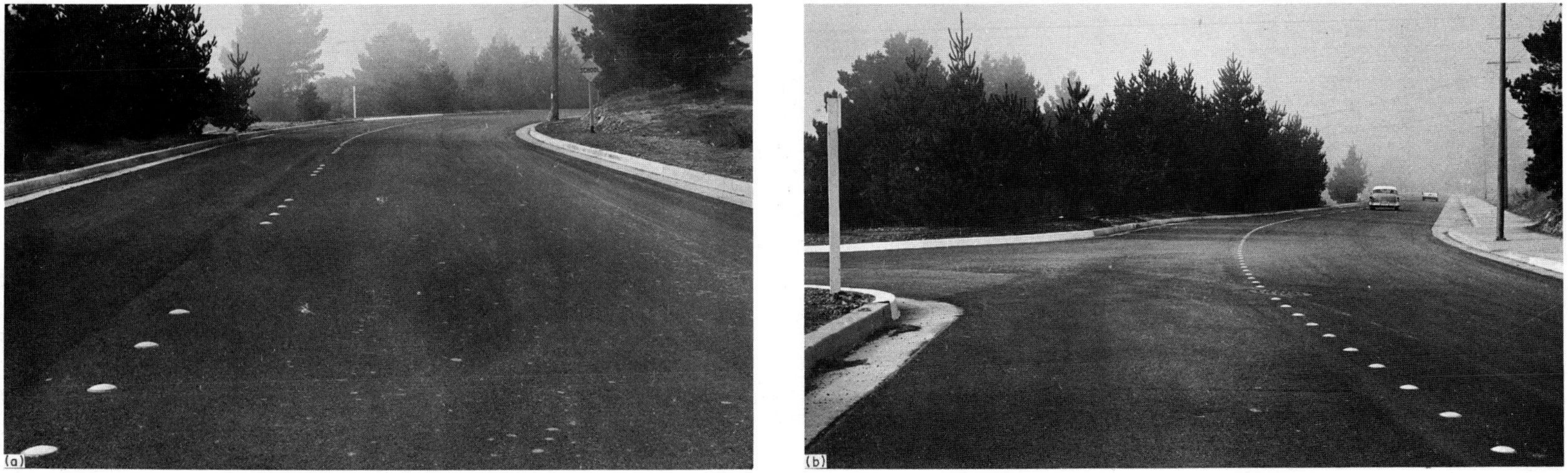


Figure 4. Daytime views of test section on Skyline Boulevard. (a) Inconspicuous curb lights mounted on both sides of test section near Bacon Road. There is a gap in light pattern at curve. (b) Straight portion of test section seen from curve shown in (a).

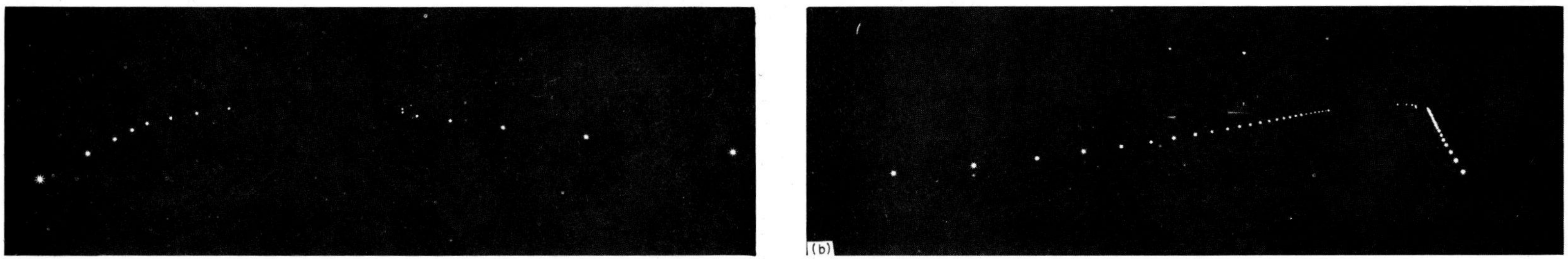


Figure 5. Nighttime views of test section on Skyline Boulevard. (a) Same view as Figure 4a. Lights left of road end at median opening. (b) Same view as Figure 4b, slightly closer to light standard.

Work is continuing on the use of centerline and lane marking lights, particularly under fog and rain conditions. It is hoped that delineation lighting of this type will provide improved visual conditions for many very unsatisfactory areas that now exist.

REFERENCES

1. Finch, D.M., "Surface-Mounted Lights on Roadways for Guidance." HRB Bull. 226, 16-26 (1959).
2. Finch, D.M., "Surface-Mounted Lights on Roadways—Fog Studies." HRB Bull. 298, 24-34 (1961).
3. Finch, D.M., and Horonjeff, R., "An Evaluation of Surface Mounted Lights for Runway Guidance." Univ. of California, Berkeley, Inst. of Transportation and Traffic Engineering, Special Report (June 1960).

Transient Adaptation of the Eyes of a Motorist

GLENN A. FRY, School of Optometry, Ohio State University

• THIS IS a brief report of a project sponsored by Wright Air Development Division, Air Research and Development Command, U. S. Air Force.

The project is concerned with the development of a device that will aid in the study of transient adaptation of the eyes of a motorist in driving along a highway at night where he is confronted with street lights and the head lights of oncoming automobiles. It is necessary to move down the highway in an automobile equipped with a glare meter that will assess the stray light at the fovea and a second meter that will measure the average luminance of a small portion of the visual field centered around the primary line of sight. If it is assumed that the eyes are fixed on the edge of the road at a constant distance in front of the automobile, these devices can be mounted in a fixed position in the automobile. Compensation could be made for changes in the pitch and direction of the road. One could set up a complicated arrangement in which these devices actually track the eyes of the driver. The two types of information (stray light and average luminance) will be fed into an electronic analog computer that will evaluate the state of adaptation at the fovea and consider the immediate past history of the eyes of the observer. It is figured that this is an easier way to measure changes in the adaptation of the typical observer than to attempt to make measurements of adaptation directly.

The present project is part of a program outlined in a paper that was presented at the CIE meeting in Zurich in 1955 called Physiological Bases of Disability Glare.

An Improved Instrument for Measurement of Pavement Marking Reflective Performance

THOMAS L. HARRINGTON and McRAE D. JOHNSON, Reflective Products Division, Minnesota Mining and Manufacturing Company

• ACCURATE field measurement of reflective pavement marking performance requires portable instrumentation exactly simulating night illumination and visibility conditions. Precise duplication of optical and geometrical relationships between headlamps, driver, and pavement marking is essential for correlation with actual visual appearance.

Significant angles affecting reflective performance are the entrance or incident angle of the impinging light beam and the two divergence angles, which are functions of the eye from headlamp deviation. For pavement markings, the incident light beam approaches at a grazing angle ranging from 87° at 50-ft distance to over 89.5° beyond 300-ft distance. Incident angles for instrument simulation must be representative of this range.

More critical is the exact simulation of divergence, defined as the angle between incident and reflective beams; i.e., the headlamp-pavement marking observer's eye angle. Efficiency of reflective materials varies greatly with divergence angle, which also varies at a different rate for left and right headlamps. Left lamp divergence ranges from 1.3° at 50 ft to less than 0.2° beyond 500 ft, whereas right lamp divergence is generally more than twice these amounts. Correct divergence simulation, therefore, requires separate headlamp consideration in addition to accurate geometric simulation. Accurate instrument assessment of field performance of reflective materials depends on exact duplication of these divergence conditions.

Previous instruments, such as the Hill-Ecker portable photometer and the Hunter night visibility meter, have been handicapped by difficulties in miniaturization resulting in divergence and incidence angles representative of only 40- to 200-ft distance from the vehicle and lacking desired resolution, color response, and sensitivity. Recent reflective materials of improved efficiency are more affected by such variations, and their evaluation requires instrumentation that precisely duplicates the actual viewing situation. Table 1, for example, gives the wide variation in relative reflectance values obtained for different reflective materials depending on the divergence angle.

The new instrument combines many of the desirable features of earlier units (such as portability and direct reading) while eliminating the need for sacrificing precise duplication of field conditions Principal innovations permitting these improvements are the use of transistors and unique design to eliminate stray light and establish exact

TABLE 1

Divergence Angle (°)	Directional Reflectance	
	High Effic. Reflective Material	Conventional Reflective Material
0.0	780.6	66.6
0.4	411.0	46.0
0.8	120.1	39.2
1.2	88.6	33.3
1.7	45.3	25.8

divergence angles. Geometrical relationships are maintained with a size reduction of 100 to 1 from field conditions. The situation duplicated is a 300-ft viewing distance, representative of visibility requirements based on 60-mph minimum stopping distance of 306 ft on dry, level concrete. Proportional consideration of left and right lamp illumination from modern dual headlamps is simulated. Similarly, dual divergence angles for left and right lamps are provided with data integrated into one meter reading.

The photocell detector is color-corrected to CIE standard observer response, maintaining instrument resolution at 0.1° with direct meter reading eliminating subjective effects. Ambient daylight effects are minimized by use of source light interrupted at a frequency also required for detection. Power is supplied by rechargeable dry cells, permitting convenient portability.

Table 2 compares salient design and performance features of both the earlier and new instruments with actual highway vehicle conditions.

A setting is also provided approximating aircraft landing conditions for use in measurement of reflective runway markings. Modern jet aircraft landing approaches are commonly 2° to 3°, corresponding to incidence angles of 87° to 88°, with 2.5° instrument approaches for all aircraft generally required. Landing light location varies among aircraft, but a recent study revealed most military aircraft with 10- to 20-ft distance from pilot's eyes to landing lights. Resulting divergence ranges from 0.28° to 0.57° for moderate visibility distance of 2,000 ft and 0.05° to 0.12° for total approach distance of 10,000 ft. The airfield instrument setting of 0.33° divergence is representative of this range.

TABLE 2

COMPARISON OF PRINCIPAL HIGHWAY PHOTOMETERS AND NIGHT VIEWING CONDITIONS

Item	Actual Highway Condition	Hill-Ecker Meter	Hunter Night Vis. Meter	New Highway Photometer
Source-Color Temp. (°K)	2,770 - 3,080	2,280	2,600 - 2,840	2,210
Geometry (°):				
Incidence angle	89.5	87.9	88.3	89.5 or 88
Divergence angle	0.33 and 0.78	1.5	1.2	0.33 and 0.78
Construction:				
Weight (lb)		41	25	33
Battery		Wet	Dry	Dry and rechargeable
External dimensions		20.75 × 6 × 12.25	25.5 × 4.5 × 11	17.5 × 6.25 × 12.75
Type reading		Photo-electric	Visual comparison	Photo-electric
Accuracy:				
Resolution (°)	0.05	0.98	0.79	0.11
Stray light elimination		Fair	Poor	Excellent
Reproducibility		1 in 25	1 in 5	1 in 5 to 1 in 10
Detector-color response	Photopic eye	Scotopic	Photopic eye	Photopic

Extensive measurements of various retro-reflective materials on both concrete and bituminous pavements have been conducted, and yield reproducible results highly consistent with visual experience. Measurement of newer, more efficient reflective materials (such as high refractive index granules and beads) is now possible along with increased sensitivity in measurement of traditional reflective marking paints. Substantially improved accuracy results for both research purposes and pavement marking performance testing.

Relation of Visual Acuity and Contrast Sensitivity Under Nighttime Driving Conditions

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• THERE appear to be no data available to indicate any definite relationship of visual acuity and the ability to detect low-contrast differences at night.

Over the years, the company has conducted a number of dynamic seeing-distance tests using observer-drivers. The observers' eyes were checked with the standard AMA test chart and also with the Luckiesh-Moss low-contrast chart. About two years ago, the eyes of some 30 observers who were attending a lighting test demonstration at Phoenix, Arizona, were checked with these two charts.

Though a sufficient number of observers has not been checked to make absolutely certain there is no correlation between visual acuity and the ability to detect low-contrast differences at night, in all the checks so far there has been no correlation; that is, observers who had 20/20 or better visual acuity oftentimes made a poor showing with the low-contrast chart. Conversely, sometimes those with acuity as low as 20/40 made a good showing with the low-contrast chart. Some had good performance both ways, some had poor performance both ways.

Obviously, the best combination from the standpoint of nighttime driving safety is excellent visual acuity plus excellent ability to detect low-contrast differences at night. However, it is the author's opinion that of the two, the latter is the more important.

With the limited number of observers used in conducting seeing-distance tests in moving cars, those with the best performance with the Luckiesh-Moss low-contrast chart also gave the best seeing-distance performance on the tests. Conversely, those with the poorest rating with the Luckiesh-Moss low-contrast chart gave the poorest results in the seeing-distance tests. In the case of these particular tests observers with 20/20 acuity rating or with spectacles giving correction to 20/20 were used. More data are needed.

THE NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL is a private, nonprofit organization of scientists, dedicated to the furtherance of science and to its use for the general welfare. The ACADEMY itself was established in 1863 under a congressional charter signed by President Lincoln. Empowered to provide for all activities appropriate to academies of science, it was also required by its charter to act as an adviser to the federal government in scientific matters. This provision accounts for the close ties that have always existed between the ACADEMY and the government, although the ACADEMY is not a governmental agency.

The NATIONAL RESEARCH COUNCIL was established by the ACADEMY in 1916, at the request of President Wilson, to enable scientists generally to associate their efforts with those of the limited membership of the ACADEMY in service to the nation, to society, and to science at home and abroad. Members of the NATIONAL RESEARCH COUNCIL receive their appointments from the president of the ACADEMY. They include representatives nominated by the major scientific and technical societies, representatives of the federal government, and a number of members at large. In addition, several thousand scientists and engineers take part in the activities of the research council through membership on its various boards and committees.

Receiving funds from both public and private sources, by contribution, grant, or contract, the ACADEMY and its RESEARCH COUNCIL thus work to stimulate research and its applications, to survey the broad possibilities of science, to promote effective utilization of the scientific and technical resources of the country, to serve the government, and to further the general interests of science.

The HIGHWAY RESEARCH BOARD was organized November 11, 1920, as an agency of the Division of Engineering and Industrial Research, one of the eight functional divisions of the NATIONAL RESEARCH COUNCIL. The BOARD is a cooperative organization of the highway technologists of America operating under the auspices of the ACADEMY–COUNCIL and with the support of the several highway departments, the Bureau of Public Roads, and many other organizations interested in the development of highway transportation. The purposes of the BOARD are to encourage research and to provide a national clearinghouse and correlation service for research activities and information on highway administration and technology.