This paper describes a research program in progress whose goal is the development of a head lamp evaluation model. The model will evaluate headlight systems in terms of a single overall figure of merit representing several measures of driver visual performance under night driving conditions. The model simulates relevant aspects of the night highway environment and incorporates a seeing distance model that determines the photometric conditions produced by vehicle lighting and environmental factors and computes glare and seeing distance to pedestrian and pavement delineation targets. The seeing distance and glare calculations used in the seeing distance model are derived from laboratory formulations of human vision capabilities. A program of field research has been initiated to verify the seeing distance model and to provide data for the simulation of those aspects of the nighttime highway environment that determine head lamp illumination of target and pavement and, hence, visual performance.

DEVELOPMENT OF A HEADLIGHT EVALUATION MODEL

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With few exceptions, headlight-seeing distance research has been conducted under structured test situations that represent the least difficult conditions encountered in night driving: straight, level, dry roads; young, alert observers; test vehicles with clean, properly aimed head lamps and clean windshields; and small vertical targets. Often, seeing distance has been measured to targets placed only at the right edge of the driving lane. In general, the visibility of road markings and path delineation elements as a measure of headlight performance has been ignored as a topic for systematic study. These practices reflect the procedural difficulty and cost of representing or working in the whole highway environment rather than a lack of sophistication on the part of the experimenters. Nevertheless, failure to consider a broader range of operating conditions can lead to errors of two types:

1. Because the structured conditions under which most headlight-seeing distance research is performed are ideal, differences between head lamp systems tend to be exaggerated and not necessarily representative of real-world differences; and
2. More important, the performance ranking of a set of head lamp systems may change with the conditions of observation.

Figure 1, which shows seeing distance test results obtained by Adler and Lunenfeld (1), illustrates a case in point. In these tests, a 16-in. square, 7 percent reflectance target was located 5 ft to the right of the driving lane and equidistant longitudinally between the glare and observer vehicles. The glare car, when it was used, had the same head lamp system as the observer car. Of interest is the reversal in low- and mid-beam performance between the no-glare and glare conditions and the fact that seeing distance was greater for both systems when the glare and observer vehicles were in adjacent lanes than when they were separated by an intervening lane, despite the greater glare. An explanation of these findings is suggested by the size and reflectance of the target; it is assumed that the target is darker than the surface immediately behind it and against which it is seen and, hence, is detected in negative contrast. In the absence of opposing headlights, target-background contrast is the same for low and mid beams. However, because the mid beam produces more intense illumination in the direction of the target than the low beam does, it produces longer seeing distances. Opposing headlights in the adjacent lane increase the contrast by backlighting the pavement behind the target; however, because of its beam pattern, the mid beam produces much more glare than the low beam but only slightly more backlighting, which results in a net loss for the mid beam. In the case of an intervening lane, glare is still present but the backlighting is substantially reduced. In fact, because road surface retroreflectance is less at short than at long distances, it is possible that, in the case of an intervening lane, the target was brighter than its background when detected.

Whether or not this explanation is correct for this particular set of findings, it is plausible and illustrates the possibilities for complex interactions among variables such as target size, reflectance, and location; pavement reflectance; beam pattern, and presence or absence of a glare source. Because the relative performance of a set of head lamps may vary with the test conditions, it is difficult to define a meaningful and representative set of test conditions for evaluating and comparing them. Nor, as a practical matter, is it possible to conduct systematic seeing distance and glare tests of head lamp systems under the full range of conditions that obtain in actual driving. Furthermore, even if such an undertaking were feasible, there would still remain the problem of weighting and combining the various performance measures obtained across the range of conditions tested to produce an overall measure of performance.

These considerations led Ford Motor Company to undertake the development of a headlight evaluation model to evaluate and compare existing and proposed headlight systems in terms of several integrated driver performance measures under a wide range of driving conditions. Ultimately, it is hoped that the model can be used to define the characteristics of an optimum system.

The structure of the model, the underlying concepts, and supporting field research are described in the following sections.

DEVELOPMENT OF A COMPREHENSIVE HEADLIGHT EVALUATION MODEL

The Ford headlight evaluation model simulates night driving situations, computes driver visual performance under a variety of situations, and outputs an overall figure of merit or score for each headlight system tested.

Figure of Merit

The figure of merit for a given headlighting system is the total distance traveled on a simulated test route under adequate illumination by a vehicle using that system. Illumination is considered to be adequate when seeing distances to both pedestrian and pavement targets are equal to or greater than some criterion distance and when the discomfort glare experienced by opposing drivers is less than some criterion value.

The computation of the figure of merit is shown in Figure 2. The figure shows the observer vehicle on a section of a standardized test route approaching two pedestrians and two opposing vehicles. The three graphs show seeing distance to delineation features and pedestrians for the driver of the observer vehicle as he proceeds along the test section and the discomfort level of the opposing drivers. Seeing distance to the delineation (shown on the ordinate) is greater than the criterion (CL_1) except when the opposing vehicles are close enough to produce disability glare. Seeing distance to the first pedestrian (shown by the crosshatched segments) is less than the criterion distance (CL_2), but the visibility of the second pedestrian is greater than the criterion level. Discomfort glare (shown on the ordinate) is within limits (CL_3) except when the two opposing vehicles pass. The bottom line shows those parts of the test section in which all three criteria are met. The sum of all the mileage traveled within the criteria levels on all of the test sections constitutes the figure of merit.

The criterion seeing distance for stand-up targets is the stopping distance computed from reaction time, speed, and tire-pavement friction values drawn randomly from appropriate distributions. The criterion seeing distance to pavement delineations is that that will provide the preview a driver needs for lane keeping and path following. The preview value used currently is 2 sec (2), but this is subject to change based on further study of the literature. The discomfort glare criterion applies only to low and mid beams. At present the criterion is set at 110 percent of the glare that current low beams produce in an encounter. However, this too is subject to change depending on the outcome of current Ford field research.

Standardized Test Route

The test route is a computer simulation of a series of highway sections incorporating environmental factors that influence driver visual performance, such as topography, reflectance and ambient brightness of the road and road elements, highway type, traffic characteristics, target characteristics, and weather. The values of the various environmental variables (e.g., pavement reflectance) that characterize a given section are drawn randomly from distributions of these variables as determined by Ford surveys and analyses. Although originally defined by random selection, the same standardized test route will be used to evaluate all headlight systems.

Structure of the Model

Figure 3 shows a flow chart of the evaluation model as it is conceived. Input data consist of the standardized test route; properties of opposing vehicles such as head lamp location, configuration, and misaim; the isocandle diagrams of the test and opposing headlighting systems and driver characteristics, that is, laboratory formulations of human contrast detection and glare susceptibility as validated for highway application by Ford research. An evaluation run with the model will consist of a series of target encounters on the various sections of the test route, each involving a randomly drawn set of environmental, oncoming vehicle, and driver characteristics. In an encounter, traffic density determines whether an oncoming vehicle will be present and, if so, its speed and distance from the observer car at the start of the encounter. Together, environmental factors and the characteristics of the opposing and test headlights determine the driver's visual environment.

The heart of the evaluation model is the Ford seeing distance model. This is represented in the flow chart by the driver's visual environment, visibility and glare computations, and seeing distance to targets. The seeing distance model accepts the environmental, driver vision, vehicular, and head lamp characteristics and computes the relevant aspects of the driver's visual environment: target and background luminance (photometric brightness), glare, adaptation level, and apparent target size. Once the visual environment has been established, driver target detection and glare susceptibility characteristics provide the basis for seeing distance and glare computations. The effect of disability glare in the model is to reduce seeing distances in accordance with veiling glare formulations found in the literature and confirmed or modified by Ford research. In addition, a feedback loop is provided to simulate dimming requests in response to discomfort glare. Excessive discomfort glare produced by mid or high beams will result in a dimming request, as determined by the Ford glare acceptance study, i.e., the glare and/or observer vehicles will switch to low beams. The seeing distance model is discussed more fully below.

On each section of the standardized test route the distance traveled under adequate illumination is computed, and this figure is accumulated over all of the sections of the test route to produce the final figure of merit.

The basic programming for the evaluation model is complete. The seeing distance model will accept head lamp and driver characteristics and environmental data from the files that constitute the standardized test route and will determine for an encounter whether the performance of a head lamp system meets all criterion values. Refinements of the veiling glare and seeing distance formulations may be required, pending further analysis of field data. The data files of environmental characteristics of the standardized test route are only partially complete. Collection and analysis of field

Figure 1. Seeing distance with low and mid beams.

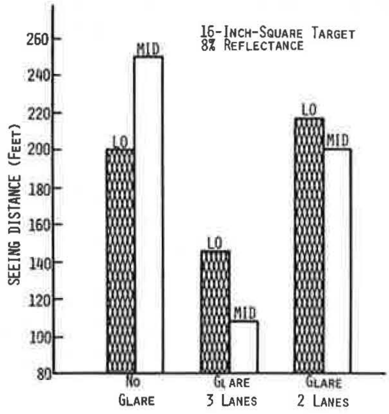


Figure 2. Miles driven under adequate illumination on standardized test route.

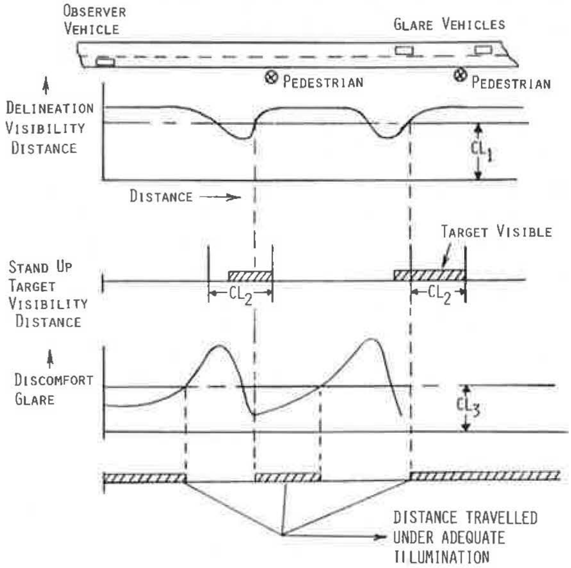


Figure 3. Headlight evaluation model.

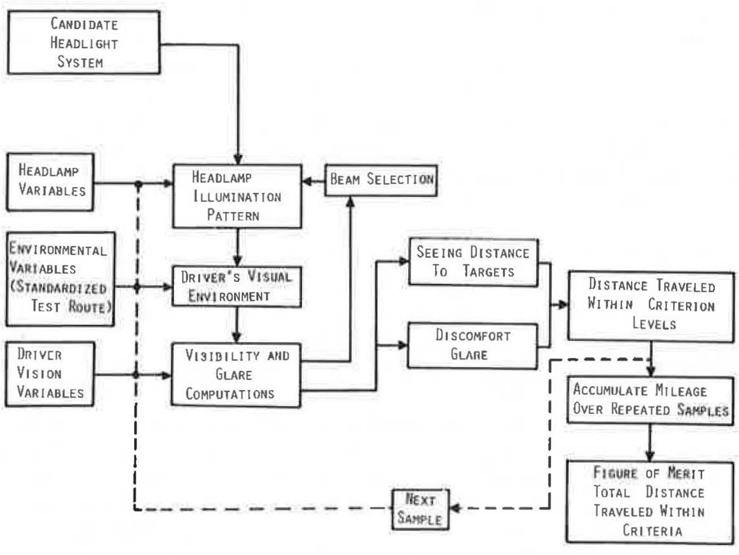
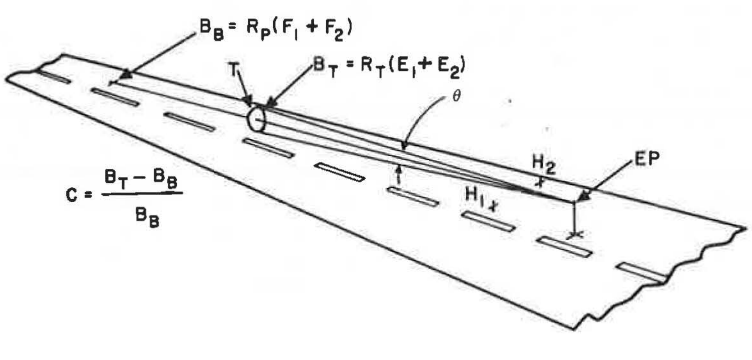


Figure 4. Illustration of target contrast.



survey data are in progress to provide this information.

SEEING DISTANCE MODEL

The visibility and glare calculations in the evaluation model are performed by the Ford seeing distance model. The seeing distance model is based on Blackwell's (3) luminance contrast threshold (minimum contrast required for detection) curves, as modified for highway application by Ford field research. Figure 4 shows the concept of luminance contrast and its application to the highway setting. The target T subtends a visual angle θ at the driver's eye point EP and is illuminated by headlights H_1 and H_2. The target luminance B_T is given by the target reflectance factor R_T times the sum of the incident illumination $(E_1 + E_2)$. The portion of the pavement that serves as the observer's background of the target has luminance B_B, which is the product of the pavement reflectance factor R_P and the illumination falling on the pavement at that point $(F_1 + F_2)$. Contrast is defined as

$$C = \frac{B_T - B_B}{B_B}$$

The form taken by the contrast threshold is shown in Figure 5 (3). Log threshold contrast is plotted as a function of background luminance in foot-lamberts for various target sizes. The contrast threshold increases with decreasing background luminance and target size. The area above a curve represents the region in which a target of size θ is visible to an observer. This particular graph is for a target exposure time of $1/30$ sec, which, according to Blackwell (3), is "appropriate for evaluating visual detection in night driving." Longer or shorter exposures give rise to similar functions: The longer the duration is, the lower the contrast required for detection is. The thresholds for positive and negative contrast are the same except for the sign.

Veiling glare B_V from oncoming vehicles (or any other light source) is computed from an expression developed by Fisher and Christie (4):

$$B_V = (0.2A + 5.8)\Pi \sum_{i=1}^{n} E_i \theta_i^{-2.2}$$

where

A = observer's age in years,
E_i = illuminance of the i th glare source in foot-candles, and
θ_i = angle to the i th source, measured from the observer's line of sight.

B_V thus computed is added to the denominator of the contrast expression to give

$$C = \frac{B_T - B_B}{B_B + B_V} = \frac{B_T - B_B}{B_B'}$$

and the Blackwell curves are entered with $B_B' = B_B + B_V$ on the abscissa to find the required contrast.

Figure 6 shows contrast threshold data transformed into units appropriate for highway target detection tasks. The solid lines shown the log threshold background luminance required for detection plotted as a function of observer distance from the target.

Figure 5. Liminal contrast as a function of background luminance for various target sizes.

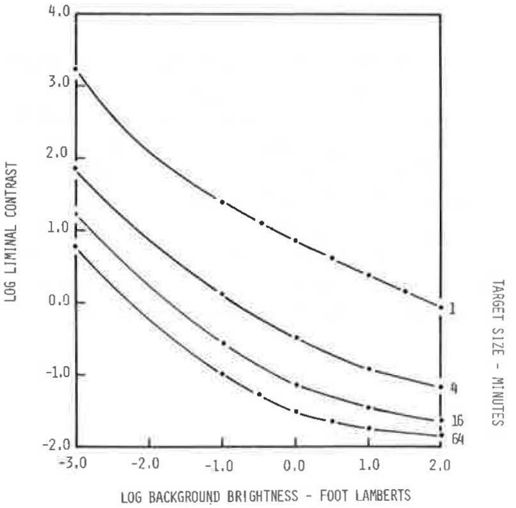


Figure 6. Detection of a pedestrian target with 10 percent reflectance under high and low beams.

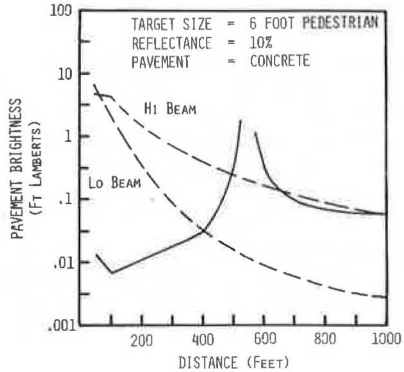


Figure 7. Pavement brightness and probability of target detection.

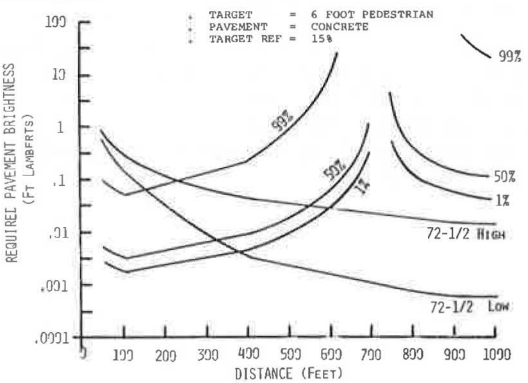


Table 1. Comparison of observed and predicted seeing distances (feet).

	Observed		Predicted	
Head Lamp	Pedestrian Target[a] (5)	Square Target[b] (1)	Pedestrian Target	Square Target
Low beams	375	199	370	195
Mid beams		253		300
High beams	780	256	775	335

[a]Pedestrian target of 17.5 percent reflectance.
[b]Sixteen-inch square target of 8 percent reflectance.

To generate this curve requires that target size and reflectance and pavement retroreflectance properties be specified. The contrast and angular size of the target can then be computed for any distance, and the required background luminance can be read from Figure 5. If it is assumed that the road surface at the base of the target is the relevant background, contrast is given simply by the difference between target and background reflectance divided by background reflectance, inasmuch as illumination is the same for both (Fig. 4). Performing these operations at each of several distances yields the solid line curve shown in Figure 6. The directional reflectance of the pavement used in the computations to generate the curve increases with distance. At some point between 500 and 600 ft, pavement reflectance is equal to 10 percent, the same as the target, and contrast is zero as shown by the break in the curve. At lesser distances the target is in positive contrast with (brighter than) the pavement, and at larger distances the target is in negative contrast with (darker than) the pavement.

The dotted lines in Figure 6 show the background luminance levels produced at various distances by typical high and low beams. Detection is predicted at the point where a headlight curve crosses the threshold curve. With low beams, the target is detected in positive contrast at about 400 ft. With high beams, the target is detected first in negative contrast at about 950 ft, disappears at about 700 ft, and is detected again in positive contrast at 500 ft.

The formulations shown in Figures 5 and 6 indicate that under certain conditions a target of low reflectance may be seen at a greater distance than a target of somewhat higher reflectance. Further, seeing distances to a target whose reflectance is near the midpoint of the pavement reflectance gradient are likely to be highly variable because of the double threshold; that is, some observers will see the target first in negative contrast and others will detect it only when it is close enough to be in positive contrast.

Figure 7 shows similar information except that, instead of a single contrast threshold detection curve, there are curves for 99th, 50th, and 1st percentile detection. For the conditions specified, a 30-fold increase in background brightness (and hence in candlepower) is required to increase the probability of detection at 300 ft from 50 to 99 percent.

Table 1 gives a comparison of observed (1) and predicted (from the Ford seeing distance model) seeing distances. The predicted seeing distances included analyses of directional reflectance properties of a Ford Proving Ground asphalt surface. Isocandela diagrams for the type of head lamp used in the field tests were used, but there is no way of knowing how closely these agreed with the beam patterns of the head lamp used in field experiments. The predicted seeing distances agree closely with Hemion's field data (5) and with Adler and Lunenfeld's low-beam data (1) but not with the mid- or high-beam data. The poor prediction of the Adler and Lunenfeld mid- and high-beam seeing distances may be due to inaccurate representation of the surface or the mid- and high-beam patterns used in their study.

FIELD EXPERIMENTS, SURVEYS, AND ANALYSES

A program of field studies, literature reviews, and surveys is under way at Ford to (a) validate the seeing distance model for pedestrian and delineation targets, (b) develop formulations for dealing systematically with discomfort glare, and (c) obtain representative data on the night driving environment for the standardized test route.

Seeing Distance Studies

Seeing distance tests were conducted to validate the contrast detection and veiling glare formulations used in the seeing distance model and to determine the effect of increased foreground illumination on down-the-road seeing distance. The second objective was addressed because some controversy exists on how much foreground illumination is desirable, and at least one study (6) has found that high-beam seeing distances are reduced by a bright foreground. Seeing distances to pedestrian silhouette targets and pavement lines were determined for 12 observers under various conditions of illumination, glare, and target reflectance. Trials were conducted with type 5 (government proposed) high beams, with type 2 low beams, and with both to simulate a high beam with a very bright foreground. In these observations, the glare source was stationary. Predicted and actual results for pedestrian and delineation targets in the absence of glare are shown in Figures 8 and 9. Figure 10 shows predicted and actual seeing distances to line targets in the presence of glare plotted as a function of the distance between the target and the glare sources. In all cases, Blackwell's $1/30$-sec exposure, contrast detection curves (3) were the basis of the predictions. In general, the data conform to the predictions. The fit to the pedestrian target data is very good, but the delineation seeing distance predictions with or without glare differ from the means by as much as 25 percent.

The data shown in Figures 8 and 9 provide no evidence that a bright foreground decreases the visibility of distant targets, i.e., the addition of a low beam had no effect on high-beam seeing distances.

Analysis is under way to resolve the discrepancies between predicted and actual seeing distances to delineation targets and to further evaluate glare data.

Discomfort Glare

A common finding in headlight studies in which glare and observer headlights are the same is that seeing distance remains constant or increases as head lamp intensity increases, despite the increase in glare (5). For example, when opposing cars meet, seeing distances may be greater for high than for low beams (6). The contrast threshold and disability glare formulations used in the Ford model would predict the same outcome. This is because, as head lamp intensity increases, contrast remains the same but the effective background luminance ($B_B + B_V$) increases; and, as Figure 5 shows, the contrast required for detection decreases with increasing background luminance. Low-beam head lamp intensity is thus limited more by discomfort glare than by disability glare. Disability glare has a quantifiable effect on seeing distance, and this effect is incorporated in the model. Discomfort glare is more difficult to quantify but is important because it determines the maximum acceptable intensity of low beams and the conditions under which opposing drivers will request dimming of high or mid beams. Current low beams produce levels of glare that would be rated as unacceptable by models developed to quantify discomfort glare in environments other than night driving. Nevertheless, low beams are tolerated because they represent a reasonable compromise between glare and visibility that has evolved over the years. This is why current low-beam intensity provides the basis for the maximum acceptable discomfort glare level used in the present version of figure of merit in the evaluation model.

The problem of dealing with the discomfort glare produced by mid and high beams is somewhat different because they can be dimmed in response to requests from opposing drivers. High beams are normally dimmed as a matter of course in meeting situations, but the question arises of whether increases in high-beam intensity beyond a certain point produce a net loss in seeing distance because the increased glare results in dimming at greater separation distances.

The potential advantage of mid beams is based on considering them as an augmented low beam rather than a type of high beam; i.e., they need not necessarily be dimmed in meeting situations. In particular, their usefulness will depend on the range of highway conditions under which they can be used in meeting situations. Whether mid beams can be used in a given situation will depend on the level of discomfort glare they produce. At some level of intensity, an opposing driver will request dimming. This intensity will vary from one situation to another depending on distance, highway geometry, ambient brightness, and head lamp misaim.

Determining a maximum acceptable low-beam discomfort level empirically is difficult. Discomfort rating scales are of questionable validity because there is no way to estimate the extent or direction of the bias introduced by the test subjects in a

Figure 8. Observed and predicted seeing distances to pedestrian targets.

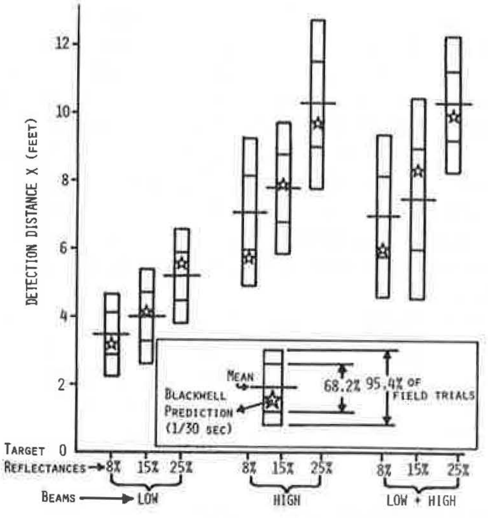


Figure 9. Observed and predicted seeing distances to line targets.

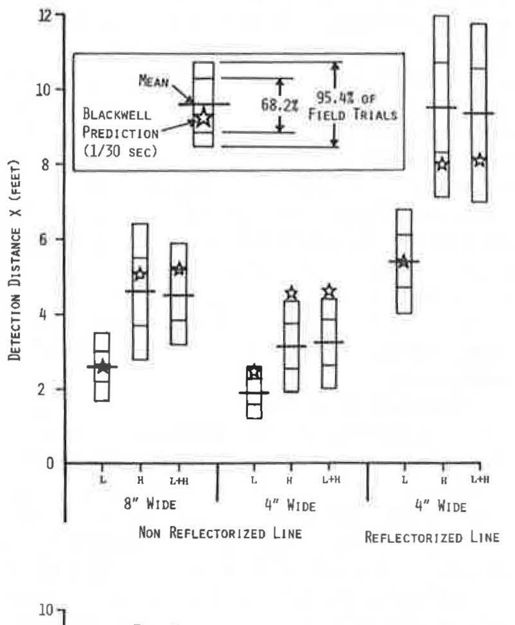
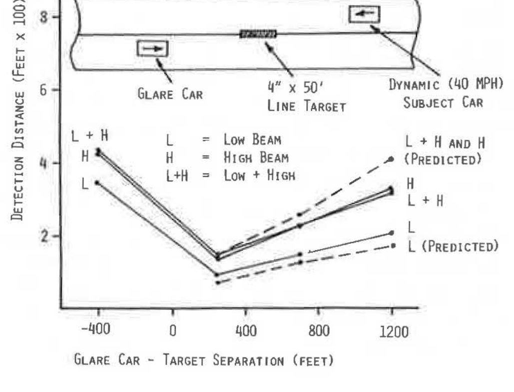


Figure 10. Observed and predicted seeing distances to 4-in. by 50-ft reflectorized line targets.



structured test situation. Counting dimming requests to lamps of varying intensity in actual traffic is also of questionable value in the case of low beams because there is no way of knowing whether opposing drivers are responding to discomfort, brightness, or their estimate of the opposing car's beam type. Further current research by Ford indicates that drivers will tolerate an occasional glare source, without making a dimming request, that is at a far higher level of intensity than would be acceptable on a routine basis. Nevertheless, to the extent that frequency of dimming requests is an index of discomfort, such data can be used to estimate the percentage of drivers discomforted by various levels of glare. Such a formulation might be used as the basis of a somewhat more sophisticated definition of the role of low-beam discomfort glare in the evaluation model.

In the case of high or mid beams, the concern is not with discomfort as such, but with the effect of discomfort, real or anticipated, on beam use. The problem is to determine the conditions under which drivers will permit each other to use mid and high beams. For this purpose, a study of actual dimming requests in response to lamps of various intensities is appropriate.

Glare Acceptance Research

A pilot study was performed to explore some of the factors influencing glare acceptance on public roads. In this study, an instrumented vehicle equipped with three different head lamp systems was driven on a 2½-mile straight section of a lightly traveled non-illuminated public road. The systems were (a) two 7-in. lamps, (b) two 5-in. lamps, and (c) four 5-in. lamps. In system c the intensity relationship between inboard and outboard lamps was as in current four-lamp, two-beam systems. The measure of glare acceptance was the percentage of opposing drivers requesting dimming at various distances. Each head lamp system was exposed to oncoming traffic 30 times under the following three intensity levels: 3,000 cd, equivalent to current low-beam glare; 60,000 cd, equivalent to current high-beam glare; and 105,000 cd, equivalent to a government proposed high-beam system. The candela values are the totals for all the lamps of a system, measured along a vector to an opposing driver's eye point 1,200 ft away. These are, of course, nominal values. Actual illumination levels for each system at the location of an opposing driver's eyes were measured at various distances.

Analysis of the data revealed no effect of total lamp area or number of lamps. However, as expected, the distance at which a given percentage of dimming requests took place was greater for 105,000 than 60,000 cd. None of the 3,000-cd systems resulted in dimming requests. A number of discomfort glare models (7, 8, 9) were investigated to provide a context for organizing the data. The Guth (7) and Linde (8) models were not found to be useful for this purpose. The DeBoer (9) model, however, provides a discomfort scale that is consistent with the Ford dimming request data. Discomfort is scaled by DeBoer as a function of illumination, the observer's line-of-sight angle (the angle between the observer's line of sight and the vector from the observer to the glare source), and adaptation (ambient) brightness. Figure 11 shows isodiscomfort lines plotted according to DeBoer's expression and illustrates the path of the candela levels through DeBoer space as the opposing vehicles close. (Note that the DeBoer index value decreases with increasing discomfort.) The adaptation level assumed was 0.01 ft-L. Also shown are the percentages of dimming request signals by drivers who had not previously signaled for each level of candela and region of DeBoer space. The two high-intensity paths are close to each other in DeBoer space, and the percentages of dimming requests in corresponding discomfort regions are similar for the two intensities. This suggests that the discomfort index accounts, at least in part, for dimming request behavior. However, distance is obviously a factor in that, within about 1,000 ft of the opposing vehicle, drivers who have not yet signaled are less likely to signal as the distance closes, despite the increase in the glare index. Very few dimming requests occur within 250 ft, and a certain percentage of drivers never request dimming in an encounter. Apparently for those drivers who do ultimately signal, the

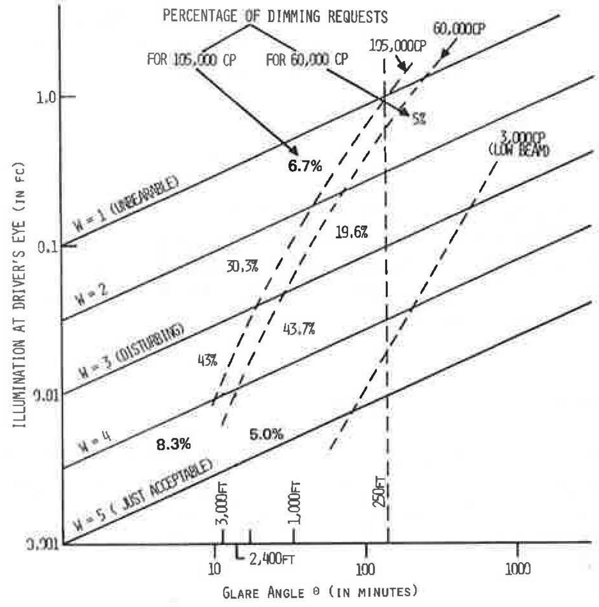


Figure 11. Relationship of dimming requests to discomfort glare.

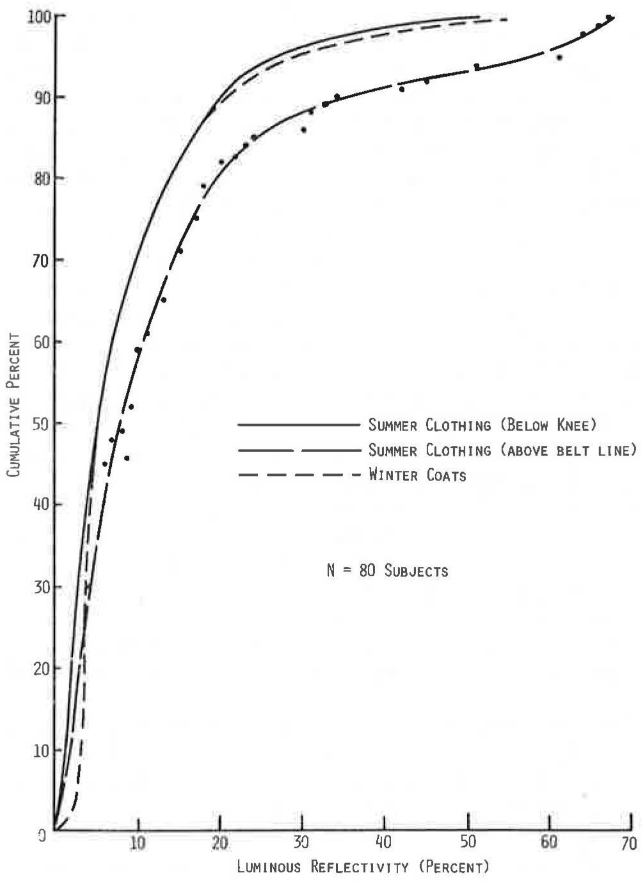


Figure 12. Cumulative distribution of reflectivities.

median discomfort threshold is reached at a discomfort index between 2.5 and 3.5.

Data collection is continuing on this problem to further evaluate the DeBoer model and to determine duration-of-exposure effects associated with highway geometry.

Reflectance and Ambient Brightness Surveys

Target contrast is dependent on the reflectance of both the target and background and the ambient brightness. To provide representative data for the standardized test route, two survey programs have been undertaken, one on pedestrian reflectance and the other on the reflectance of pavement, shoulder, and delineation and the ambient brightness of the highway environment at night.

Pedestrian Reflectance Survey

The pedestrian reflectance survey has been completed (Fig. 12). The data were obtained by measuring the reflectance of the summer and winter clothing of Ford employees. The reflectance of the pedestrian targets represented in the standardized test route will be randomly drawn from these distributions.

Highway Reflectance Survey

Pavement reflectance data will be obtained at sites in a number of states. The reflectance of a surface is defined as the ratio of its luminance to the incident illumination. Two types of reflectance will be considered: retroreflectance, the percentage of head lamp illumination returned by the highway surface to a driver from his own head lamps, and forward reflectance, the percentage reflected by the surface to an observer in an opposing vehicle. Because of the low angles of incidence and reflectance (less than 1 deg beyond 150 to 300 ft), the necessary measurements are tedious and difficult, and there has been only one systematic study of head lamp illumination reflectance (10).

Data collection has been simplified by the development of a photographic technique for measuring reflectance. A calibrated, stabilized light source of known candela distribution is used to illuminate the highway section to be photographed. A telescope fixed to the light source is used to aim the optical axis of the lamp at a precise point on the roadway. The illuminated section is then photographed with Kodak 2475 film. Figure 13 shows a print of such an exposure. Each roll of film is calibrated by photographing a gray scale with known luminance values so that luminance can be scaled in terms of film density. The luminance of the pavement at any point can then be determined by measuring the density of the negative at that point. Luminances measured by the photographic technique are within a tenth of a log unit of the same values measured with a Pritchard photometer. The illumination from the source lamp at that location is obtained from its isocandle diagram. This is determined by finding the azimuth and elevation of the measured point relative to the source lamp's optical axis and reading the candela off that point in the isocandle diagram. The candela so obtained is divided by the square of the distance between the lamp and the measured point to yield illumination. Reflectance is then given by the ratio of luminance to illumination. This procedure is carried out on various points on the paved surface, the shoulder, and the delineation.

Retroreflectance data for several Ford Proving Ground surfaces are given in Figure 14. In general, retroreflectance increases with increasing distance from the source. Based on the limited data available, the retroreflectance of the road surface does not vary significantly with the lateral position of the measured point beyond a distance of 100 ft.

Forward reflectance data (taken with the camera looking toward the light source 800 ft away) are shown in Figure 15. This figure shows contours of equal reflectance on a plan view of the pavement. Forward reflectance values are 10 to 100 times greater

Figure 13. Print of retroreflectivity of pavement and gray scale used for calibration.

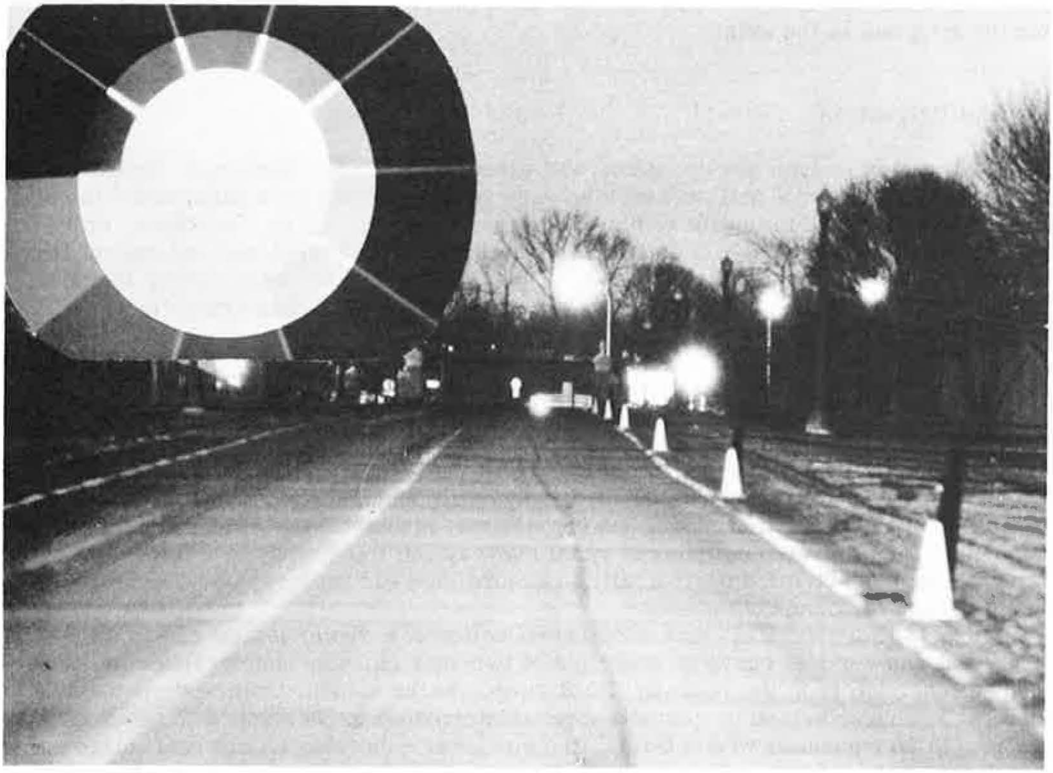
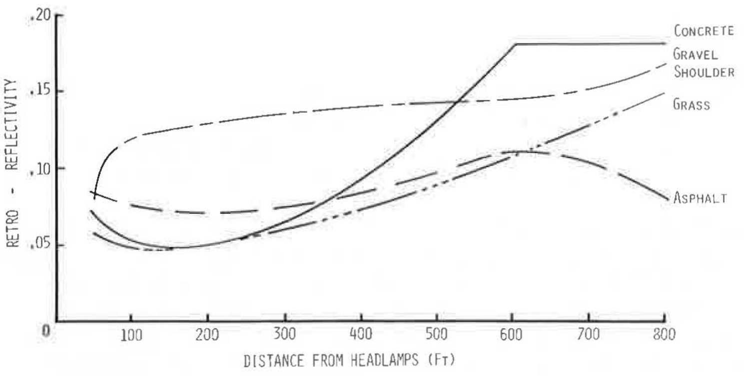


Figure 14. Retroreflectivity coefficients as a function of distance for various road surfaces.



than retroreflectance values because there is a large specular component. Maximum values lie along the source-observer axis and peak at a point that lies between the lamp and the midpoint of the axis.

Ambient Brightness

Path delineation is seen wholly against the pavement surface. However, portions of a pedestrian-sized target will normally be seen against the sky or a background too distant for head lamp illumination to have any effect (Fig. 16). It is, therefore, important to have representative data on the ambient luminance of the night sky and distant backgrounds as well as the nearer surfaces. These values will be measured by the photographic technique at the same time that pavement reflectance data are collected.

Topography Survey

Hills and curves have an important influence on head lamp performance because they displace the beam pattern from the roadway. A photographic survey of road topography has been performed to provide data for the development of the standardized test route to be used in the evaluation model. A camera was mounted in a vehicle driven over a 1,500-mile route of various types of rural highway and topography in a five-state area. The camera was activated periodically to record the road topography. The film was then digitized for computer storage.

Figure 16 is a computer-generated reproduction of a driver's view of a combined horizontal and vertical curve on a section of two-lane highway photographed in the survey; a pedestrian is in the roadway 400 ft away. In the standardized test route each segment is characterized by geometric parameters such as were used to generate Figure 16. In an encounter with a target, the computer generates an internal image similar to that depicted in the figure. The computer then determines the location of the targets and the background with respect to the driver and the optical axis of each working head lamp to permit computation of the photometric quantities, which, in turn, determine seeing distance.

Driver Attention

One of the more important considerations governing visual performance under actual highway conditions at night is the state of alertness of the driver. Headlight-seeing distance tests are typically conducted with an alerted observer who understands that his task is to detect targets as soon as possible. Often the observer knows the exact location of the target.

In 1938 Roper (11) compared the detection distances of alerted and unalerted drivers to a pedestrian dummy placed in the middle of a driving lane on a lightly traveled public road. Roper considered that detection occurred when the unalerted driver lifted his foot from the throttle. The same observer then was allowed a second detection trial with the same target after having been alerted to its presence. On the average, detection distances for alerted observers were two times those of unalerted performance. Cumulative curves of percentage of seeing distance for alerted and unalerted drivers, based on Roper's findings and Blackwell contrast threshold data (representing the alerted driver), are shown in Figure 17.

These curves, generated by the Ford seeing distance model, indicate that the median detection distance for the alerted driver is almost twice that of the unalerted driver. An important consequence of this finding is that differences in seeing distance between head lamp systems as measured in formal seeing distance tests with alerted drivers would, on the average, be twice as great as those expected in the real world. Thus, a 60-ft seeing advantage for a system in a test situation would translate to a 30-ft difference in the real world.

Figure 15. Contour of constant forward reflectivity.

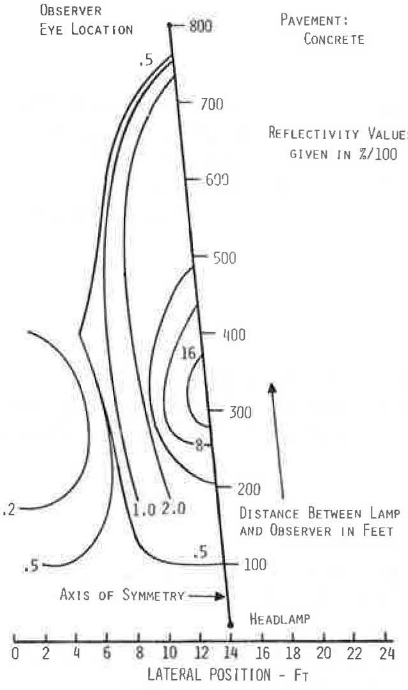


Figure 16. Computer reproduction of highway geometry and pedestrian target.

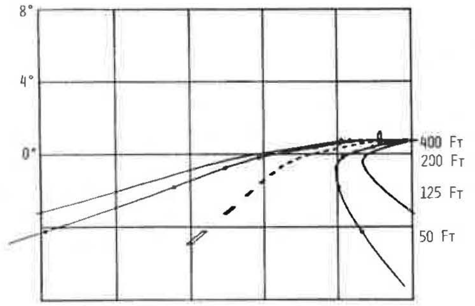


Figure 17. Cumulative probability of detection as a function of target distance.

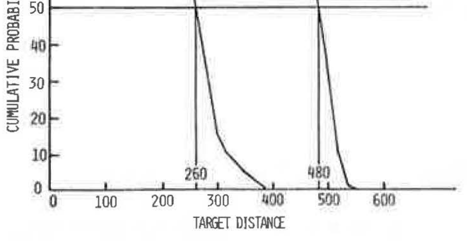
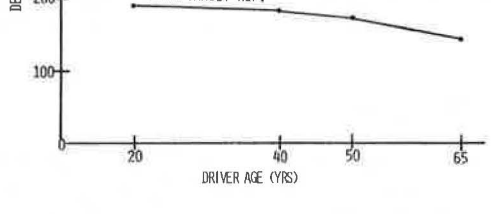


Figure 18. Target detection distance as a function of age of driver.



Roper's findings will be used in the evaluation model to represent driver performance under actual highway conditions rather than formal test conditions.

Driver Age

Figure 18 shows the effect of age on seeing distance and is based on data developed by Blackwell (12). The encounters simulated did not include glare from an opposing vehicle. In glare situations, a further decrement of seeing distance with age would be anticipated because of the greater susceptibility of older people to disability glare. This effect has been modeled by Fisher and Christie (4) and others and is incorporated into the Ford seeing distance model.

Head Lamp Misaim

Head lamp misaim data collected by Hull (13) have been analyzed to provide distributions of misaim in the U.S. vehicle population. These distributions will be used to generate random levels of misaim in the observer and opposing vehicles in the simulations.

CONCLUSIONS

Experience to date from field testing, analysis, and model development has tended to confirm the assumptions under which the program was undertaken.

1. Important measurable aspects of driver visual performance at night (i.e., seeing distance and response to glare) can be predicted from laboratory formulations describing human brightness-contrast detection thresholds and glare susceptibility.
2. The environmental and vehicle factors that determine night driving visibility conditions can be defined and expressed in terms suitable for computer simulation.
3. Because these human and physical factors can be reduced to mathematical expressions, the development of a computer model to evaluate headlight systems in terms of objective measures of driver performance under various conditions is a feasible and worthwhile undertaking.

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This paper addresses the problem of the specification of lighting for the automobile driving operation. The empirical relationship between a measure of driver visual performance and several methods of quantifying visibility is explored in an effort to develop roadway lighting specifications based on visibility needs. Physical contrast, equivalent contrast, relative contrast sensitivity, and glare exposure are discussed. Field measurements of the visual performance of 941 unalerted motorists are analyzed, and a precise method of quantifying visibility is identified. The form of the suggested visibility term uses physical contrast, contrast sensitivity, and a disability glare factor. A method of prescribing visibility in terms of safe stopping requirements is discussed. Follow-up research that will enhance the reliability of the measures, extend the general applicability of the concept, and further develop the prescription approach is outlined.

CONTRAST REQUIREMENTS OF URBAN DRIVING

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The purpose of this study was to develop a technique for quantifying and specifying the visibility needs of urban drivers in a manner consistent with state-of-the-art lighting engineering capabilities and practices.

Lighting specifications are typically given as units of average flux with limits of uniformity or dispersion. Warrants are typically related to traffic, geometric, and road use conditions. The specification of lighting has undergone much debate especially as attempts are made to provide international compatibility of standards. There has been much disagreement on the efficacy of specific warranting criteria and on the question of flux units. Many organizations have expressed lighting requirements in terms of pavement luminance. Since the eye requires reflected light to detect objects in space, this approach is clearly related to the needs of drivers. These units present a complex measurement dilemma, however, because pavement luminance cannot be predicted reliably based on the distribution of flux output of luminaires. This is mainly because light reflected off paving surfaces is not uniformly diffuse (1).

The eye responds to small differences in luminous intensity and exposure duration. The limitations of this information processing system must be considered in the context of the human operation under study. Therefore, the problem is addressed in terms of drivers' information and visibility needs. This study assesses the predictive strengths of various visibility concepts and formulations. The experimental conditions have been described in detail by Gallagher and Meguire (2).

EXPERIMENTAL CONDITIONS

Driver Performance Measure

The critical measure of driver visual performance was the time separation between the vehicle and a target when an evasive response was initiated. We measured the point of response as distinguished from the point of perception because the evasive response of a driver to a roadway obstacle of high visibility is largely unconstrained and the driver exercises considerable judgment concerning when he will brake or change lanes. However, when target visibility is lower, the time between perception and response is reduced largely because of the driver's interest in maintaining some