PCDETECT: A Revised Version of the DETECT Seeing Distance Model

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Described in this paper is a revised version of the Ford Motor Company DETECT seeing distance model. The revised model, known as PCDETECT, is written in QuickBASIC for IBM-compatible personal computers. PCDETECT calculates the distances at which a driver can see various objects on the road at night as illuminated by the headlamp system specified by the user. The revised algorithms are based on Blackwell's recent contrast sensitivity research. They include new formulations for calculating contrast thresholds and take into account driver age, target size, background luminance, and individual differences. The revised model also incorporates a driver age factor for calculating veiling glare. The seeing distances calculated using the old and revised versions are generally in close correspondence. However, at low illumination levels, the new algorithm predicts seeing distances that are as much as 12 percent greater than the original version. This can be traced to differences between the old and revised contrast threshold functions. The age and variability factors in the new algorithm have a substantial impact on seeing distances. Against a low beam glare source at 300 ft, the seeing distance to a pavement edgeline was 413 ft for an average 20 yr old and 130 ft for a 15th percentile 70 yr old.

In 1976 the Ford Motor Company published the results of a nighttime field study to validate the use of human contrast sensitivity functions to predict seeing distance to objects illuminated by motor vehicle headlights (*1*). We found that the seeing distance predictions based on these functions were generally in accord with the actual seeing distances measured in our field studies. As a result of these tests, we proceeded with the development of a computer seeing distance model, written in FORTRAN for mainframe application, which has become known as DETECT.

Described in this paper is a revised version of DETECT, written in Microsoft QuickBASIC for IBM-compatible personal computers. The revised version is known as PCDETECT. The development of PCDETECT was undertaken for several reasons. The primary reason was to incorporate the newer and more comprehensive vision algorithms that have become available in the literature since the original version of DETECT was developed. A second reason was to produce a more comprehensible and better documented program. The original FORTRAN version of DETECT is largely undocumented and is very difficult to maintain and modify. The new version has revised and thoroughly self-documented codes. Also, we felt that a program written for a personal computer would be accessible to more users than a mainframe version. Finally, we wanted to develop a more interactive and user-friendly interface to specify and vary systematically the input conditions.

Microsoft QuickBASIC was chosen as the development language because it is powerful and easy to use. QuickBASIC is a fast, compiled version of BASIC for IBM-compatible personal computers that incorporates advanced modular programming features and produces stand-alone machine language files.

In the rest of the paper, DETECT refers to the original mainframe FORTRAN version of the model and PCDETECT refers to the revised version written in QuickBASIC.

HOW PCDETECT WORKS

DETECT and PCDETECT are headlamp seeing distance models. They use human contrast sensitivity formulations to calculate the distance at which various types of objects (referred to as "targets"), illuminated by headlamps, first become visible to approaching drivers. In DETECT, the only targets are pedestrians and longitudinal lane lines. PCDETECT deals with eight types of targets, as follows:

1. Longitudinal lane lines,
2. Transverse lane lines (e.g., pedestrian walkway markings),
3. Other pavement markings (e.g., words, symbols on surface),
4. Reflective pavement markers,
5. Traffic signs,
6. Post-mounted delineators,
7. Freestanding markers (e.g., traffic cones), and
8. Pedestrians.

The definition of "visibility" depends on the target. For all target types except 3 and 5, the visibility distance is the distance at which the driver is first able to *see* the target as a separate object. No assumptions are made regarding the relationship between seeing and recognition. The algorithms assume an attentive driver. For traffic sign targets, PCDETECT calculates both the seeing distance to the sign panel itself and the legibility distance of the sign elements, that is, letters or symbols. For type 3 targets, the visibility distance criterion is also legibility.

As background for a discussion of the revisions, it is useful to review the workings of the model in its present version. The core of PCDETECT is an algorithm for determining the threshold luminance contrast between an object and its back-

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ground. The threshold contrast is the contrast at which the object is just discernible to an attentive observer.

Both DETECT and PCDETECT use an iterative procedure to increase and decrease the distance between the observer's vehicle and the target until it finds the distance at which the target is at the threshold, that is, is just visible to the observer-driver. However, in DETECT the observer's location is fixed and the target is moved; in PCDETECT, the target is fixed and the observer's vehicle is moved. In both versions of the model, the distance between the observer's vehicle and the glare source is held constant throughout the iteration process. This means that in PCDETECT, the glare car moves back and forth with the observer's car during the distance iteration process. PCDETECT also differs from the older version in that PCDETECT provides the option of multiple glare vehicles whose distances from the observer's are based on traffic volume.

The procedure for determining whether or not the target is visible at each "trial" distance is outlined below.

First, the model calculates the total candlepower from all of the vehicle headlamps falling on the target. The luminance of the target is then given by

$$L_t = R \sum_{i=1}^{n} (CP_i/D_i^2) \qquad (1)$$

where

R = reflectance of the target,
CP_i = incident candlepower from the ith headlamp, and
D_i = distance between the ith headlamp and the target.

Background luminance (assuming that the effective background is the road surface or a sign panel) is similarly calculated. For more distant backgrounds, the luminance is assumed to be an ambient value unaffected by the headlamps.

It is also necessary to determine the size of the target. Size is defined as the angle subtended at the observer's eye by the diameter of a visually equivalent disk. Blackwell defines the equivalent disk as a disk having the same area as the projected area of the target.

To make these calculations it is necessary to have the candlepower tables for the particular set of headlamps to be represented in the model, the dimensions of the target, the locations of the vehicle and the target on the road with respect to some common coordinate system, and the geometry of the road itself, that is, the horizontal and vertical curvature.

Once target and background brightness have been determined, the target-background contrast is calculated. Contrast is defined as

$$C = \frac{|L_t - L_b|}{L_b} \qquad (2)$$

where L_t and L_b are target and background luminance values, respectively.

The effect of glare from opposing vehicles is represented by adding the veiling luminance (B_v) to the denominator of Equation 2:

$$C = \frac{|L_t - L_b|}{L_b + B_v} \qquad (2a)$$

This contrast is then compared with the threshold contrast, that is, the contrast required for detection, calculated by PCDETECT's visibility algorithm. The distance is increased or decreased according to whether the actual contrast is greater or less than the threshold detection contrast. The actual and required contrast values are computed at the new distance and the process continues until the ratio of the actual and threshold contrast values reaches some criterion level. The distance at which this occurs is the "seeing distance."

These visibility calculations are described in the next section.

DETECT VISIBILITY ALGORITHM

The visibility algorithm in the original version of DETECT is based on threshold contrast curves published by Blackwell in 1952 (*2*) and shown here in Figure 1. Threshold contrast is plotted as a function of background luminance for disk targets of various diameters. The threshold contrast increases with decreasing luminance and decreasing target size, that is, less contrast is required to see large objects against a bright background than small objects against a dim background. The curves in Figure 1 are for targets exposed to the observer for 1/30 sec. This particular set of curves is incorporated into DETECT in the form of empirically fitted equations.

The curves in Figure 1 are based on data from only two observers. However, DETECT incorporates adjustments to these curves for age and individual differences, which are based on data from a large sample of observers (*3*). The data on individual differences are used to estimate seeing distance percentiles, i.e., the distance at which some percentage of drivers will be able to see the specified target.

The calculation of disability glare in DETECT is based on Fry's veiling glare equation (*4*). This equation incorporates no adjustment for driver age.

PCDETECT and the "19/2" Model

Blackwell's visibility research results, as they apply to highway illumination, are summarized in Publication 19/2.1 of the Commission Internationale de l'Eclairage (CIE) (*5*). The CIE

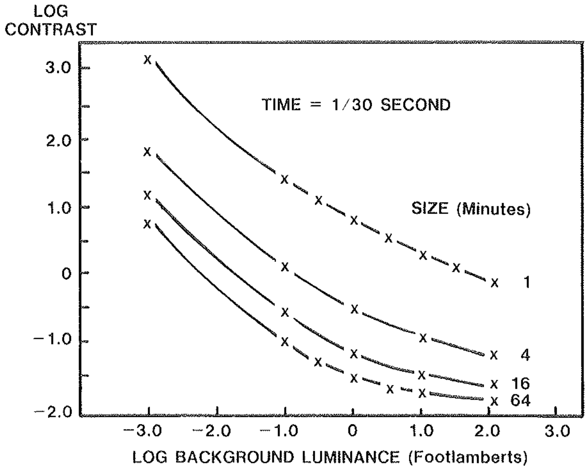


FIGURE 1 Log threshold contrast as a function of background luminance for different size targets.

report tries to organize his findings to evaluate the adequacy of roadway illumination. The whole system as it is presented in CIE 19/2.1 is not suitable for inclusion in a headlamp seeing distance model. However, many of the underlying formulations are applicable and it is these with which we are concerned. These newer formulations are based on laboratory research conducted by Blackwell over a 10-yr period using several hundred observers of varying age and visual capability.

As noted above, the original version of DETECT uses an empirical fit to the 1952 contrast threshold data, which has no theoretical basis. By contrast, CIE 19/2.1 presents an analytical expression for contrast sensitivity that has its roots in vision theory. The form of the equation used to calculate threshold contrast in PCDETECT is as follows:

$$C_{\rm th} = cx\,\frac{0.0923}{n}\left[\left(\frac{S}{tL_e}\right)^{0.4}+1\right]^{2.5} \qquad (3)$$

where

$C_{\rm th}$ = threshold contrast
cx = target size factor
S and t = parameters that depend on observer age and target size (discussed below),

$L_e = L_b + B_v$, the effective background luminance, and

$$n = \left[\left(\frac{S}{100t}\right)^{0.4}+1\right]^{2.5} \qquad (4)$$

Figure 2, taken from the CIE report, is a plot of Equation 3 for a 4-min disk target and a 22-yr-old observer.

The S parameter in Equation 3 is a function of both age and target size:

$$\log S = 0.5900 - 0.6235 \log d - s \qquad (5)$$

where d is target size (diameter) in minutes of arc and s is an age-related factor (see below).

The effect of the S parameter is shown in Figure 3, which is a plot of the relative contrast sensitivity (RCS) function. The RCS function is the inverse of the threshold contrast function shown in Figure 2, normalized to have a "reference" value of 1.0 and 100 cd/m². The S parameter changes the *shape* of the curve, as shown in Figure 3, but not the reference value.

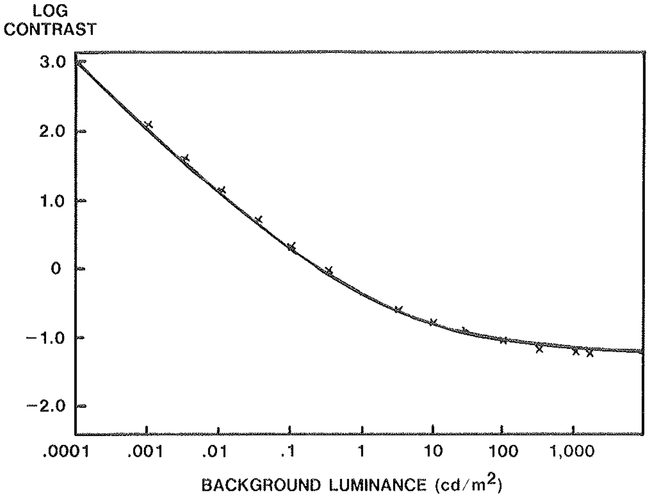


FIGURE 2 Log threshold contrast as a function of background luminance.

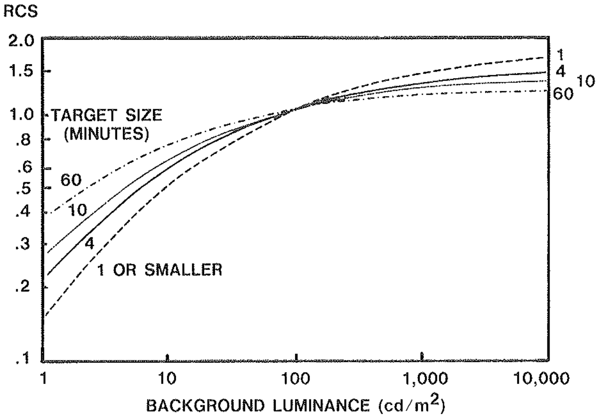


FIGURE 3 The effect of target size on relative contrast sensitivity.

Target Size in PCDETECT

In Blackwell's new system, target size is regarded as a visual task difficulty factor for which an empirically determined contrast multiplier must be supplied. In the original version of DETECT, the effect of target size was built into the equations to produce a near exact fit to the family of curves shown in Figure 1. In PCDETECT, a separate algorithm was developed to generate a size factor, cx, as follows:

$$d \le 10: \quad cx = 3(0.37)^{\log_2 d}$$

$$d > 10: \quad cx = 0.106 - 0.0006d \qquad (6)$$

where d is target size in minutes.

The algorithm expressed in Equation 6 was developed to produce approximately the same effect of size on the magnitude of the threshold contrast as the algorithm in the original version of DETECT. Figure 4 shows the contrast threshold function used in the DETECT model (shown in Figure 1) compared with the size-adjusted thresholds produced by

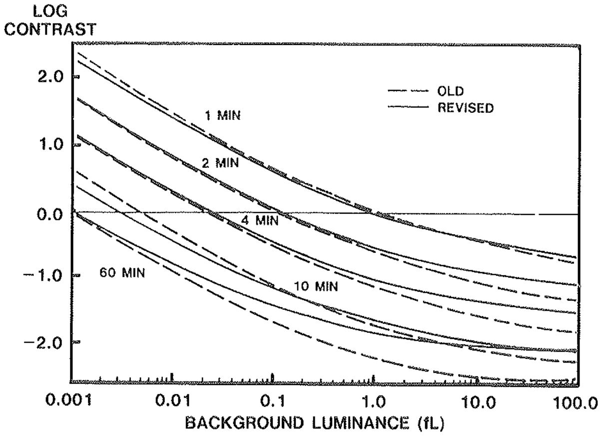


FIGURE 4 Log threshold contrast function for different target sizes using old and revised algorithms.

Equation 3. Note that while the two sets generally conform below 0.1 fL, they tend to separate at higher values because the newer curves generated by Equation 3 are somewhat flatter than the old curves, especially for larger target sizes. At low levels of background brightness, and for targets between 10 and 60 min, the new algorithm gives lower thresholds. This leads to differences in seeing distance predictions between the old and the new algorithms, as we shall see below.

In Blackwell's paradigm, the size of noncircular objects is defined as the diameter of a circle having the same projected area as the object, expressed in minutes of arc. In DETECT, size is defined as the diameter of a circle with an equal perimeter. This definition was used because it gave a better fit to the field data collected in the Ford validation studies (*1*) than the equal-area definition. Both algorithms are incorporated into PCDETECT; however, at present, only the perimeter algorithm is carried out. This algorithm is used to calculate size for all targets except letters and symbols. For letters, symbols, and other graphic elements, both on vertical surfaces and on the road surface, the target size is the stroke width of the element in minutes.

Age and Individual Differences

In PCDETECT, the age of the observer affects both the shape of the threshold contrast curve and the magnitude of the threshold. Earlier it was mentioned that the s and t parameters, which determine the shape of the threshold function, are age-related. The functions for s and t are given in CIE 19/2.1, as follows:

$$\begin{aligned} \text{Age } 20\text{–}44&: \quad s = 0 \\ 44\text{–}64&: \quad s = 0.00406\,(A - 44) \\ 64\text{–}80&: \quad s = 0.0812 + 0.00667\,(A - 64) \qquad (7) \end{aligned}$$

$$\begin{aligned} \text{Age } 20\text{–}30&: \quad \log t = 0 \\ 30\text{–}44&: \quad \log t = -0.01053\,(A - 30) \\ 44\text{–}64&: \quad \log t = -0.1474 - 0.0134\,(A - 44) \\ 64\text{–}80&: \quad \log t = -0.4154 - 0.0175\,(A - 64) \qquad (8) \end{aligned}$$

where A is observer age in years.

Contrast threshold values increase considerably with age. Figure 5, taken from Blackwell (*3*), is a scatter diagram of the log threshold contrast values obtained from 156 observers at a background luminance of 0.01 fL, which is a typical pavement luminance several hundred feet from the vehicle. Note that the effects of age and individual differences are roughly comparable. Contrast sensitivity decreases by a factor of about five between the ages of 20 and 80. The age effect is represented by a contrast multiplier, which Blackwell refers to as m_1. The function, as given in CIE 19/2.1, is as follows:

$$\begin{aligned} \text{Age } 20\text{–}42&: \quad m_1 = 1.000 + 0.00795\,(A - 20) \\ 42\text{–}64&: \quad m_1 = 1.175 + 0.0289\,(A - 42) \\ 64\text{–}80&: \quad m_1 = 1.811 + 0.1873\,(A - 64) \qquad (9) \end{aligned}$$

The variability of thresholds also increases with age. The expression for the relationship between age and variability of the threshold was derived from data summarized in Figure 6, taken from Blackwell (*3*), and is as follows:

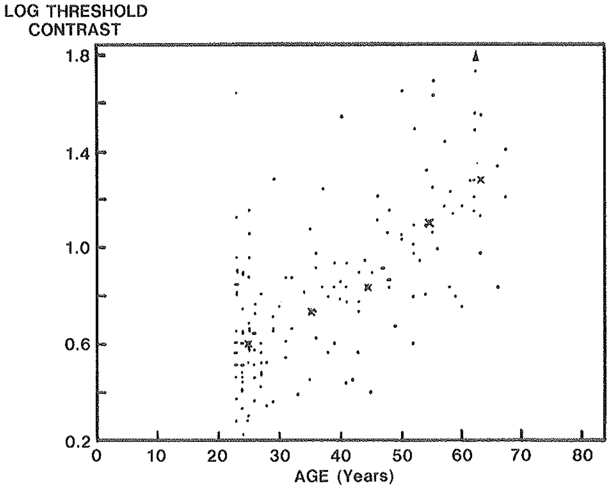


FIGURE 5 Log threshold contrast as a function of age at 1 fL background luminance.

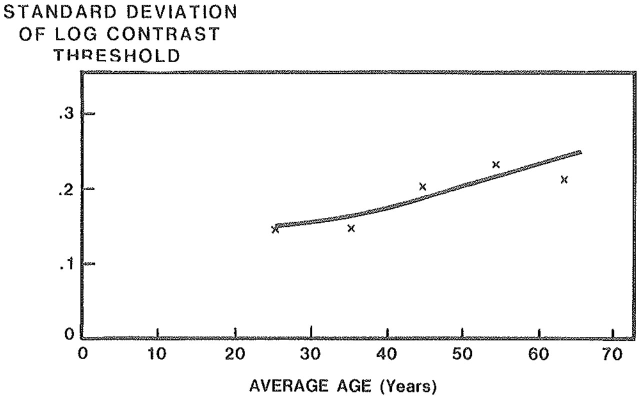


FIGURE 6 Observer variability as a function of age.

$$\begin{aligned} \text{Age} \le 35&: \quad \sigma_{\log} = 0.124 + 0.001133\,A \\ > 35&: \quad \sigma_{\log} = 0.064 + 0.002850\,A \qquad (10) \end{aligned}$$

where A equals driver age in years and $\sigma_{\log}$ is the standard deviation of the log contrast threshold values.

Variability also increases with decreasing background luminance. Accordingly, a correction factor is applied to the log standard deviation. The correction factor was developed from the relationship shown in Figure 7, also taken from Blackwell (*3*). The correction factor is as follows:

$$\begin{aligned} \log L_b \le -0.5&: \quad cf = 1.0875 - 0.065 \log L_b \\ \log L_b > -0.5&: \quad cf = 1.012 - 0.216 \log L_b \qquad (11) \end{aligned}$$

where L_b is the background luminance and cf is the correction factor. The correction factor is multiplied by the standard deviation of the log threshold contrast ($\log C_{th}$) to obtain the corrected value for the standard deviation.

The combined result of the age and luminance effects on variability is substantial. For example, the standard deviation

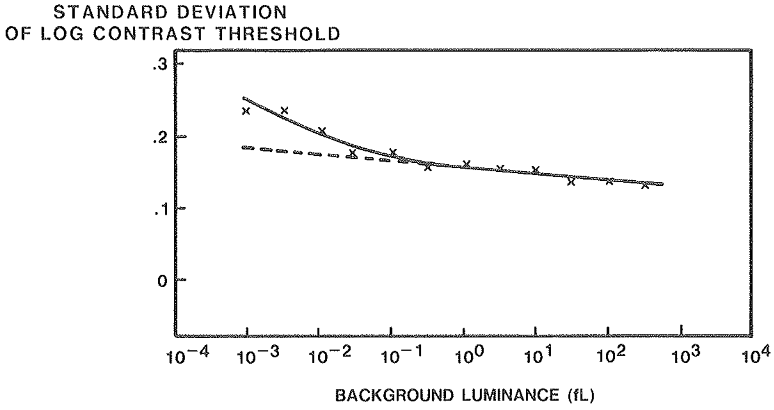


FIGURE 7 Variability among 20- to 30-yr-old observers as a function of background luminance.

of the log threshold contrast for a 60-yr-old observer at 0.01 fL is more than twice that for a 20-yr-old observer at 10 fL.

The probability distribution of contrast thresholds is lognormal (*3*), which permits the use of normal curve analytical tools for dealing with variation. A contrast multiplier is used to adjust the threshold to represent an observer at a given percentile level of performance. The adjustment factor is given by

$$cmp = 10 z_p \, \sigma_{\log C_{th}} \tag{12}$$

where

cmp = contrast multiplier,
$\sigma_{\log C_{th}}$ = corrected standard deviation of the log-normal threshold distribution, and
z_p = z-score (standard normal variable) associated with the pth percentile.

For example, the z-score associated with the 95th percentile is about 1.65. If the observer age is 35 and the background luminance is 0.3 cd/m^2, then from Equations 11 and 12, the corrected standard deviation is 0.184 and log cmp is 0.303. The antilog of this value, 2.01, is the contrast multiplier associated with the 95th percentile level. From Equation 8, the value of m_1 for a 35-yr-old observer is 1.12. To accommodate 95 percent of 35 yr olds, the threshold computed from Equation 3 must be increased by a factor of 2.01 × 1.12 = 2.25.

Disability Glare

The formula for calculating disability glare (B_v) used in the original version of DETECT is the Fry formula (*4*):

$$B_v = k \pi \sum_{i=1}^{n} \frac{E_v \operatorname{Cos}(\theta)}{\theta(\theta + 1.5)} \tag{13a}$$

where

k = 10,
n = number of glare sources (e.g., lamps),
E_v = illumination from the glare source at the observer's eye, and
θ = observer's line of sight angle between the glare source and the target, measured in degrees.

The Fry formula includes no adjustment for driver age (*6*). Blackwell recommends an algorithm based on more recent and comprehensive data that does include a correction factor to reflect increasing sensitivity to disability glare with age. Veiling luminance (L_v in Blackwell's notation) is given as follows:

$$L_v = k \sum_{i=1}^{n} \frac{E_v \operatorname{Cos}(\theta)}{\theta^2} \tag{13b}$$

where k depends on driver age and the other parameters are as described for Equation 13a.

Both versions are programmed into PCDETECT. At present, Equation 13a is carried out to maintain consistency with the original version of DETECT. However, whereas the value of k is fixed at 10 in the original version, in PCDETECT k takes on different values depending on driver age, as described below.

Glare sensitivity, as expressed by the magnitude of the k factor, increases with age. Blackwell's results on the effect of age on glare sensitivity are reported in a 1980 paper (*6*). Figures 8 and 9 show the factors, m_3 and m_4, by which k increases with age for background luminance of 100 and 1.7 cd/m^2, respectively. Note that age increases the glare sensitivity by a factor of about 2.5. The value of k in Equation 12b is 10 m_3 or 10 m_4 depending on the value of L_b. In

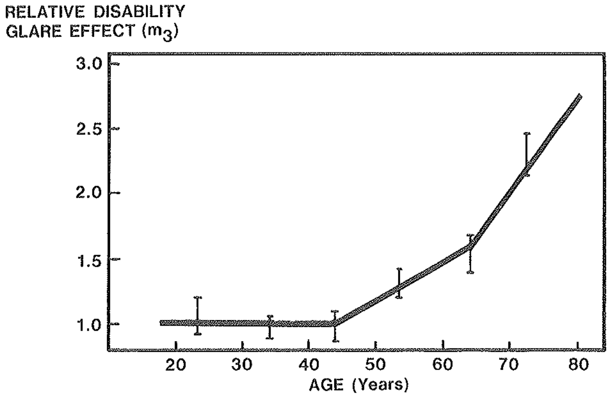


FIGURE 8 Disability glare contrast multiplier as a function of age for background luminance values near 100 cd/m^2.

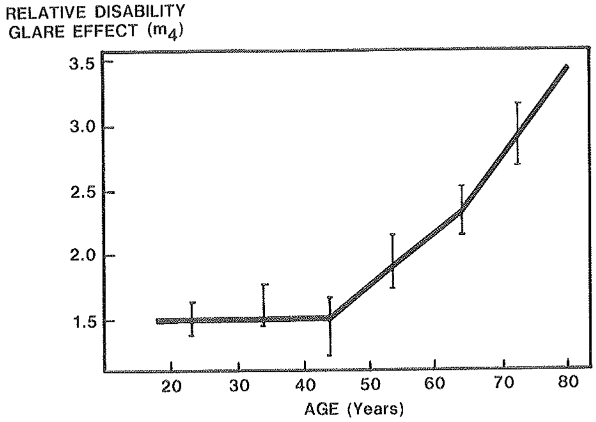


FIGURE 9 Disability glare contrast multiplier as a function of age for background luminance values near 1.7 cd/m^2.

PCDETECT, m_3 is used for values of L_b equal to or greater than 3.8 fL and m_4 is used for smaller values.

The analytical expressions for m_3 and m_4 provided by Blackwell in CIE 19/2.1 are as follows:

$$m_3 \begin{cases} \text{Age} < 44\text{:} & m_3 = 1.000 \\ \text{Age } 44\text{–}64\text{:} & m_3 = 1.000 + 0.0301\,(\text{age} - 44) \\ \text{Age} \geq 64\text{:} & m_3 = 1.620 + 0.0725\,(\text{age} - 64) \end{cases}$$

$$m_4 \begin{cases} \text{Age} < 44\text{:} & m_4 = 1.5 \\ \text{Age } 44\text{–}64\text{:} & m_4 = 1.500 + 0.0419\,(\text{age} - 44) \\ \text{Age} \geq 64\text{:} & m_4 = 2.338 + 0.0668\,(\text{age} - 64) \end{cases} \qquad (14)$$

In the older procedure, the veiling glare (B_v, as calculated by Equation 13a) is added to the denominator of the contrast expression (Equation 2a). PCDETECT follows the newer procedure of calculating a disability glare factor, which is subsequently used as a contrast multiplier. This gives the same results mathematically as the older procedure. The disability glare factor (DGF) is then given by

$$DGF = \frac{L_b}{L_b + vbf \times B_v} \qquad (15)$$

where vbf is the veiling brightness factor, given by

$$\theta < {}^1\!/_2 \; vbf = 30.0$$

$${}^1\!/_2 < \theta < 1 \; vbf = 59.0 - (58.0)\theta$$

$$\theta > 1 \; vbf = 1.0$$

and θ is the glare angle.

The basis for the veiling brightness factor is discussed below.

Glare at Small Angles

In the original version of DETECT, the threshold contrast for delineation targets is increased by a factor of 30 whenever glare from an opposing vehicle is present. This field factor is applied in addition to the veiling glare effect. This adjustment was necessary to reconcile predicted seeing distances with the actual seeing distances obtained in the Ford research (*1*). In the field research, center lines were the only delineation targets studies with glare, and the glare source used with this target was a pair of high beams. The combination of a small glare angle and intense glare source makes this a very severe glare condition. Nevertheless, in DETECT the 30-fold adjustment factor is used for all delineation targets when glare is present, no matter how distant or dim the glare source and no matter where the target is located laterally. No such field factor was needed in DETECT for pedestrian targets seen against glare; the veiling glare algorithm was sufficient.

The need for the adjustment factor for delineation probably is because of the small glare angle. Unfortunately, the available glare algorithms are not valid for glare angles less than about 1. It is difficult to study glare effects at small angles and the available research does not address glare angles below 0.75. Evidently, the effect can be considerable at small angles, as the Ford field research indicates.

Based on these considerations, PCDETECT uses a somewhat different procedure. The assumptions are made that (a) the additional visual task difficulty represented by the field factor is due to small glare angles and (b) the effect should be expressed as an increase in B_v rather than as a contrast multiplier. Accordingly, a veiling brightness factor is used that has the value of 1.0 for glare angles larger than 1 and 30.0 for angles less than 0.5 with a linear ramp between 0.5 and 1. This is the algorithm shown in Equation 15. At low glare angles and high levels of B_v, this algorithm produces about the same effect as the 30-fold contrast multiplier used in DETECT.

Calculating the Visibility Level

Visibility level (VL) is defined as

$$VL = C/C_{\text{th}} \qquad (16)$$

where C is the actual contrast between the target and its background and C_{th} is the threshold contrast as predicted, for example, by Equation 3.

This form is correct only for a 20 yr old, 50th percentile observer with no glare. To take age, percentile, and glare into account we need to apply the contrast multipliers described above, as follows:

$$VL = 1/m_1 \times 1/cmp \times DGF \times C/C_{\text{th}} \qquad (16a)$$

This is the expression used in PCDETECT. When $VL = 1$ the object is by definition at the borderline of detectability or legibility. At higher values of VL the object becomes increasingly visible. Under a given set of conditions, an observer is increasingly likely to detect it or, in the case of sign elements, to find it legible.

The threshold contrast values predicted by Equation 3 represent laboratory conditions and may under- or overpredict the contrast required for reliable detection under field conditions. Some field adjustment factor will probably be necessary to apply the prediction to conditions involving more complex tasks and distractions of a real-world environment. The PCDETECT input menus allow the user to supply such a field factor in the form of a criterion visibility level (CVL), which differs from the nominal visibility level of 1.0 by some multiple. In order for the target to be regarded as detectable, the value of *VL* would have to be equal to or greater than *CVL*, i.e., detection takes place when $VL = CVL$. A *CVL* of 2.0, for example, would mean that the target is regarded as being visible when the contrast is twice the threshold contrast.

DETECT builds in field factors to reconcile calculated seeing distances with the actual seeing distances measured in Ford's field research (*1*). A factor of 0.2 is used for pedestrians. This means that the threshold contrast for pedestrian targets is ⅕ as great as that predicted by the 1952 1/30-sec Blackwell curves (*2*). In PCDETECT, this field factor is built into the target size scaling algorithm given in Equation 6. An additional field factor of 0.2 is applied for delineation targets in both versions of the model, i.e., delineation targets require 1/25 the contrast predicted by the 1/30-sec curves for threshold visibility.

ROAD GEOMETRY

PCDETECT has a revised set of road geometry routines for dealing with horizontal and vertical curvature. These routines determine the locations and orientation of the target, the observer, and the observer and glare vehicle lamps with respect to a common coordinate system to calculate headlamp illumination levels and glare. Horizontal and vertical curvature are specified off-line by the user in a file that is referenced as part of the input process. The information can be taken directly from highway engineering blueprints.

PCDETECT also includes a routine for checking lines of sight over hill crests to determine when a crest vertical curve obscures an observer's view of the target or cuts off the line of sight from headlamps to the target or from a glare source to the observer.

INPUT CONDITIONS AND THE PCDETECT USER INTERFACE

PCDETECT allows a very complete definition of the roadway visibility environment. This is necessary because there are many factors that influence seeing distance and thus need to be taken into account. The user must specify the headlamp beam patterns and configuration of the observer and glare vehicles; the characteristics of the driver; the geometry of the roadway, including lane geometry and horizontal and vertical curvature; the nature, characteristics, and location of the target on the roadway; and ambient luminance and reflectance values. Altogether there are more than 40 parameters that must be specified. One of the major objectives in developing PCDETECT was to make it easy to create, save, retrieve, and modify the input conditions for a given model run or series of runs. PCDETECT accomplishes this via a menu-driven user interface. This interface allows the user to create a new data set or retrieve a previously created set from disk storage. When creating an input data set, the user is lead through a series of input menus that provide reasonable default values for most of the parameters. Figure 10 is an example of such a menu. The user has the option of accepting the default values or entering new values. A new or old input data set can be run, modified, run again, and/or saved at the option of the user. One option is to develop a disk file with multiple input data sets. This allows the user to create and save a series of systematically modified input data sets in the same disk file. When the user elects to run this file, all of the input data sets will be run, one after the other.

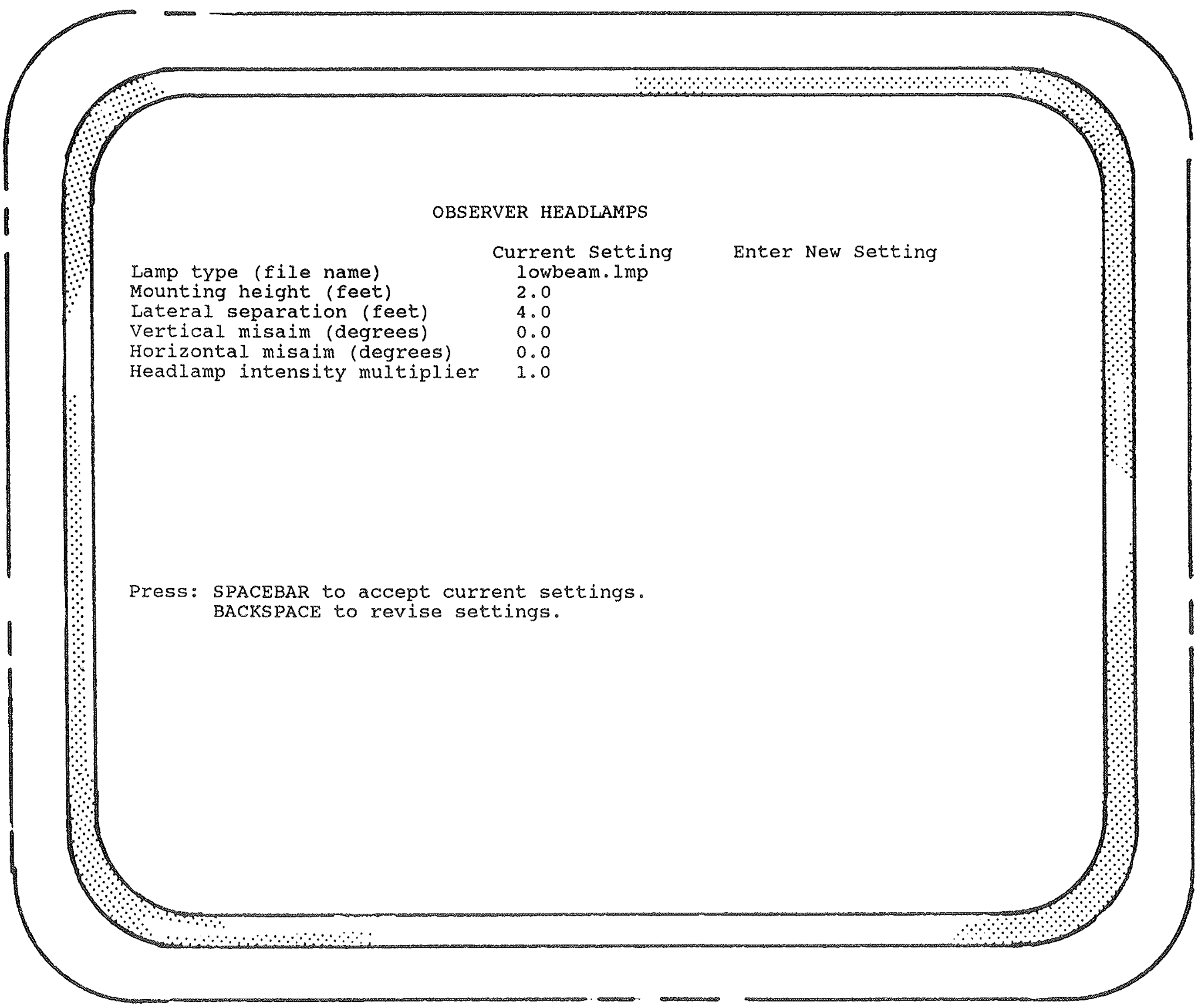
OUTPUT

At present, all output from PCDETECT is directed to the screen. Figure 11 is an example of the output. This screen is displayed with each distance iteration as the observer car is moved back and forth in search of the threshold. The screen displays the current estimate of the seeing distance, values for target and glare candlepower, the visibility level, veiling glare, and other parameters. The user is prompted after each iteration for a keypress to continue. Distance iterations continue until the visibility level differs from the criterion visibility level by less than 2 percent *or* the current seeing distance estimate differs from the previous estimate by less than 2 ft.

SEEING DISTANCE PREDICTIONS WITH THE ORIGINAL AND REVISED ALGORITHMS

Model runs were made using the old and revised algorithms to calculate seeing distances to a 100-ft long, 4-in wide pavement line having a contrast of 1.0 with the pavement. The runs were made at different illumination intensity levels. A 20-yr-old observer was assumed. Both left-lane edge and right-lane edge lines were modeled. At the same distance, the incident candlepower is about four times higher on the right-lane edge than the left. The results are shown in Figure 12. In general, the correspondence between the two sets of predictions is very close. At high relative intensities, the older algorithm predicts somewhat longer seeing distances than the revised version, but the reverse holds at lower intensities. This is consistent with the difference in the contrast sensitivity curves as shown in Figure 4. The newer algorithm gives lower thresholds at low luminance levels for targets approximately 10 min or larger. The line target studied has an equivalent size of 10 min at 210 ft.

The model was run with the new algorithm to show the sensitivity of seeing distances to glare, age, and percentile level. The results are shown in Figure 13, which shows seeing distances, with and without glare, as a function of age for drivers with 15th and 50th percentile contrast sensitivities. The target was an 8 percent reflectance pedestrian, located 1 ft to the left of the right-edge line, and the glare vehicle was at 300 ft. Seeing distances declined with age, with the rate of the decline increasing with age. The decrease in seeing distances from age 20 to age 70 ranged from 45 percent to 59 percent under the four conditions. The aggregate effect of age, glare, and percentile level is considerable. Under the conditions simulated here, seeing distance ranges from 413 ft for a 50th percentile, 20-yr-old driver without glare to 130 ft for a 15th percentile, 70 yr old with glare. The rate at which seeing distance decreases with age is greater without glare, despite the fact that glare sensitivity increases with age. The reason is that the effect of glare is less at greater background



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                         OBSERVER HEADLAMPS

                              Current Setting     Enter New Setting
Lamp type (file name)           lowbeam.lmp
Mounting height (feet)          2.0
Lateral separation (feet)       4.0
Vertical misaim (degrees)       0.0
Horizontal misaim (degrees)     0.0
Headlamp intensity multiplier   1.0




Press: SPACEBAR to accept current settings.
       BACKSPACE to revise settings.
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FIGURE 10 PCDETECT input menu for headlamp characteristics.

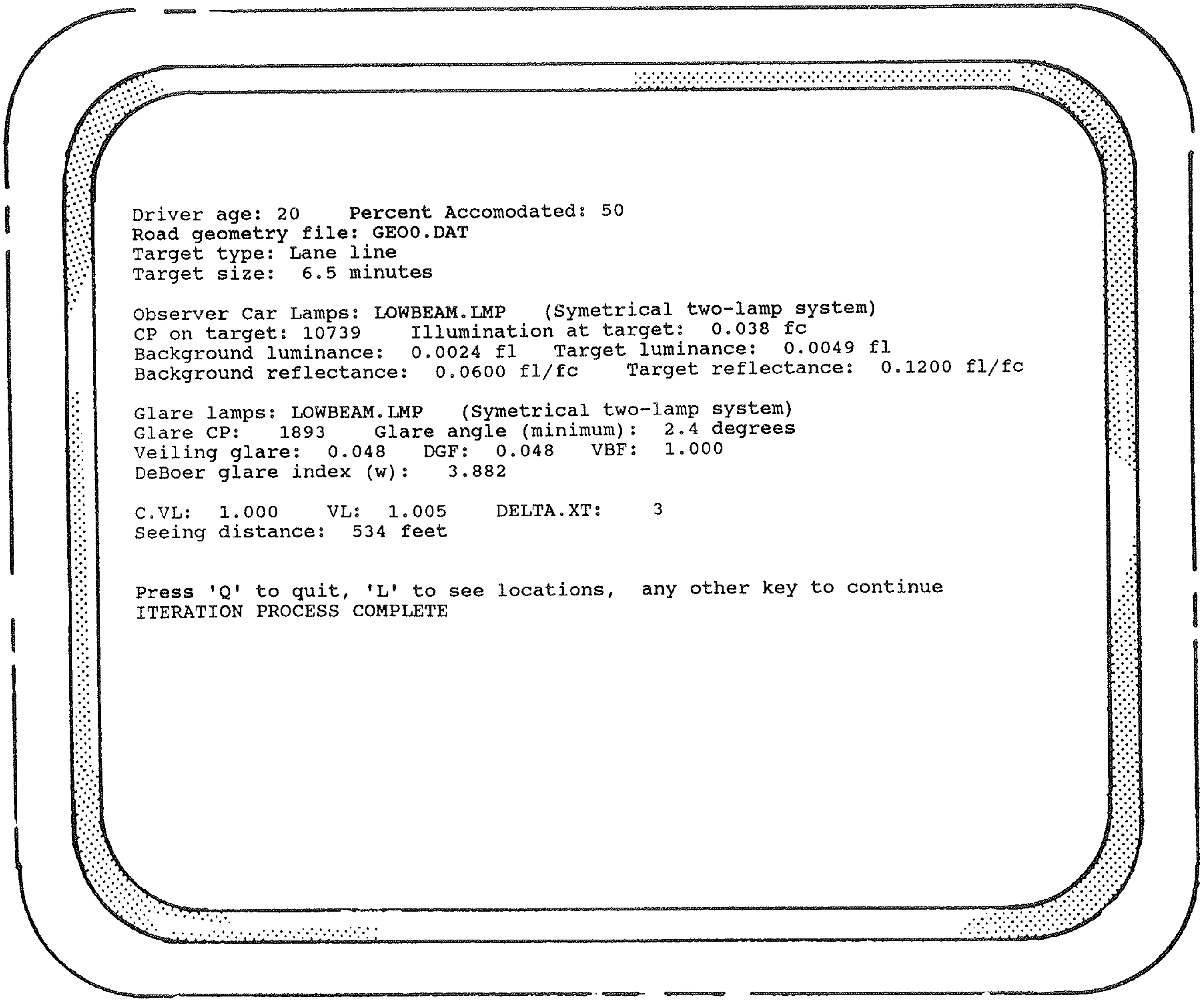
brightness levels and glare angles than at shorter seeing distances.

VALIDATION

Blackwell's contrast sensitivity paradigm was applied to night vision with headlamps and validated in a general way in the Ford research mentioned earlier (*1*). In that study, seeing distances to delineation and pedestrian-shaped targets were determined in nighttime field research and compared with predicted seeing distances based on the Blackwell formulations. The various field factors and adjustments discussed above were used to tune the DETECT model. Further fine tuning of DETECT was done by selecting target definitions that gave the best fit to the data. Once these adjustments were made, the correspondence between field data and predicted seeing distance values was good, with the predicted values generally falling within one standard deviation.

PCDETECT has not been validated in a separate field study. However, PCDETECT was "tuned" to give results close to those of DETECT in situations common to both models.

We believe that the DETECT and PCDETECT algorithms based on this research are accurate enough to be useful. However, it has been approximately 14 yr since the Ford validation study was conducted and that research was not extensive. For example, only 12 subjects of varying ages were used in the study; target and background luminance values were estimated rather than measured for some targets; and the range of test conditions studied was very limited. Seeing distance to pavement lines against glare was measured only for the center line and against high beams as the glare source. In analyzing the results, the average performance of the 12 subjects was used and no attempt was made to account for age effects. Subjects were not "calibrated" to determine their contrast sensitivity in a laboratory setting. As Figure 5 shows, age effects and individual differences in contrast sensitivity are substantial. For all of these reasons, we believe that addi-



```
Driver age: 20    Percent Accomodated: 50
Road geometry file: GEO0.DAT
Target type: Lane line
Target size:  6.5 minutes

Observer Car Lamps: LOWBEAM.LMP   (Symetrical two-lamp system)
CP on target: 10739    Illumination at target:  0.038 fc
Background luminance:  0.0024 fl   Target luminance:  0.0049 fl
Background reflectance:  0.0600 fl/fc    Target reflectance:  0.1200 fl/fc

Glare lamps: LOWBEAM.LMP   (Symetrical two-lamp system)
Glare CP:   1893   Glare angle (minimum):  2.4 degrees
Veiling glare:  0.048   DGF:  0.048   VBF:  1.000
DeBoer glare index (w):   3.882

C.VL:  1.000    VL:  1.005    DELTA.XT:    3
Seeing distance:  534 feet


Press 'Q' to quit, 'L' to see locations,  any other key to continue
ITERATION PROCESS COMPLETE
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FIGURE 11 Example of PCDETECT output screen.

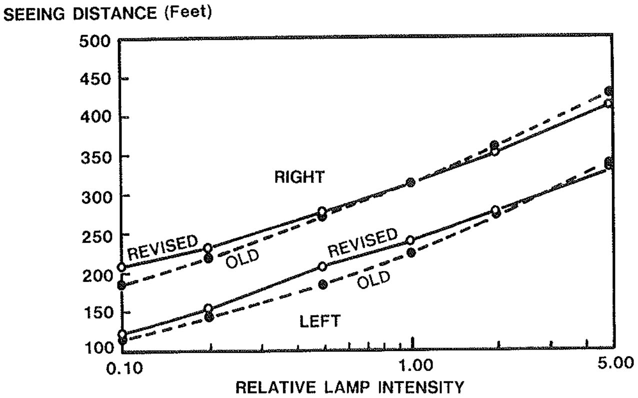

FIGURE 12 Seeing distance to left- and right-side lane lines as a function of lamp intensity using old and revised algorithms.

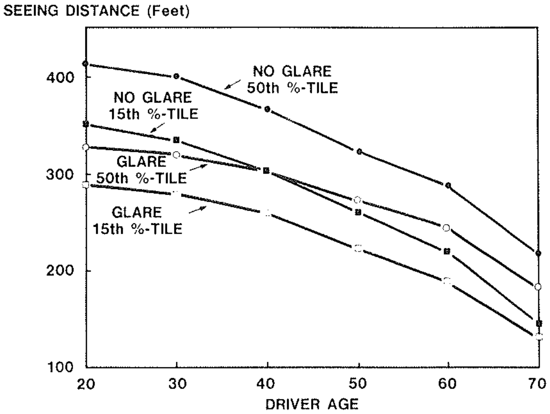

FIGURE 13 Seeing distance as a function of age with and without glare for 50th and 15th percentile drivers.

tional work is needed to substantiate more thoroughly the field factors and assumptions used in both DETECT and PCDETECT.

We would very much like to see other organizations with an interest in headlamp seeing distance models address some of these issues. It is probably not necessary to use large subject sample sizes or to engage in extensive nighttime field work. A more efficient alternative is to use a smaller number of carefully "calibrated" subjects, that is, observers whose contrast sensitivity has been established in the laboratory. Some of the issues can be addressed in detail in the laboratory and the results validated subsequently in the field. An example of such an issue is defining the equivalent Blackwell target for pavement lines. Validation would then consist of demonstrating that there is a general transfer function for predicting field performance from laboratory data.

We will be happy to consult with researchers who have interests along these lines. We invite comments from all interested parties regarding our implementation of the Blackwell formulations and the algorithms based on them that are described here.

APPLICATIONS AND LIMITATIONS OF PCDETECT

PCDETECT (and the original version of DETECT) can determine the relative performance of different headlamp systems, expressed in terms of seeing distance, under some conditions. It can also determine the relative effect on seeing distance of varying such input parameters as misaim, glare intensity, driver age, and target reflectance. For such applications, it is sufficient to use representative or typical values of the fixed input parameters. However, PCDETECT cannot be used to calculate an accurate estimate of the seeing distance to a given object unless correct values for all of the parameters that define the target and viewing conditions are known, including the contrast sensitivity and glare susceptibility of the observer. Even with all important physical parameters held constant, the seeing distance for a given driver will vary from instance to instance because of underlying variability in sensory performance. Also, PCDETECT assumes a highly vigilant driver-observer, i.e., a driver who is looking for the visual target. Such high levels of vigilance are not sustained in actual driving. On the average, the seeing distance of a driver who has been alerted to look for a specific object is about twice that of a driver who is not expecting the object (*7*).

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PCDETECT is a copyrighted, proprietary Ford Motor Company program. Ford will make it available, under a licensing arrangement, to government agencies and other institutions and responsible individuals with an interest in headlamp and driver night vision research. We invite comment and suggestions with regard to the algorithms and the program structure described in this paper.

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