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DEVELOPMENT OF A HEADLIGHT SYSTEM PERFORMANCE EVALUATION TOOL

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16. Abstract

This report summarizes four investigations carried out to assist in the development and evaluation of a headlighting visibility model developed by NHTSA. In the first study the adaptation level of drivers was measured under various conditions. It was found that the levels calculated by the model are generally too low. In the second study data were developed on discomfort glare in order to obtain a more accurate estimate for use in the model.

In the third and fourth studies, comparisons were made between the visibility of pedestrian and delineation targets as measured in the field and predicted by the model. These results suggest that the model is reasonably accurate for pedestrian targets with drivers aged 35, but significantly in error for older drivers (65+). There was also a significant discrepancy in the case of delination targets. However, the data from the delineation studies were themselves quite inconsistent, so recommendations for corrections cannot be made with any degree of confidence.

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INTRODUCTION

This report describes several investigations that were undertaken to assess certain aspects of a headlamp visibility model developed at the National Highway Traffic Safety Administration (NHTSA). The model was developed as part of a program to prepare performance-based regulations for motor vehicle headlighting.

A detailed description of the model has been provided by NHTSA as part of a notice of proposed rulemaking issued May 9, 1989. In brief, the model considers speed as an input and calculates the candlepower that must be directed at pedestrian and delineation targets in order to render them visible at safe distances. Variations of the model consider hills and curves, glare from rearview mirrors, and the visibility of overhead signs.

The model must take into account a number of variables in making its determination of the candlepower required to reveal a specified target at a certain distance. The information on each of these varies from good to scanty. Since the performance of the model depends on the accuracy of this information, there is merit in having it as accurate as possible.

Four studies were carried out as part of this contract. The first of these measured driver adaptation. The model calculates a background luminance for the target and assumes that luminance value determines the level of adaptation. If this is significantly in error, it makes a difference in the predictions provided. There are no published data on driver adaptation, so an effort was made to measure it in this contract.

Discomfort glare is another model parameter of importance. Discomfort is modeled based on laboratory studies carried out several years ago. Other work, conducted under actual driving conditions, suggests that model may not be completely accurate. Thus, the second study was designed to provide improved predictions of discomfort glare.

The third study was an evaluation of the ability of the model to predict visibility distance of specified targets, as well as the threshold luminance values associated with that detection.

The fourth study was similar to the third, but looked only at the visibility of delineation.

THE MEASUREMENT OF ADAPTATION LEVEL

Introduction

Changes in levels of illumination result in changes in the eye generally known as "adaptation." These changes occur at the retinal level of the eye and are necessary to extend visual performance through a wide range of illumination levels. In fact, some vision is possible through approximately eleven log units of illumination. At the highest levels of illumination vision is by means of receptors in the retina known as cones. The cones function from illumination levels somewhat in excess of 10,000 ft-Lamberts (approximating fresh snow in bright sunlight) at the maximum to about 0.001 ft-Lambert (about equal to average earth under a full moon). At the lowest levels of illumination vision is by means of receptors known as rods. The rods function from about 3 ft-Lamberts (about equal to a piece of white paper held one foot from a 3 cp source), down to about 0.000001 ft-Lambert (about equal to earth in starlight). Note that there is an area of overlap where both rods and cones are functioning, extending from about 3 ft-Lamberts to about 0.001 ft-Lambert.

The driver's level of adaptation is a significant parameter in the NHTSA headlighting models. In the models, adaptation is assumed to be controlled by the luminance of the background of the target object. Thus, it varies with vehicle speed and target reflectivity. For example, using a 12% pedestrian target, the adaptation level is assumed to be 0.040 ft-L at 25 mph, and 0.065 ft-L at 35 mph.

The importance of adaptation lies in the way it affects other components of the models. For example, if the eyes are adapted to a higher level than assumed, the sensitivity of the eyes will be altered in such a way that more illumination must be directed toward the target in order to render it visible. In addition, adaptation is a component in the discomfort glare equation. Again, if actual adaptation is different than assumed in the models, more or less glare will be required to reach a given level of discomfort. If the glare level is changed to match a discomfort criterion, this will have an effect on disabling glare. For example, if adaptation is higher than assumed, this will result in an increase in glare to maintain the same discomfort criterion. The increase in glare will reduce the subject's ability to detect the target, requiring that more illumination be provided in order to maintain a given detection distance. The increase in glare will probably affect the driver's adaptation level as well. However, the effect of glare on adaptation is not considered in the models.

There is no information on driver adaptation level in the literature. Therefore, it was decided to take measurements for this project. The effort started with measurements under certain standard conditions of interest, and was extended to the special conditions of the field validation scheduled for later in the project.

Method

The level of adaptation has an effect on the luminance required of a target object to make it visible to the observer. That is, as one adapts to increasing levels of illumination, the luminance required of a target object to keep it just visible must be increased as well. This principle was used to calibrate a threshold target detection device for a single observer in a laboratory. The device was then taken into the field and used to measure the adaptation of the same individual under the conditions of interest.

The use of a single subject in this work is entirely appropriate. There is no inference that his threshold performance in any way represents that of the rest of the driving population. In effect he was part of an instrumentation package, calibrated in the laboratory, and used in the field to obtain estimates of adaptation level. The use of another individual, or a number of other individuals would have produced a different threshold, but that threshold would be the same in the laboratory and in the field at the same level of adaptation.

Equipment

A schematic of the threshold-measuring device is shown in Figure 1. It was a metal enclosure housing a four-inch-diameter, sealed-beam, 12-volt spot lamp. Two pieces of white plastic were placed in front of it to act as dispersion filters. The front of the unit was closed off except for an opening the size of a 35 mm slide, which constituted the "target" for the subject. Neutral-density filters in 35 mm slide mounts could be inserted in front of the opening and were used to adjust the luminance of the detection task. The whole unit was painted flat black. A shield about two feet long was provided around the device, to prevent illumination from car headlamps, etc. impinging directly on its face. Voltage to the lamp was continuously monitored using a digital voltmeter.

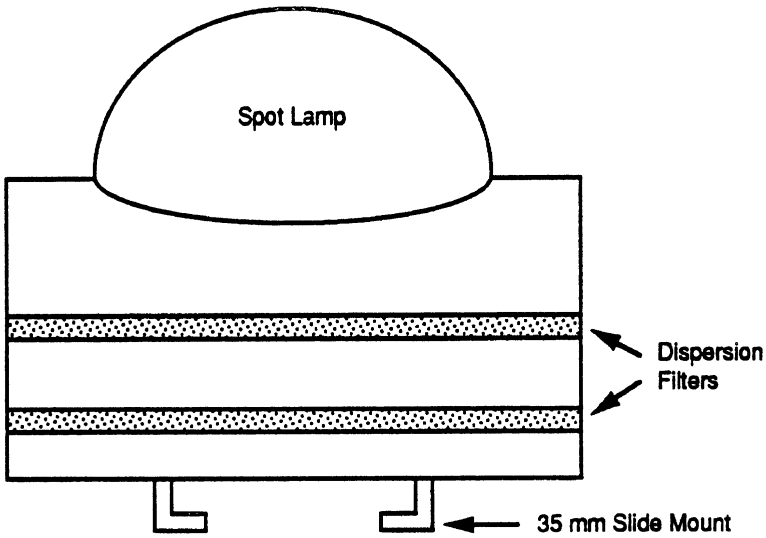

Figure 1. Schematic of threshold detection device.

A series of neutral density filters was prepared. These were evaluated over a period of time, seeking a set that would span the desired range of adaptation, with a spacing between each that would give reasonable accuracy without creating excessive noise in the data. The final set consisted of eleven slides. The percent transmission of each, and the luminance of the surface presented to the subject is shown in Table 1.

Table 1. Description of Neutral Density Slides Used in Dark Adaptation Study

Filter Number	Percent Transmission	Luminance (Ft-L)
1	0.38	0.84
2	0.73	1.61
3	1.10	2.42
4	1.55	3.41
5	2.08	4.58
6	2.79	6.16
7	4.07	8.96
8	5.21	11.65
9	7.01	15.44
10	10.36	22.83
11	12.89	28.40
No Filter	100.00	220.37

Procedure

The threshold task was used with a single subject (one of the experimenters). The first step was to give that subject sufficient practice time with the device to reduce error variance to the lowest level possible. This was done while selecting the set of neutral density slides.

The next step was to calibrate the device, relating its luminance to the adaptation level of the subject. The calibration was done in a laboratory, using a large, gray screen (12 feet wide by 8 feet high). The screen was placed twenty feet from the subject, and uniformly illuminated at 0.005, 0.01, 0.1, 1.0, or 2.0 ft-L to establish the adaptation level. Care was taken to ensure that no other surfaces within the range of vision of the subject had greater luminance. The threshold device was placed in front of the screen, about one foot below the subject's eye height, with its face shielded from direct illumination by the light source. The bulb was driven at 12.8 volts by a regulated power supply. Neutral density filters were inserted in a random order and exposed to the subject, who reported the target as "seen" or "not seen." At each of the adaptation levels noted earlier, the threshold was established in the conventional way as the target luminance level at which the probability of a report of "seen" was 0.5. These data were used to generate the curve shown in Figure 2, which defines the relationship between source luminance and adaptation luminance for this subject.

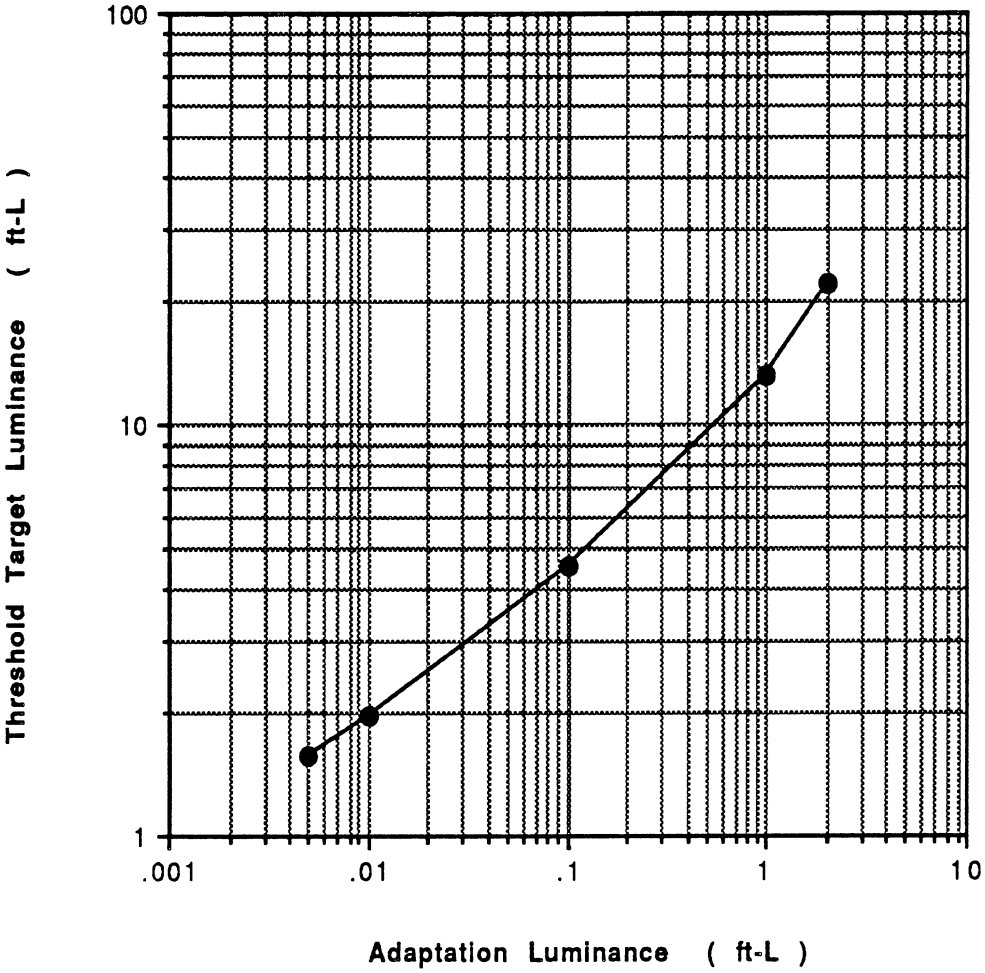

Figure 2. Relationship between threshold visibility of target detection task and level of adaptation.

To take data in the field the threshold device was placed approximately 20 feet in front of the subject, who was seated in a car. The height of the instrument was such that it was about on line with the horizon. A second vehicle, provided with precision voltage control equipment, was used to drive the bulb at 12.8 volts. This car was placed off the road to the subject's right, and covered with a large, black sheet. Neutral density filters were placed in the threshold device in a random order and exposed to the subject, who reported the target as "seen" or "not seen," just as in the calibration sessions. Between trials the subject looked up the road at the horizon level. The source luminance at which the probability of a "yes" response was approximately 0.5 was taken as the level of adaptation.

A total of five tests were run. These can be described as follows:

a. No illumination. This test was run at the site at which data were collected for the validation of the NHTSA models (see chapter headed "Field Validation Study.") The road is situated in a rural area. It is very dark, with no significant sources of illumination, signs, or other distractions. All lamps on both vehicles were extinguished.

b. Low beams. This test was run at the same site as the first test, with the low-beam headlamps of the vehicle in which the subject was seated turned on.

c. High beams. The conditions were identical to test a and b, except that the high beams were used.

d. Shielded foreground. To see what effect foreground illumination had on dark adaptation, this test was run with low-beam headlamps as in test b, except that the subject held a shield in front of his face so that the foreground (i.e., the relatively highly illuminated area immediately in front of the vehicle) could not be seen. The shield was positioned so that the threshold target, and the roadway environment about 200 feet and more ahead of the subject were still in the field of view.

e. High-luminance surround. This test was conducted in an area that had a high level of fixed illumination. The installation had been in place for about a year, and used high-pressure sodium vapor sources. It is representative of a quality installation, having relatively high levels of i illumination and minimum variation in illumination levels. The vehicle in which the subject was seated used low beams.

Results

The adaptation levels measured for the various conditions were as follows:

Condition a (no illumination): 0.005 ft-L
Condition b (low beams): 0.3 ft-L
Condition c (high beams): 1.7 ft-L
Condition d (shielded foreground): 0.2 ft-L
Condition e (high luminance surround): 1.5 - 2.0 ft-L (approximate)

Unlike the other conditions, the high-luminance surround presented problems in data collection, and a clean threshold was not obtained. Hence, the level shown above is labeled "approximate."

The adaptation levels shown do not include the effect of glare from oncoming vehicle's headlamps. Other work has been reported (Olson and Aoki, 1989) describing the effect of glare on adaptation. This investigation used the same subject and equipment as the one described here, except that the dependent measure was readaptation time after the glare had been extinguished.

The findings of this study are that the adaptation level in the presence of a glaring vehicle about 100 feet distant, on low and high beams, is about 5 and 20 ft-L respectively.

Discussion

The adaptation levels measured in this study, coupled with those reported by Olson and Aoki with glare, provide some indication of the range of levels to which the eye must adjust in normal driving. The measured adaptations also indicate that the levels calculated in the NHTSA models are low. They are far enough off in the case of the pedestrian target to make a significant difference in the predicted levels of illumination. This issue will be discussed further in a later section of this report headed "Field Validation Study."

A key question is how and to what extent the adaptation data reported here can be utilized in the NHTSA model. In essence the work reported here provides information on adaptation level at two illumination levels. To the extent that the illumination required to reveal a specific target falls within or near the range studied these data can be used to approximate the adaptation level.

FIELD DISCOMFORT GLARE EVALUATION

Introduction

The most important work on discomfort glare in the context of vehicle headlamps is that of Schmidt-Clausen and Bindels (1974). This was a laboratory study in which glare intensity, glare angle, and level of adaptation were varied. Subjects were given brief (one second) exposures to fixed levels of glare, and assessed discomfort using a rating scale originally described by deBoer (1973). This is a 9-point scale as follows:

1. Unbearable
2.
3. Disturbing
4.
5. Just Acceptable
6.
7. Satisfactory
8.
9. Just Noticeable

The investigation led to the development of a mathematical model of glare discomfort, one version of which is given below:

$$W = 2 \log 10 (1 + \sqrt{85.66\ L}) - 2 \log 10 (\Sigma\ E_i/T_i 0.46) - 2.1097$$

Where:

W = Glare rating on the deBoer scale
L = Adaptation luminance in foot-Lamberts
E_i = Glare illuminance from the ith source in foot-candelas
T_i = Glare angle from the ith source in minutes

In reviewing the results of the Schmidt-Clausen and Bindels study two questions arise that may affect the interpretation of the data. One of these is whether Americans, who are exposed to higher levels of glare while driving due to the type of headlamps used in this country, would rate glare the same way as the European subjects of Schmidt-Clausen and Bindels. To address this question Olson and Sivak (1983) carried out a laboratory study that replicated one of the conditions tested by Schmidt-Clausen and Bindels. They found that their US subjects rated the same levels of glare more comfortable than did the European subjects. (Note: the 1983 report indicates that the ratings of the two groups were the same. This is not correct.) Olson and Sivak's corrected results are shown in Figure 3. In mid-range, the difference between predicted (based on the Schmidt-Clausen and Bindels equation) and measured discomfort values for the full-range stimulus set was about one deBoer unit. A possible explanation for this difference is that Americans are more tolerant of glare than are Europeans, perhaps because they are exposed to higher levels while operating an automobile. To follow up on this issue, Sivak, Olson and Zeltner (1988) carried out a field study of discomfort glare specifically to compare ratings provided by American subjects (students at the University of Michigan) and Europeans who had recently arrived to study at the University. The European subjects rated the same levels of glare as being more uncomfortable than did the American subjects. The difference averaged 0.7 deBoer unit over the range of glare values used, and was about one deBoer unit in mid-range, the same difference found in the laboratory study.

The other question concerning the Schmidt-Clausen and Bindels study grows out of the fact that it utilized a methodology that was a relatively poor simulation of the way glare is actually experienced during a typical meeting with another vehicle. To investigate this issue Olson and Sivak (1983) carried out a field study of discomfort glare in which the subjects sat in a stationary vehicle while vehicles with glare lamps were driven by them. Calculated ratings were based on the glare intensity and angle associated with a 100-foot separation, which was determined to give about the lowest deBoer value. The results of this study are shown in Figure 4. The difference between predicted discomfort ratings and those obtained from the subjects in this study is 2.5 to 3.0 deBoer units in mid range. The predicted performance line, however, is based on an adaptation level of 0.01 ft-L, which was assumed to be reasonable by the authors. If a dark adaptation level of 0.3 ft-L is used instead (as suggested by the results of the dark adaptation study described in the first chapter of this report) the prediction improves considerably, and is actually quite close to the empirical results at the extremes. In mid range there is still a discrepancy of 1.5 to 2.0 deBoer units.

The field study by Olson and Sivak, while a better simulation of real-world glare encounters than the laboratory approach, is deficient in that only the glare vehicles were moving. Sivak, Olson and Zeltner (1988) used an opposite approach, with the glare vehicle stationary and the subjects moving. The test protocol, however, used two glare exposures on each run. These came at different distances and were often at different levels. Hence the results cannot be directly compared with the 1983 study. It was felt necessary to carry out a fully dynamic study, simulating a typical meeting with another vehicle, in order to develop adequate information about discomfort glare for modeling purposes.

Method

Independent Variables

Glare levels. In the primary study five levels of glare were used, plus one asymmetrical system that was intended to simulate badly misaimed headlamps. Glare was provided by a pair of 6052 (large rectangular, non-halogen) headlamps on high beam. Neutral density filters were placed in front of the lamps to alter the intensity directed toward the subjects.

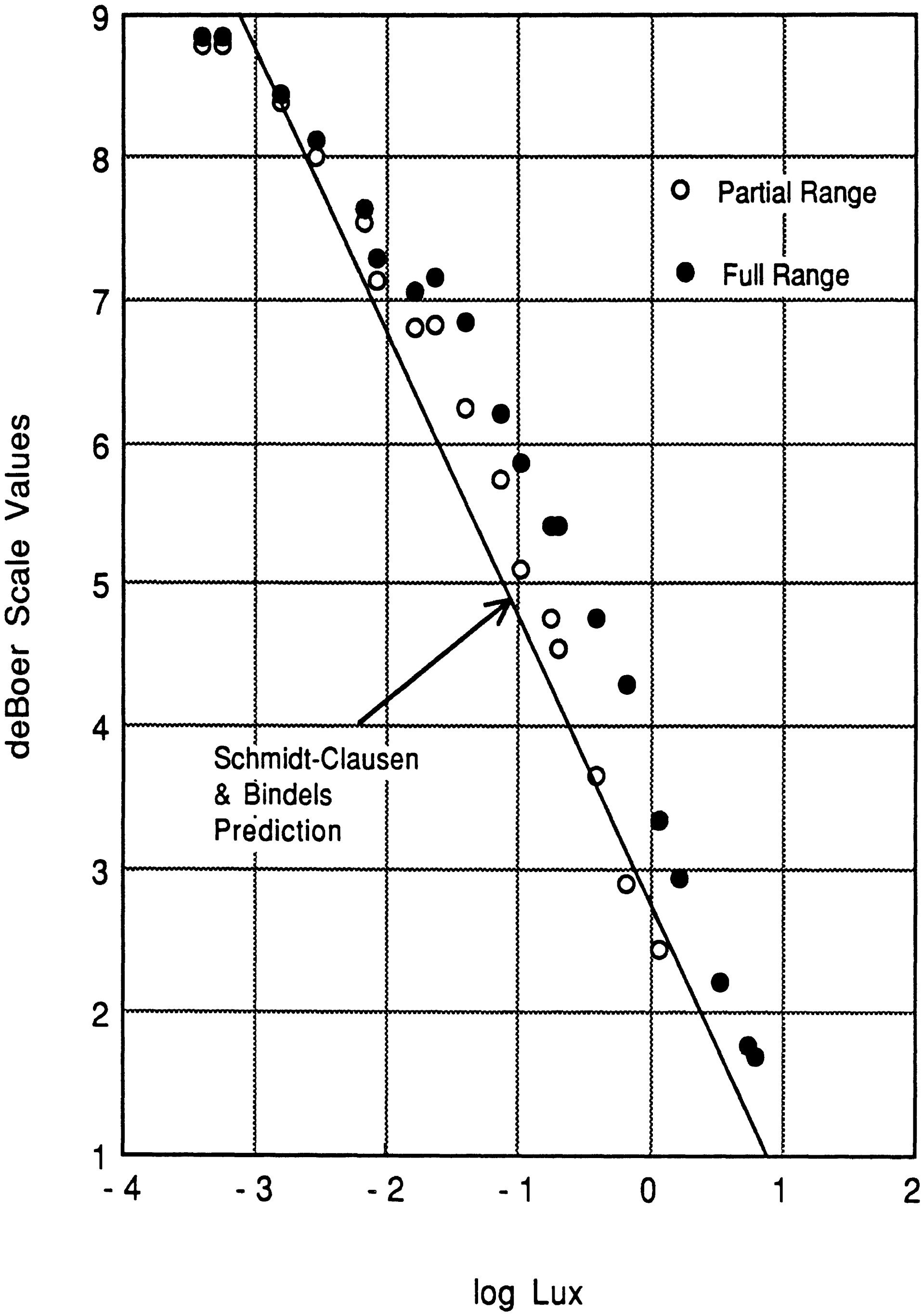

Figure 3. Results of Laboratory Discomfort Glare Evaluation
From : Olson and Sivak, 1983

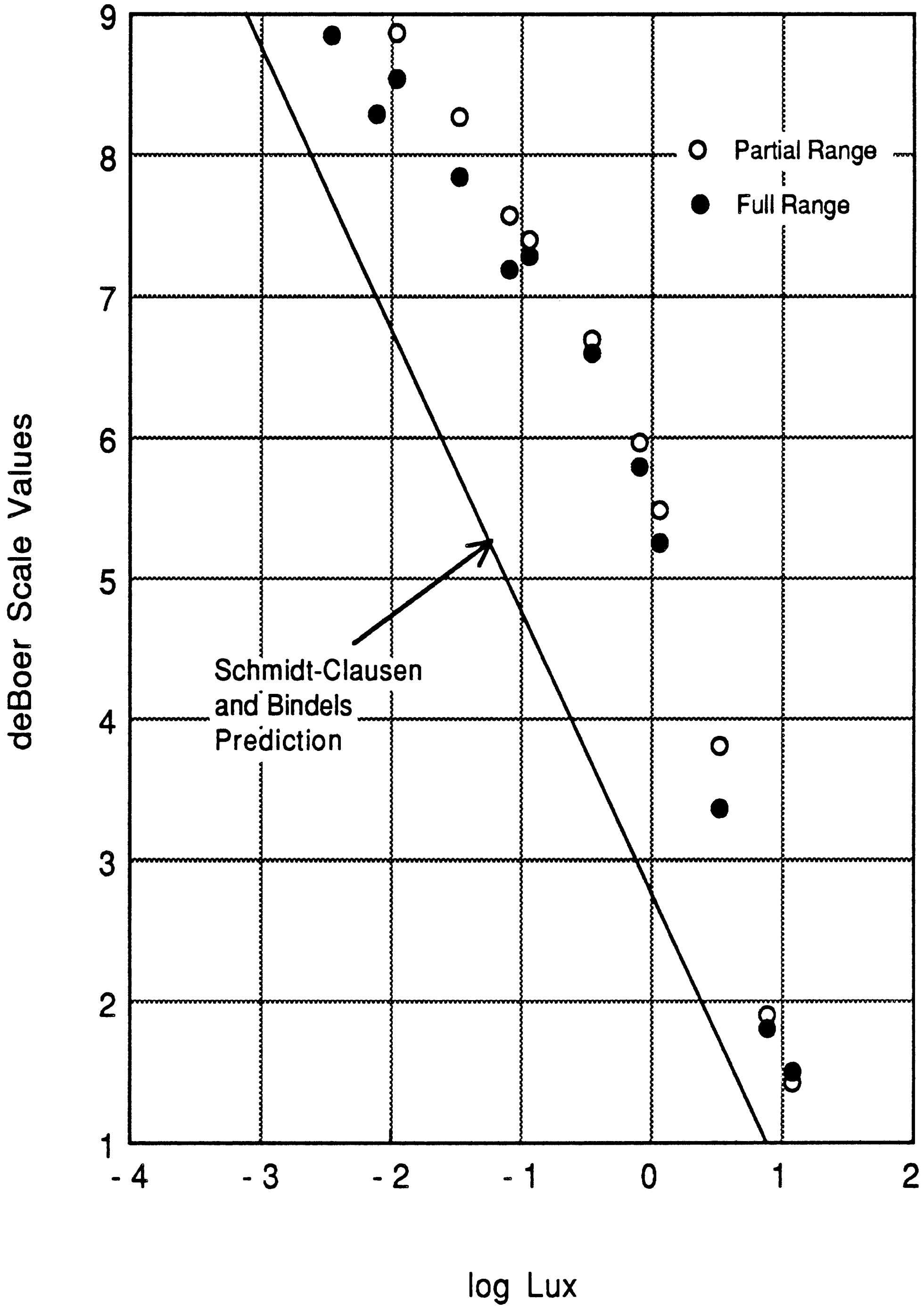

Figure 4. Results of Field Discomfort Glare Evaluation
From : Olson and Sivak, 1983

Measures were taken of the glare levels at the subject's eyes at various separation distances out to 1,500 feet. To take these data the glare car was carefully aligned so that its long axis was parallel with the road, and its transmission was placed in park. The subject vehicle was moved to the furthest measurement position, and also parked. An experimenter in the subject vehicle held up the sensor plate of a lux meter in a position corresponding to the eyes of a subject seated in the middle of the front seat and noted the reading. This was repeated for all of the glare levels. The car was then moved to the next closer position, and the process repeated. These data are shown in Figure 5. The maximum curve represents the unfiltered high beams. The asymmetrical system was created by using a number 4 filter on the passenger side of the glare car and a number 2 filter on the driver's side.

Direction of gaze. Three levels. In the primary study the subjects were asked to look directly up the road in the lane occupied by their vehicle. Additional data were collected (1) while the subjects looked directly at the headlamps (using all but the number 4 filter and the asymmetrical system), and (2), while they looked toward the right edge of their lane (using filter 1 and filter 3).

Replications. Three replications of each glare situation were used in the primary study and the portion where subjects were required to look toward the right edge of the lane. Two replications were used in that portion of the study in which the subjects were required to look directly at the glare lamps.

Subject age. A total of 30 subjects participated in the study. Half of these were young (i.e., 30-40 years of age), and half older (i.e., 65-77 years of age).

Dependent Variables

The primary dependent measure throughout this study was ratings of glare discomfort using the deBoer scale described earlier. In addition, in that portion of the study in which subjects looked directly at the glare lamps, they were asked whether they would be willing to look at those lamps to determine whether the car was showing a turn signal, "yes" or "no."

Equipment

The glare car was a full-size station wagon, fitted with a light bar across the front. On the light bar was mounted the test headlamps and filter holders. The lamps were driven by a system that allowed control of voltage to the filament accurate to within 0.05 volt. This system was used to keep the lamps operating at 12.8 volts.

The subjects rode in another full-size station wagon, along with an experimenter. This car was operated on its standard low-beam headlamps at all times. Both cars were equipped with two-way radios.

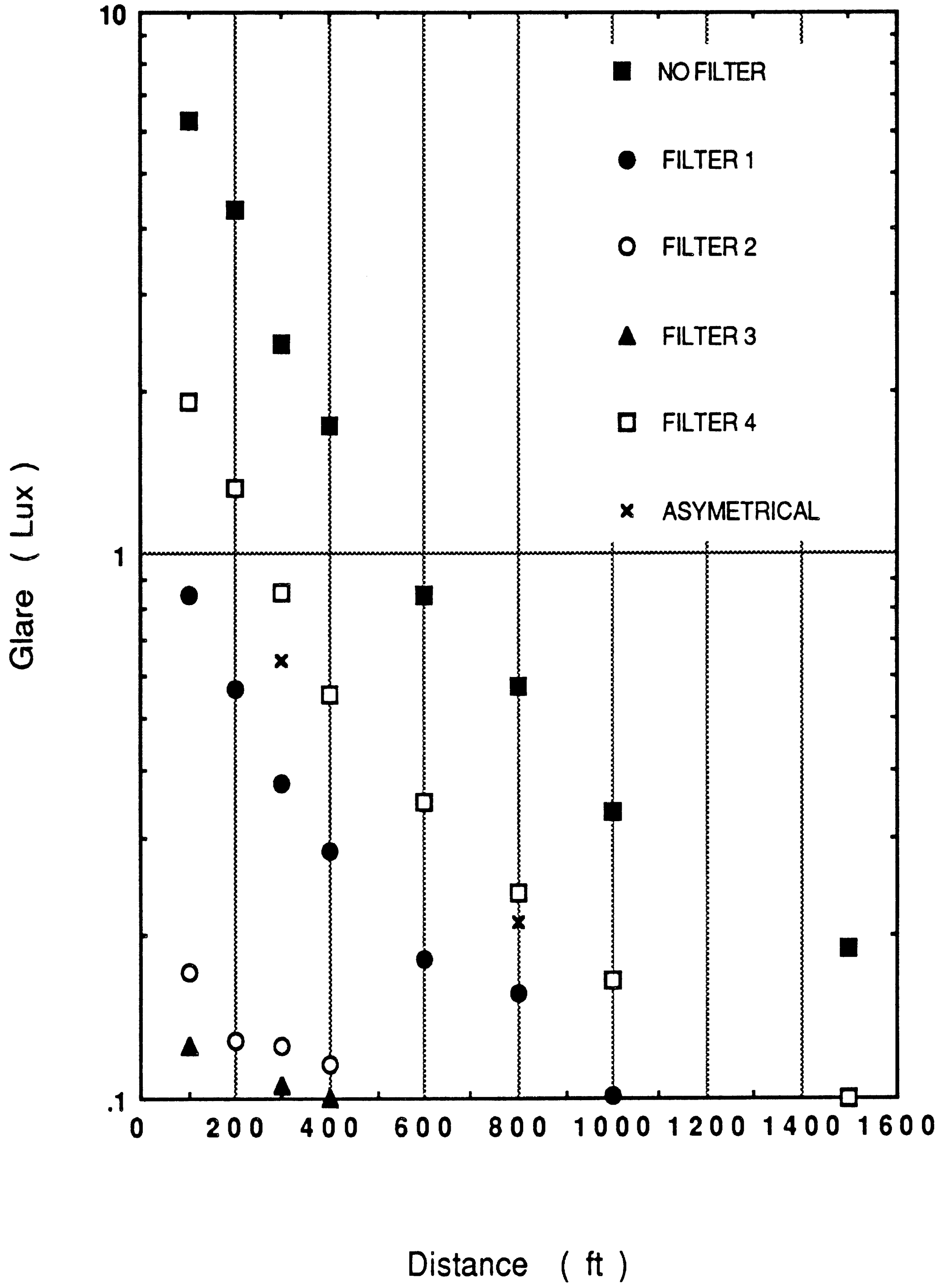

Figure 5. Glare Measured at the Subject's Eyes for Various Levels in the Field Discomfort Evaluation

Subject Screening

The subjects were screened using two low-luminance tests prior to participating in the field study. In the first of these, subjects were administered a test of threshold target luminance in the presence of glare. As expected, the results indicated an age difference. The mean threshold of target luminance (in $\log_{10}$ ft-L) was 0.21 and 0.81 for the young and old groups respectively. The second test required that the subjects provide ratings of glare discomfort, using the deBoer scale, for eight levels of glare presented for one second each. These results are shown in Figures 6-1 and 6-2. The solid diagonal line in each chart represents results expected based on application of the Schmidt-Clausen and Bindels model. The dashed diagonal line is a fit to the empirical data. The 0.77 and 0.76 notations on the lines fitted to the young and old data respectively represent the exponent that must be applied to the glare angle element in the Schmidt-Clausen and Bindels equation (currently 0.46) to generate the dashed line. The difference between the two lines is about 1.5 deBoer units. There were no statistically significant differences between age groups.

Facility

The test was conducted on a private road in a rural area. The road is about 2,500 feet long, straight and flat. The surface is paved with asphalt, in very good condition, is about 20 feet wide, and is delineated with a yellow skip line in the center and white edge lines. The area is quite dark. There are no sources of artificial illumination on or near the facility.

Procedure

Subjects were run in groups of three. They were driven to the test road, a volunteer driver was solicited, and all three were seated in the front seat of the test car. (Sivak and Olson [1987] found that seat position had no effect on judgments of glare discomfort.) The instructions were read to them (see Appendix A), and any questions answered. The instructions emphasized that they were to look directly up the road in front of them and make their ratings based on the entire glare exposure.

When it was determined that everybody was ready the subject driver switched on the vehicle's headlamps. They then waited until they saw the lights of the glare car come on at the opposite end of the road. At that time each driver accelerated to 25 mph and held that speed until the vehicles passed. After passing, each driver continued down to the opposite end of the road, turned around, stopped, and turned off the headlamps. The experimenters in the glare car changed the filters as required for the next run, while the subjects filled in their rating sheets. The process was then repeated in the opposite direction. The test typically took 1.25 hours to complete.

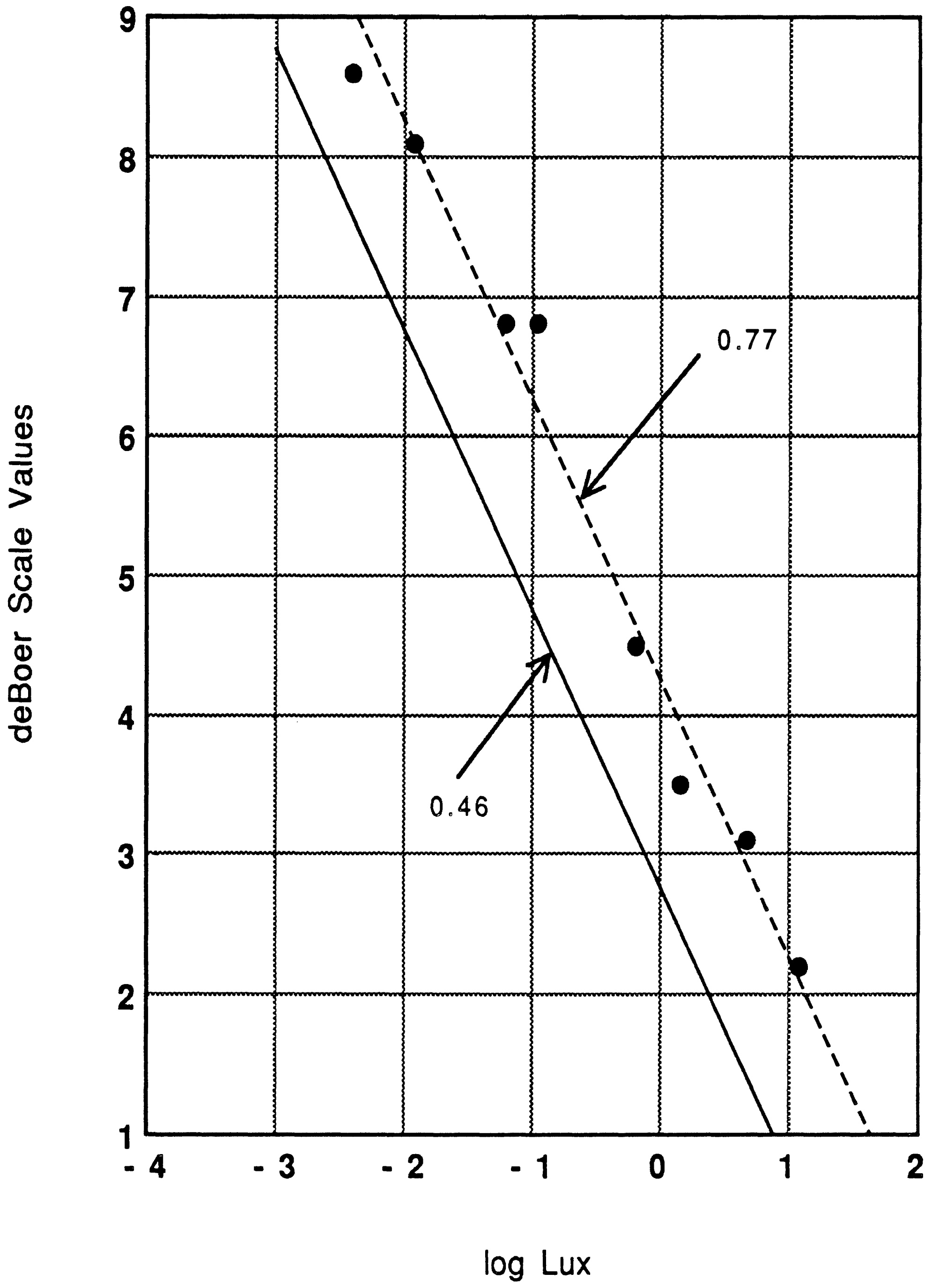

Figure 6-1. Results of Discomfort Glare Screening for Young Age Group

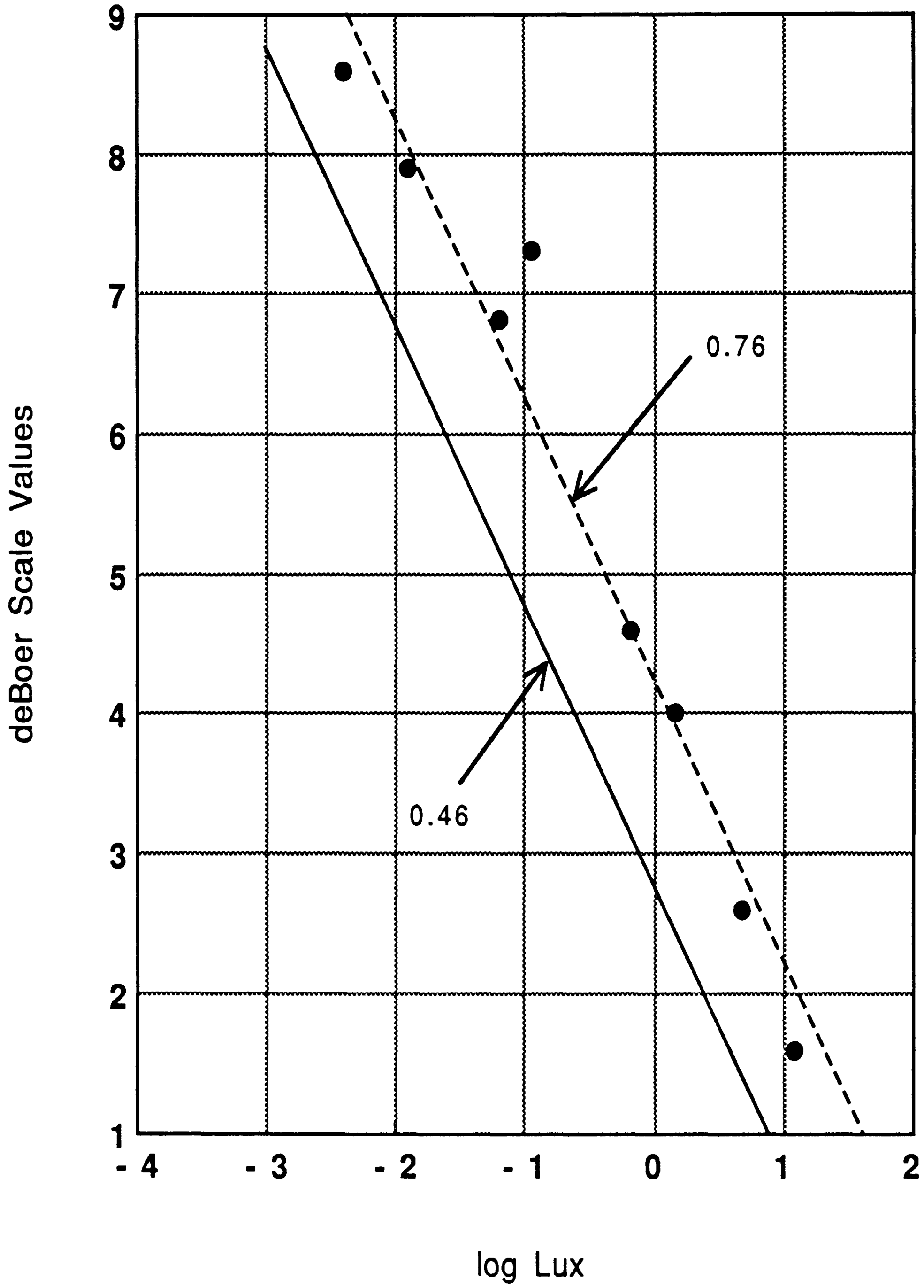

Figure 6-2. Results of Discomfort Glare Screening for Old Age Group

Results

The results of the primary study are shown in Figure 7. This figure shows the mean rating obtained on the deBoer scale as a function of glare illuminance (based on a longitudinal separation of 100 feet) for both age groups of subjects. The solid diagonal line represents predicted ratings based on use of the Schmidt-Clausen and Bindel's equation, assuming an adaptation luminance of 0.3 ft-L. At mid range, the difference between predicted and measured values is between 1.0 and 2.0 deBoer units. These results correspond very closely to those reported in the 1983 study for NHTSA (see Figure 4).

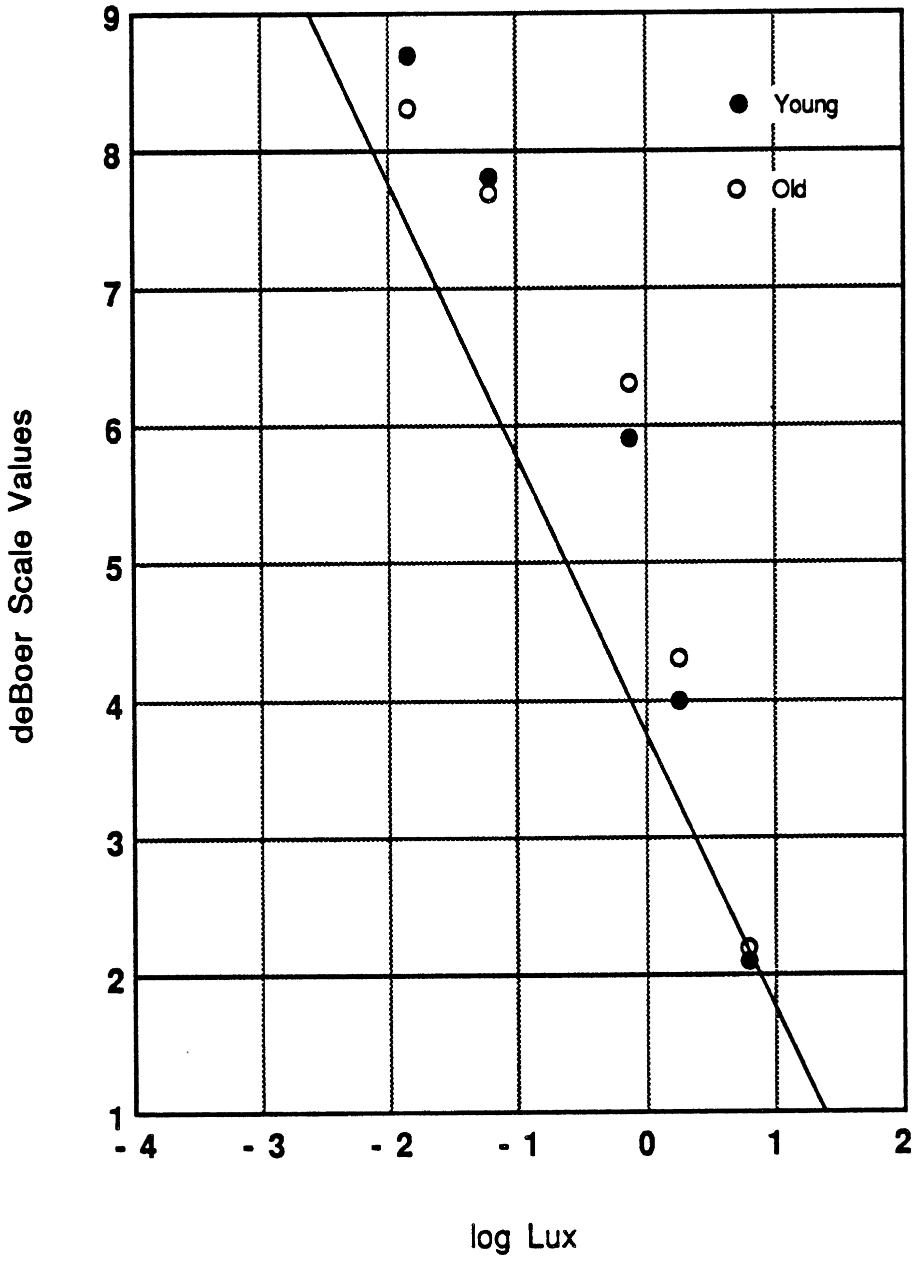

Figure 7. Results of Dynamic Discomfort Glare Evaluation

Table 2 compares the mean deBoer ratings for all subjects as a function of the direction in which they were to look. For the test in which the subjects were to look directly at the glare lamps, higher levels of discomfort (i.e., lower numerical ratings) were expected. Although the results are not statistically significant, this is what was found in each of the four glare levels tested. Conversely, for the test in which the subjects were to look away from the glare lamps, lower levels of discomfort (i.e., higher numerical ratings) were expected. In this case one of the ratings is the same as in the straight ahead condition. The other is higher, although again the difference is not statistically significant.

Table 2. Mean Discomfort Ratings for all Subjects as a Function of Direction of Gaze

Glare (log lux at 100')	Direction of Gaze: Straight Ahead	At Glare Source	Right Edge of Lane
0.79	2.2	2.0	-
0.26	4.2	3.9	4.2
-0.14	6.1	5.6	-
-1.22	7.7	7.5	7.8

In that portion of the test in which subjects were asked to look directly at the glare, they were requested to indicate whether they would be willing to look into that glare to see if the oncoming vehicle had its turn signal on. Table 3 lists the results of this portion of the test. Averaged across all subjects, the results indicate that drivers would be willing to do so only about 20% of the time when facing glare approximating that provided by high beams.

The data from Table 3 are graphed in Figure 8 as a function of glare. Plotted this way the three data points form a near-perfect straight line that intercepts the abscissa at a log lux level of -0.35.

Table 3. Percent of trials in which subjects said they would not be willing to look into the glare to see if the turn sign were on

Glare (log lux at 100')	Age Group		Means	
	Young	Older	Percentage	deBoer Rating
0.79	87	73	80	2.0
0.26	47	37	42	3.9
-0.14	13	17	15	5.6

The ratings on the asymmetrical system were somewhat lower on average (i.e., more glaring) than those for the number 4 system for the older subjects (3.7 vs. 4.3). This difference is significant at the 0.05 level, based on the sign test. The difference for the young subjects was in the opposite direction (i.e., 4.1 vs. 4.0), although it was short of statistical significance. For the entire group of 30 subjects the mean ratings were: asymmetrical: 3.9, symmetrical - filter 4: 4.2. This difference is also short of statistical significance.

Discussion

The results of this investigation support those of the semi-dynamic study reported in 1983, and indicate that: (1) Americans rate glare as less uncomfortable than do Europeans, and (2) the laboratory method of Schmidt-Clausen and Bindles yields glare limit recommendations that are somewhat lower than those obtained in a more realistic field setting.

Using a presumed dark adaptation level of 0.3 ft-L, the difference in glare between predicted and measured discomfort at levels in mid range (i.e., at deBoer 5) is about fivefold. In other words, if use of the Schmidt-Clausen and Bindels equation predicts a given maximum level of glare to stay within W = 5 for a meeting on a straight-flat road, these data indicate the glare could be about five times greater. A large portion of this difference is apparently due to the greater glare tolerance of Americans, the rest is attributable to differences in test methodology. On this basis it appears that some increase in glare should be acceptable even to Europeans. This would permit the design of lamps that would have significantly higher illuminating intensities and still meet discomfort glare criteria worldwide. This recommendation is, admittedly, controversial. From the point of view of this project however, it is clear that the discomfort glare equation needs to be modified to more accurately model the responses noted in this investigation.

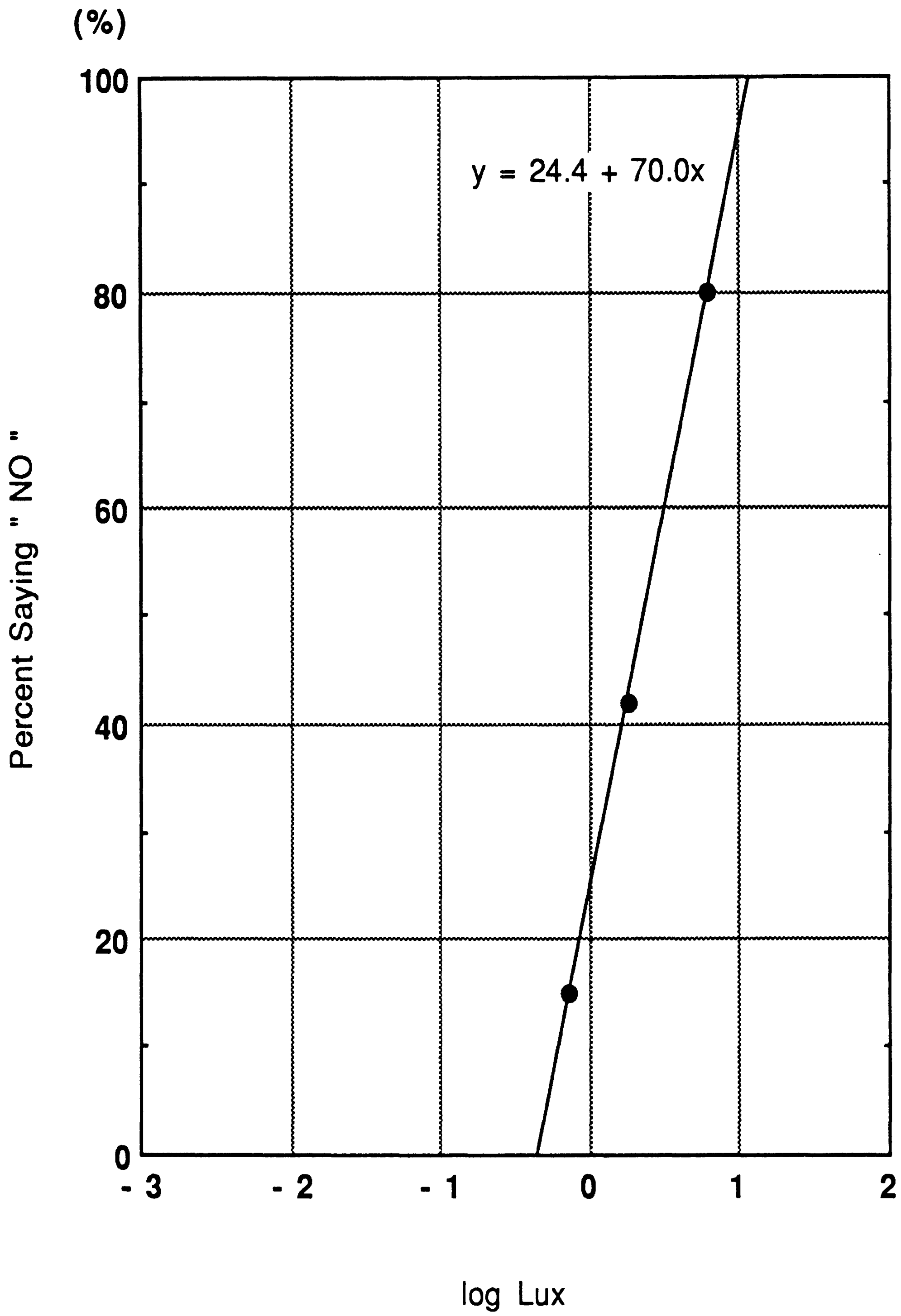

Figure 8. Percent of trials in which subjects indicated they would not be willing to look into the glare to determine whether the turn signals were on.

The laboratory studies of discomfort glare produce results that are log-linear, as illustrated by the screening results in Figure 6. On the other hand, the field data show a curvilinear relationship between glare and expressions of discomfort on a log-linear plot, as shown in Figure 7. The interesting aspect of this is that the most critical portion of the glare spectrum, i.e., from about deBoer 6 down, is characterized by a much steeper slope than predicted by the Schmidt-Clausen and Bindels equation. That equation predicts a slope such that the difference between a rating of 6 and a rating of 4 is separated by about one log unit of glare. The field data from both this and the 1983 study indicate that the separation is about half of that. On this basis an increase in glare of one log unit would change a presumably good rating of 6 to a near-unbearable 2.

These results suggest a dichotomy of sorts in the reaction to glare. Below a value of about 1 lux glare may be considered tolerable, and changes in glare of less importance. Above 1 lux glare apparently becomes more of a problem, and further increases result in a stronger negative reaction. In terms of glare control this relationship presents difficulties. Utilizing a criterion such as deBoer 5 to establish an upper limit places the glare level on a steep portion of the curve, such that relatively small changes result in significant increases in discomfort. Assuming the logic outlined above is correct, one solution is to try to keep glare at or below 1 lux. This is equivalent to a criterion of deBoer 6, and would result in reduced illumination for visibility purposes as well.

One final note before leaving the subject of discomfort glare. Recent research (Sivak et al., 1989) has shown that judgments of glare discomfort are to some extent dependent on task difficulty. This suggests, for example, that the same glare would be judged more uncomfortable on a road with poor delineation than on one with good delineation, due to the greater difficulty in determining road direction in the former case.

It is perhaps not surprising that persons asked to make a difficult subjective judgment will make use of whatever objective information may be available to aid them. One such objective indication is the degree to which the glare obscures details of the environment toward which one is looking. A greater loss of visibility indicates a higher level of glare, which should be more uncomfortable. The results of the Sivak et al. study do not mean that discomfort can be ignored as an issue in lamp design, but they are a further indication of the difficulties involved in establishing glare limits using a discomfort criterion.

FIELD VALIDATION STUDY

Introduction

The purpose of the study described in this section was to develop data on driver visibility that could be used to compare with predictions provided by the NHTSA models. The data were collected in the field, using an instrumented vehicle and a variety of targets.

Method

Independent variables

Targets. Two types of targets were used in the study, "pedestrian," and "delineation." The pedestrian targets were plywood, one-foot wide and either 30 or 72 inches tall. The 30-inch pedestrian was employed using three levels of reflectivity, 6, 12 and 25%. (The 12%, 30-inch pedestrian corresponds to the standard pedestrian target used in the NHTSA models.) The 72-inch pedestrian was employed using two levels of reflectivity, 6 and 25%. Target reflectivities were established by having a paint store prepare paint based on samples of known reflectivity. The values were confirmed by use of a photometer prior to the test.

The delineation targets were fabricated by cutting strips of 1/8th-inch hardboard four inches wide and eight feet long. Pavement marking tape in either white or yellow was attached to these strips. Two sets of two strips were made in each color, for a total of eight strips. One set in each color was darkened by lightly overspraying them with black paint. This resulted in a "high" and "low" set in each color. Two strips were placed end to end to create a target 16 feet long when taking data.

Headlamp beam. Three "beams" were used in the study. Two of these were standard SAE high and low beams provided by the lamps with which the test vehicle was equipped. These were large rectangular, non-halogen sealed beams. Figure 9 shows iso-lux curves for each lamp on both beams. The third beam was arrived at by using neutral density filters to reduce the intensity of the high beam to produce approximately the same level of illumination on the lower portion of the 30-inch 12% target, at 100 feet, while in the right-hand position, as did the low beams.

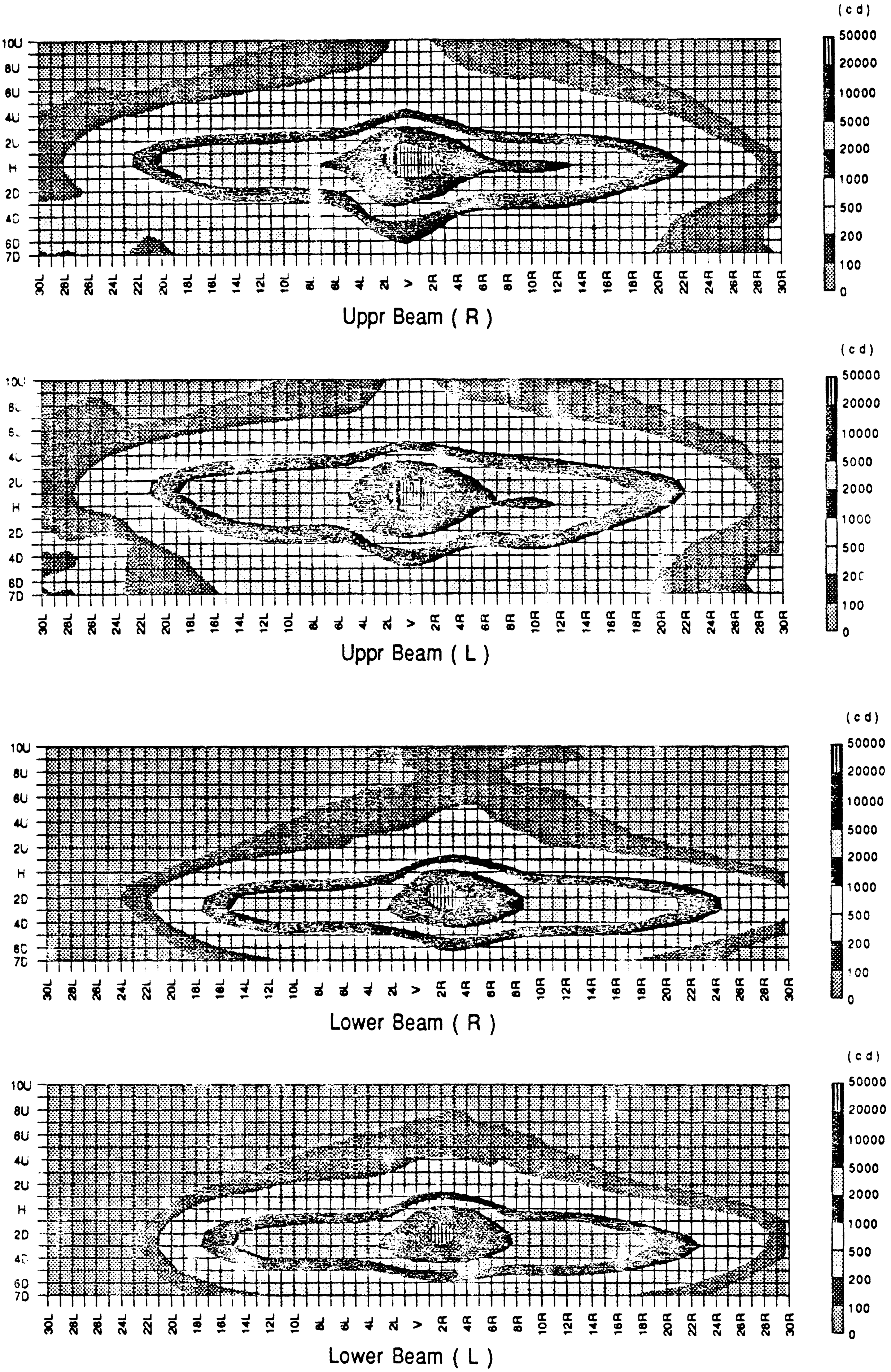

Figure 9. Iso-cd Curves

Target position. The targets could appear on the right or left of the test vehicle. All of the pedestrian targets appeared on both sides. Only the white delineation was used on the right, only the yellow on the left. Since there was both center and edge delineation (albeit faded) on the test road, the test delineation was placed about one foot away from it to maximize contrast. It proved very difficult for some subjects to stay on the road using the dimmed low beam with targets on the left side. In the interests of safety, no data were taken in this condition.

Subjects. A total of 30 subjects were screened for the study. Of these 15 were in the age range from 30 to 40, and 15 were aged 60 and older.

Dependent variable

The dependent variable in this study was the distance from the target when the subject could detect it.

Equipment

The subjects drove a station wagon fitted with a precision voltage control system for the headlamps. The accuracy of this system was within 0.05 volt. The headlamps were operated at 12.8 volts in this test. The car was also equipped with a distance measuring system driven off the left front wheel. This system provided four counts/wheel revolution. On this basis one count was equal to 1.72 feet. The output was recorded on a digital counter.

On most trials glare was provided by a fixed source attached to the hood of the test vehicle. The source was a dual-filament automotive stop lamp bulb, run on the lower-output filament. The bulb was mounted on a mast that allowed its height and lateral position to be readily adjusted. The unit was driven by a controllable source so that its intensity could be changed as required.

In one series of trials glare was provided by a fixed source located in the center of the opposite lane. The lamp was a standard 5 3/4 inch diameter sealed beam, type 2 (i.e., 2-filament). It was run on the low-beam filament. The lamp mounting placed its center seven inches above the road surface. This unit was driven by a second car parked on the shoulder behind it, through an adjustable control source, so that its output could be changed as required.

Test Facility

The test was carried out on a private road in a rural area. The road is 2550 feet long, is paved in asphalt (which, although worn, is in very good condition), and is flat and straight. There are two 9-foot lanes, and virtually no shoulders. The area is lacking in any significant sources of artificial illumination, so it is quite dark.

Targets were placed at three points along the road, at roughly 600-foot separations. Each target station was manned by an experimental assistant who had a minimum of three different targets. The assistants' job was to make sure that the appropriate target was in the correct position for each run.

Photometry

Prior to starting data collection, extensive photometric measurements were taken of each target and its background, in both right and left positions (where appropriate), at a range of distances, using all three beams. These measurements were taken at the test site, using the headlamps employed in the test, at the design voltage of 12.8.

Measures were made at 100, 150, 200, 300, and 400 feet. The car was placed in the center of the lane at the desired distance, and its long axis was aligned with the lane using reference marks on the front and rear windows provided for that purpose. The photometer was set at the rear of the vehicle, looking through the open rear window at the approximate height of a typical driver. In this way the photometer viewed the target through the front window in the same way that the subjects would.

Luminance readings were taken at three points (top, middle, bottom) of the 30-inch pedestrian target. Background luminance readings were taken at the same height on either side, as well as at the top and bottom. Five readings were taken on the face of the six-foot pedestrian target (top, middle, bottom, and at two points between). Background luminance readings were also taken at the same height on each side, as well as at the top and bottom. Only four readings were made on the delineation target, one on the target at the end closest to the observer, one on the pavement on each side, and one on the pavement in front. A complete listing of the photometric readings is given in Appendix B. Those data were used in a simple interpolation routine to estimate luminance readings at in-between points.

Subject Screening

The subjects were screened using a test that measured their ability to detect a low-contrast target in the presence of glare. The test was set up to approximate one of the conditions given in the NHTSA models when a speed of 25 mph is specified. That is, the target was a circular disc, subtending 77 minutes. The glare source provided 0.75 lux to the eyes of the observer, and was separated from the target by 538 minutes (center to center of each). The laboratory illumination was adjusted to provide a dark-adaptation level of 0.3 ft-L, using the equipment and subject described in the section on the measurement of dark adaptation level. The level of 0.3 ft-L is higher than what is generally assumed in the model, but is realistic, based on the measurements made as part of this investigation.

Subjects were informed that the target would appear at a specific point on the screen that was surrounded by four lines at the 12, 3, 6, and 9 o'clock positions. The target projector was then switched on at a high level so they could see the target clearly as an aid in determining its size, color, and location.

The test was run using a simple "staircase" technique. Subjects were given brief (1-second) exposures to the stimulus and responded by saying either "yes" they could see the target, or "no" they could not. If the answer was "yes," on the next trial the target was made dimmer; if the answer was "no," on the next trial the target was made brighter. Two sequences were run in parallel, so the subject would not become aware of the strategy being employed. Target luminance could be set at 11 levels, as shown in Table 4.

Table 4. Listing of Target Luminance Values Used in Subject Screening

Number	Luminance
1	0.159
2	0.107
3	0.080
4	0.075
5	0.070
6	0.065
7	0.050
8	0.046
9	0.043
10	0.041
11	0.039
Background	0.037

The results of the screening are given in Table 5. The young subjects, as would be expected, produced lower threshold luminance values, and were more homogeneous. Indeed, the threshold scores for fourteen of the fifteen young subjects ranged from 0.040 to 0.043 ft-L. The score for one young subject was 0.046. The threshold scores for nine of the fourteen older subjects were greater than 0.043 ft-L, and ranged up to 0.069 ft-L. One older subject of the original fifteen could not perform the test at all, and was dropped from the study. After the field test had started, it became apparent that some of the older subjects were having trouble staying in their lane while performing the task. In the interests of safety the individuals with the highest screening scores (0.054 ft-L and higher) were not run in the field test. This resulted in a total of ten older subjects.

Table 5. Subject Screening Threshold Scores

Young Subjects		Older Subjects	
Number	Threshold (Ft-L)	Number	Threshold (Ft-L)
1	0.040	1	0.041
2	0.040	2	0.042
3	0.041	3	0.045
4	0.040	4	0.046
5	0.040	5	0.045
6	0.042	6	0.059
7	0.041	7	0.048
8	0.040	8	0.043
9	0.040	9	0.043
10	0.043	10	0.043
11	0.040	11	0.044
12	0.046	12	0.054
13	0.041	13	0.058
14	0.042		
15	0.041		

Procedure

Subjects were run individually. They were brought to the area, seated in the test car, and told to make themselves comfortable by adjusting the seat position and mirrors as necessary. The car was then positioned in the right lane of the road, and the experimenter adjusted the location of the glare source so that it was in the same position as the center of an oncoming car at a distance of about 200 feet. (The intensity of the glare source was previously set at 0.04 lux, using a lux meter positioned at the driver's eyes.)

Instructions were then provided (see Appendix A). Basically the subject was told that there were two different types of targets, pedestrians and delineation, that the former came in different sizes and reflectivities, that there would always be three targets per run, and that they could appear on either side of the car, but he/she would always be told in advance where to look for them. A practice run was then provided in each direction on the road, during which the subject saw at least one example of each type of target, and became generally familiar with their location. Data collection then started. Car speed was 25 mph on all runs, regulated by a cruise control. On each run, as the subject detected each target they would call out "target," at which time the experimenter started a distance counter running. The counter was put in hold as the target was passed. The experimenter then wrote the number down and reset the counter.

Either at the start or end of the session, data were taken using the fixed glare source and the 12% small pedestrian target. To do this the test car was first positioned 94 feet from the target, and the glare source was set up in the center of the opposite lane, 94 feet on the far side of the target. The glare source was then adjusted until illumination at the eye of the subject measured 0.04 lux. While the car was in position the experimenter pointed out the target to the subject, and explained the general procedure. The car was then backed up to the end of the road. If the fixed glare source work was done at the start of the session, the subject was given a practice trial. If it was given at the end of the session, no practice was provided. On each run (total of three) the subject drove forward, called out "target" as appropriate, passed the target and the glare source, turned around in a ramp area, and returned to the end of the road for the next run.

Results

Before considering the results of this investigation it would be appropriate to say a few words about the difficulties involved in trying to validate the NHTSA models. The first of these difficulties comes from the basic nature of how the models work. The models are designed to input speed and output the candlepower required to reveal the target at a "safe" distance. One way to carry out the field test would be to set up a lighting system that would direct the intensity specified by the model at the target and see if the predicted and measured visibility distances compare. In this test it was desired to look at several targets and have those targets located both to the right and left of the car.

Therefore, a compromise procedure was adopted that provided several beams, one of which would be reasonably close to that specified for certain speeds in the model. As an alternative way of looking at the data, it is also possible to adjust the input speeds in the model so that the predicted and measured visibility distances were the same, and make a comparison of the predicted and measured photometrics. The problem here is that changing speed also changes the glare levels and glare angles somewhat. However, it is probably the most accurate way of comparing the photometric results, given the way this test was conducted.

Another problem is the assumptions the model makes about glare. It places the glare source at a distance on the other side of the target equal to the detection distance. The glare source is fixed, the glare illumination constant. This cannot be duplicated in a dynamic test situation. The best compromise was to place the glare source on the car so that the intensity, and angular relationship remained constant. Our concern was that by so doing, the subject's adaptation level would be altered in a way that was not realistic. Hence, the test with the fixed glare source was set up, to provide a basis for comparison.

The models also make certain assumptions about key factors such as background reflectivity, and model both the target and its background as having uniform luminance. In a real target detection situation the luminance of the target and the background vary greatly. This makes it very difficult to compare the field results with the predictions. If the detection distances compare, that is a good sign, but the luminance and contrast levels should also make sense. It was in these comparisons that the greatest degree of difficulty was experienced.

Young subjects. The results will be described with the aid of several tables. The first of these is Table 6. Table 6 gives a general overview of the results of the investigation, and certain calculations derived from the NHTSA model. To explain the headings, starting from the left, the first is target position. Under "X" is the distance, in feet, of the target to the right or left of the vehicle centerline. "T" is for target type, 1 being pedestrian, 2 being delineation. "V" is for velocity of the test car. This column is blank for the pedestrian targets. The values shown next to the delineation targets represent the speed (in mph) that could be used and still have two seconds view of the delineation at the visibility distances shown. The next section of the table lists the dimensions of the targets (in feet), their reflectivity, and the mean detection distances (in feet) for the young subjects before a correction for expectancy. The rest of the table lists values calculated from the NHTSA model. First is luminance (in ft-L), starting with the background (BB), the target (BT), and adaptation luminance (BA). The next column is the intensity (in cd) that must be directed toward the target in order to provide the luminance values shown. Values of a million cd or more are shown as "over range." That is followed by the illumination at the target (in lux). The last two columns are the glare intensity directed at the subject's eyes from the oncoming car (in cd), and the glare illumination at the driver's eyes (in lux). These were selected in each case so that, together with the glare angle, they would yield a glare discomfort rating of "4" on the deBoer scale.

Table 6. Basic Results of Validation Study

		target position	car velocity	target hight	width		distance	luminance backgr	target	adapt	observer car		glare car	
		X	T	V	H	W	R	D	BB	BT	BA	cd	lx	G-cd	G-lx
Actual Distance	Small Target	8	1	0	2.5	1.0	6%	207	0.316	0.556	0.451	568,310	13.24	14,144	0.081
		8	1	0	2.5	1.0	6%	189	0.260	0.471	0.371	401,410	11.22	11,325	0.077
		8	1	0	2.5	1.0	6%	164	0.199	0.376	0.284	241,380	8.95	8,153	0.074
		8	1	0	2.5	1.0	12%	269	0.107	0.341	0.152	294,090	4.06	13,489	0.046
		8	1	0	2.5	1.0	12%	263	0.102	0.330	0.146	272,000	3.93	12,821	0.046
		8	1	0	2.5	1.0	12%	243	0.089	0.295	0.127	207,740	3.51	10,759	0.045
		8	1	0	2.5	1.0	25%	387	0.078	0.442	0.111	378,440	2.53	20,853	0.034
		8	1	0	2.5	1.0	25%	372	0.072	0.418	0.103	329,970	2.38	19,072	0.034
		8	1	0	2.5	1.0	25%	371	0.072	0.416	0.103	326,920	2.37	18,957	0.034
	Large Target	8	1	0	6.0	1.0	6%	251	0.336	0.552	0.480	829,420	13.15	19,490	0.076
		8	1	0	6.0	1.0	6%	241	0.308	0.514	0.440	711,620	12.24	17,642	0.075
		8	1	0	6.0	1.0	6%	236	0.295	0.496	0.421	658,680	11.81	16,774	0.074
		8	1	0	6.0	1.0	25%	421	0.059	0.318	0.084	322,110	1.82	21,342	0.030
		8	1	0	6.0	1.0	25%	427	0.060	0.324	0.086	336,770	1.85	21,995	0.030
		8	1	0	6.0	1.0	25%	413	0.057	0.312	0.081	303,330	1.78	20,490	0.030
Right Side Target	Yellow Delineation	6	2	101			14%	295	0.842	2.095	1.203	over range	21.68	35,739	0.101
		6	2	82.2			14%	241	0.359	0.988	0.513	579,870	9.98	17,949	0.076
		6	2	98.9			14%	290	0.774	1.943	1.106	over range	20.06	33,509	0.098
		6	2	84.2			14%	247	0.394	1.073	0.563	662,850	10.86	19,410	0.078
		6	2	84.9			14%	249	0.406	1.102	0.581	692,440	11.16	19,915	0.079
		6	2	77.4			14%	227	0.290	0.820	0.414	423,940	8.22	14,935	0.071
1 / 2 Distance	Small Target	8	1	0	2.5	1.0	6%	103	0.105	0.224	0.151	56,830	5.33	3,116	0.070
		8	1	0	2.5	1.0	6%	94	0.096	0.209	0.138	44,190	4.97	2,622	0.071
		8	1	0	2.5	1.0	6%	82	0.086	0.191	0.123	30,870	4.55	2,043	0.072
		8	1	0	2.5	1.0	12%	134	0.039	0.154	0.055	33,020	1.83	3,210	0.043
		8	1	0	2.5	1.0	12%	132	0.038	0.152	0.054	31,650	1.81	3,120	0.043
		8	1	0	2.5	1.0	12%	121	0.035	0.142	0.050	24,830	1.69	2,652	0.044
		8	1	0	2.5	1.0	25%	193	0.025	0.189	0.036	40,270	1.08	4,865	0.032
		8	1	0	2.5	1.0	25%	186	0.024	0.183	0.035	36,080	1.04	4,530	0.032
		8	1	0	2.5	1.0	25%	186	0.024	0.183	0.035	36,080	1.04	4,530	0.032
	Large Target	8	1	0	6.0	1.0	6%	126	0.125	0.254	0.179	96,210	6.04	4,523	0.069
		8	1	0	6.0	1.0	6%	121	0.121	0.248	0.173	86,720	5.90	4,199	0.069
		8	1	0	6.0	1.0	6%	118	0.119	0.245	0.170	81,400	5.82	4,011	0.069
		8	1	0	6.0	1.0	25%	210	0.023	0.168	0.033	42,280	0.96	5,378	0.030
		8	1	0	6.0	1.0	25%	213	0.024	0.170	0.034	43,940	0.97	5,521	0.030
		8	1	0	6.0	1.0	25%	207	0.023	0.166	0.033	40,660	0.95	5,236	0.030
Right Side Target	Yellow Delineation	6	2	50.5			15%	148	0.088	0.293	0.126	62,210	2.84	4,795	0.053
		6	2	41.3			15%	121	0.059	0.208	0.084	29,250	1.99	3,042	0.050
		6	2	49.4			15%	145	0.084	0.282	0.120	57,400	2.73	4,569	0.053
		6	2	41.9			15%	123	0.061	0.214	0.087	31,010	2.05	3,152	0.050
		6	2	42.3			15%	124	0.062	0.216	0.088	31,930	2.07	3,209	0.050
		6	2	38.9			15%	114	0.053	0.191	0.076	23,750	1.82	2,679	0.049

The first of the data tables is Table 7. It lists predictions from the NHTSA model as well as the field test results for the small pedestrian targets, positioned on the right side of the road, with the young subjects. The table is in three main sections, one for each level of target reflectivity. Within each section, on the left under the heading "Predicted," two speeds (25 and 35 mph) appear. Vehicle speed fixes detection distance in the model, so the distances of 94 and 155 feet appear for each target. Also within each section, on the right under the heading "Measured," are the results for each of the three beams used in the test.

The columns on the left of the table, with the heading "Predicted," also list the predicted target and background luminance levels. Two predicted luminances are shown for each speed. The top one is the unmodified prediction. For example, for the 6% small target, the target luminance (shown inside the square) is predicted to be 0.21 ft-L, the background luminance is predicted to be 0.096 ft-L. The predicted adaptation luminance (BA) is 0.14 ft-L. Just below these data are the predictions obtained from the model if the adaptation luminance is changed to 0.30 ft-L, which was found to be appropriate for the low-beam lighting system and test conditions used in the validation. For the particular set of conditions involving the 6% target, the change in adaptation luminance makes a very small change (about 5%) in the required intensity of the headlamps. The adaptation level measured in the field for the high beam units used in the study was 1.7 ft-L, and this value is used as a correction in the 35 mph case. While there is no certainty that this is a completely correct estimate, improving visibility by about 60% over the 25 mph case can be achieved only with something approximating high beams. This change results in an almost six-fold increase in adaptation luminance over that calculated by the model, and a substantial change (about 25%) in required illuminating intensity.

Table 7. Comparison of Measured and Predicted Values - Small Pedestrian Targets on the Right Side - Young Subjects

	PREDICTED				MEASURED							
					Actual				1/2 Distance			
	Distance (ft)	Luminance (Ft-L)			Distance (ft)	Luminance (Ft-L)			Distance (ft)	Luminance (Ft-L)		
6%	(25 mph)			Low			0.008				0.029	
Small				Beam		0.010	0.021	0.010		0.025	0.043	0.018
Target	94	0.096	0.21		207	0.017	0.023	0.009	103	0.045	0.056	0.012
						0.027	0.028	0.027		0.077	0.080	0.099
							0.038				0.117	
		BA=	0.14									
					predicted	0.316	0.556		predicted	0.105	0.224	
						BA=	0.451			BA=	0.151	
		0.10	0.22									
				High			0.014				0.043	
		BA=	**0.3**	Beam		0.017	0.033	0.023		0.027	0.093	0.031
					189	0.018	0.030	0.015	94	0.028	0.080	0.016
						0.032	0.030	0.028		0.041	0.057	0.060
							0.036				0.067	
	(35 mph)											
					predicted	0.260	0.471		predicted	0.096	0.209	
	155	0.18	0.35									
						BA=	0.371			BA=	0.138	
		BA=	0.26									
				Dim-Hi			0.011				0.030	
				Beam		0.012	0.029	0.017		0.016	0.078	0.046
					164	0.010	0.025	0.011	82	0.024	0.069	0.023
		0.23	0.44			0.027	0.025	0.029		0.014	0.048	0.050
							0.029				0.057	
Right Side		**BA=**	**1.7**		predicted	0.199	0.376		predicted	0.086	0.191	
						BA=	0.284			BA=	0.123	
12%	(25 mph)			Low			0.007				0.021	
Small				Beam		0.007	0.022	0.011		0.021	0.065	0.013
Target	94	0.028	0.12		269	0.012	0.025	0.008	134	0.032	0.080	0.011
						0.019	0.029	0.022		0.074	0.108	0.066
							0.025				0.087	
		BA=	0.04									
					predicted	0.107	0.341		predicted	0.039	0.154	
						BA=	0.152			BA=	0.055	
		0.034	0.15									
				High			0.012				0.025	
		BA=	**0.3**	Beam		0.013	0.037	0.016		0.026	0.110	0.028
					263	0.014	0.035	0.012	132	0.029	0.095	0.017
						0.020	0.033	0.023		0.033	0.070	0.049
							0.025				0.052	
	(35 mph)											
					predicted	0.102	0.330		predicted	0.038	0.152	
	155	0.046	0.18									
						BA=	0.146			BA=	0.054	
		BA=	0.065									
				Dim-Hi			0.009				0.019	
				Beam		0.008	0.027	0.011		0.014	0.096	0.028
					243	0.008	0.025	0.008	121	0.014	0.084	0.018
		0.077	0.30			0.015	0.026	0.019		0.016	0.062	0.042
							0.019				0.043	
Right Side		**BA=**	**1.7**		predicted	0.089	0.295		predicted	0.035	0.142	
						BA=	0.127			BA=	0.050	

Table 7. Continued

25%	(25 mph)			Low			0.005				0.011	
Small				Beam		0.005	0.020	0.008		0.013	0.096	0.019
Target	94	0.012	0.11		387	0.008	0.023	0.008	193	0.026	0.111	0.016
						0.009	0.024	0.011		0.033	0.128	0.039
							0.012				0.045	
		BA=	0.017									
					predicted	0.078	0.442		predicted	0.025	0.189	
						BA=	0.111			BA=	0.036	
		0.017	0.16									
				High			0.007				0.018	
		BA=	0.3	Beam		0.008	0.045	0.013		0.020	0.165	0.018
					372	0.011	0.044	0.011	186	0.018	0.137	0.012
						0.014	0.044	0.014		0.029	0.125	0.033
							0.016				0.038	
	(35 mph)											
					predicted	0.072	0.418		predicted	0.024	0.183	
	155	0.019	0.15									
						BA=	0.103			BA=	0.035	
		BA=	0.028									
				Dim-Hi			0.004				0.013	
				Beam		0.004	0.027	0.008		0.013	0.109	0.018
					371	0.007	0.027	0.005	186	0.011	0.100	0.009
		0.039	0.31			0.008	0.025	0.010		0.016	0.092	0.030
							0.010				0.027	
Right		BA=	1.7		predicted	0.072	0.416		predicted	0.024	0.183	
Side												
						BA=	0.103			BA=	0.035	

The columns on the right side of the table, headed "Measured," give the results of the field test. Under the heading "Actual" are the mean detection distances measured for the young subjects. For example, for the 6% small target, with low beams, the mean detection distance was 207 feet. The matrix of values next to the distance gives the field photometric measures for that target at 207 feet. The three values within the little box are measures made on the target itself at the top, middle, and bottom. The values around the box are background measures. Below that, labeled "predicted" are target and background luminance values predicted by the NHTSA model for 207 feet. The adaptation luminance (BA) calculated for that case is 0.451 ft-L.

On the far right of the table is an identical summary, where the detection distance is reduced by 50% as a means of correcting for subject expectancy. The 50% figure comes from the work of Roper and Howard (1938), who found that subjects who are not expecting to encounter a target will, on average, detect it at half the distance that they will when it is expected. These are the data that should be compared with the predicted values on the left side of the table.

The main target of interest in Table 7 is the 12% small target, which corresponds to the pedestrian in the NHTSA model. An inspection of the right-hand column of the table shows that the measured detection distances were similar for all three beams, and closer to the 25 than the 35 mph predictions given by the model. But the main comparison of interest is between the predicted luminance values for the 1/2 distances and those measured on the targets in the field. In general the measured luminance values for the low and high beam are very similar, while those for the dimmed high beam are slightly lower. The measured target luminance values are generally below those predicted by the model, while the background luminance values average out reasonably close to the predictions. This seems to be generally true throughout the data, and indicates that the targets were detected at significantly lower levels of contrast than predicted by the model.

The discrepancy between predicted and measured luminance values seems to vary with target reflectivity. It is greatest for the 6% target, and least for the 25% target, although the model always overpredicts target luminance.

Data for the six-foot pedestrian target are given in Table 8. The format here is the same as in Table 7, except there were only two of the larger targets. At some point in the development of the models the thirty-inch tall, 12% target was selected as being equivalent to a six-foot tall, 6% target. Hence, it is interesting to compare the two. This is most easily done on high beam, where the illumination is more homogeneous. Such a comparison shows that the mean 1/2 identification distances for these two targets were similar, 121 feet for the six-footer compared to 132 feet for the 30-incher. More to the point, the target and background luminance levels were similar at their respective mean detection distances. The model, however, predicts very different luminance values for those targets at those distances.

Table 8. Comparison of Measured and Predicted Values - Large Pedestrian Targets on the Right Side - Young Subjects

	PREDICTED				MEASURED							
					Actual				1/2 Distance			
	Distance (ft)	Luminance (Ft-L)			Distance (ft)	Luminance (Ft-L)			Distance (ft)	Luminance (Ft-L)		
6% Large Target	(25 mph)			Low Beam			0.003				0.003	
						0.003	0.006	0.003		0.003	0.006	0.003
						0.004	0.009	0.004		0.005	0.010	0.003
	94	0.10	0.22		251	0.004	0.012	0.006	126	0.010	0.023	0.007
						0.008	0.016	0.008		0.025	0.044	0.015
						0.019	0.021	0.022		0.066	0.069	0.045
							0.028				0.098	
		BA=	0.15									
					predicted	0.336	0.552		predicted	0.125	0.254	
						BA=	0.480			BA=	0.179	
		0.11	0.24									
				High Beam			0.008				0.016	
						0.006	0.031	0.007		0.014	0.070	0.016
						0.008	0.031	0.008		0.016	0.085	0.017
		BA=	0.3		241	0.009	0.029	0.013	121	0.021	0.086	0.025
						0.011	0.025	0.011		0.034	0.071	0.027
						0.015	0.023	0.018		0.024	0.050	0.037
							0.025				0.061	
	(35 mph)											
					predicted	0.308	0.514		predicted	0.121	0.248	
	155	0.15	0.30			BA=	0.440			BA=	0.173	
				Dim-Hi Beam			0.005				0.009	
		BA=	0.22			0.006	0.018	0.006		0.009	0.042	0.008
						0.006	0.018	0.007		0.013	0.055	0.013
					236	0.003	0.018	0.007	118	0.014	0.062	0.022
						0.008	0.016	0.007		0.023	0.051	0.027
						0.010	0.014	0.017		0.010	0.037	0.038
		0.20	0.39				0.019				0.046	
Right Side					predicted	0.295	0.496		predicted	0.119	0.245	
		BA=	1.7			BA=	0.421			BA=	0.170	
25% Large Target	(25 mph)			Low Beam			0.004				0.003	
						0.004	0.009	0.004		0.005	0.022	0.005
						0.004	0.010	0.005		0.006	0.033	0.007
	94	0.013	0.11		421	0.004	0.013	0.006	210	0.009	0.048	0.008
						0.005	0.013	0.006		0.009	0.076	0.010
						0.006	0.016	0.007		0.018	0.101	0.025
							0.008				0.037	
		BA=	0.018									
					predicted	0.059	0.318		predicted	0.023	0.168	
						BA=	0.084			BA=	0.033	
		0.018	0.16									
				High Beam			0.003				0.013	
						0.004	0.036	0.007		0.009	0.181	0.009
						0.007	0.033	0.008		0.012	0.189	0.007
		BA=	0.3		427	0.006	0.034	0.009	213	0.013	0.203	0.024
						0.005	0.036	0.007		0.018	0.204	0.020
						0.011	0.032	0.010		0.041	0.197	0.048
							0.013				0.061	
	(35 mph)											
					predicted	0.060	0.324		predicted	0.024	0.170	
	155	0.017	0.14			BA=	0.086			BA=	0.034	
				Dim-Hi Beam			0.004				0.005	
		BA=	0.025			0.005	0.022	0.006		0.010	0.100	0.007
						0.004	0.023	0.005		0.016	0.097	0.007
					413	0.004	0.023	0.005	207	0.007	0.098	0.010
						0.005	0.023	0.004		0.014	0.087	0.011
						0.008	0.023	0.008		0.014	0.072	0.024
		0.036	0.29				0.009				0.023	
Right Side					predicted	0.057	0.312		predicted	0.023	0.166	
		BA=	1.7			BA=	0.081			BA=	0.033	

Comparing the measured and predicted target and background luminances in the right-hand column of Table 8 shows that, as in the case of the smaller target, the model tends to overpredict luminance levels at detection. The discrepancies are quite large for both the target and its background with the 6% target, and substantially less for the 25% target. As a matter of fact, with the high beam and 25% target, the predicted target luminance value is, if anything, slightly low, while the predicted background luminance value looks reasonable.

The results for right-side (white) delineation are shown in Table 9. It should be noted that the prescribed detection distances listed in the left-hand side of the table, 74 and 103 feet for 25 and 35 mph respectively, differ from the distances used in the earlier tables. The values in this table simply represent the distance the car would travel in two seconds at the indicated speed. The distances given in the first two tables included a perception-response time and a stopping distance.

Looking at the right-hand column of Table 9, and comparing measured and predicted luminance values, a trend different than noted with the pedestrian targets is apparent. In this case the predicted target luminances are considerably less than those measured in the field. On the other hand, the predicted background luminances are, in several instances at least, fairly close to those measured in the field. Thus, it would appear that detection of the delineation required higher levels of contrast than predicted by the model

The results for small pedestrian targets on the left side of the car are given in Table 10. The format is the same as the first three tables, except for the fact that there are no data for the dimmed high beam. A comparison of the measured and predicted 1/2 distances in the right-hand column shows the same trend as was noted with targets on the right, i.e., the model predicts higher target luminances than were measured in the field test. In this case the predicted background luminances are also generally much above those measured in the field, although the differences tend to decrease as target reflectivity increases.

Table 11 gives the results for the large pedestrian target on the left side. The same trends are evident as in the case of the small pedestrian target, with the model predicting substantially higher luminance values than were measured in the field test. As before, it is interesting to compare performance with the large 6% and small 12% targets. The mean detection distances are within about 10%, and the measured luminances for both the target and the background are reasonably close. As before, however, the model predicts quite different luminance values for the two targets at the indicated distances.

Table 12 gives the results for the yellow delineation on the left side. The same trends are evident as with the white delineation on the right side. The model predicts that detection will be accomplished at a lower target luminance and about the same background luminance as measured in the field study.

Table 9. Comparison of Measured and Predicted Values - White Delineation Targets on the Right Side - Young Subjects

	PREDICTED		MEASURED				
				Actual		1/2 Distance	
	Distance (ft)	Luminance (Ft-L)		Distance (ft)	Luminance (Ft-L)	Distance (ft)	Luminance (Ft-L)
Low White Delineation	(25 mph)		Low Beam	295	0.018 $\boxed{0.186}$ 0.033 0.018	148	0.061 $\boxed{0.481}$ 0.071 0.062
	74	0.031 $\boxed{0.12}$		predicted	0.842 $\boxed{2.095}$	predicted	0.088 $\boxed{0.293}$
		BA= 0.044			BA= 1.203		BA= 0.126
		0.037 $\boxed{0.15}$	High Beam	241	0.013 $\boxed{0.294}$ 0.030 0.014	121	0.040 $\boxed{0.566}$ 0.064 0.044
		BA= 0.3		predicted	0.359 $\boxed{0.988}$	predicted	0.059 $\boxed{0.208}$
					BA= 0.513		BA= 0.084
	(35 mph)		Dim-Hi Beam	290	0.009 $\boxed{0.091}$ 0.012 0.006	145	0.015 $\boxed{0.313}$ 0.044 0.018
	103	0.045 $\boxed{0.17}$		predicted	0.774 $\boxed{1.943}$	predicted	0.084 $\boxed{0.282}$
Right Side		BA= 0.065			BA= 1.106		BA= 0.120
High White Delineation		0.072 $\boxed{0.26}$	Low Beam	247	0.019 $\boxed{0.569}$ 0.052 0.027	123	0.082 $\boxed{1.832}$ 0.117 0.103
		BA= 1.7		predicted	0.394 $\boxed{1.073}$	predicted	0.061 $\boxed{0.214}$
					BA= 0.563		BA= 0.087
			High Beam	249	0.020 $\boxed{0.456}$ 0.029 0.013	124	0.034 $\boxed{0.687}$ 0.060 0.038
				predicted	0.406 $\boxed{1.102}$	predicted	0.062 $\boxed{0.216}$
					BA= 0.581		BA= 0.088
			Dim-Hi Beam	227	0.005 $\boxed{0.312}$ 0.053 0.009	114	0.035 $\boxed{0.613}$ 0.080 0.038
Right Side				predicted	0.290 $\boxed{0.820}$	predicted	0.053 $\boxed{0.191}$
					BA= 0.414		BA= 0.076

Table 10. Comparison of Measured and Predicted Values - Small Pedestrian Targets on the Left Side - Young Subjects

	PREDICTED				MEASURED							
					Actual				1/2 Distance			
	Distance (ft)		Luminance (Ft-L)		Distance (ft)		Luminance (Ft-L)		Distance (ft)		Luminance (Ft-L)	
6%	(25 mph)			Low			0.005				0.006	
Small	94	0.17	0.36	Beam		0.009	0.023	0.009		0.016	0.036	0.017
Target					132	0.017	0.026	0.008	66	0.026	0.053	0.024
		BA=	0.24			0.029	0.040	0.046		0.042	0.077	0.096
							0.069				0.147	
		0.17	0.37		predicted	0.257	0.515		predicted	0.121	0.277	
		BA=	**0.3**			BA=	0.368			BA=	0.172	
	(35 mph)			High			0.011				0.014	
	155	0.33	0.64	Beam		0.016	0.034	0.017		0.031	0.079	0.022
					154	0.024	0.033	0.013	77	0.042	0.073	0.037
		BA=	0.47			0.025	0.032	0.032		0.047	0.056	0.057
							0.035				0.058	
Left Side		0.43	0.83		predicted	0.329	0.633		predicted	0.137	0.306	
		BA=	**1.7**			BA=	0.470			BA=	0.195	
12%	(25 mph)			Low			0.003				0.008	
Small	94	0.054	0.23	Beam		0.007	0.021	0.008		0.013	0.054	0.015
Target					204	0.012	0.025	0.007	102	0.025	0.059	0.022
		BA=	0.077			0.015	0.028	0.021		0.039	0.096	0.077
							0.025				0.109	
		0.069	0.30		predicted	0.140	0.494		predicted	0.059	0.249	
		BA=	**0.3**			BA=	0.200			BA=	0.084	
	(35 mph)			High			0.009				0.014	
	155	0.094	0.36	Beam		0.011	0.035	0.013		0.030	0.111	0.021
					230	0.016	0.032	0.017	115	0.035	0.085	0.025
		BA=	0.14			0.018	0.029	0.023		0.038	0.070	0.051
							0.025				0.049	
Left Side		0.17	0.63		predicted	0.170	0.575		predicted	0.066	0.274	
		BA=	**1.7**			BA=	0.242			BA=	0.095	
25%	(25 mph)			Low			0.003				0.006	
Small	94	0.025	0.23	Beam		0.005	0.031	0.006		0.014	0.085	0.008
Target					311	0.011	0.033	0.006	155	0.023	0.101	0.008
		BA=	0.036			0.010	0.032	0.016		0.024	0.110	0.042
							0.015				0.044	
		0.037	0.33		predicted	0.113	0.706		predicted	0.042	0.336	
		BA=	**0.3**			BA=	0.161			BA=	0.060	
	(35 mph)			High			0.005				0.014	
	155	0.042	0.34	Beam		0.008	0.039	0.009		0.018	0.141	0.017
					327	0.010	0.038	0.008	164	0.030	0.130	0.012
		BA=	0.060			0.011	0.038	0.017		0.026	0.106	0.039
							0.015				0.037	
Left Side		0.087	0.70		predicted	0.123	0.753		predicted	0.045	0.354	
		BA=	**1.7**			BA=	0.175			BA=	0.064	

Table 11. Comparison of Measured and Predicted Values - Large Pedestrian Targets on the Left Side - Young Subjects

	PREDICTED (25 mph)			MEASURED								
					Actual				1/2 Distance			
	Distance (ft)	Luminance (Ft-L)			Distance (ft)	Luminance (Ft-L)			Distance (ft)	Luminance (Ft-L)		
6%	(25 mph)			Low			0.001				0.002	
Large				Beam		0.002	0.004	0.002		0.001	0.002	0.002
Target	94	0.18	0.39			0.003	0.006	0.002		0.004	0.008	0.004
					173	0.003	0.014	0.004	86	0.005	0.021	0.007
		BA=	0.26			0.010	0.016	0.003		0.018	0.040	0.010
						0.019	0.024	0.025		0.040	0.063	0.079
							0.036				0.123	
		0.18	0.40									
					predicted	0.338	0.628		predicted	0.170	0.372	
		BA=	**0.3**									
						BA=	0.482			BA=	0.242	
	(35 mph)			High			0.004				0.002	
				Beam		0.006	0.021	0.011		0.008	0.036	0.007
	155	0.29	0.56			0.010	0.021	0.006		0.020	0.090	0.014
					205	0.008	0.024	0.011	102	0.014	0.085	0.012
		BA=	0.42			0.015	0.021	0.009		0.033	0.069	0.019
						0.018	0.022	0.022		0.039	0.051	0.050
							0.027				0.055	
		0.39	0.76									
Left					predicted	0.442	0.780		predicted	0.190	0.404	
Side		**BA=**	**1.7**									
						BA=	0.631			BA=	0.272	
25%	(25 mph)			Low			0.002				0.002	
Large				Beam		0.003	0.015	0.004		0.004	0.016	0.005
Target	94	0.026	0.24			0.005	0.017	0.003		0.005	0.027	0.002
					337	0.006	0.020	0.006	168	0.002	0.053	0.007
		BA=	0.038			0.009	0.023	0.006		0.014	0.084	0.003
						0.008	0.027	0.013		0.019	0.103	0.031
							0.012				0.038	
		0.038	0.34									
					predicted	0.090	0.548		predicted	0.041	0.318	
		BA=	**0.3**									
						BA=	0.129			BA=	0.058	
	(35 mph)			High			0.007				0.006	
				Beam		0.008	0.048	0.005		0.011	0.137	0.014
	155	0.038	0.30			0.009	0.044	0.005		0.021	0.158	0.009
					352	0.009	0.040	0.010	176	0.009	0.142	0.016
		BA=	0.054			0.014	0.040	0.007		0.024	0.121	0.008
						0.012	0.038	0.015		0.023	0.102	0.031
							0.015				0.034	
		0.080	0.64									
Left					predicted	0.096	0.571		predicted	0.043	0.328	
Side		**BA=**	**1.7**									
						BA=	0.137			BA=	0.061	

Table 12. Comparison of Measured and Predicted Values - Yellow Delineation Targets on the Left Side - Young Subjects

	PREDICTED (25 mph)			MEASURED			
				Actual		1/2 Distance	
	Distance (ft)	Luminance (Ft-L)		Distance (ft)	Luminance (Ft-L)	Distance (ft)	Luminance (Ft-L)
Low Yellow Delineation	(25 mph)		Low Beam	181	0.017 0.183 0.034 0.027	90	0.067 0.591 0.118 0.117
	74	0.050 0.20		predicted	0.288 0.892	predicted	0.065 0.247
		BA= 0.071			BA= 0.411		BA= 0.093
		0.063 0.25	High Beam	196	0.015 0.146 0.031 0.018	98	0.048 0.365 0.110 0.053
		BA= 0.3					
Left Side				predicted	0.366 1.101	predicted	0.075 0.276
					BA= 0.523		BA= 0.106
High Yellow Delineation	(35 mph)		Low Beam	198	0.010 0.210 0.058 0.025	99	0.047 0.800 0.199 0.083
	103	0.080 0.30		predicted	0.378 1.131	predicted	0.076 0.280
		BA= 0.12			BA= 0.540		BA= 0.108
		0.14 0.50	High Beam	215	0.017 0.175 0.021 0.016	107	0.051 0.500 0.102 0.051
		BA= 1.7					
Left Side				predicted	0.497 1.440	predicted	0.086 0.314
					BA= 0.710		BA= 0.123

Older subjects. Table 13 lists the results of measured and predicted detection distances for the small pedestrian targets on the right side for the older subjects. This table is identical in format to the others, and is directly comparable to Table 7, which shows the same relationships for the young subjects.

A comparison of Table 13 with Table 7 shows that, as expected, the older subjects required substantially higher levels of illumination to detect the targets, hence detection occurred at shorter distances. Comparing actual and predicted luminance and contrast levels, however, shows that the model is overpredicting illumination by a large margin. For example, with the 12% target at 25 mph, the predicted target luminance was about 0.60 ft-L, while the average of the measured luminances was less than a third of that. The average of the surround luminances is about one-third to one-half of the predicted luminances.

Table 14 lists the results with the large target on the right side. With the 6% target the discrepancy between measured and predicted luminances is greater than in the case of the small targets. However, in the case of the 25% targets, the predictions are fairly close. The same relationship was found in the case of the young subjects (see Table 8). The 6% large target and the 12% small target yielded roughly comparable detection distance, particularly in the case of the dimmed high beam, but the model predicts very different luminance values for each.

Table 15 lists the results for the white delineation on the right side of the car. The results vary greatly with the beam pattern employed. With the low beam the predicted luminance of the delineation was about one-third of the measured luminance. The predicted background, however, was about double the luminance of the measured background. For the other two beams, the predicted and measured delineation luminances are much closer, although the model still underpredicts the luminance of the delineation and overpredicts the luminance of the background. Thus, the test delineation required higher luminance and greater contrast than predicted by the model. This is generally the same trend as found for the young subjects.

Table 16 lists the results for the small targets on the left side. The trend here is the same as noted earlier, with the model substantially overpredicting the luminance of both the target and the background.

Table 17 lists the results for the large targets on the left side. The same trend is evident as in the other pedestrian analyses, i.e., the model yields luminance estimates that are much higher than measured in the field. This is true for both the 6 and 25% targets, although the differences are not as great in the case of the latter target.

Table 13. Comparison of Measured and Predicted Values - Small Pedestrian Targets on the Right Side - Older Subjects

	PREDICTED		MEASURED	Actual		1/2 Distance	
	Distance (ft)	Luminance (Ft-L)		Distance (ft)	Luminance (Ft-L)	Distance (ft)	Luminance (Ft-L)
6% Small Target	(25 mph) 94	0.92 1.98 BA= 1.31 0.87 1.9	Low Beam	87 predicted	0.033 0.028 0.047 0.022 0.052 0.063 0.012 0.087 0.093 0.118 0.134 0.85 1.86 BA= 1.21	43 predicted	0.043 0.037 0.057 0.032 0.071 0.080 0.014 0.112 0.124 0.170 0.178 0.62 1.53 BA= 0.89
	(35 mph) 155	**BA= 0.3** 2.12 4.08	High Beam	94 predicted	0.043 0.027 0.093 0.031 0.028 0.080 0.016 0.041 0.057 0.060 0.067 0.92 1.99 BA= 1.32	47 predicted	0.062 0.031 0.134 0.032 0.031 0.118 0.014 0.049 0.074 0.082 0.084 0.62 1.52 BA= 0.89
Right Side		BA= 3.03 2.0 3.9 **BA= 1.7**	Dim-Hi Beam	105 predicted	0.024 0.015 0.062 0.036 0.019 0.054 0.020 0.019 0.041 0.044 0.048 1.06 2.23 BA= 1.51	53 predicted	0.037 0.017 0.097 0.058 0.030 0.087 0.028 0.008 0.057 0.059 0.067 0.64 1.52 BA= 0.91
12% Small Target	(25 mph) 94	0.14 0.60 BA= 0.20 0.14 0.62	Low Beam	141 predicted	0.020 0.019 0.062 0.012 0.028 0.076 0.010 0.067 0.099 0.062 0.080 0.21 0.82 BA= 0.30	71 predicted	0.033 0.042 0.092 0.021 0.068 0.120 0.023 0.144 0.196 0.109 0.145 0.12 0.53 BA= 0.17
	(35 mph) 155	**BA= 0.3** 0.24 0.90	High Beam	157 predicted	0.021 0.022 0.077 0.023 0.028 0.066 0.014 0.031 0.055 0.041 0.042 0.24 0.92 BA= 0.34	78 predicted	0.036 0.037 0.194 0.045 0.027 0.170 0.027 0.038 0.112 0.067 0.078 0.12 0.55 BA= 0.18
Right Side		BA= 0.34 0.29 1.1 **BA= 1.7**	Dim-Hi Beam	129 predicted	0.017 0.013 0.086 0.026 0.013 0.076 0.016 0.016 0.058 0.040 0.040 0.19 0.75 BA= 0.27	64 predicted	0.030 0.016 0.170 0.048 0.022 0.146 0.030 0.018 0.096 0.061 0.064 0.11 0.52 BA= 0.16

Table 13. Continued

<table>
<tr>
<td rowspan="3">25%
Small
Target

Right
Side</td>
<td rowspan="3">(25 mph)
94   0.04   0.40
BA= 0.06

0.052   0.47
BA= 0.3

(35 mph)
155   0.07   0.57
BA= 0.10

0.11   0.88
BA= 1.7</td>
<td>Low
Beam</td>
<td>0.008
0.010 0.067 0.016
241   0.021 0.075 0.013
0.023 0.086 0.030
0.031

predicted   0.14   0.94
BA= 0.19</td>
<td>0.025
0.026 0.180 0.021
121   0.039 0.244 0.016
0.078 0.321 0.075
0.103

predicted   0.06   0.47
BA= 0.08</td>
</tr>
<tr>
<td>High
Beam</td>
<td>0.014
0.017 0.122 0.018
227   0.015 0.100 0.012
0.026 0.097 0.027
0.031

predicted   0.12   0.87
BA= 0.18</td>
<td>0.032
0.027 0.369 0.035
114   0.030 0.313 0.022
0.040 0.227 0.056
0.061

predicted   0.05   0.45
BA= 0.07</td>
</tr>
<tr>
<td>Dim-Hi
Beam</td>
<td>0.011
0.011 0.078 0.015
222   0.011 0.075 0.007
0.014 0.071 0.024
0.021

predicted   0.12   0.84
BA= 0.17</td>
<td>0.023
0.027 0.284 0.033
111   0.018 0.248 0.020
0.027 0.178 0.049
0.049

predicted   0.05   0.44
BA= 0.07</td>
</tr>
</table>

Table 14. Comparison of Measured and Predicted Values - Large Pedestrian Targets on the Right Side - Older Subjects

	PREDICTED			MEASURED								
					Actual				1/2 Distance			
	Distance (ft)	Luminance (Ft-L)			Distance (ft)	Luminance (Ft-L)			Distance (ft)	Luminance (Ft-L)		
6% Large Target	(25 mph)			Low Beam			0.002				0.000	
						0.003	0.005	0.003		0.002	0.003	0.001
						0.005	0.009	0.004		0.005	0.006	0.004
	94	1.15	2.50		107	0.011	0.025	0.007	54	0.014	0.031	0.007
						0.035	0.050	0.017		0.063	0.068	0.024
						0.078	0.080	0.047		0.111	0.113	0.053
							0.119				0.181	
		BA=	1.65									
					predicted	1.23	2.59		predicted	1.29	3.08	
						BA=	1.76			BA=	1.84	
		1.1	2.4									
				High Beam			0.016				0.013	
						0.014	0.070	0.016		0.018	0.093	0.017
						0.016	0.085	0.017		0.020	0.122	0.028
		BA=	0.3		121	0.021	0.085	0.025	61	0.032	0.141	0.022
						0.033	0.071	0.027		0.065	0.119	0.050
						0.024	0.050	0.037		0.031	0.070	0.063
							0.061				0.094	
	(35 mph)											
					predicted	1.34	2.75		predicted	1.20	2.81	
	155	1.80	3.46			BA=	1.92			BA=	1.71	
				Dim-Hi Beam			0.008				0.012	
		BA=	2.57			0.009	0.040	0.008		0.013	0.059	0.011
						0.013	0.051	0.013		0.013	0.088	0.016
					125	0.013	0.057	0.020	62	0.020	0.104	0.036
Right Side						0.021	0.047	0.023		0.040	0.086	0.057
						0.010	0.034	0.035		0.009	0.057	0.056
		1.8	3.4				0.043				0.069	
					predicted	1.38	2.81		predicted	1.18	2.76	
		BA=	1.7			BA=	1.97			BA=	1.69	
25% Large Target	(25 mph)			Low Beam			0.003				0.004	
						0.004	0.022	0.004		0.004	0.022	0.004
						0.007	0.029	0.006		0.007	0.039	0.005
	94	0.047	0.42		239	0.007	0.041	0.008	120	0.017	0.111	0.011
						0.009	0.063	0.009		0.034	0.206	0.014
						0.016	0.083	0.023		0.069	0.312	0.055
							0.031				0.105	
		BA=	0.067									
					predicted	0.10	0.67		predicted	0.052	0.44	
						BA=	0.14			BA=	0.074	
		0.054	0.49									
				High Beam			0.013				0.016	
						0.010	0.139	0.008		0.014	0.343	0.011
						0.010	0.142	0.007		0.017	0.374	0.019
		BA=	0.3		251	0.010	0.148	0.020	125	0.025	0.374	0.026
						0.015	0.146	0.017		0.034	0.295	0.029
						0.031	0.138	0.037		0.030	0.204	0.049
							0.044				0.058	
	(35 mph)											
					predicted	0.10	0.70		predicted	0.053	0.45	
	155	0.062	0.50			BA=	0.15			BA=	0.076	
				Dim-Hi Beam			0.005				0.009	
		BA=	0.089			0.009	0.082	0.007		0.010	0.226	0.009
						0.013	0.081	0.006		0.027	0.263	0.019
					238	0.005	0.080	0.014	119	0.017	0.285	0.022
Right Side						0.011	0.071	0.012		0.039	0.249	0.036
						0.012	0.059	0.021		0.022	0.183	0.055
		0.10	0.79				0.019				0.065	
					predicted	0.10	0.67		predicted	0.052	0.44	
		BA=	1.7			BA=	0.14			BA=	0.074	

Table 15. Comparison of Measured and Predicted Values - White Delineation Targets on the Right Side - Older Subjects

	PREDICTED			MEASURED								
					Actual				1/2 Distance			
	Distance (ft)		Luminance (Ft-L)		Distance (ft)		Luminance (Ft-L)		Distance (ft)		Luminance (Ft-L)	
Low	(25 mph)			Low	182	0.038	0.569	0.096	91	0.120	2.435	0.149
White				Beam			0.043				0.151	
	73	0.17	0.65									
					predicted	1.16	3.58		predicted	0.21	0.81	
		BA=	0.24									
						BA=	1.65			BA=	0.31	
Delineation												
		0.17	0.66									
				High	123	0.039	0.553	0.060	62	0.075	0.908	0.164
		BA=	**0.3**	Beam			0.043				0.068	
					predicted	0.37	1.29		predicted	0.15	0.59	
						BA=	0.52			BA=	0.21	
Right	(35 mph)			Dim-Hi	141	0.017	0.332	0.050	71	0.063	0.665	0.170
Side				Beam			0.021				0.070	
	103	0.26	0.95									
					predicted	0.51	1.73		predicted	0.16	0.64	
		BA=	0.37									
						BA=	0.73			BA=	0.23	
		0.10	0.79									
High				Low	175	0.039	0.935	0.070	88	0.122	2.982	0.197
White		**BA=**	**1.7**	Beam			0.047				0.164	
					predicted	1.00	3.14		predicted	0.20	0.77	
						BA=	1.43			BA=	0.29	
Delineation												
				High	135	0.027	0.647	0.051	67	0.071	0.903	0.110
				Beam			0.031				0.078	
					predicted	0.46	1.56		predicted	0.16	0.62	
						BA=	0.65			BA=	0.22	
Right				Dim-Hi	138	0.019	0.426	0.065	69	0.064	0.950	0.106
Side				Beam			0.022				0.067	
					predicted	0.48	1.64		predicted	0.16	0.63	
						BA=	0.69			BA=	0.23	

Table 16. Comparison of Measured and Predicted Values - Small Pedestrian Targets on the Left Side - Older Subjects

	PREDICTED			MEASURED								
					Actual				1/2 Distance			
	Distance (ft)	Luminance (Ft-L)			Distance (ft)	Luminance (Ft-L)			Distance (ft)	Luminance (Ft-L)		
6%	(25 mph)			Low			0.006				0.006	
Small	94	1.3	2.8	Beam		0.015	0.035	0.016		0.019	0.042	0.020
Target					72	0.025	0.050	0.022	36	0.031	0.065	0.031
		BA=	1.9			0.041	0.073	0.091		0.048	0.093	0.118
							0.140				0.183	
		1.1	2.3		predicted	1.00	2.26		predicted	0.82	2.02	
		BA=	**0.3**			BA=	1.43			BA=	1.17	
	(35 mph)			High			0.014				0.015	
	155	2.7	5.3	Beam		0.032	0.083	0.023		0.039	0.105	0.025
					71	0.043	0.076	0.039	35	0.052	0.095	0.050
		BA=	3.9			0.049	0.058	0.059		0.060	0.070	0.071
							0.060				0.071	
		2.7	5.3		predicted	0.99	2.24		predicted	0.82	2.03	
		BA=	**1.7**			BA=	1.41			BA=	1.17	
12%	(25 mph)			Low			0.009				0.013	
Small	94	0.23	0.99	Beam		0.014	0.056	0.015		0.015	0.073	0.021
Target					95	0.026	0.061	0.024	48	0.031	0.076	0.039
		BA=	0.33			0.041	0.102	0.083		0.056	0.150	0.122
							0.117				0.178	
		0.23	0.98		predicted	0.23	1.01		predicted	0.15	0.72	
		BA=	**0.3**			BA=	0.33			BA=	0.21	
	(35 mph)			High			0.012				0.021	
	155	0.42	1.6	Beam		0.025	0.093	0.019		0.047	0.178	0.028
					128	0.033	0.075	0.020	64	0.042	0.121	0.046
		BA=	0.60			0.034	0.060	0.045		0.055	0.105	0.072
							0.045				0.063	
		0.52	2.01		predicted	0.33	1.31		predicted	0.17	0.79	
		BA=	**1.7**			BA=	0.47			BA=	0.24	
25%	(25 mph)			Low			0.007				0.018	
Small	94	0.08	0.74	Beam		0.015	0.098	0.009		0.014	0.186	0.020
Target					144	0.024	0.118	0.010	72	0.032	0.224	0.037
		BA=	0.12			0.027	0.130	0.048		0.045	0.276	0.104
							0.054				0.143	
		0.10	0.87		predicted	0.13	1.06		predicted	0.07	0.63	
		BA=	**0.3**			BA=	0.19			BA=	0.10	
	(35 mph)			High			0.013				0.014	
	155	0.14	1.14	Beam		0.014	0.121	0.016		0.039	0.333	0.030
					182	0.028	0.112	0.012	91	0.040	0.290	0.033
		BA=	0.20			0.024	0.093	0.034		0.045	0.214	0.062
							0.033				0.059	
		0.23	1.8		predicted	0.18	1.36		predicted	0.08	0.73	
		BA=	**1.7**			BA=	0.25			BA=	0.12	

Table 17. Comparison of Measured and Predicted Values - Large Pedestrian Targets on the Left Side - Older Subjects

	PREDICTED			MEASURED								
					Actual				1/2 Distance			
	Distance (ft)		Luminance (Ft-L)		Distance (ft)		Luminance (Ft-L)		Distance (ft)		Luminance (Ft-L)	
6%	(25 mph)			Low			0.002				0.002	
Large	94	1.7	3.6	Beam		0.001	0.002	0.002		0.001	0.001	0.002
Target						0.005	0.009	0.005		0.006	0.010	0.005
		BA=	2.4		44	0.007	0.024	0.009	22	0.008	0.025	0.009
						0.022	0.053	0.015		0.024	0.060	0.017
						0.051	0.084	0.110		0.057	0.096	0.126
		1.3	2.9				0.175				0.202	
		BA=	**0.3**		predicted	2.06	5.01		predicted			
						BA=	2.95			BA=		
	(35 mph)											
	155	2.7	5.3									
				High			0.002				0.002	
		BA=	3.9	Beam		0.008	0.036	0.008		0.006	0.036	0.003
						0.020	0.085	0.014		0.020	0.143	0.017
					107	0.013	0.081	0.012	53	0.016	0.129	0.011
		2.5	4.7			0.032	0.065	0.018		0.044	0.107	0.028
						0.038	0.049	0.048		0.056	0.072	0.072
		BA=	1.7				0.053				0.072	
					predicted	1.82	3.83		predicted	1.73	4.09	
						BA=	2.60			BA=	2.47	
25%	(25 mph)			Low			0.002				0.000	
Large	94	0.09	0.78	Beam		0.004	0.016	0.005		0.001	0.003	0.001
Target						0.005	0.028	0.002		0.010	0.034	0.003
		BA=	0.12		154	0.002	0.060	0.007	77	0.006	0.105	0.011
						0.014	0.098	0.003		0.022	0.214	0.017
						0.022	0.119	0.035		0.074	0.180	0.086
		0.10	0.92				0.044				0.137	
		BA=	**0.3**		predicted	0.13	1.01		predicted	0.08	0.74	
						BA=	0.18			BA=	0.11	
	(35 mph)											
	155	0.13	1.0									
				High			0.006				0.001	
		BA=	0.18	Beam		0.011	0.136	0.014		0.004	0.169	0.009
						0.021	0.157	0.009		0.018	0.524	0.015
					176	0.009	0.142	0.016	88	0.015	0.533	0.009
		0.21	1.7			0.024	0.121	0.008		0.024	0.383	0.018
						0.023	0.102	0.031		0.035	0.262	0.034
		BA=	**1.7**				0.034				0.063	
					predicted	0.14	1.10		predicted	0.08	0.77	
						BA=	0.20			BA=	0.12	

Table 18 lists the results for the yellow delineation on the left of the test car. In this case the actual and predicted delineation luminance values for the one-half distance case are reasonably close. If an average is taken of the three background luminance values they are always less than predicted, but, again, are reasonably close. Of all the configurations checked, this is the only one that consistently gave results close to the model's predictions.

Discussion

The results of this investigation are very complex. A brief and fair summary would be to say that, in many cases at least, the models yield predictions that are not beyond reason. Given their complexity, they perform relatively well. On the other hand, there are significant discrepancies, particularly in the case of the older driver data, and there may be merit in seeking to improve on the models' predictive capability. Data such as presented in this report should be of some assistance in this respect.

Table 18. Comparison of Measured and Predicted Values - Yellow Delineation Targets on the Left Side - Older Subjects

PREDICTED				MEASURED								
					Actual				1/2 Distance			
	Distance (ft)		Luminance (Ft-L)		Distance (ft)		Luminance (Ft-L)		Distance (ft)		Luminance (Ft-L)	
Low	(25 mph)			Low	114	0.053	0.464	0.086	57	0.088	0.771	0.164
Yellow	73	0.24	0.93	Beam			0.088				0.158	
		BA=	0.34		predicted	0.52	1.84		predicted	0.19	0.76	
						BA=	0.74			BA=	0.27	
Delineation		0.23	0.92									
		BA=	**0.3**	High	104	0.044	0.347	0.103	52	0.075	0.502	0.167
				Beam			0.051				0.075	
	(35 mph)				predicted	0.42	1.54		predicted	0.18	0.73	
	103	0.41	1.5									
						BA=	0.60			BA=	0.25	
		BA=	0.59									
High				Low	111	0.042	0.711	0.162	55	0.065	1.115	0.332
Yellow		0.49	1.8	Beam			0.074				0.113	
		BA=	**1.7**		predicted	0.48	1.74		predicted	0.18	0.75	
						BA=	0.69			BA=	0.26	
Delineation												
				High	112	0.048	0.481	0.099	56	0.084	0.719	0.141
				Beam			0.049				0.081	
					predicted	0.49	1.77		predicted	0.18	0.75	
						BA=	0.70			BA=	0.26	

THE VISIBILITY OF DELINEATION

Introduction

The NHTSA headlighting models also consider the visibility of delineation. In the validation study described earlier in this report the results of the delineation work showed relatively large differences between predicted and measured visibility. However, there were discrepancies between the assumptions in the models and the stimuli employed in the field test. Specifically, the models assume a stripe 50 feet long, while the test used sixteen-foot sections. In view of that problem it was deemed advisable to conduct a further study of delineation visibility.

Method

In the investigation, subjects drove a test car down the center of a two-lane road at a speed of about 25 mph. The delineation under investigation consisted of two 48-foot strips positioned on one side of the car. At the far end of one of these strips (from the perspective of the subject) a 16-foot section of delineation was placed on about a 45^{o} angle to simulate the start of a right or left curve. Distances were measured from where the subject could make out the delineation to the start of the delineation, and from where the subject could identify the curve to the start of the curve.

Independent Variables

The primary independent variables were delineation position (right or left of the car), turn direction (right or left), and headlamp intensity (three levels: full low-beam, and 33% and 20% of full low-beam).

Glare was provided by an adjustable source on the hood of the car (just as described in the validation study) on all trials when the delineation was on the subject's right. On one set of trials, using the full low-beam, glare was provided by a single headlamp positioned in the middle of the "oncoming lane." Again, this is the same approach used in the validation study. Glare was not provided when the delineation was on the subject's left, except during the set of trials when the single headlamp on the road was used for glare.

Subjects

A total of 19 subjects participated in the study. Of these 8 were "old" (i.e., 60 and older), and 11 were in the range of 30 to 40. As a preliminary step, 32 individuals (16 in each age group) were subjected to three brief screening tests. This will be described in a later section.

Dependent Variable

The dependent measure was the distance from the start of the delineation and the start of the curve where the subject indicated detection of each.

Test Site

The test was carried out on a private road at an airport. The road is newly constructed of asphaltic concrete, and consists of two twelve-foot lanes, with gravel shoulders. The road is approximately 2,000 feet long, flat and straight. A center skip line is present, there are no edge lines.

Photometry

Measures were made of the luminance of the delineation and the surrounding pavement, as described in the validation study, using the test vehicle's headlamps. Luminance measures were made using a Model 1980A Spectra-Pritchard Photometer, using the same approach described in the validation chapter. For each set of measurements the test car was positioned with its headlights at the required distance and aligned with the center of the road. The photometer was set behind the car, aiming through the open rear window over the driver's position. Readings were taken of the luminance of the strip at the point nearest the car, and of the pavement on either side and in front.

Equipment

The test vehicle was a full-size station wagon. It was equipped with a precision voltage control system, which was used to drive the headlamps. It was also equipped with a digital counter, driven off the left front wheel (four counts, each equal to 1.72 feet, per revolution).

The delineation was in the form of 4-inch striping tape, of the type used in construction areas, etc., supplied by 3M. Hardboard, 1/8-inch thick, was used as a backing. The hardboard was cut into 4-inch strips and the tape attached to it. Six of these strips, each eight feet long, were placed end to end to make the 48-foot stripe. The intent was that the subject drive down the center of the road, so the delineation was placed six feet to one side of the existing skip line.

Subject Screening

As a first step in the study subjects were brought into the Institute and given a brief screening battery. Measures were taken of glare discomfort, choice reaction time, and several vision characteristics, using a Titmus Vision Tester.

In the glare discomfort test subjects experienced a two-second exposure to glare from a 35mm projector. The glare levels (measured at the plane of the subject's eyes) ranged from about 50 lux to 0.004 lux, and the source was separated from the fixation point by two degrees. Dark adaptation was established by illuminating a wall behind the glare apparatus to a level of 0.3 ft-L (about 1 cd/m^2).

The results of this screening are given in Figure 10. In general, the data conform to other data taken under similar circumstances (e.g., Olson and Sivak, 1983). Although the differences are not statistically significant, the older drivers in this sample tended to rate each level of glare less comfortable than did the younger drivers, which has not been the usual finding. The data from this screening were used to set the glare level for each subject to that which they judged equal to deBoer "4."

The second test was a measure of reaction time. It was run on a personal computer. Each trial was preceded by an alerting tone. Shortly after, a numeral 1, 2, or 3 appeared on the screen. The subject's task was to press a corresponding key on the computer keyboard as soon as possible. A total of 30 trials were administered.

The final test was a general visual screening using a Titmus Vision Tester. Test were run of far acuity, vertical and lateral phoria, and color vision.

The results of the entire screening battery are given in Table 19. Subject numbers are shown on the left. Far point visual acuity is shown in the usual way. None of the subjects showed much of a vertical or lateral phoria. The color test results show the number hidden in the plate and the subjects' responses. Bold face entries indicate errors. With few exceptions, most subjects had little trouble with the color test. The entries under deBoer=4 show the glare level (in lux) that corresponded to deBoer 4 in the discomfort glare screening. Finally, mean reaction times are shown in the last column.

Procedure

Subjects were run individually. They reported to the Institute, signed a consent form, and were driven to the test site. At the site the car was parked centered in the road, facing toward the test delineation strips, and about 100 feet away. The experimenter mounted the glare lamp on the hood, and set it in a position appropriate for an oncoming car about 150-200 feet away. The instructions were read to the subject at this point, and any questions were answered. The experimenter then drove the car to one end of the road and moved to the rear seat while the subject moved to the driver's seat. The glare level was set, using a lux meter. Two practice trials were made, and the test started.

On each run through the course the subjects were instructed to press one button when they could see the delineation, and a second button when they could make out the curve. Each button press started a counter, which the experimenter stopped when the start of the curve was reached. The distance from that point to the start of the delineation was subtracted from the total on the first counter.

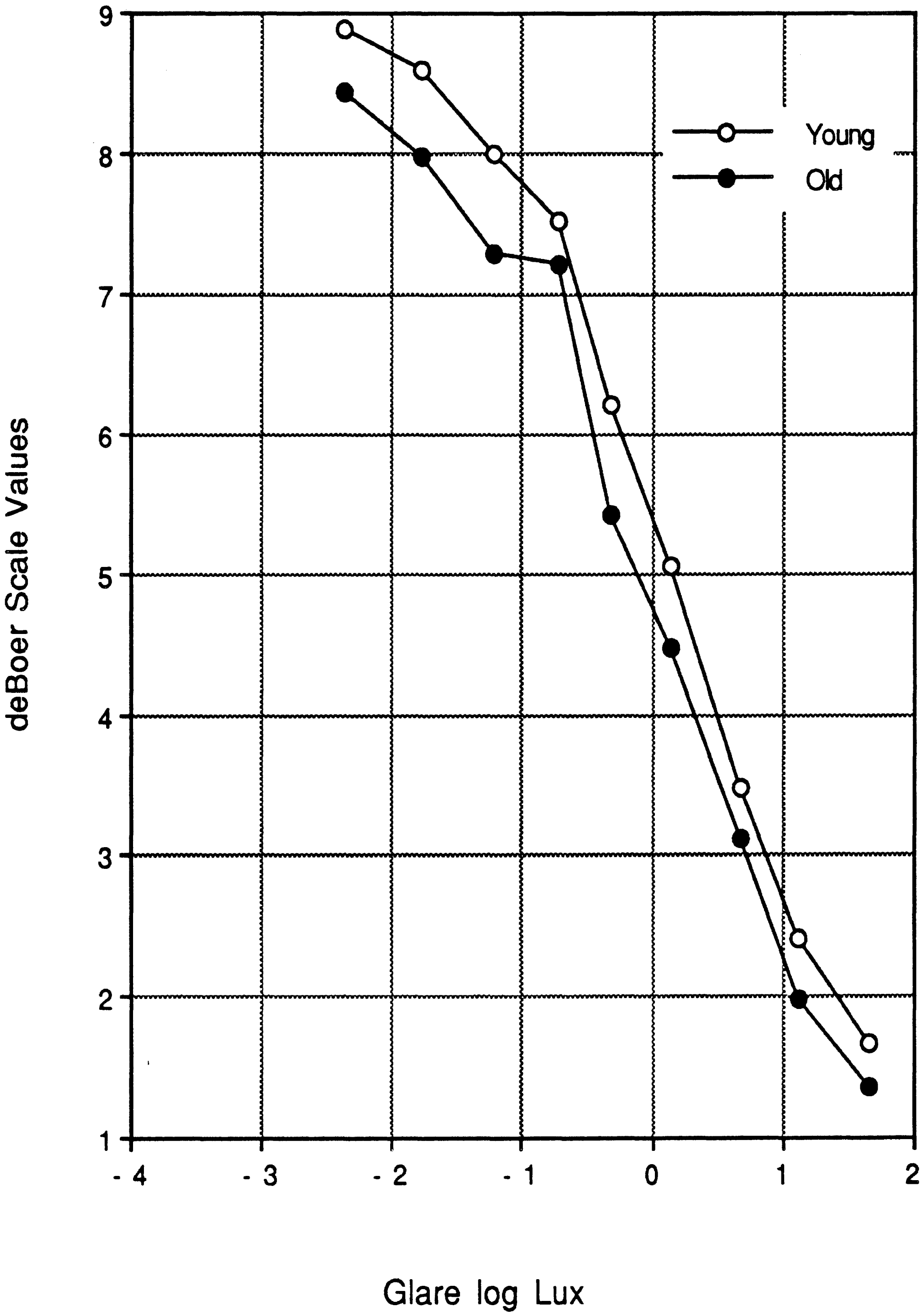

Figure 10. Results of Discomfort Glare Screening for Delineation Study

Table 19. Result of Subject Screening

Younger Subjects

Sub#		Far Point		Vertical		Lateral		Color						DeBoer=4	Reaction
				4		8		12	5	26	6	16	can't	(Lx)	(sec)
1	M	7	20 / 30	2	D 1	9	R 1	12	no	26	6	no	can't	0.60	0.70
2	F	12	20 / 17	4	0	8	0	12	5	26	6	16	can't	2.59	0.50
3	M	14	20 / 13	4	0	10	R 2	12	no	26	6	16	can't	13.0	0.59
4	F	8	20 / 25	4	0	7	L 1	12	6	26	6	16	can't	0.99	0.66
5	M	14	20 / 13	5	U 1/2	10	R 2	12	5	26	6	16	can't	1.63	0.61
6	M	13	20 / 15	4	0	8	0	12	5	26	6	16	can't	2.59	0.62
7	M	10	20 / 20	3	D 1/2	9	R 1	12	no	26	6	no	can't	3.53	0.69
8	M	10	20 / 20	5	U 1/2	9	R 1	12	5	26	6	16	can't	2.59	0.56
9	F	10	20 / 20	4	0	9	R 1	12	5	26	6	16	can't	2.59	0.60
10	F	14	20 / 13	4	0	8	0	12	5	26	6	16	can't	2.59	0.63
11	F	10	20 / 20	4	0	9	R 1	12	5	26	6	16	can't	5.86	0.62
12	F	9	20 / 22	4	0	9	R 1	12	5	26	6	16	can't	0.92	0.57
13	F	14	20 / 13	5	U 1/2	9	R 1	12	no	no	6	no	can't	1.99	0.66
14	F	14	20 / 13	4	0	9	R 1	12	5	26	6	16	can't	2.74	0.63
15	F	12	20 / 17	4	0	9	R 1	12	5	26	6	16	can't	3.65	0.67
16	M	14	20 / 13	4	0	10	R 2	12	5	26	6	36	20	4.80	0.65
Average		11.6												3.29	0.62

Elder Subjects

Sub#		Far Point		Vertical		Lateral		Color						DeBoer=4	Reaction
														(Lx)	(sec)
1	M	6	20 / 35	3	D 1/2	10	R 2	12	no	26	8	no	can't	2.59	0.61
2	F	9	20 / 22	4	0	10	R 2	12	5	26	6	no	can't	8.48	0.57
3	M	9	20 / 22	4	0	7	L 1	12	5	26	6	16	can't	4.80	0.68
4	M	13	20 / 15	6	U 1	9	R 1	12	no	26	6	no	can't	0.36	0.70
5	F	4	20 / 50	4	0	8	0	12	no	26	6	no	can't	0.42	0.68
6	M	6	20 / 35	4	0	8	0	12	no	26	6	no	can't	3.02	0.93
7	M	7	20 / 30	5	U 1/2	7	L 1	12	no	26	6	8	8	0.95	1.22
8	M	11	20 / 18	3	D 1/2	9	R 1	12	5	26	6	no	can't	1.18	0.94
9	M	9	20 / 22	2	D 1	4	L 4	12	5	26	6	6	28	1.21	0.74
10	F	5	20 / 40	5	U 1/2	5	L 3	12	5	26	6	16	can't	0.75	0.86
11	F	12	20 / 17	3	D 1/2	10	R 2	12	no	36	6	no	can't	0.41	0.81
12	M	8	20 / 25	5	U 1/2	6	L 2	12	no	86	6	no	can't	2.37	0.61
13	F	7	20 / 30	5	U 1/2	9	R 1	12	no	26	6	no	can't	5.44	0.81
14	M	4	20 / 50	5	U 1/2	10	R 2	12	5	26	6	16	28	6.16	0.74
15	F	4	20 / 50	5	U 1/2	10	R 2	12	no	26	6	no	can't	5.44	0.81
16	M	4	20 / 50	1	D 1-1/2	10	R 2	12	no	26	6	no	can't	4.80	1.65
Average		7.4												3.02	0.84

There were eight treatment combinations (right or left curve, shown beyond the first or second strip of delineation, appearing on the left or right of the car). Each was viewed once by each subject under each of the three illumination levels. A fourth set of trials was run with the glare source on the road. This was done, as with the hood-mounted glare source, when the delineation was to the right of the test car. On the return run of this series the hood-mounted glare source was used when the delineation was on the left, for the only time in the test.

Conventional balancing techniques were used to neutralize time and order effects. The test, including set up, instructions, and practice trials, took about one hour to complete.

Results

The results of this study are summarized in four tables, two for each age group. Table 20 provides the results for the young subjects in detecting straight sections of delineation.

Table 20 is divided into two main sections, labeled "measurement" (which lists the results of the field tests, as well as the half-distance data appropriate for unalerted subjects) and "predicted" (which lists results obtained using the NHTSA models). The labels across the top have the following meaning:

Light: filter condition
Direction: run direction, north or south
Target position: whether the target was on the right or left of the car
Distance: mean detection distance
Target luminance: target luminance at mean detection distance
Road luminance: road luminance at mean detection distance
Contrast: target luminance divided by road luminance
Illuminance: foot candelas measured at the target at the mean detection distance
Intensity: candelas directed toward the target at the mean detection distance
Average glare illuminance: foot candelas at the subject's eye from the glare source
Target reflectance: target luminance divided by illuminance
Road reflectance: road luminance divided by illuminance

Three categories of measurements are noted: i.e., 1. no glare, 2. glare employing the hood-mounted source set at deBoer 4 for each subject, and 3. fixed glare from the headlamp in the center of the next lane. Under each of these are listed the measured mean detection distances together with relevant photometric information.

Table 20. Straight Delineation Visibility Analysis - Young Subjects

			Light	Direction	Target Position	Distance (ft)	Target Luminance (ft-L)	Road Luminance (ft-L)	Contrast [TGT / Rd]	Illuminance (Ft-c)	Intensity (cd)	Average Glare Illuminance (Ft-c)	Target Reflectance (ft-L/ft-c)	Road Reflectance (ft-L/ft-c)
Measurement	Straight Delineation	1. No Glare	Lowbeam	S	L	399	0.10	0.010	9.7	0.087				
			Filter 1	S	L	315	0.039	0.0040	9.7	0.035				
			Filter 2	S	L	241	0.022	0.0022	9.7	0.019				
		2. Glare (Deboer=4)	Lowbeam	N	R	245	0.48	0.031	15.3	0.59	35,449	0.26	0.82	0.053
			Lowbeam	S	L	241	0.18	0.018	9.7	0.16	9,223	0.26	1.13	0.12
			Filter 1	N	R	188	0.24	0.016	15.0	0.30	10,635	0.26	0.80	0.053
			Filter 2	N	R	141	0.16	0.012	13.9	0.22	4,366	0.26	0.74	0.053
		3. Fixed Glare	Lowbeam	N	R	265	0.40	0.026	15.3	0.50	34,878	0.26	0.82	0.053
	1/2 Distance Straight Delineation	2b. Glare (Deboer=4)	Lowbeam	N	R	123	1.80	0.13	13.5	2.50	27,114	0.26	0.72	0.053
			Lowbeam	S	L	120	0.58	0.07	8.87	0.56	8,392	0.26	1.03	0.116
			Filter 1	N	R	94	0.76	0.06	12.9	1.10	6,675	0.26	0.69	0.053
			Filter 2	N	R	71	0.36	0.03	12.6	0.53	1,774	0.26	0.67	0.053

			Vehicle Velocity (mph)	Target Position	Distance (ft)	Target Luminance (ft-L)	Road Luminance (ft-L)	Contrast (-)	Target Illuminance (Ft-c)	Intensity (cd)	Glare Illuminance (Ft-c)	Target Reflectance (ft-L/ft-c)	Road Reflectance (ft-L/ft-c)
Predicted	Delineation	2-2. Glare	84	R	245	1.04	0.38	1.33	10.6	634,100	0.077	0.14	0.14
			82	L	241	2.08	0.76	1.11	21.0	1,220,760	0.068	0.14	0.14
			64	R	188	0.49	0.16	1.52	4.83	170,930	0.060	0.14	0.11
			48	R	141	0.27	0.079	1.72	2.59	51,500	0.052	0.15	0.078
		3-2. Fixed Glare	90	R	265	1.37	0.52	1.28	14.0	984,860	0.086	0.14	0.16
	Delineation **1/2 Distance**	2-3. Glare	42	R	123	0.21	0.06	1.83	2.04	31,010	0.050	0.15	0.067
			41	L	121	0.38	0.11	1.36	3.66	53,780	0.041	0.15	0.066
			32	R	94	0.15	0.040	2.05	1.42	12,620	0.049	0.15	0.050
			24	R	71	0.12	0.030	2.30	1.10	5,610	0.050	0.15	0.037
		3-3. Fixed Glare	45	R	133	0.24	0.071	1.77	2.33	41,280	0.051	0.15	0.073

calculated with Age = 35

An inspection of the measurement results makes it immediately apparent that there is little relationship between detection distance and the photometric measures. For example, under the no-glare heading, detection distance declines with filter density, as expected. However, detection also occurred at progressively lower levels of target and road luminance. The same phenomenon can be noted under the glare conditions. For example, detection occurred at almost the same mean distance on the right and left, although the photometric measures are very different.

The results of the measurements noted in the preceding paragraph suggest that there will be some problems in establishing a correlation with the predictions from the NHTSA model. This is supported by a comparison between the measured and computed half-distance data. The predictions provided by the model indicate far lower target luminance values than were in fact measured for the half-distance condition. The road luminance values are, however, reasonably close to those measured at this site. The result is that the predicted contrast between delineation and road surface is much smaller than what was measured. This is the same trend noted in the validation study.

Table 21 gives the results for the young subjects in detecting curves. The same general pattern is evident here in that the model predicts much lower luminance levels for delineation, and lower contrast levels than were measured.

Tables 22 and 23 provide the results for the older subjects. In this case the model is reasonably accurate in predicting the delineation luminance, it is the road luminance values that are much higher than those measured at the site. The net result, again, is that the predicted contrast is much lower than the measured contrast.

Discussion

The results of this investigation, coupled with the data reported in the validation study, suggest that the measurement of the visibility of retroreflective surfaces such as delineators is complicated by unknown factors that make it much more difficult to write a prediction model than in the case of diffuse reflectors. The large and consistent differences between predicted and measured contrast suggest that some adjustments could be made to the model to reduce that discrepancy, but substantial discrepancies can still be expected under at least some conditions.

Table 21. Curve Delineation Visibility Analysis - Young Subjects

			Light	Direction	Target Position	Distance (ft)	Target Luminance (ft-L)	Road Luminance (ft-L)	Contrast [TGT / Rd]	Illuminance (Ft-c)	Intensity (cd)	Average Glare Illuminance (Ft-c)	Target Reflectance (ft-L/ft-c)	Road Reflectance (ft-L/ft-c)
Measurement	**Curve** Delineation	1. No Glare	Lowbeam	S	L	344	0.12	0.012	9.73	0.10				
			Filter 1	S	L	278	0.05	0.005	9.73	0.04				
			Filter 2	S	L	219	0.02	0.002	9.73	0.02				
		2. Glare	Lowbeam	N	R	244	0.49	0.032	15.29	0.59	35,438	0.26	0.82	0.053
		(Deboer=4)	Lowbeam	S	L	212	0.20	0.021	9.73	0.18	8,087	0.26	1.13	0.116
			Filter 1	N	R	187	0.25	0.016	14.98	0.31	10,672	0.26	0.80	0.053
			Filter 2	N	R	148	0.14	0.010	14.07	0.19	4,147	0.26	0.75	0.053
		3. Fixed Glare	Lowbeam	N	R	275	0.37	0.024	15.29	0.45	34,027	0.26	0.82	0.053
	1 / 2 Distance Curve Delineation	2b. Glare	Lowbeam	N	R	122	1.81	0.13	13.46	2.52	27,061	0.26	0.72	0.053
		(Deboer=4)	Lowbeam	S	L	106	0.68	0.079	8.71	0.68	7,694	0.26	1.01	0.116
			Filter 1	N	R	93	0.76	0.059	12.86	1.11	6,636	0.26	0.69	0.053
			Filter 2	N	R	74	0.35	0.028	12.63	0.52	1,898	0.26	0.67	0.053

			Vehicle Velocity (mph)	Target Position	Distance (ft)	Target Luminance (ft-L)	Road Luminance (ft-L)	Contrast (-)	Target Illuminance (Ft-c)	Intensity (cd)	Glare Illuminance (Ft-c)	Target Reflectance (ft-L/ft-c)	Road Reflectance (ft-L/ft-c)
Predicted	Delineation	2-2. Glare	83	R	244	1.03	0.38	1.34	10.4	619,660	0.077	0.14	0.14
			72	L	212	1.38	0.47	1.15	13.8	618,670	0.058	0.14	0.12
			64	R	187	0.48	0.16	1.52	4.77	166,860	0.060	0.14	0.11
			50	R	148	0.29	0.088	1.69	2.84	62,210	0.053	0.15	0.082
		3-2. Fixed Glare	94	R	275	1.57	0.61	1.25	16.1	1,220,900	0.090	0.14	0.16
	Delineation **1 / 2 Distance**	2-3. Glare	42	R	122	0.21	0.060	1.83	2.02	30,120	0.050	0.15	0.066
			36	L	106	0.31	0.085	1.42	2.94	33,150	0.039	0.15	0.057
			32	R	93	0.15	0.040	2.06	1.40	12,200	0.049	0.15	0.049
			25	R	74	0.12	0.031	2.27	1.14	6,270	0.050	0.15	0.038
		3-3. Fixed Glare	47	R	138	0.26	0.076	1.74	2.49	47,430	0.052	0.15	0.076

calculated with Age = 35

Table 22. Straight Delineation Visibility Analysis - Older Subjects

			Light	Direction	Target Position	Distance (ft)	Target Luminance (ft-L)	Road Luminance (ft-L)	Contrast [TGT / Rd]	Illuminance (Ft-c)	Intensity (cd)	Average Glare Illuminance (Ft-c)	Target Reflectance (ft-L/ft-c)	Road Reflectance (ft-L/ft-c)
Measurement	**Straight** Delineation	1. No Glare	Lowbeam	S	L	324	0.12	0.013	9.73	0.11				
			Filter 1	S	L	242	0.055	0.0057	9.73	0.049				
			Filter 2	S	L	196	0.027	0.0028	9.68	0.024				
		2. Glare	Lowbeam	N	R	192	0.74	0.049	15.10	0.92	33,706	0.28	0.81	0.053
		(Deboer=4)	Lowbeam	S	L	181	0.27	0.028	9.52	0.24	7,891	0.28	1.11	0.12
			Filter 1	N	R	129	0.51	0.038	13.62	0.70	11,718	0.28	0.73	0.053
			Filter 2	N	R	101	0.27	0.021	12.96	0.40	4,026	0.28	0.69	0.053
		3. Fixed Glare	Lowbeam	N	R	182	0.84	0.057	14.86	1.06	34,908	0.28	0.79	0.053
	1 / 2 Distance Straight Delineation	2b. Glare	Lowbeam	N	R	96	2.40	0.19	12.89	3.49	22,057	0.28	0.69	0.053
		(Deboer=4)	Lowbeam	S	L	90	0.80	0.093	8.60	0.80	6,533	0.28	1.00	0.12
			Filter 1	N	R	64	0.96	0.077	12.52	1.44	3,997	0.28	0.67	0.053
			Filter 2	N	R	50	0.41	0.033	12.36	0.62	1,034	0.28	0.66	0.053

			Vehicle Velocity (mph)	Target Position	Distance (ft)	Target Luminance (ft-L)	Road Luminance (ft-L)	Contrast (-)	Target Illuminance (Ft-c)	Intensity (cd)	Glare Illuminance (Ft-c)	Target Reflectance (ft-L/ft-c)	Road Reflectance (ft-L/ft-c)
Predicted	Delineation	2-2. Glare	65	R	192	4.28	1.41	1.84	42.2	1,558,730	0.16	0.14	0.11
			62	L	181	6.61	2.13	1.68	65.0	2,131,790	0.13	0.15	0.10
			44	R	129	1.42	0.41	2.19	13.6	226,970	0.11	0.15	0.071
			34	R	101	0.92	0.25	2.40	8.76	89,680	0.10	0.15	0.054
		3-2. Fixed Glare	62	R	182	3.54	1.14	1.88	34.9	1,155,880	0.14	0.15	0.10
	Delineation **1 / 2 Distance**	2-3. Glare	33	R	96	0.86	0.23	2.44	8.15	75,390	0.095	0.15	0.051
			31	L	90	1.21	0.32	2.10	11.5	93,160	0.072	0.15	0.048
			22	R	64	0.60	0.15	2.78	5.62	23,230	0.095	0.15	0.033
			17	R	50	0.58	0.14	2.97	5.34	13,550	0.10	0.15	0.025
		3-3. Fixed Glare	31	R	91	0.80	0.21	2.49	7.60	63,200	0.094	0.15	0.048

calculated with Age = 65

Table 23. Curve Delineation Visibility Analysis - Older Subjects

			Light	Direction	Target Position	Distance (ft)	Target Luminance (ft-L)	Road Luminance (ft-L)	Contrast [TGT / Rd]	Illuminance (Ft-c)	Intensity (cd)	Average Glare Illuminance (Ft-c)	Target Reflectance (ft-L/ft-c)	Road Reflectance (ft-L/ft-c)
Measurement	**Curve** Delineation	1. No Glare	Lowbeam	S	L	272	0.15	0.016	9.73	0.14				
			Filter 1	S	L	227	0.06	0.006	9.73	0.05				
			Filter 2	S	L	182	0.03	0.003	9.54	0.03				
		2. Glare	Lowbeam	N	R	195	0.70	0.046	15.18	0.87	33,089	0.26	0.81	0.053
		(Deboer=4)	Lowbeam	S	L	195	0.23	0.024	9.67	0.20	7,705	0.26	1.12	0.116
			Filter 1	N	R	145	0.39	0.028	13.99	0.53	11,020	0.26	0.75	0.053
			Filter 2	N	R	116	0.23	0.018	13.33	0.33	4,445	0.26	0.71	0.053
		3. Fixed Glare	Lowbeam	N	R	224	0.56	0.037	15.29	0.69	34,541	0.26	0.82	0.053
	1 / 2 Distance Curve Delineation	2b. Glare	Lowbeam	N	R	98	2.36	0.18	12.91	3.42	22,480	0.26	0.69	0.053
		(Deboer=4)	Lowbeam	S	L	97	0.75	0.087	8.63	0.75	7,078	0.26	1.00	0.12
			Filter 1	N	R	72	0.91	0.072	12.61	1.35	4,747	0.26	0.67	0.053
			Filter 2	N	R	58	0.39	0.031	12.45	0.58	1,316	0.26	0.66	0.053

			Vehicle Velocity (mph)	Target Position	Distance (ft)	Target Luminance (ft-L)	Road Luminance (ft-L)	Contrast (-)	Target Illuminance (Ft-c)	Intensity (cd)	Glare Illuminance (Ft-c)	Target Reflectance (ft-L/ft-c)	Road Reflectance (ft-L/ft-c)
Predicted	Delineation	2-2. Glare	66	R	195	4.52	1.50	1.82	44.7	1,702,020	0.16	0.14	0.11
			66	L	195	7.97	2.64	1.62	78.8	3,020,000	0.13	0.14	0.11
			49	R	145	1.84	0.55	2.08	17.8	375,900	0.12	0.15	0.080
			40	R	116	1.15	0.32	2.28	11.0	148,710	0.10	0.15	0.063
		3-2. Fixed Glare	76	R	224	5.96	2.09	1.67	59.7	3,020,000	0.17	0.14	0.13
	Delineation **1 / 2 Distance**	2-3. Glare	33	R	98	0.88	0.24	2.42	8.38	80,830	0.10	0.15	0.052
			33	L	97	1.36	0.37	2.05	12.9	122,080	0.074	0.15	0.052
			25	R	72	0.64	0.16	2.68	6.04	31,510	0.093	0.15	0.037
			20	R	58	0.58	0.14	2.86	5.42	18,430	0.10	0.15	0.030
		3-3. Fixed Glare	38	R	112	1.09	0.30	2.31	10.4	130,210	0.10	0.15	0.060

calculated with Age = 65

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APPENDIX A

SUBJECT INSTRUCTIONS

A-1 FIELD DISCOMFORT GLARE STUDY

From your own experience you know that bright lights in your field of view while driving at night can cause discomfort. Minimizing this discomfort is an important objective in the design of vehicle lighting systems. In order to do this job more effectively we need better data about glare discomfort than we have now. The purpose of this study is to obtain such data.

What we are going to do is drive up and down this road. Another car will be driving in the opposite direction so that you will meet at about the half way point on each run. The other car will have headlights of differing intensities. At the conclusion of each run I would like you to rate the discomfort you experienced from those headlights.

In making the ratings I would like you to use the scale printed at the top of the score sheet I gave you. Look at that scale now. Note that it goes from one to nine, and that the odd intervals have descriptors such as disturbing, just acceptable, and so on. Also note that the scale is kind of upside down in that small numbers are associated with intense glare. On each run decide which point on that scale best describes the glare that you just experienced and write that number in the blank next to the trial number. Note that you can use even as well as odd numbers in making your ratings.

I would like to make two very important points: First, where your eyes are directed has a major effect on the sensation of glare, so please only look straight ahead up the road in front of you while the glare car is in sight. Second, do not make your ratings until the glare car has passed. In other words, don't base your ratings on what the lights look like when they first come on or something like that. Base your rating on the whole glare experience.

Now, for the driver only. At the conclusion of each run make a turn around and bring the car to a stop at a location that I will point out to you. Turn off your headlights. When everyone has finished writing down their ratings, turn the headlights on again. That will tell the guy in the other car that we are ready to go. When you see that car's headlights come on accelerate to 25 mph and hold that speed as best you can until we reach the other end of the road.

Do you have any questions?

PART 2

For the next series of trials we will do something different. Up to now I have asked you to not look at the oncoming car's headlamps. Now I would like you look directly at those headlamps while they are visible during each run. Also, I would like you to make two ratings on each run. The first is a rating of discomfort using the same 9-point scale you used in the first 24 runs. Then ask yourself "would I be willing to look into those headlamps to see if the turn signal was on?" If the answer is "yes" put a Y next to the numerical rating. If it is "no" put a N there instead.

So, for each run on this part of the test you should give me two ratings. The first will be a number from 1 to 9 indicating the degree of discomfort you experienced. The other is a Y or N, indicating whether you would be willing to look into those headlamps to see if the turn signal was on.

PART 3

For the last series of trials I would like you to look away from the glare. While the headlights of the other car are in sight you should look toward the right edge of the road. At the conclusion of each run make a single, numerical rating of the discomfort you experienced using the 9-point scale as before.

APPENDIX A-2

SUBJECT INSTRUCTIONS: VALIDATION STUDY

The purpose of this study is to measure the distance at which drivers can detect specific targets under night driving conditions.

You will drive this car up and down this road at a speed of 25 mph. At three points on each run you will encounter a target. when you see the target, press one of the white buttons on the box on the seat to your right.

There are two types of targets in this study. One I call a "pedestrian." The pedestrian target comes in two sizes and different colors ranging from medium gray to black. The other type of target is delineation; i.e., reflective lines on the road.

On each run you will encounter three targets. You can never be sure which type of target will be in place at any time. The targets can also be located on either side of the car, although I will tell you at the start of each run on which side they will appear.

On most runs glare will be provided by a small lamp located on the hood of the car. On some runs glare will be provided by a lamp placed on the road about 500 feet from where we are now sitting. Prior to using either glare source we will have to make some adjustments and measurements.

We will be using three different beams in this study to see what effect that has on your ability to detect the targets. I will change the beams from my control panel, so you don't have to worry about that. But, I will tell you each time the beam is changed.

Prior to starting the test we will make one run in each direction for practice so that you can see the types of targets we are using and where they will be located. Do you have any questions?

APPENDIX A-3

SUBJECT INSTRUCTIONS: DELINEATION VISIBILITY

This is a study of the visibility of lane lines under nighttime driving conditions. You will be driving this car up and down this road at about 25 mph and looking for lane lines on either your right or left.

If you look forward you can see the lane lines ahead of you now. On the right is a solid line such as you typically see on Michigan highways. On the left are what are known as raised pavement markers, which are commonly used in sun-belt states. Now, look back at the line on the right. Note that at the far end of it the line appears to go off to the right, as though it were marking a right turn. On each run through the course I would like you to indicate when you see the begging of the lane line <u>and</u> when you see the beginning of the curve. Note that there are two lane lines on your right. The curve may appear beyond either one, and may indicate either right or left.

We'll start each run at one or the other end of this road. Stay centered over the road centerline as you are now. Drive forward at about 25 mph. When you see the lane line press a button on the leftmost panel on the seat next to you. When you see the curve press a button on the right panel. Then just continue on to the stop sign and turn around.

Glare will be provided on some of the runs by means of a special light source mounted on the hood of this car. I will have to set that up before we start. On some runs glare will be provided by a lamp placed on the road near where the lane lines are located. We'll have to set that up too.

At the start we'll be working only with the lane lines on your right. The raised pavement markers will come later. I'll remind you prior to the start of each run where the delineation will be located.

One last thing. The lane lines you see are attached to thin pieces of board. If you run over them with the wheels of the car they may be damaged. Please try to avoid doing that. When the lines show a left turn they will be across your lane. In that case steer left to avoid running over them. Watch out for the boards to which the raised pavement markers are attached when you do that.

Any questions?

APPENDIX B
FIELD PHOTOMETRIC READINGS

FIELD PHOTOMETRIC DATA

The tables in this appendix contain the photometric measurements collected during the field validation work. The method used is described in that chapter of this report.

The data are presented in matrix form, and show luminance readings taken both on the target and it's immediate surround. For example, in the upper left-hand corner of the first page of the table are the measurements taken on the 6% small (i.e., 30-inch tall) pedestrian target, using low beams at 100 feet. The reading just above the target ("sky") was 0.030 ft-L. The reading on the target itself, at the top, was 0.044 ft-L. The background readings, at the same height, were 0.026 and 0.019 ft-L on the left and right respectively. Other luminance readings were taken in the same way at the approximate middle and bottom of the target, and on the background at the same height, both left and right. Finally, the luminance of the pavement directly in front of the target was read. At each distance a reading was also taken on a sheet of white paper, placed at the bottom of the target. This was done with each beam.

Luminance was read at five points on the 6-foot tall pedestrian target, and at only one point on the delineation.

Target Luminance (Small Target , Right Side) (ft-L)

			100 ft			150 ft			200 ft			300 ft			400 ft		
			LEFT	TARGET	RIGHT	LEFT	TARGET	RIGHT	LEFT	TARGET	RIGHT	LEFT	TARGET	RIGHT	LEFT	TARGET	RIGHT
6% Small Target	Low Beam	SKY		0.030			0.019			0.008			0.005				
		TOP	0.026	0.044	0.019	0.016	0.032	0.007	0.011	0.021	0.010	0.006	0.010	0.011			
		CENTER	0.046	0.057	0.012	0.025	0.038	0.010	0.017	0.024	0.009	0.009	0.012	0.012			
		BOTTOM	0.079	0.083	0.103	0.050	0.047	0.044	0.028	0.029	0.027	0.013	0.013	0.015			
		GROUND		0.121			0.070			0.040			0.015				
	High Beam	SKY		0.041			0.020			0.013			0.009			0.008	
		TOP	0.026	0.088	0.031	0.021	0.045	0.030	0.016	0.030	0.020	0.007	0.017	0.013	0.005	0.010	0.008
		CENTER	0.028	0.076	0.016	0.024	0.036	0.018	0.016	0.029	0.014	0.011	0.016	0.012	0.008	0.011	0.009
		BOTTOM	0.040	0.055	0.058	0.032	0.036	0.035	0.032	0.028	0.026	0.017	0.016	0.017	0.011	0.012	0.012
		GROUND		0.065			0.047			0.033			0.019			0.014	
	Dim-Hi Beam	SKY		0.025			0.012			0.007			0.004			0.004	
		TOP	0.015	0.066	0.038	0.013	0.033	0.018	0.009	0.020	0.014	0.003	0.009	0.007	0.004	0.007	0.004
		CENTER	0.020	0.057	0.020	0.010	0.027	0.013	0.008	0.020	0.008	0.004	0.009	0.006	0.004	0.007	0.005
Right Side		BOTTOM	0.018	0.043	0.046	0.029	0.027	0.032	0.020	0.019	0.021	0.007	0.009	0.010	0.007	0.007	0.008
		GROUND		0.050			0.032			0.022			0.011			0.008	
12% Small Target	Low Beam	SKY		0.028			0.018			0.011			0.006			0.005	
		TOP	0.032	0.080	0.018	0.016	0.058	0.011	0.011	0.035	0.012	0.006	0.016	0.011	0.005	0.009	0.006
		CENTER	0.052	0.101	0.017	0.023	0.070	0.008	0.018	0.042	0.008	0.009	0.018	0.007	0.007	0.009	0.006
		BOTTOM	0.112	0.155	0.089	0.057	0.087	0.056	0.032	0.049	0.032	0.014	0.020	0.018	0.008	0.010	0.008
		GROUND		0.118			0.072			0.040			0.018			0.010	
	High Beam	SKY		0.032			0.021			0.019			0.008			0.007	
		TOP	0.033	0.160	0.039	0.022	0.081	0.022	0.020	0.054	0.024	0.008	0.027	0.012	0.006	0.018	0.010
		CENTER	0.028	0.140	0.023	0.029	0.069	0.014	0.018	0.052	0.012	0.012	0.026	0.011	0.010	0.017	0.011
		BOTTOM	0.036	0.095	0.060	0.032	0.056	0.042	0.025	0.047	0.030	0.018	0.025	0.018	0.012	0.017	0.014
		GROUND		0.068			0.043			0.034			0.020			0.015	
	Dim-Hi Beam	SKY		0.023			0.013			0.013			0.005			0.004	
		TOP	0.015	0.123	0.036	0.013	0.058	0.018	0.011	0.034	0.015	0.004	0.018	0.007	0.003	0.010	0.005
		CENTER	0.017	0.107	0.022	0.011	0.053	0.012	0.011	0.032	0.008	0.005	0.015	0.007	0.004	0.011	0.005
Right Side		BOTTOM	0.017	0.075	0.049	0.015	0.045	0.033	0.020	0.034	0.025	0.009	0.015	0.012	0.007	0.010	0.008
		GROUND		0.051			0.033			0.025			0.012			0.008	
25% Small Target	Low Beam	SKY		0.031			0.018			0.010			0.006			0.005	
		TOP	0.034	0.204	0.025	0.016	0.146	0.015	0.012	0.089	0.019	0.007	0.037	0.012	0.005	0.017	0.008
		CENTER	0.049	0.278	0.014	0.025	0.196	0.020	0.026	0.099	0.015	0.013	0.041	0.011	0.007	0.020	0.008
		BOTTOM	0.092	0.397	0.087	0.057	0.215	0.059	0.029	0.115	0.036	0.014	0.045	0.020	0.008	0.021	0.010
		GROUND		0.123			0.074			0.041			0.018			0.011	
	High Beam	SKY		0.036			0.022			0.016			0.008			0.007	
		TOP	0.029	0.426	0.042	0.021	0.218	0.018	0.019	0.145	0.019	0.013	0.061	0.018	0.007	0.039	0.011
		CENTER	0.032	0.361	0.025	0.024	0.186	0.012	0.015	0.118	0.012	0.013	0.054	0.012	0.010	0.040	0.010
		BOTTOM	0.043	0.254	0.061	0.031	0.156	0.044	0.029	0.113	0.029	0.017	0.057	0.021	0.013	0.039	0.012
		GROUND		0.067			0.048			0.034			0.020			0.015	
	Dim-Hi Beam	SKY		0.026			0.013			0.013			0.006			0.003	
		TOP	0.029	0.319	0.036	0.016	0.158	0.022	0.012	0.089	0.017	0.006	0.040	0.010	0.004	0.022	0.007
		CENTER	0.020	0.279	0.022	0.011	0.135	0.014	0.012	0.086	0.007	0.007	0.037	0.006	0.007	0.023	0.005
Right Side		BOTTOM	0.030	0.194	0.052	0.019	0.119	0.037	0.015	0.080	0.027	0.010	0.036	0.013	0.008	0.021	0.008
		GROUND		0.054			0.034			0.024			0.012			0.009	
White Paper	Low	BOTTOM		0.878			0.484			0.308			0.096			0.047	
	High	BOTTOM		0.665			-			0.285			0.146			0.099	
	Dim-Hi	BOTTOM		0.341			0.304			0.188			0.090			0.055	

Target Luminance (Large Target , Right Side) (ft-L)

			100 ft LEFT	100 ft TARGET	100 ft RIGHT	150 ft LEFT	150 ft TARGET	150 ft RIGHT	200 ft LEFT	200 ft TARGET	200 ft RIGHT	300 ft LEFT	300 ft TARGET	300 ft RIGHT	400 ft LEFT	400 ft TARGET	400 ft RIGHT
6% Large Target	Low Beam	SKY		0.002			0.004			0.004			0.002			0.004	
		TOP	0.003	0.005	0.003	0.004	0.008	0.004	0.004	0.007	0.004	0.002	0.005	0.003	0.003	0.004	0.003
		T.CENTER	0.005	0.008	0.004	0.005	0.011	0.003	0.006	0.011	0.004	0.003	0.007	0.003	0.004	0.005	0.004
		MIDDLE	0.011	0.026	0.007	0.008	0.020	0.007	0.005	0.016	0.006	0.003	0.008	0.006	0.004	0.006	0.006
		L CENTER	0.039	0.053	0.018	0.012	0.036	0.012	0.011	0.023	0.008	0.004	0.010	0.008	0.005	0.006	0.006
		BOTTOM	0.082	0.084	0.048	0.051	0.054	0.042	0.027	0.031	0.031	0.011	0.012	0.013	0.007	0.008	0.008
		GROUND		0.127			0.069			0.040			0.016			0.009	
	High Beam	SKY		0.015			0.018			0.008			0.009			0.006	
		TOP	0.015	0.078	0.016	0.012	0.059	0.016	0.007	0.039	0.007	0.006	0.019	0.007	0.006	0.013	0.005
		T.CENTER	0.018	0.097	0.021	0.015	0.067	0.012	0.009	0.041	0.006	0.006	0.018	0.011	0.006	0.013	0.007
		MIDDLE	0.025	0.105	0.024	0.015	0.058	0.027	0.012	0.038	0.014	0.005	0.017	0.012	0.005	0.011	0.009
		L CENTER	0.044	0.088	0.035	0.018	0.048	0.018	0.013	0.031	0.010	0.007	0.017	0.013	0.005	0.011	0.008
		BOTTOM	0.027	0.057	0.046	0.021	0.040	0.025	0.015	0.028	0.020	0.014	0.016	0.017	0.011	0.011	0.011
		GROUND		0.072			0.046			0.029			0.018			0.014	
	Dim-Hi Beam	SKY		0.010			0.007			0.005			0.004			0.004	
		TOP	0.010	0.048	0.009	0.007	0.032	0.007	0.007	0.022	0.007	0.003	0.011	0.004	0.004	0.007	0.003
		T.CENTER	0.013	0.066	0.014	0.013	0.036	0.011	0.007	0.022	0.008	0.004	0.011	0.006	0.004	0.007	0.004
		MIDDLE	0.016	0.076	0.027	0.010	0.037	0.014	0.004	0.022	0.009	0.003	0.011	0.005	0.003	0.007	0.005
Right Side		L CENTER	0.029	0.062	0.036	0.013	0.031	0.009	0.010	0.019	0.007	0.004	0.010	0.007	0.004	0.007	0.004
		BOTTOM	0.010	0.043	0.043	0.011	0.025	0.027	0.011	0.017	0.020	0.008	0.009	0.010	0.007	0.007	0.008
		GROUND		0.054			0.033			0.023			0.012			0.009	
25% Large Target	Low Beam	SKY		0.003			0.006			0.004			0.003			0.004	
		TOP	0.004	0.018	0.005	0.004	0.028	0.004	0.005	0.023	0.005	0.004	0.020	0.003	0.004	0.011	0.004
		T.CENTER	0.008	0.034	0.005	0.006	0.048	0.006	0.006	0.034	0.008	0.007	0.022	0.004	0.004	0.012	0.004
		MIDDLE	0.018	0.126	0.012	0.014	0.087	0.009	0.010	0.051	0.008	0.004	0.027	0.009	0.004	0.015	0.006
		L CENTER	0.045	0.246	0.017	0.018	0.144	0.009	0.009	0.080	0.011	0.009	0.036	0.007	0.005	0.017	0.006
		BOTTOM	0.082	0.378	0.066	0.048	0.210	0.039	0.018	0.107	0.026	0.013	0.045	0.018	0.008	0.021	0.009
		GROUND		0.123			0.076			0.039			0.019			0.010	
	High Beam	SKY		0.022			0.010			0.013			0.013			0.006	
		TOP	0.019	0.422	0.015	0.010	0.266	0.008	0.009	0.196	0.009	0.011	0.084	0.008	0.006	0.046	0.007
		T.CENTER	0.025	0.485	0.025	0.010	0.266	0.014	0.013	0.205	0.007	0.008	0.080	0.008	0.007	0.043	0.008
		MIDDLE	0.022	0.481	0.020	0.027	0.269	0.032	0.015	0.223	0.026	0.005	0.075	0.013	0.006	0.043	0.010
		L CENTER	0.046	0.384	0.030	0.022	0.209	0.027	0.019	0.224	0.021	0.011	0.069	0.014	0.006	0.043	0.009
		BOTTOM	0.029	0.255	0.059	0.031	0.155	0.040	0.045	0.218	0.051	0.017	0.059	0.023	0.012	0.038	0.013
		GROUND		0.069			0.047			0.067			0.021			0.015	
	Dim-HI Beam	SKY		0.011			0.006			0.005			0.004			0.004	
		TOP	0.011	0.258	0.010	0.008	0.172	0.008	0.010	0.104	0.007	0.006	0.046	0.006	0.005	0.025	0.006
		T.CENTER	0.036	0.318	0.024	0.011	0.173	0.010	0.017	0.100	0.007	0.007	0.048	0.005	0.004	0.026	0.005
		MIDDLE	0.022	0.354	0.030	0.009	0.171	0.009	0.007	0.102	0.010	0.003	0.044	0.021	0.004	0.025	0.007
Right Side		L CENTER	0.051	0.306	0.050	0.020	0.156	0.014	0.015	0.091	0.010	0.004	0.040	0.015	0.005	0.025	0.005
		BOTTOM	0.026	0.225	0.069	0.015	0.116	0.032	0.014	0.074	0.024	0.010	0.034	0.015	0.008	0.024	0.008
		GROUND		0.085			0.034			0.024			0.012			0.009	

[Table 9-a] Target Luminance (Delineation Target , Right Side) (ft-L)

			100 ft LEFT	100 ft TARGET	100 ft RIGHT	150 ft LEFT	150 ft TARGET	150 ft RIGHT	200 ft LEFT	200 ft TARGET	200 ft RIGHT	300 ft LEFT	300 ft TARGET	300 ft RIGHT	400 ft LEFT	400 ft TARGET	400 ft RIGHT
Low White Delineation	Low Beam	Delineation	0.111	2.131	0.137	0.058	0.394	0.067	0.026	0.663	0.111	0.018	0.161	0.029			
		Ground		0.137			0.058			0.035			0.018				
	High Beam	Delineation	0.053	0.686	0.099	0.023	0.397	0.015	0.015	0.449	0.044	0.012	0.076	0.012			
		Ground		0.053			0.032			0.018			0.009				
Right Side	Dim-HI Beam	Delineation	0.044	0.525	0.120	0.012	0.289	0.035	0.009	0.306	0.044	0.009	0.067	0.009			
		Ground		0.050			0.015			0.012			0.006				
High White Delineation	Low Beam	Delineation	0.108	2.586	0.169	0.052	0.978	0.058	0.026	0.893	0.082	0.012	0.201	0.018			
		Ground		0.143			0.058			0.035			0.018				
	High Beam	Delineation	0.050	0.779	0.082	0.018	0.590	0.038	0.015	0.765	0.038	0.026	0.128	0.020			
		Ground		0.055			0.020			0.018			0.009				
Right Side	Dim-HI Beam	Delineation	0.044	0.715	0.088	0.012	0.336	0.058	0.006	0.382	0.070	0.003	0.123	0.006			
		Ground		0.047			0.015			0.012			0.003				

Target Luminance (Small Target , Left Side) (ft-L)

			100 ft			150 ft			200 ft			300 ft			400 ft		
			LEFT	TARGET	RIGHT	LEFT	TARGET	RIGHT	LEFT	TARGET	RIGHT	LEFT	TARGET	RIGHT	LEFT	TARGET	RIGHT
6%	Low	SKY		0.006			0.005			0.004			0.004				
Small	Beam	TOP	0.012	0.029	0.013	0.007	0.019	0.006	0.006	0.012	0.006	0.004	0.010	0.004			
Target		CENTER	0.021	0.039	0.015	0.014	0.019	0.004	0.010	0.014	0.006	0.007	0.010	0.005			
		BOTTOM	0.035	0.058	0.070	0.026	0.030	0.033	0.015	0.018	0.020	0.010	0.011	0.012			
		GROUND		0.107			0.047			0.022			0.013				
	High	SKY		0.013			0.011			0.009			0.008			0.005	
	Beam	TOP	0.026	0.065	0.021	0.016	0.035	0.017	0.011	0.023	0.010	0.008	0.014	0.008	0.005	0.010	0.005
		CENTER	0.036	0.060	0.029	0.025	0.034	0.013	0.015	0.022	0.012	0.011	0.014	0.011	0.007	0.011	0.009
		BOTTOM	0.041	0.049	0.049	0.026	0.032	0.032	0.020	0.023	0.023	0.013	0.014	0.013	0.009	0.010	0.013
		GROUND		0.051			0.035			0.029			0.015			0.015	
	Dim-Hi	SKY		0.009			0.006			0.004			0.003				
	Beam	TOP	0.013	0.031	0.013	0.008	0.016	0.008	0.007	0.012	0.007	0.003	0.006	0.004			
		CENTER	0.017	0.028	0.017	0.008	0.017	0.007	0.008	0.012	0.011	0.004	0.007	0.006			
Left		BOTTOM	0.018	0.024	0.025	0.011	0.016	0.017	0.009	0.011	0.012	0.006	0.007	0.007			
Side		GROUND		0.026			0.020			0.015			0.009				
12%	Low	SKY		0.008			0.004			0.003			0.004				
Small	Beam	TOP	0.013	0.054	0.015	0.012	0.037	0.009	0.008	0.021	0.008	0.005	0.014	0.006			
Target		CENTER	0.025	0.060	0.023	0.020	0.044	0.007	0.012	0.026	0.006	0.008	0.015	0.009			
		BOTTOM	0.040	0.098	0.079	0.024	0.048	0.038	0.015	0.029	0.021	0.011	0.017	0.013			
		GROUND		0.111			0.048			0.026			0.016				
	High	SKY		0.016			0.009			0.010			0.005			0.005	
	Beam	TOP	0.035	0.130	0.023	0.018	0.064	0.016	0.012	0.041	0.015	0.008	0.020	0.009	0.005	0.016	0.006
		CENTER	0.037	0.095	0.032	0.030	0.059	0.011	0.019	0.038	0.019	0.010	0.019	0.011	0.007	0.016	0.008
		BOTTOM	0.043	0.080	0.057	0.027	0.045	0.036	0.021	0.034	0.026	0.012	0.018	0.015	0.010	0.014	0.013
		GROUND		0.053			0.039			0.029			0.016			0.015	
	Dim-Hi	SKY		0.011			0.008			0.004			0.003			0.003	
	Beam	TOP	0.013	0.051	0.016	0.010	0.030	0.013	0.007	0.019	0.007	0.004	0.010	0.006	0.004	0.009	0.004
		CENTER	0.017	0.048	0.018	0.014	0.030	0.008	0.008	0.020	0.008	0.006	0.010	0.006	0.007	0.009	0.005
Left		BOTTOM	0.018	0.044	0.028	0.014	0.028	0.019	0.010	0.018	0.015	0.007	0.011	0.008	0.006	0.009	0.008
Side		GROUND		0.027			0.021			0.020			0.009			0.010	
25%	Low	SKY		0.014			0.006			0.007			0.004			0.003	
Small	Beam	TOP	0.014	0.151	0.016	0.015	0.090	0.008	0.007	0.051	0.009	0.005	0.033	0.007	0.004	0.011	0.004
Target		CENTER	0.029	0.182	0.026	0.024	0.109	0.008	0.015	0.038	0.011	0.011	0.036	0.007	0.006	0.012	0.004
		BOTTOM	0.038	0.218	0.082	0.025	0.116	0.043	0.015	0.057	0.035	0.010	0.034	0.017	0.005	0.013	0.007
		GROUND		0.108			0.046			0.027			0.015			0.008	
	High	SKY		0.014			0.014			0.013			0.005			0.004	
	Beam	TOP	0.036	0.306	0.028	0.020	0.157	0.018	0.011	0.101	0.015	0.008	0.039	0.010	0.005	0.036	0.005
		CENTER	0.039	0.268	0.030	0.032	0.142	0.012	0.026	0.096	0.012	0.008	0.039	0.009	0.015	0.036	0.004
		BOTTOM	0.043	0.199	0.059	0.028	0.116	0.042	0.022	0.080	0.030	0.011	0.039	0.018	0.010	0.035	0.014
		GROUND		0.056			0.039			0.029			0.015			0.014	
	Dim-Hi	SKY		0.009			0.006			0.004			0.003			0.003	
	Beam	TOP	0.018	0.123	0.020	0.015	0.068	0.020	0.010	0.047	0.015	0.006	0.024	0.007	0.004	0.021	0.004
		CENTER	0.017	0.107	0.019	0.011	0.067	0.010	0.015	0.044	0.012	0.009	0.025	0.006	0.010	0.020	0.005
Left		BOTTOM	0.018	0.088	0.034	0.014	0.060	0.022	0.011	0.046	0.019	0.007	0.021	0.012	0.006	0.021	0.010
Side		GROUND		0.028			0.022			0.015			0.009			0.009	
White	Low	BOTTOM		0.555			0.312			-			0.095			0.029	
Paper	High	BOTTOM		0.528			0.319			0.219			0.102			0.082	
	Dim-Hi	BOTTOM		0.247			0.175			0.114			0.061			0.053	

Target Luminance (Large Target , Left Side) (ft-L)

			100 ft			150 ft			200 ft			300 ft			400 ft		
			LEFT	TARGET	RIGHT	LEFT	TARGET	RIGHT	LEFT	TARGET	RIGHT	LEFT	TARGET	RIGHT	LEFT	TARGET	RIGHT
6% Large Target	Low Beam	SKY		0.001			0.001			0.001			0.002				
		TOP	0.001	0.003	0.002	0.002	0.004	0.002	0.003	0.004	0.002	0.004	0.006	0.003			
		T.CENTER	0.004	0.008	0.003	0.003	0.007	0.002	0.002	0.004	0.001	0.003	0.007	0.002			
		MIDDLE	0.005	0.020	0.007	0.003	0.018	0.005	0.002	0.009	0.003	0.003	0.007	0.003			
		L.CENTER	0.017	0.036	0.009	0.013	0.020	0.004	0.007	0.012	0.002	0.005	0.009	0.004			
		BOTTOM	0.036	0.056	0.069	0.023	0.030	0.032	0.014	0.016	0.016	0.010	0.010	0.010			
		GROUND		0.107			0.046			0.025			0.016				
	High Beam	SKY		0.002			0.003			0.004			0.005			0.003	
		TOP	0.008	0.036	0.007	0.010	0.036	0.011	0.006	0.022	0.011	0.005	0.011	0.006	0.004	0.010	0.004
		T.CENTER	0.020	0.093	0.015	0.020	0.039	0.013	0.011	0.022	0.006	0.006	0.013	0.005	0.006	0.010	0.004
		MIDDLE	0.014	0.087	0.012	0.011	0.041	0.013	0.008	0.025	0.011	0.006	0.012	0.007	0.005	0.011	0.004
		L.CENTER	0.034	0.071	0.019	0.023	0.031	0.010	0.016	0.022	0.009	0.008	0.012	0.006	0.013	0.010	0.005
		BOTTOM	0.040	0.052	0.051	0.023	0.032	0.028	0.018	0.023	0.023	0.012	0.013	0.013	0.009	0.010	0.011
		GROUND		0.056			0.038			0.028			0.016			0.010	
	Dim-Hi Beam	SKY		0.001			0.004			0.002			0.003			0.002	
		TOP	0.003	0.014	0.003	0.004	0.017	0.006	0.004	0.013	0.006	0.003	0.006	0.004	0.002	0.006	0.002
		T.CENTER	0.017	0.035	0.007	0.010	0.018	0.006	0.005	0.013	0.003	0.003	0.006	0.003	0.003	0.006	0.002
		MIDDLE	0.008	0.031	0.012	0.005	0.015	0.008	0.004	0.012	0.006	0.003	0.006	0.003	0.003	0.006	0.003
Left Side		L.CENTER	0.016	0.030	0.014	0.011	0.015	0.006	0.006	0.012	0.006	0.004	0.006	0.004	0.004	0.006	0.002
		BOTTOM	0.017	0.026	0.027	0.011	0.015	0.016	0.010	0.012	0.013	0.006	0.007	0.007	0.005	0.006	0.006
		GROUND		0.028			0.021			0.015			0.014			0.006	
25% Large Target	Low Beam	SKY		0.001			0.002			0.003			0.002			0.002	
		TOP	0.001	0.007	0.002	0.004	0.016	0.005	0.004	0.015	0.006	0.003	0.020	0.005	0.003	0.007	0.003
		T.CENTER	0.008	0.032	0.003	0.004	0.028	0.002	0.007	0.025	0.002	0.006	0.022	0.002	0.004	0.008	0.003
		MIDDLE	0.005	0.092	0.010	0.002	0.063	0.007	0.002	0.037	0.008	0.004	0.026	0.007	0.011	0.011	0.004
		L.CENTER	0.020	0.179	0.013	0.014	0.102	0.003	0.014	0.053	0.004	0.010	0.030	0.005	0.009	0.012	0.006
		BOTTOM	0.058	0.162	0.070	0.022	0.123	0.036	0.014	0.067	0.024	0.010	0.035	0.015	0.006	0.013	0.008
		GROUND		0.109			0.045			0.026			0.015			0.007	
	High Beam	SKY		0.002			0.006			0.007			0.007			0.006	
		TOP	0.005	0.171	0.010	0.009	0.179	0.015	0.013	0.097	0.013	0.013	0.057	0.007	0.004	0.039	0.004
		T.CENTER	0.019	0.461	0.014	0.024	0.200	0.010	0.017	0.118	0.007	0.012	0.050	0.006	0.007	0.038	0.004
		MIDDLE	0.014	0.464	0.010	0.011	0.174	0.015	0.008	0.112	0.016	0.009	0.045	0.012	0.009	0.036	0.008
		L.CENTER	0.025	0.337	0.016	0.030	0.147	0.009	0.018	0.097	0.007	0.011	0.045	0.007	0.016	0.035	0.007
		BOTTOM	0.034	0.235	0.035	0.026	0.121	0.036	0.020	0.084	0.026	0.013	0.042	0.016	0.010	0.034	0.014
		GROUND		0.058			0.038			0.029			0.017			0.013	
	Dim-Hi Beam	SKY		0.009			0.005			0.005			0.004			0.001	
		TOP	0.002	0.068	0.016	0.012	0.074	0.013	0.007	0.049	0.010	0.007	0.030	0.007	0.004	0.022	0.004
		T.CENTER	0.006	0.146	0.010	0.019	0.074	0.005	0.010	0.049	0.004	0.007	0.025	0.004	0.005	0.021	0.002
		MIDDLE	0.008	0.121	0.006	0.004	0.074	0.013	0.004	0.045	0.013	0.004	0.023	0.009	0.015	0.022	0.005
Left Side		L.CENTER	0.012	0.265	0.013	0.014	0.067	0.006	0.009	0.046	0.004	0.006	0.024	0.004	0.014	0.021	0.005
		BOTTOM	0.016	0.121	0.004	0.010	0.061	0.029	0.008	0.040	0.016	0.007	0.026	0.010	0.007	0.019	0.009
		GROUND		0.027			0.021			0.014			0.009			0.008	

[Table 12-a] Target Luminance (Delineation Target , Left Side) (ft-L)

			100 ft			150 ft			200 ft			300 ft			400 ft		
			LEFT	TARGET	RIGHT	LEFT	TARGET	RIGHT	LEFT	TARGET	RIGHT	LEFT	TARGET	RIGHT	LEFT	TARGET	RIGHT
Low Yellow Delineation	Low Beam	Delineation	0.061	0.540	0.105	0.030	0.271	0.036	0.009	0.128	0.032	0.009	0.035	0.015			
		Ground		0.105			0.043			0.018			0.012				
	High Beam	Delineation	0.047	0.359	0.108	0.018	0.210	0.047	0.015	0.140	0.029	0.012	0.032	0.009			
		Ground		0.053			0.029			0.018			0.009				
Left Side	Dim-Hi Beam	Delineation	0.020	0.158	0.035	0.006	0.105	0.018	0.003	0.114	0.009	0.003	0.018	0.003			
		Ground		0.026			0.009			0.009			0.003				
High Yellow Delineation	Low Beam	Delineation	0.047	0.791	0.196	0.027	0.428	0.042	0.009	0.198	0.058	0.012	0.064	0.018			
		Ground		0.082			0.047			0.023			0.012				
	High Beam	Delineation	0.055	0.531	0.108	0.023	0.318	0.070	0.018	0.196	0.023	0.012	0.053	0.009			
		Ground		0.055			0.026			0.018			0.009				
Left Side	Dim-Hi Beam	Delineation	0.020	0.242	0.050	0.012	0.114	0.009	0.018	0.114	0.015	0.003	0.029	0.006			
		Ground		0.026			0.012			0.006			0.006				