

The development of targets for use in field tests to measure visibility distances of drivers and to evaluate head lamp beams is described. The test procedure used appears to have satisfactory statistical reliability. The test provides discriminations in the visibility distances attributable to variations in head lamp beams. In addition, tests that evaluate glare effects to opposing drivers and those due to reflections in mirrors from the head lamps of a following vehicle are described. The development of a computer simulation model that predicts visibility distances and glare effects is described. Model predictions and the results of the field tests are compared and provide a good fit. Some examples of the use of this model to evaluate the effects of head lamp aim and various meeting beam patterns are described.

FIELD AND COMPUTER-SIMULATED EVALUATION OF HEAD LAMP BEAMS

Rudolf G. Mortimer,*

Department of Health and Safety Education, University of Illinois at Urbana-Champaign

Before we can evaluate head lamp beams, we must measure those aspects of the driver's visual environment that provide useful information. Studies using eye marker devices (1, 2) have provided valuable information on the visual cues used by drivers, mostly in daytime driving. Such studies are only lately being performed for night driving (3, 4).

One study (4) on night driving tested three head lamp beams. Drivers' eye fixations at night were compared with eye fixations in daytime to determine the extent to which a particular beam provides illumination in those areas of the roadway environment that drivers wish to see. A major finding of that study was that drivers fixated closer to the car at night than in daytime, indicating one of the limitations imposed by vehicle head lamps. Also, the lateral distribution of eye fixations was related to the pattern of the beams.

Although analyses of accident data have not been conclusive in determining the role of vehicle headlighting in nighttime crashes (5), data on eye fixations and subjective impressions clearly show that vehicle headlighting does not provide adequate seeing distances.

To develop improved vehicle headlighting systems requires that the effectiveness of alternative beam patterns be adequately evaluated. There is currently no uniform testing procedure available. In addition to a procedure for testing head lamps, the type of targets to be used must be determined.

A uniform testing procedure would permit better comparisons of the findings of different studies. Among the objectives of the studies reported here were development of procedures for objectively and subjectively measuring performance; development of suitable visibility test targets; and development of a mathematical model to predict the visibility and glare effects of head lamp beams.

DEVELOPMENT OF TEST TARGETS

Three of the targets evaluated, i.e., vertical, up/down, and choice position targets, are shown in Figure 1. The pedestrian target used consisted of a sheet of plywood,

*The author was with the Highway Safety Research Institute, University of Michigan, when this report was developed.

16 in. (0.4 m) wide and 72 in (1.8 m) high, painted a flat gray for reflectance values of 14 and 22 percent. In the visibility evaluations, the targets were located at the right edge of a flat road and an automobile was driven toward them. There was no opposing traffic. The driver's task was to depress a switch when he detected the target or made the appropriate discrimination, which allowed the visibility distance of the target to be measured.

Results

The mean visibility distances of the vertical target are shown in Figure 2. With low beams, the detection distances did not vary with target reflectance or target size. With high beams, the visibility distance increased as the reflectance and height of the target increased.

The mean visibility distances of the up/down, pedestrian, and choice targets showed more consistent effects of target reflectance, size, and mounting height.

Discussion

The pilot tests showed that each of the targets was at least partly suitable for head-lighting tests. However, the vertical target was eliminated because it did not provide a clear-cut effect of reflectance with low beams. In addition, because the vertical target tended to cast a shadow on the road, it was detected on that basis rather than on the basis of illumination.

Visibility distances of the up/down and pedestrian targets increased reasonably consistently with target reflectance. In addition, visibility distances of the up/down target varied with the vertical position of the target face: Visibility distances were greater when the target face was close to the pavement. However, both targets could be seen in silhouette, which showed that the configuration used was undesirable.

Because of these disadvantages, a choice target was developed. The effects of target reflectance and low and high beams on visibility distances were consistent with this target. However, this target did not permit evaluation of the effects of locating the target close to and above the pavement.

The following advantages of the targets evaluated in these studies were incorporated in the target used in the headlighting field test:

1. A choice target that requires identification of target detail or orientation,
2. Target faces that can be positioned close to the pavement and at some distance above it, and
3. A target that has its own background so that it is not affected by silhouettes or by the contrast of the road or shoulder.

These considerations led to the development of the target shown in Figure 3. After further considerations of the practical visibility requirements of drivers, two other targets that simulate aspects of road and route guidance signs (Fig. 4) were developed.

FIELD TEST PROCEDURE FOR VISIBILITY DISTANCE TEST

In the visibility distance tests, two vehicles were driven toward each other on a straight, flat road that was free of other traffic. Each vehicle was equipped with a special front panel that could accommodate as many as 14 head lamps, which could be selected remotely. The orientation of each test target was controlled so that the subject's responses could be checked against the actual orientation of the target on a given run. The responses of the driver and the passenger, when used, and other pertinent data were recorded on paper strip charts. The subjects pressed push buttons to indicate the orientation of the target. Reflective panels placed behind each target were sensed

Figure 1. (a) Vertical, (b) up/down, and (c) choice targets.

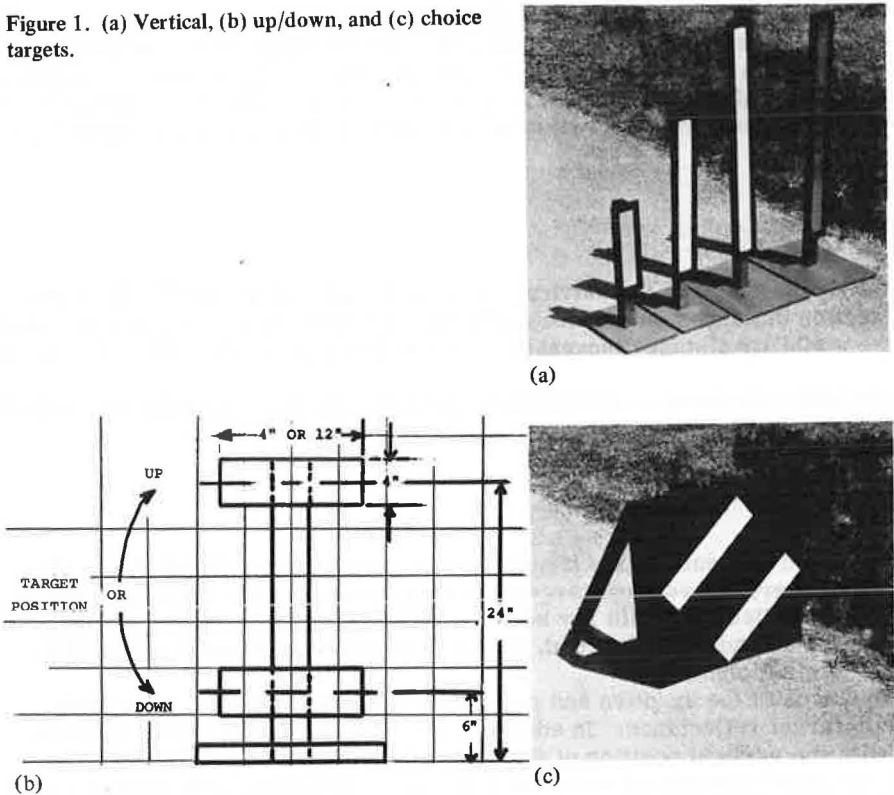
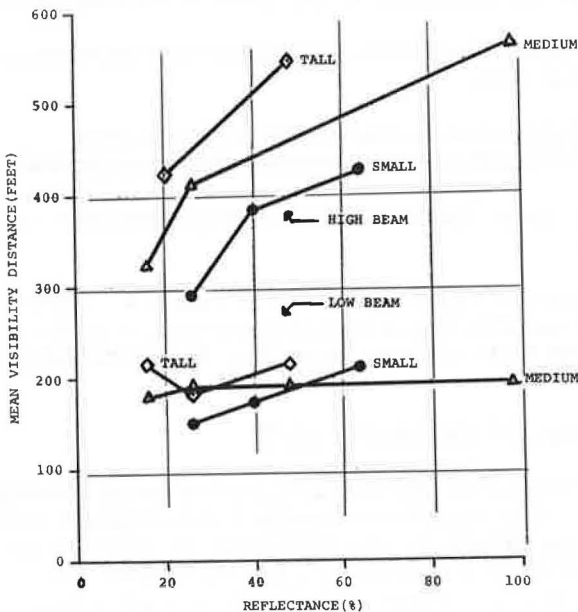


Figure 2. Mean visibility distances of vertical targets.



by a detector device consisting of an infrared source and photocell attached to the rear bumper. Twelve of the type 1 targets were used on each side of the course, either at the right edge of the road, at the left side of the lane, on the centerline, or in the center of the lane. When targets were placed in the center of the lane, tape switches were positioned 80 ft (24 m) in front of each target. A vehicle passing over the tape switch triggered a solenoid that released the support structure of the target, which was hinged at its lower edge, and allowed the target to fall down flat on the road. At the end of each run these targets were repositioned perpendicular to the road.

Each run began with two cars at each end of the course. On signal, each driver accelerated the car to a speed just beyond the lock-in setting of the automatic speed control and then released the accelerator. The subject's task was to indicate the orientation of each of the targets as soon as possible.

Effects of Beams, Target Reflectance, and Target Location

Mean visibility distances of targets with 12 and 54 percent reflectance mounted on the right side of the lane are shown in Figure 5. These distance measurements were made when the lateral separation between the vehicles, which were equipped with type 6014 low beams, was 7 and 36 ft (2.1 and 11 m). The effect of target reflectance on visibility distances is clearly indicated, whereas lateral separation distances between vehicles had a relatively small effect. The trends show the typical initial reduction in visibility during the meeting and an increase in visibility after the meeting and the driver has recovered from glare.

Figure 6 shows the mean visibility distances of targets with 12 and 54 percent reflectance positioned in the center of the lane. The meeting vehicles had low and high beams and a lateral separation of 7 ft (2.1 m). In high beam meetings the minimum visibility is less than in low beam meetings, and the minimum visibility distance was reached further from the meeting point when the targets were located in the center of the lane than when they were at the right of the lane (Fig. 5).

Effect of Test Vehicle Speed

Four of the subjects used to collect the data for targets on the right side of the lane were used to evaluate the effect of vehicle speed on visibility distances. Data were collected when vehicle speed was held constant at either 40 or 70 ft/sec (12.2 or 21.3 m/s). Analysis of variance of the visibility distances obtained in these two tests showed no significant differences in mean visibility distances due to the speeds used, although the mean visibility distances tended to be greater when the test was conducted at the lower speed.

Reliability of Field Test Procedure

Four subjects were exposed twice to a number of tests consisting of meetings of vehicles equipped with type 6014 high and low beams. Targets of 12 and 54 percent reflectance were positioned at the right and left of the lane, and the face of the target was 6 in. (152 mm) above the pavement. Each of the subjects made two replications of a block of eight runs. The means of the visibility distances obtained in the first replication were compared with those in the second replication. The second replication was consistently lower (Fig. 7), but the discrepancy did not exceed 5 percent. The correlation between the mean visibility distances in the two replications was 0.97.

Reliability of Test Sites and Drivers

A subsequent test evaluated a number of beams, including the low and high beams used

Figure 3. Type 1 target selected for use in field tests.

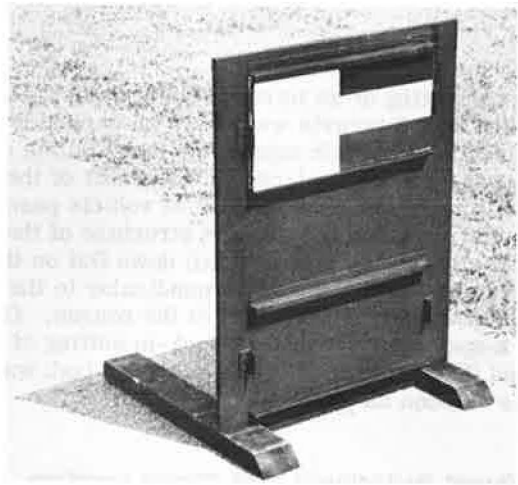


Figure 4. (a) Type 2 (road sign) and (b) type 3 (route guidance) targets.

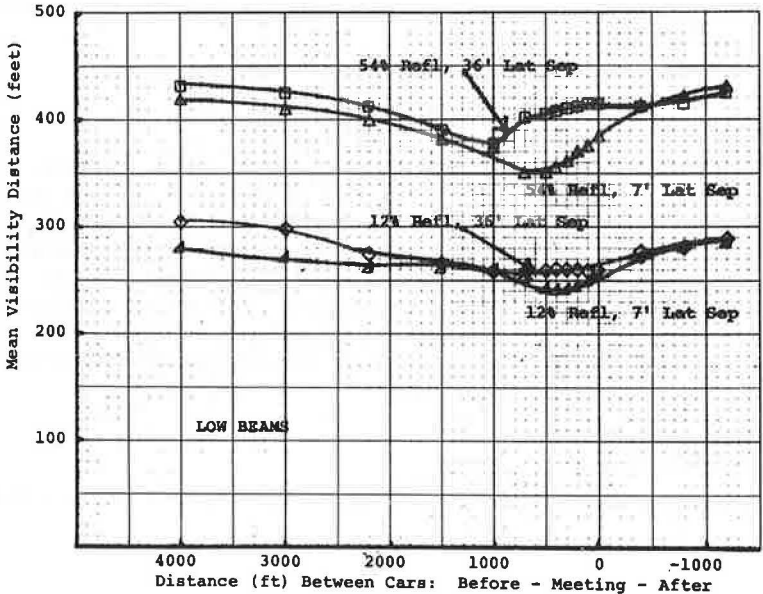


(a)



(b)

Figure 5. Mean visibility distances of targets in low beam meetings.



in the initial test. The second test was conducted about 12 months after the first one at a private air strip with a usable paved area about 3,500 ft (1.07 km) long. The procedure was modified in that the glare car was kept stationary because of the limited length of the runway. A different group of test subjects was used, and the head lamps were readjusted for the second test. The maximum longitudinal separation between the vehicles at which data could be compared with the first test was 1,500 ft (457 m).

The mean visibility distances of the type 1 targets located at the right side of the road were 10 to 15 percent greater in the second test than in the first in low beam meetings. This difference is partly due to random error and to differences in the vertical alignment of the head lamps used in the two tests. A 0.5-deg difference in vertical aim of the low beam head lamps could easily account for this discrepancy and is believed to be the major cause. The fact that the mean visibility distances obtained in meetings with the high beams were almost identical in the two tests shows that the general procedure used was quite similar. Small variations in vertical alignment of high beam head lamps should not affect mean visibility distances much because the high beam pattern is more uniform than that of low beams. In other respects the correspondence between the shape of the visibility distance curves obtained in the two tests with the low beams is quite similar, indicating that the same effects of glare on visibility were obtained. Product-moment correlations of the mean visibility distances obtained in the first and second tests at various longitudinal separations in low and high beam meetings were 0.96 and 0.97.

Type 2 Sign Target

The mean distances at which the orientation of the reflectorized white line against the low-reflectivity black background was identified were considerably greater than for the type 1 target. In addition, consistently greater visibility distances were obtained with the high beam than with the low beam.

Type 3 Route Guidance Sign Target

In meetings between the vehicles with high and low beams and at a lateral separation of 7 ft (2.1 m), the mean visibility distances at which the orientation of the E was identifiable were considerably less than for the type 2 target. Visibility distances were similar for the high and low beams. Because the high beam provides greater upward scatter of light than the low beam, visibility with the high beam should have been greater. This was not the case, in part probably because relatively few subjects were tested. But a number of subjects reported that they experienced a considerable amount of glare from the target itself, which reduced their ability to determine the orientation of the letter. The green high-intensity sheeting used as the background for the letter had a reflectivity of 80 percent, and the letter E was made of silver high-intensity sheeting, with a reflectivity of 675 percent. The data suggest that the luminosity of route guidance signs made with retroreflective materials may be too great for optimum legibility, at least with high beams.

Road Test of Discomfort Glare

To determine the discomfort glare associated with various head lamp beams, a study was conducted on public highways. The frequency with which opposing drivers flashed their high beam head lamps at the test car equipped with various beams was noted. The beams used were conventional U.S. and ECE low beams; the U.S. low beams augmented by a third lamp aimed in two different ways to provide a type of mid beam; 6014 U.S. and H₄ ECE high beams; and a system of two 6014 U.S. low beams and two H₄ low beams.

The percentage of oncoming drivers who flashed high beams at the test vehicle when it was using the various beams is shown in Figure 8. The test was conducted on two-

Figure 6. Mean visibility distances of type 1 targets in low and high beam meetings.

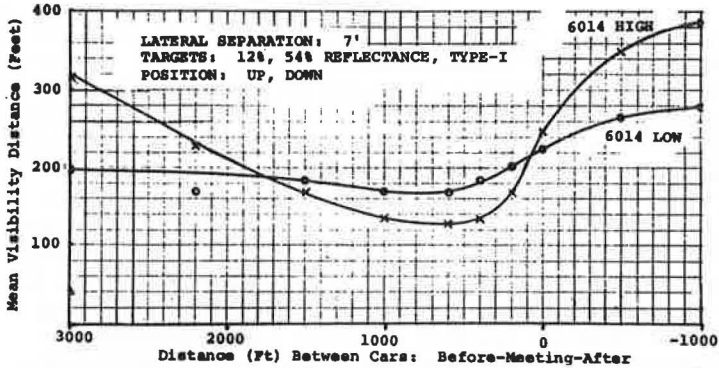


Figure 7. Comparison of mean visibility distances for subjects exposed twice to the same meeting situations.

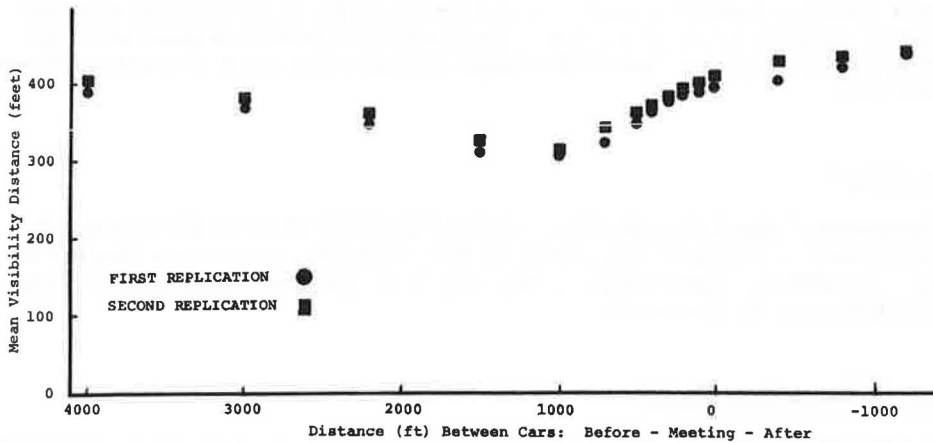
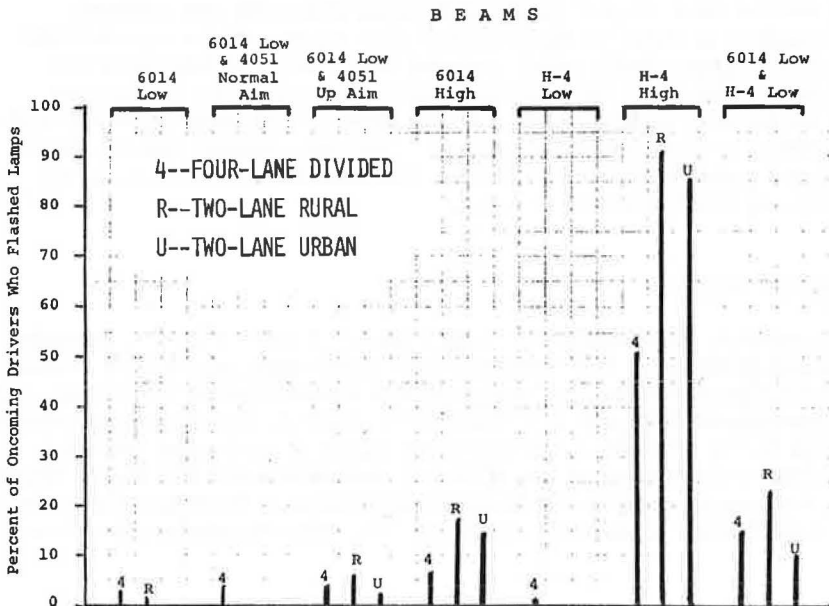


Figure 8. Percentage of oncoming drivers who flashed their lamps when opposed by the indicated beams.



lane urban roads, two-lane rural roads, and a four-lane divided highway. Relatively few responses were made by oncoming drivers when low and mid beams were used. About 18 percent of drivers responded to the 6014 high beam, whereas in the same condition with the H₄ high beam about 92 percent of oncoming drivers responded. Oncoming drivers were also influenced by the number of head lamps on the car: They made more responses when opposed by the four-lamp combination of the U.S. and ECE low beams, although these provided low glare levels, than when opposed by the U.S. high beam.

Glare in Rearview Mirrors

The effects of head lamp glare reflected in rearview mirrors were determined in a subjective evaluation. The subject drove the lead car, which was followed by the car used in the previous test. Tests were conducted on a two-lane rural road, a four-lane unlighted urban road, and a four-lane urban road with fixed lighting. The subject's task was to compare the discomfort glare from the experimental beams with the glare from the standard pair of low beams. He used a 9-point rating scale: -4 denoted no glare; 0 denoted glare as produced by the type 4000 reference low beams; and +4 denoted extremely discomforting glare. Normally, the reference low beam was used on the following car. On command of the experimenter in the lead car, the driver in the following car switched to the desired test beam and then back to the reference beam. The subject then made his judgment, which was recorded by the experimenter. Mirror data were collected in day (78 percent reflectivity) and night (4 percent reflectivity) settings with each of the test beams.

The mean glare ratings were uniformly greater with the mirror in the day than in the night setting. The trends of the mean ratings of the beams are the same on the three types of roads, as well as in the day and night settings. No differences in the ratings were attributable to the road conditions. The results are quite comparable to those found in the test of the glare responses of oncoming drivers to the same beams. The high beams were rated as more glaring in mirror tests than in the meetings. One difference between the two tests was in the response to the combined U.S. and ECE low beams, which was rated the same as the reference beam. Thus drivers responded to the glare illumination and not the total number of lamps lighted.

COMPUTER SIMULATION

A major objective of the field test was to develop empirical data in meetings of vehicles using different beams for development of and comparison with a mathematical model to predict the visibility distances and to compute glare values. The model is described elsewhere (6, 7).

Input data used in the simulation consist of the basic geometry of the situation, such as the location of the head lamps on the vehicles, the eye position of the driver of the main vehicle for whom the visibility and glare effect are to be computed, lateral separation between the vehicles, location of the target, and so on. In addition, a grid defining the intensities radiated by the individual head lamps at angular coordinates is used. The underlying concept of target visibility, as developed by Jehu (8), consists of the relationship between the illumination of a target and the effect of glare in determining the visibility distance. The disability glare effect is computed by using the equation proposed by Fry (9).

A major consideration in the development of the model was to predict visibility both before the vehicles meet and after the meeting point to show recovery from glare. This is accomplished by modeling an adaptation stage to prevailing glare; readaptation, which occurs at the point of maximum equivalent veiling glare; and recovery, which occurs when the veiling glare due to the opposing vehicle's head lamps decreases faster than could be followed by the photochemical process of the eyes.

Figure 9. Comparison of computer simulation and field test in low beam meetings.

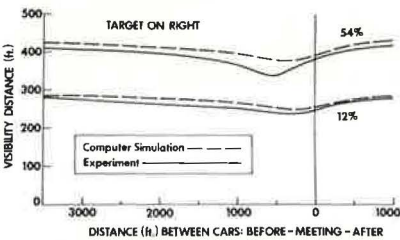


Figure 11. Computed visibility distances with U.S. and European low beams and a mid beam in nominal aim.

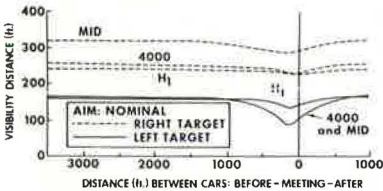


Figure 10. Visibility distances predicted by computer simulation.

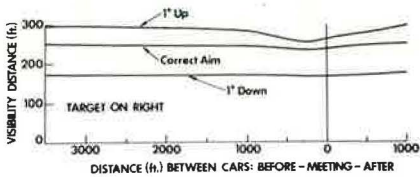


Table 1. Glare intensity and illumination from oncoming beams at 1,200 ft.

Beam	Aim	Intensity (cd)	Illumination (ft-c)	Ratio
H ₁ low	Nominal	714	0.0005	0.3
4000 low	Nominal	2,204	0.0015	1.0
Mid	Nominal	2,635	0.0018	1.2
H ₁ low	1 deg up	12,716	0.0089	5.8
4000 low	1 deg up	8,588	0.0060	3.9
Mid	1 deg up	8,853	0.0062	4.0

Note: 1 ft = 0.3 m. 1 ft-c = 10.7 lux.

Comparisons Between Computer Simulations and Field Test Data

The validity of the model was established by comparing predictions of the computer simulation with the results of the field tests. For example, Figure 9 shows the results of meetings between vehicles using low beams, with targets of 12 and 54 percent reflectance at the right edge of the road and 7-ft (2.1-m) lateral separation between the cars, as obtained in the field test and computer simulation. A large number of comparisons of this type were made with the many different conditions in which the field test data were collected to show the effect of variables such as lateral separation, beams, target location, and reflectance (6).

Applications of the Model

The model has a variety of applications that can provide insights into the influence of many variables on visibility distances and glare.

Figure 10 shows the effect of vertical alignment of a U.S. low beam head lamp on visibility of a type 1 target of 12 percent reflectance located at the right side of the road in meetings with a similarly equipped vehicle. Headlight misalignment of 1 deg up or down causes substantial changes in the visibility distances (10).

U.S., European, and Mid Beams

The computer simulation was also used to further evaluate the effectiveness of various meeting beams on targets located at the right and left of the lane and at various degrees of head lamp misalignment. Figure 11 shows computed visibility distances with U.S. and European low beams and a mid beam, with all beams in nominal aim condition, for targets located at the right and left of the lane. The mid beam provided greater visi-

bility than the low beams for the target at the right of the lane. For the target at the left of the lane there were no differences between the U.S. low beam and the mid beam, since the mid beam provides little illumination on the left side.

Table 1 gives the glare intensities of oncoming beams on vehicles separated by 1,200 ft (366 m), with the beams in nominal aim and with a misaim of 1 deg up. The table indicates that the ECE low beam produces the lowest glare intensities in nominal aim but also produces the greatest glaring intensities with a misaim of 1 deg up. This confirms the sensitivity of this beam to vertical alignment, which is an important consideration in the selection of meeting beams (11).

Other Computations

The model has now been extended to predict visibility distances in vehicle meetings on roads having horizontal or vertical curvature and the effects on visibility distances of the head lamps of a following car reflected in interior and exterior mirrors. In addition, the discomfort glare model proposed by de Boer (12) has been incorporated, though this must be validated further in dynamic field tests. These capabilities of the simulation have been used (13) to assess the compatibility of headlighting on cars and trucks.

REFERENCES

1. R. R. Mourant and T. H. Rockwell. Strategies of Visual Search by Novice and Experienced Drivers. *Human Factors*, Vol. 14, No. 4, 1972, pp. 325-336.
2. R. G. Mortimer and C. M. Jorgeson. Eye Fixations of Drivers as Affected by Highway and Traffic Characteristics and Moderate Doses of Alcohol. *Proc., 16th Annual Meeting of Human Factors Society*, 1972.
3. T. H. Rockwell. Driver Search and Scan Patterns in Night Driving. *Research Symposium on Driver Visual Needs in Night Driving*, Ohio State Univ., Sept. 1974.
4. R. G. Mortimer and C. M. Jorgeson. Effects of U.S., European and Mid Beam Headlamps on Eye Fixations of Drivers in Night Driving. *Highway Safety Research Institute, Univ. of Michigan, Rept. UM-HSRI-HF-74-17*, 1974.
5. R. G. Mortimer and P. L. Olson. Use of Driving Tests to Evaluate Headlamp Beams. *Highway Safety Research Institute, Univ. of Michigan, Rept. UM-HSRI-HF-74-14*, March 1974.
6. R. G. Mortimer and J. M. Becker. Development of a Computer Simulation to Predict the Visibility Distance Provided by Headlamp Beams. *Highway Safety Research Institute, Univ. of Michigan, Rept. UM-HSRI-HF-73-15*, 1973.
7. R. G. Mortimer and J. M. Becker. Computer Simulation to Predict Night Driving Visibility as a Function of Headlamp Beams. *Proc. First Internat. Conference on Driver Behavior*, Zurich, Oct. 1973.
8. V. J. Jehu. A Method of Evaluating Seeing Distances on a Straight Road for Vehicle Meeting Beams. *Trans., Illuminating Engineering Society*, Vol. 20, No. 2, 1955, pp. 57-68.
9. G. A. Fry. Evaluating Disabling Effects of Approaching Automobile Headlights. *HRB Bull.* 89, 1954, pp. 38-42.
10. R. G. Mortimer and J. M. Becker. Some Operational Considerations Affecting the Performance of Current and Proposed Head-Lamp Beams. *Transportation Research Record* 502, 1974.
11. R. G. Mortimer and J. M. Becker. Computer Simulation Evaluation of Current U.S. and European Headlamp Meeting Beams, and a Proposed Mid Beam. *Society of Automotive Engineers, Rept. 740311*, 1974.
12. J. B. DeBoer. Quality Criteria for the Passing Beam of Motorcar Headlights. Presented at GTB, Walldorf, West Germany, Sept. 1973.
13. R. G. Mortimer. Some Effects of Road, Truck and Headlamp Characteristics on Visibility and Glare in Night Driving. *Society of Automotive Engineers, Rept. 740615*, Aug. 1974.

A thorough review of the relevant literature was combined with a rigorous and systematic examination of the driving task to derive a set of visual functions important to the driving task. The functions included both static and dynamic measures, containing both sensory and perceptual aspects. A device was developed to test performance on these functions, including three measures related to night vision: static acuity under low levels of illumination, in the presence of veiling glare, and under spot glare. The battery of tests was administered to a total of 669 passenger car drivers and 235 truck and bus drivers. Three-year driving records were obtained for all subjects and were examined in relation to performance on the vision tests. Because no data on night accidents were available, an adequate evaluation of the night-vision-related tests was not possible; however, the results showed a high degree of variability in visual acuity performance obtained under conditions similar to those encountered in night driving and also showed that acuity measured under normal light conditions does not adequately predict acuity under typical night driving conditions.

DRIVER SCREENING FOR NIGHT DRIVING

R. L. Henderson,*
National Highway Traffic Safety Administration; and
A. Burg,
University of California, Los Angeles

The importance of vision to driving is well recognized. This recognition has been intuitive, for until recently there has been no evidence that poor vision is associated with increased accident likelihood. All states require driver license applicants to pass some test of visual performance, usually static acuity, at least for their first license. However, there is no standardization of tests, test procedures, minimum standards, or frequency of retesting among the states. In states without renewal examination, there is no assurance that even the minimal level of visual performance originally required is maintained by the driver over the years. When viewed in an international context, the problem is even more complex.

This paper describes a research program conducted to provide some of the information necessary before standards for driver vision screening can be established. The study had several specific objectives:

1. To determine analytically the basic visual requirements of driving by drawing on the existing literature relevant to the problem and by conducting a rigorous and systematic examination of the driving task;
2. To devise tests suitable for use in state driver licensing programs for visual performance parameters determined to be important to driving; and
3. To evaluate the accuracy of the empirical analysis and the adequacy of the devised tests by experimentally determining the relationship between visual capability as measured by tests and past accident involvement of those tested.

Only those tests that demonstrated a relationship between poor performance and high accident involvement would be appropriate for use in screening driver license appli-

*The research described in this paper was performed while Mr. Henderson was with the System Development Corporation.