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Evaluation of Meeting Beams by Field Tests and Computer Simulation

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Abstract

The objective of this study was to conduct field experiments to evaluate alternative meeting beams in terms of visibility distances and glare effects. The conventional U.S. and European low beams were used as a basis for comparison with the experimental mid beams.

Computer simulation evaluations were first made to indicate the most effective aim of the Type-III lamp used to augment the conventional low beam headlamps in providing mid beams. Two aiming specifications for this lamp were derived, in one of which the lamp was aimed with its maximum intensity 2° R, 0.5° D and in the other 2.5° R, 10° D. The former was intended to provide greater visibility and somewhat greater glare while the latter was intended to produce lower glare values and lower visibility.

Results of the field tests showed that visibility of Type-I targets positioned in the center of the two-lane road used, was about half that for targets at the right side of the lane. The visibility distances for the targets in the left of the lane were not different with the various beams, except at close to the meeting point where the beams using the ECE low beam provided slightly greater visibility. For targets on the right of the lane, the mid beam A and the ECE-U.S. mid beam produced the greatest visibility distances, up to 24% greater than the low beams by themselves. The results of this test and corresponding conditions in previous studies were in reasonably good agreement, indicating that the procedure was fairly reliable. Glare ratings were found not to differ between the beams for targets on the right side of the road but for targets on the left side of the road the glare ratings were better for the two beams using the ECE low beam than the mid beams A or B. Visibility distances for a pedestrian target were about the same as for the Type-I target used in these studies. The data suggest that, a mid beam, composed of the ECE low beam and a Type-III lamp can be expected to provide about a 20% increase in seeing distance for targets along the right side of the road with negligible increases on glare for meetings on straight, flat, two-lane roads.

There was generally good agreement between computer simulation predicted visibility distances and those obtained in the field test.

It was concluded that improved meeting beams should incorporate the general characteristics of the mid beams used in these tests and that, based on the test findings and those of previous computer simulations, the mid beams should be dimmed when meeting another vehicle which is in the outside lane and when following another vehicle at distances of less than about 200 ft.

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OBJECTIVES

The objectives of this study were:

1. To utilize a field test procedure developed in previous phases of this research for the evaluation of headlamp beams.

2. Conduct preliminary computer simulation evaluations of meeting beams and derive a subset for evaluation in a field test.

3. Carry out a field test of meeting beams.

4. Recommend general photometric beam characteristics of an improved meeting beam.

SUMMARY OF FINDINGS

1. With all five beams evaluated (see Table 1, page 11), mean minimum visibility of the Type-I targets on the left was about half that of targets on the right, during meeting situations.

2. The absolute magnitude of differences between beams in mean minimum visibility distances of Type-I targets on the left of the lane was 24 ft or less (25%). The U.S. low and mid beam-A produced significantly lower mean visibility distances than the ECE low beam and the ECE-U.S. low beam only close to the meeting point.

3. There were larger absolute differences between beams in the mean visibility distances of Type-I targets on the right side of the lane. Greatest visibility distances, throughout the meetings, were obtained with the mid beam-A and the ECE-U.S. mid beam, with increments in visibility of up to 24% over conventional low beams (209 vs 259 ft).

4. No differences were found in visibility distances of targets on the right of the lane between representative U.S. low and ECE low beams.

5. Glare discomfort was significantly greater, for all beams, when the targets were on the left than on the right. With targets on the right, there were no differences in glare ratings between beams. With targets on the left, the ECE low beam and ECE-U.S. mid beam were rated less glaring than mid beams A and B.

6. Mean minimum and maximum (no-glare) distances at which the 7% reflectance pedestrian target was detected was about the same as for identification of the orientation of the 12% reflective Type-I targets.

7. Comparisons between some of these tests and corresponding ones made in previous phases of this research program, showed about identical mean visibility distances of Type-I targets on the left of the lane, with a maximum discrepancy of 20% in mean visibility distance near the meeting point for targets on the right (210 vs 250 ft in Figure 16).

8. Comparisons between the mean visibility distances obtained in the meetings simulated in the field test and those derived by the computer simulation model for the five beams, were in general agreement for Type-I targets on the left. For targets on the right, the field test data showed shorter visibility distances in the region near the meeting point, than the computer simulation. The average maximum deviation between the computer simulation and field test data was 20% of the field test mean minimum visibility distance, for the tests conducted with the target on the right side of the lane.

9. The results of this investigation suggest that the use of a meeting beam having the characteristics of the ECE-U.S. mid beam used in these tests would produce about a 20% increase in visibility distance for meetings on straight, flat, two-lane roads. This seeing distance increase would be accompanied by a slight increase in glare discomfort.

FOREWORD AND ACKNOWLEDGMENTS

This report describes the latest in a series of studies concerned with vehicle headlighting performance, sponsored by the Motor Vehicle Manufacturers Association of the U.S., Inc., during the period 1971-1974.

This report is issued under the general contract title, "Passenger Car and Truck Lighting Research: Headlighting, Phase III, Evaluation of Candidate Systems." Other reports describe the development of a mathematical model to predict the seeing distance provided by different beam patterns in opposed and unopposed traffic conditions, multi-beam switching, factors affecting headlamp aim, and the development of headlighting field tests.

During the conduct of this work periodic meetings were held with the MVMA Lighting Committee, Headlighting Research Task Force, consisting of Mr. W. Rankin, Chairman, Mr. R. Donohue, Mr. P. Lawrenz, Mr. P. Maurer and Mr. B. Preston. The members of this committee were very helpful and their comments and suggestions contributed materially to the progress of the work.

The field tests described in this study were conducted at the General Motors Corporation Proving Ground, Milford, Michigan. We are most grateful to GM for providing the use of their facilities.

Craig Jorgeson and Corwin Moore, of the Human Factors Department, HSRI, provided assistance in the conduct of this study.

INTRODUCTION

In their first report concerning a headlamp field test program (Mortimer and Olson, 1974), the authors described targets, methods and the results of tests run with a number of beam patterns.

One of the important purposes of the work was to provide background data for the development of an analytical model of headlamp performance based on visibility distance. Work on the model has progressed substantially (Mortimer and Becker, 1973; Becker and Mortimer, 1974). A number of beam patterns have been analyzed using the technique and its validity, based on comparison with field test data, appears adequate.

The purpose of the test program to be described in this report was to evaluate several beam patterns representing present low and potential mid beams. These beam patterns have been subjected to analysis by the model as well and the results are presented for comparison.

METHOD

TEST COURSE

A dynamic approach was used as before, with two cars being driven toward each other to simulate a meeting at night on a two-lane road. Each car was equipped with the test lamps, subjects and the necessary measurement and recording instrumentation.

A schematic drawing of the course is given in Figure 1. Not shown are the start positions for each car, which were located 1,000 feet back of the positions labelled "Begin" in the figure. The distances shown on the figure are in

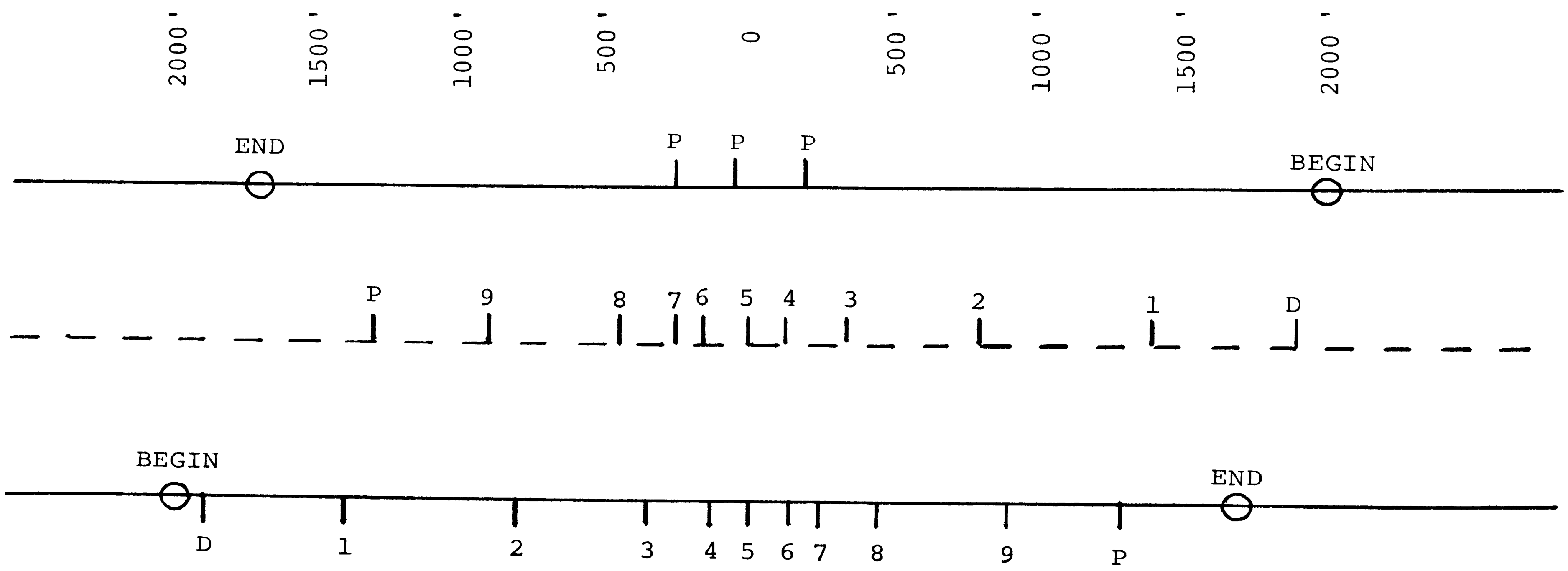

Figure 1. The test course used in the field study. "Begin" and "End" were marked by traffic cones and used as start and stop points for the timer. Type-I targets were used at positions D, and 1 through 9. The 6' x 1.5' "pedestrian" target was used at position P. The three P targets close together on one side of the road were used in one phase of the test, after all other targets in that lane had been removed.

feet from the designated meet point at target 5. The separation distance between the two test cars as they progressed through a run was about double the distances shown at each point. Thus, as a test car passed the "Begin" point at 2,000 feet, it would be about 4,000 feet away from the other car; as it passed target 1 the separation distance would be about 2,800 feet, and so on. Separation distance at the time a target was identified was about double the sum of the target distance and the visibility distance. These are approximations due to trial-to-trial variations in car position. Due account was taken of these variations in the data analysis.

The course was arranged so that the targets would appear on the subjects' right when running in one direction and on their left when running in the opposite direction. The three closely grouped targets marked "P" in Figure 1 were present only in one phase of the study, as will be explained later. The targets in the center of the road were removed for that phase.

TARGETS

Two types of targets were used in this study. The targets located at positions "C" and 1-9 in Figure 1 were the Type-I targets used in the earlier investigations, and are fully described in that report (Mortimer and Olson, 1974). A photograph of one of them is given in Figure 2. Basically, the target consists of a 24" x 30" flat black (3% reflectance) background on which the reflective faces are mounted. The reflective portions of the target consist of a 4" x 10" bar and an 8" x 8" square which could be located at either end of the bar. The subjects' task was to determine whether the square was located at the left or right end of the bar. The faces are available in different reflectance levels,

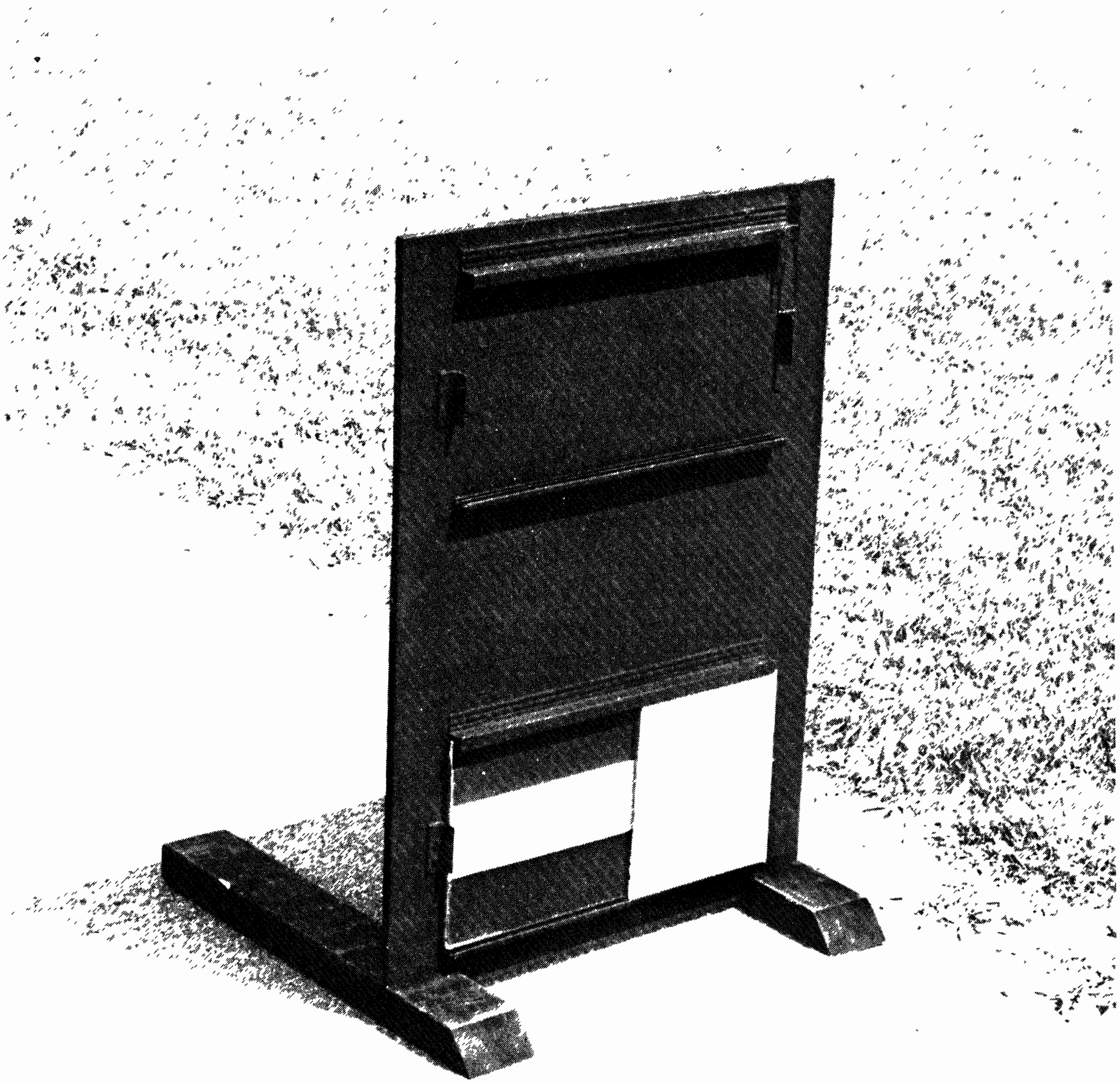

Figure 2. The Type-I Target.

with 12% faces being used in this test. The center of the faces of the targets were mounted 6 in. above the pavement.

The Type-I targets which were placed on the center line of the road had their backing plates cut off at a height of 18 in. This was done to insure that they did not block the headlamps of the oncoming car at any time.

The "D" target was a dummy in the sense that it was not included in the data analysis. It had been determined in previous work that visibility distances for the first target in a series tended to be unduly short, so a practice was developed of inserting an extra target forward of the intended first target. The subjects were not aware that their response to this dummy target did not count, and its right-left orientation was changed on the same basis as all other targets.

The targets at positions "P" in Figure 1 were intended to simulate a pedestrian. They were rectangles, 16 in. wide and 72 in. high, painted dark gray (7% reflectance). The subjects' task was to detect their presence.

TEST CARS

Two identical station wagons were employed (Figure 3). They were the same cars used in earlier studies and are fully described in that report (Mortimer and Olson, 1974). Briefly, the cars were equipped with a front-mounted panel to which the headlamps are attached at a height of 24 in. Special circuitry enabled the voltages supplied to the filaments to be controlled precisely. The cars were also equipped with cruise controls. Two subjects were carried at a time in each car, one driving and the other in the front passenger seat. Data were taken on a strip-chart recorder.

Both cars were equipped with photodetector systems to mark target positions. These devices (Figure 4) were attached to the rear of the cars on the passenger side. Basically, they consisted of a light source and a photocell. Retroreflective markers, 3 in. wide and 18 in. tall, were placed at each target position and triggered the unit, placing a mark on the recorder as the car passed each target.

The subject who drove the car depressed the right or the left horn button to indicate his response to the orientation of the face of each target as soon as it became discriminable. The subject in the right front passenger's seat moved a wafer switch to the right or left to indicate his response.

SUBJECTS

Sixteen subjects participated in the test program. The visibility data from two of these were lost due to recorder problems, although rating data were obtained. The subjects, who were recruited from newspaper advertisements, ranged in age from 20 to 51; nine were males, seven were females.

TEST SITE

The test was conducted on a straight, flat road, 1.2 miles long, which was free of other traffic. The paved surface (moderately worn asphalt) was 24 feet wide with white edge stripes and an alternating black and white center divider. The directional reflectivity of the pavement, at 2° incidence angle, was measured at 10%. Shoulders were gravel of varying width, the minimum being about 15 feet.

PROCEDURE

The subjects were given a far-acuity test to be sure their vision was at least equal to the minimum set by

Figure 3. A headlighting test car.

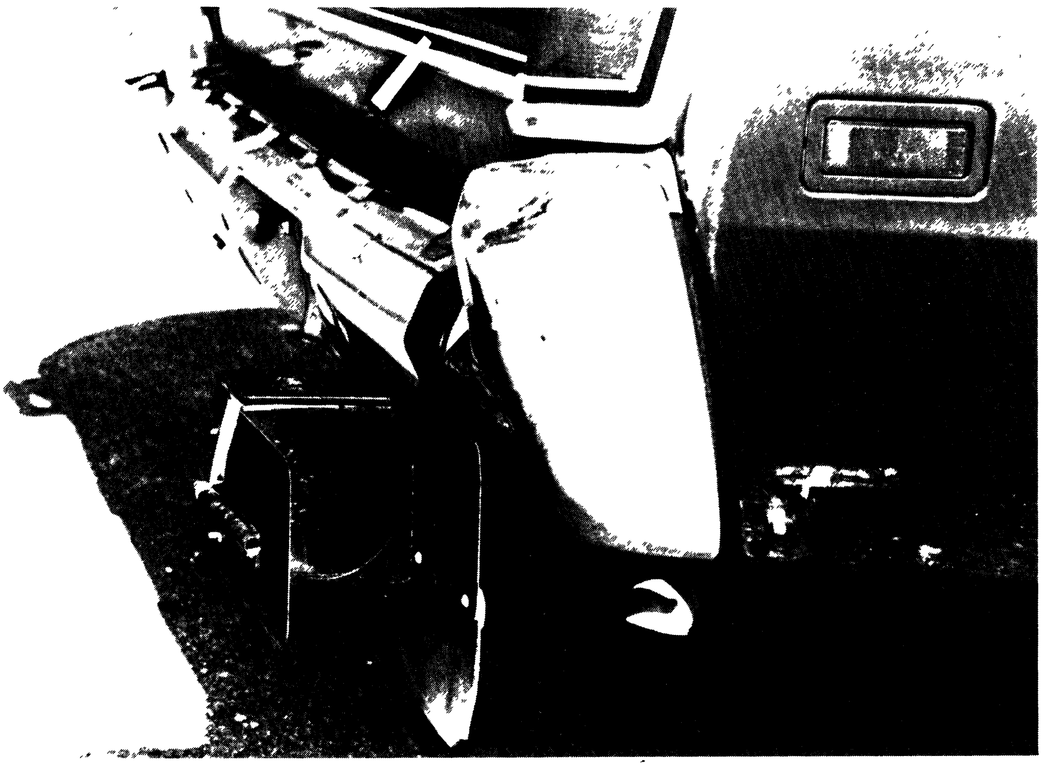

Figure 4. The target position photodetector mounted at the rear of a test car.

Michigan law (20/40), and transported to the test site. They were seated in the test car, instructions were read (see Appendix I), questions answered, and a minimum of two practice trials given.

Each run started with the two cars stationary, facing each other, 1,000 feet back of the "Begin" point. As each experimenter completed preparations for the next run he switched off the headlamps on his car. One experimenter then switched his lamps on and, when the other experimenter did likewise, both drivers accelerated moderately to about 32 mph and removed their foot from the accelerator. The cars then slowed to the test speed (40 ft/sec) at which point speed was maintained by the cruise-control.

The experimenter started the chart recorder as the cone marking the "Begin" point became visible and pressed a switch, putting a mark on the recorder and starting a timer, as the car passed it. The experimenter also marked the point at which the vehicles met at mid course and the point at which the car passed the cone marking the end of the course, the latter action also stopping the timer. The driver continued on down to the end of the road, turned around and stopped to await the next run.

At the conclusion of each run the subjects were asked to use a nine-point scale to rate the visibility (5 = same as American low beam, 1 = very much less effective, 9 = very much more effective) and maximum glare discomfort (1 = intolerable, 3 = disturbing, 5 = just acceptable, 7 = satisfactory, 9 = not noticeable) associated with the beam pattern just used on the opposing vehicle. This glare discomfort scale has been widely used for evaluations of fixed lighting installations (deBoer, 1967).

Two studies were conducted. All subjects participated in the main study, using the Type-I and pedestrian targets on the right edge of the road and in the center of the road, as shown in Figure 1. The three pedestrian targets on the one side near the meeting point were not in place.

The beams to be used in these tests were selected on the basis of computer simulation evaluations of the optimal aim of the Type-III headlamps, used with conventional low beams, to form the mid beam.

The independent variables for this study were:

1. Headlamp beam patterns, 5 levels. A listing of the beam patterns is given in Table 1. Two "Type-III" headlamps, one in each aim condition, were used with low beam headlamps to form a mid beam. These were mounted on the driver's side of the car. The maximum candela output for each lamp was adjusted to the value shown and maintained throughout the study. The beam patterns and aim of these lamps are shown in Figures 5-8.

2. Target position, 2 levels: at the right or left edge of the lane used by the test vehicle.

3. Longitudinal separation between the test vehicles, 14 levels.

4. Replications, 2 levels: two runs were made by each subject under each condition.

5. Subjects, 14.

A second study was conducted using four subjects and the three pedestrian targets on one side of the road. The targets in the center of the road were removed. The operational procedures were the same as for the primary study except that data could be taken when running only in one direction. The vehicle running in the opposite direction provided glare.

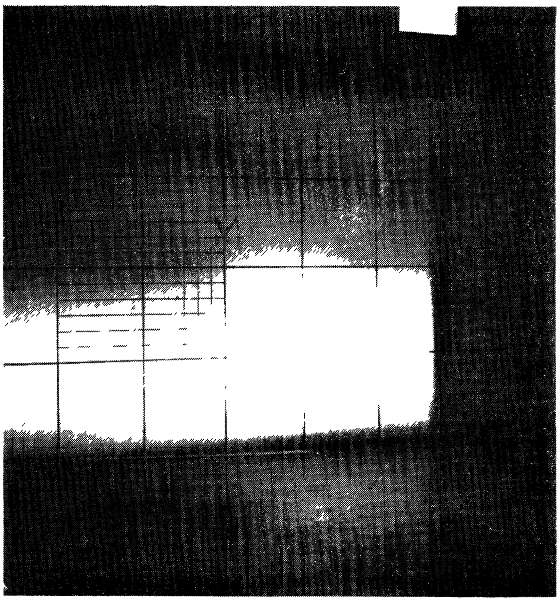

Figure 5. Aim of Type 4000, U.S. low beam

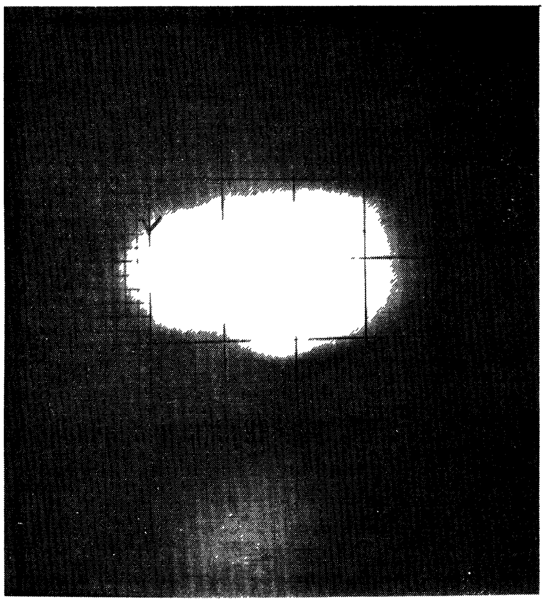

Figure 6. Aim of Type-III headlamp used in mid beam-A and ECE-U.S. mid beam.

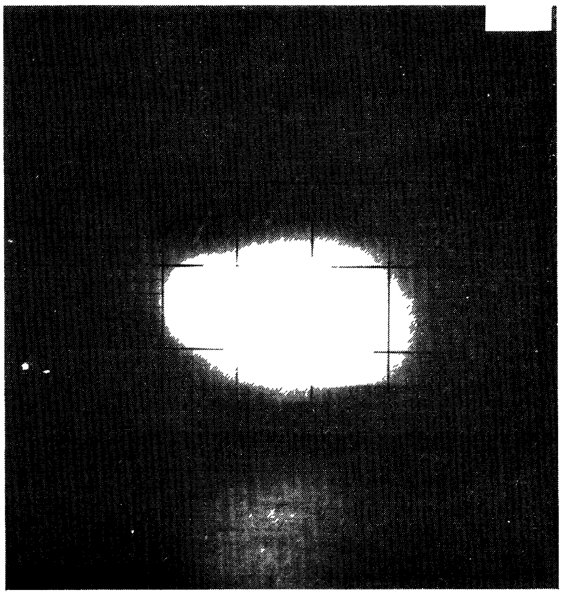

Figure 7. Aim of Type-III headlamp used in mid beam-B.

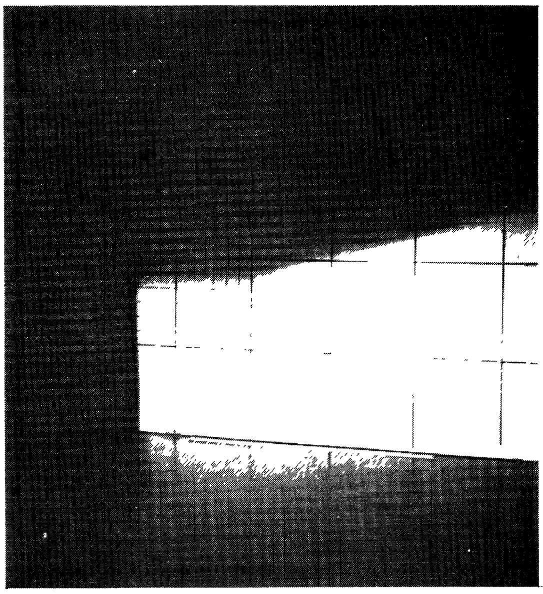

Figure 8. Aim of Type-H_4, ECE low beam.

TABLE 1. The Headlamp Beams.

BEAM	LAMPS	MAXIMUM INTENSITY (cd)	AIM OF MAXIMUM INTENSITY
US LOW	Two Type 4000	26,000	3° R, 2° D
MID-A	Two Type 4000	26,000	3° R, 2° D
	One Type III	50,000	2° R, 0.5° D
MID-B	Two Type 4000	26,000	3° R, 2° D
	One Type III	50,000	2.5° R, 1° D
ECE LOW	Two Type H_4	18,000	3° R, 1° D
ECE-US MID	Two Type H_4	18,000	3° R, 1° D
	One Type III	50,000	2° R, 0.5° D

Independent variables for this study were:

1. Headlamp beam patterns, 2 levels. The beams described as U.S. low and Mid-A (Table 1) were used.

2. Longitudinal separation, 14 levels.

3. Replications, 2 levels.

4. Subjects, 4.

DATA RECORDING

The following information was obtained on each run:

1. The time required to run the 3,700 feet from the Begin to End points on the course. At 40 ft/sec this should have been 92.5 seconds. Almost all runs were within one second of this figure.

2. The distance on the chart paper required to run from the Begin to End points.

3. The distance on the chart paper from the Begin to Meeting points.

4. The distance on the chart paper from the subject's identification of each target until it was passed by the photodetector on the car.

RESULTS

TYPE-I TARGETS

VISIBILITY DISTANCE. For each run the desired information, for each target at the time it was correctly identified, was its distance from the subject's eyes and the longitudinal separation between the two cars. In making these calculations corrections were allowed for the mean speed of each car and chart recorder. It was assumed that the subject took 0.5 sec to respond after he had detected the target orientation. This increased visibility distance by 20 ft.

The data from the first analysis yielded different separation distances for each target-run-subject combination. To conduct a statistical analysis common separation distances were required. To obtain these, the data were run through a curve-fitting routine, and the interpolated visibility distances at predetermined separation distances measured. These are the data on which the subsequent analysis was based.

Figures 9 and 10 show the mean visibility distances obtained with each beam pattern as a function of longitudinal separation from an opposing vehicle with the same beams for Type-I targets on the left and right of the lane, respectively.

The analysis of variance (ANOVA) for these data revealed that there were no significant differences between drivers and passengers in this task ($p > .05$), and that visibility distances were greater for all beams for targets on the right than left of the lane ($p < .05$).

In general, visibility distances did not differ significantly for the various beams for the left target except at small separation distances between the vehicles (100-200 feet), where the European (ECE) low and the ECE-U.S. mid beam were significantly better ($p < .05$) than the U.S. low beam and mid beam-A.

In the case of the right hand target, most of the apparent differences shown were significant ($p < .05$) at all separation distances. The U.S. and ECE low beams did not differ significantly, but produced lower visibility distances than the mid beams. Nor were there any significant differences in visibility distances between mid beam-A and the ECE-U.S. mid beam, but they produced greater visibility distances than the other beams.

Table 2 is a comparison of key aspects of beam patterns

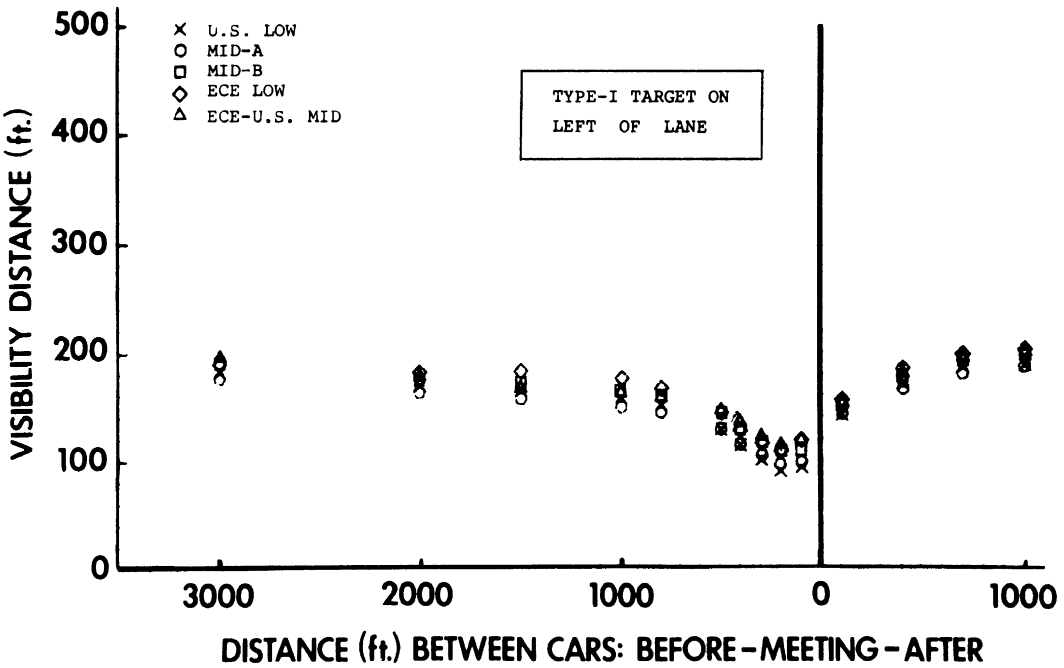

Figure 9. Mean visibility distances of the 12% Type-I targets during meetings of vehicles with five beams on a two-lane, straight, flat road: targets on left of lane.

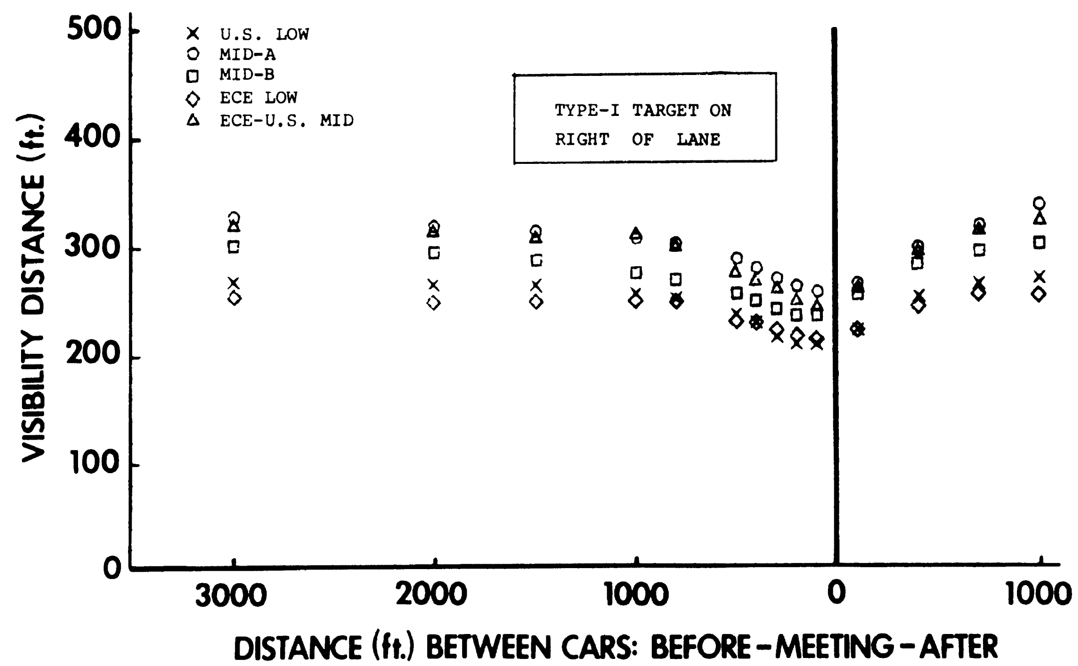

Figure 10. Mean visibility distances of the 12% Type-I targets during meetings of vehicles with five beams on a two-lane, straight, flat road: targets on right of lane.

TABLE 2. Minimum and Maximum Mean Visibility Distances of Type-I Targets on the Right and Left Side of the Lane.

BEAM	MINIMUM VISIBILITY DISTANCE (feet)	RATIO OF VISIBILITY DISTANCE	MAXIMUM VISIBILITY DISTANCE (feet)	RATIO OF MIN./MAX. VISIBILITY DISTANCE
TARGET ON RIGHT				
US LOW	209	1.00	273	0.77
MID-A	259	1.24	339	0.76
MID-B	237	1.13	304	0.78
ECE LOW	213	1.02	256	0.83
ECE-US MID	246	1.18	325	0.76
TARGET ON LEFT				
US LOW	93	1.00	191	0.49
MID-A	97	1.04	190	0.51
MID-B	111	1.19	200	0.56
ECE LOW	111	1.19	204	0.54
ECE-US MID	117	1.26	202	0.58

performance. This table makes it clear that not only was maximum (actually non-glare) visibility better for the right hand targets, but the percent loss due to glare is only about half that of targets on the left side of the road. The table also shows that the absolute differences in mean visibility distances between the beams is quite small when the target is on the left of the lane. Minimum visibility distances of the target on the left were about half, or less than half of those for the target on the right.

COMPARISON OF COMPUTER SIMULATION AND EXPERIMENT. Figures 11-20 compare empirical data for each lamp-target configuration with results predicted by the model. In general, the fit is very satisfactory. The empirical data tend to show a greater drop at the minimum visibility point than the results predicted by the model primarily when the target is at the right of the lane.

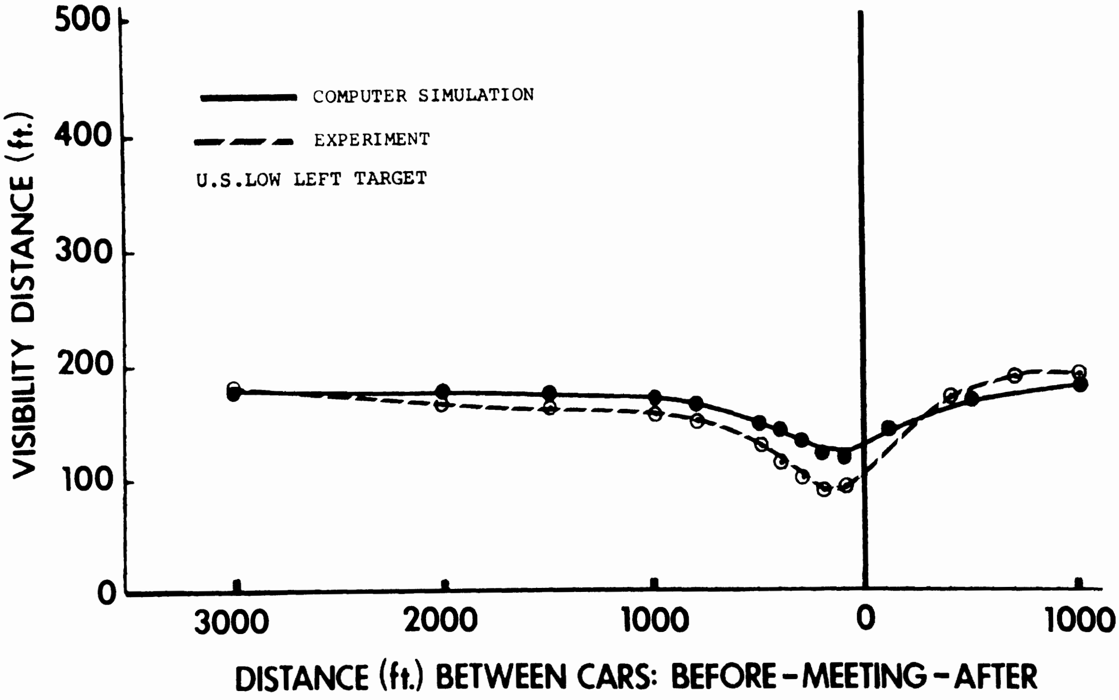

Figure 11. Computer simulation and experiment test results for meetings on a two-lane road with U.S. low beams, 12% reflectance target on the left of the lane.

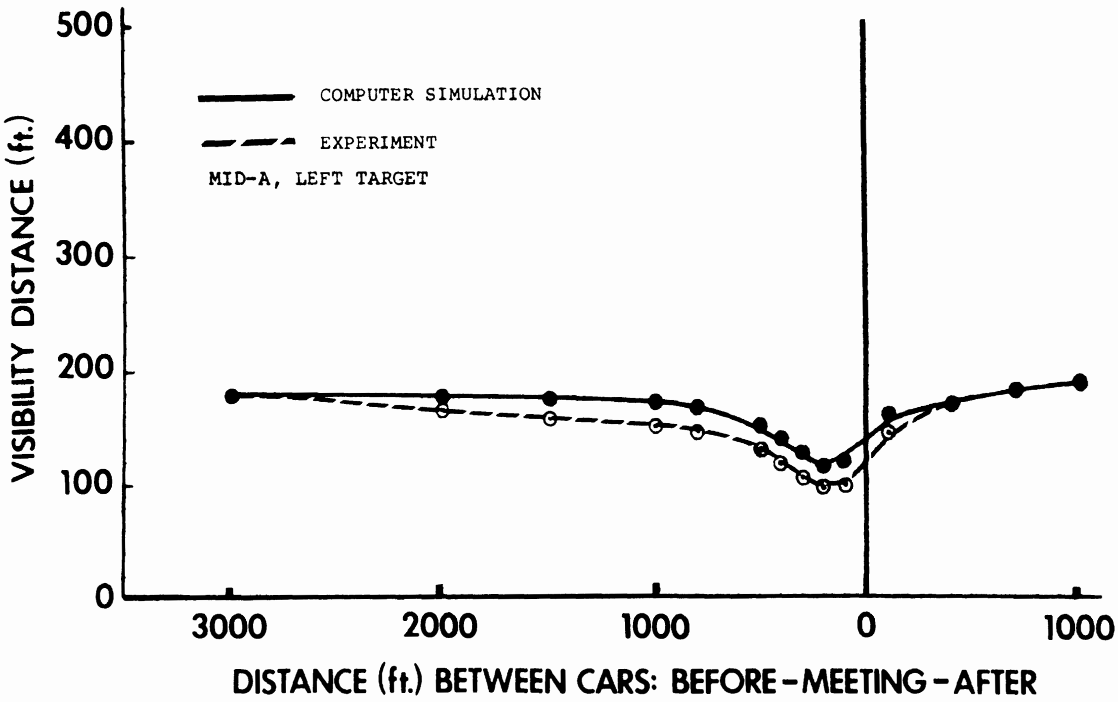

Figure 12. Computer simulation and experiment test results for meetings on a two-lane road with mid-A beams, 12% reflectance target on the left of the lane.

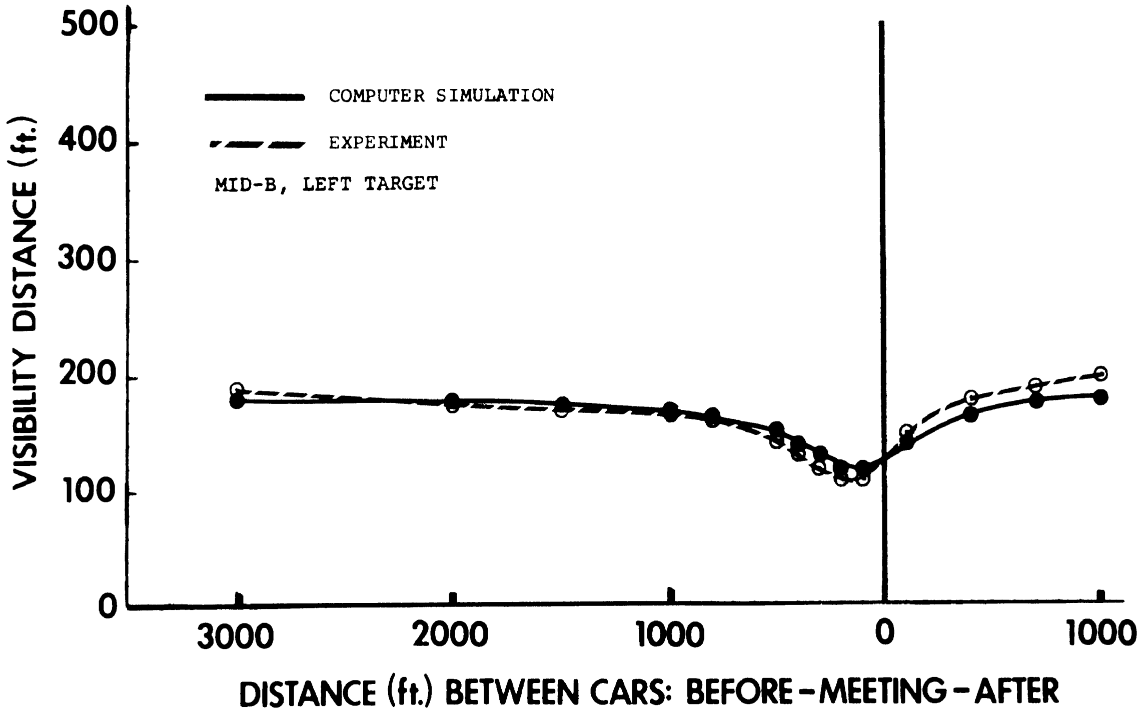

Figure 13. Computer simulation and experiment test results for meetings on a two-lane road with mid-B beams, 12% reflectance target on the left of the lane.

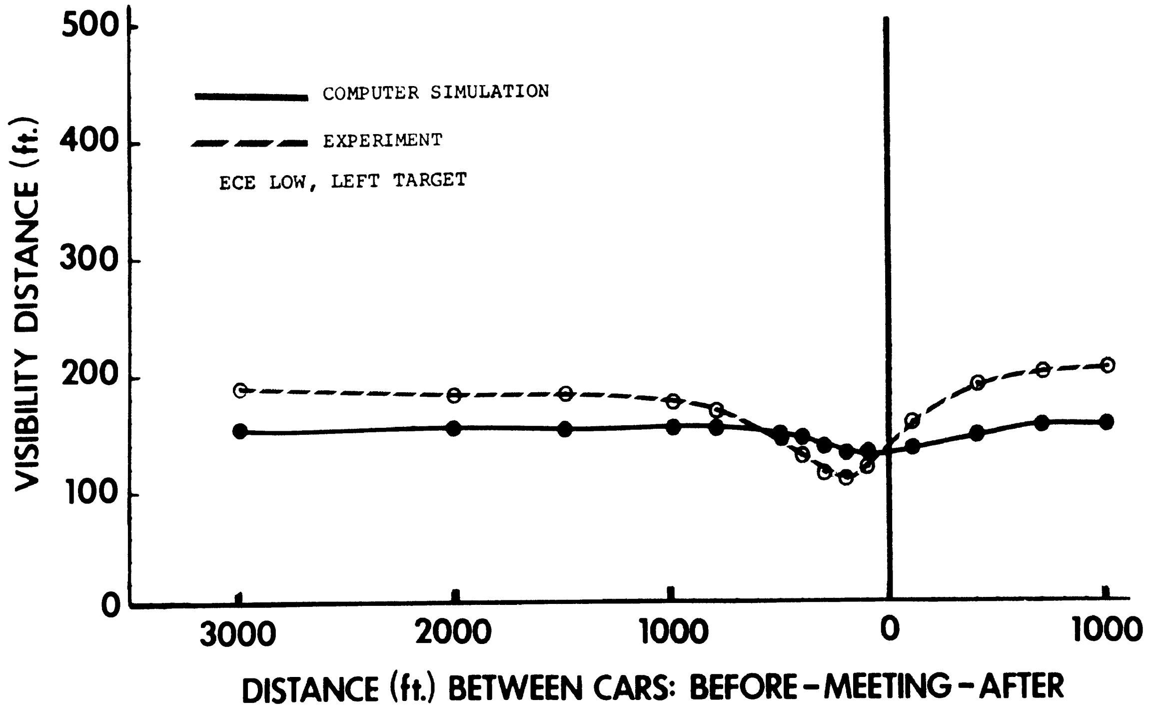

Figure 14. Computer simulation and experiment test results for meetings on a two-lane road with ECE low beams, 12% reflectance target on the left of the lane.

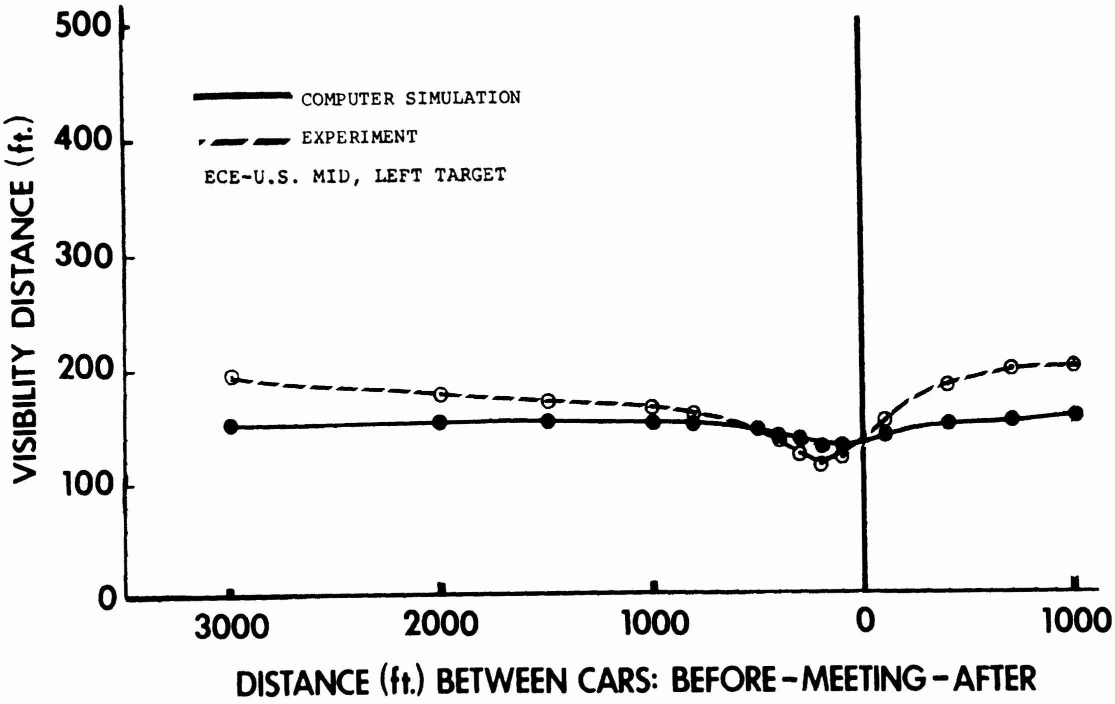

Figure 15. Computer simulation and experiment test results for meetings on a two-lane road with ECE-U.S. mid beams, 12% reflectance target on the left of the lane.

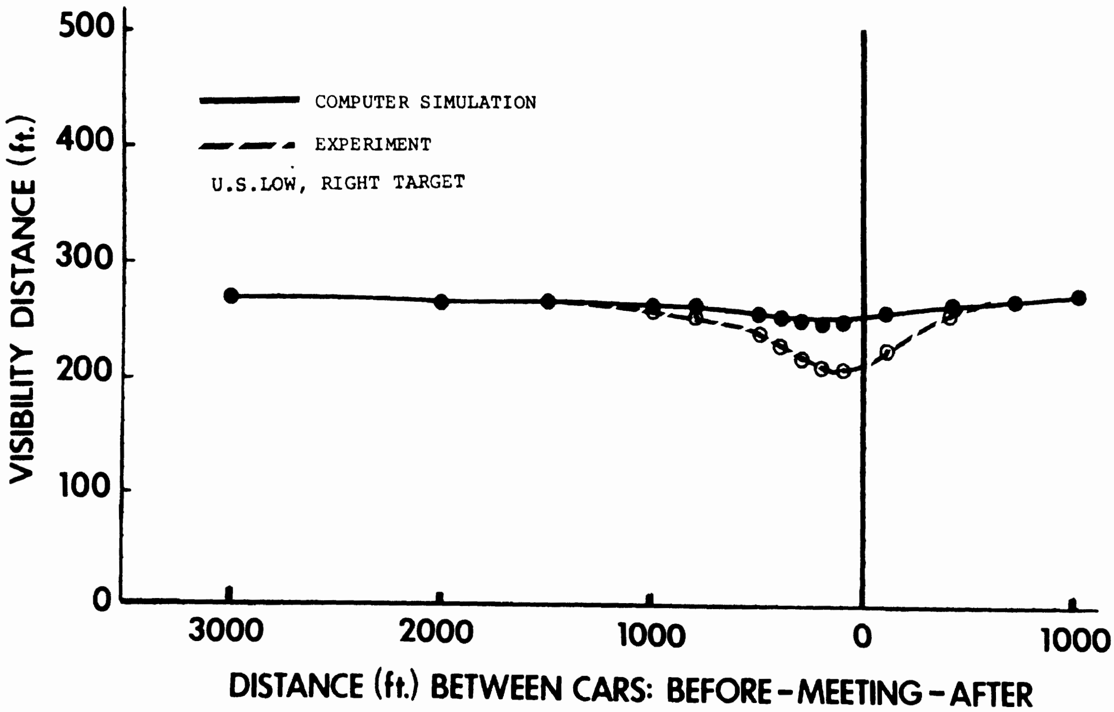

Figure 16. Computer simulation and experiment test results for meetings on a two-lane road with U.S. low beams, 12% reflectance target on the right of the lane.

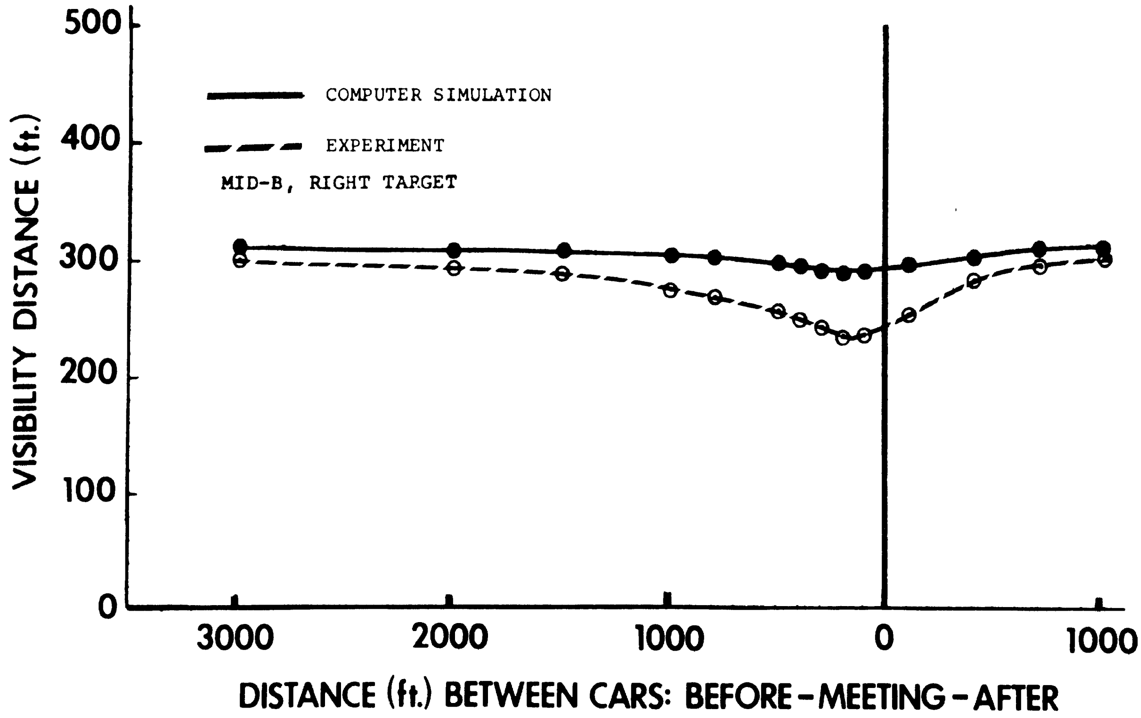

Figure 17. Computer simulation and experiment test results for meetings on a two-lane road with mid-A beams, 12% reflectance target on the right of the lane.

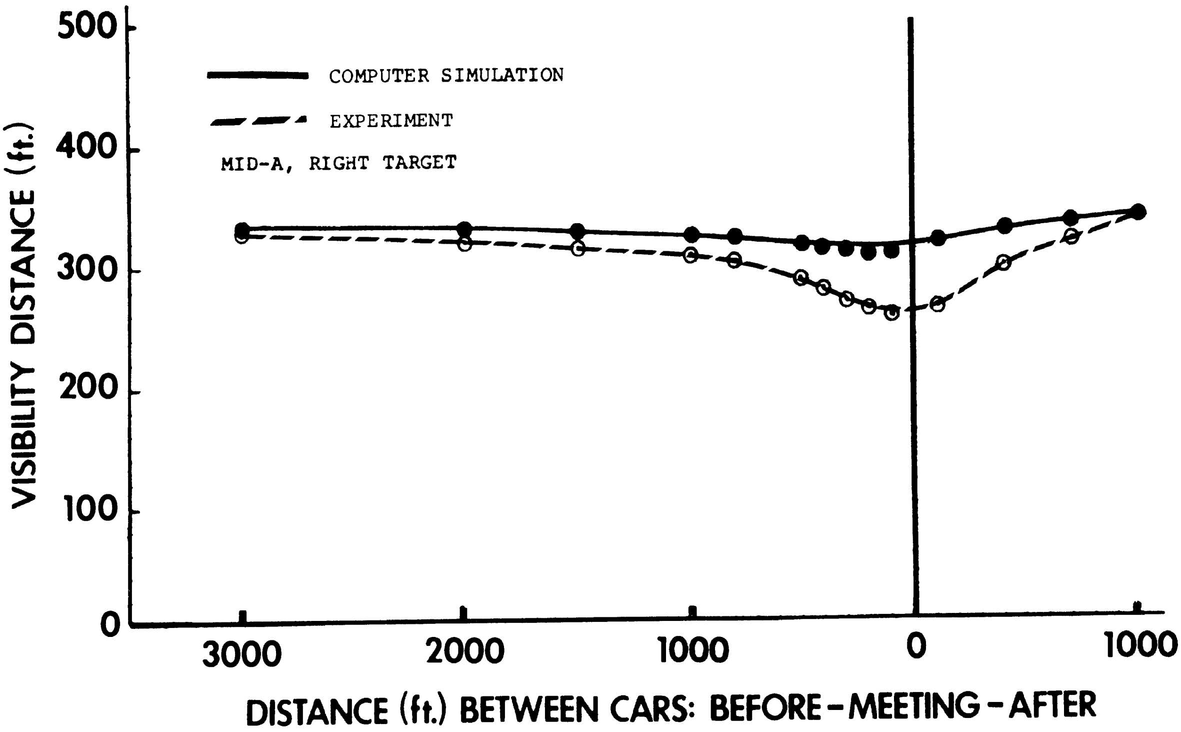

Figure 18. Computer simulation and experiment test results for meetings on a two-lane road with mid-B beams, 12% reflectance target on the right of the lane.

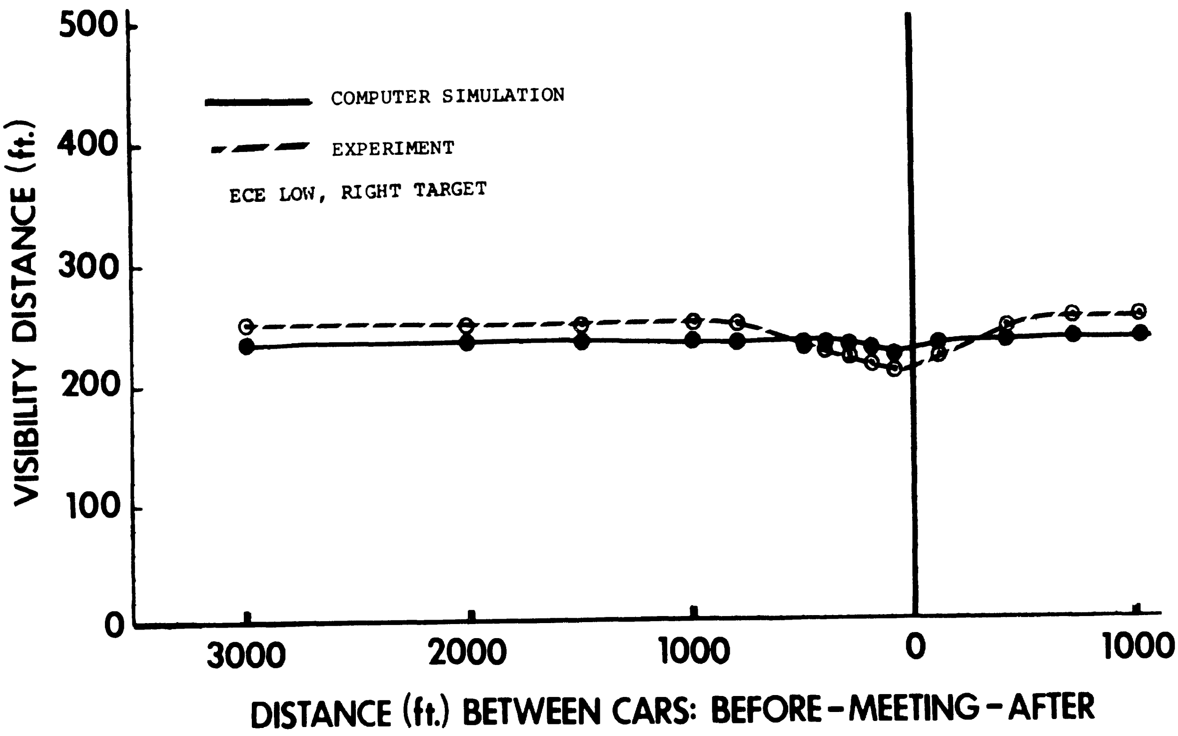

Figure 19. Computer simulation and experiment test results for meetings on a two-lane road with ECE low beams, 12% reflectance target on the right of the lane.

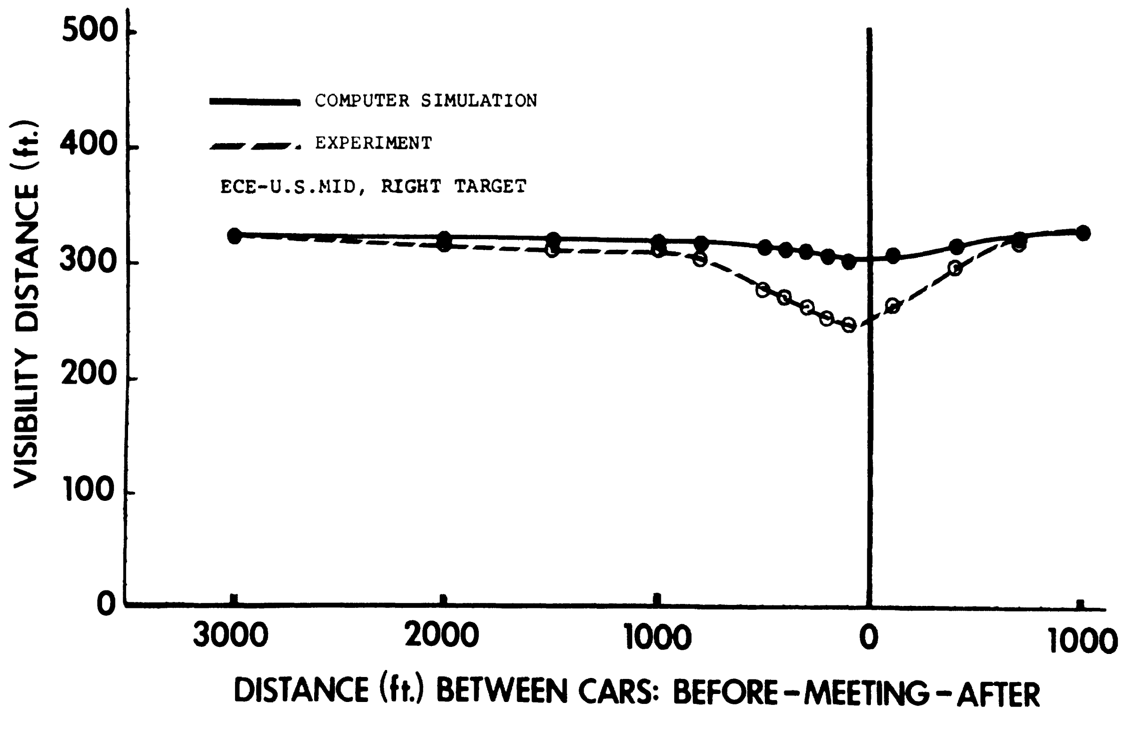

Figure 20. Computer simulation and experiment test results for meetings on a two-lane road with ECE-U.S. mid beams, 12% reflectance target on the right of the lane.

COMPARISON WITH PREVIOUS TESTS. Three combinations of lamp, target and other conditions were identical to some tested earlier. These were the U.S. low beam with targets on the right and left, and the ECE low beam with the target on the right. Figures 21-23 reproduce these results. The comparison between data from this and the earlier study for the case where the target is on the left is excellent. The fit in the other two cases, for the target on the right of the lane, is also good under low glare conditions, with a maximum difference in visibility distance of about 40 ft (about 20%) occurring at the point of minimum visibility.

GLARE AND VISIBILITY. Figures 24 and 25 show the mean ratings obtained for both glare and visibility, respectively.

The mean glare ratings showed that drivers experienced less discomfort ($p < .05$) for every beam when the targets were on the right than on the left. The differences between beams were not significant when the targets were on the right; but the ECE low and ECE-U.S. mid beams were rated significantly less glaring ($p < .05$) than mid beams A or B when the targets were on the left of the lane.

Visibility ratings were also significantly better ($p < .05$) for all beams when the targets were on the right as compared with the left. For right side targets the ECE-U.S. mid beam was rated significantly better ($p < .01$) than the U.S. low beam For left side targets the ECE-U.S. mid beam was rated significantly better ($p < .05$) than all other lamps, and the ECE low beam was rated better ($p < .05$) than mid beams A or B.

PEDESTRIAN TARGETS

VISIBILITY DISTANCE. Figure 26 shows the mean visibility distances obtained for the single pedestrian target placed at the end of the line of Type-I targets during the regular study. This target was encountered after the test vehicles

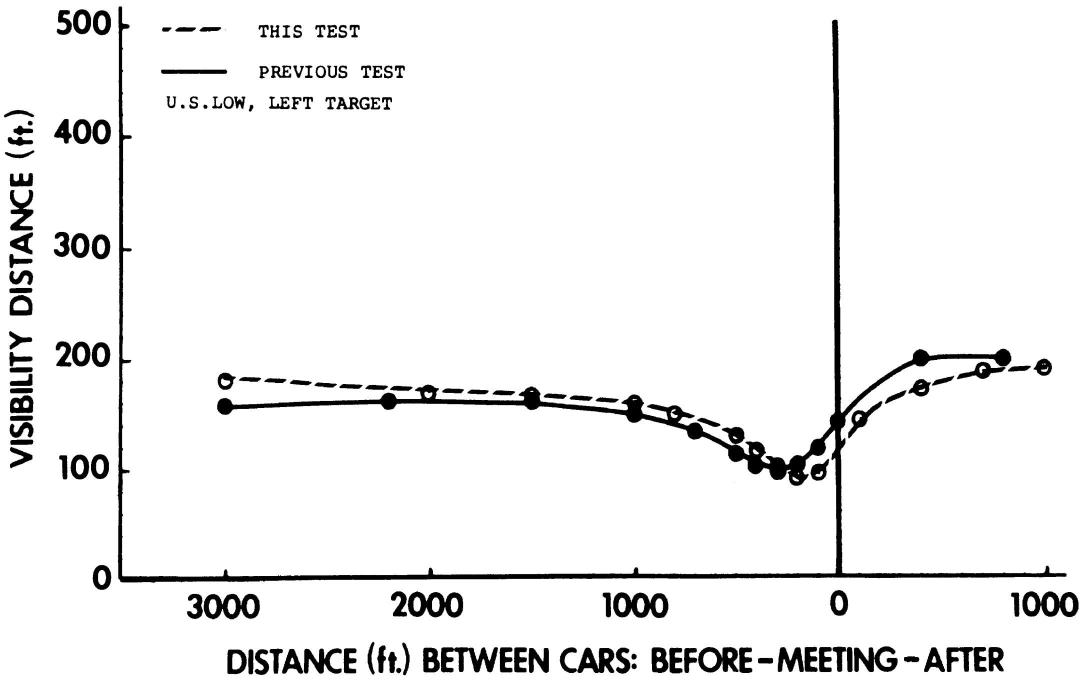

Figure 21. Comparsion of the mean visibility of Type-I targets in meetings with U.S. low beams in this and previous tests: targets on the left of the lane.

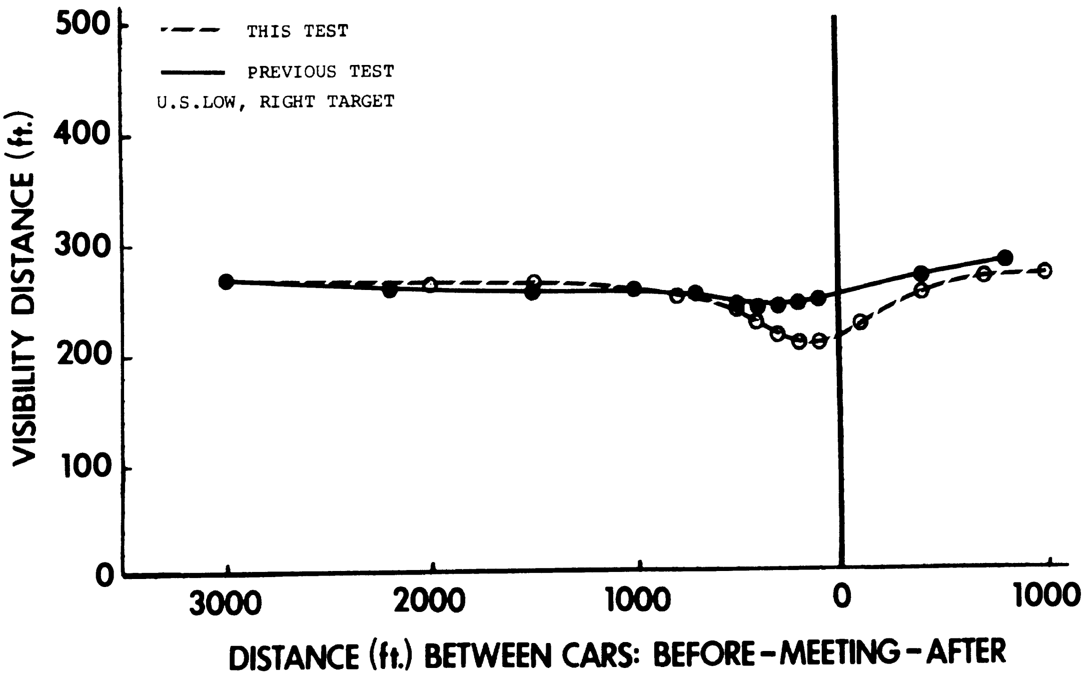

Figure 22. Comparison of the mean visibility of Type-I targets in meetings with U.S. low beams in this and previous tests: targets on the right of the lane.

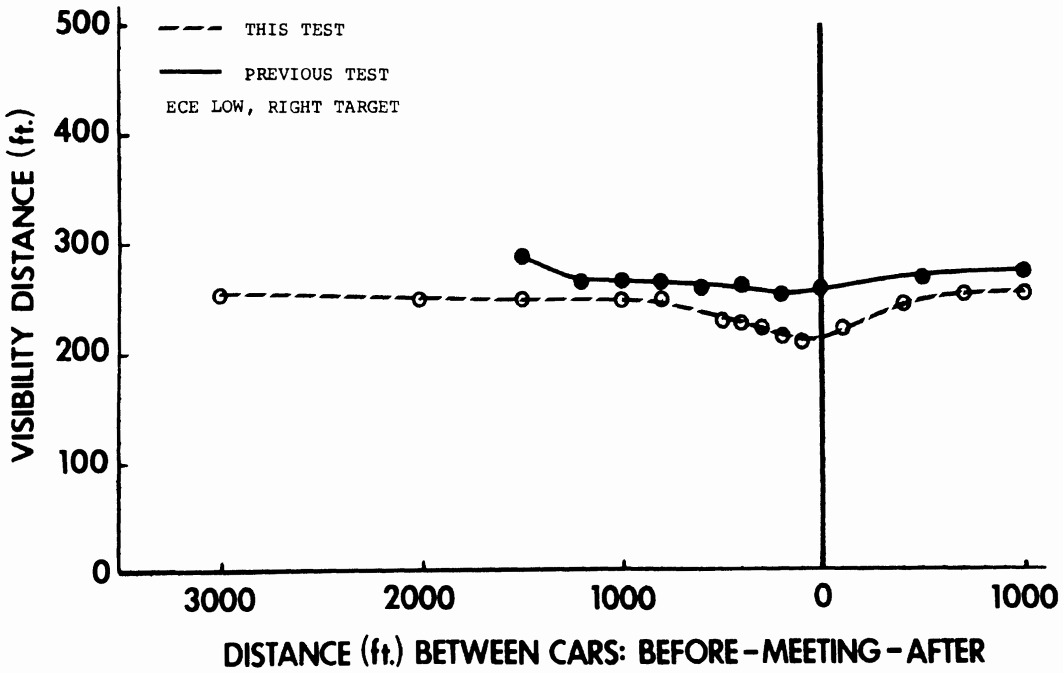

Figure 23. Comparison of the mean visibility of Type-I targets in meetings with ECE low beams in this and previous tests: targets on the right of the lane.

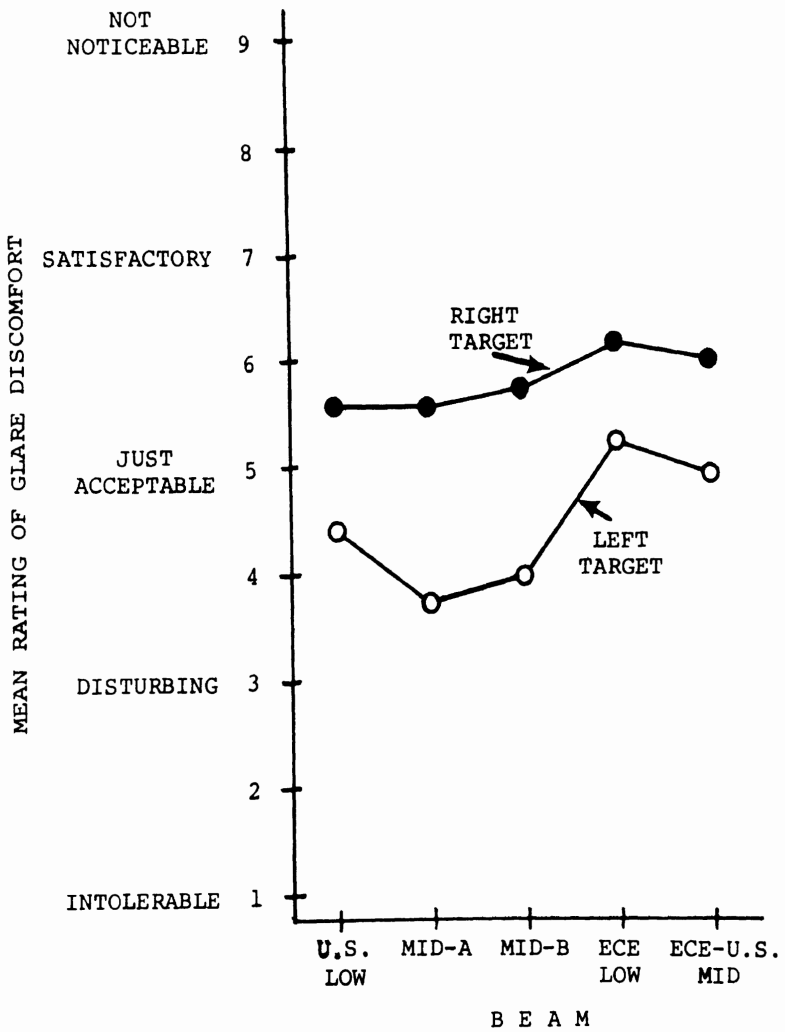

Figure 24. Mean ratings of maximum glare discomfort in meetings with five beams when searching for targets on the right and left side of the lane.

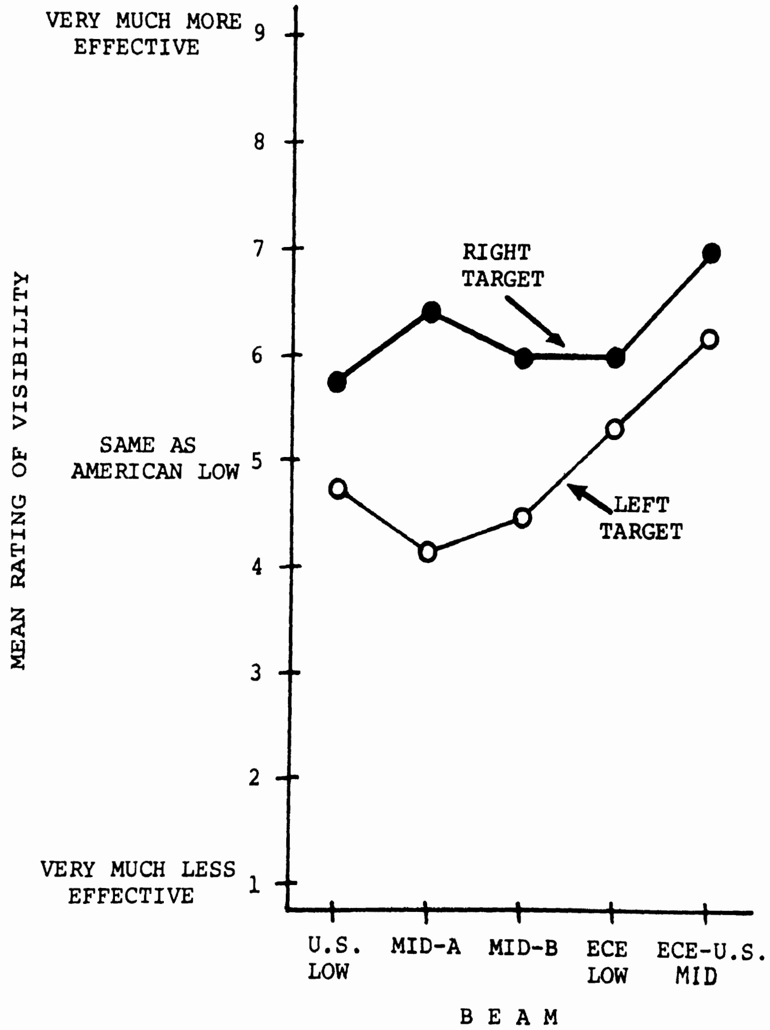

Figure 25. Mean ratings of visibility afforded by five beams when searching for targets on the right and left side of the lane.

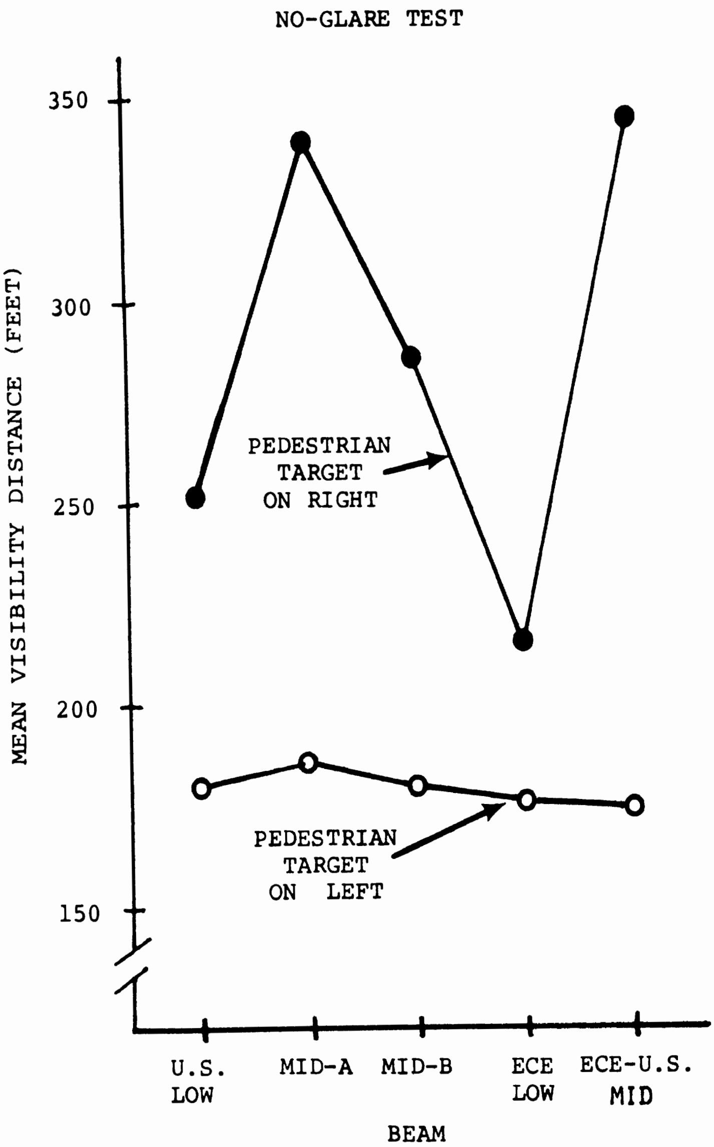

Figure 26. Mean visibility distances with five beams under no-glare conditions: pedestrian target on right and left side of the lane.

had passed at mid course. Hence, it was seen under no-glare conditions, although the subjects' eyes may have still been recovering from glare. The analysis indicated that visibility distances were significantly greater ($p < .05$) for all beams for this target on the right as compared with the left side. Further, there were no differences among beams ($p > .05$) on the left side. The mean visibility distances of the pedestrian target with mid beam-A and the ECE-U.S. mid beam did not differ from each other, but were greater than the other beams, which also differed from each other. The ECE low beam provided the least visibility distance.

Figure 27 is a plot of the mean visibility distance obtained of the pedestrian targets during the special test where only pedestrian targets were in use. The most extreme data after the meeting point were obtained from the single pedestrian target included in the main tests, the more extreme before-meeting data are extrapolations from the data on targets actually in position for the test. There was no significant change in visibility distance for the U.S. low beam as a function of separation distance, but there was for the mid beam ($p < .05$).

Table 3 is a listing of key performance measures for the two headlamp beam patterns used with the pedestrian targets. While the mid beam-A produced about 10% greater minimum visibility than the U.S. low beam it produced 30% greater visibility than the low beam when the separation distance between the vehicles was large or after the meeting point.

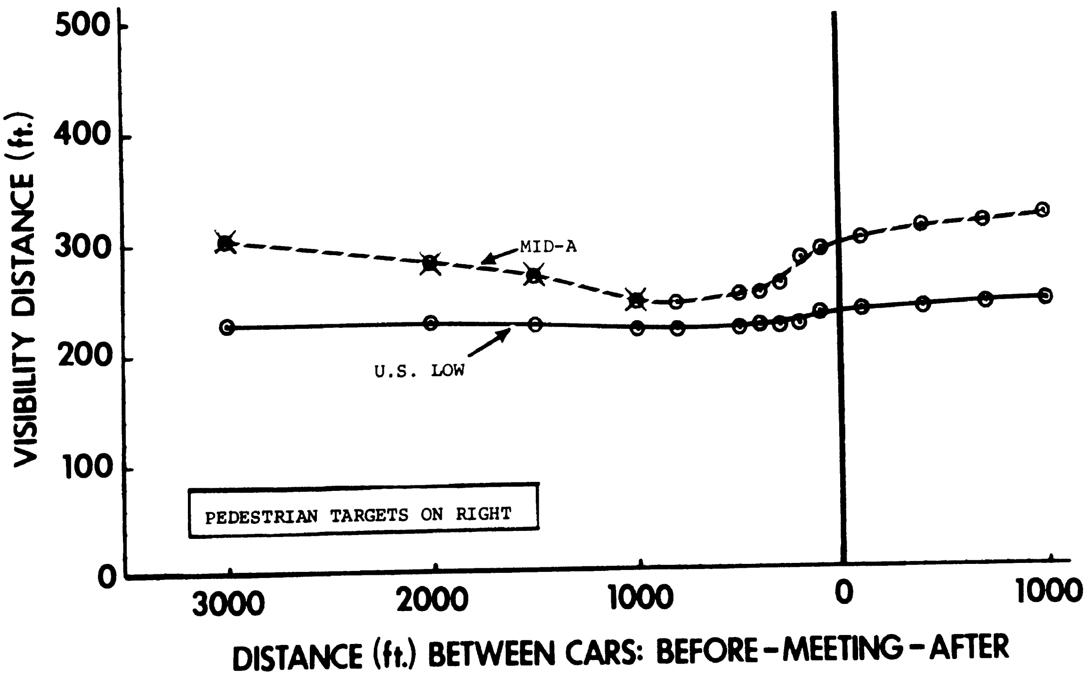

Figure 27. Mean visibility distances obtained with the U.S. low and mid beam-A as a function of longitudinal separation between the vehicles: pedestrian targets on right side of lane.

X = Extrapolated from experimental data.

TABLE 3. Comparison of Beam Performance for Pedestrian Targets on the Right of the Lane.

BEAM	MINIMUM VISIBILITY DISTANCE (feet)	RATIO OF MINIMUM VISIBILITY DISTANCE	MAXIMUM VISIBILITY DISTANCE (feet)	RATIO OF MIN./MAX. VISIBILITY DISTANCE
US LOW	221	1.00	241	0.92
MID-A	244	1.10	320	0.76

DISCUSSION

The results of this study suggest that differences in performance between U.S. and ECE low beams are slight, at least for conditions approximated by this test. It also appears that visibility distances for objects on the right edge of the road may be increased by 20 to 30% through use of mid beams of the type tested here.

Visibility for objects on the left side of the road is poorer than for objects on the right side. This is attributable to the asymmetrical nature of the beams tested and the glare angles involved.

The mid beams tested were designed to project very little light to the left. The near-parallel nature of the curves in Figures 9 and 10 indicates that these units provide very little disability glare. It is true that Figure 27 indicates a significant disability glare effect for mid beam-A with the pedestrian target. It should be recalled however, that Figure 27 includes an extrapolation for extreme pre-meet distances (as denoted by X's in the figure) and data from another study for the extreme post-meet distance. Therefore, it is possible that the apparent interaction of beam and separation distance is an artifact.

It is particularly interesting to compare the subjective and objective data. For example, the visibility ratings associated with left targets (Figure 25) show a relatively strong preference for the low and mid beams which used the ECE low beam. In fact, the visibility distances in Figure 9 show advantages for these systems only close to the meeting point. On the other hand, the visibility distance data show relatively large differences among beam patterns for right hand targets (Figure 10) but the subjective data would indicate the differences were generally minor. Mid beam-B and the ECE low beam, for example, differed in visibility distance by as much as 20% but were rated the same.

The glare ratings may provide a clue as to why the discrepancies in objective and subjective visibility data came about. Figure 24 indicates a significant preference for the European combinations when searching for left side targets. Overall, ratings were higher and more uniform when searching for targets to the right. Since discomfort glare is a readily perceived phenomenon and is less with ECE than U.S. low beams, it is quite possible that glare influenced the visibility ratings. In addition, the ECE low beams project higher intensities on the pavement close to the car to produce higher foreground brightness than the U.S. low beam, and the ECE lamps burn at a higher color temperature. Both these effects may have created the impression that the ECE headlamps are of greater intensity and provide more visibility. Thus, subjective rating appears to be an unreliable means of evaluating the visibility provided by headlamp beams. Certainly, subjective data should not be used as the sole means of evaluating headlamp beams.

This study indicates that the headlamp performance model developed at HSRI is a useful predictive device as demonstrated by the data in Figures 12, 13, 15, 17, 18 and 20 for the mid beams. These mid beam systems had not been field tested before, but the model predicted the visibility they provided with considerable accuracy.

Deviations between the prediction of the model and the experimental data are no greater than between the experimental results of this study and those of previous tests, as shown in Figures 21-23. Thus, the differences between the visibility distances predicted between the model and the experimental data are within the error of the experimental data.

While the experimental findings of this study are for the limited case of meetings between vehicles on the straight, flat sections of two-lane roads, other evaluations have been made using the computer simulation. Those evaluations used these same U.S. low beams and the mid beam-A which were used in this test (Mortimer and Becker, 1974; Mortimer, 1974). Those results of the computer simulation can be used to assess the effect of variations in aim of the beams, the effect of horizontal road curvature, and of disability and discomfort glare of these beams mounted in a following vehicle and reflected in the interior and exterior mirrors.

In comparing the effect of 1° upward and downward misaim of the U.S. low beam and mid beam-A upon visibility, when meeting a vehicle with the same beams in the same extent of misaim, it was found that the mid beam is less affected by misaim of this type than the U.S. low beam, for targets at the right side of the lane. Those evaluations (Mortimer and Becker, 1974) showed that the U.S. low beam misaimed down by 1° resulted in a loss of visibility of about 30% compared to the visibility attained when correctly aimed. A misaim of 1° down with the mid beam still produced visibility distances equal to that provided by using the low beams in correct aim without the mid beam.

Studies concerned with the effect on visibility distances of the U.S. low and mid beam-A on horizontal curves (Mortimer, 1974) showed that there was an advantage obtained when the vehicle is on the inside of the curve and using the mid beam compared to the low beam. However, an examination of the effects found when meeting vehicles on the mid beam, showed that the driver of the vehicle on the outside of the curve experienced extremely high glaring intensities at some portion of the meeting, causing a substantial reduction in visibility and severe glare discomfort. Therefore, it was concluded that the driver of the vehicle using the mid beam on the inside of the curve would be required to dim his lamps to the low beam to reduce glaring intensities to which the driver on the outside of the curve would be exposed. The necessity of doing this would depend upon the radius of curvature of the curve, and would apply primarily to meetings on the two-lane roads, rather than divided highways.

This same evaluation (Mortimer, 1974) also examined the effects upon both visibility and discomfort glare caused by the headlamps of a following vehicle reflected in the interior and exterior mirrors of the preceding car. The analysis showed that the glare intensities to which the drivers of the preceding vehicle can be exposed are frequently greater than those found when meeting an oncoming vehicle, as also found by Miller, Baumgardner and Mortimer (1974). Furthermore, discomfort glare levels can be quite substantial. While the effect on visibility is not large, in general, the effect is of some significance in reducing visibility of targets that will be located in the center of the road (i.e., at the left of the lane).

It was therefore concluded that drivers would need to dim from the mid beam to the low beam when following another vehicle within about 100-200 ft, and that the Type-III lamp of the mid beam should not be mounted at a height of more than 30 in.

Computer based visibility distance analyses have also been carried out for the ECE-U.S. mid beam which was used in these field studies and computer simulation evaluations. In general, the ECE-U.S. mid beam provided somewhat less visibility distance, of the order of 5%, compared to mid beam-A. However, it offered a small advantage in visibility of targets at the left side of the lane when the separation distance between vehicles in a meeting was about 200 ft and until the meeting point (Table 2). The glare levels with the ECE-U.S. mid beam are somewhat lower than for mid beam-A in meetings on straight road sections, but are comparable in meetings on horizontal curves inasmuch as the driver on the outside of the curve is concerned. Therefore, on horizontal curves the same constraints will apply with this mid beam as mid beam-A. Similarly, the same constraint of dimming when following another vehicle would have to be considered with the ECE-U.S. mid beam as with mid beam-A as already mentioned.

Based on this analysis, it would appear that visibility distances can be increased to the greatest extent by the use of mid beam-A in most driving situations at night. The difference between the visibility distances provided by mid beam-A and the ECE-U.S. mid beam are fairly small, so that the other characteristics of these beams need to be considered. One consideration is that the low beam system which forms a component of the mid beam, will also be used a fairly large proportion of time, primarily in urban driving conditions. In such conditions, the present U.S. low beam provides higher glaring intensities than the ECE low beam. Based upon glare considerations, the ECE low beam may be more suited to an urban driving beam than the U.S. low beam.

It is concluded, that the most effective mid beam of those tested is the ECE-U.S. mid beam, such as developed in this study. Such a beam will provide lower glare than the present U.S. low beam while providing adequate visibility for driving in residential areas where street lighting may be poor or nonexistent. On unlighted streets and highways, the mid beam can be used. It is probable that the small reduction in visibility to the right side of the lane provided by the ECE-U.S.mid beam compared to mid beam-A is of little consequence. This loss is also partly outweighed by a small increase in visibility distance associated with the ECE-U.S. mid beam on the left side of the lane at short separation distances.

Since the mid beam tested was specifically designed for merging with U.S.-style low beams, it is possible that a more effective beam could be developed for merging with the ECE low beam headlamps.

Such a combination of lamps would provide an overall improvement in vehicle headlighting, in terms of an improved urban driving beam, and an improved meeting beam for use on two-lane roads and divided highways where the greatest improvements in night driving visibility are presently needed.

REFERENCES

Miller, Norma D., Baumgardner, D. and Mortimer, R.G. An Evaluation of Glare in Nighttime Driving Caused by Headlights Reflected from Rearview Mirrors. Society of Automotive Engineers, Report No. 740962, October 1974.

Mortimer, R.G. Some Effects of Road, Truck and Headlamp Characteristics on Visibility and Glare in Night Driving. Society of Automotive Engineers, Report No. 740615, August 1974.

Mortimer, R.G. and Becker, J.M. Computer Simulation of Current U.S. and European Headlamp Meeting Beams. Society of Automotive Engineers, Report No. 740311, February 1974.

Mortimer, R.G. and Olson, P.L. Development and Use of Driving Tests to Evaluate Headlamp Beams. Highway Safety Research Institute, University of Michigan, Report No. UM-HSRI-HF-74-14, March 1974.

APPENDICES

APPENDIX I

INSTRUCTIONS TO THE TEST SUBJECTS

In this study we are trying to learn how well you can see while driving at night using different headlighting systems. You will be driving or riding in this car and, depending on which lane you are in on a given run, you will be responding to targets which are positioned either to the right or left of your vehicle.

Most of the targets look like the one in this sketch. Your task is to indicate whether the square is on the right or left end of the line. To do this the driver should firmly press with his thumb either the left or right button on the steering wheel yoke, as appropriate. The passenger should move the switch on the box in his lap either to the left or right, as appropriate. You should respond to each target in this way just as soon as it is possible for you to identify its orientation. Avoid errors. If you do make an error, correct it as soon as possible.

At the end of each line of the targets which I have just shown you is a single "pedestrian" target. This target is six feet high and 18 inches wide and is a uniform dark grey color. Your task is merely to detect the presence of this target, so when you see it, so indicate by pressing either the right or left switch, it doesn't matter which.

When making runs in the direction we are presently facing the targets will be on your right; when making runs in the opposite direction the targets will be on your left. I will remind you on which side the targets will appear at the start of each run.

Each run will start with this car at one end of the course and the other car at the opposite end of the course facing us. To begin a run the driver should position the car so that the starting traffic cone is just outside his window on the left. Leave the car in drive and keep your foot on the brake. As soon as the equipment has been prepared for a run, each experimenter indicates he is ready by switching off his headlamps. Car 1 will then turn on his headlamps and, when car 2 turns on his headlamps you should accelerate moderately to 32 mph. When the car reaches 32 mph take your foot off the accelerator. The car will slow some until the speed control takes hold. Please, driver, KEEP YOUR FOOT COMPLETELY OFF THE ACCELERATOR DURING THE RUN. Drive through the course to the far end of the track and follow the arrow into the turn-around. Stay on the flat part of the turn-around, please, and pull up to the starting cone and stop.

At the end of each run we will ask you for an opinion regarding the visibility and glare characteristics of the lamp just used. Use these sheets to remember the scale. I am giving you a pack of small sheets on which you should write, on top, your visibility rating and, on the bottom, your glare rating at the end of each run. Then pass the sheet back to me.

Keep the interior rearview mirror turned up out of the way, as it is not needed during this test and may get in your way. Please do not smoke during the test.

Any questions?

APPENDIX II

THE RATING SCALES USED BY SUBJECTS TO JUDGE DISCOMFORT GLARE AND VISIBILITY OF THE BEAMS

Rate the maximum degree of discomfort which you experienced due to glare from the oncoming car's headlamps during this pass. Select a number between 1 (discomfort is intolerable for night driving) and 9 (there was virtually no discomfort due to glare).

GLARE DISCOMFORT

9 Not Noticeable

8

7 Satisfactory

6

5 Just Acceptable

4

3 Disturbing

2

1 Intolerable

Rate the effectiveness of the lamps you have just used in providing illumination on the road and other objects compared to standard American low beams such as you have on your own car. Select a number between 9 (very much more effective) and 1 (very much less effective). A rating of 5 means the beam is equal in effectiveness to a standard American low beam.

VISIBILITY

9 Very Much More Effective

8

7

6

5 Same as American Low Beam

4

3

2

1 Very Much Less Effective