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Report No. UM-HSRI-HF-74-14

DEVELOPMENT AND USE OF DRIVING TESTS TO EVALUATE HEADLAMP BEAMS

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March 1974

Contract No. UM 7102-C128
Motor Vehicle Manufacturers Association
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THE UNIVERSITY OF MICHIGAN

18 September 1974

Mr. John C. Scowcroft
Motor Vehicle Manufacturers Association
320 New Center Building
Detroit, Mich. 48202

Dear Mr. Scowcroft:

We are sending to you 50 copies of a report entitled "Development and Use of Driving Tests to Evaluate Headlamp Beams," which is a final report describing the field test work carried out in our headlighting project with MVMA under Phases I and II.

These reports should be received by MVMA tomorrow. I hope that this report will be of interest to members of the Lighting Committee, as well as others concerned with matters of vehicle headlighting in the industry. I hope that the report will get fairly wide distribution as I would hope that it could make a contribution in the development of a uniform field testing method.

Yours sincerely,

Rudolf G. Mortimer, Ph.D.
Head, Human Factors

RGM/md

for [illegible] [illegible] approved this in July; copies will be provided shortly.

John

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.

4. Title and Subtitle	5. Report Date
Development and Use of Driving Tests to Evaluate Headlamp Beams	March 1974
	6.
7. Author(s) Rudolf G. Mortimer and Paul L. Olson	8. Performing Organization Rept. No. UM-HSRI-HF-74-14
9. Performing Organization Name and Address Highway Safety Research Institute The University of Michigan Ann Arbor, Michigan 48105	10. Project/Task/Work Unit No. 320015 11. Contract/Grant No. UM7102-C128
12. Sponsoring Organization Name and Address Motor Vehicle Manufacturers Association 320 New Center Building Detroit, Michigan 48202	13. Type of Report & Period Covered Final Report 14.

15. Supplementary Notes

16. Abstract. Results of analyses of accident data to evaluate the contributory role of headlighting were inconclusive. Reflectance values of various objects in the driver's field-of-view were measured. Pilot studies were made to evaluate test targets, and the results were used to describe desirable characteristics of a test target for use in subsequent tests.

A series of headlighting field tests were carried out to develop a reliable field test method, evaluate variables affecting visibility provided by headlamps, and generate data for use in validating a mathematical model. Driving tests were also used to evaluate glare effects of various beams to oncoming and preceding drivers.

Three types of targets were developed for the work: a simulated overhead sign, a simulated roadside sign, and a general purpose target to simulate objects on or near the roadway. The latter target could be placed to the right or left of the test vehicle or in the center of its lane of travel. In addition, its reflectivity could be changed.

The following variables were investigated: (1) headlamp beam, (2) lateral separation between vehicles, (3) longitudinal separation between vehicles, (4) target type, (5) target reflectivity, (6) target position relative to car path, and (7) target height.

All of the above variables were found to be significantly related to the distance at which the orientation of the target could be identified.

Targets positioned to the right of the lane are more easily seen than those on the left under glare conditions, and with low beams. Other factors being equal, the closer a target is to the pavement, the more easily it is seen. Petro-reflective targets are seen at far greater distances than painted targets, but very high levels of reflective brilliance may actually impede their legibility by making the target itself a glare source.

The test-retest coefficient of reliability of the field test procedure developed in this program is estimated to be 0.97, producing a variation of less than 5% in the visibility distances when the same subjects are retested on the same night. When a different group of subjects, a different test road, headlamps aimed independently on the two occasions, and a stationary glare car in one case and a fully dynamic test in the other case, were used the differences in the mean visibility distances did not exceed about 15%. Thus, test reliability is considered to be satisfactory.

Comparisons between U.S. low and high beams showed that on two-lane roads visibility is greatest if dimming occurs from high to low beams at about 1500 feet. The U.S. low beam headlamps used in these tests provided greater visibility of a target on the right side of the lane than the European H_4 headlamps that were used. A type of mid beam provided greater visibility on the right than the U.S. or European beams.

Road evaluations of glare from the headlamp beams showed that the European high beam produced relatively much more requests for dimming from oncoming drivers than the U.S. high beam. Drivers were also influenced by the number of headlamps on the oncoming vehicle, but not in the case of the following vehicle. Discomfort glare due to beams reflected in rearview mirrors was affected by mirror reflectivity and beam intensity, but not by the presence or absence of road lighting.

17. **Identifiers/Open-Ended Terms. Headlamp beam test procedure, glare, headlamp test targets, U.S. and European beams, night visibility, rearview mirror glare, night driving accidents.**

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 163+
	20. Security Class (This Page UNCLASSIFIED	22. Price

FORM NTIS-35 (REV. 3-72) USCOMM-DC 14952-P72

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OBJECTIVES

The objectives of these studies were:

1. Conduct an analysis of accident data to try to discern the role of vehicle headlighting in crashes.

2. Devise a set of targets for use in field tests of headlamp performance in terms of the drivers' visibility distance, and measure reflectance values of objects in the driver's field-of- view.

3. Develop a field test data collection and analysis method.

4. Conduct evaluations using the method to determine its reliability, and to provide basic data of the effects upon visibility distance of variables such as beam pattern, target location, target reflectance, etc., for subsequent use in validating an analytical model.

5. Conduct road tests to evaluate headlamp beams in terms of glare responses of oncoming drivers and those in a preceding vehicle due to rearview mirrors.

SUMMARY OF FINDINGS

1. An analysis of accident data was made by comparing the relative frequency of classes of accidents in the day and night, without finding any evidence to show that headlighting was an involved element. This does not mean that headlighting is not involved in night crashes, however, nor that improved lighting would not help to reduce such crashes.

2. Photometric measurements of the reflectance of pavements, road delineation lines, and other objects in the drivers' field-of-view show most of these to have reflectances of 0.10-0.30.

3. A number of preliminary tests were made of various visibility targets by which the characteristics of a suitable target were evolved.

4. A general purpose (Type I) target was developed requiring recognition of the orientation of the target face. The target can be placed on the right or left of the lane or in the center of the lane in the path of the vehicle. Two other targets, using reflectorized materials, were also used.

5. A dynamic field test procedure was developed and used to measure the visibility distance of the test targets in a variety of test treatments.

6. Test-retest reliability was of the order of 0.97.

7. Basic parametric data were obtained of the effects of various factors on target visibility distances, and used as validation data in development of an analytical model carried out in a separate phase of this program.

8. Visibility distances were greater for targets on the right than left of the lane for low beams. When meeting an opposing vehicle, the same was true for high beams. For the specific lamps and aims employed in these tests, the U.S. 6014 low beams provided greater visibility on the right side of the lane

than ECE H_4 low beams. A type of mid beam provided greater visibility in these meeting situations on the right of the lane than either low beam.

9. Glare responses of oncoming drivers in these tests, and other road tests, indicated that the ECE low beam provides least glare, but the U.S. low beam appeared to be acceptable. The H_4 high beam created far greater glare responses than the U.S. high beam. These findings were also true for the effects of glare in rearview mirrors of images of headlamps of a following car.

10. It was concluded that a satisfactorily reliable field test method to measure visibility has been devised, basic data of the effects of important parameters affecting visibility were obtained, beam evaluations were conducted showing the likely benefits of a mid beam, and methods for evaluating glare acceptance of headlamp beams were found to be discriminative for both the cases of oncoming and preceding drivers.

FOREWORD AND ACKNOWLEDGEMENTS

This research program report describes one of a series of HSRI studies concerned with headlighting performance, sponsored by the Motor Vehicle Manufacturers Association of the U.S., Inc.

This report is issued under the general contract title: "Passenger Car and Truck Lighting Research: Headlighting Phase I, Beam Pattern Evaluation." 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, and factors affecting headlamp aim.

During the conduct of this work periodic meetings were held with the MVMA Lighting Committee, Headlighting Research Task Force, consisting of Mr. G. Gardner and Mr. R. Rossio, chairmen; Mr. P. Lawrenz, Mr. P. Maurer and Mr. B. Preston. The members of this group were very helpful and their comments and suggestions contributed materially to the progress of the work.

Many of the tests described in this report were conducted at the General Motors Proving Ground, Milford, Michigan. The cooperation rendered by GM in providing use of their facilities is gratefully acknowledged. Some work was conducted on an airstrip owned by Tecumseh Products, Inc., Tecumseh, Michigan. Their kind cooperation is greatly appreciated.

A number of members of the Human Factors Department at HSRI participated in the study including: David Post, Corwin Moore, Craig Jorgeson, Samuel Sturgis, Janice Smith, Jerold Lower and Arthur Poskocil. William Carlson, Systems Analysis Department, carried out the analyses of accident data. The test cars were prepared under the direction of John D. Campbell of the Physical Factors Department.

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INTRODUCTION

Despite a great deal of effort on the part of a number of investigators no great progress has been made toward the design of an optimum lighting system. There are several reasons for this state of affairs. One is a conspicuous lack of uniformity in experimental methodology; different targets, different procedures, etc. Another reason concerns the difficulty of quantifying certain phenomena. For example, a target to the left of the observer may be visible in silhouette against the glare source at a far greater distance than it could be seen directly. Silhouette seeing is an unstable phenomenon, dependent on a number of factors such as road surface and lateral separation. The information it provides to drivers is difficult to quantify. Another basic reason for slow progress in this area is a lack of agreement in basic philosophy. For example, how important is it that light be projected to the left side of the road? Disagreement over such issues influences the weighting of criteria and has a significant effect on the outcome of research.

To resolve many of these issues an integrated, objective and subjective, test approach is needed. At present the most useful approach would be one which yielded data of general utility, not locked into a particular philosophical format. To that end the research reported sought to measure visibility distances under glare and no-glare conditions as a function of beam patterns, target types, target reflectivity, target location and lateral separation of the vehicles. These data have been used to develop and validate an analytical model which, hopefully, will remove the necessity of full-scale testing in future headlamp development. A description and application of the model will be found in Mortimer and Becker (1973a, 1973b). Two other studies are reported as well, dealing with glare evaluations in rearview mirrors and responses of drivers to various lamp configurations and glare levels.

Providing light sufficient to be able to detect all significant obstacles far enough ahead to take appropriate action requires intensities which can cause discomfort and disability glare to oncoming drivers. Unfortunately, intensities which are reasonably acceptable to oncoming drivers provide seeing distances which are adequate only for relatively moderate speeds. If oncoming traffic were encountered infrequently this discrepancy would not pose a significant problem with the two-beam system in use today. However, traffic densities are such that many drivers rarely use their high beams, even on freeways at 70 mph or more.

At higher speeds there is a substantial gap between stopping distance and the distance at which the driver can see an obstacle of low reflectance (e.g., a pedestrian wearing dark clothing). Average speeds have gone up over the years. In Michigan, for example, in 1973 it has been estimated that about half the vehicle miles were driven at speeds of 50 mph or higher (Esch, 1973). This figure may be lower at night, but undoubtedly a large percentage of driving is done under "unsafe" seeing conditions.

Recognition of the problems described above has resulted in the accumulation of a substantial body of research over the years. A significant portion of this work has originated from three agencies: the University of Uppsala in Sweden, the Road Research Laboratory in Great Britan and the Southwest Research Institute in the United States.

There is no agreed-upon procedure or visual task for conducting headlighting research. Various investigators have employed a variety of approaches and produced results which sometimes do not agree. For example, there is a dispute regarding the advisability of changing to low beams when meeting, and no concensus has been reached regarding the relative merits of American and European beams.

The ultimate criterion in headlighting research is visibility distance. Visibility distance is usually measured as a function of illumination provided by one set of lamps and the glare from another set of lamps, usually but not always identical to those providing the illumination. Other pertinent variables have also been investigated.

Research on driver vision provided by headlamps under meeting conditions first began appearing in print prior to World War II. Most of this work had to do with trade-offs between glare and intensity (Bouma, 1936; Roper and Howard, 1938; and Roper and Scott, 1939), although the first work with Polarized headlighting was also conducted in this period (e.g., Roper and Scott, 1941). Considerable technical development took place in this period and after the war, making possible better control of the beam, higher intensities and improved lamp life. An excellent summary of the literature through mid 1960's is contained in Webster and Yeatman (1968). This review will deal largely with work reported since then.

As already noted, a variety of experimental techniques have been utilized. However, simulation has rarely been employed and this is perhaps surprising in view of the difficulties involved in field work. Christie et al. (1968) report a simulation study of the value of amber headlights. They used a visual acuity criterion (Landolt rings) and determined that amber was associated with a slight improvement in acuity if the loss in intensity due to the filter was restored.

Forsgren and Thorell (1970) used a simulator to measure thresholds for 7% reflectance rectangular "pedestrian" targets. They then attempted to replicate the results in a field study employing a stationary glare source and a moving subject car. Targets in the field test were 100 X 40 cm rectangles of 4% reflectance. While the results were in general agreement, thresholds were somewhat higher in the laboratory study, possibly due, the authors feel, to the static nature of the test and predictable target locations.

Completely static field studies have been reported. For example, Schwab (1965) used a static set-up and two types of targets, a red reflector on the back of a black, unlighted car 500 feet distant and a section of standard pavement stripe 200 feet distant. Glare measurements were made with a photometer and visibility distances calculated.

The most usual approach has been to employ a static glare source and move the subjects toward it. For example, Jehu (1955) employed such a technique in the development of a model of visibility in a meeting situation. Jehu used two targets, a 1.5 foot diameter circle and a 1.75 x 1.0 foot rectangle, both at 7% reflectance. Only one target was used on a given run and the subject's task was to determine which was in place. This identification procedure contrasts with the more usual target detection task.

Faulkner and Older (1967) also utilized an identification task, in this case a 1.0 foot diameter circle with a protrusion which could be set in various positions. This was mounted atop a 3.0-foot high support. Reflectances were 4% and 11.5%. The subjects were required to identify the orientation of the protrusion. A single target was used, placed in any of six positions from 400 feet in front to 300 feet behind the glare car.

Webster and Yeatman (1968) used two targets, one being a tail-light reflector 27 inches above the pavement and the other a cube, 16 inches to a side, the reflectance of which was 8.5%. One or both of these was used on each run.

Several studies have been reported which have used identical targets 100 cm high by 40 cm wide at 4% reflectance.

Ohlon and Zaccherini (1972) compared various beam configurations with such a target, looking also at reflectances of 10% and 24%. Rumar (1970a) compared halogen and conventional headlamps. Rumar et al. (1970) compared laminated and tempered windshields in polarized light, and Rumar et al. (1973) compared American and European beams, also employing target reflectances of 10% and 24%. The latter study investigated visibility both to the right and left side of the car.

Johannson et al. (1969) used targets 140 cm high and 40 cm wide at 5% reflectance. Subjects encountered from one to seven targets in front of the glare car on each run in these investigations of various problems of polarized headlamps.

In an unusual study to test the effectiveness of lamps in use, Rumar (1970b) had naive subjects drive their own cars toward a target positioned next to a glare source until the target, a man-size dummy at 5% reflectance, became visible. The same target was used in another phase of the study with regular experimental subjects and test lamps.

Hemion (1969b) also used a dummy as a target in addition to a traffic sign and a no-passing line. The subject car moved at various speeds but usually at 55 mph. There were ten possible target positions.

In a study of road surface characteristics, Helmers and Rumar (1973) used a target 40 cm square (reflectance 2%, 7% or 26%). The subject car was in the same lane as the glare source and was driven directly toward it. The target was placed next to the glare source. A later phase used two more targets having a reflectance of 7%, at 100 m and 250 m in front of the glare source.

Working toward the development of a mathematical model of visibility afforded by headlamps, Frederiksen and Jorgensen (1972) developed data using targets 20 cm square (3.5% reflectance). One of these was positioned in the middle of the driving lane and one was two meters to the right. Both were next to the glare source. Only the response to the one in the driving lane was counted.

Several investigators have used techniques where both the glare source and observers were in motion. For example, Adler and Lunenfeld (1973) used such a procedure with both vehicles moving at 40 mph, in their investigation of three-beam headlamp systems. They employed one target (16 inches square, 8% reflectance) at any one of five positions.

Roper and Meese (1965) used a virtually identical procedure and visual task except ten targets were in position, five before and five after the meet point. They were investigating the effect of beam intensity, misaim and road geometry.

The work performed at the Southwest Research Institute has also generally used two vehicles moving toward each other (Hemion, 1969a; Hemion and Hull, 1973; Cadena and Hemion, 1969; and Hull et al., 1971). They have used various targets (six foot tall, three dimensional dummy at 7% reflectance; roadside sign and a no-passing sign). Only one target of a given type was employed on a run through the course, its position being shifted between runs.

A variety of techniques were employed by Powers and Solomon (1965) in their tests of the effect of lateral separation. In the first of these the glare car was stationary and the observer car moved toward it. The second test employed the reverse procedure. In each case the target was an unlighted car in the lane ahead of the observer car. The third study was procedurally the same as the second except the target was changed to a 21 x 26-inch translucent glass, illuminated from behind. As the glare car approached, the subjects were required to adjust the intensity of the target so that it was just visible. The authors felt that, for visibility distance measures, the first technique is superior, provided several targets are used.

The foregoing review has summarized the variety of approaches which have been employed in headlighting research. A careful analysis of this information, coupled with pilot testing of a variety of target configurations (Appendix C) led to the approach adopted for this effort. Procedural details are given in the Method section of this report. As a brief overview, the following description is offered.

A dynamic approach was selected and, where space allowed, both glare and subject vehicles were moving, primarily to speed the data collection process.

The visual task was target identification as opposed to target detection. Identification is a higher level task, more in line with the actual demands of driving. Further, this procedure allows an element of uncertainty to be introduced without having to move or remove targets. Pilot testing suggested that error variance may be lower with an identification task as well, and it is not affected by silhouette effects.

As an added refinement the targets were equipped with their own background. A target's contrast with its background is a critical factor in its visibility. The typical roadway environment is quite variable in reflectance levels depending on whether the target is seen against open field, the shoulder, road surface, or the headlamps of oncoming cars.

Finally, the data were taken in a way which permitted the use of tests of statistical significance. Since the tests were intended to compare several beam configurations it was felt essential to be able to make statements concerning the probability of the results occurring by chance, and to measure the reliability of the field test method.

GENERAL PROCEDURES USED IN FIELD TESTS OF VISIBILITY DISTANCE

The following section describes the test equipment, test sites, the type of test, and the analysis procedures used in the studies conducted to measure visibility distances.

VEHICLES

Two identical 1971 Plymouth station wagons (Figure 1) were employed in the test. They were equipped with a special front panel capable of mounting up to 14 headlamps (Figure 2), eleven across the top row and three across the bottom row, partially hidden behind the "bumper," in Figure 2.

Up to 14 filaments could be switched, voltages monitored and controlled separately from the control panel shown in Figure 3. Prior to use in any test, headlamps were burned in for three hours.

Figure 1. Photograph of vehicle used in headlighting field tests.

Figure 2. Close-up photograph of headlamp mounting panel.

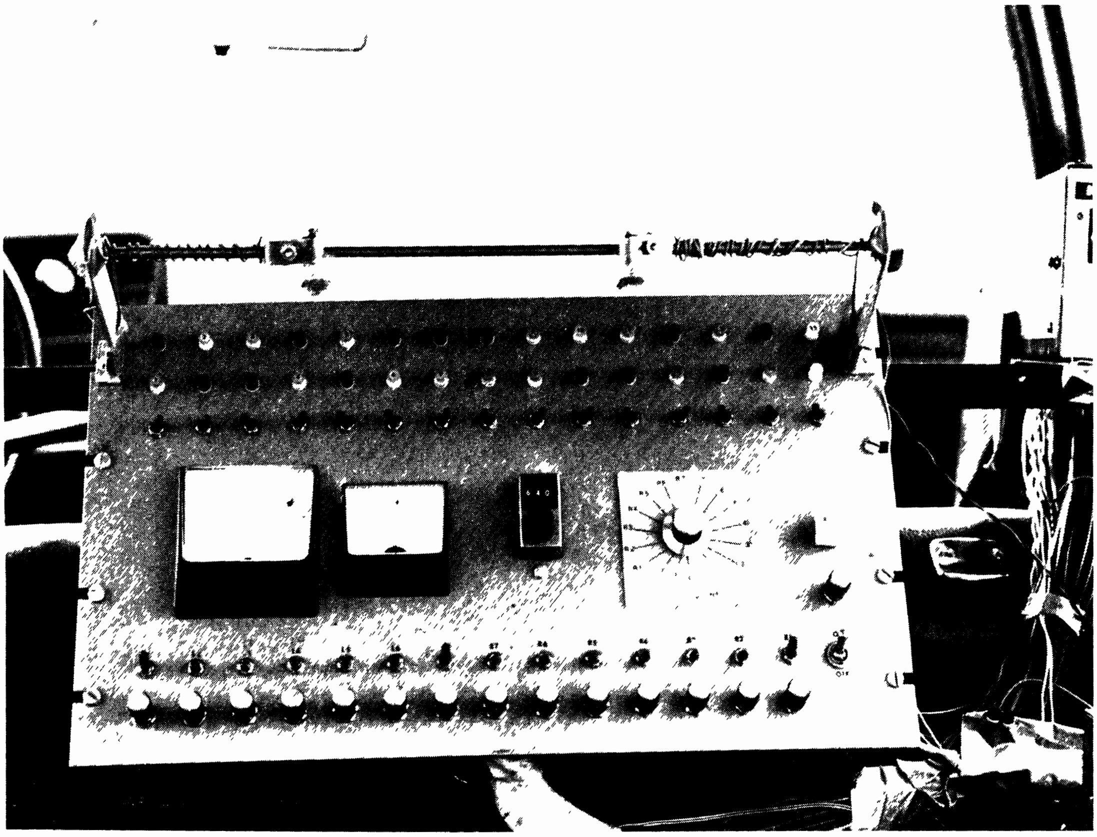

Figure 3. Experimenter's control panel.

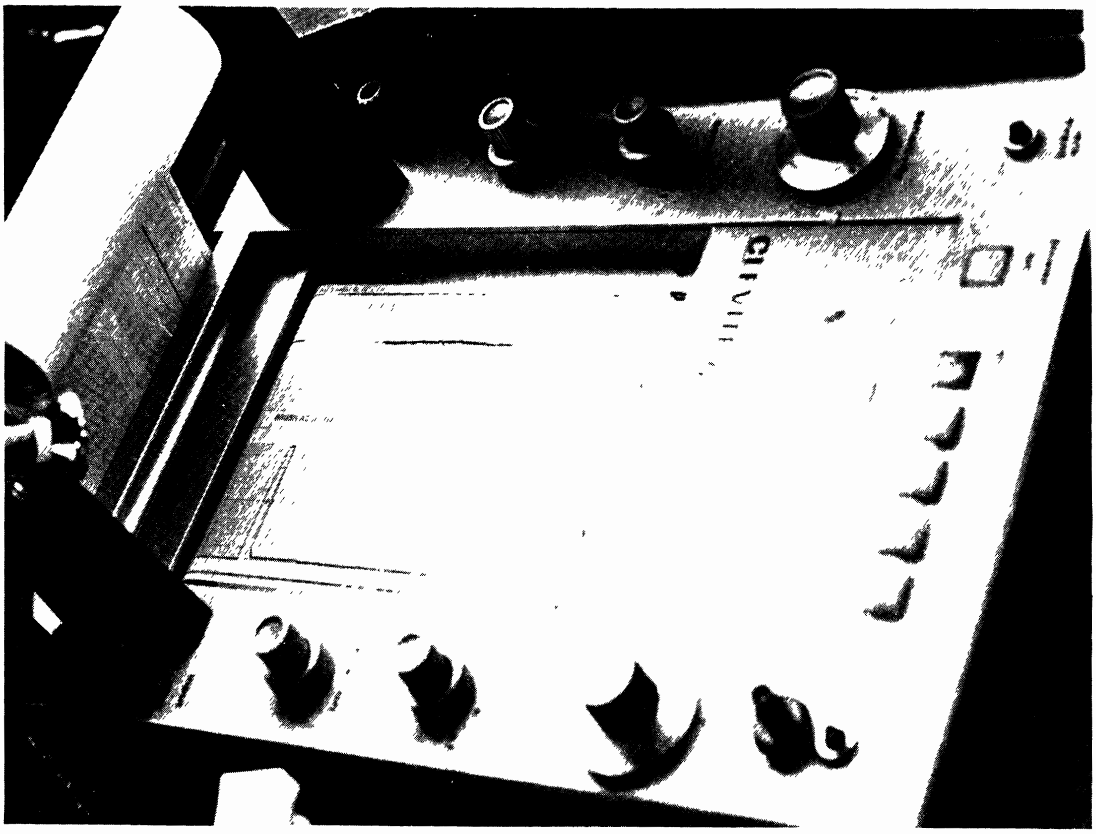

Figure 4. Strip Chart Recorder.

The row of switches near the top of the panel shown in Figure 3 was used to set for target orientation when running single subjects (driver only). A response corresponding to the switch setting resulted in the top lamp being illuminated while an opposite response (error) caused the lamp below it to light. The large voltmeter monitored voltage at the filament for any lamp selected by the rotary switch at the right-center. The galvanometer was used in conjunction with the trim pots across the bottom of the panel to zero the voltages at the lamp filament to that given by the precision potentiometer in the center of the panel. The row of switches near the bottom turned lamps on and off.

Subjects' responses and other pertinent data were recorded on paper strip charts (Figure 4). The subjects pressed push-button switches to indicate the orientation of a target, causing a pen to deflect right or left. Narrow reflective panels placed behind each target were "sensed" by a detector device consisting of an infrared source and photocell (Figure 5) attached to the rear bumper. This put another mark on the strip chart as each target was passed.

The time required for the car to run through the course was measured in milliseconds by an electronic counter operated by the experimenter.

Each car was equipped with a speed control device capable of maintaining speed (on the level course used for the tests) within ± 1 mph. The speed controls had a memory feature so that they could be set once to the desired speed (40 feet per second) and readily re-engaged by the subjects at the start of each run.

The subjects indicated their judgment of the orientation of the target by use of silent switches. The driver pressed either the right or left horn button (the horn was disconnected) and the passenger moved a center-off wafer switch either right or left. All cars involved in the study were equipped with two-way radios.

TEST TARGETS

Dimensional drawings of the three types of targets used in the studies are given in Appendix A.

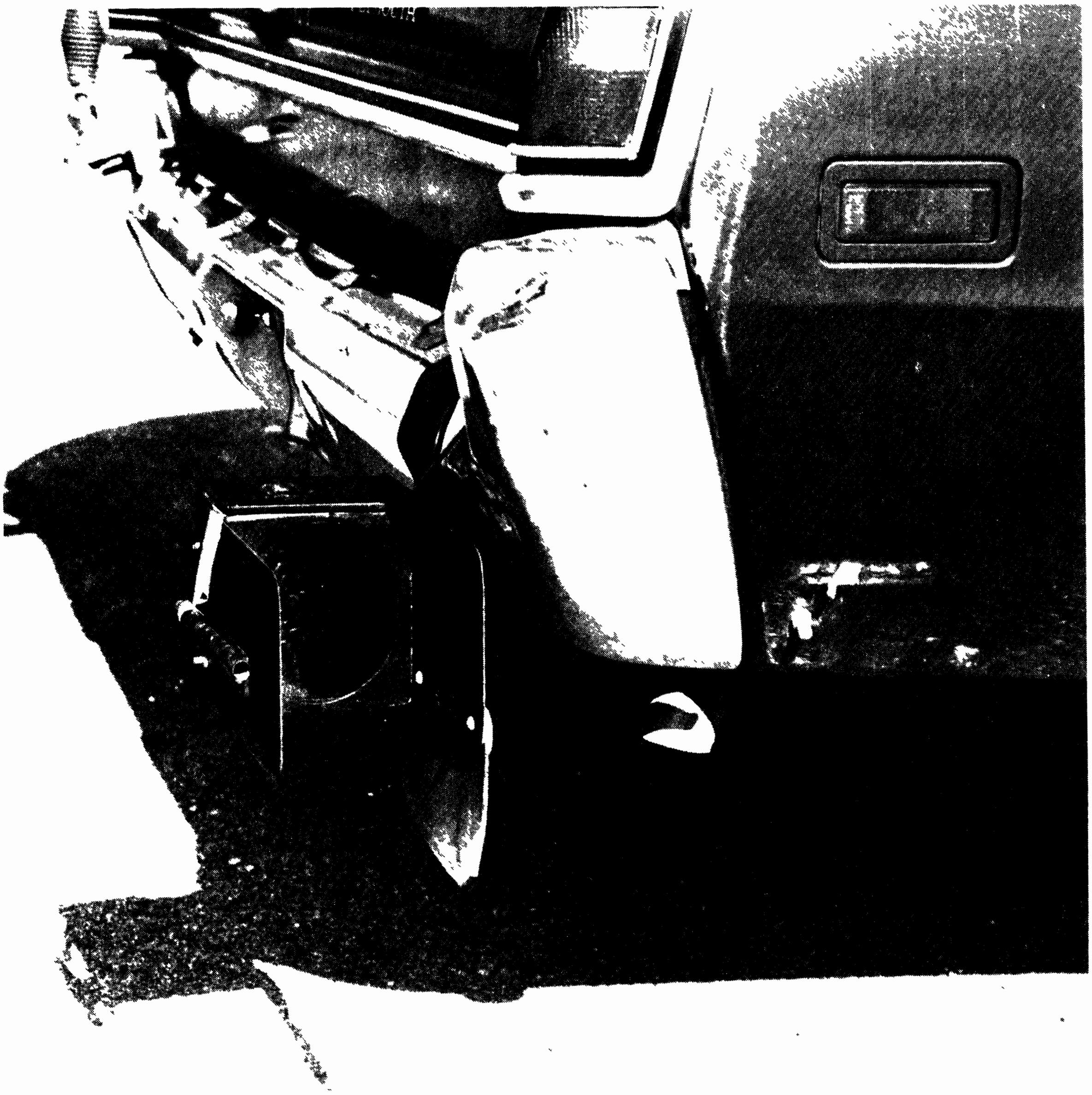

Figure 5. Target detector system.

The type I target (Figure 6) is the basic unit used throughout the studies. The target face consists of a bar, 4 inches wide and 18 inches long, and an 8-inch by 8-inch square which can be moved to either the right or left end of the bar. The subjects' task was to determine at which end of the bar the square was located, right or left. The target faces could be placed in either an upper (18 inches) or lower (6 inches) position above the pavement and were available in five reflectance levels (6.1%, 11.8%, 26.2% 26.2%, 54.1%, 87.1%). The target support was painted flat black, of 3% reflectance. In practice the target square were moved often enough to prevent the subjects from learning their orientation. A modification of the type I target, intended for use in the center of the traffic lane, is shown in Figure 7. The vertical support is hinged and spring loaded. A tape switch was attached to the road 75 feet ahead of the target. When a car passed over the switch it triggered a solenoid which released a catch, allowing the target to fall backward as shown in Figure 8. These units were reduced in height so that the faces or other parts of the target could not be catapulted into the windshield should it fail to drop and be struck by the car.

The type II target (Figure 9) was intended to simulate a roadside traffic sign (e.g., speed, yield or stop sign). It was always placed on the driver's right. In accordance with sign regulation R2-1-24 of the Michigan Manual of Uniform Traffic Control Devices (MMUTCD) this sign was 24 inches by 30 inches and had a 10-inch by 1.75-inch diagonal bar which was used instead of numerals. A 3475 Minnesota Mining and Manufacturing (3M) reflective sheeting was used for a background. The reflective brilliance of the background was approximately 0.05, while the 3270 silver-white (3M) bar has a reflective brilliance of 225. (Reflective brilliance is the number of times that a surface is brighter than flat white paint where the paint approximates a perfect diffuse reflector. These values were measured using an angle of 0.33° between light source and photometer (divergence angle), with the source normal to the sign, for an incidence angle of 0°). This white on black configuration was used to provide an acceptable

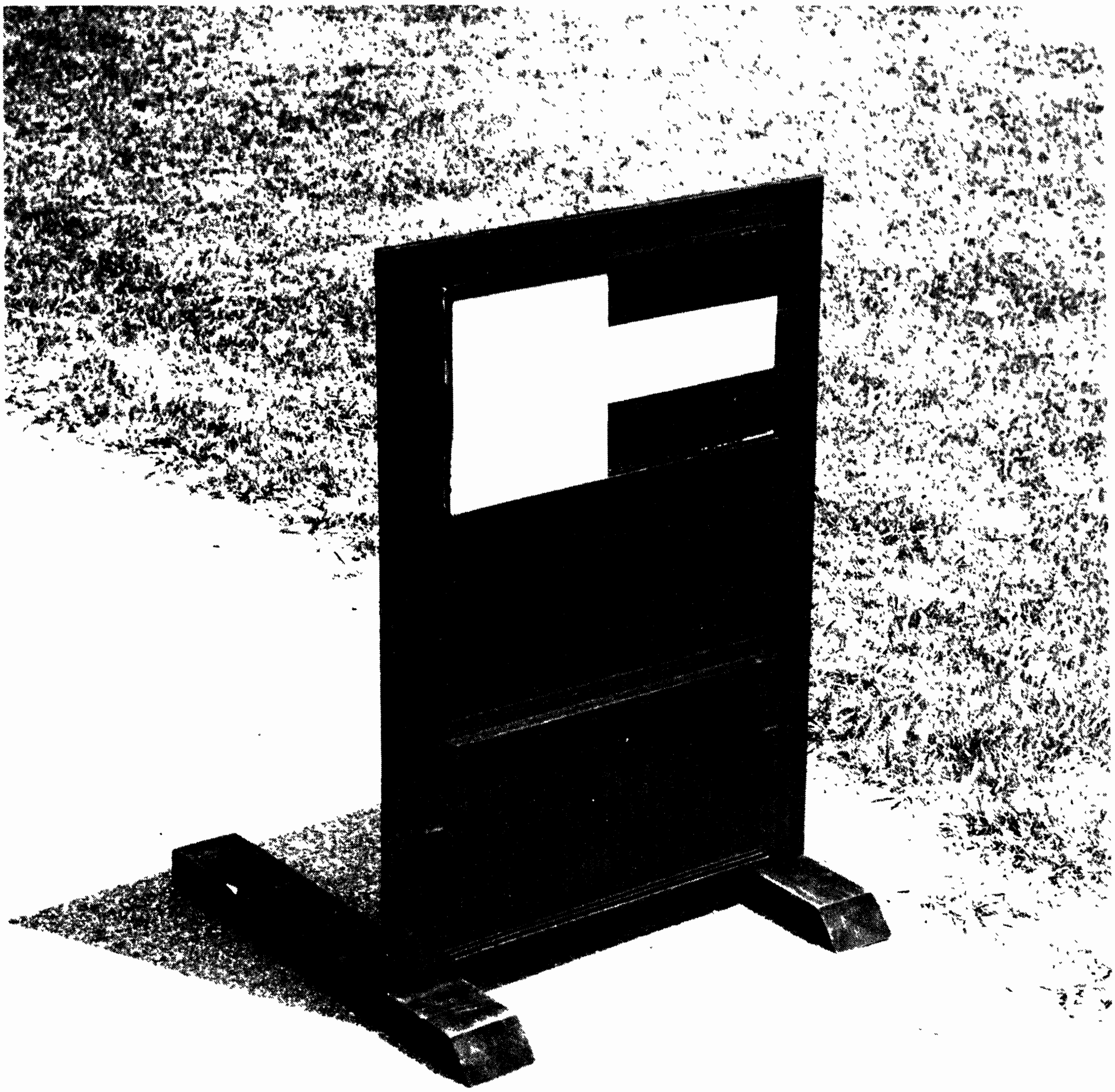

Figure 6. Type-I target.

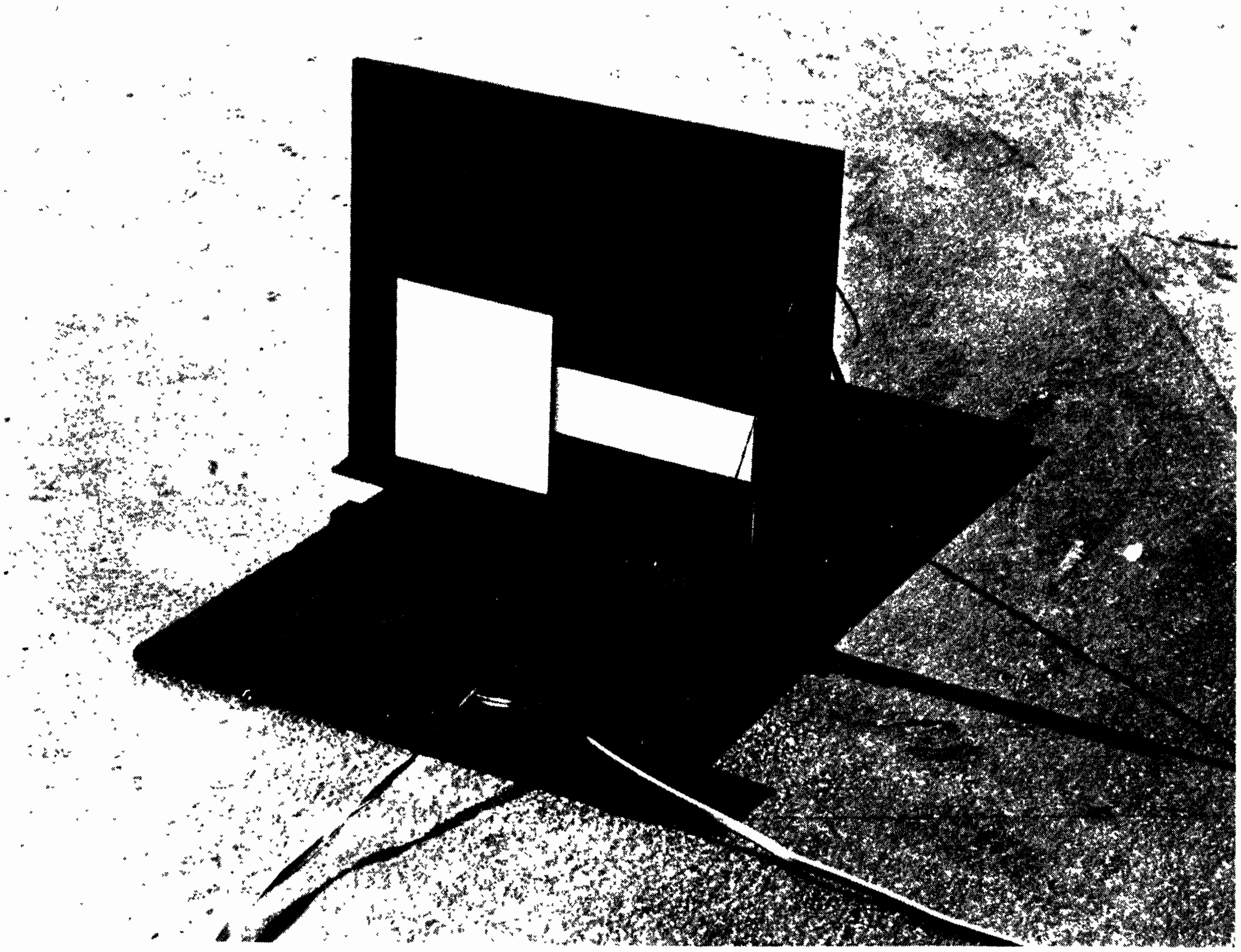

Figure 7. Type-I target modified for use in lane center.

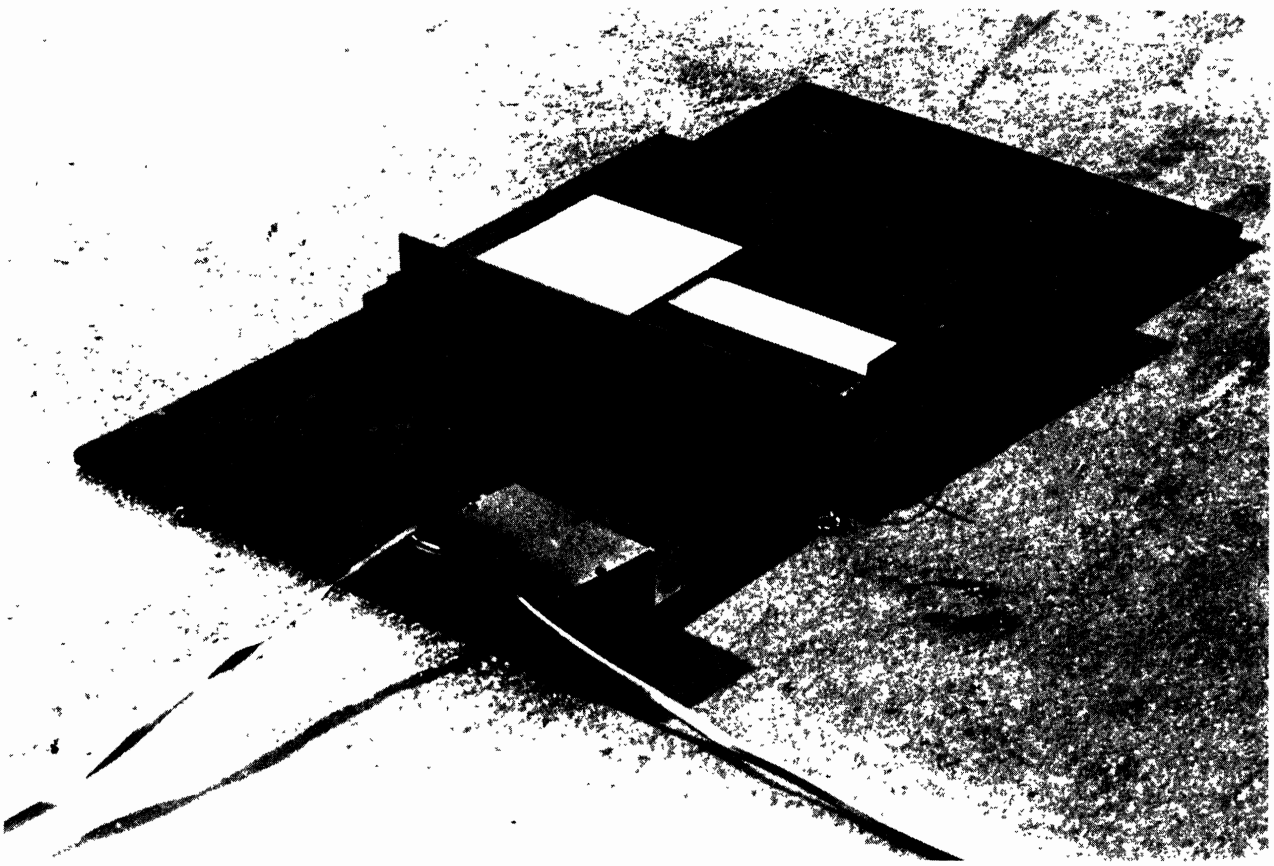

Figure 8. Type-I lane center target in down position.

visibility distance for experimental purposes. The height of this target was 7 feet (measured to the bottom of the sign), which is specified by MMUTCD for placement on a roadway with curb or on a non-curbed roadway where parking is likely to occur or where there are other obstructions to view.

The height is in accordance with the Manual on Uniform Traffic and Control Devices for Streets and Highways (MUTCDSH) requirement for signs located at the side of the road in rural, business and residential districts and in any case where parking is likely to occur or where there are other obstructions to view. This manual also prescribes a minimum height of 7 feet for interstate roadside directional signs. A lateral displacement of 5.5 feet to the right of the roadway was used, as MMUTCD specifies 2 feet for curbed roads and 10 feet minimum for non-curbed roads. The MUTCDSH specifies a lateral clearance of 6-12 feet where conditions permit, or 2 feet from a curb line, guardrail, or paved shoulder. The lateral separation used is slightly below the minimum as conditions did not permit a larger value.

The subjects' task with the type II target was to determine whether the top of the white bar was inclined to the right or left.

The type III target (Figure 10) was intended to simulate an overhead sign. This sign had a background of 3877 green high-intensity 3M sheeting with a reflective brilliance of 80. The reversible letter "E" was 3870 silver high-intensity sheeting with a reflective brilliance of 675. The letter "E" occupied a space 12 inches high and 8 inches wide; stroke width was 2.4 inches. The background measured 28 inches square. The 12-inch letter corresponds to MMUTCD specifications for overhead exit instructions on supplemental advance exit signs, and exit directions signs. A height of 17 feet (measured to the bottom of the sign) above the roadway was used, which meets the MMUTCD requirements of a minimum height of 15 feet, 6 inches for non-interstate clearance and approximates the 17 feet, 3 inches interstate minimum clearance. The MUTCDSH prescribes a vertical clearance of at least 17 feet for interstate roads. This manual also specifies 12-inch capital

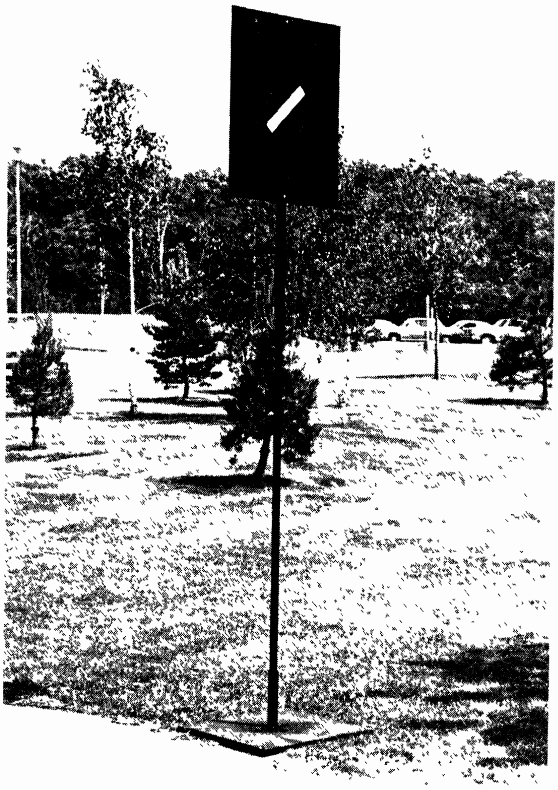

Figure 9. Type-II target.

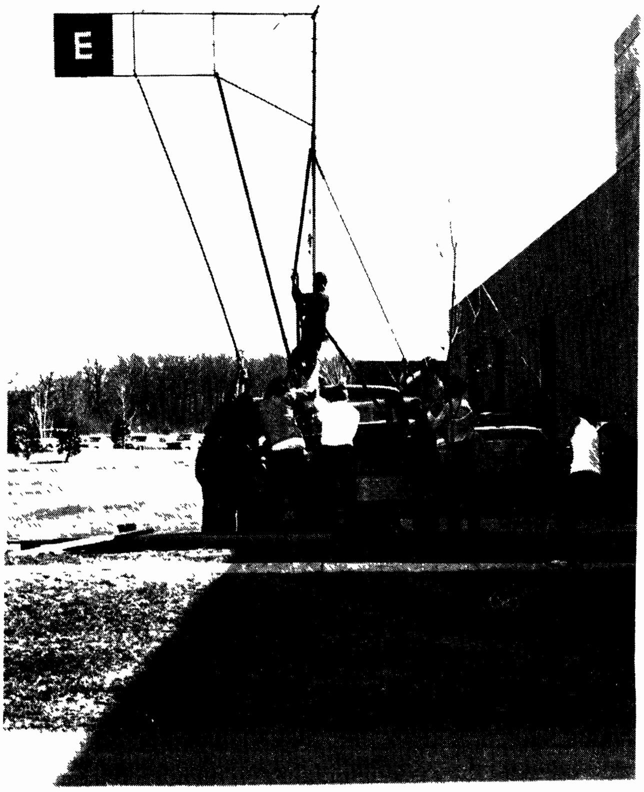

Figure 10. Type-III target being erected on truck.

letters for "EXIT" overhead gore signs and 12-inch numerals for overhead gore sign route numbers. The overhead sign was located such that the "E" was centered over the lane that the subjects were using. The sign was mounted on a truck so that it could be readily moved to various positions along the course. The subjects' task with this target was to determine whether the arms of the "E" were pointed right or left.

COURSE LAYOUT

The basic geometry of the course used in the first four studies is given in Figure 11. Shown are the relative positions of the 12 type-I targets used on each side. The course is symmetrical about target number 8, the intended meet point. The distance into the course at which various targets and markers were placed is given in feet. The overall distance from the start point for the northbound car to the start point for the southbound car is 6,400 feet. The intended lateral separation between the two vehicles (side to side) was 7 feet when targets were placed on the right side. The type-I targets were set so their center was 9 feet to the right or 6.5 feet to the left of the driver's intended position. It was necessary, when the targets were set to the left side, to offset them so that the targets for the northbound car would not obscure those for the southbound car and vice versa. Thus, the center lines of the respective target courses were separated by 4 feet. This affected the lateral separation of the vehicles, increasing it to about 14 feet in the left-hand target condition.

SUBJECTS

The 56 test subjects used in these studies were all drivers. About one-third of them were females. The age of the subjects was 18-60 years.

PROCEDURE

Two subjects occupied each vehicle, one driving and the other in the right front seat. Each run began with the two cars stopped facing each other at their respective start points. When

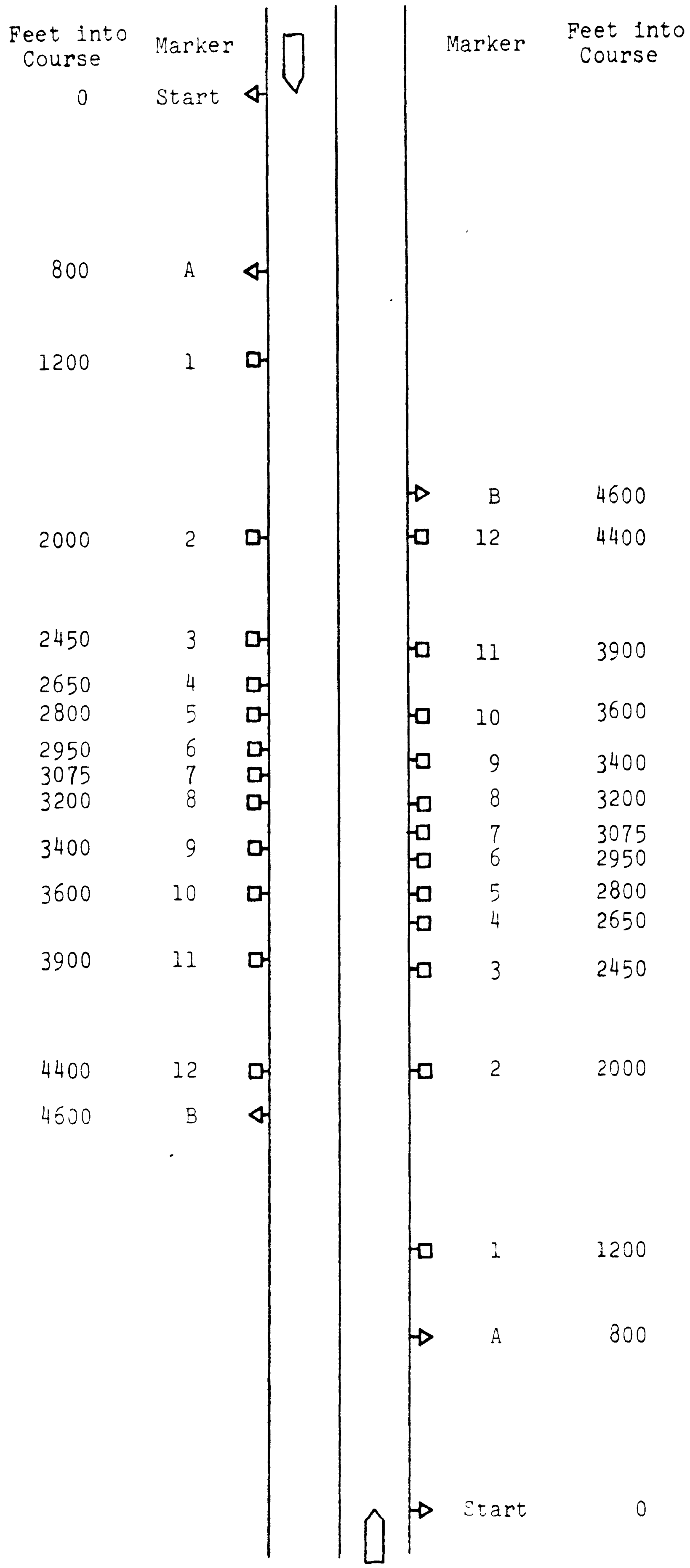

Figure 11. Basic layout of markers and targets.

preparations for the run were complete, the headlamps were switched off to so indicate to the other vehicle. One car then switched the appropriate lamps on and, when the other car switched its beams on, both accelerated moderately to the latch-in point for the speed control. This would be accomplished and the speed stabilized when point A (marked by a traffic cone) was reached. The experimenter indicated the A point on the recorder and started the timer by pressing a switch as the cone was passed. The experimenter also indicated the point at which the cars passed in mid course and the end marker, point B (simultaneously stopping the timer) in the same way. The cars then continued on past the start point for the opposite course, made a U-turn and stopped to get ready for the next run.

Driver subjects were asked to indicate verbally the point at which, during any run, they felt the glare from the oncoming car's headlamps became intolerable. This was further defined as a point where they would surely request dimming were they able to do so. Most drivers responded only to high beams, as would be expected, but some drivers responded rarely even to high beams. This "glare point" was entered on the strip chart and the longitudinal separation at which it occurred analyzed later. A summary of this analysis for the first four studies is presented in this paper.

The first four of the studies to be described were run on the north-south straightaway at the GM Proving Grounds in Milford, Michigan. This road is a straight, level facility, 2.5 miles long, with three ten-foot lanes in each direction separated by a twenty-foot grassy median. For studies simulating two-lane meeting situations, two courses such as are shown in Figure 11 were set up, one on each side of the median. This way data could be collected continuously on one course while necessary changes were being made to the other.

DATA REDUCTION AND ANALYSIS

The data handling was accomplished in three steps: first the data were digitized from the strip charts; second, a curve fit routine was employed to obtain the visibility distances, for each subject and condition, for each meeting; and third, visibility distances for fifteen selected longitudinal separation distances between the opposing vehicles were computed from the curves. These values were then used in statistical analyses.

The data were digitized by measuring the distance on the strip chart from the point at which the subject indicated the target orientation to the point where the vehicle passed the target. The A to B distance was also noted, as was the time for each run. These data were punched on cards and analyzed by a computer program which corrected for average car-chart recorder speeds using the A to B time data. The output of the program was a listing of the distance at which each target was identified for each subject and experimental condition, assuming a reaction time of 0.5 second. Since the intention was to conduct the analysis based on separation between driver and glare car (separation distance), a further modification of the data was necessary.

At this point a curve was fitted to the data for each subject and condition using least squares methods. The estimated visibility distances for any separation distance could be taken from these curves. Fifteen separation distances were selected (4000, 3000, 2200, 1500, 1000, 700, 500, 400, 300. 200, 100, 0, -400, -800 and -1200 feet). These calculated visibility distances were the basic data for the analysis which followed.

STUDY 1

METHOD

This study measured visibility distances of type-I targets as a function of: (1) target reflectance, 6%, 12%, 26%, 54% and 87%; (2) target location, right or left of lane; (3) target face height, high or low position on target board and; (4) headlamp beam, standard high or low beam as provided by two 6014 (the 6014 is a 7" diameter, sealed-beam lamp with standard U.S. beam pattern) headlamps. This resulted in 40 combinations of conditions, each of which was presented once to each of 16 subjects. The subjects were run in groups of eight, with four running and four resting at any one time. Thus, the subjects were collecting data for no more than a half an hour at a time, which minimized fatigue effects.

RESULTS

The analysis of variance for this study is given in Table 1. Virtually all main effects and interactions are significant at or beyond the 0.01 level. For purposes of this analysis, separation distance is treated as a factor having three levels. The data for the first five separation distances listed above were combined, as were the data from the second and third five.

The following statements summarize the results of this study:

High beams have longer visibility distances than low beams under no-glare conditions, but shorter visibility distances as the cars neared the meeting point (Figure 12). This effect was more pronounced with the target on the left than on the right (Figure 13), and with targets of higher reflectance (Figure 14). The crossover point of the high and low beam visibility distance curves varied with experimental conditions, but was generally between 1500-1800 feet.

As noted in Figure 13, average visibility distances for high and low beams are 320 and 310 feet respectively for right-hand targets, which is not statistically significant. The corresponding values for left-hand targets are 250 and 180 feet, which is statistically significant. These differences appear more clearly in Figure 15, which shows visibility distance as a function of beam, target location and separation distance. As would be expected, visibility with either beam is affected more by glare when the target is to the left of the lane than when it is on the right. For a target on the right the asymmetrical low beam nearly matches high beam performance, being slightly poorer under no-glare conditions but slightly better under glare conditions. The high beam provides greater visibility for left-hand targets, except near the meeting point.

TABLE 1. Analysis of Variance of Visibility Distance Data - Study 1.

DIVISION OF VARIANCE

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	RATIO
F	0.1688264E 08	15	1125509.	
A	0.2509984E 08	2	0.1254992E 08	179.41**
AF	2098480.	30	69949.31	0.0
B	0.5048880E 08	4	0.1262220E 08	306.95**
BF	2467264.	60	41121.07	0.0
AB	2967829.	8	370978.6	52.905**
ABF	841456.2	120	7012.133	0.0
C	1927552.	1	1927552.	32.738**
CF	883174.5	15	58878.30	0.0
AC	14142.91	2	7071.453	1.0293
ACF	206108.8	30	6870.293	0.0
BC	498815.6	4	124703.9	14.975**
BCF	499664.8	60	8327.746	0.0
ABC	51507.52	8	6438.438	1.7186
ABCF	449557.4	120	3746.311	0.0
D	0.2173982E 08	1	0.2173982E 08	143.72**
DF	2268993.	15	151266.2	0.0
AD	3990049.	2	1995024.	89.479**
ADF	668883.2	30	22296.11	0.0
BD	1303078.	4	325769.5	20.455**
BDF	955560.5	60	15926.01	0.0
ABD	981683.4	8	122710.4	23.362**
ABDF	630296.8	120	5252.473	0.0
CD	353989.6	1	353989.6	12.770**
CDF	415822.4	15	27721.49	0.0
ACD	60057.28	2	30028.64	4.2494*
ACDF	211995.2	30	7066.504	0.0
BCD	122161.4	4	30540.36	3.4140*
BCDF	536734.9	60	8945.578	0.0
ABCD	62675.45	8	7834.430	1.9651
ABCDF	478419.0	120	3986.825	1.3828
E	3358269.	1	3358269.	120.01**
EF	419745.2	15	27983.02	0.0
AE	4840885.	2	2420442.	117.22**
AEF	619467.7	30	20648.92	0.0
BE	217803.7	4	54450.94	5.5226**
BEF	591583.6	60	9859.723	0.0
ABE	291875.2	8	36484.40	11.650**
ABEF	375804.6	120	3131.705	0.0
CE	106889.9	1	106889.9	9.7826**
CEF	163898.7	15	10926.58	0.0
ACE	4586.258	2	2293.129	0.46985
ACEF	146417.7	30	4880.590	0.0
BCE	75695.00	4	18923.75	2.6440*
BCEF	429434.2	60	7157.234	0.0
ABCE	29094.16	8	3636.771	0.90914
ABCEF	480029.3	120	4000.244	1.3875
DE	2409124.	1	2409124.	267.17**
DEF	135260.2	15	9017.344	0.0
ADE	653943.2	2	326971.6	76.584**
ADEF	128083.9	30	4269.461	0.0
BDE	76581.50	4	19145.37	2.9982*
BDEF	383139.8	60	6385.660	0.0
ABDE	65971.44	8	8246.430	2.3396*
ABDEF	422961.2	120	3524.677	1.2225
CDE	90889.31	1	90889.31	10.263**
CDEF	132843.7	15	8856.242	0.0
ACDE	11096.32	2	5548.156	1.2080
ACDEF	137786.1	30	4592.867	1.5930
BCDE	8312.715	4	2078.179	0.31141
BCDEF	400407.6	60	6673.457	2.3147
ABCDE	75697.19	8	9462.148	3.2819**
ABCDEF	345971.2	120	2883.093	0.81798
WITHIN CELLS	0.2706933E 08	7680	3524.652	
TOTAL	0.1848559E 09	9599		

NUMBER OF REPLICATIONS 5

A - Longitudinal Separation Distance
B - Target Reflectance
C - Target Position
D - Target Location
E - Beam
F - Subjects

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*$p \leq 0.05$

**$p \leq 0.01$

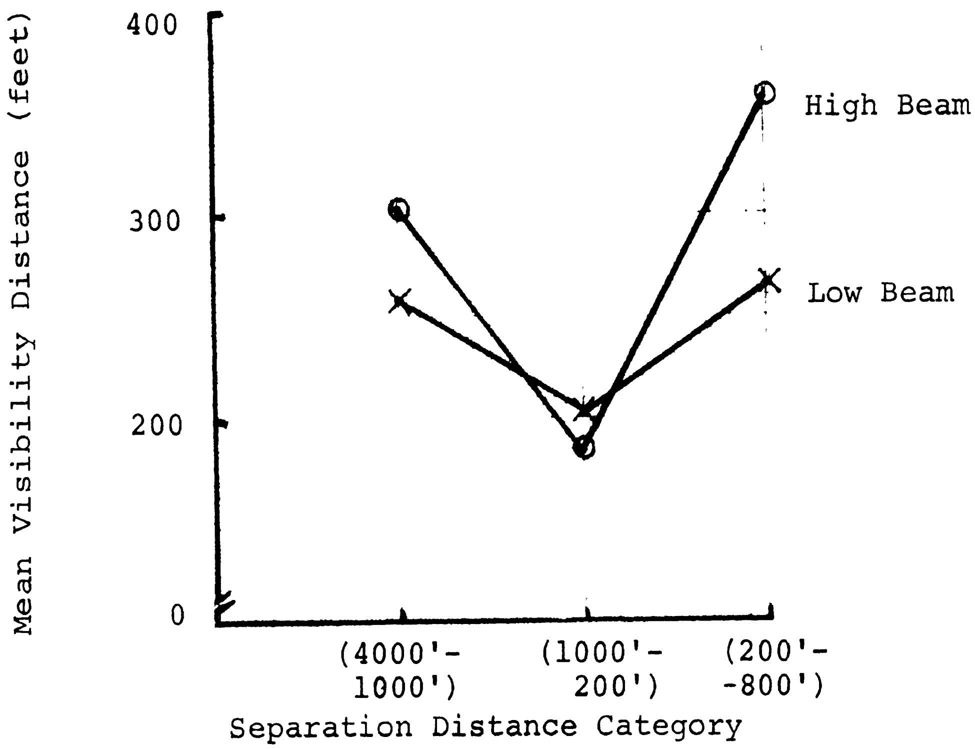

Figure 12. Visibility distances provided by high and low beams as a function of longitudinal separation from glare source, in study 1, averaged over the other variables (e.g., target reflectance, location and vertical position).

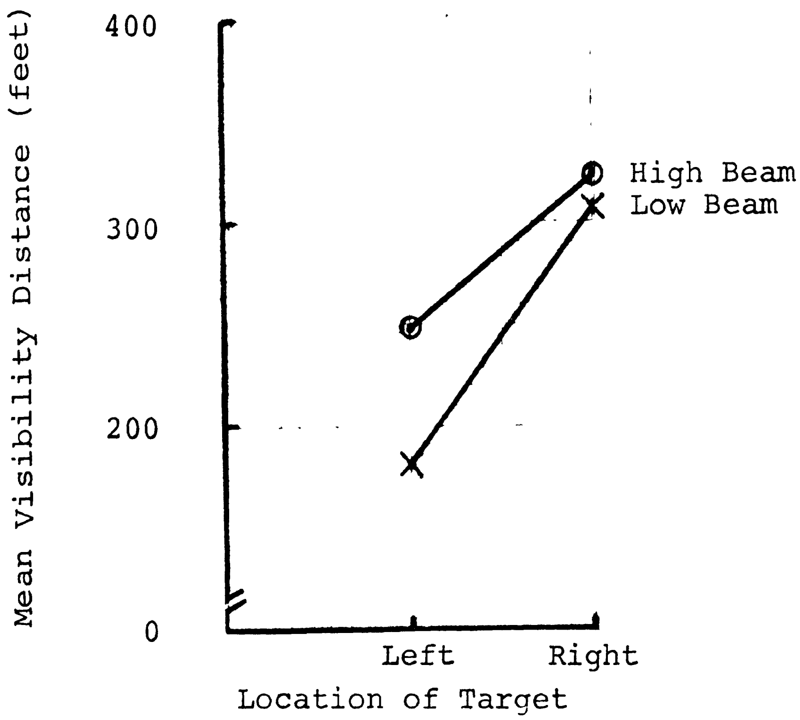

Figure 13. Visibility distances provided by high and low beams for targets located to the left and right of the lane, in study 1.

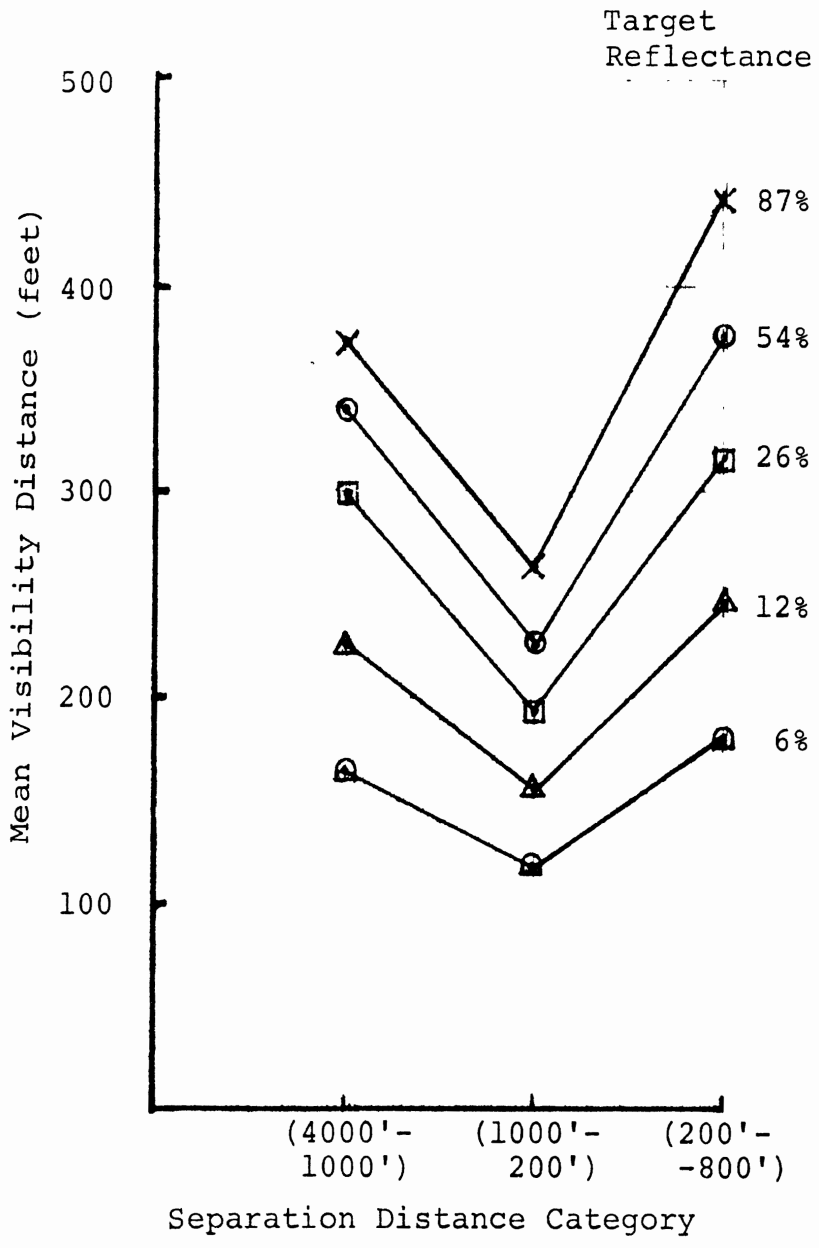

Figure 14. Visibility distances associated with various target reflectances as a function of longitudinal separation from glare source, in study 1.

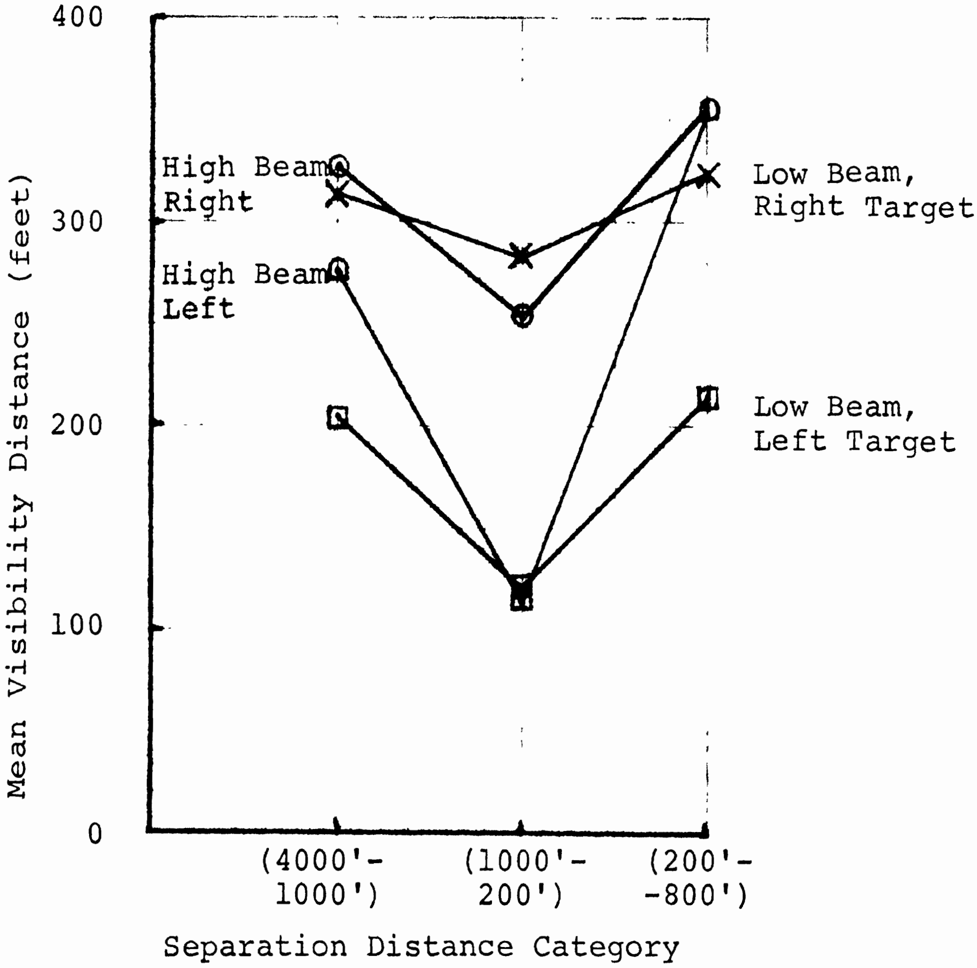

Figure 15. Visibility distance as a function of beam, longitudinal separation from glare source and location of target to left or right of lane, in study 1.

Target reflectance had a very significant effect on visibility distance (Figure 16). Targets to the right of the car show an orderly increase in visibility distance as reflectance increases. While glare reduces visibility distance it is by roughly the same amount in each case. However, the presence of glare for the left-hand targets has a far greater effect on the targets of high reflectance. Interestingly, the proportional visibility distances remain nearly constant from separation distance category 1 to 2 for left-hand targets.

The height of the reflective target faces above the pavement made a significant difference in visibility distance (Figure 17). The difference was greater for low beams than high beams and varied at will with target reflectivity, being greater for more highly reflective targets. The lower target face position provided greater visibility distances.

STUDY 2

METHOD

This study was intended as a replication of the first effort except that the lateral separation between vehicles was greater, approximately 36 feet, as compared with 7 feet in study 1. In addition, the reflectance factor was reduced from five to two levels, 12% and 54%. This resulted in 16 combinations of variables, each of which was presented once to each of 12 subjects.

In addition to the foregoing, four of the twelve subjects made another eight runs at a higher speed (70 feet per second) to determine whether performance changed with speed. In this series the start point was moved back an additional 1000 feet, from point A, to allow adequate distance to get up to speed, but the course was otherwise unchanged.

RESULTS

The analysis of variance for this study is reproduced in Table 2. The results follow much the same pattern as the first study.

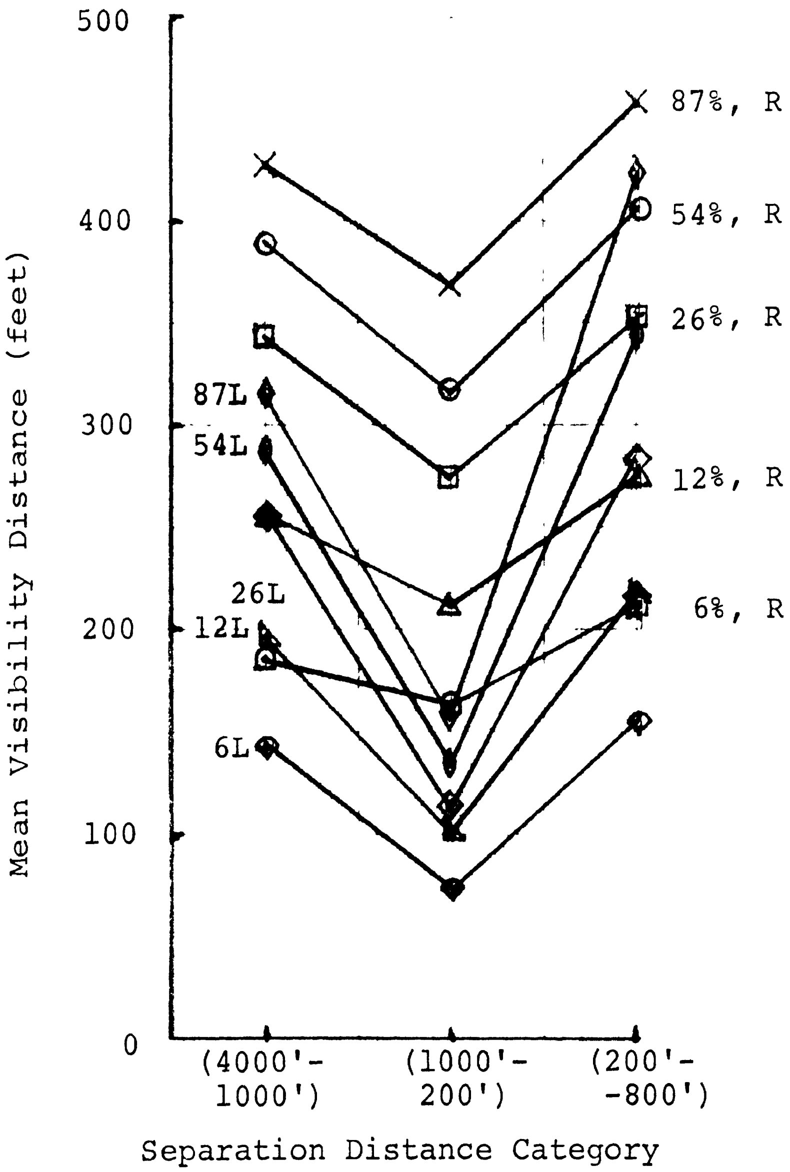

Figure 16. Visibility distance as a function of reflectance, longitudinal separation from glare source and location of target to left(L) or right(R) of lane, in study 1.

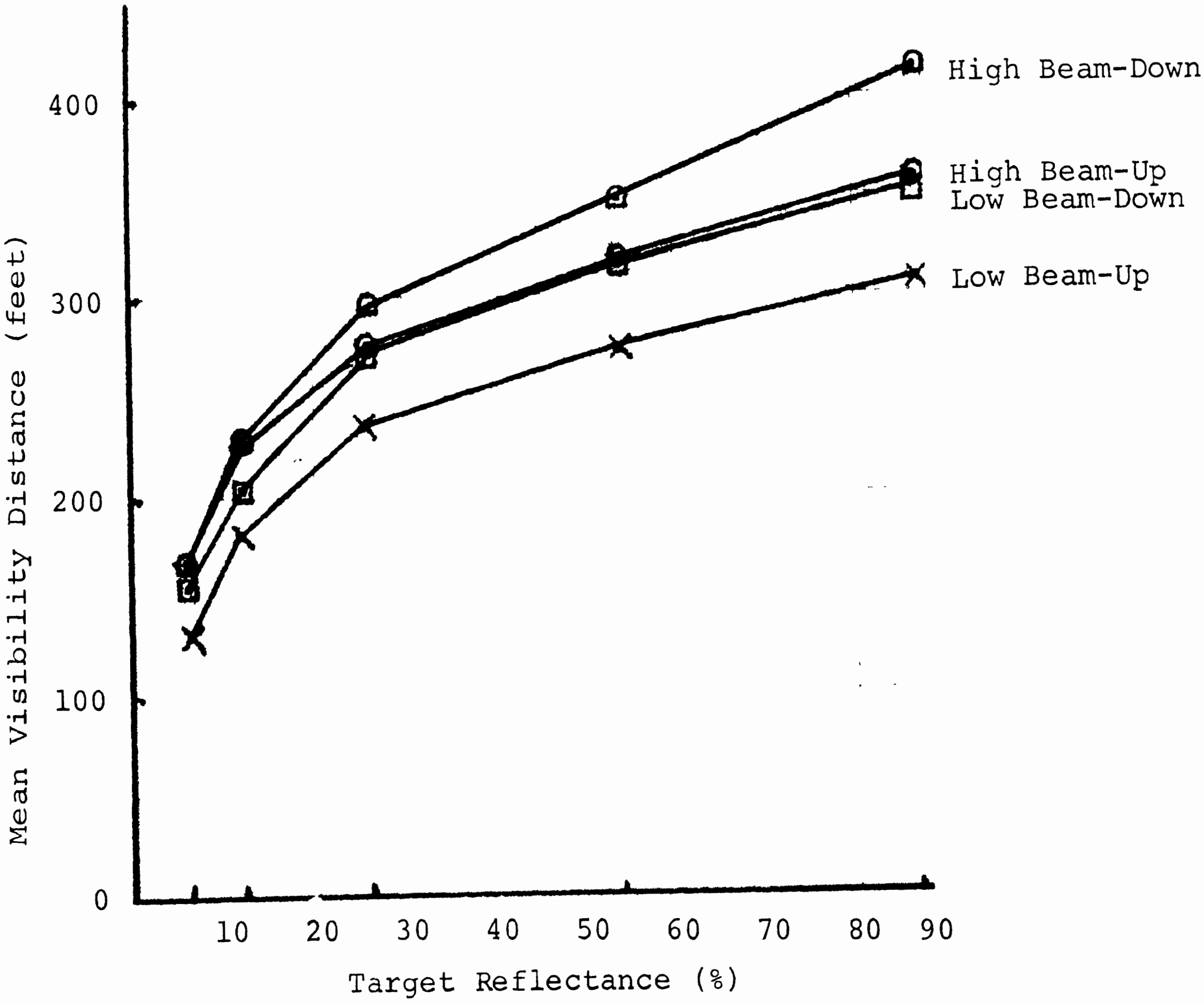

Figure 17. Visibility distance as a function of target reflectance, beam and vertical position (down-6 in; up-18 in.) of the target, in study 1.

TABLE 2. Analysis of Variance of Visibility Distance Data - Study 2.

DIVISION OF VARIANCE

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	RATIO
F..............	3527470.	11	320679.1	.
A..............	2210416.	2	1105208.	116.58**
AF.............	208563.7	22	9480.168	0.0
B..............	5627054.	1	5627054.	202.48**
BF.............	305692.5	11	27790.23	0.0
AB.............	29046.44	2	14523.22	5.0927*
ABF............	62738.78	22	2851.763	0.0
C..............	249158.2	1	249158.2	21.665**
CF.............	126506.2	11	11500.56	0.0
AC.............	65049.54	2	32524.77	15.886**
ACF............	45041.18	22	2047.326	0.0
BC.............	62131.14	1	62131.14	11.436**
BCF............	59763.61	11	5433.055	0.0
ABC............	48741.18	2	24370.59	7.2879**
ABCF...........	73567.25	22	3343.966	0.0
D..............	2352098.	1	2352098.	105.62**
DF.............	244952.7	11	22268.43	0.0
AD.............	262442.9	2	131221.4	41.965**
ADF............	68792.56	22	3126.935	0.0
BD.............	18207.08	1	18207.08	2.2278
BDF............	89898.69	11	8172.605	0.0
ABD............	31765.07	2	15882.54	6.5276**
ABDF...........	53529.18	22	2433.145	0.0
CD.............	36704.75	1	36704.75	4.5939
CDF............	87888.00	11	7989.816	0.0
ACD............	37220.86	2	18610.43	9.4043**
ACDF...........	43536.62	22	1978.937	0.0
BCD............	29654.15	1	29654.15	5.3571*
BCDF...........	60890.58	11	5535.504	0.0
ABCD...........	2805.377	2	1402.688	0.30969
ABCDF..........	99643.69	22	4529.258	1.2557
E..............	2549354.	1	2549354.	120.33**
EF.............	233052.2	11	21186.57	0.0
AE.............	434037.4	2	217018.7	60.933**
AEF............	78355.44	22	3561.611	0.0
BE.............	154025.9	1	154025.9	52.151**
BEF............	32487.88	11	2953.443	0.0
ABE............	56100.89	2	28050.44	10.616**
ABEF...........	58128.69	22	2642.213	0.0
CE.............	1315.420	1	1315.420	0.53756
CEF............	26917.32	11	2447.029	0.0
ACF............	1445.725	2	722.8625	0.56626
ACEF...........	28084.10	22	1276.550	0.0
BCE............	5619.750	1	5619.750	2.0748
BCEF...........	29794.61	11	2708.601	0.0
ABCF...........	4118.047	2	2059.023	0.69721
ABCEF..........	64970.98	22	2953.227	0.81877
DE.............	156720.9	1	156720.9	25.148**
DEF............	68550.81	11	6231.891	0.0
ADE............	96182.63	2	48091.31	16.009**
ADEF...........	66088.19	22	3004.008	0.0
BDE............	2297.299	1	2297.299	0.23607
BDEF...........	107047.2	11	9731.566	0.0
ABDE...........	39315.04	2	19657.52	4.3696*
ABDEF..........	98971.94	22	4498.723	1.2472
CDE............	2734.301	1	2734.301	1.1402
CDEF...........	26378.04	11	2398.003	0.0
ACDE...........	2904.698	2	1452.349	1.0183
ACDEF..........	31378.37	22	1426.289	0.39543
BCDE...........	6050.902	1	6050.902	2.2744
BCDEF..........	29264.70	11	2660.427	0.73759
ABCDF..........	2721.381	2	1360.691	0.37725
ABCDEF.........	79352.13	22	3606.915	5.0535
WITHIN CELLS	411119.2	576	713.7465	
TOTAL	0.21205860 08	1151		

NUMBER OF REPLICATIONS 2

A - Longitudinal Separation Distance
B - Target Reflectance
C - Target Position
D - Target Location
E - Beam
F - Subjects

*$p \leq 0.05$
**$p \leq 0.01$

The primary difference in results comparing this study with the first, is the lack of a crossover point between high and low beams (see Figure 18). This is true regardless of whether the target is on the right or left of the lane (Figure 19). Thus, the data suggest that two cars separated by even a moderate median should not dim from high to low beams to maximize visibility, at least on straight roads. It should be noted that this suggestion does not take into account discomfort glare effects.

There were differences in visibility distance associated with beams and target reflectance (greater difference at 54% than 12% reflectance, see Figure 20) and target location (greater difference for targets on the left side of the lane than for targets on the right side, see Figure 21). However, at the 7-foot lateral separation condition, visibility distance for the right-hand targets was much the same for the two beams (Figure 13), whereas at the 36-foot lateral separation condition the mean visibility distances for the two beams differ by about 70 feet.

Figures 22 and 23 provide a comparison of performance for typical conditions (12% and 54% reflectance targets on right side, in down position) for the two lateral separation conditions used in studies 1 and 2. The high degree of correspondence in the mean visibility distances after the meeting point is striking especially for the low beam (Figure 22). This is because visibility finally becomes a function only of target reflectance and is no longer affected by the lateral separation. The curves are more divergent for the high beam condition (Figure 23), even after the meeting point, but recovery is probably still taking place. It should be noted that, for both high and low beams, the point of minimum visibility is reached at a greater longitudinal separation and represents less of a decrement at the 36-foot than the 7-foot lateral separation.

EFFECTS OF TEST VEHICLE SPEED. The analysis of variance for the high speed runs is reproduced in Table 3. Virtually all main

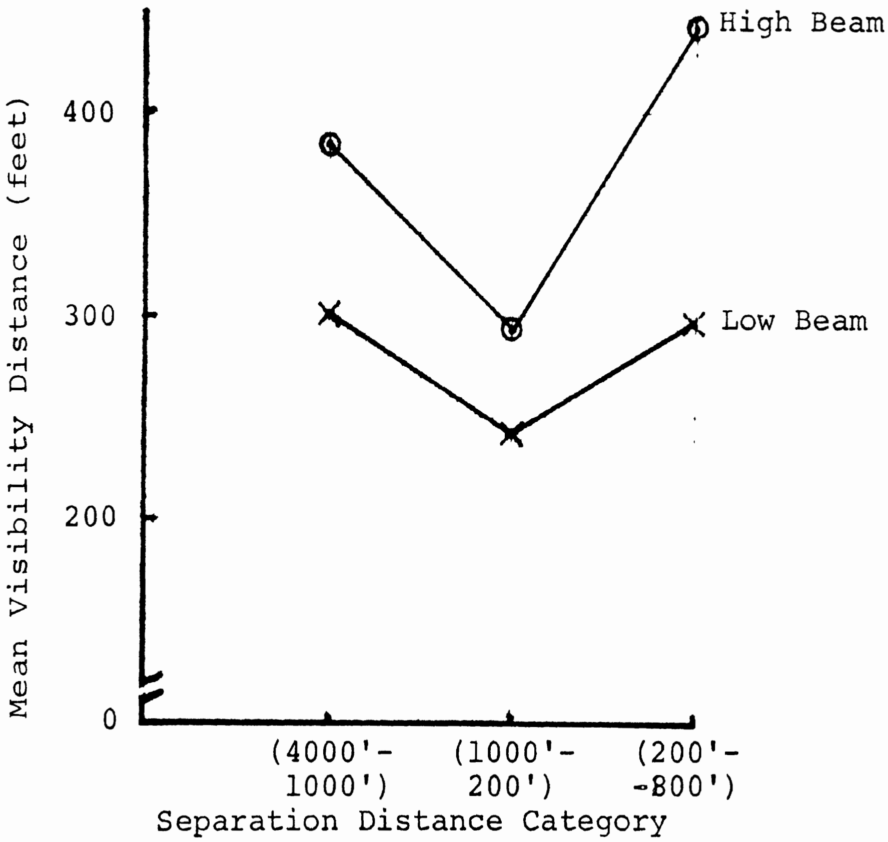

Figure 18. Visibility distance as a function of beam and longitudinal separation from glare source; 36' lateral separation condition, in study 2.

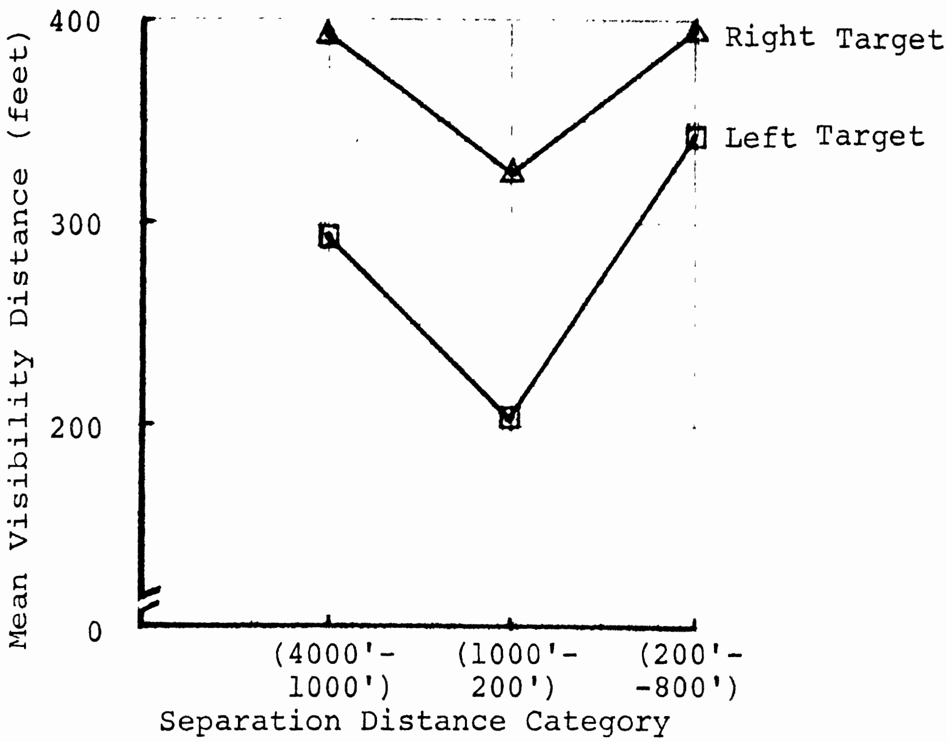

Figure 19. Visibility distance as a function of longitudinal separation from glare source and location of target to left or right of vehicle; 36' lateral separation condition, in study 2.

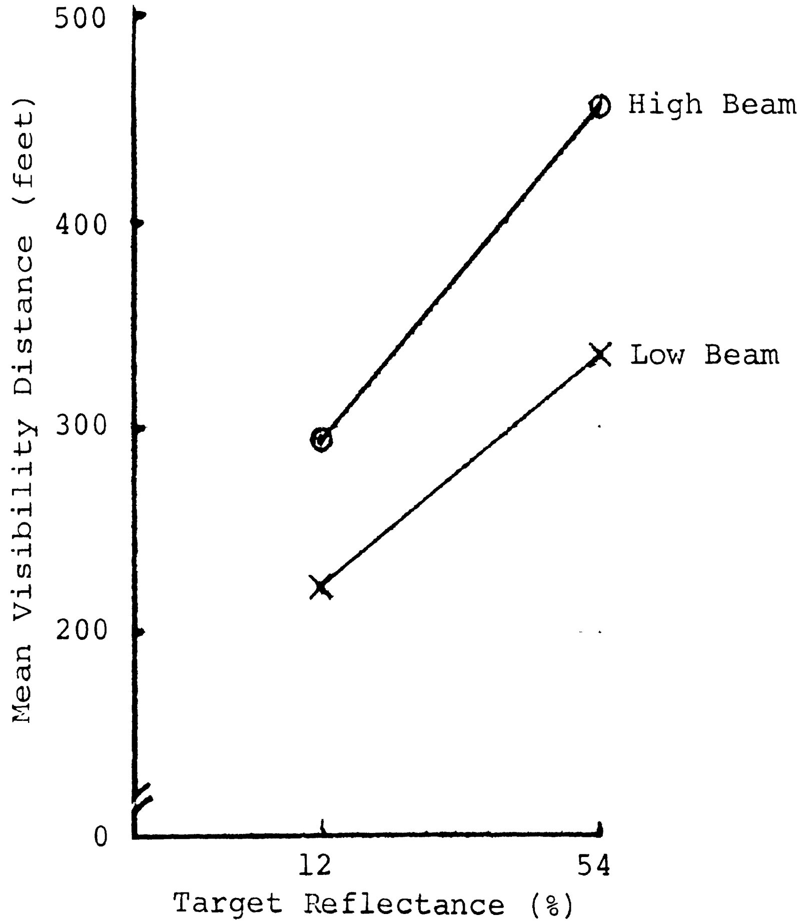

Figure 20. Visibility distance as a function of beam and target reflectivity; 36' lateral separation condition, in study 2.

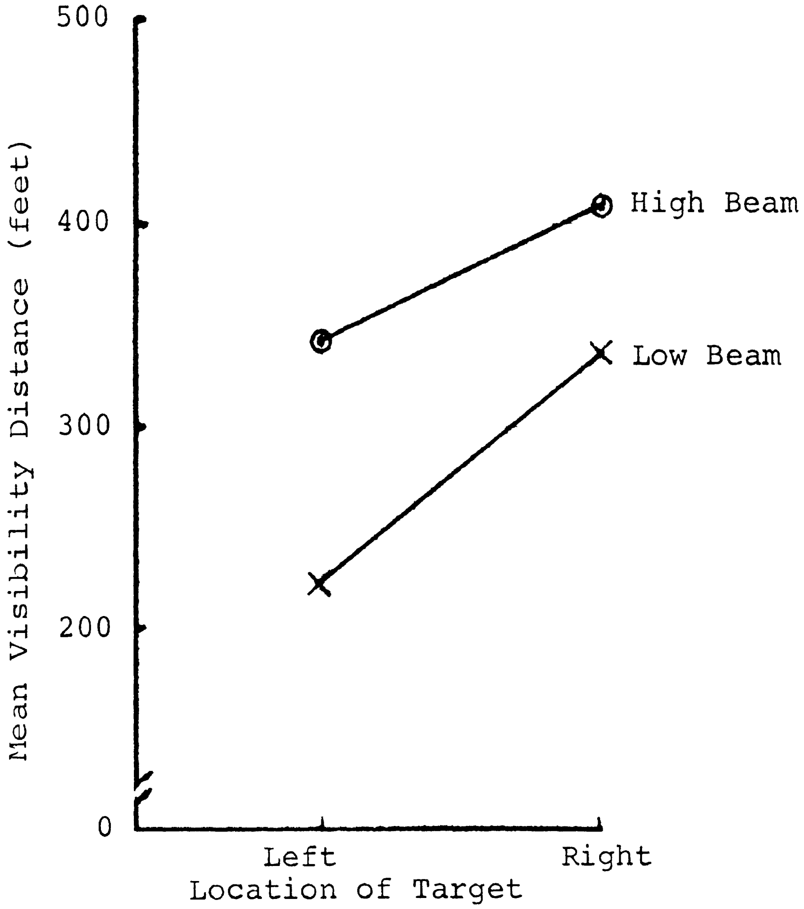

Figure 21. Visibility distance as a function of beam and location of target to right or left of lane; 36' lateral separation condition, in study 2.

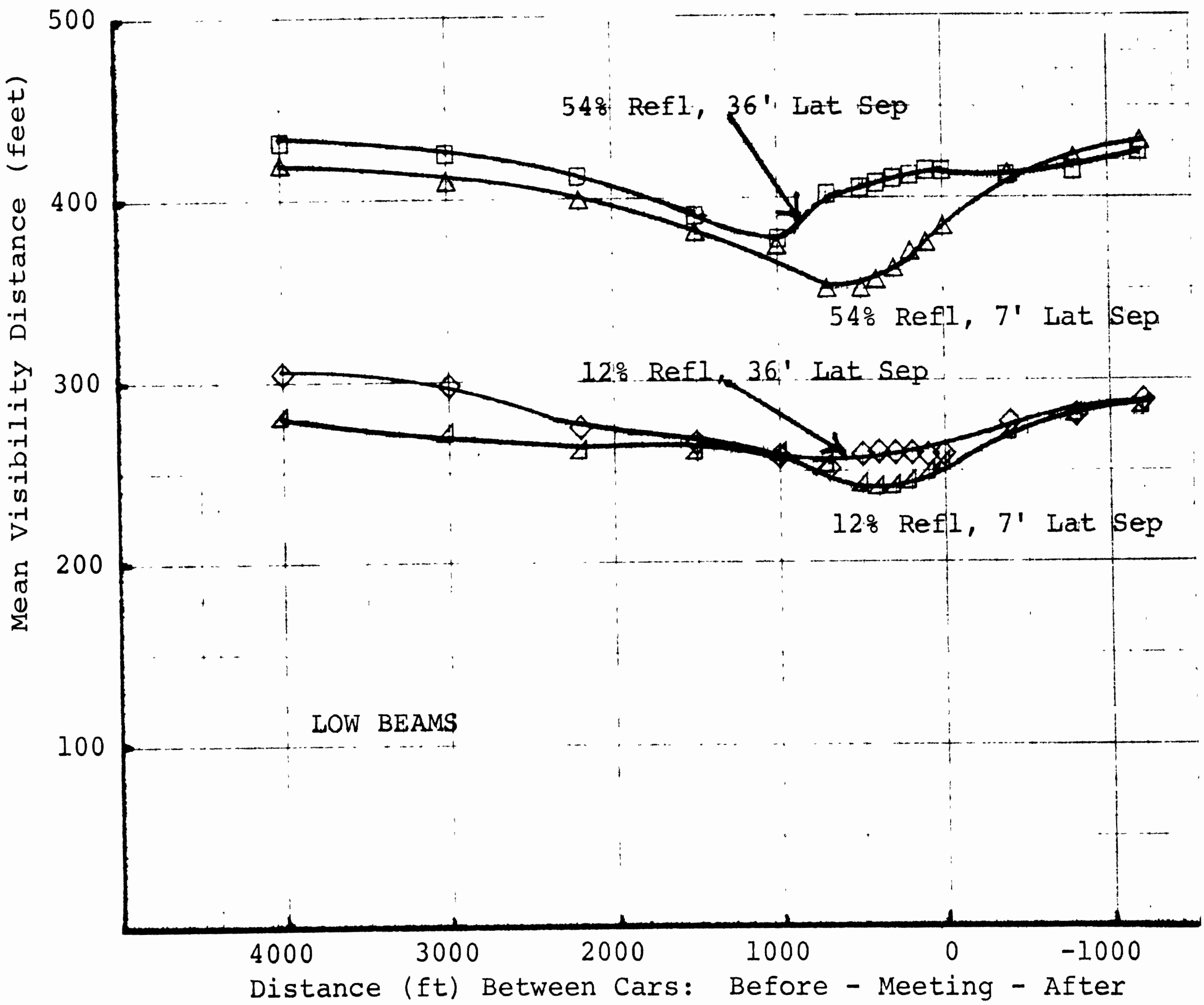

Figure 22. Visibility distance of the 12% and 54% reflectance targets on the right side of the lane in meetings with low beams, for lateral separations of 7 feet and 36 feet.

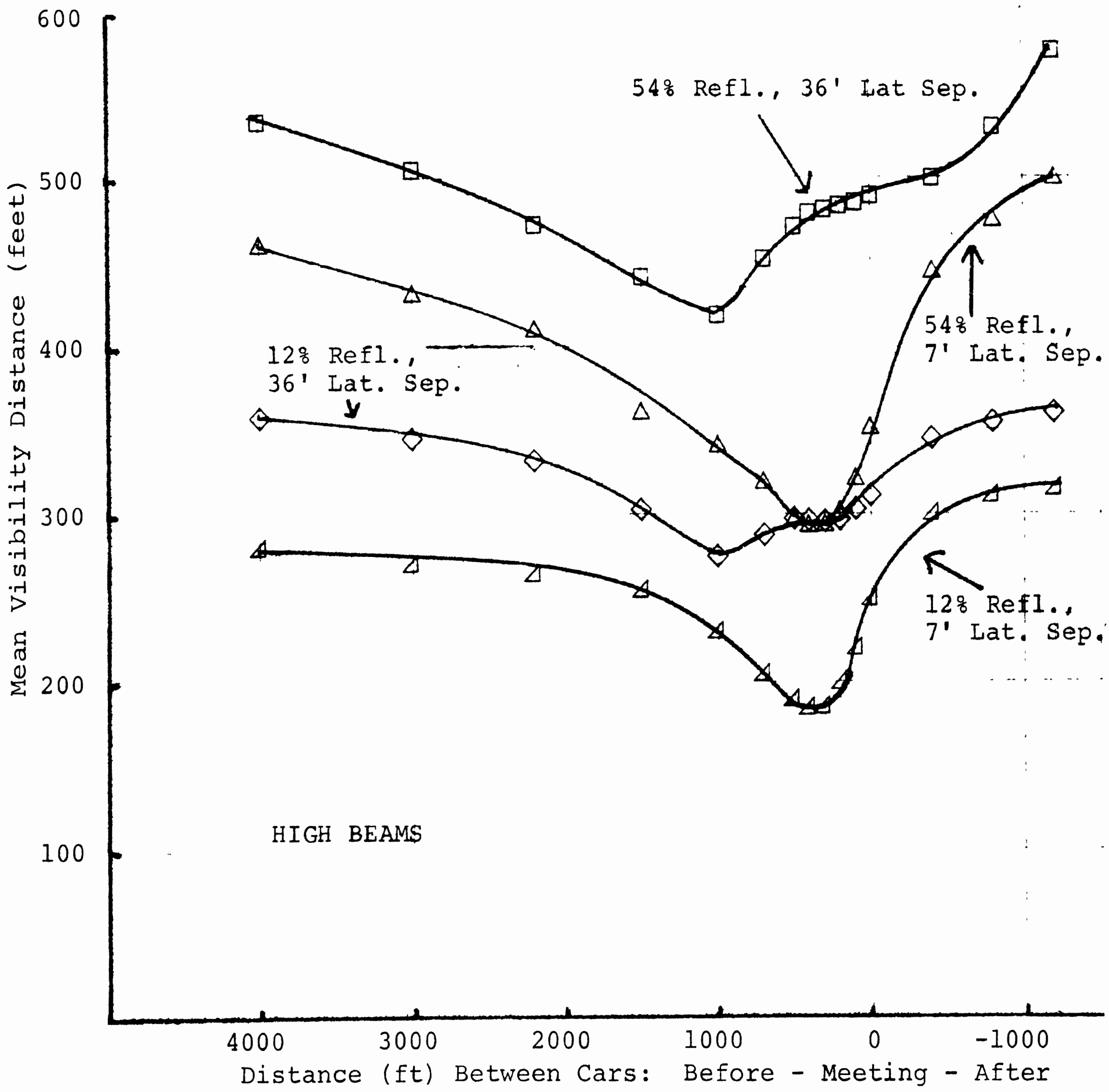

Figure 23. Visibility distance of the 12% and 54% reflectance targets on the right side of the lane in meetings with high beams, for lateral separations of 7 feet and 36 feet.

TABLE 3. Analysis of Variance of Visibility Distance Data - Study 2, Higher Speed (70 ft/sec).

DIVISION OF VARIANCE

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	RATIO
D..............	0.7155720E 08	3	0.2385240E 08	
A..............	0.2852160E 08	14	2037257.	7.2344**
AD.............	0.1182747E 08	42	281606.4	0.0
B..............	0.3015762E 09	1	0.3015762E 09	112.40**
BD.............	8049064.	3	2683021.	0.0
AB.............	4074414.	14	291029.6	3.5204**
ABD............	3472095.	42	82668.88	0.63964
C..............	0.6171432E 08	1	0.6171432E 08	87.657**
CD.............	2112132.	3	704044.0	0.0
AC.............	0.1099107E 08	14	785076.3	2.9083**
ACD............	0.1133775E 08	42	269946.3	2.0887
BC.............	1990088.	1	1990088.	1.6739
BCD............	3566579.	3	1188859.	9.1986
ABC............	1339456.	14	95675.38	0.74027
ABCD...........	5428216.	42	129243.2	0.79544
WITHIN CELLS	0.3899518E 08	240	162479.9	
TOTAL	0.5665528E 09	479		

NUMBER OF REPLICATIONS 2

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*$p \leq 0.05$

**$p \leq 0.01$

A - Longitudinal Separation Distance
B - Target Reflectance
C - Beam
D - Subjects

effects and interactions are significant at or beyond the 0.01 level.

Performance on the high speed (70 ft/sec) runs was compared with performance, for the same subjects and conditions, on low speed (40 ft/sec) runs. Differences were small and short of accepted levels of statistical significance. For example, Figure 24 shows visibility distance as a function of target reflectance and beam for the same four subjects at the two different speeds.

RELIABILITY OF THE FIELD TEST PROCEDURE. To provide an indication of the test-retest reliability of the field data collection method just described, four subjects were exposed twice to the same sequence of eight trials.

Twelve subjects had participated in the study, looking at two levels each of beam (high and low, as provided by 6014 lamps), target position (right or left of lane), target height (6 in. and 18 in.) and target reflectivity (12% and 54%). The study was run with a lateral separation of about 36 feet between the vehicles. At the conclusion of the 16 trials necessary for a full replication, four subjects were selected randomly and run through the last eight trials a second time. Target height was constant (6 in.) in this phase of the test. All other factors were as listed above. The right-left position of the 8 x 8-inch square on the target was changed randomly to preclude memory effects.

Figure 25 gives the results for this study. Each point on the figure is the mean of eight trials for four subjects, a total of 32 distance judgments. While the visibility distances for the second replication are consistently longer, they are generally within fifteen feet, a discrepancy of 5% or less. The correlation between the mean visibility distances in the two replications is 0.97.

STUDY 3

METHOD

This study investigated visibility distance using type-I, II and III targets, where the type-I targets were of the fold-down variety and were positioned in the center of the lane.

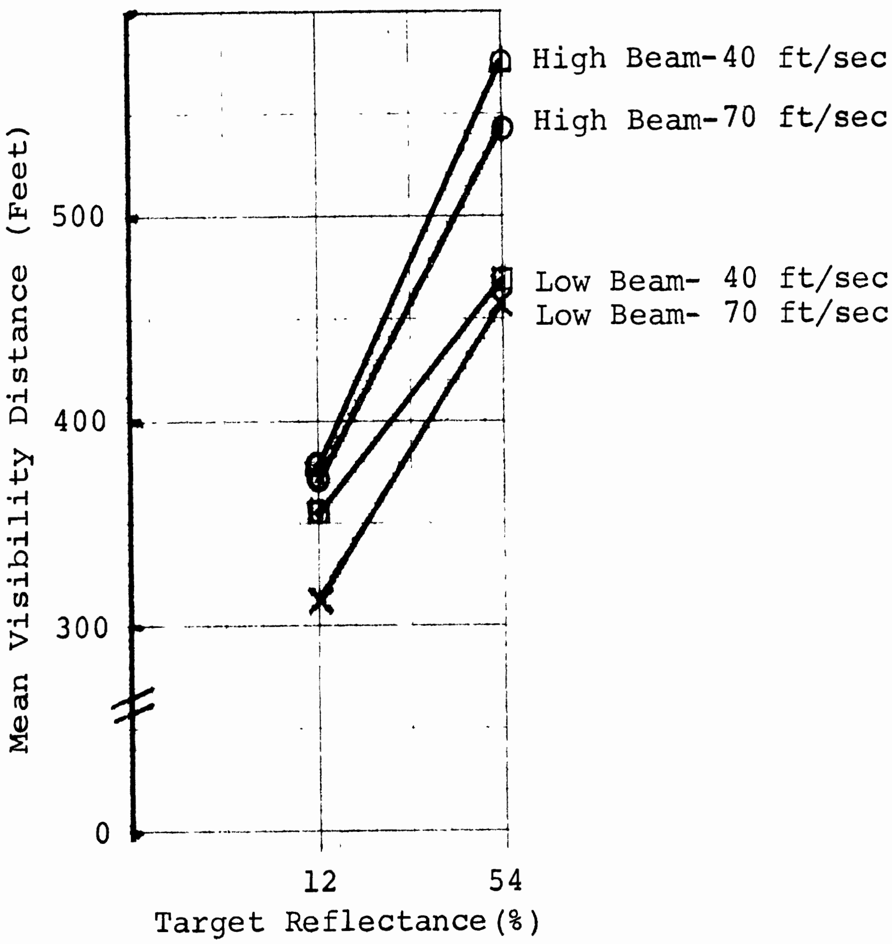


Figure 24. Visibility distance as a function of target reflectance, beam and vehicle speed. Four subjects, right hand targets only, in study 2.

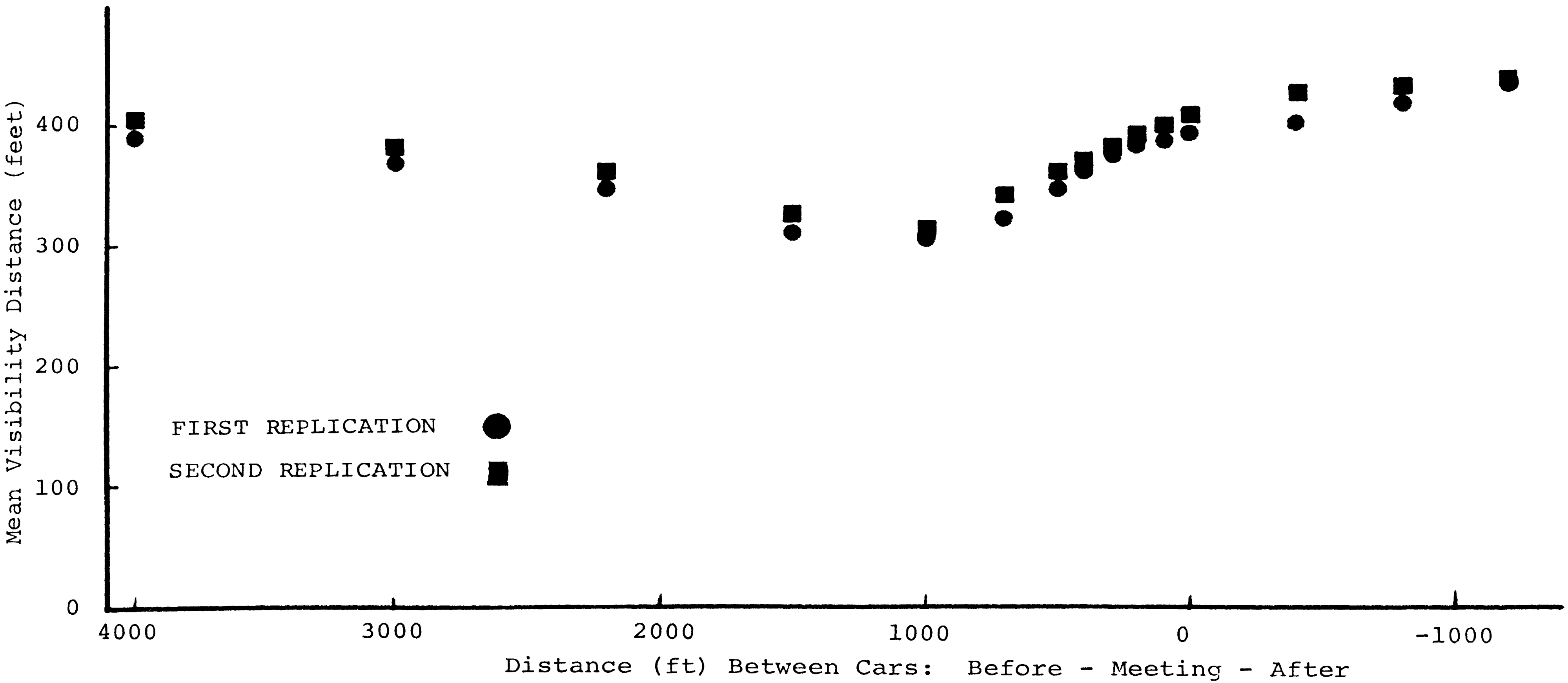


Figure 25. Comparison of the performance of the same four subjects exposed twice to the same experimental conditions, in study 2.

Because there were only four each of the collapsible type-1 and type-II targets and one of the type-III targets, the course layouts and procedures were modified to insure an adequate number of pre- and post-meeting point samples. A diagram of the course layout is given in Figure 26.

The side of the track on which the type-I targets were located used the same geometry as in studies 1 and 2, except there were only four targets and they were located in the center of the lane. Two start positions were used on the other side of the track (marked 1 and 2 with subscripts), each with its own "A" point. When starting from 1 the cars would meet at about X_1, and when starting from 2 the cars would meet at about X_2. In this way the same targets would give pre- and post-meet data on successive runs.

The type-III target was used at the same position as the type-II after they had been removed. It was first positioned at target station 1 until all necessary data had been collected, then moved to station 2 and so on.

In effect, three studies were run at one setting. For the type-I targets reflectivity was held at two levels (12% and 54%), target face in down and up vertical position (6 in., 18 in.), and beam at two levels (low, high). For both the type-II and type-III targets all factors were constant except headlamp beam, at two levels.

Because of the reduced number of targets, visibility distances were analyzed at ten longitudinal separations instead of fifteen. The new distances were 3000, 2200, 1500, 1000, 600, 400, 200, 0, -500, and -1000 feet.

Eight subjects participated in this study, being exposed to each combination of variables at least once. General procedure was identical to that used in previous studies except for the necessity of alternating start positions on the one side of the track.

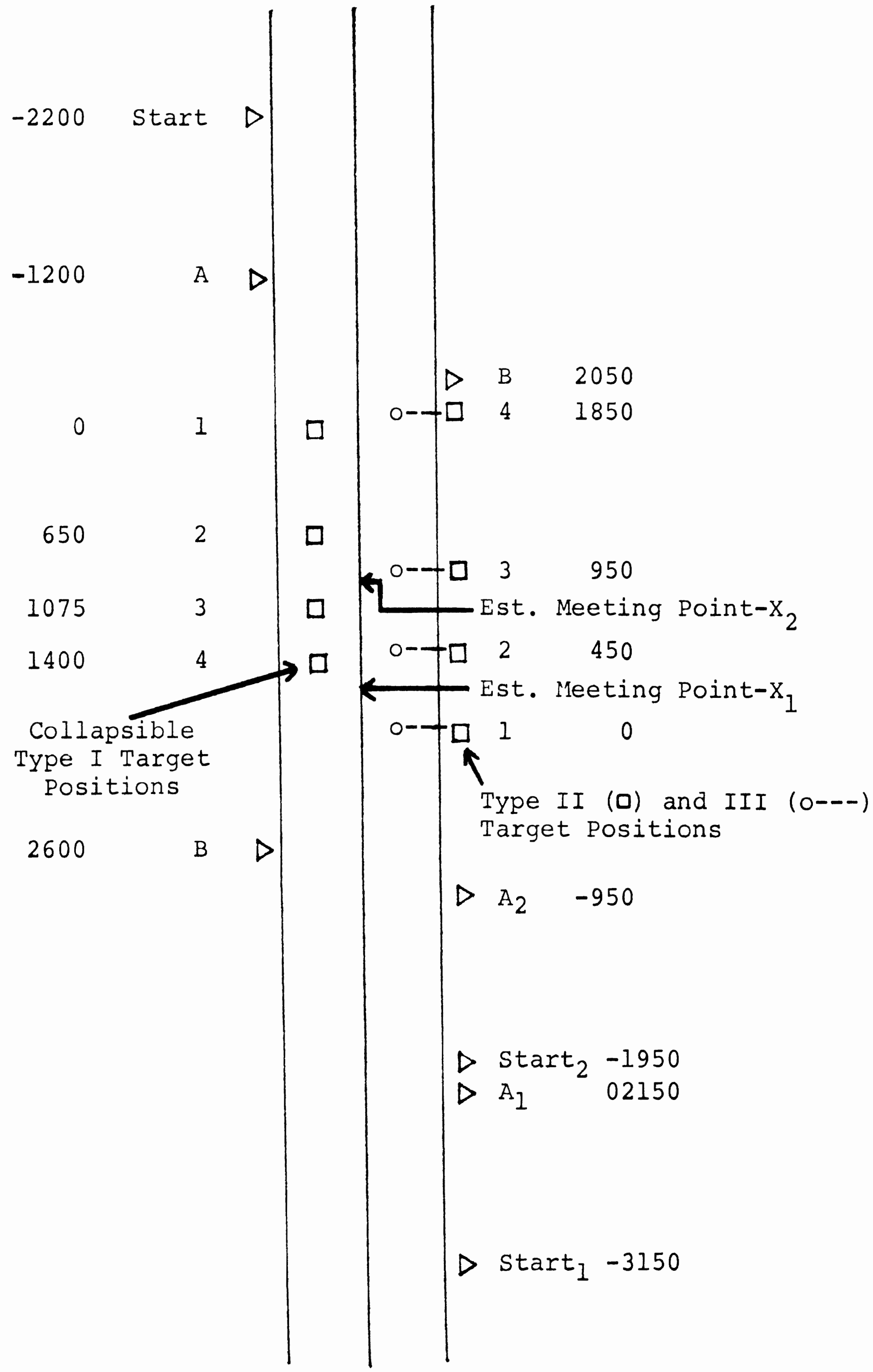


Figure 26. Diagram of course layout used in study 3. Dimensions shown are in feet referenced from the first target on either lane.

RESULTS: TYPE-I TARGETS

The analysis of variance for the type-I targets in this study is reproduced in Table 4. All main effects except beam and four interactions are significant at the 0.01 level. (The beam factor is not significant because of the interaction with separation distance.)

Plots of visibility distance for different beams as a function of longitudinal separation (Figure 27) show much the same pattern as study 1. The plots cross at a separation distance of about 1800 feet, the high beam giving better visibility distance under low- and no-glare conditions.

Figure 28 shows visibility distance as a function of target reflectance (12%, 54%), vertical position (down, up), and longitudinal separation for high and low beams. Visibility distances were greater for the down position at most longitudinal separations.

Target reflectance had the expected effect on visibility distance throughout the meeting, as also indicated in Figure 28.

Target reflectance interacted with vertical position so that, in the upper position there were no statistically significant differences in visibility distance regardless of reflectivity. There were differences in visibility distance as a function of reflectivity when targets were in the lower position, however. This also is illustrated in Figure 28.

RESULTS: TYPE-II TARGETS

The analysis of variance for the type-II targets is reproduced in Table 5. As each subject was exposed to each condition twice, replication is included as a factor (although it was not significant). Several other factors and interactions are significant.

The visibility distances for this type of target are much

TABLE 4. Analysis of Variance of Visibility Distance Data - Study 3, Type-I Targets in Center of Lane.

DIVISION OF VARIANCE

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	RATIO
E..............	637368.9	7	91052.69	
A..............	2125882.	9	236209.1	75.765**
AE..............	196413.3	63	3117.671	0.0
B..............	999876.7	1	999876.7	91.051**
BE..............	76870.13	7	10981.45	0.0
AB..............	66209.75	9	7356.637	4.4161**
ABE............	104949.3	63	1665.862	0.0
C..............	55978.41	1	55978.41	18.073**
CE..............	21681.25	7	3097.322	0.0
AC..............	45095.16	9	5010.570	3.3457**
ACE............	94350.50	63	1497.627	0.0
BC..............	37483.35	1	37483.35	14.365**
BCE............	18265.87	7	2609.411	0.0
ABC............	5440.633	9	604.5146	0.54268
ABCE..........	70178.13	63	1113.938	0.74463
D..............	25868.48	1	25868.48	2.2804
DE..............	79407.81	7	11343.97	0.0
AD..............	340176.9	9	37797.44	21.155**
ADE............	112559.3	63	1786.656	0.0
BD..............	271.5637	1	271.5637	0.12068
BDE............	15752.36	7	2250.337	0.0
ABD............	9754.176	9	1083.797	0.81755
ABDE..........	83517.13	63	1325.668	0.88616
CD..............	288.4995	1	288.4995	0.45059E-01
CDE............	44819.17	7	6402.738	0.0
ACD............	7449.891	9	827.7656	0.53426
ACDE..........	97610.44	63	1549.372	1.0357
BCD............	29.80066	1	29.80066	0.92327E-02
BCDE..........	22594.00	7	3227.714	2.1576
ABCD..........	6161.691	9	684.6323	0.45765
ABCDE..........	94246.00	63	1495.968	0.0
TOTAL	5496550.	639		

NUMBER OF REPLICATIONS 1

*p≤0.05

**p≤0.01

A - Longitudinal Separation Distance
B - Target Position
C - Target Reflectance
D - Beam
E - Subjects

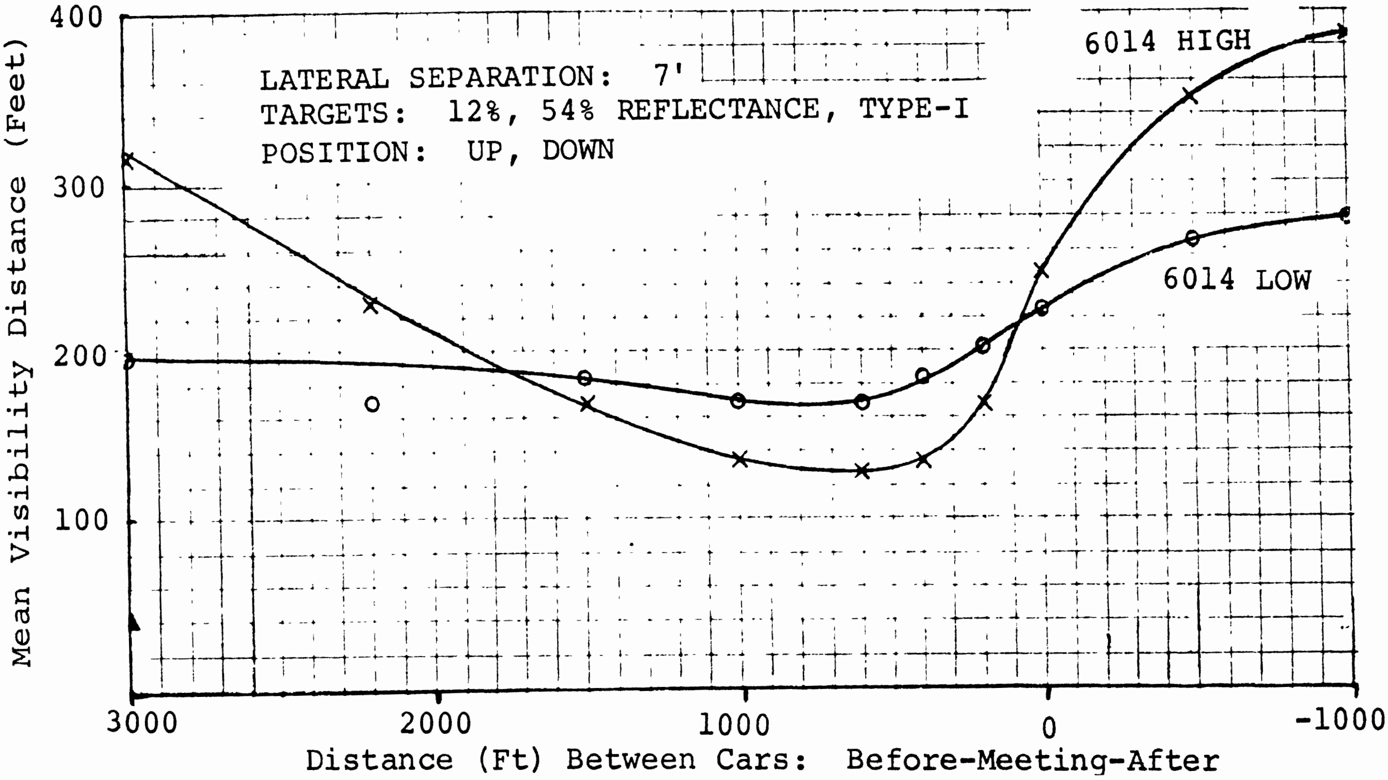


Figure 27. Visibility distance of Type-I targets in center of lane as a function of beam and longitudinal separation, in study 3, averaged over target reflectances and positions.

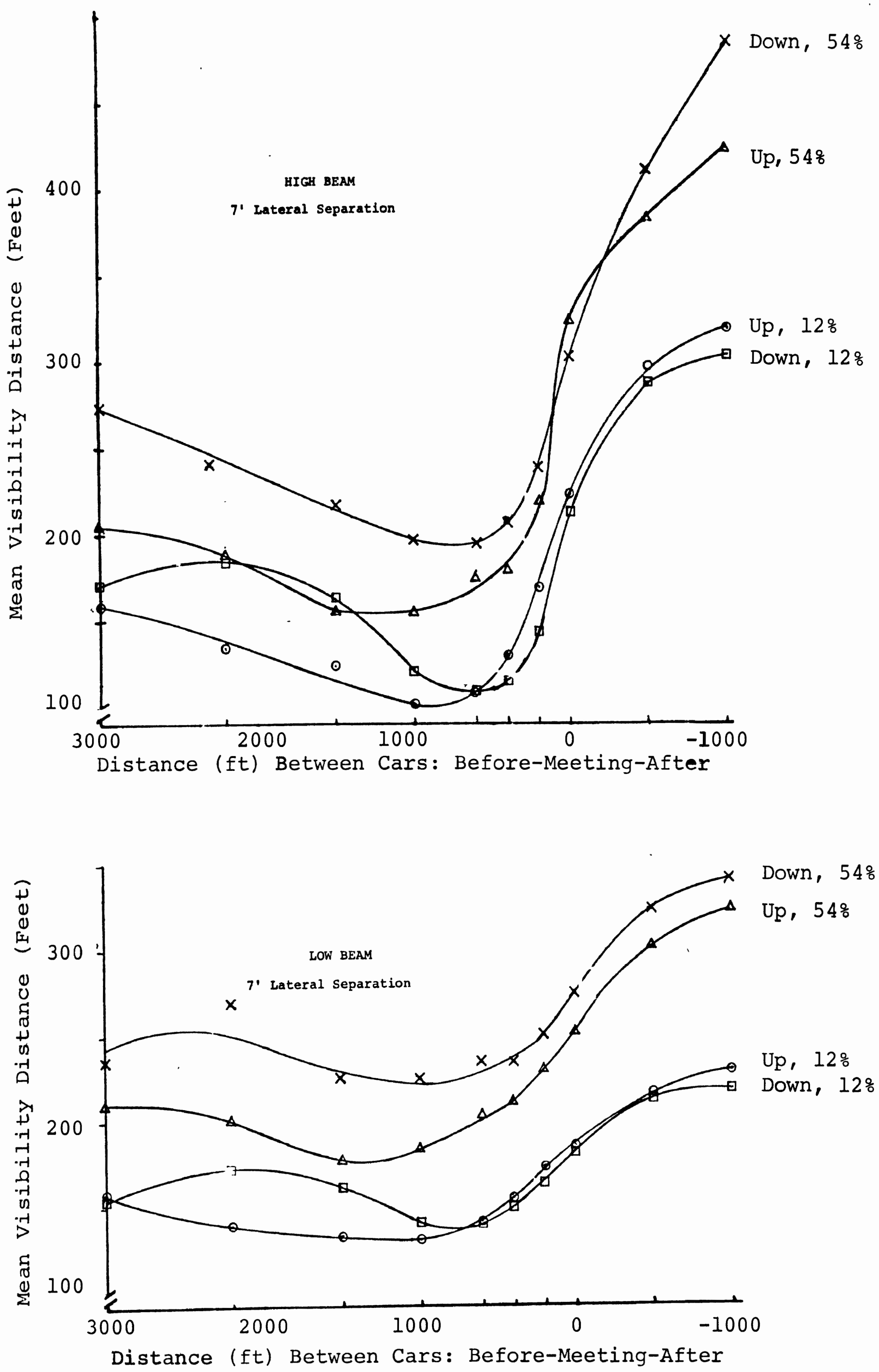


Figure 28. Visibility distance of Type-I targets in center of lane as a function of longitudinal separation, vertical position and target reflectivity for high and low beams, in study 3.

TABLE 5. Analysis of Variance of Visibility Distance Data - Study 3, Type-II Targets.

DIVISION OF VARIANCE

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	RATIO
D.............	0.1519950E 08	7	2171357.	
A..............	3976679.	9	441853.2	8.9377**
AD............	3114529.	63	49436.96	0.0
B..............	327340.0	1	327340.0	0.85748
BD............	2672222.	7	381746.0	0.0
AB............	973847.0	9	108205.2	2.5743*
ABD...........	2648070.	63	42032.86	2.3064
C..............	1354819.	1	1354819.	9.4078*
CD............	1008070.	7	144010.0	0.0
AC............	314181.1	9	34909.00	1.1908
ACD...........	1846897.	63	29315.32	1.6086
BC............	34821.61	1	34821.61	0.48628
BCD...........	501259.2	7	71608.44	3.9293
ABC...........	52980.76	9	5886.750	0.32302
ABCD..........	1148125.	63	18224.20	0.0
TOTAL	0.3517334E 08	319		

NUMBER OF REPLICATIONS 1

$^{*}p \leq 0.05$

$^{**}p \leq 0.01$

A - Longitudinal Separation Distance
B - Target Reflectance
C - Beam
D - Subjects

greater than for the type-I. As can be seen in Figure 29, the high beams always gave longer visibility distances under any glare condition.

RESULTS: TYPE-III TARGETS

The analysis of variance for the type-III targets is reproduced in Table 6. The only factors found to be significant are beam and the beam and separation distance interaction.

Visibility distances associated with the two beams for the type-III target are shown in Figure 30. The visibility distances at which the orientation of the letter "E" was identifiable are appreciably shorter than for the type-II target, but greater than the type-I target. The most interesting (and surprising) effect, however, was the similar performance of the low beam (with relatively little upward scatter of light) and high beam. It had been anticipated that the high beam would greatly outperform the low beam in this test. However, subjects did report a serious "back glare" from the target when highly illuminated, which made it more difficult to see. The target thus appears to be "self limiting" in that more light does not improve, and may actually impair its legibility.

STUDY 4

METHOD

The fourth study was a partial replication of study 3, using a greater lateral separation to simulate a divided highway. In this case the intended lateral separation was 36 feet. For this study the type-III target was not used. Except for the change in lateral separation, the course and general procedures were identical to those used in test 3. Eight subjects took part in the test.

RESULTS: TYPE-I TARGETS

The analysis of variance for the type-I targets is repro-

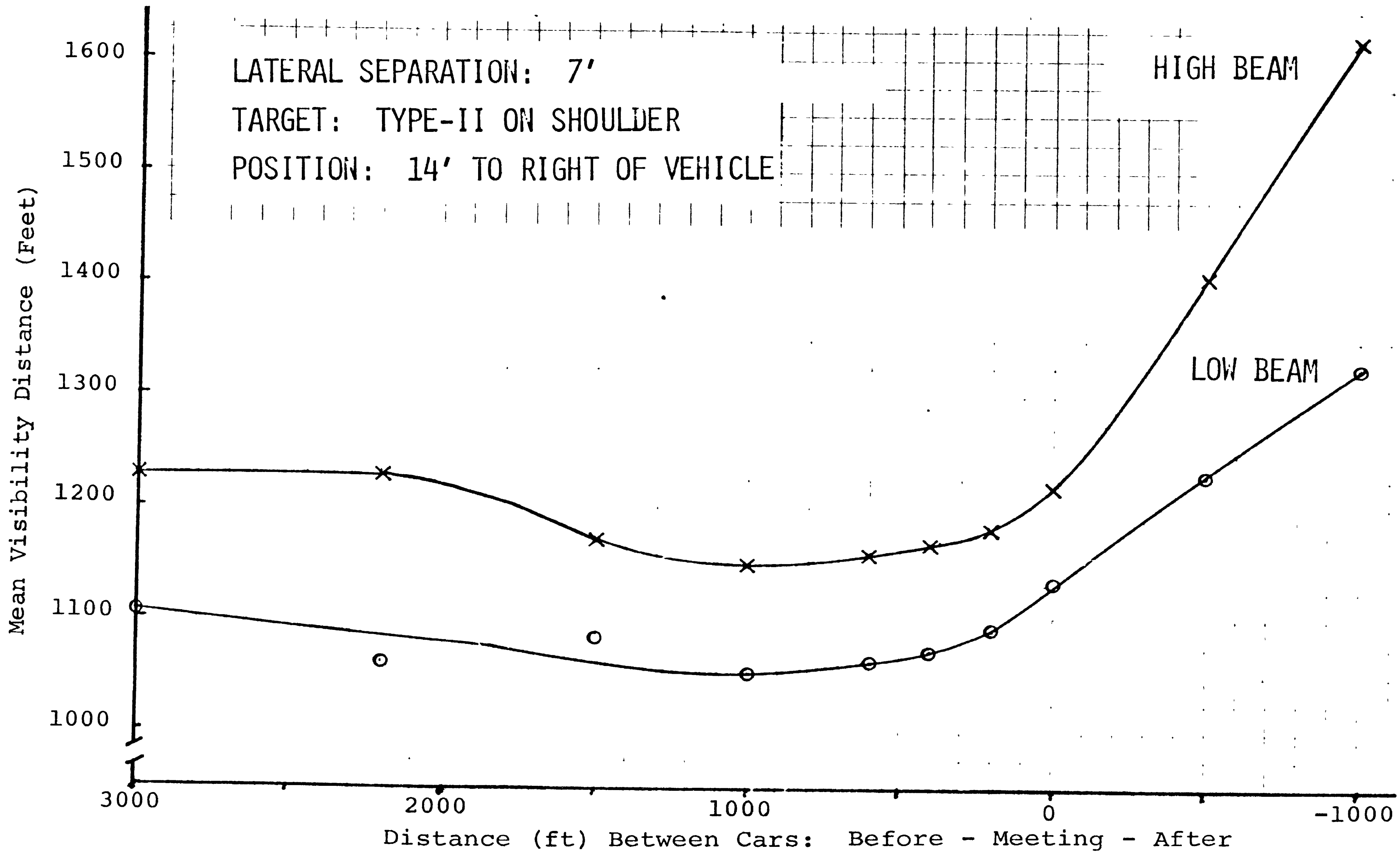


Figure 29: Visibility distance as a function of beam and longitudinal separation for type II targets in study 3.

TABLE 6. Analysis of Variance of Visibility Distance Data - Study 3, Type-III Target.

DIVISION OF VARIANCE

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	RATIO
C..............	1,712,715.	7	244673.6	
A..............	895893.4	9	99543.69	1.4423
AC.............	4,348001.	63	69015.88	1.0232
B..............	252062.7	1	252062.7	6.4135*
BC.............	275111.7	7	39301.68	0.58264
AB.............	1,421,227.	9	157914.1	2.3411*
ABC............	4249602.	63	67454.00	0.0
TOTAL	0.13,154,61E 08	159		

NUMBER OF REPLICATIONS 1

*$p \leq 0.05$

A - Longitudinal Separation Distance
B - Beam
C - Subjects

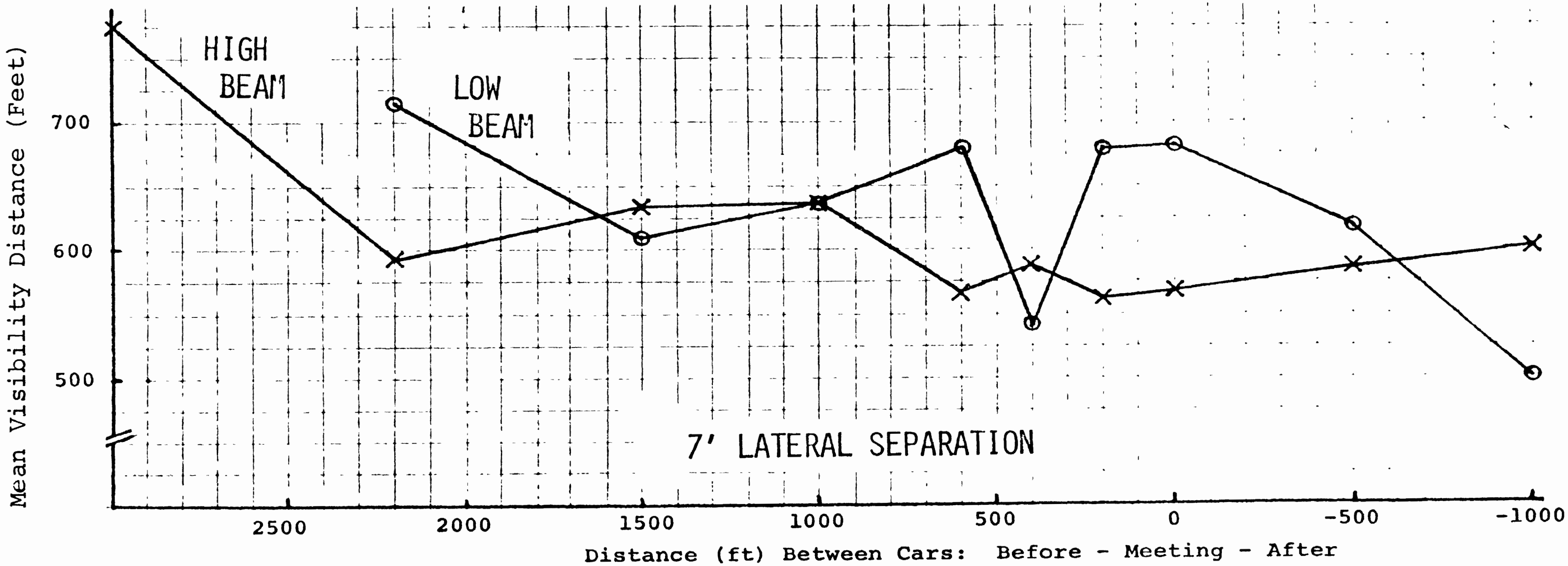


Figure 30. Visibility distances as a function of beam and longitudinal separation for Type-III targets in study 3.

duced in Table 7. All main effects except position are significant at the 0.01 level, as are several interactions.

Figure 31 shows visibility distance as a function of beam and longitudinal separation. This figure should be compared with Figure 27. It will be noted, as in study 2, the curves for the two beams do not cross, even with a moderate lateral separation.

Figure 32 shows visibility distance as a function of vertical position of the target and longitudinal separation. The performance for the two positions is identical except for about 500 feet before the meeting point where performance for the down position is somewhat (although statistically significant) poorer.

The visibility distances provided by headlamp beams depended on target reflectance (Figure 33) to a great (and statistically significant) extent, but very little on the vertical position of the target (Figure 34). The differences due to vertical target face positions within beams were not found to be significant.

RESULTS: TYPE-II TARGETS

The analysis of variance for the type-II target is reproduced in Table 8. Only the main effect for beams is significant.

Figure 35 shows the visibility distances provided by high and low beams as a function of longitudinal separation. This figure should be compared with Figure 29. The same pattern can be seen with the type-II target in either lateral separation condition. The high beam provides consistently better visibility regardless of glare condition and much improved visibility under no-glare conditions.

GLARE RESPONSE: STUDIES 1-4

METHOD

As already noted, the driver subjects were asked to respond in each run at the point where glare became intolerable. The

TABLE 7. Analysis of Variance of Visibility Distance Data - Study 4, Type-I Target in Center of Lane.

DIVISION OF VARIANCE

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	RATIO
E..............	3706470.	7	529495.7	
A..............	118032.1	9	13114.67	4.6507**
AE.............	177655.2	63	2819.925	0.0
B..............	2296526.	1	2296526.	70.523**
BE.............	227949.2	7	32564.18	0.0
AB.............	28128.14	9	3125.348	1.8974
ABE............	103769.3	63	1647.132	0.0
C..............	556.3569	1	556.3569	0.15394
CE.............	25298.47	7	3614.067	0.0
AC.............	34601.96	9	3844.662	4.0405
ACE............	59946.60	63	951.5332	0.0
BC.............	5037.145	1	5037.145	1.5379
BCE............	22928.02	7	3275.432	0.0
ABC............	14420.99	9	1602.332	1.1282
ABCE...........	89479.13	63	1420.303	1.3970
D..............	593170.4	1	593170.4	74.463**
DE.............	55761.52	7	7965.930	0.0
AD.............	75263.63	9	8362.625	6.8699**
ADE............	76689.31	63	1217.291	0.0
BD.............	342.3955	1	342.3955	0.10169
BDE............	23569.15	7	3367.021	0.0
ABD............	35856.11	9	3984.012	3.1224**
ABDE...........	80384.38	63	1275.942	1.2550
CD.............	14966.27	1	14966.27	6.4104*
CDE............	16342.75	7	2334.678	0.0
ACD............	8465.336	9	940.5928	0.57580
ACDE...........	102912.4	63	1633.530	1.6067
BCD............	17.85330	1	17.85330	0.10541E-01
BCDE...........	11856.30	7	1693.757	1.6659
ABCD...........	24010.21	9	2667.801	2.6240*
ABCDE..........	64052.73	63	1016.710	0.0
TOTAL	8094459.	639		

NUMBER OF REPLICATIONS 1

*$p \leq 0.05$

**$p \leq 0.01$

A - Longitudinal Separation Distance
B - Target Reflectance
C - Target Position
D - Beam
E - Subjects

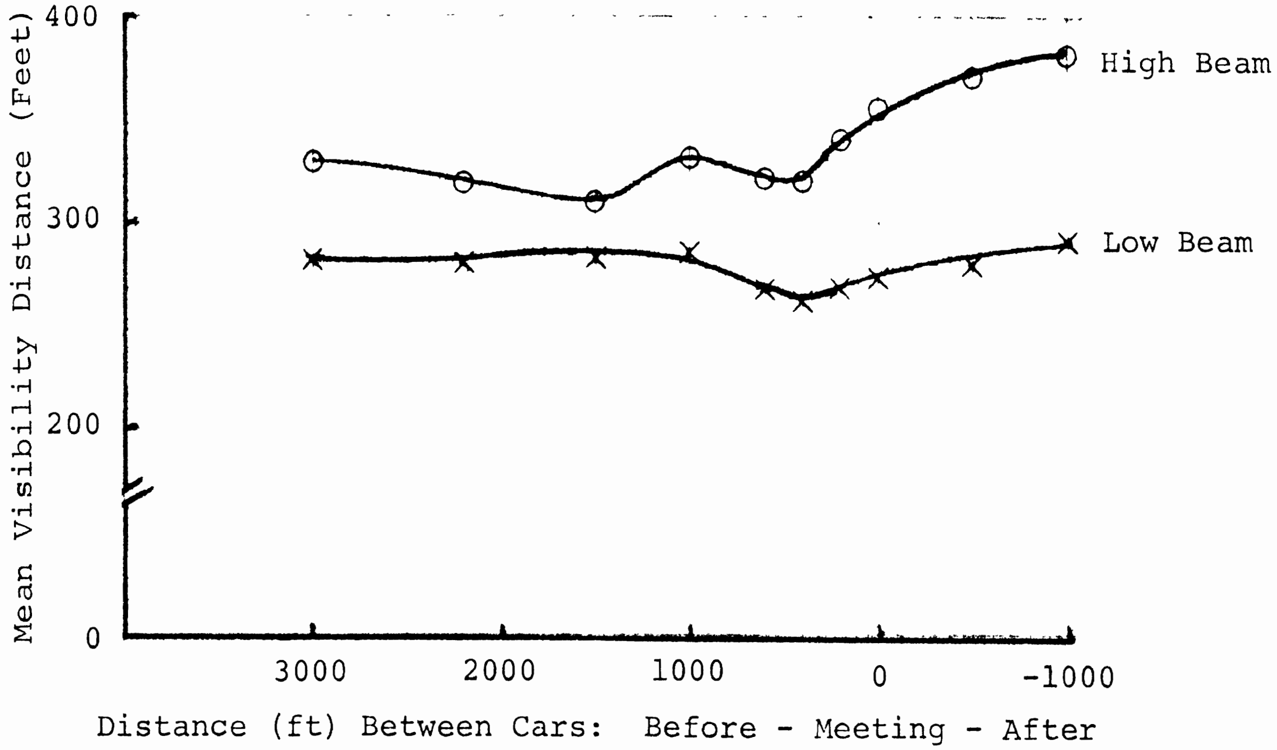


Figure 31. Visibility distances for high and low beams of type I targets in the center of the lane in study 4.

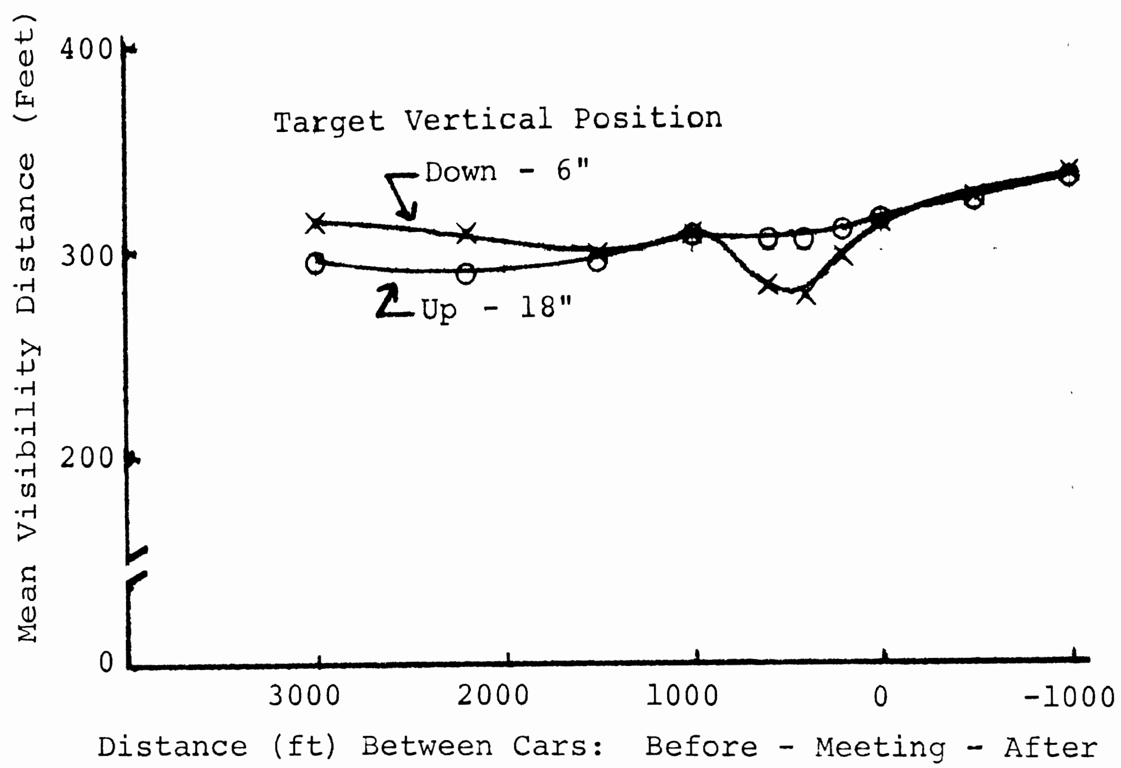


Figure 32. Visibility distances associated with vertical target position as a function of longitudinal separation for type I targets in the center of the lane in study 4, averaged over low and high beam data.

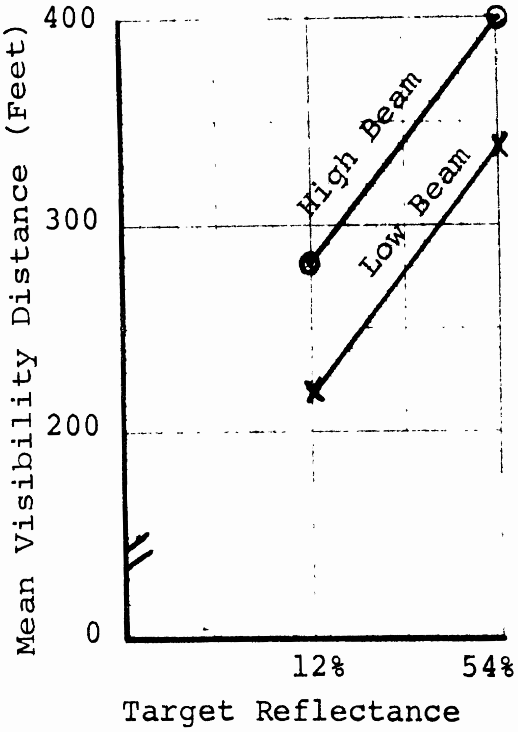


Figure 33. Visibility distances provided by high and low beams as a function of target reflectivity. Type-I targets in the center of the lane in study 4.

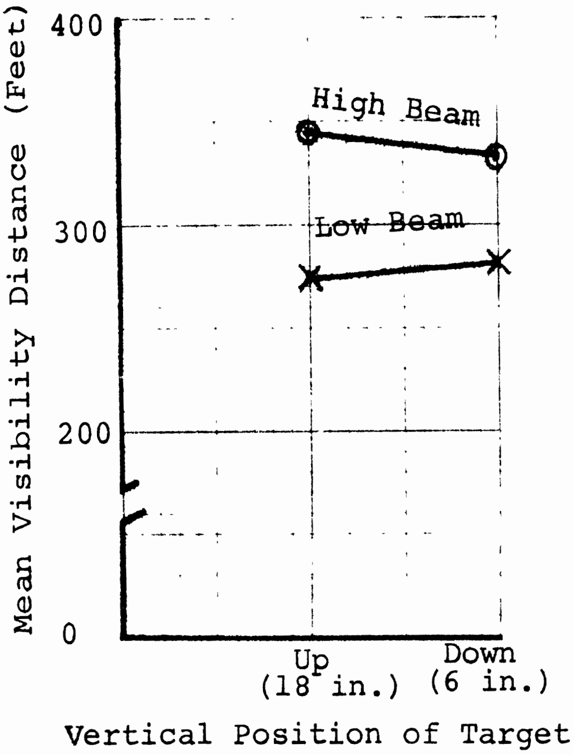


Figure 34. Visibility distances provided by high and low beams as a function of vertical position of the target. Type-I targets in the center of the lane in study 4.

TABLE 8. Analysis of Variance of Visibility Distance Data - Study 4, Type-II Target.

DIVISION OF VARIANCE

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FEEEDOM	MEAN SQUARES	RATIO
D.............	0.5768568E 08	7	8240811.	
A..............	334874.4	9	37208.26	1.4464
AD............	1620674.	63	25724.98	0.0
B..............	801595.6	1	801595.6	2.8900
BD............	1941595.	7	277370.7	0.0
AB............	275783.6	9	30642.62	1.2668
ABD...........	1523883.	63	24188.62	0.92162
C..............	3966901.	1	3966901.	15.419**
CD............	1800903.	7	257271.8	0.0
AC............	616228.9	9	68469.88	1.7677
ACD...........	24403-2.	63	38734.95	1.4759
BC............	5589.578	1	5589.578	0.39638E-01
BCD...........	987121.2	7	141017.3	5.3730
ABC...........	76441.13	9	8493.457	0.32361
ABCD..........	1653477.	63	26245.66	0.0
TOTAL	0.7573104E 08	319		

NUMBER OF REPLICATIONS 2

*$p \leq 0.05$

**$p \leq 0.01$

A - Longitudinal Separation Distance
B - Target Reflectance
C - Beam
D - Subjects

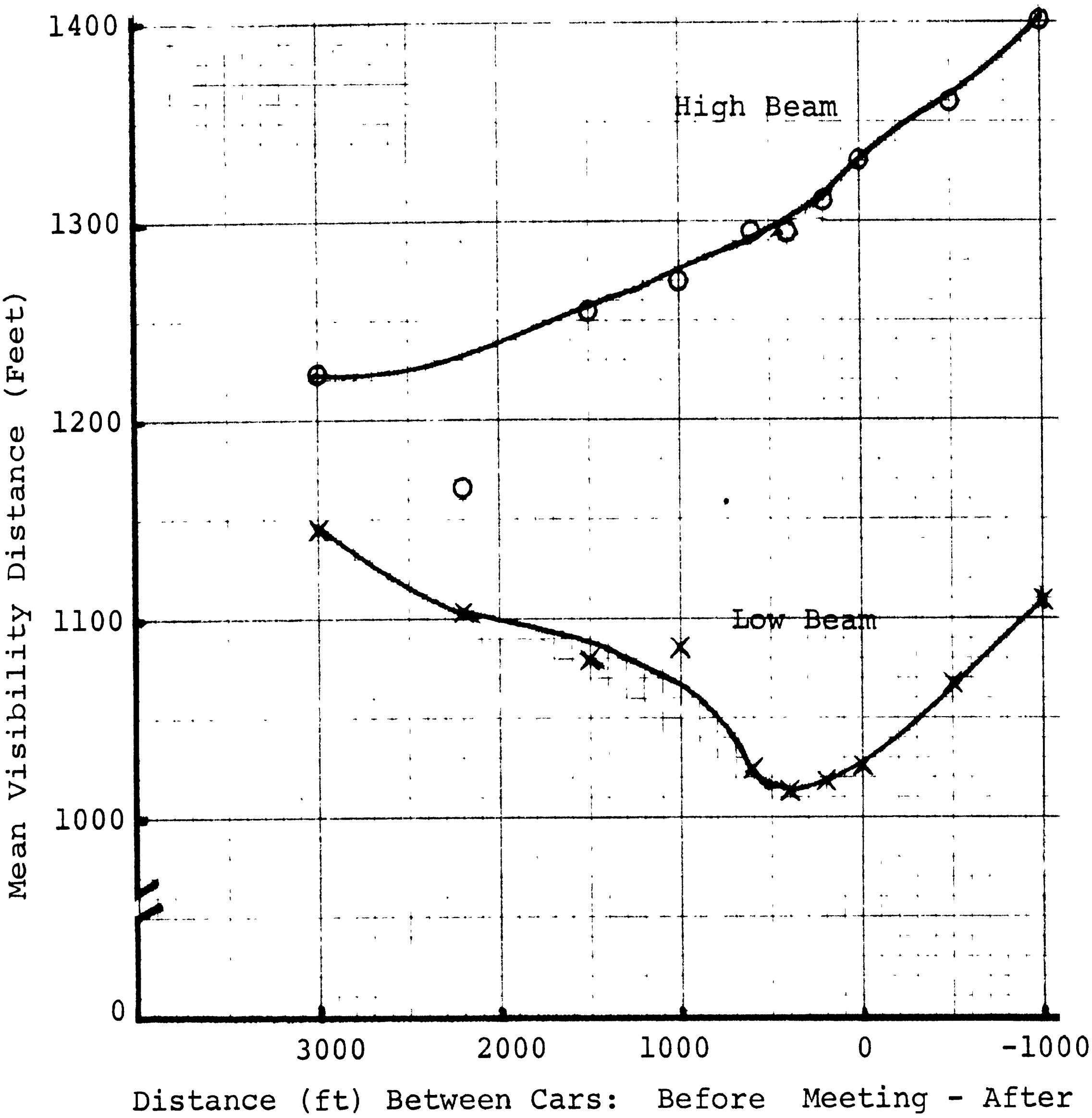


Figure 35. Visibility distances provided by high and low beams as a function of longitudinal separation, for type II targets in study 4.

number of trials on which subjects did and did not make discomfort glare responses for each combination of beam and lateral separation is shown in Table 9.

Because of the lack of independence between different trials involving the same subject and conditions, chi-square tests using the above frequencies were considered invalid. Therefore, the data were retabulated comparing the number of subjects who made one or more glare responses with those who made no glare responses. These are presented in Table 10.

RESULTS

A chi-square test was performed on the relationship between glare response and lateral separation. A χ^2 of 8.34 was obtained, which is significant at the 0.01 level. Another chi-square test was conducted between high and low beams. This yielded a χ^2 of 15.88, also significant at the 0.01 level.

Thus, it appears that significantly more subjects reported glare discomfort when the lateral separation was 7 feet than 36 feet, and more reported discomfort with high beams than with low.

The means and standard deviations of the longitudinal separation distances between cars when the glare response occurred are given in Table 11 for the various conditions. Trials on which no response occurred are not included.

An examination of Table 11 makes it apparent that response to glare is highly variable. The standard deviation of 900+ feet represents over 11 seconds at the closing speed of 80 fps.

STUDY 5

METHOD

This study was intended to provide information on the performance of headlamp systems not yet tested in this program. Thus, while the earlier studies had measured the visibility dis-

TABLE 9. Number of Trials in Which Subjects Did or Did Not Make a Discomfort Glare Response in Tests 1-4.

Beam	Lateral Separation					
	7'		36'		Overall	
	Response	No Response	Response	No Response	Response	No Response
High	213	235	30	194	243	429
Low	34	414	0	224	34	638
Total	247	649	30	418	277	1067

TABLE 10. Number of Subjects Who Did or Did Not Make a Discomfort Glare Response for Various Conditions in Studies 1-4.

Beam	Lateral Separation					
	7'		36'		Overall	
	Response	No Response	Response	No Response	Response	No Response
High	20	6	11	9	31	15
Low	10	16	0	20	10	36
Total	30	22	11	29	41	51

TABLE 11. Mean and Standard Deviation Longitudinal Separation Distance at Discomfort Glare Response in Studies 1-4.

Lateral Separation	Beam	No. of Trials	Longitudinal Separation Distance, Feet	
			$\overline{X}$	S. D.
7'	High	213	1193.68	919.02
	Low	34	797.25	542.35
36'	High	30	1495.99	753.01
	Low	0	-	-

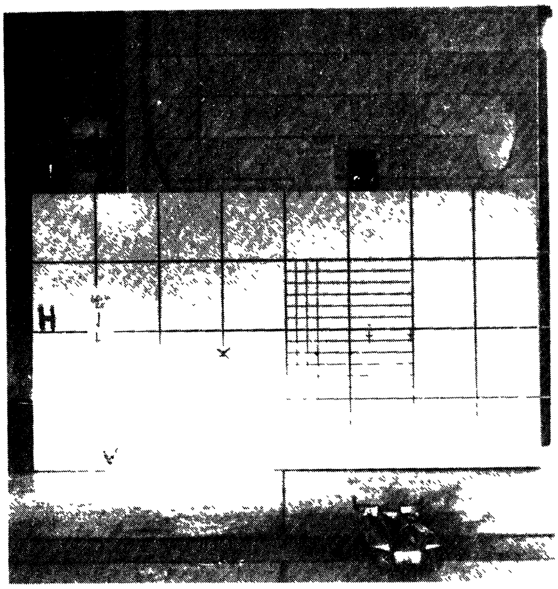
tances associated with a 6014 lamp, both high and low beam, this study measured visibility distances provided by eight different beam systems, including the two from the 6014.

Pictures of some of the beams used, as projected on a screen set 25 feet from the lamps, are shown in Figure 36. The 6014 and H_4 lamps (the H_4 is a quartz-halogen lamp, 7 in. in diameter, having a standard European beam pattern) were aimed on low beam as shown in Figure 36, and the high beam provided was accepted on an as-is basis. The proper high beam pattern would be centered on the H-V.

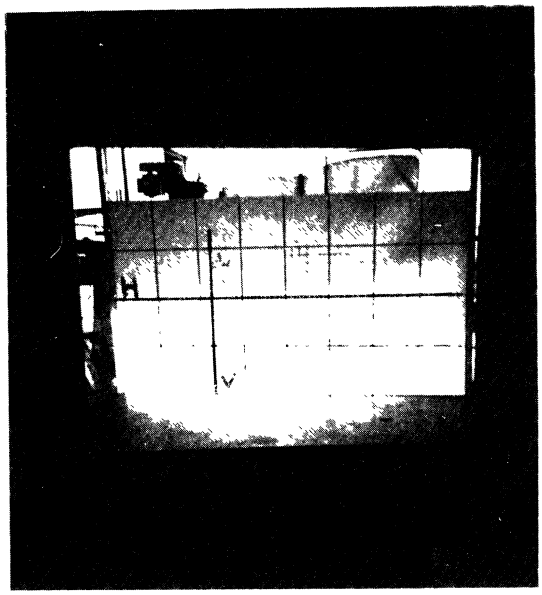
The following beam systems were employed:

1. Standard U.S. low beam provided by two 6014 units, as shown in Figure 36a.
2. Standard U.S. high beam provided by two 6014 units.
3. Same as beam 1, plus supplemental lamp Q4051 (Q4051 is a quartz-halogen sealed beam, 5 3/4" in diameter) aimed nominally, as shown in Figure 36c.
4. Same as 3, except the Q4051 was aimed 3/4° up and 1/2° left, as shown in Figure 36d.
5. Standard European low beam, provided by two H_4 units, aimed as shown in Figure 36b.
6. Standard European high beam, provided by two H_4 units.
7. Same as 6, but polarized. The subjects wore glasses polarized in the same plane as the lamps on their own car during these runs.
8. Same as beam 2, plus supplemental high beam lamp Type IV (type IV is an 85 watt, quartz-halogen, sealed beam unit, 5 3/4" in diameter), aimed with the maximum (≈ 100,000 cd) zone symmetrical about the vertical and 1/2° down. This beam was run under no-glare conditions only.

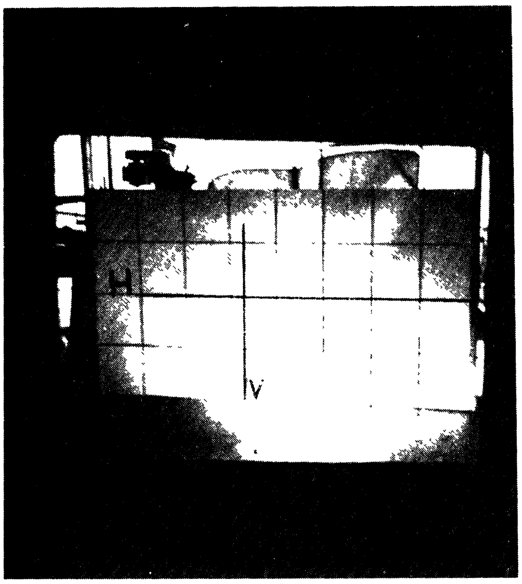
Procedural changes were instituted as well. These were mostly necessitated by a change in test site, which was the runway of a private airport. This facility provided



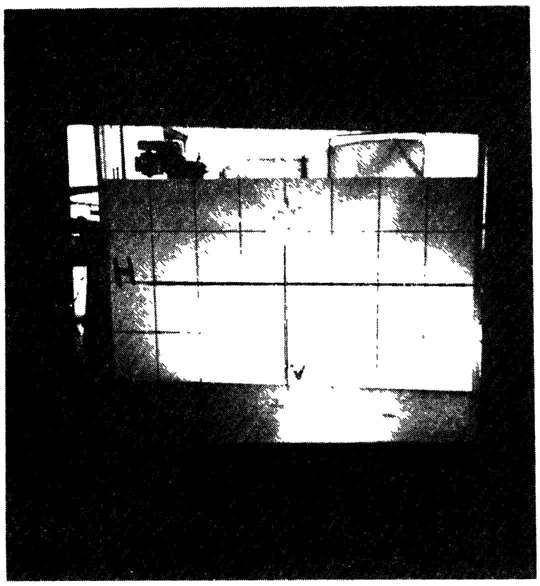
(a) 6014 low beam



(b) H_4 low beam



(c) Q4051 in nominal aim



(d) Q4051 in 1/2°L, 3/4° Up aim

Figure 36. Photographs of some beam patterns used in study 5.

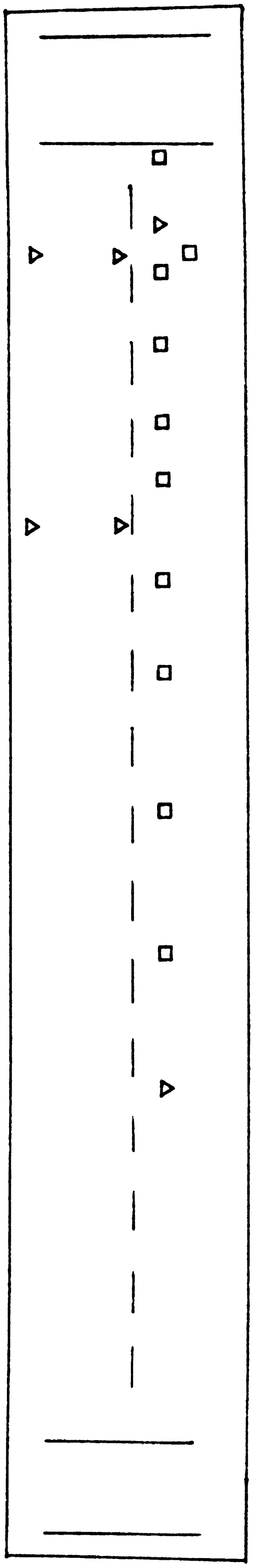
a good quality asphalt surface 60 feet wide, but only 3300 feet long. The limited distance available made it impossible to run two cars at the same time, so one served as a static glare source while the other was used to collect data in the same way as before.

The course layout is shown in Figure 37. A reference line down the center of the runway was used as the left lane marker and the drivers were instructed to try to keep their left wheels in contact with it.

Nine type-I targets were used, with 12% reflectance faces in the down position. These were set with their centers ten feet to the right of the reference line. The first type-I target encountered by the subject ("0" on the figure) was not counted in the data; its purpose being to alert the subjects and reduce the greater response variance that was found with the first target in studies 1 through 4. One type-II target was used, toward the end of the course as shown in Figure 37. It was set with its center 17' 5" to the right of the reference line. The start and end points were marked with cones and served the same function as the A and B points previously.

Four glare car positions marked with cones will be noted in Figure 37. When the glare car was positioned at 2300 feet, most of the targets were encountered post-meet, while most were encountered pre-meet when the glare car was positioned at 3300 feet. By combining data from both conditions an adequate sample of pre- and post-meet data could be accumulated. When the glare car was in position close to the reference line the lateral separation between glare and subject cars was about 7 feet. In the position close to the edge of the pavement lateral separation was about 30 feet.

The subject car began each run at the end of the runway nearest to the start point. As before, when each car (subject and glare) was ready the headlamps were switched off. The sub-



Target Type	Number	Feet Into Course
I	8	3200
End		3050
II & Glare car		3000
I	7	2950
I	6	2775
I	5	2600
I	4	2400
Glare car		2300
I	3	2150
I	2	1900
I	1	1600
I	0	1200
Start		900

Figure 37. Diagram of course used in study 5.

ject car's lamps were then switched on and the driver began to accelerate. If they were required, the glare car's lamps were switched on at the same time. The subjects drove through the course as before, slowed, turned and drove back to the start point for the next run.

The subjects' instruction (Appendix B) differed from those in earlier studies in two ways: first, since type-I and type-II targets were both on the course, they were asked to differentiate by pressing the switch twice for the type-II target and once for the type-I. Second, instead of indicating a "glare point," as in the earlier studies, a more comprehensive rating scheme was developed. The instructions for this procedure are reproduced in Appendix B. Basically, both driver and passenger subjects were asked to rate the headlamps' effectiveness and glare discomfort relative to the standard American low beam on a scale from 1 (very much less) to 7 (very much more). They did this for each run immediately after passing the line of targets. The ratings were written on pieces of paper and passed to the experimenter so that the judgments of one subject would not influence the other.

The independent variables in this study were: beam at seven levels under glare conditions, eight under no-glare conditions; longitudinal separation at ten levels (maximum was 1500 feet) and lateral separation at two levels. Twelve subjects were used. For each pair of subjects, each beam was run with the glare car in each of the four positions shown in Figure 36. A no-glare condition, in which the glare car kept its lamps off, was also included. The only exception to this pattern was beam 8, which was run under no-glare conditions only.

RESULTS: TYPE-I TARGETS

The results of the analysis of variance on visibility distance for type-I targets are shown in Table 12. All effects are

TABLE 12. Analysis of Variance of Visibility Distance Data - Study 5, Type-I Target, Glare Runs Only.

DIVISION OF VARIANCE

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	RATIO
D..............	3989510.	11	362682.7	
A..............	483798.7	9	53755.41	18.706**
AD.............	284494.6	99	2873.683	0.0
B..............	2222533.	6	370422.1	81.616**
BD.............	299548.1	66	4538.605	0.0
AB.............	901501.7	54	16694.47	8.1144**
ABD............	1222091.	594	2057.392	1.2158
C..............	330067.2	1	330067.2	64.965**
CD.............	55887.58	11	5080.687	0.0
AC.............	56249.36	9	6249.926	4.0701**
ACD............	152022.8	99	1535.584	0.90741
BC.............	134499.0	6	22416.50	6.5032**
BCD............	227500.9	66	3446.984	2.0369
ABC............	104161.6	54	1928.918	1.1398
ABCD...........	1005204.	594	1692.263	0.0
TOTAL	0.1146907E 08	1679		

NUMBER OF REPLICATIONS 1

*$p \leq 0.05$

**$p \leq 0.01$

A - Longitudinal Separation Distance
B - Beam
C - Lateral Separation Distance
D - Subjects

significant ($p \leq 0.01$), except the three factor interaction.

Figure 38 summarizes the visibility distances obtained with the various beams at the tested separation distances. Because the longest separation distances available at this site are appreciably shorter than at the site employed in the first four studies, differences among lamps are affected by glare effects until after the meeting point.

Figure 39 shows the effect of lateral separation on visibility distance for the various beams. Low glare systems (e.g., number 7, the polarized system) change least with changes in lateral separation, while high glare systems (e.g., number 6, H_4 high beam) change most.

The analysis of variance for the type-I target under no-glare conditions is reproduced in Table 13. Note that there is one other beam included in this analysis that was not present in Table 12. This is beam 8, which was run under no-glare conditions only. Differences among the eight targets are not significant but differences among beams are.

Figure 40 shows the mean visibility distances measured at each of the 8 targets for each of the beams under the no-glare conditions. Lacking glare, conditions should have been equal for each target and observed differences should represent experimental error. Indeed, there is no evidence of a systematic bias operating at any target and the traces approximate a straight line.

RESULTS: TYPE-II TARGETS

The analysis of variance of visibility distance associated with the type-II target under glare conditions is reproduced in Table 14. Because there was only one type-II target, the longitudinal separation factor is limited to two levels, the number of positions taken by the glare car. Other factors remain the same as for the type-I targets. Beam and lateral separation were the only significant effects. These results are plotted in Figure 41. In general beam 5 (low beam from H_4) produced

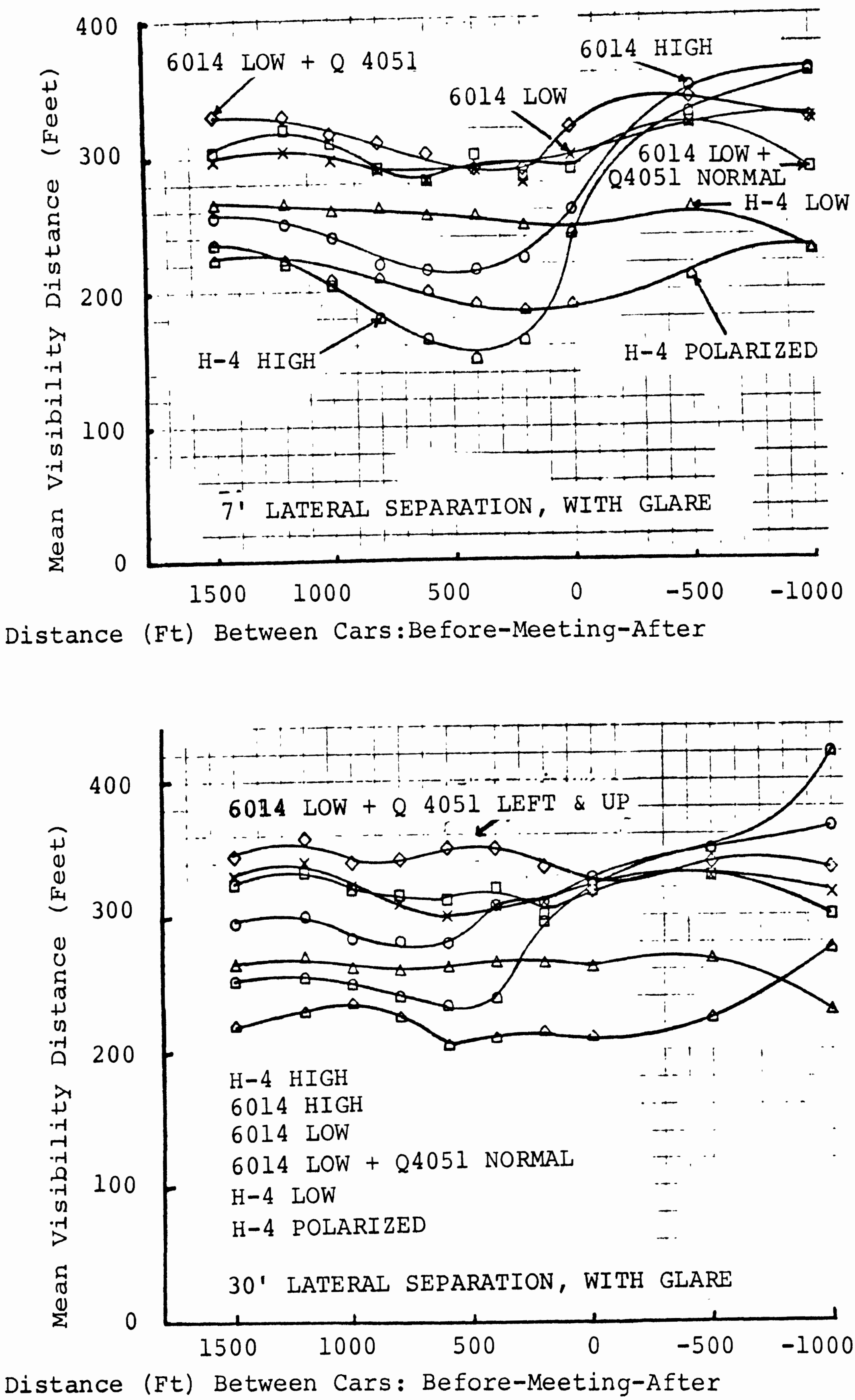


Figure 38. Mean visibility distances obtained with seven beams of 12% reflectance, Type-I targets, in down position, on the right side of lane under glare conditions for 7' and 30' lateral separations, in study 5.

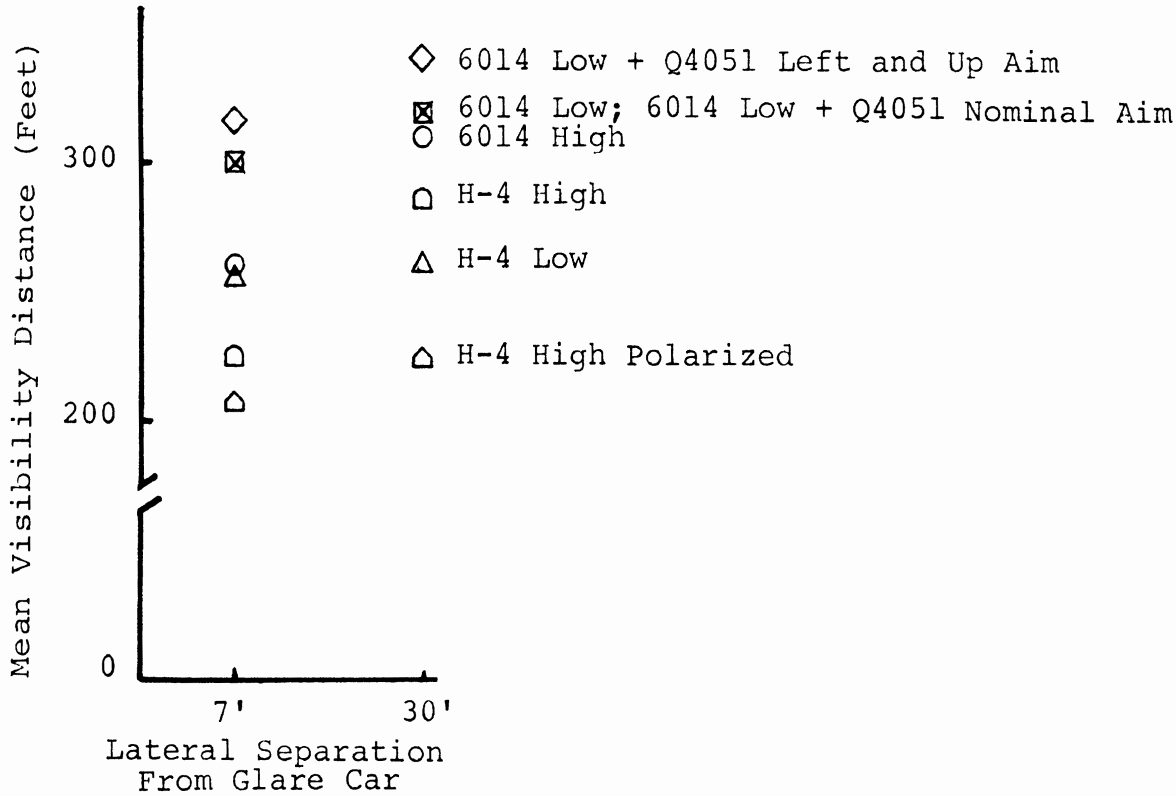


Figure 39. Mean visibility distances associated with seven different beams as a function of lateral separation from glare source, in study 5.

TABLE 13. Analysis of Variance of Visibility Distance Data - Study 5, Type-I Target, No-Glare Runs Only.

DIVISION OF VARIANCE

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	RATIO
C..............	2432463.	11	221133.0	
A..............	16694.43	7	2384.918	1.6828
AC.............	109128.1	77	1417.248	1.3192
B..............	2181979.	7	311711.2	51.356**
BC.............	467363.7	77	6069.656	5.6497
AB.............	39193.98	49	799.8770	0.74454
ABC............	579061.1	539	1074.325	0.0
TOTAL	5825883.	767		

NUMBER OF REPLICATIONS 1

---

*$p \leq 0.05$

**$p \leq 0.01$

A - Target
B - Beam
C - Subjects

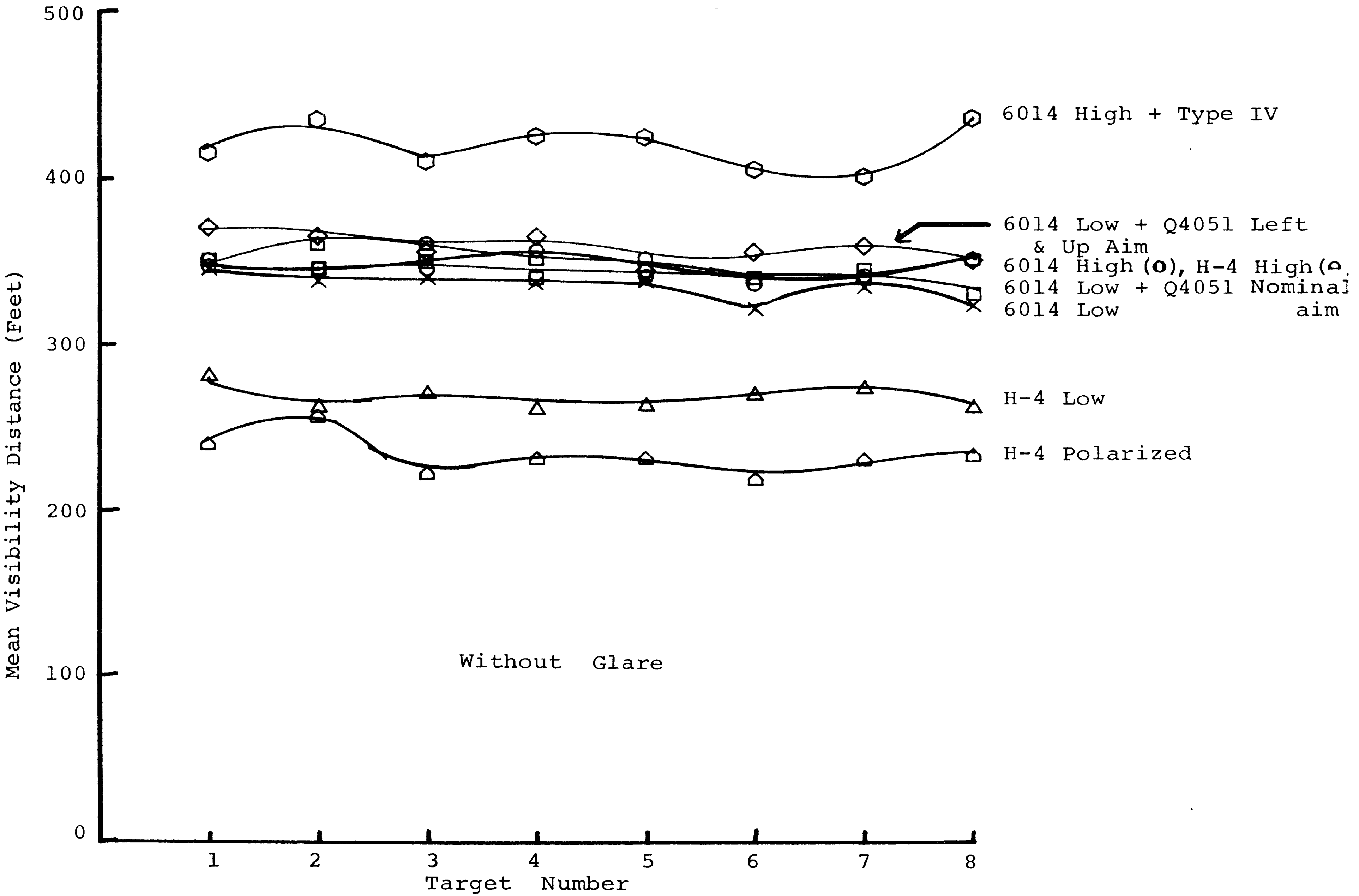


Figure 40. Visibility distances measured for eight type-I targets at 12% reflectance with various beams in no-glare condition, in study 5.

TABLE 14. Analysis of Variance of Visibility Distance Data - Study 5, Type-II Targets.

DIVISION OF VARIANCE

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	RATIO
D..............	0.2648150E 08	11	2407409.	
A..............	397.3682	1	397.3682	0.11332E-01
AD.............	385733.0	11	35066.63	0.0
B..............	4395972.	6	732662.0	14.597**
BD.............	3312739.	66	50193.01	0.0
AB.............	199502.4	6	33250.39	0.55485
ABD............	3955150.	66	59926.51	1.3473
C..............	290495.1	1	290495.1	34.778**
CD.............	91880.94	11	8352.813	0.0
AC.............	120423.2	1	120423.2	2.1170
ACD............	625710.7	11	56882.79	1.2788
BC.............	328116.9	6	54686.14	1.0664
BCD............	3384412.	66	51278.97	1.1529
ABC............	164777.7	6	27462.96	0.61742
ABCD...........	2935689.	66	44480.13	0.0
TOTAL	0.4667250E 08	335		

NUMBER OF REPLICATIONS 1

*$p \leq 0.05$

**$p \leq 0.01$

A - Longitudinal Separation Distance
B - Beam
C - Lateral Separation Distance
D - Subjects

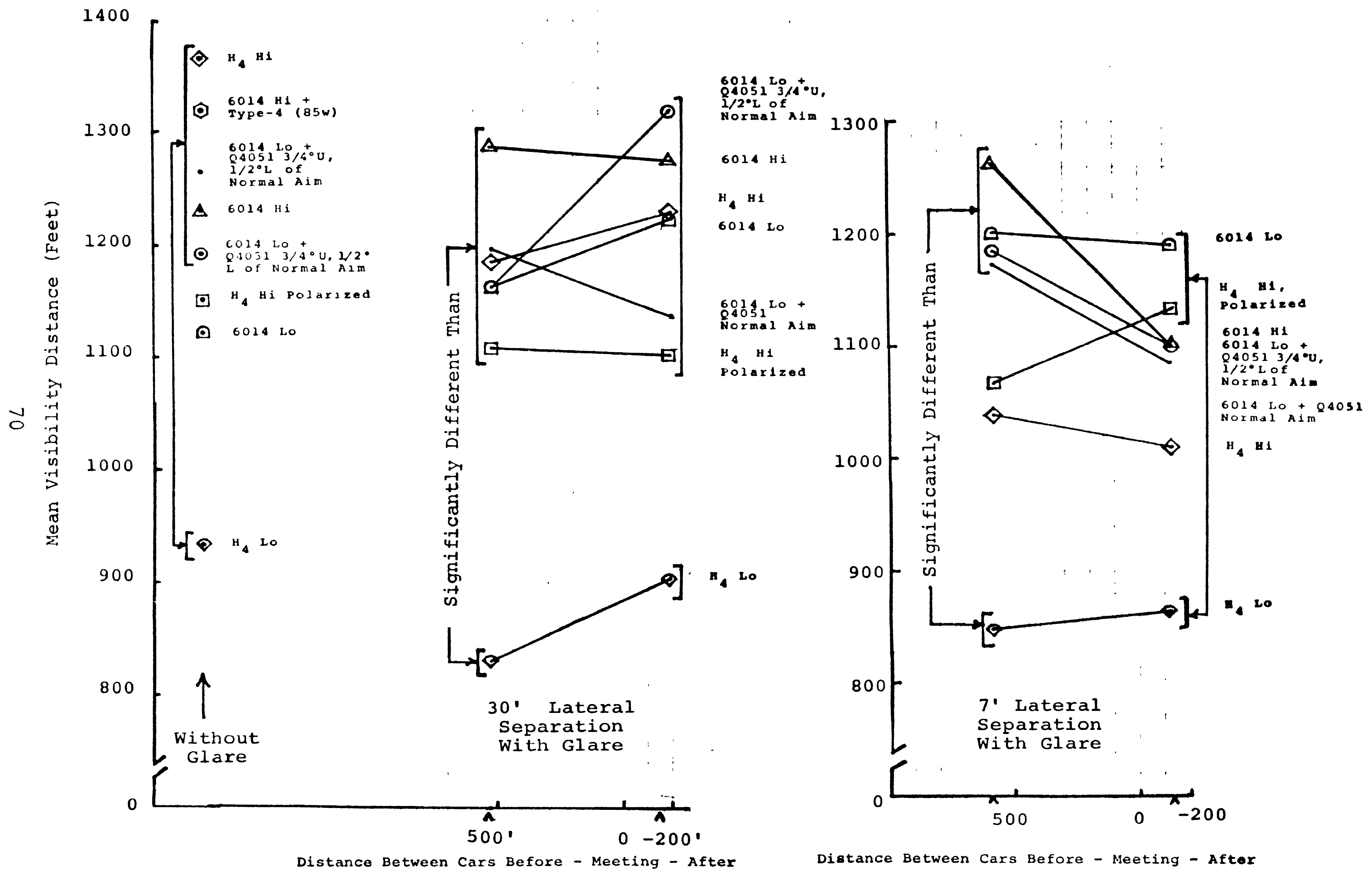


Figure 41. Visibility distance as a function of beam and lateral separation for the type-II target, in study 5.

significantly shorter visibility distances than any other tested. There were no other significant differences.

The analysis of variance for the type-II targets under no-glare conditions is reproduced in Table 15. Differences between beams are significant. As in the glare analysis, only beam 5 differed from the others.

RESULTS: ILLUMINATION AND GLARE RATINGS

The analyses of variance for ratings made of the effectiveness of illumination under opposed and unopposed conditions and glare discomfort are reproduced in Tables 16, 17 and 18 respectively. The data from one subject were lost, so the ratings are based on 11 subjects. Figure 42 shows mean rating given each beam configuration under each experimental condition. As would be expected, there is a high correlation between ratings of glare and visibility. The polarized system (number 7) was rated significantly poorer than any other in illumination under both opposed and unopposed conditions. For both levels of lateral separation, the 6014 and H_4 high beams were rated significantly more glaring.

RELIABILITY: COMPARISON OF STUDY 5 AND STUDIES 1 AND 2

The substantial change in methodology used in study 5 compared with those which had preceded it raises a question regarding repeatability of results. The 6014 lamps were used in study 5 in part to provide an answer to this question.

Figures 43 and 44 compare visibility distances measured in studies 1 and 5 (7-foot lateral separation) for the 6014 low and high beams for a particular set of target conditions repeated in both studies. The same data from studies 2 and 5 (36- and 30-foot lateral separation, respectively) are reproduced in Figures 45 and 46.

An examination of Figures 43-46 will reveal that the shapes of the curves compare well, and that minima occur at the same longitudinal separation. However, particularly in the case of the low beams, there is a consistant visibility distance discrepancy

TABLE 15. Analysis of Variance of Visibility Distance Data - Study 5, Type-II Target, No-Glare Runs Only

DIVISION OF VARIANCE

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	RATIO
B..............	0.1007630E 08	11	916027.7	
A..............	1470232.	7	210033.1	3.9834**
AB.............	4059965.	77	52726.82	0.0
TOTAL	0.1560650E 08	95		

NUMBER OF REPLICATIONS 1

*p≤0.05
**p≤0.01

A - Beam
B - Subjects

TABLE 16. Analysis of Variance of Ratings of Illumination Effectiveness of Beams - Study 5, Glare Runs.

DIVISION OF VARIANCE

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	RATIO
D..............	142.2727	10	14.22727	
A..............	199.8052	6	33.30086	18.431**
AD.............	108.4091	60	1.806818	0.0
B..............	0.3246753	1	0.3246753	0.21097
BD.............	15.38961	10	1.538960	0.0
AB.............	8.493506	6	1.415584	1.8753
ABD............	45.29221	60	0.7548701	0.57177
C..............	5.727272	1	5.727272	4.7779
CD.............	11.98701	10	1.198701	0.0
AC.............	4.818181	6	0.8030301	1.1481
ACD............	41.96753	60	0.6994588	0.52980
BC.............	4.688312	1	4.688312	3.1806
BCD............	14.74026	10	1.474026	1.1165
ABC............	2.857142	6	0.4761904	0.36069
ABCD...........	79.21428	60	1.320237	0.0
TOTAL	685.9868	307		

NUMBER OF REPLICATIONS 1

*p≤0.05
**p≤0.01

A - Lamp
B - Lateral Separation Distance
C - Longitudinal Separation Distance
D - Subjects

TABLE 17. Analysis of Variance of Ratings of Illumination Effectiveness of Beams - Study 5, No-Glare Runs Only.

DIVISION OF VARIANCE

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	RATIO
B..............	18.36363	10	1.836363	
A..............	117.5623	7	16.79460	14.093**
AB.............	83.27272	70	1.189610	0.0
TOTAL	218.9886	87		

NUMBER OF REPLICATIONS 1

---

*p≤0.05
**p≤0.01

A - Lamp
B - Subjects

TABLE 18. Analysis of Variance of Ratings of Discomfort Glare - Study 5.

DIVISION OF VARIANCE

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	RATIO
D..............	96.96103	10	9.696102	
A..............	486.4480	6	81.07466	45.139**
AD.............	107.7662	60	1.796103	0.0
B..............	15.45779	1	15.45779	10.156**
BD.............	15.22078	10	1.522078	0.0
AB.............	3.383117	6	0.5638528	0.52299
ABD............	64.68831	60	1.078138	1.2746
C..............	0.2629870	1	0.2629870	0.28805
CD.............	9.129869	10	0.9129869	0.0
AC.............	5.941558	6	0.9902596	1.4346
ACD............	41.41557	60	0.6902595	0.81602
BC.............	0.3246753E 02	1	0.3246753E-02	0.39370E 02
BCD............	8.246753	10	0.8246753	0.97492
ABC............	4.746753	6	0.7911254	0.93526
ABCD...........	50.75323	60	0.8458872	0.0
TOTAL	910.4250	307		

NUMBER OF REPLICATIONS 1

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*p≤0.05
**p≤0.01

A - Lamp
B - Lateral Separation Distance
C - Longitudinal Separation Distance
D - Subjects

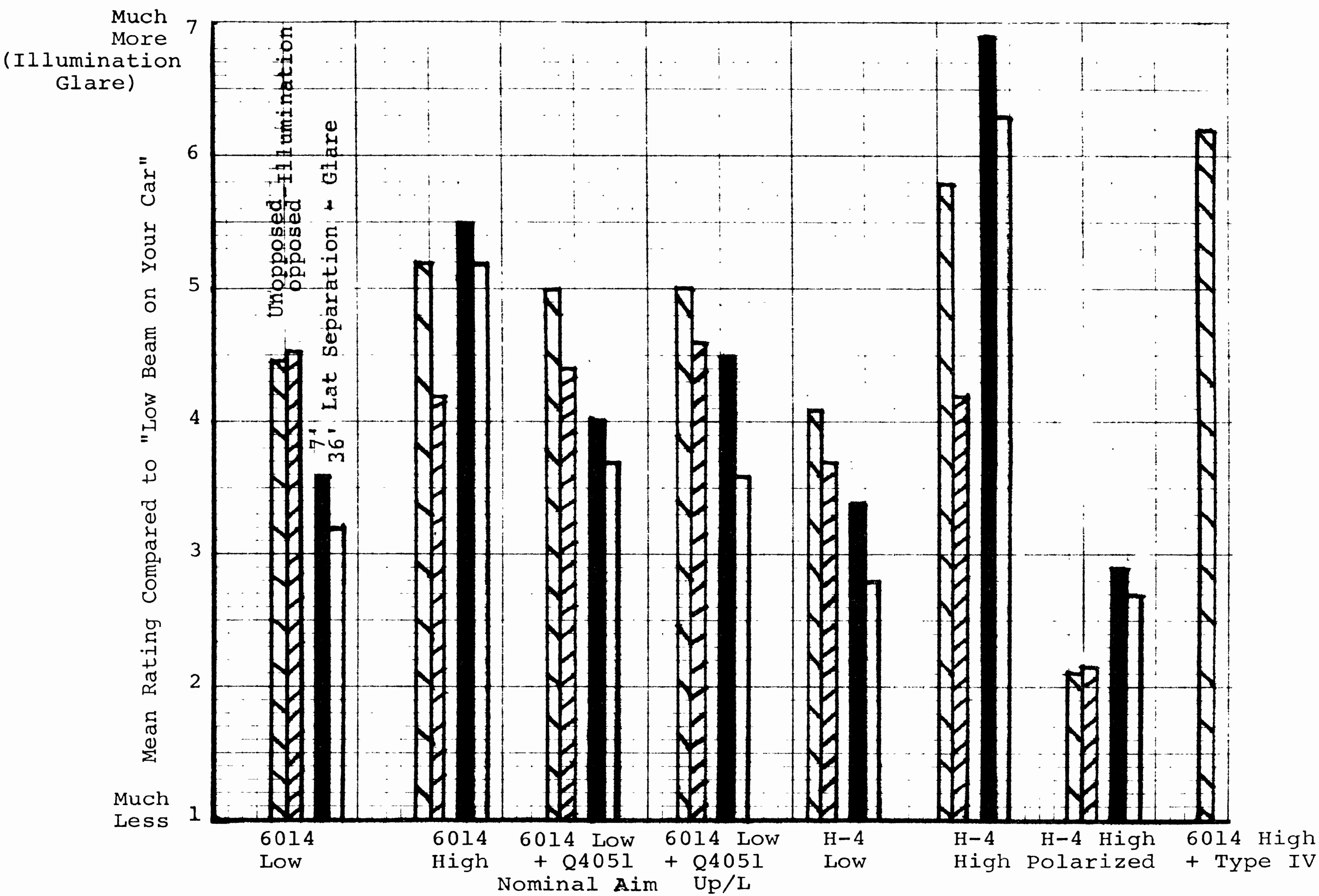

Figure 42. Mean ratings, relative to low beam, of opposed and unopposed illumination, and glare at 7' and 36' lateral vehicle separation distances in study 5.

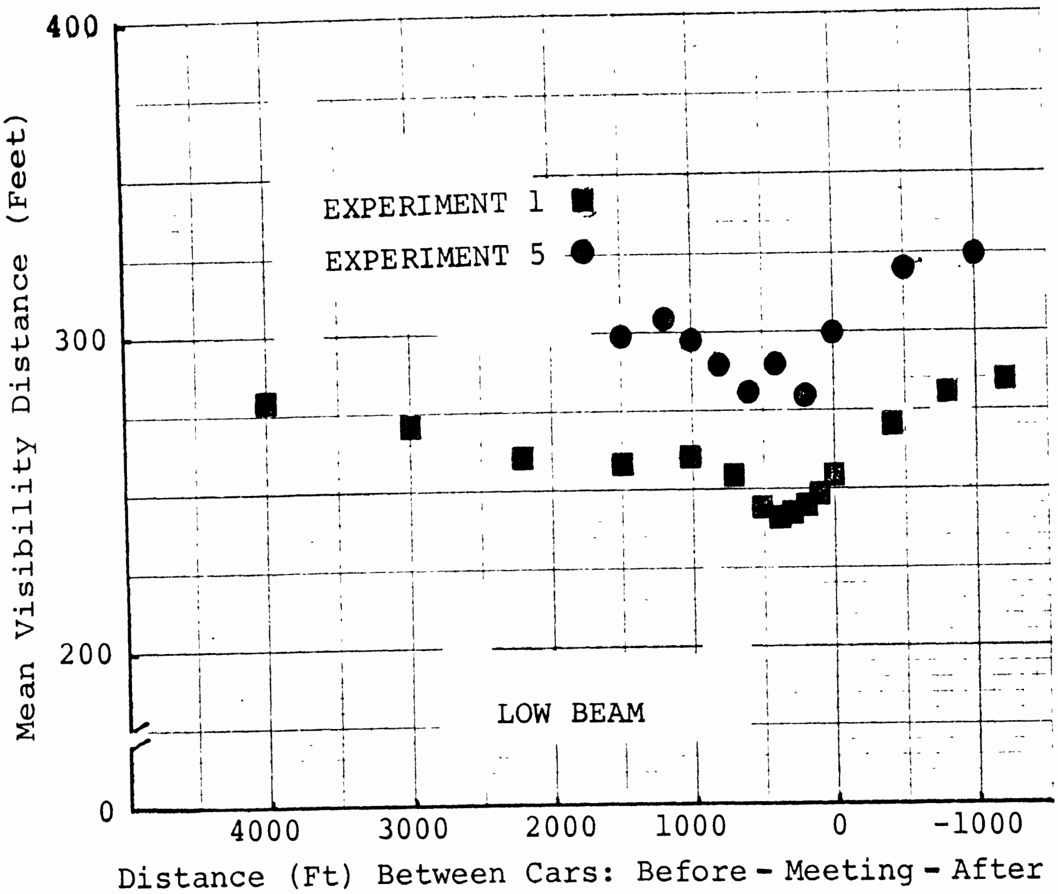

Figure 43. Comparison of visibility distance from studies 1 and 5. Low beam, seven foot lateral separation, target on right side, down position, 12% reflectance.

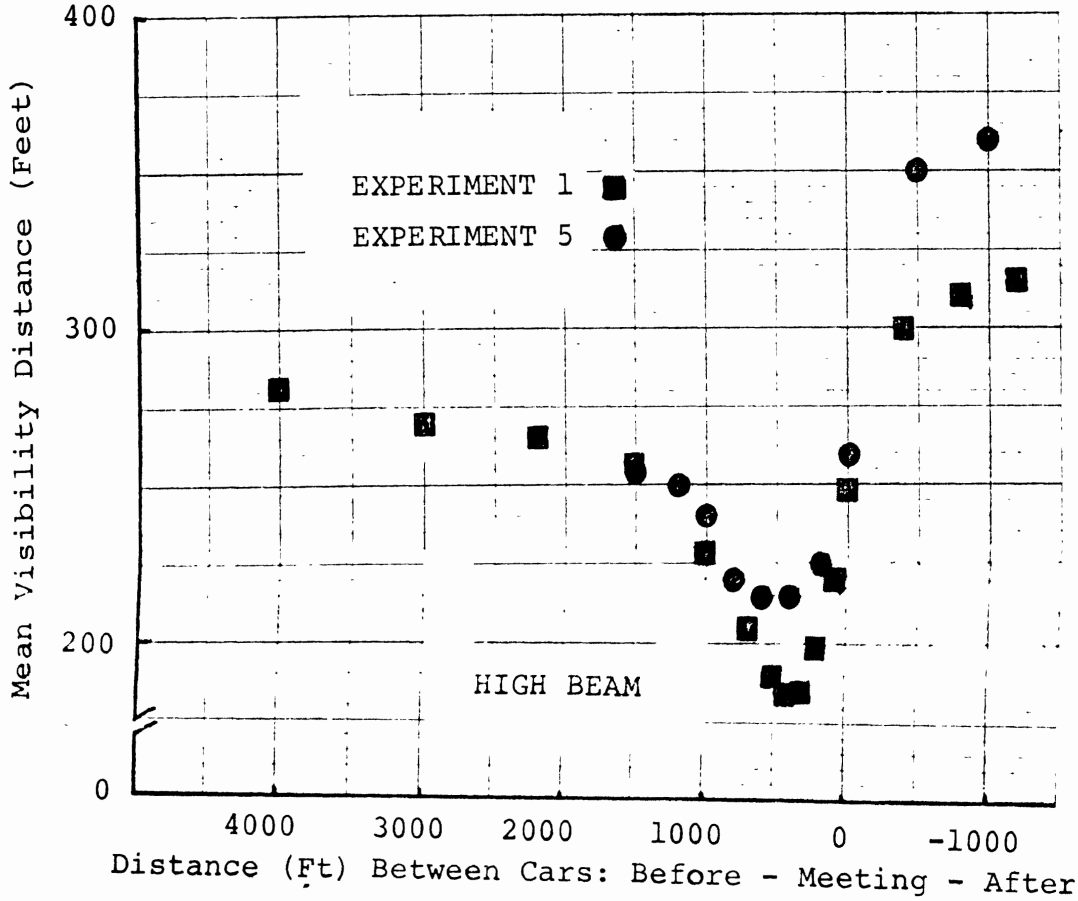

Figure 44. Comparison of visibility distances from studies 1 and 5. High beam, seven foot lateral separation target on right side, down position, 12% reflectance.

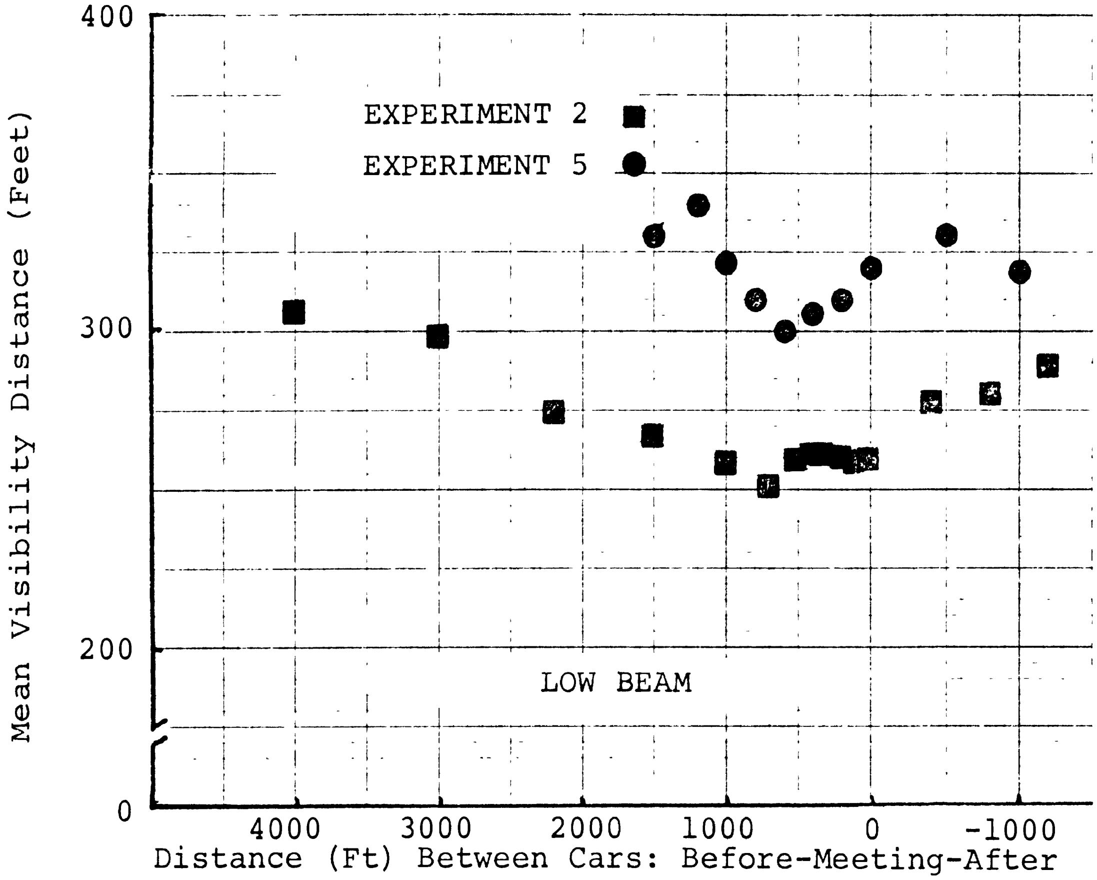

Figure 45. Comparison of visibility distances from studies 2 and 5. Low beam, 30-36 foot lateral separation, target on right side, down position, 12% reflectance.

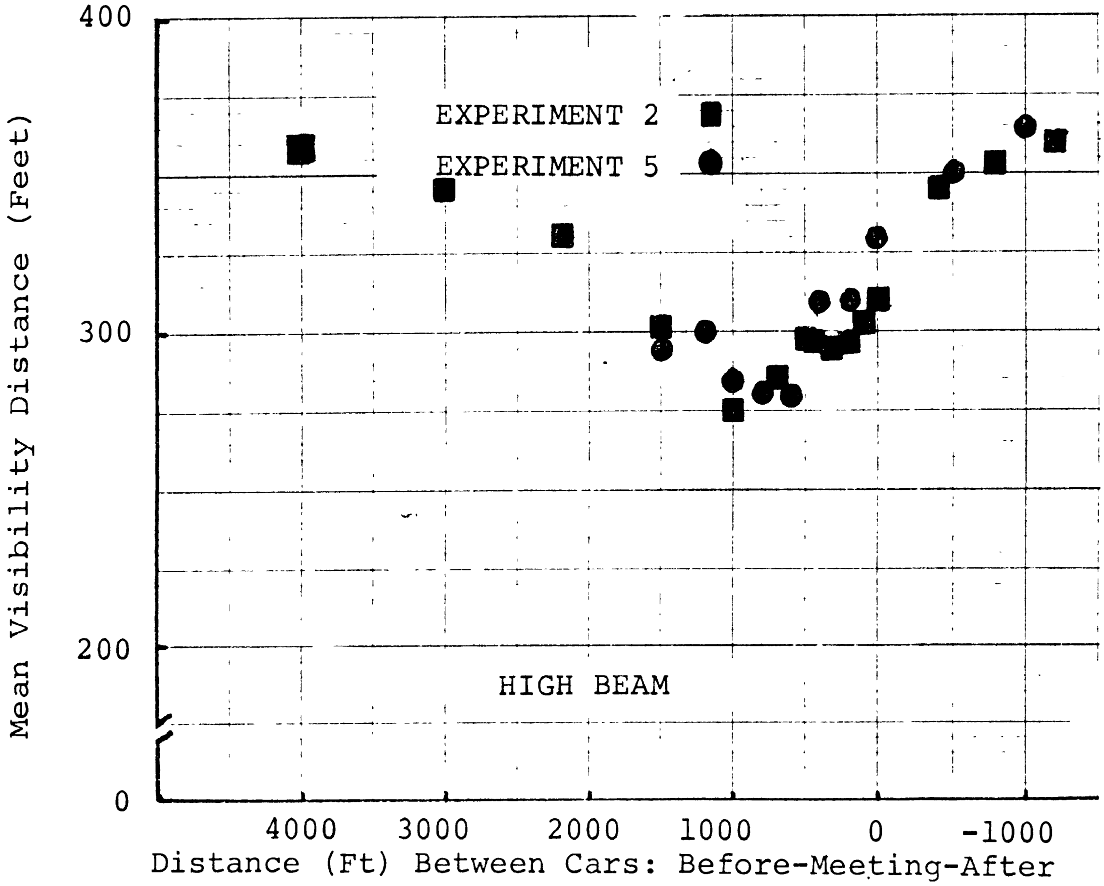

Figure 46. Comparison of visibility distances from studies 2 and 5. High beam, 30-36 foot lateral separation, target on right side, down position, 12% reflectance.

of about 10-15%, the longer visibility distances being obtained in study 5. This discrepancy seems less true in the case of the high beams, particularly at the 30-36 foot lateral separations.

The difference observed in this comparison is greater than that found in the reliability test run as part of study 2, although perhaps it is not large when considered in the context of the methodological differences. Still, it would be useful to know precisely why the difference occurred.

The consistency of the visibility distance difference, especially in the case of the low beams, implies that it does not result from random error. There are a number of possible reasons for such a difference to occur, but the fact that it was more pronounced in the case of the low beam suggests an aim problem. The aim of all lamps was checked mechanically prior to each night's testing. However, substantial changes in the beam direction are possible that could not be detected mechanically (Olson and Mortimer, 1973). Aim changes would be expected to have more effect on low beam performance than high beams, due to the sharper gradients characteristic of the former. Thus, aim changes are a distinct possibility in accounting for the visibility distance differences, but this is not certain at this time.

STUDY 6

This study measured discomfort glare associated with a variety of headlamp beams by noting the relative frequency with which other drivers requested dimming (by flashing their lights) under normal driving conditions on three types of roads.

METHOD

The beams used were the same as used in field test 5 except that the high beam using the type-IV lamps was not used. Another beam combination was included (6014 and H_4 both on low beam) which showed four lights but produced low glaring intensities.

The data were collected after dark from 9:30 p.m. to as late as 3:00 a.m. on three types of roads in the Ann Arbor area. The three roads were: (1) four-lane divided highway, (2) two-lane rural road, and (3) two-lane street in town. It was noted whether the subject cars were encountered in straight sections or in a right- or left-hand curve.

The total number of cars met in each lamp-road category varied considerably but was generally in excess of 100. Dropped from the totals were all cars which approached the meet with their high beams on and did not flash.

RESULTS

The results of the study are summarized in Figure 47. The frequency of dimming requests was about 50% on the freeway and 90% for two-lane roads for the H_4 high beam. Other responses were much lower. Interestingly, the frequencies are about the same for the 6014 high as for the dual low beam although the latter was far less glaring. This indicated that requests for dimming are influenced by the number of lamps lighted as well as actual glare levels.

The analysis of responses by road geometry revealed, as might have been expected, that complaints were more frequent on right-hand curves than on straight sections or left-hand curves.

STUDY 7

The purpose of this study was to subjectively compare the glare produced in a rearview mirror by various headlighting systems.

METHOD

With the exception of the polarized beam, all of the lighting systems used in test 5 were also used in this test. The polarized system was replaced by a beam composed of two 6014 and two H_4 lamps,

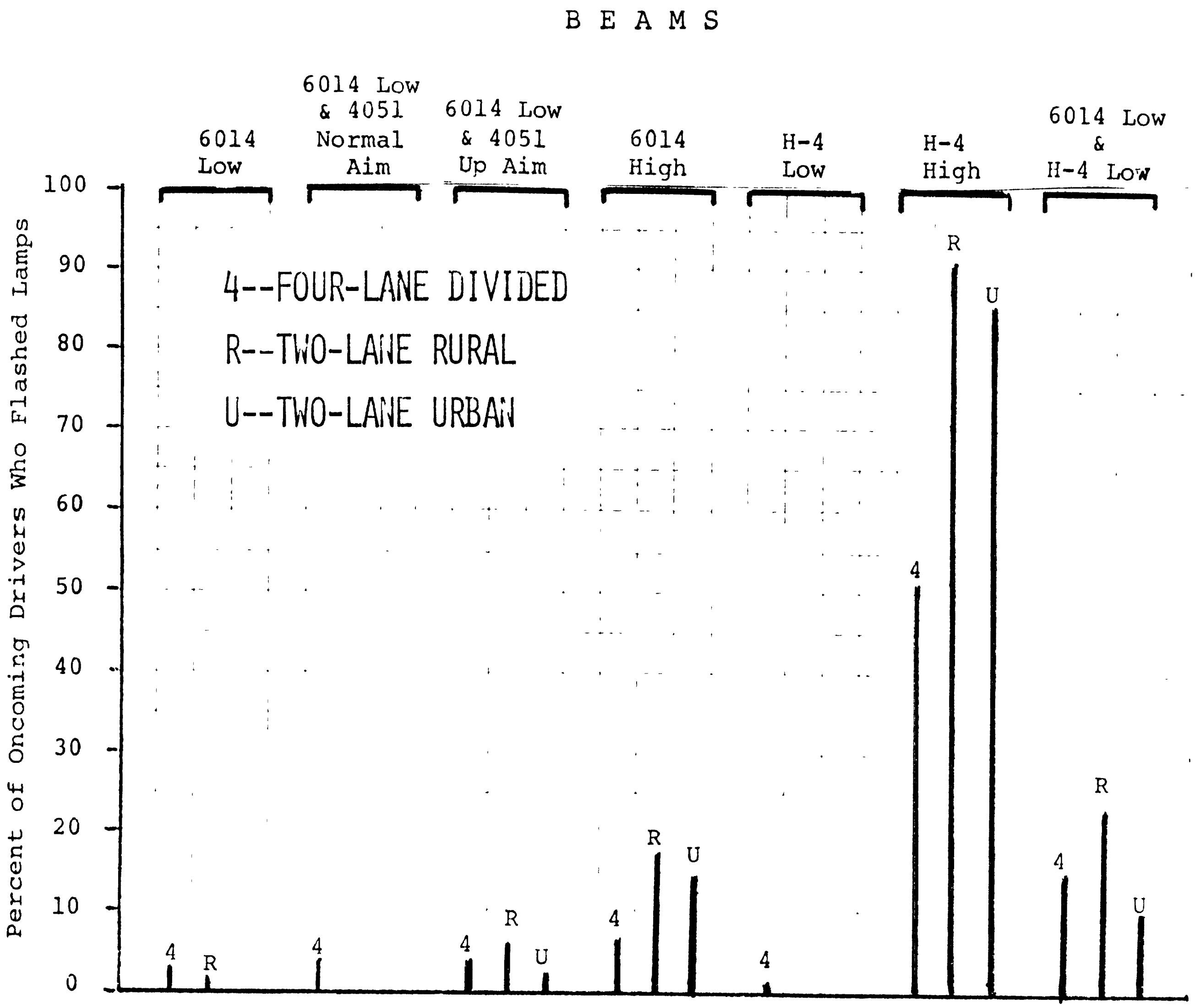

Figure 47. Percent of oncoming drivers who flashed their lamps when confronted with indicated beams under three road conditions.

on low beam. In study 6, checking the responses of oncoming traffic, this double low beam combination had elicited about the same percentage of dimming requests as the 6014 high beam. It was thought useful to determine whether equivalent results would be obtained in this different context.

The test was run on three different roads: a dark, lightly travelled, two-lane rural road; a four-lane urban street, unlighted but well travelled; a brightly-lighted, heavily travelled four-lane urban street.

The subject drove the lead car. He was accompanied by an experimenter who read the instructions, recorded data and generally monitored the subject's performance. Another car, equipped with the lighting systems, followed at a separation of 3-5 car lengths.

The basic task for the subject was to compare the glare from the experimental beams with the glare from a standard pair of 4000 low beams. He used a 9-point rating scale ranging from -4 (glare is equivalent to no lights at all) through 0 (glare is same as that provided by the 4000 reference beams) to +4 (glare is extremely discomforting). Normally the 4000 low beams were showing on the following car. On command from the experimenter in the lead car, the experimenter in the following car switched to the desired beam and, a few seconds later, back again to the reference beam. The subject then called out his judgment, which was recorded by the experimenter.

The eight beam conditions were presented twice in random order to each subject using the day setting on the inside rear-view mirror and once using the night setting. The outside rear-view mirror was turned down so that it could not be used. A total of eight subjects participated in this study, taking about three hours each. All lamps were carefully aimed mechanically and checked visually before the tests.

RESULTS

The results of the study are summarized in Figure 48. Each point represents the mean of 16 judgments on the day setting (2 judgments from each of 8 subjects) and 8 judgments on the night setting. The three lines represent the ambient lighting conditions described earlier. However, the differences between the lines are not statistically significant.

The results of this study can be compared with the opposing car glare ratings made in study 5 (Figure 42). The six lighting systems tested for glare in both studies are ranked in the same order in both tests. With the exception of the most glaring systems, there was a tendency to rate the systems as about equal to normal low beams in test 5, where in this test they were rated more glaring. This may be attributable to the use of a pair comparison technique in the present test as opposed to relying on the subject's memory in test 5.

It will be noted that the dual low beam (6014 low + H_4 low) was rated about equal to the 6014 low by itself and only slightly more glaring than the 4000 comparison lamps. This indicates that the subjects were responding to actual glare levels and not to the number of lamps.

The glare ratings were also uniformly greater with the mirror in the "day" (≃ 80% reflectivity) than "night" (≃ 4% reflectivity), position indicating the effect of mirror reflectivity.

DISCUSSION

The work described in this paper investigated the visibility distance provided by a number of headlamp systems under a variety of conditions. The following statements summarize the results of this research.

LAMP SYSTEMS

Under no-glare conditions, the major factor affecting visibility distance is beam intensity in the direction of the target. When

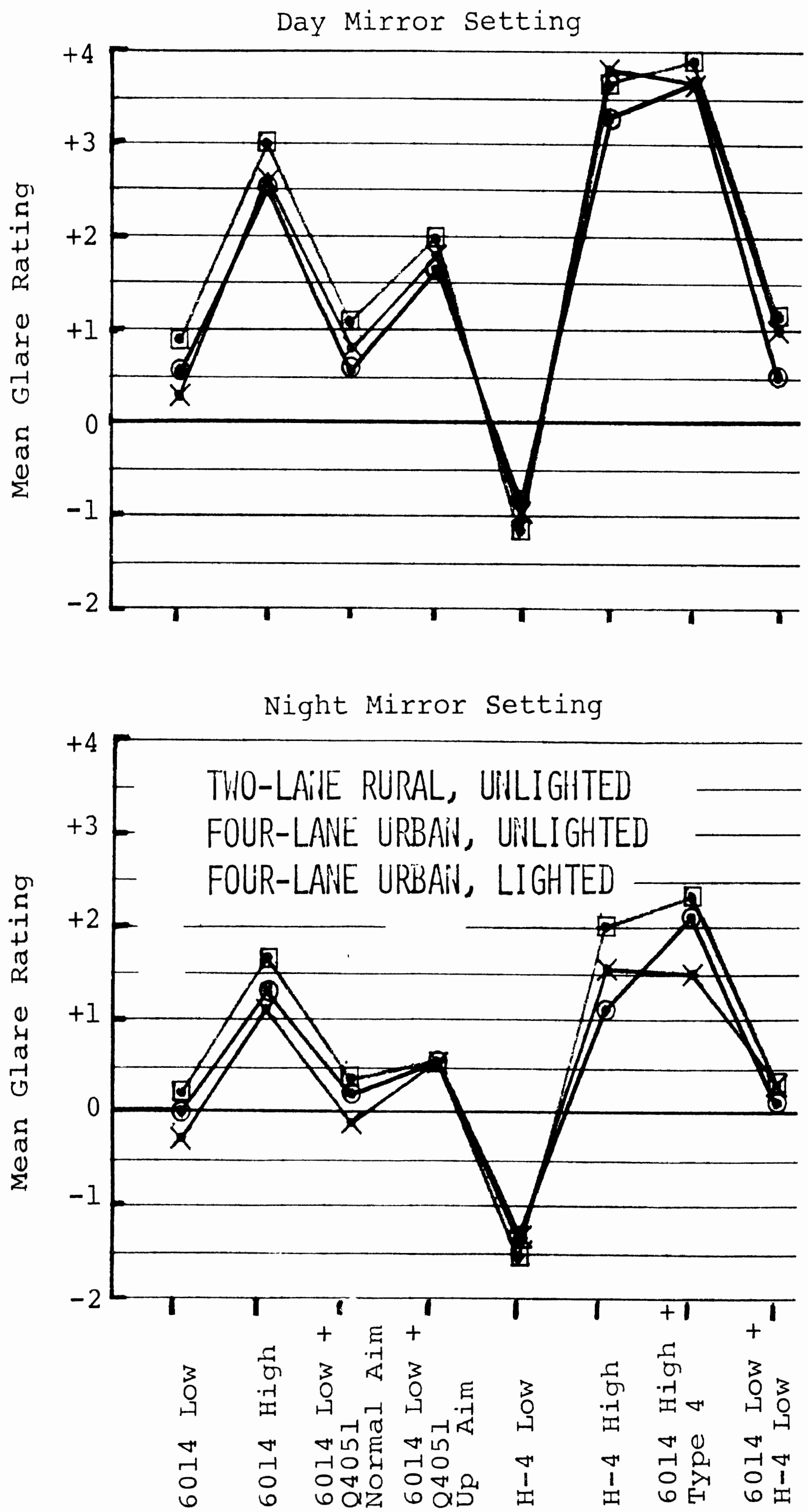

Figure 48. Subjective appraisals of glare in an interior day/night rearview mirror produced by various headlamp beams on lighted and unlighted roads. Ratings: 0, same as reference 4000 low beam; +4, extremely uncomfortable; -4, not noticeable.

approaching such a system, however, the high glare levels bring about a steep decline in visibility distance so that, even disregarding discomfort glare effects, better performance may be achieved with a beam of much lower output. In an attempt to solve this problem, meeting beams have greatly reduced output above the horizontal and concentrate most light to the right side of the lane. Such beams are significantly inferior to high beams under no-glare conditions but superior, at least on two-lane roads, when meeting another vehicle.

The European high beam, with its much greater light output, provided greater visibility only of the type-II target than the American high beam under no-glare conditions. The European low beams used in these tests provided less visibility distance than the comparable 7-inch diameter U.S. low beam, for targets on the right side of the lane, even though the latter was more glaring.

The point at which drivers feel the beams from an oncoming vehicle are uncomfortable has been shown by this research to be highly variable. Dimming should be done in response to disability glare criteria, i.e., the point at which it becomes easier to see with low beam lamps. In practice, this is an impossibility so discomfort glare criteria or "rule of thumb" judgments determine the actual dimming point. The result is that most dimming is done too soon or too late (by disability glare criteria), exacerbating the problems associated with trying to see at night.

LATERAL SEPARATION

When the lateral separation between opposing vehicles is increased there is an increase in visibility with all beams, showing that the effect of glare is reduced. The increase is smallest for meeting beams and targets on the right. For example, by comparing the mean visibility distances obtained with the 6014 low and high beams for left and right targets at 7' and 36' lateral separations (Figures 13, 21), it is seen that for the 36' lateral separation the increment in mean visibility distances compared to the 7' lateral separation for the right and left targets, respectively, is 10% and 22% for low beams and 26% and 36% for high beams. That there is little effect of lateral separation on low beam visibility of targets on the right is also shown in Figure 22, where there is a large effect of target reflectance but a quite small effect of lateral separation. By contrast, Figure 23 shows that, in the same conditions, high beam visibility does increase as lateral separation is increased from 7' to 36'. The same kinds of effects were obtained for the various meetings and high beams evaluated in study 5 (Figure 38).

The results show that increasing lateral separation provides the greatest benefit by increasing the relative visibility of targets positioned on the left of the lane, for both low and high beams, particularly for the latter. While the results of U.S. (6014) low and high beam meetings showed that visibility was greater throughout the meeting with high beams at 36' lateral separation, the minimum values near the meeting point are not much different. This suggests that high beam disability glare effects were substantial, even at 36' lateral separation, and dimming to low beam would be appropriate for visual comfort. The results of study 5 (Figure 38) show that at the 30' lateral separation used, high beam visibility distances were somewhat less than for low beams, reinforcing the suggestion that dimming to low beam is appropriate, at least for visibility of the right side of the lane.

The U.S. high beam provided greater mean seeing distances between 1500' and 200' before the meeting point than the more powerful European (H_4) high beam at both 7' and 30' lateral separation distances, showing that increasing the high beam intensity from present U.S. levels can be detrimental to visibility at up to a median separation of 30'.

The latter conclusion is supported by the glare discomfort evaluations. Glare discomfort ratings (Figure 42) showed that both the U.S. and European high beams were considered significantly more glaring than the other beams at 7' and 30' lateral separation, with the European beam rated as more glaring. That the European high beams provided more glare discomfort than the U.S. high beam is also shown in the road test results (Figure 47).

These findings on seeing distance at the right side of the lane and glare discomfort show that the lack of use of high beams by drivers when meeting other vehicles is generally appropriate, unless the median separation is substantially greater than 30'. Based on the results of these tests with preliminary versions of a mid beam, it would appear that it will provide increased visibility compared to present low beams during meetings, and without opposing traffic provides visibility distances (Figure 40) comparable to current high beams at the right of the lane. Such a beam would be very suitable on divided highways, but could also be used on at least straight sections of two-lane roads.

TARGET LOCATION

The closer a target is to a glare source, the more difficult it is to see with any beam system. Under no-glare conditions the position of a target in the lane does not matter with symmetrical high beam systems, but targets to the right are more easily seen with asymmetrical low beam systems. The closer a target is to the road surface the further away it can be seen with any beam tested under both glare and no-glare conditions.

TARGET REFLECTIVITY

Within limits, the higher the reflectivity of a target, the greater the distance at which it can be interpreted. In extreme cases, the target itself can become a glare source, reducing its interpretability. This is what was happening in the case of the type-III target used in study 3. While the target could be seen at great distances, the back-glare interfered with its interpretation until the subjects were much closer than in the case of the type-II target.

GENERAL CONCLUSIONS

Differences in methodology preclude comparisons of visibility distance between this and other studies. It is worth noting that significant improvements in visibility distance associated with greater lateral separation have been reported by other investigators as well (e.g., Webster and Yeatman, 1968; Frederiksen and Jorgensen, 1972; Powers and Solomon, 1965). On the other hand, the data reported in this paper clearly indicate that, in a two-lane situation, better visual performance will be achieved by switching from high to low beams at some point. This is at variance with the findings of other investigators (e.g., Strickland et al., 1968; Rumar, 1970a).

However, since there are many reasons why such differences are found it suggests the need for a more uniform testing procedure.

One of the reasons for undertaking these studies, was to attempt to develop a reasonable testing procedure for the evaluation of visibility distances and glare effects. Therefore, preliminary tests were conducted (Appendix C) to evaluate a number of alternative types of headlamp test visibility targets, on the basis of which the type-I target was developed. It is believed that this target would form a suitable general purpose target for use in such tests, as a baseline against which headlighting tests made by different persons or agencies and in different locations, can be compared. This testing procedure has been found to be reliable, in that it gives reasonably consistent results in spite of changes in test site, vehicle closing speeds and test subjects.

Use of this procedure would not preclude the additional use of other test targets which may be felt to have greater face-validity. It is only suggested here that the type of target and general testing approach that has been described in this report be also used as one of the test conditions.

The results of these tests have also shown that the procedure has evident validity, since it discriminates reasonably effectively between different types of beams. The findings indicate that the specific U.S. low beam employed, when compared with the specific European low beam, provided greater visibility both during and after a meeting with another vehicle equipped with the same type of headlamps. This should not be taken as strong evidence that differences between the U.S. and ECE meeting beams are necessarily meaningful. As discussed in another evaluation (Mortimer and Becker, 1974a), results are strongly dependent upon the specific lamps selected of a given type, notwithstanding the fact that they meet their respective photometrics standards.

It appears to be reasonably safe to conclude, with reference to meeting beams, that a type of mid beam configuration would provide added seeing distance in the lane and to the right of the lane compared to conventional U.S. or European low beams. Overall considerations affecting the performance of such a beam, including headlamp aim and the effects upon glare produced in rearview mirrors of preceding vehicles, need to be given particular attention (e.g., Mortimer and Becker, 1974b), as a part of the development of a satisfactory mid beam pattern.

Besides the development of a satisfactory headlighting seeing-distance test procedure, this study has also employed procedures for the evaluation of discomfort glare, both from opposing vehicles and the effects produced by reflections of headlamp beams in interior and exterior rearview mirrors. These techniques have also been found to be quite effective and sensitive to changes in the beam configurations. These types of tests should form a part of most beam evaluations, since discomfort glare is one of the important factors that set a limit upon beam characteristics.

Finally, a major objective of the detailed experiments conducted in studies 1-4, was to obtain data that could be used for validation of an analytical model to predict seeing distances.

Development of this model, and the comparisons against the field test data obtained in this study, are shown elsewhere (Mortimer and Becker, 1973) and indicate that the computer simulation model is an effective tool for the evaluation of headlamp beam performance. The model provides an opportunity to make preliminary evaluations of headlamp beams, so that a reduced number of conditions need to be confirmed in subsequent field tests.

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Appendices

Appendix A

DIMENSIONAL DRAWINGS OF THE THREE TYPES OF TARGETS USED IN THE TESTS

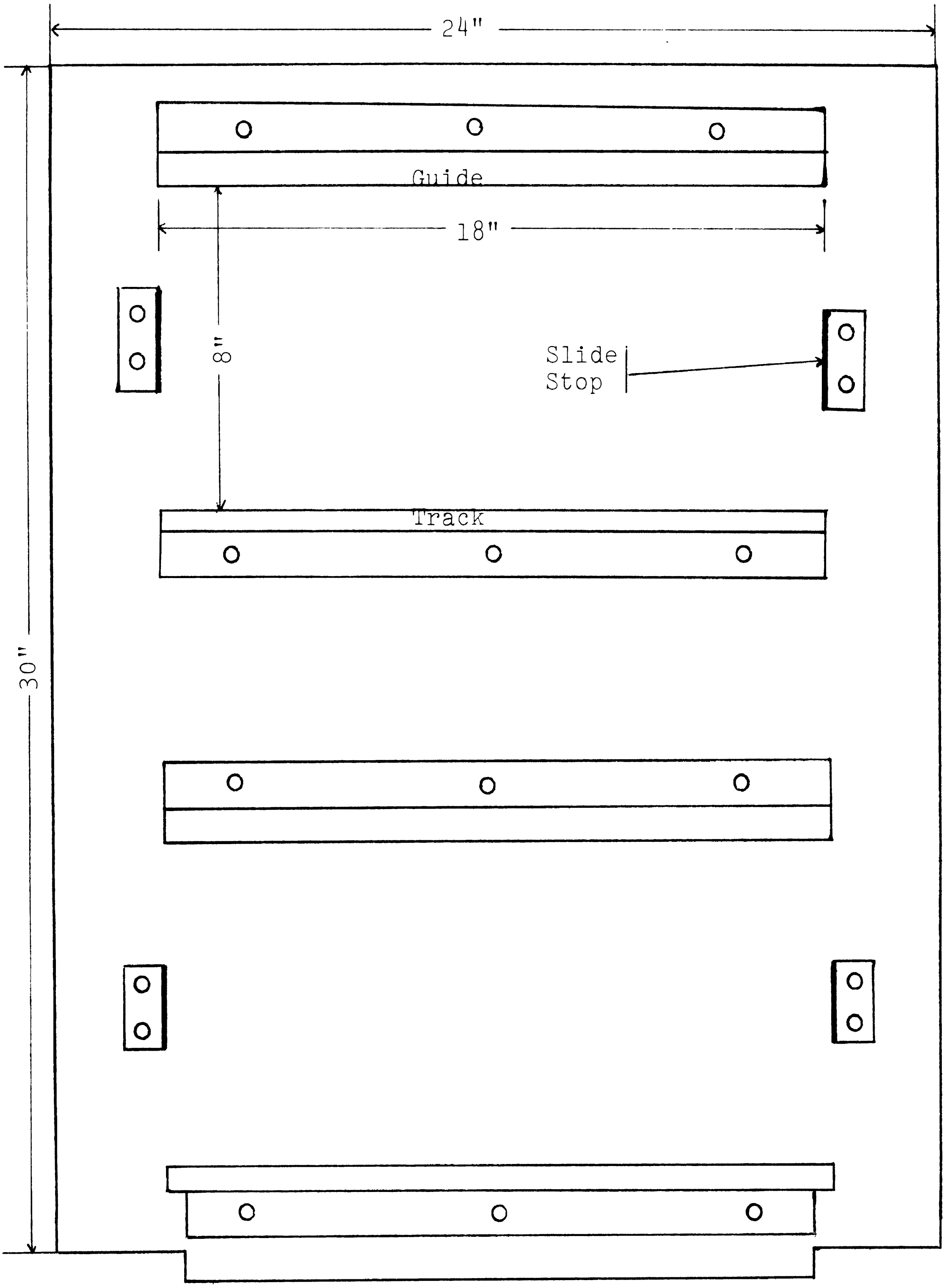


Figure A.1. Type-I target support structure: front view without target face insert.

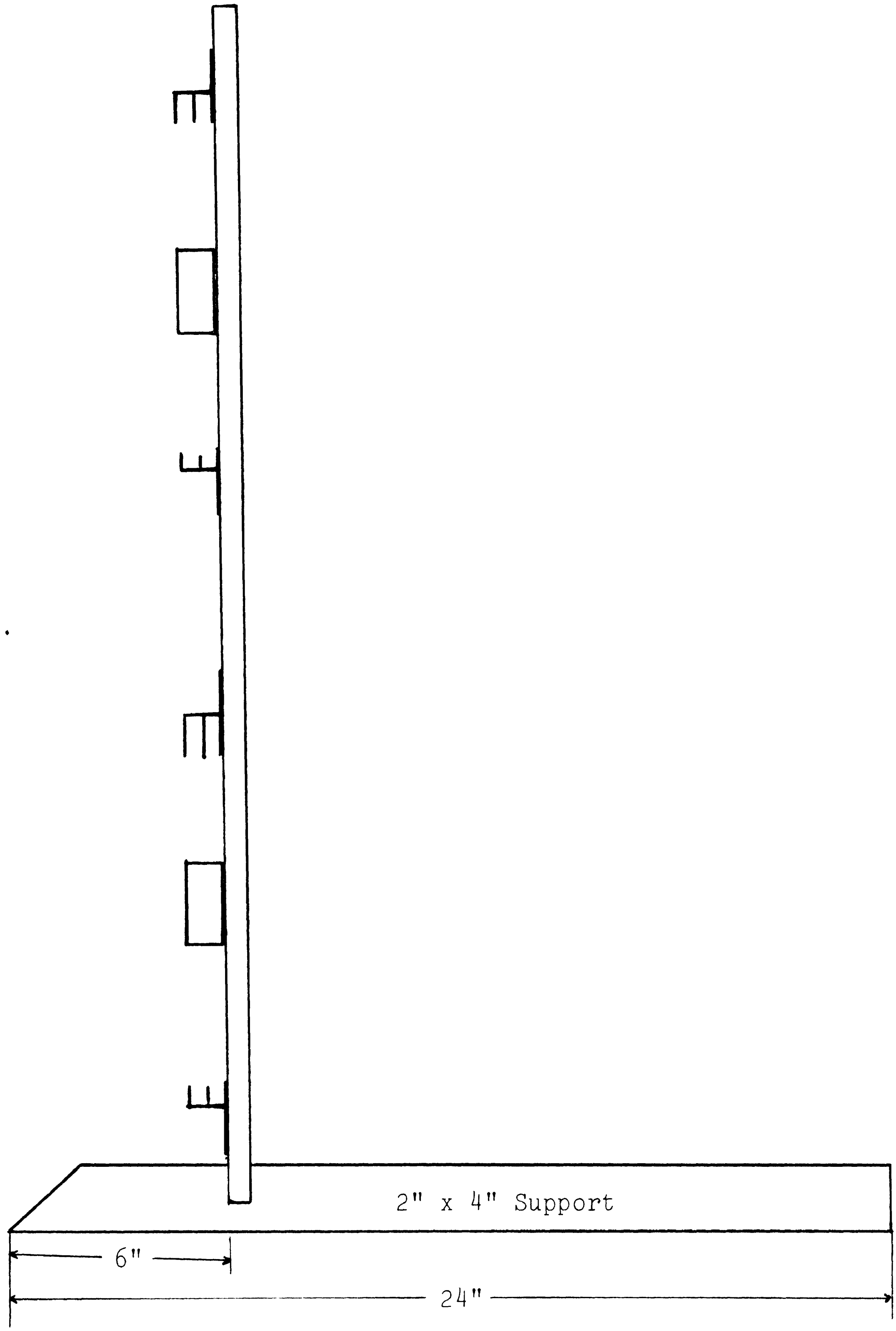


Figure A.2. Type-I target support structure: side view.

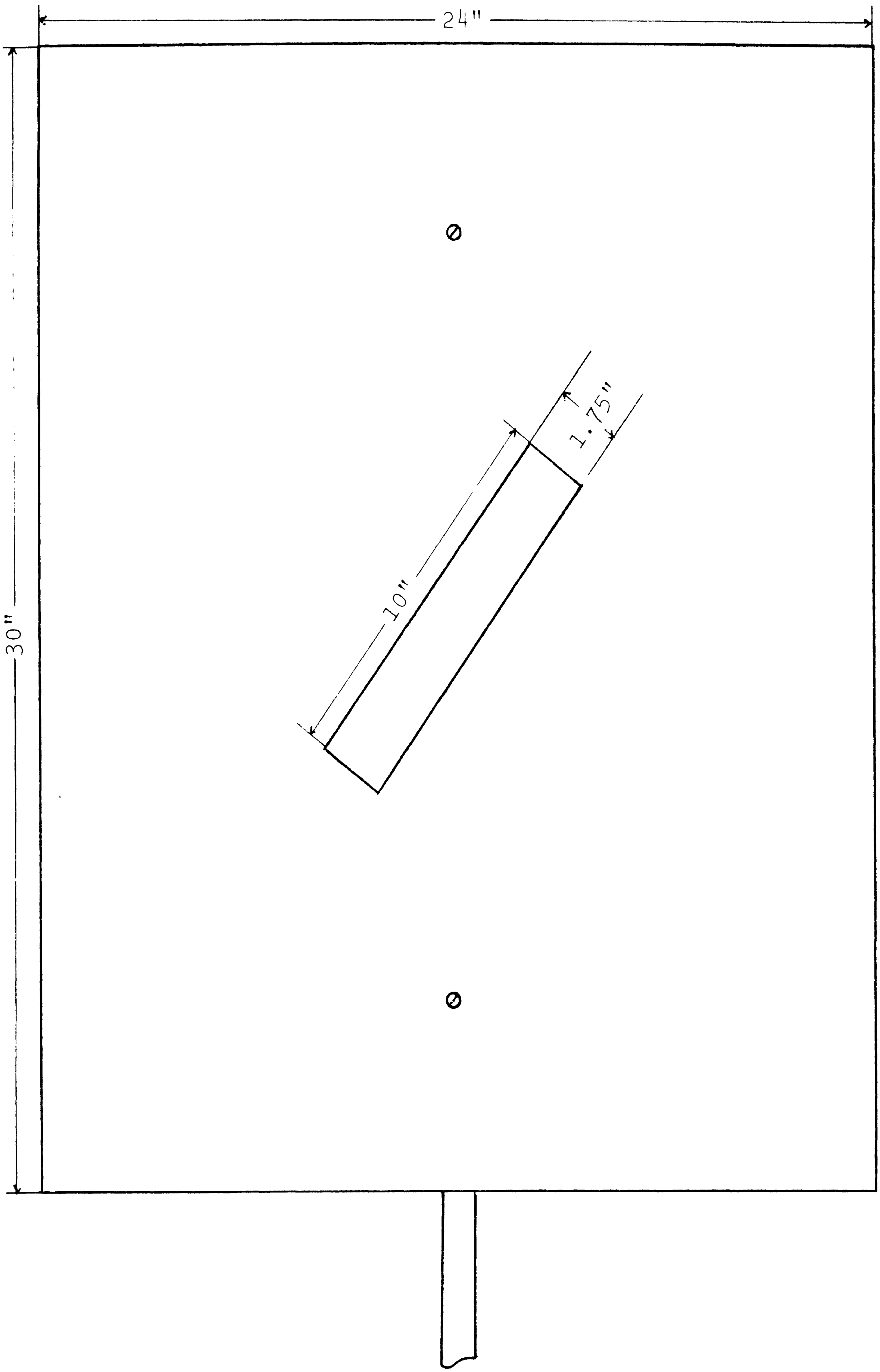


Figure A.3. Type-II target: front view.

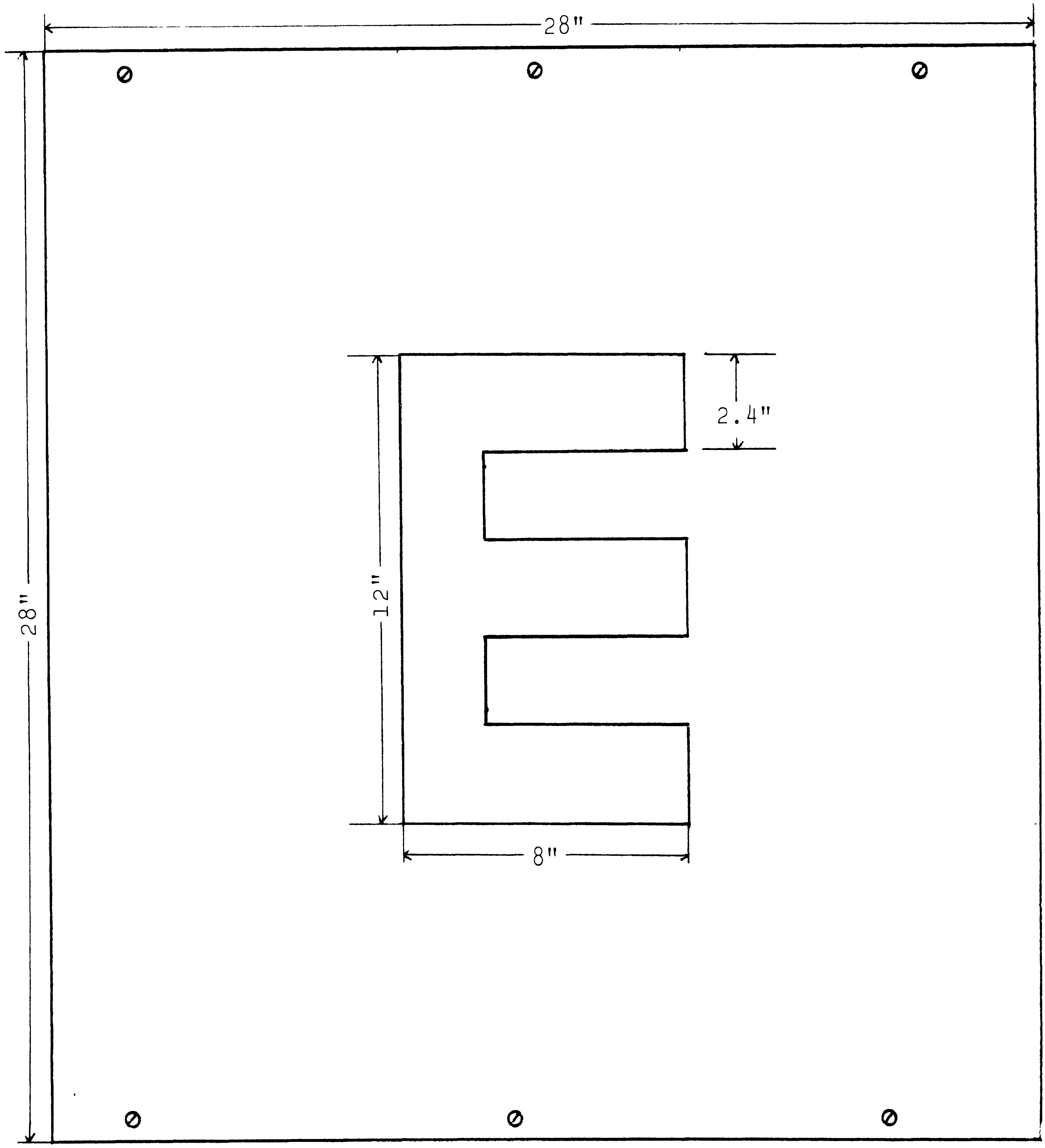


Figure A.4. Type-III target face: front view.

Appendix B

INSTRUCTIONS TO THE TEST SUBJECTS

INSTRUCTIONS FOR STUDIES 1 - 4

In this experiment we are trying to learn how well one can see in driving at night. You will be driving or riding in this car and, depending on which lane you are in or a given run, you are asked to detect the orientation of one of two types of targets.

The targets in the east lane look like this sketch (show). Your task is to tell whether the square is on the right or left end of the lane. To do this, drivers, you should press with your thumb, firmly, on either the right or left horn button, as appropriate, and you, passenger, should move the switch on the box you have either to the right or left. We want you to 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. Do not hold the switches down any longer than required to make a response.

For both east and west lane you should position your car so that the dashed lane divider is passing under your left shoulder. This is important. The targets in the east lane are positioned so that you run directly over them. As you approach them, at a distance of about 80 feet they will collapse so it is only necessary that you be sure not to hit them with your wheels as you pass over.

The targets in the west lane are along the right edge of the road. They look something like this sketch (show). If the top of the bar is tilted right, respond right and if the top of the bar is tilted left respond left.

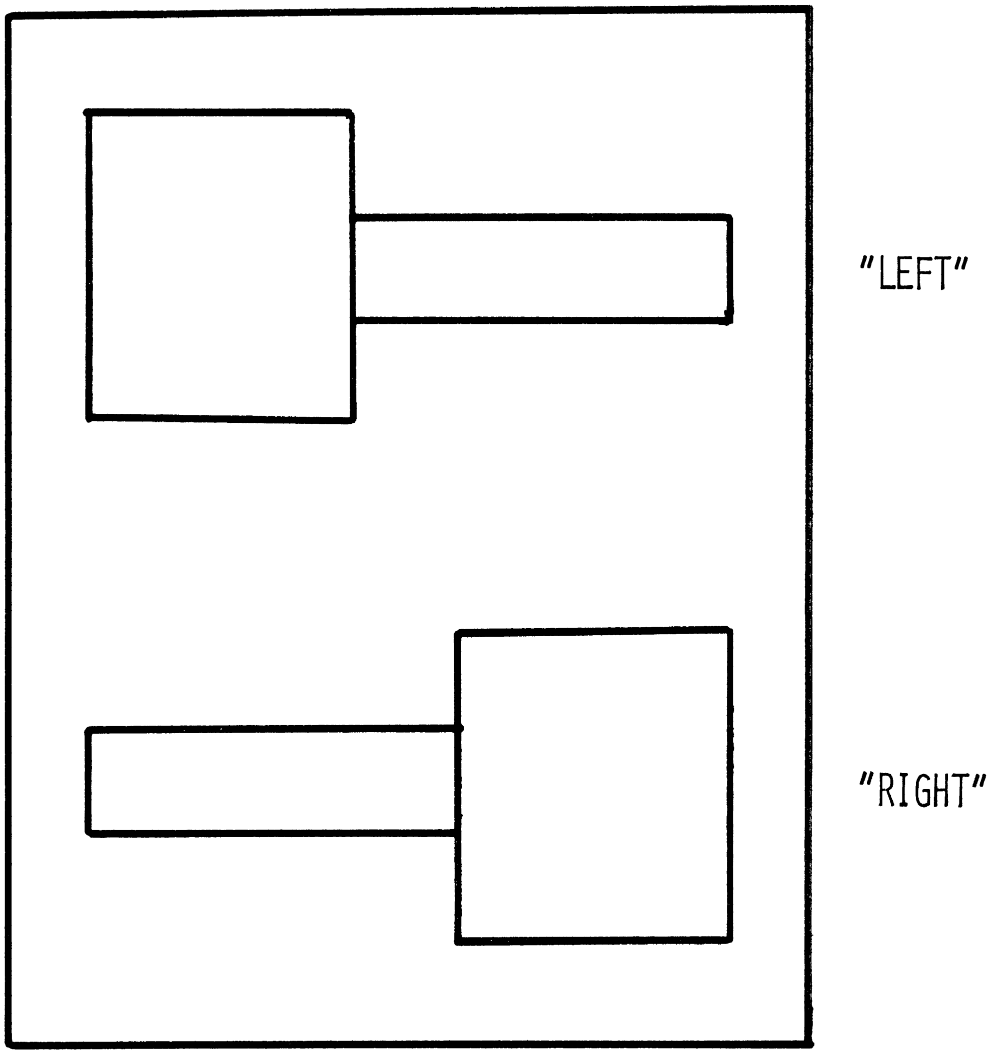
A run will start with this car at one end of the course and the other car at the far end of the course facing us. Each car indicates it is ready to run by switching off its headlamps. Car 1, in which odd numbered subjects ride, will then turn on its headlamps. When car 2 turns on its headlamps both drivers accelerate moderately to about 32 mph and release the accelerator. The cars will slow down a little until the automatic speed control device takes hold. Please keep your foot completely off the accelerator pedal during the run and the car will maintain a steady speed. Respond as soon as you can to each target, as already explained.

As the cars approach each other the glare from the other car's headlamps may reach a point where it is causing discomfort. When this point of glare discomfort occurs call out "glare." You may not find it to be a problem on all runs. Record "glare" only if the oncoming headlamps are causing more discomfort than you would care to tolerate.

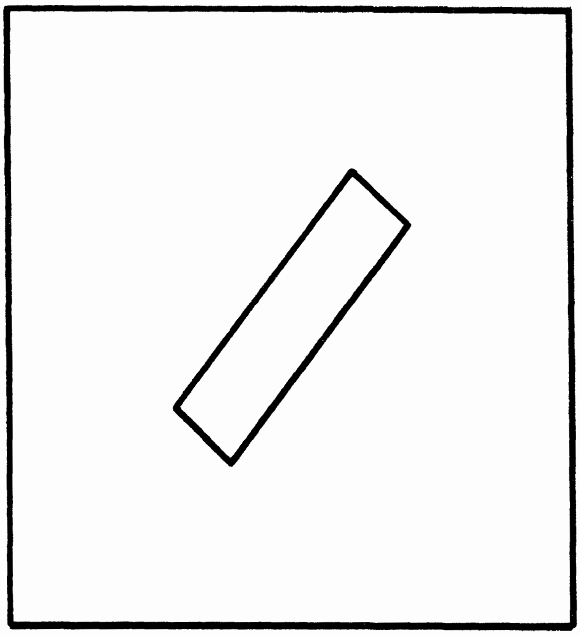
INSTRUCTIONS - OVERHEAD SIGN

On the next set of runs the roadside targets in the west lane will be replaced with a single overhead target. This target looks like this sketch (show). If the bars of the "E" are pointed right, indicate right; if they are pointed left, indicate left. This target will be directly over the lane and at different distances down the lane. The targets on the other side of this road will remain the same.

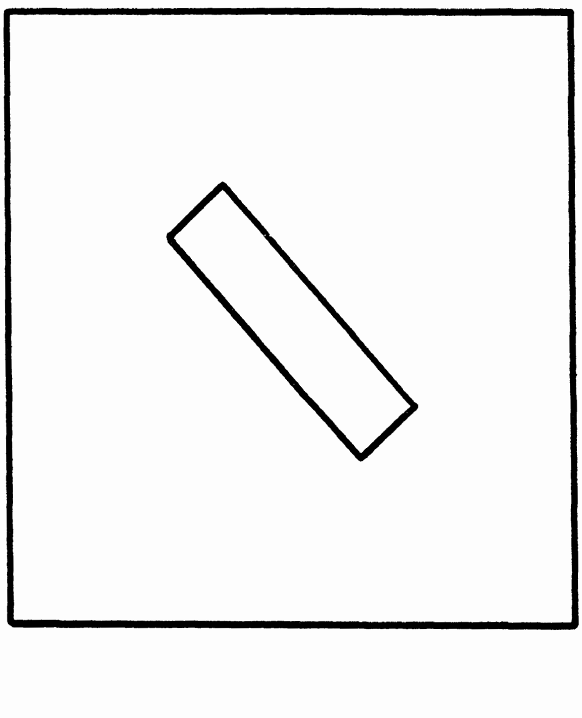
TYPE-I TARGET



TYPE-II TARGET

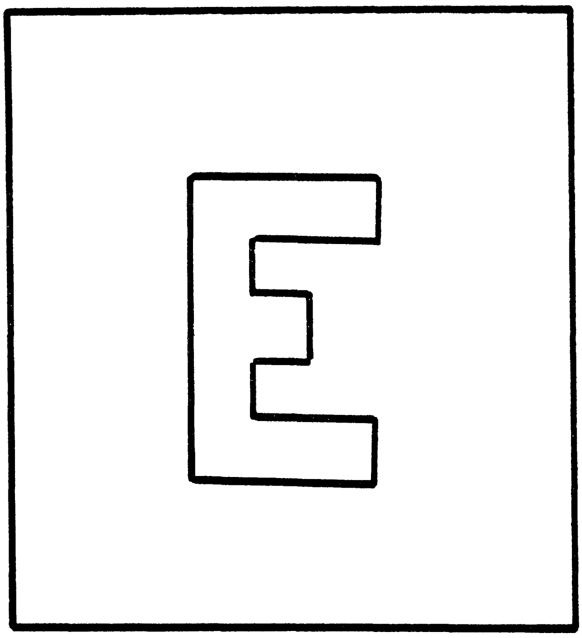


"RIGHT"

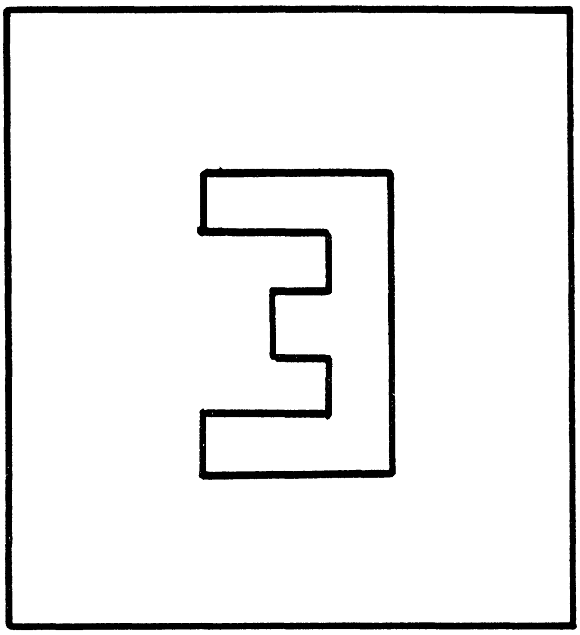


"LEFT"

TYPE-III TARGET



"RIGHT"



"LEFT"

INSTRUCTIONS FOR STUDY 5

In this experiment we are trying to learn how well one can see in driving at night. You will be driving this car in a straight line to the other end of the track. You should use the white lines in the center of the track as a guidance such that the left wheels of the vehicle are adjacent to the edge of the white line at all times. In this way you will be aimed straight down to the other end of the track.

There are a number of visual targets positioned on the right edge of the lane in which you will be traveling. There is also one additional (line) target which will be positioned on the right side.

The targets that are positioned at the right side consist of a line with a square at either the left or the right end. We want you (driver) to firmly depress the right or left horn switch on the steering wheel corresponding to the position of the square. With the square on the right depress the right switch, or the left switch if the square is on the left. The passenger should push his switch, held by thumb and index finger, in the corresponding direction when you can determine the target's position. We want you to respond to each target in this way just as soon as it is possible for you to identify the direction in which the square is oriented. Avoid making errors. If you do make an error correct it as soon as it is evident to you by depressing the switch once again. Do not hold the switch down longer than necessary to make a response.

While you are looking at the orientation of targets on the right side of the lane you should also occasionally look for the line target, which is positioned about 10 feet above the ground and to the right of the lane in which we shall be driving. (This target has a line whose top is oriented to the right or left.)

If it is pointing to the right depress the right side switch twice in quick succession. Correspondingly, if the line is pointing to the left push the left side switch twice, in quick succession, as soon as you can determine the orientation.

A run will start with this car at one end of the lane. There may or may not be another car facing us in the other lane. When everything is ready in this car I will turn off its headlights. When everything is ready in the second car the headlights on it will also be turned off. I will then ask you if you are ready to start the run. When you are ready I will turn the headlights on again on this car and at that time the driver will accelerate this car up to a speed of about 32 miles per hour and then release the accelerator. The car will then reduce its speed a little until the automatic speed control device takes hold. Continue to keep your foot completely off the accelerator. The car will maintain a steady speed. Respond as soon as you can to each target at the right side of the lane and the line target by depressing the left-right switches, as already explained. Remember, respond once only to each of the targets on the right side of the lane and respond twice in quick succession to the overhead target.

On those runs when the headlights of the other car are lighted I want the driver only to let me know when you find the light from the headlamps of the other car to be brighter than you care to tolerate and to be causing excessive visual discomfort or annoyance. When this point of glare discomfort occurs call out "glare." On some runs you may not find the other car's headlamps causing excessive discomfort, in which case you do not respond. Respond only if and when the other car's headlamps are causing you more discomfort than you would care to tolerate as the cars approach each other.

At the conclusion of each run you will be asked to make a rating of the effectiveness with which the headlamps you have used on that run provide illumination of the roadway and other objects, and to rate the extent of the glare discomfort produced by the lamps on the other car. In order to make these ratings you will use the instructions shown with the rating sheet. Your ratings will be written down by each of you independently using the pad of paper provided.

Do you have any questions?

We shall first make some practice runs so that you can become familiar with the complete procedure. If you are not clear on what you are supposed to be doing please let me know as soon as possible. We want you to remain as attentive as you can throughout this test and to respond as soon as possible, without making errors in identifying the direction of orientation of the targets.

TEST 5: RATINGS

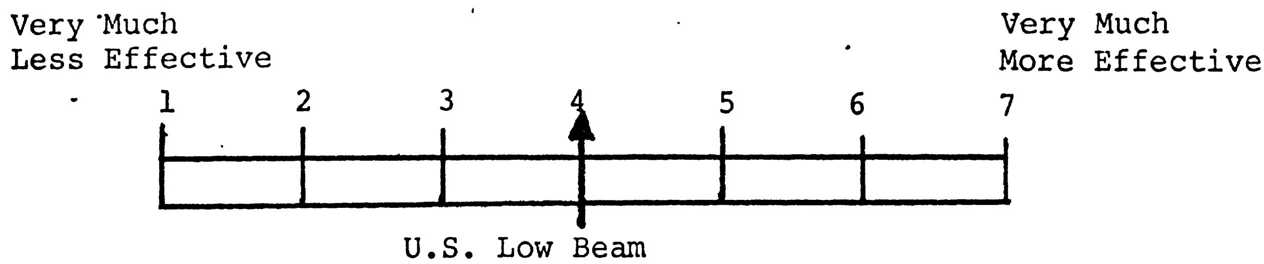
Rate the lamps you have just been using on this last run, with reference to the low beam headlights now used in the U.S. such as on your own car and other cars, for:

1. The effectiveness of the test lamps in providing illumination of the road and other objects.

2. The degree of glare discomfort experienced from the headlights of the other car.

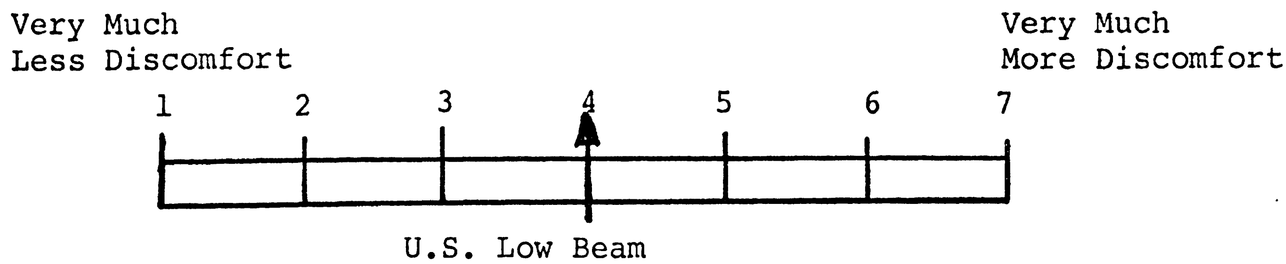
Use the rating scales shown below to select one of the values.

I.



EFFECTIVENESS IN PROVIDING ILLUMINATION

G.



DEGREE OF GLARE DISCOMFORT

Show your ratings by writing the appropriate numbers (1-7) on the pad, one number for illumination (I) effectiveness and one for glare (G) discomfort. Do not discuss your ratings until the whole test is completed.

APPENDIX C

PRELIMINARY EVALUATION OF TARGETS FOR USE IN HEADLAMP BEAM FIELD TESTS

Appendix C

PRELIMINARY EVALUATION OF TARGETS FOR USE IN HEADLAMP BEAM FIELD TESTS

PRELIMINARY CONSIDERATIONS

A number of basic considerations were felt to be important in the development of suitable targets for use in the field tests. Targets were to have a property such that their visibility was independent of limitations of the driver's visual acuity, thereby indicating some minimum size requirements. In addition, targets should have the capability of providing variable reflectance characteristics, so that this variable could be studied, since the photometric study described in Appendix D indicates that objects in the driver's field-of-view can attain different reflectance values. Targets that are suitable for use in these tests should be capable of being positioned in various locations about the lane being used by the driver. Preferably, the targets should not be visible by silhouette against the headlights of oncoming traffic or by the background lighting provided by other sources, since this would lead to evaluations that are independent of the illumination provided by the headlamps under test. Obviously, a most important property of test targets is that they should not provide spurious data, such as being detected by the shadow which they cast on the background rather than being seen directly by the illumination provided by the beams on the test car. To the extent that targets can meet the above restrictions, they should represent as much as possible, objects that are important to drivers in terms of safety.

DEVELOPMENT OF PRELIMINARY TEST TARGETS

Using an evolutionary approach, four types of test targets were developed for this preliminary evaluation.

1. <u>Vertical Target</u>. This target consisted of a rectangular panel four inches in width which was made up in three sizes, as measured in height from the ground to the top of the target structure: (a) small, 12 inches, (b) medium, 27 inches, (c) tall, 37 inches.

These targets were comprised of a panel 4 inches wide and either 12 inches (small), 20 inches (medium), 32 inches (tall) in length in the vertical dimension. They carried a border one inch wide along all the sides, which was painted a black with reflectance of about 6.5%. The area inside the rectangle was painted a flat grey, of varying reflectance values between 16-98%.

Examples of these targets are shown in Figure C.1, in each of the three size categories used.

2. Up/Down Target. This target was made up with two sizes of target faces, either of which could be positioned in an up or a down position. The target consisted of a vertical support 26 inches long, mounted on a flat board. The target faces, which could be attached to the vertical member such that their center was either 6 inches or 24 inches above the pavement, were each 4 inches in the vertical dimension and 4 or 12 inches in the horizontal direction when in position. The supporting structure was painted flat black (3% reflectance) while the target faces were made up with reflectances between 5-98%. A sketch of this target is shown in Figure C.2.

3. Pedestrian Target. A target representative of the approximate area of surface which would be presented to a driver by a pedestrian was constructed of a sheet of plywood 16 inches in width and 72 inches in length, in the vertical dimension. A suitable stand was developed to support this board. The board was painted a flat grey having reflectances of 14% and 22%.

4. Choice Position Target. A target was constructed which required the observer to make a choice concerning an aspect of the target's detail. The target consisted of a 24 inch square board supported in a vertical orientation. This background was painted black, with a reflectance of about 6.5%. A second board, 16 inches square, was pivoted at the center of the supporting board so that it could be rotated. The inner board had two lines, each 4 inches

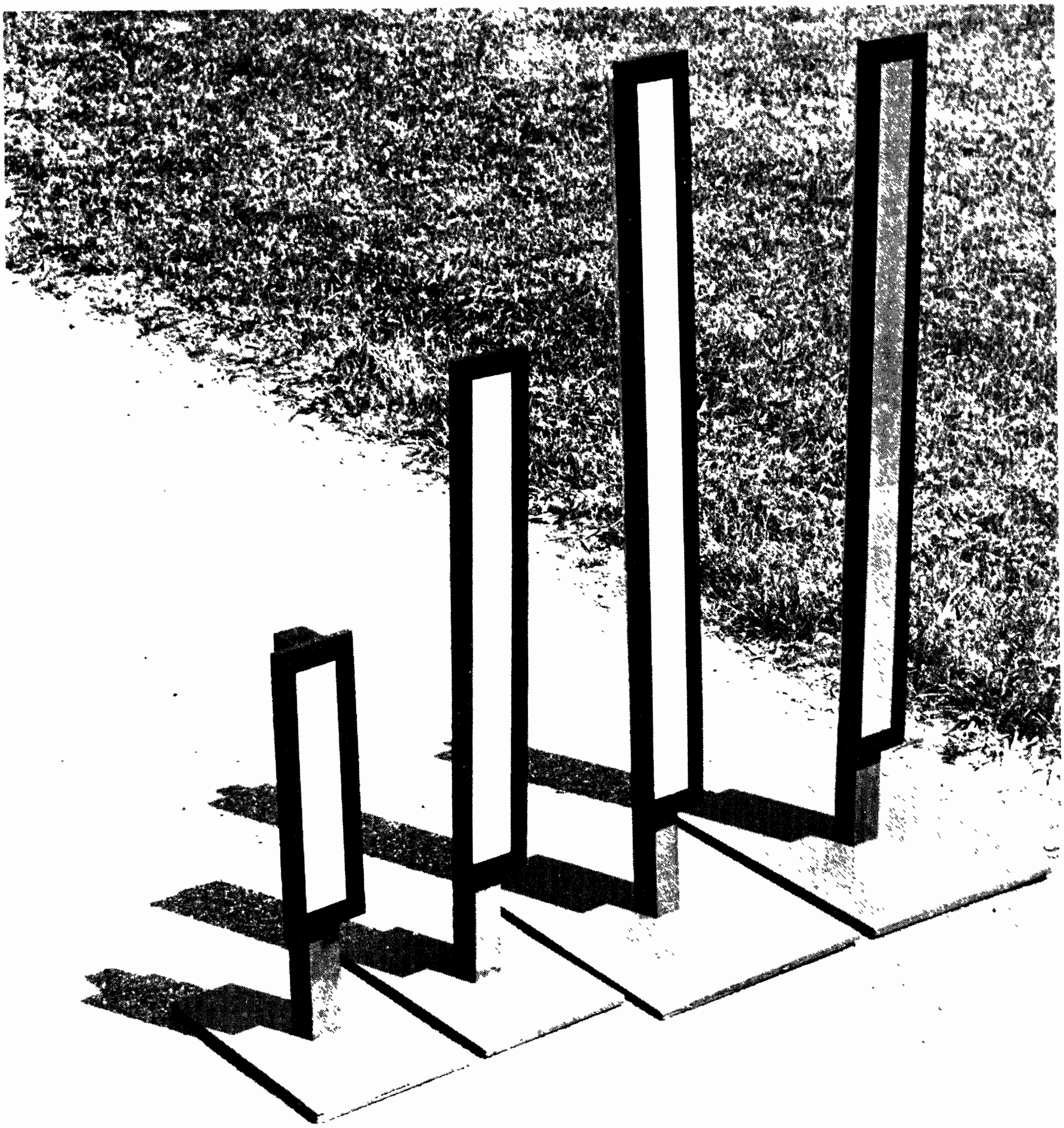


Figure C.1. The vertical targets.

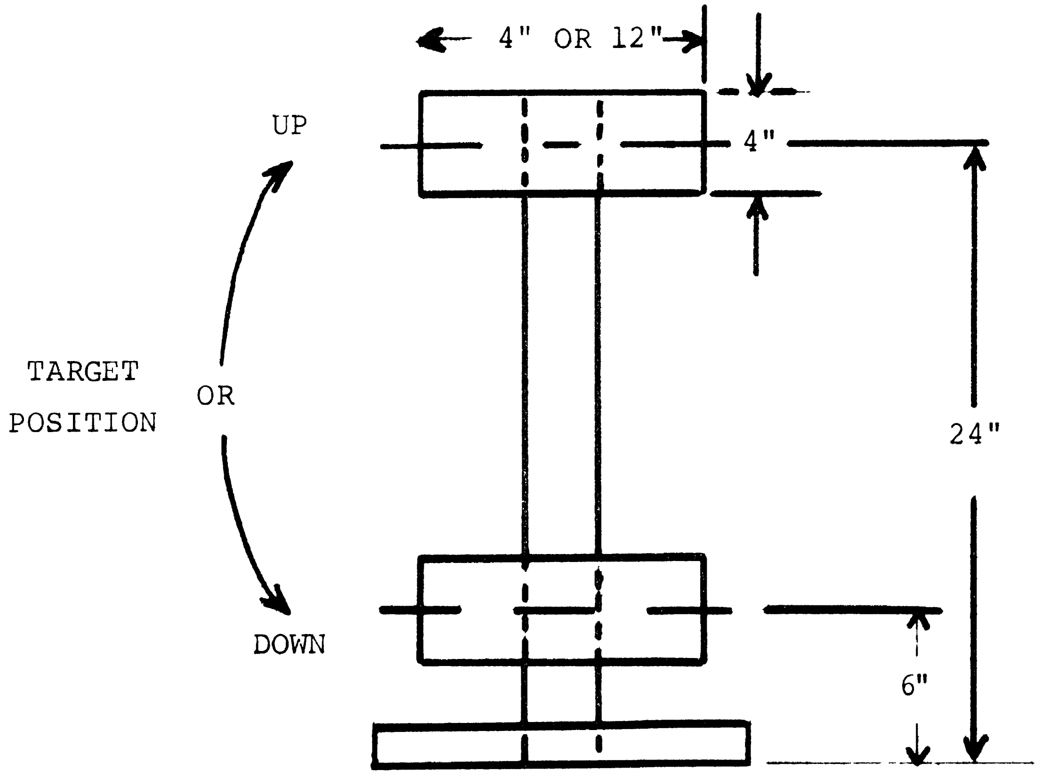


Figure C.2. Dimensions of the up/down target.

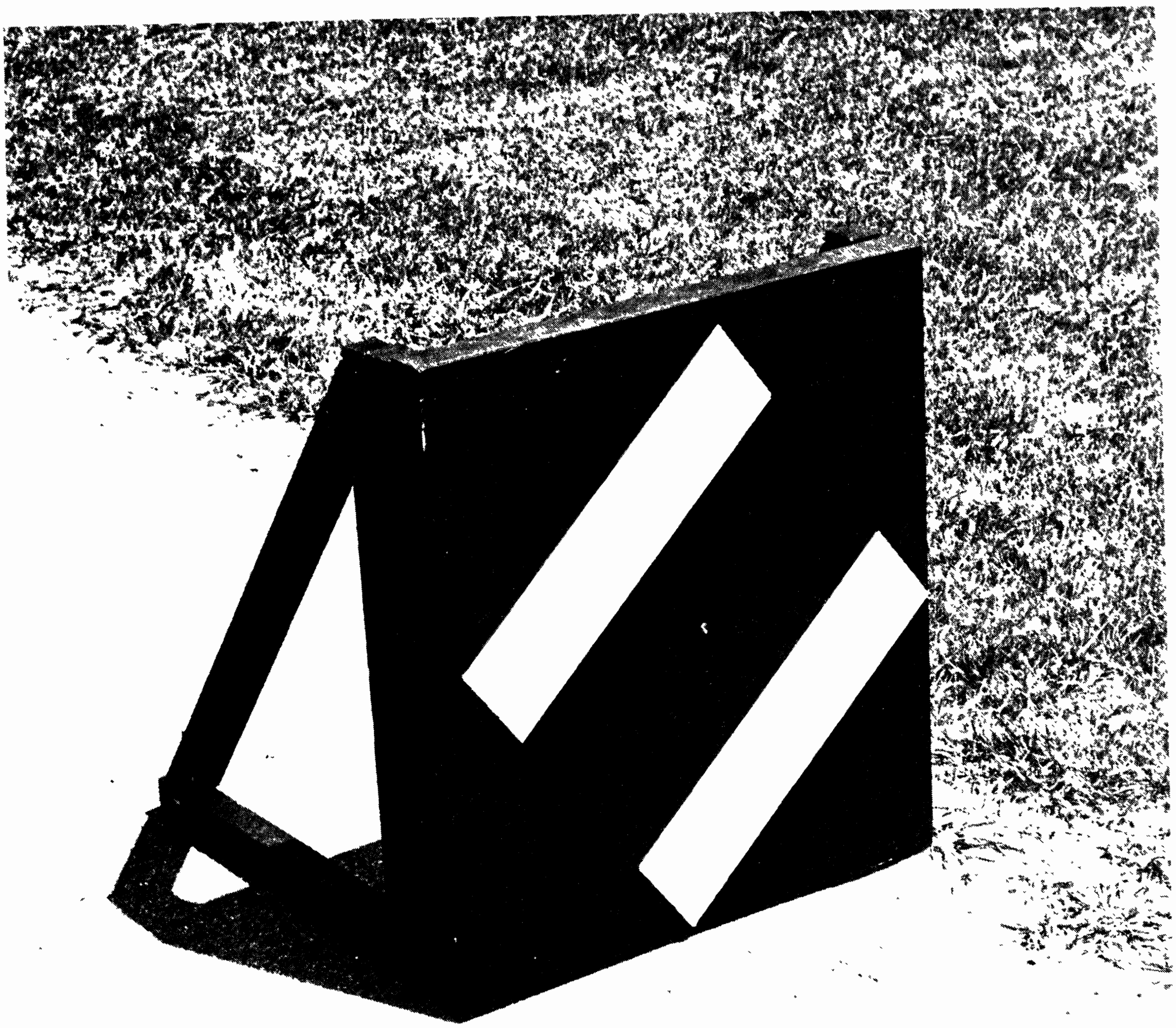


Figure C.3. The choice target.

in width along opposite sides, with the remaining 8-inch width in the center painted a flat black of 6.5% (Figure C.3).

The two parallel lines on the rotatable board were painted in various reflectances between 10-98%.

VISIBILITY DISTANCE EVALUATIONS

An automobile was driven towards one of the selected test targets located at the right edge of the road, using a flat section of roadway where there was no opposing traffic. The vehicle was equipped with a fifth wheel and distance counter. As soon as the subject was able to detect a particular target he depressed a switch and the distance from the target at which the subject responded was measured.

For each target, various reflectance values were used, to evaluate seeing distances with low and high beams. A number of trials were run for each target, using two subjects.

RESULTS

The mean visibility distances with the vertical targets are shown in Figure C.4 for low and high beams. It will be noted, that with low beams, there is no consistent effect of target reflectance, or target vertical size.

With high beams, there is a trend of increasing visibility distance as the reflectance increases, and visibility increases with target vertical dimension.

Figure C.5 shows the visibility obtained on low beams with the up/down target when the center of the target face is located either at 24 inches above the pavement or 6 inches above the pavement, as a function of reflectance and target horizontal lengths of 4 and 12 inches. For both low and high beams (Figure C.6) it can be seen that there is a reasonably consistently greater visibility for the target face in the "down" position (i.e., with the center at 6 inches above the pavement) than with the target

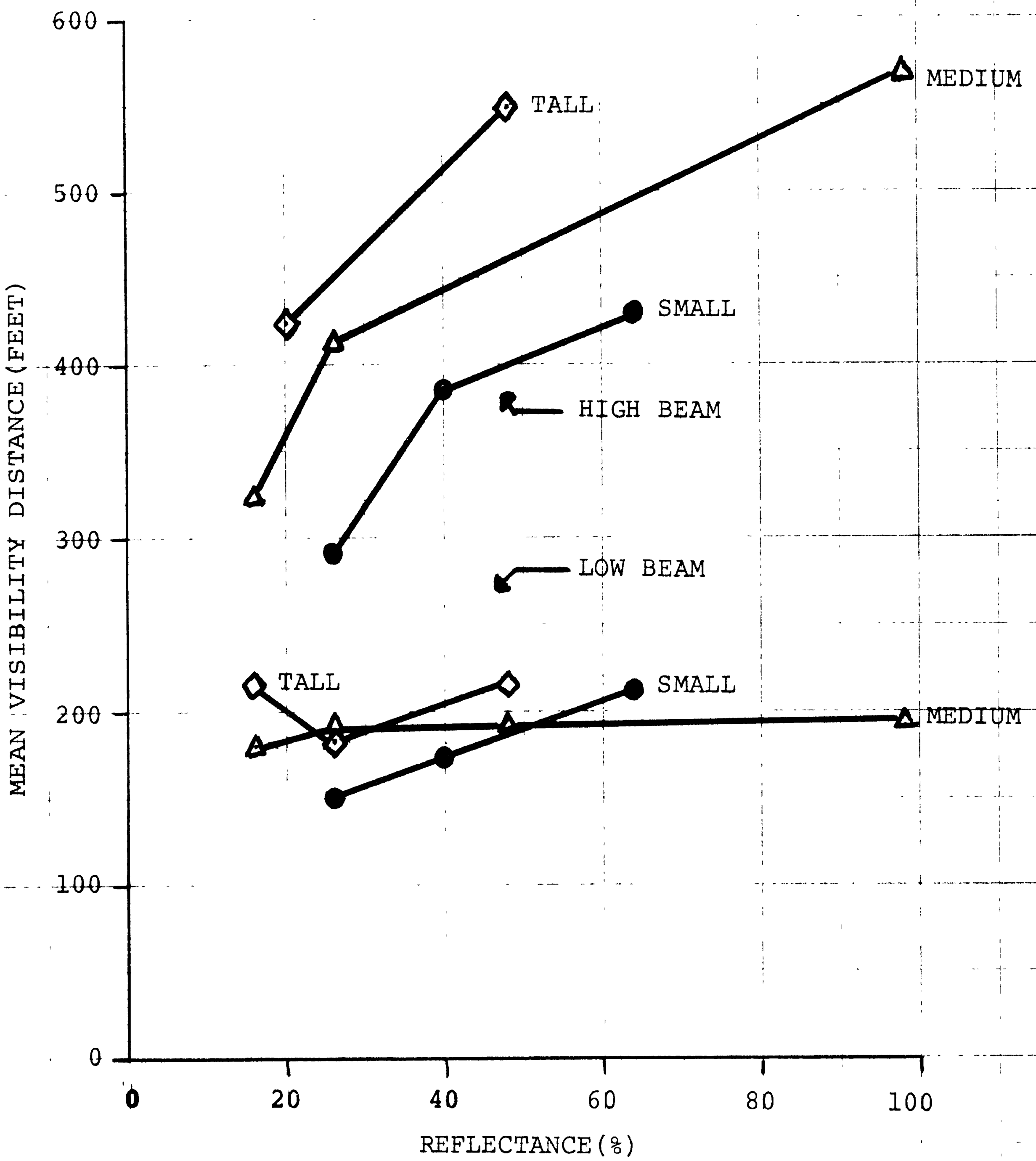


Figure C.4. Mean visibility distance of vertical targets as a function of reflectance, with low and high beams.

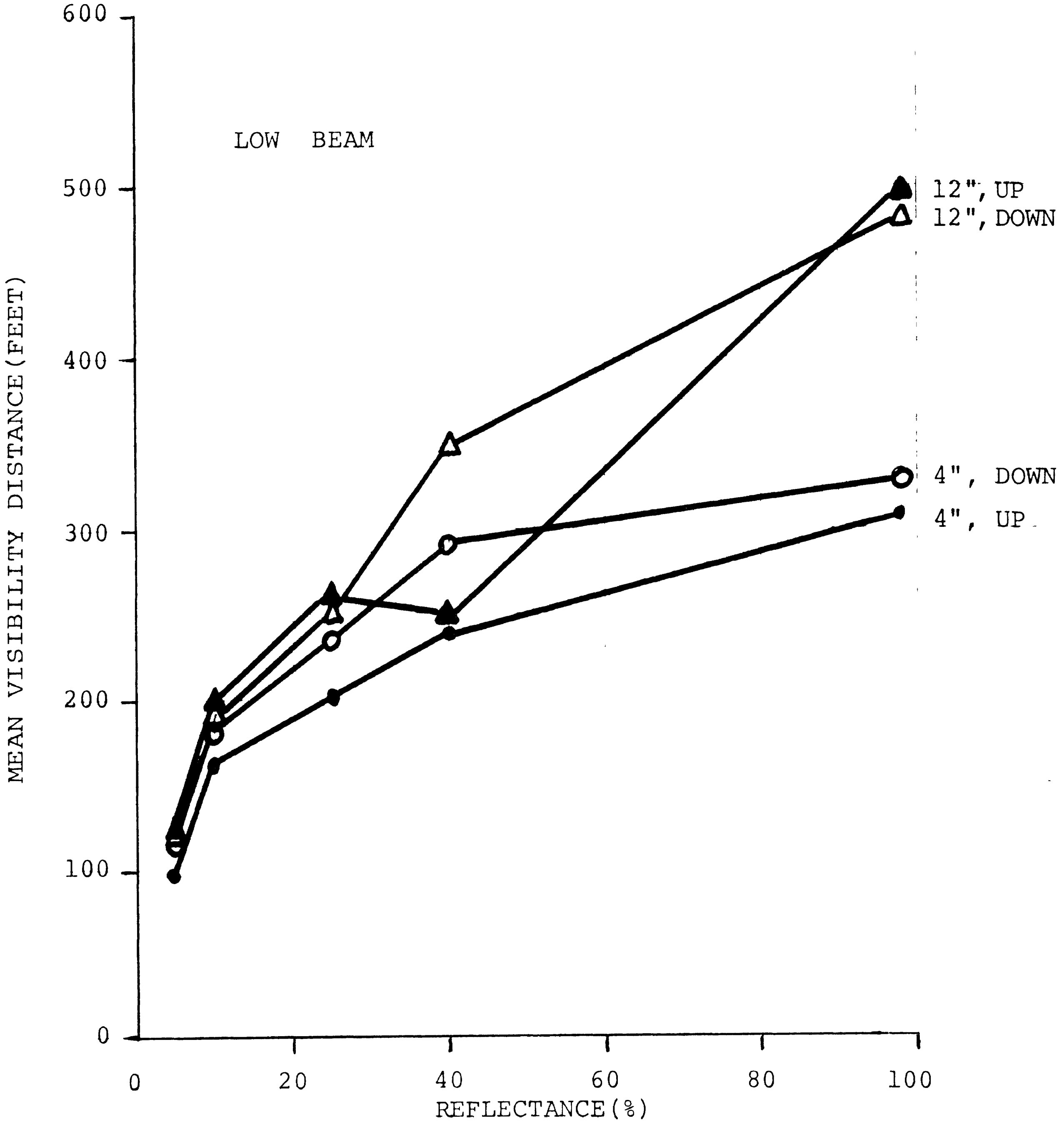


Figure C.5. Mean visibility distance of up/down target as a function of reflectance, length (4",12") and position up/down), with low beam.

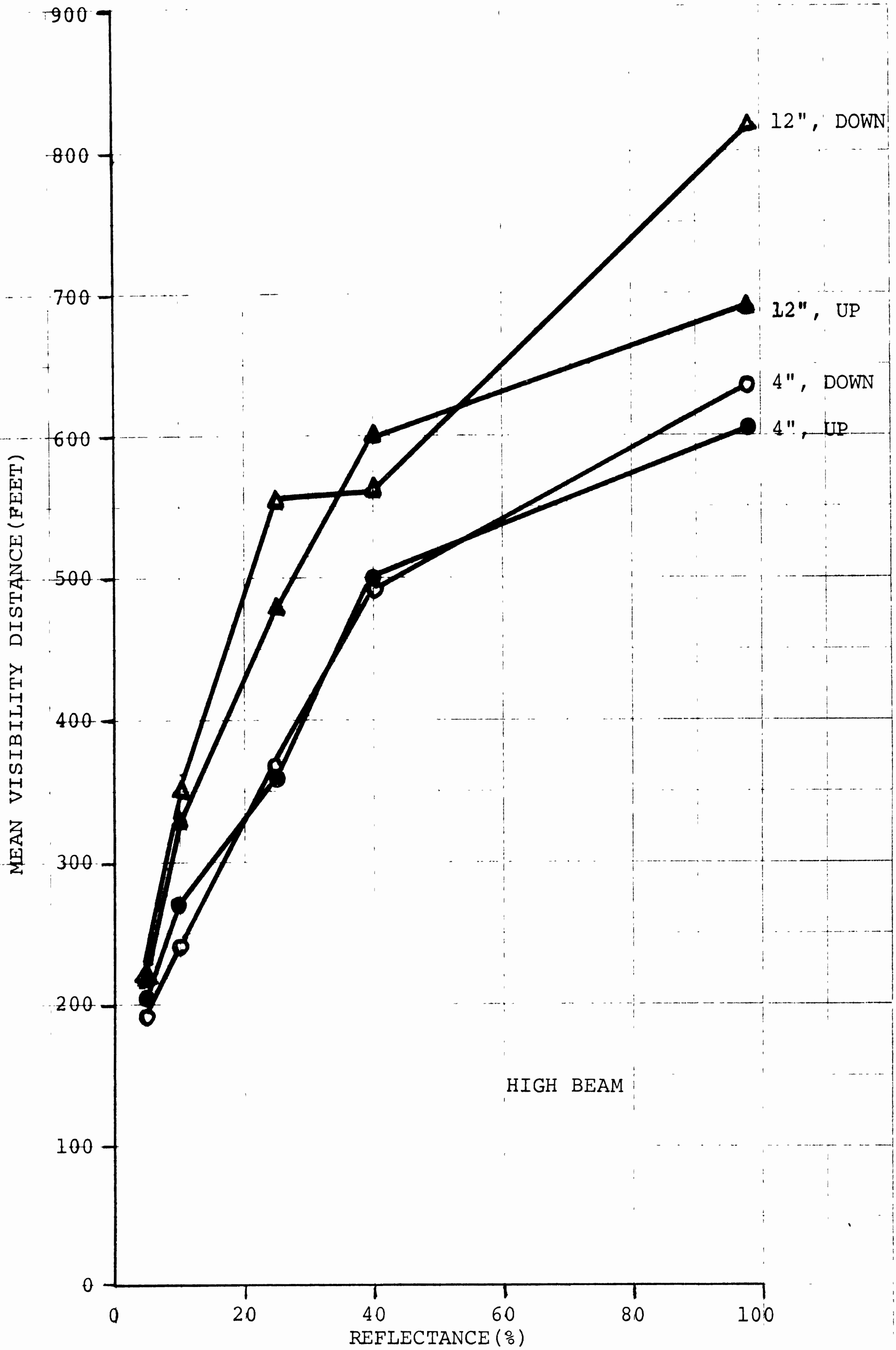


Figure C.6. Mean visibility distance of up/down target as a function of reflectance, length (4",12") and position (up/down), with high beam.

face in the upper position (i.e., with the center of the target face at 24 inches above the pavement). This effect is more clearly shown in the high beam data. In addition, when the horizontal dimension of the target was increased from 4 inches to 12 inches there was also an increase in visibility. There was also a strong effect of target reflectance, as would be expected.

Mean visibility distances obtained with the pedestrian and the choice targets are shown in Figure C.7. In both cases, visibility was affected by target reflectance and the differences between the low and high beams are also clear-cut.

CONCLUSIONS

Based upon the findings of these pilot tests, it was concluded that all of these targets lent themselves in some measure as being suitable for headlighting field tests. However, there were differences in the reliability of the data obtained. Thus, the vertical target was discarded from further testing because it did not provide a clear-cut effect of reflectance with low beams, indicating lack of sensitivity in expected data to evaluate beam and other effects. In addition, it was noted that with this target there was some tendency for shadows to be cast on the road, allowing the target to be detected on that basis rather than on the illumination of the central portion of the target face.

The findings with the up/down target appeared to be reasonably consistent, based on the limited data collected. In both low and high beams there was an effect of target reflectance, with the curves showing appropriate shapes. In addition, this target showed differences attributable to the vertical position of the target face. This indicated that the target located in the upper position, with its center at 24 inches above the pavement, provided less visibility for either beam than the target face in the lower position.

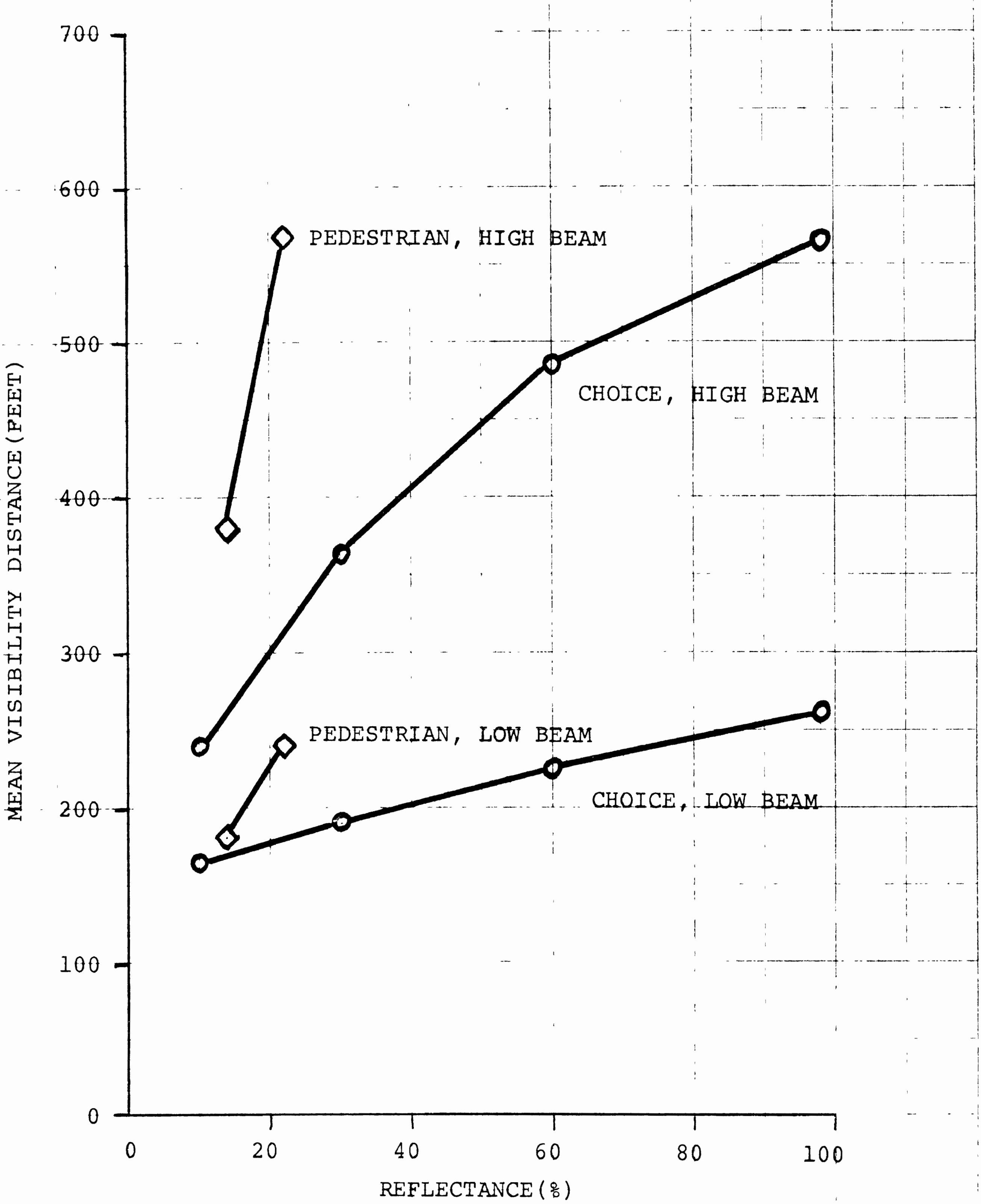


Figure C.7. Mean visibility distance of pedestrian and choice targets as a function of reflectance, with low and high beams.

One purpose of having a target with the capability of moving the target face to an upper or lower position is to ensure that beam evaluations take into account the requirement of beams to provide illumination near the road surface, for vehicle guidance, as well as above the surface for obstacle detection. It would also be important to avoid using a target which may lead to design of a beam which does not provide adequate illumination on the pavement, while providing good illumination of obstacles which protrude some distance above the pavement. In this respect it is believed that this type of target has desirable characteristics. Clear discriminations were also obtained between low and high beam effectiveness.

It is concluded that the general characteristics of this target would make it suitable for use in headlighting field test evaluations, when silhouette seeing conditions are not involved. Since that poses a potential drawback of this specific target, it suggested that the characteristics of this target should be utilized but in a different format.

The evaluations made with the pedestrian target indicated that it provided good discriminability based upon performance with low and high beams, and indicated appropriate effects due to differences in reflectance. However, this target suffers from shadows cast on the background which may cause spurious detection responses to be made. In addition, it is clearly visible in silhouette seeing conditions.

In order to overcome some of the foregoing disadvantages of detection targets, which were found in the preceding three types of targets, the choice target was developed. Responses obtained with this target were consistent in terms of the effects of target reflectance and the effects of headlamp beams. However, this target did not facilitate the evaluation, which was feasible with the up/down target, of the effects of beams both close to the pavement and at some point above the pavement. It was noted that the responses made with this target were generally consistent, and they were not affected by many of the other drawbacks associated with purely detection targets.

Based on the foregoing findings, it was determined that the major target to be used in the headlighting field tests should embody the major advantages of the targets evaluated in these studies. Thus, the target should be a choice-type of target, requiring an identification of target detail or orientation. In addition, the target faces should be able to be positioned close to the pavement and at some distance above it. The target should be one that carries its own background, so that it is not affected by silhouette seeing or by the contrast with the road or shoulder. These considerations led to the development of the type-I target described earlier (Figure 6). In addition, since there was a requirement to be able to obtain visibility distances for a target positioned in the lane used by the test car, the type-I target was modified as shown in Figure 7.

Additional considerations of drivers' visibility requirements suggested that two other targets would be required, simulating aspects of road signs and route guidance signs. Such targets were subsequently developed for use in the tests that were carried out, and are shown in Figures 9 and 10.

Appendix D

REFLECTANCE OF SOME OBJECTS IN A DRIVER'S VISUAL ENVIRONMENT

MEASUREMENTS OF PAVEMENT DIRECTIONAL REFLECTANCE AND OF OTHER OBJECTS

Pavement reflectance is not a useful unit by which to infer the amount of light a driver of a vehicle receives, as the incident and viewing angles affect the perceived luminance of roadway and various objects. Therefore, King and Finch (1968) formulated that:

Pavement Luminance = Directional Reflectance Factor x Horizontal Illumination.

This equation can be used to convert illumination in foot-candles incident upon a surface to the luminance in foot-lamberts that will be received by the human eye. It should be clear that the Directional Reflectance Factor (DRF) is specified to a particular angle of incidence and angle of observation.

A comprehensive investigation of pavement luminance was reported by King and Finch (1968). Using incident angles of 5-88° and horizontal angles of 0-360°, they simulated viewing distances of 50-600 feet by varying the height of the measuring instrument. Data were presented for a sample of in-service asphaltic concrete pavement worn for about four years. Attempting to relate the angular variables to typical highway usage, it was determined that the roadway more than about 25 feet ahead of a vehicle would receive light from the headlights at less than a 5° angle of incidence. Angles of incidences of headlights for roadway distances of 50-600 feet would typically be 2° 17' to 0° 11'. Thus, data cited for incidence angles of 5° will only approximate that which might be obtained in an actual automobile situation. For a horizontal angle of 0° and vertical angle of 5° the Directional Reflectance Factor (DRF) was found to vary from .04 to .015 for simulated viewing distances of 50 to 600 feet. The DRF is not appreciably affected by changes in the horizontal angle for low vertical angles (including 5°).

For distances of 50-600 feet horizontal angles of 160-180° would provide DRF approximately equal to those obtained with a horizontal angle of 0°. Thus the DRF of the roadway sample used is practically a constant with a value of .04-.015 depending on distance (50-600 feet) for horizontal angles representative of one's own headlights and those of opposing automobiles.

For example, a headlamp providing 1 ft-c of illumination on asphaltic concrete pavement ahead of an automobile driver would provide a driver with between .04-.015 FL of luminance. This luminance would be provided regardless of whether the illumination was provided by the driver's own headlamps or those of an oncoming car.

Measurements taken by HSRI of pavements were at 50 feet distance (photometer to object) with a 0° horizontal angle and a 6° vertical angle of incidence. (It was not convenient to use a smaller vertical angle of incidence.) For an asphaltic concrete surface (extremely worn) a Directional Reflectance Factor (DRF) of .09 was found. For a smoother (less pitted) worn asphalt surface covered with a light coating of sand a DRF of .10 was determined. The source of the variation of the pavement DRF values between King and Finch and HSRI is not known, but may well be in part caused by variations between laboratory procedure and field measurement techniques.

Computed values of DRF for these and other field measurements are given in Table D.1 and are in general agreement with those reported by Forbes (1966) shown in Table D.2.

Other work by Finch and Marxheimer (1952) dealing with pavement reflectance used dry, damp, and wet surfaces. Worn plant-mixed asphalt surfacing was found to have a diffuse reflectance of 6% dry and 3% damp (measurements made by Baumgartner Reflectometer with angle of incidence 30°). Worn asphaltic concrete was found to have a diffuse reflectance of 11-14% dry, 8-10% damp and 5% wet. Worn P.C. concrete was found to have a diffuse reflectance of 24-27% dry and 12% wet (Table D.3.).

The Directional Reflectance Factors for these materials are also shown. While P.C. concrete was found to have the highest brightness factor, wet asphaltic concrete had a greater DRF than wet P.C. concrete. The latter effect was caused by the light color stone aggregate. In all comparisons the plant-mixed asphalt surface had the lowest reflectance values.

RETRO-REFLECTIVE SIGNS

Retro-reflective signs are not diffuse reflectors and thus total reflectivity is not an appropriate measurement unit for them. For such signs light is returned near the axis of the incident light. Information on reflective efficiency of retro-reflective signs is provided in an article by Elstad, Fitzpatrick and Woltman (1962). More recent information is provided by Youngblood and Woltman (1971) in an article which specifies the sign luminance provided by headlamps for distances of 150-1500 feet.

CONCLUSIONS

Most of the natural and man-vehicle objects in a driver's field-of-view have reflectance factors of around 0.10, including many types of pavement. Road delineation by striping can increase the reflectance of the important road center and edges to about 0.20-0.30, though wear reduces the maximum value. Pedestrian clothing is frequently of very low reflectance. These data should be helpful in selecting reflectance values for headlighting test targets.

TABLE D.1. Directional Reflectance Factors Measured for Various Objects. (Horizontal Angle = 0°, Source Vertical Angle = 6°, Receiver Vertical Angle = 4°)

Target	DRF
Asphalt Aggregate	
White stripe	.18
New yellow stripe	.31
Old yellow stripe	.18
Black stripe	.03
Pavement	.09
Old Asphalt	
Pavement	.10
Yellow stripe	.13
New Asphalt	
Pavement	.01
White Vinyl Tape	.05
Cement	
Pavement	.10
White stripe	.17
Black stripe	.03
Curb	.14
Bridge abutment*	.38
Dirt	
Roadside	.16
Roadway	.11
Greenery	
Grass	.06
Weeds	.08
Clothes	
Blue jeans	.03
White T-shirt*	.46

*Receiver angle is 0°.

TABLE D.2. Reflectance Factors Given by Forbes (1966)

Target	DRF	
Pine Trees	.02-.08	
Grass	.08-.16	Long, dormant, pale green
Grass	.10-.18	Lush green, closely mowed
Forest	.02-.26	Mixed green
Dirt	.23-.43	Packed, yellowish
Asphalt	.06-.13	Oily with dust film
Concrete	.25-.37	White aged
Pedestrians	.055	Median of 54 winter coats
Pedestrians	.03	5th percentile winter coats

TABLE D.3. Percent Diffuse Reflectance(R) and Directional Reflectance Factors* (k) of Three Types of Worn Pavement in Dry, Damp and Wet Condition (Adapted from Finch and Marxheimer, 1952)

Condition	Pavement					
	Plant-Mixed Asphalt		Asphaltic Concrete		Pre-Cast Concrete	
	R	K	R	K	R	K
Dry	6	.05	11-14	.20	24-27	0.40
Damp	3	.02	8-10	.10	-	-
Wet	-	-	5	.09	12	.07

*At 2° receiver vertical angle.

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King, E.L. and Finch, D.M. A laboratory Method for Obtaining Pavement Classification Data. Annual Meeting of the Highway Research Board, 1968.

Youngblood, W.D. and Woltman, H.L. A Brightness Inventory of Contemporary Signing Materials for Guide Signs. Highway Research Record, No. 377, 69-91, 1971.

Appendix E

COMPARISON OF DAY AND NIGHT CRASHES TO DISCERN THE CONTRIBUTION OF VEHICLE HEADLIGHTING

SUMMARY

Crash data from three sources - Washtenaw County, Oakland County and the National Accident Summary (1969) - have been extensively analyzed to define characteristics of night crashes. The objective has been to provide a better understanding of the conditions surrounding night crashes and the nature of deficiencies in vehicle headlighting, if discernable from the data.

The basic methodology has been a comparison of day and night crashes over a large number of variables. In this manner it is possible to identify combinations of conditions that are over-involved in crashes occurring during darkness relative to crashes not involving darkness.

Single-vehicle crashes involving alcohol occur much more frequently at night. However, head-on and side swipe alcohol-related crashes also occur more frequently at night. A larger percentage of night, single-vehicle crashes occurred on city streets compared to rural roads.

The level of detail in the data does not support any analyses to determine any direct effects of lighting on crash occurrence. In addition, personal conversations with HSRI crash investigators failed to provide any particular cases in which lighting was directly implicated as the major causal factor. This does not necessarily mean that lighting is not an important factor in crash prevention. It may be due to an inability to clearly identify its effect. Therefore, the results of this analysis should be seen as an identification of the problems - in terms of crash characteristics - that lighting should be designed to reduce.

WASHTENAW COUNTY AND NATIONAL ACCIDENT SUMMARY ANALYSIS

The first step in the analysis process consisted of an analysis of the 1970 Washtenaw County crashes using the AID (Automatic Interaction Detector) algorithm. The dependent variable for this analysis was a binary variable assigning crashes to either darkness or daylight. For this analysis crashes occurring at dusk were excluded. The result of that analysis is a measure of the percentage of crashes - within subsets defined by various combinations of variables - occurring at night (Figure E.1).

The most important predictor of night crashes was alcohol involvement. This was followed by essentially a split between single vehicle and multiple vehicle crashes. Head-on and side swipe crashes were included with run-off the road crashes in a group having 73% of its crashes occurring at night. Thus it can be seen that night crashes tend to have two major characteristics - they involve drinking and they tend to be single-vehicle crashes. To a somewhat lesser extent head-on crashes are also more likely to occur at night. Tables E.5-E.8 show a detailed identification of the variables used in the AID run and an indication of the percentage of night crashes occurring, within the four major subgroups at various levels of these crash identifying variables.

Tables E.1 and E.2 provide additional analysis of ambient lighting by crash type for both the National Accident Summary file and the Washtenaw County crash file. The statistic presented in the cells is an involvement ratio. If there was no relationship between lighting and crash type all of these ratios would be 1.0. Ratios larger than 1.0 identify crash type by lighting combinations that occur more often than would normally be expected. The conclusion again is that single-vehicle crashes occur more frequently at night. Additional analysis of the National Accident Summary file also indicate that 49% of the rural single-vehicle crashes occur at night, whereas 40% of the urban single-vehicle crashes occur at night.

OAKLAND COUNTY CRASH ANALYSIS

Oakland County crashes which occurred on different road types were also analyzed to identify conditions under which lighting may have been a factor. A dependent variable - percent of crashes occurring at night - was used in a dummy variable multiple regression model, for single-vehicle crashes only. The data used for this analysis are shown in Table E.3. This regression model indicated that only the drinking variable had a statistically significant effect on the prediction of percentage of crashes at night. The statistical significance test used an arcsine transformation of proportion of crashes at night as the dependent variable, to satisfy the assumptions of the test.

The regression model developed is as follows:

$$Y = 90 - 5X_1 - 6X_2 - 6X_3 + 4X_4 - 18X_5 - 42X_6$$

$R^2 = 0.88$

$S = 0.08$

$df = 17$

Y = Percentage of crashes of the designated type which occurred at night

X_1 = 1 County Road
0 Otherwise

X_2 = 1 Rural State Highway
0 Otherwise

X_3 = 1 Expressway
0 Otherwise

X_4 = 1 Straight Road
0 Otherwise (Curve)

X_5 = 1 Not Known if Drinking
0 Otherwise

X_6 = 1 Had Not Been Drinking
0 Otherwise

Thus the coefficients indicate the additive effect of a particular crash condition. For example, crashes on a rural county road occur 5% less frequently than do crashes on city streets. However, that difference is not statistically significant. Conversely, crashes in which the driver had not been drinking (based upon the police officer's judgment) occurred at night 42% less frequently. That difference is statistically significant.

Table 4 was prepared to show the relationship for multiple-vehicle crashes between road alignment and drinking. Again, the proportion of drinking crashes occurring at night is quite evident.

Thus, the analyses of the Oakland County data show that:

1. Alcohol usage is a major predictor of single-vehicle night crashes given constant road type and curvature conditions.

2. City streets had the highest percentage of night crashes. However, the difference was not statistically significant.

3. Single-vehicle crashes on straight roads occur slightly more often than on curves, at night. But, the difference is not statistically significant.

CONCLUSIONS

The findings of these analyses indicate that drivers who have been drinking are involved in relatively more crashes at night than in daytime. Also, single-vehicle crashes of various kinds occur relatively more often at night than in daytime.

While it might have been expected that there would be a greater proportion of single vehicle crashes on curves than on straight sections of road at night, there was a non-significant opposite effect. If headlighting deficiencies were important contributors to night, single-vehicle crashes, it might have been expected that this would be shown by relatively more night than day crashes on curves because of the more critical visibility and glare conditions existing on curves than straight sections of road at night than in the day.

However, there were proportionately more single-vehicle crashes at night than in daytime. While alcohol is a known co-variate of these crashes, it is possible that limitations of visibility and glare effects were also involved, but are hidden because of failure to be specifically reported.

When the effect of alcohol is removed it will be seen (e.g., Table E.3) that the percent of crashes of a given type that occur at night is substantially reduced. This can also be seen by reviewing the percent of crashes of various kinds that occurred at night in Table E.5. For example (Variable 35, Table E.5), out-of-control crashes which did not involve drinking are no more frequent at night compared to daytime, than are rear-end, head-on, or intersection collisions. Since out-of-control would involve headlighting, these data do not provide evidence of this. Variable 42 (Table E.5) shows that a somewhat greater proportion of night, compared to day, crashes involved a sober driver who was left of the center line. Perhaps this could be related to headlighting.

Table E.7 shows (Variables 35 and 42) similar effects for drinking drivers who did show a greater proportion of out-of-control crashes compared to other types, and again more driving left of center violations. The clear-cut difference in these alcohol-involved crashes is the far greater proportion occurring at night than in daytime in all categories.

Therefore, these analyses do not provide any insights into the role of headlighting in night crashes. This was also inferred by Hull et al. (1972)[1] who attempted to evaluate the involvement of headlighting factors in accidents, including a comparison of the effects of periodic vehicle inspection. The reported involvement of defective or "improper" vehicle lighting was quite low, and no differences were attributable to inspection programs.

While it has not been possible to demonstrate that current vehicle headlighting is a contributor to night crashes, the converse cannot be assumed to be true. A different form of investigation, of an intensive type, is needed to establish if there exists a relation between particular types of crashes at night and vehicle headlighting.

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[1] Hull, R.W., Hemion, R.H. and Cadena, D.G. Guidelines for Improving the Stability of Headlamp Aim. Rept. No. DOT HS-800-739, 1972.

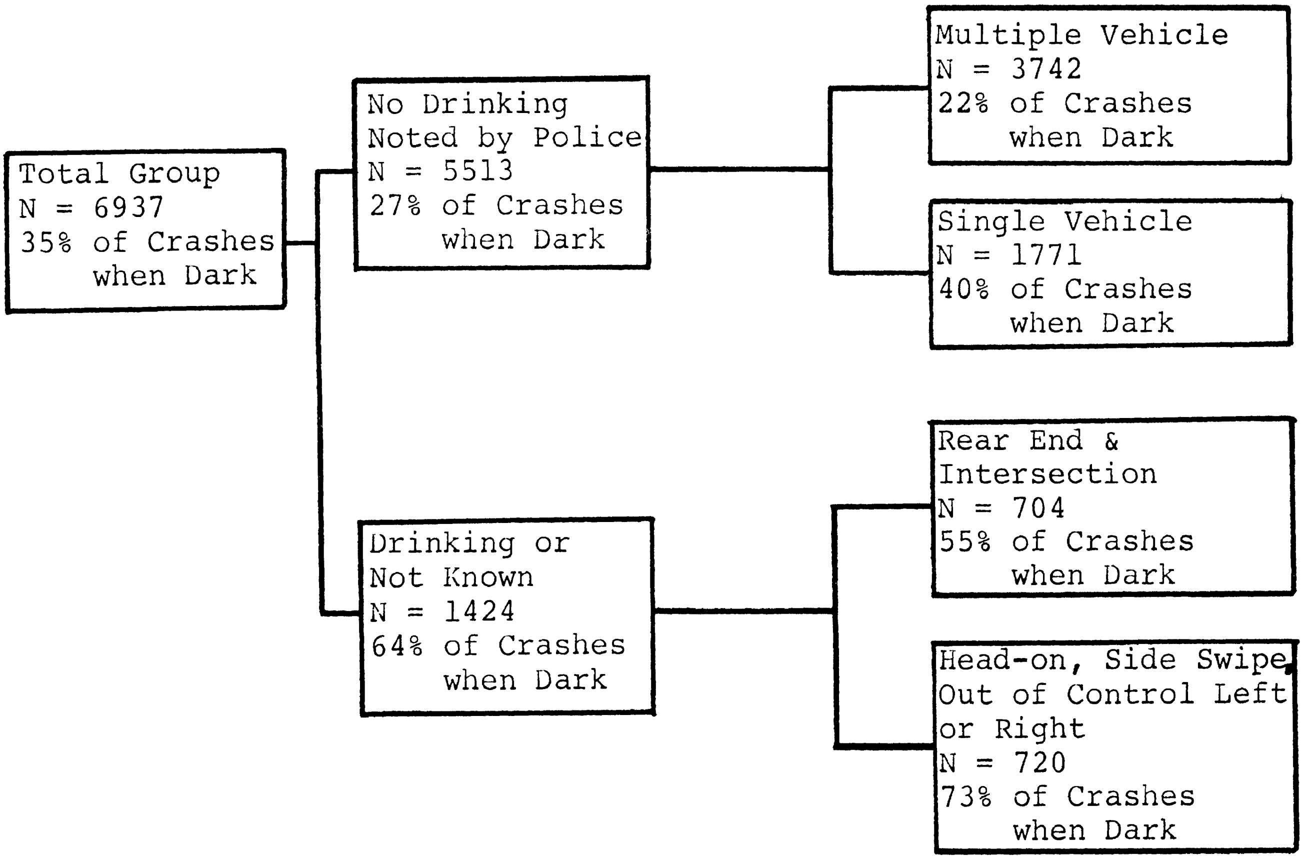

Figure E.1. Results of AID analysis.

TABLE E.1. Comparison of Crash Type by Ambient Lighting Condition*

	Daylight	Dawn or Dusk	Darkness	Total Number Observed
Pedestrian	$\frac{600}{579}$ = 1.04†	$\frac{42}{38}$ = 1.10	$\frac{234}{258}$ = .91	876
Non-Motor Vehicle	$\frac{196}{256}$ = .76	$\frac{33}{17}$ = 1.94	$\frac{158}{114}$ = 1.38	387
Fixed Object	$\frac{580}{858}$ = .68	$\frac{59}{57}$ = 1.04	$\frac{659}{383}$ = 1.72	1298
Run Off Road	$\frac{960}{1394}$ = .69	$\frac{86}{93}$ = .92	$\frac{1063}{622}$ = 1.71	2109
Overturned	$\frac{74}{90}$ = .82	$\frac{6}{6}$ = 1.00	$\frac{56}{40}$ = 1.40	136
Head-On	$\frac{794}{830}$ = .96	$\frac{55}{55}$ = 1.00	$\frac{406}{370}$ = 1.10	1255
Angle Collision	$\frac{7263}{6679}$ = 1.09	$\frac{432}{444}$ = .97	$\frac{2411}{2982}$ = .81	10106
Rear End	$\frac{5481}{5263}$ = 1.04	$\frac{348}{350}$ = .99	$\frac{2134}{2350}$ = .91	7963

*Based on 1969 National Accident Summary - Traffic Units ÷ 100.

†Cell entries are: observed number of crashes / expected number of crashes = involvement ratio

The expected number of crashes is computed under the assumption that there is no relationship between crash type and ambient lighting. An involvement ratio greater than one indicates that a particular crash type occurs more frequently under the given light condition.

TABLE E.2. Comparison of Crash Type by Ambient Lighting Condition*

	Daylight	Dawn or Dusk	Darkness	Total Number Observed
Rear-End	$\frac{4039}{3740}$ = 1.08†	$\frac{325}{338}$ = .96	$\frac{1644}{1930}$ = .85	6008
Head-On	$\frac{923}{987}$ = .94	$\frac{93}{89}$ = 1.04	$\frac{570}{510}$ = 1.12	1586
Intersection	$\frac{6221}{5688}$ = 1.09	$\frac{527}{513}$ = 1.03	$\frac{2388}{2935}$ = .81	9136
Side Swipe Same Direction	$\frac{1048}{1009}$ = 1.04	$\frac{80}{91}$ = .88	$\frac{492}{520}$ = .95	1620
Side Swipe Opposite Direction	$\frac{34}{44}$ = .77	$\frac{6}{4}$ = 1.50	$\frac{30}{22}$ = 1.36	70
Out of Control Right Side of Road	$\frac{1366}{1807}$ = .76	$\frac{167}{163}$ = 1.02	$\frac{1369}{932}$ = 1.47	2902
Out of Control Left Side of Road	$\frac{1059}{1416}$ = .75	$\frac{128}{128}$ = 1.00	$\frac{1087}{731}$ = 1.49	2274
Total	14690	1326	7580	23596

Chi-Square = 817

D.F. = 12

α < 0.001

*Based on Washtenaw County crashes Jan. 1968-June 1971.

†Cell entries are: observed number of crashes / expected number of crashes = involvement ratio

TABLE E.3. Oakland County 1970 Single-Vehicle Crashes

Road Type	Alignment	Drinking	Total # of Crashes	Number at Night	Percent at Night
City Street	Curve	Yes	77	64	83
		No	134	67	50
		Not Known	33	23	70
	Straight	Yes	496	485	98
		No	1827	1200	66
		Not Known	559	342	61
County Road	Curve	Yes	216	182	84
		No	363	168	46
		Not Known	89	67	75
	Straight	Yes	404	326	81
		No	1000	416	42
		Not Known	186	132	71
Rural State Highway	Curve	Yes	19	16	84
		No	45	13	29
		Not Known	4	3	75
	Straight	Yes	77	72	94
		No	225	94	42
		Not Known	29	18	62
Expressway	Curve	Yes	62	52	84
		No	217	84	39
		Not Known	24	15	62
	Straight	Yes	107	96	90
		No	371	175	47
		Not Known	46	32	70

TABLE E.4. Oakland County 1970 Multiple-Vehicle Crashes on Rural County Roads.

Road Alignment	Drinking	Total # of Crashes	Number at Night	Percent at Night
Curve	Drinking	66	50	76
	Not Drinking	394	78	20
	Not Known	11	4	36
Straight	Drinking	431	301	70
	Not Drinking	2592	71	27
	Not Known	160	48	30

Addendum

TABLES E.5-E.8

TABLE E.5. Washtenaw County Day vs. Night Crashes Involving A Single Vehicle with No Drinking, 1971.

Variable 8 - Reporting Department

Code	Variable	Number	% Crashes at Night
0	Ann Arbor Police	258	33
1	Washtenaw County Sheriff	713	44
3	Manchester	4	25
4	Saline	60	28
5	Brighton, State Police Post 12	27	40
6	Ypsilanti, State Police Post 26	454	37
8	Milan	31	32
9	Other	224	40

Variable 20 - Road Surface Condition

Code	Variable	Number	% Crashes at Night
1	Dry	976	39
2	Wet	369	38
3	Snowy or Icy	411	40
4	Other (e.g. Gravel, Dirt or Sand)	10	10
9	Missing Data	5	20

Variable 26 - Area of Vehicle #1 Hit

Code	Variable	Number	% Crashes at Night
0	Top or Rollover	313	42
1	Front	499	46
2	Right Front	204	41
3	Right Side	116	32
4	Right Rear	42	33
5	Rear	56	37
6	Left Rear	35	46
7	Left Side	109	37
8	Left Front	153	40
9	More Than One Major Inclusive Area Damaged	244	26

TABLE E.5. (cont.)

Variable 28 - Total Number of Vehicles

Code	Variable	Number	% Crashes at Night
1	One Vehicle Involved	1428	40
2	Two Vehicles Involved	310	35
3	Three Vehicles Involved	26	53
4	Four Vehicles Involved	1	0
5	Five Vehicles Involved	2	0
8	Eight or More Vehicles Involved	4	25

Variable 29 - Total Number of Lanes

Code	Variable	Number	% Crashes at Night
2	Two Lanes	169	37
3	Three Lanes	63	31
4	Four Lanes	1298	40
5	Five Lanes	2	0
9	Missing Data	239	39

Variable 34 - Traffic Control Present?

Code	Variable	Number	% Crashes at Night
0	No Traffic Control Present	944	30
2	Stop Sign, Stop-Go Officer, R.R., and All Other	147	39
9	Missing Data	678	42

Variable 35 - Accident Diagram Interpretation

Code	Variable	Number	% Crashes at Night
1	Rear-End Collision	161	44
2	Head-On Collision	169	43
3	Intersection Collision	308	47
4	Side Swipe (Vehicles Traveling in Same Direction)	35	23
6	Out of Control (To Right Side of Road)	570	38
7	Out of Control (To Left Side of Road)	485	35
9	Fire	43	32

TABLE E.5. (cont.)

Variable 36 - Road Straight or Curve

Code	Variable	Number	% Crashes at Night
1	Straight Road	1297	40
2	Curve Toad	448	40
9	Missing Data	26	31

Variable 37 - Vehicle #1 Movement

Code	Variable	Number	% Crashes at Night
0	Going Straight Ahead	1380	42
1	Overtaking Another Vehicle	53	20
2	Making Right Turn	83	31
3	Making Left Turn	63	52
4	Making U-Turn	2	50
5	Slowing, Stopping or Remaining Stopped in Traffic	45	29
6	Starting in Traffic	3	66
7	Starting from Parked Position	5	20
8	Backing	122	29
9	Remaining Parked (With or Without Vehicle Occupants)	15	13

Variable 38 - Vehicle #2 Movement*

Code	Variable	Number	% Crashes at Night
9	Remaining Parked (With or Without Vehicle Occupants)	1771	39

Variable 41 - Accident Severity

Code	Variable	Number	% Crashes at Night
1	Fatal	7	43
2	Injury	546	37
3	Property Damage	1218	40

*For pedestrians see Washtenaw County Dictionary, 4 August 1971.

TABLE E.5. (cont.)

Variable 42 - Violation Driver #1

Code	Variable	Number	% Crashes at Night
0	More Than One Violation Indicated	74	32
1	Speed Too Fast	451	40
2	Failure to Yield Right-of-Way, Failure to Stop	13	53
3	Drove Left of Center	7	57
4	Improper Overtaking	13	31
5	Followed Too Closely	13	31
6	Made Improper Turn or Failed to Signal	15	26
7	Improper Parking Location	3	66
8	Other	571	36
9	Not Known Due to Hit and Run	611	44

Variable 43 - Driver #1 Drinking Noted

Code	Variable	Number	% Crashes at Night
2	Had Not Been Drinking	1771	39

Variable 46 - Sex of Driver #1

Code	Variable	Number	% Crashes at Night
1	Male	1269	43
2	Female	490	32
9	Missing Data	12	42

Variable 51 - Type of Vehicle #1

Code	Variable	Number	% Crashes at Night
0	Full Size	1338	40
1	Intermediate	14	36
2	Compact	195	46
3	Sports Car	48	37
5	Jeep Type	2	0
7	Unit or Straight Tractor	3	33
8	Truck or Tractor (Semi)	52	35
9	Other or Not Known	119	32

TABLE E.5. (concl.)

Variable 149 - Speed Car #1, Bracket-A

Code	Variable	Number	% Crashes at Night
0	0 Mph.	14	28
1	1-10 Mph.	268	24
2	11-20 Mph.	193	39
3	21-30 Mph.	282	42
4	31-40 Mph.	328	41
5	41-50 Mph.	324	47
6	51-60 Mph.	183	40
7	61-70 Mph.	147	48
8	71-80 Mph.	13	30
9	81-90 Mph.	19	26

Variable 157 - Age Driver #1, Bracket-B

Code	Variable	Number	% Crashes at Night
0	0-15 Yrs.	23	17
1	16 Yrs.	95	37
2	17 Yrs.	100	50
3	18-19 Yrs.	239	46
4	20-21 Yrs.	188	40
5	22-24 Yrs.	259	41
6	25-29 Yrs.	208	38
7	30-34 Yrs.	131	41
8	35-44 Yrs.	219	36
9	45-54 Yrs.	309	34

TABLE E.6. Washtenaw County Day vs. Night Crashes Involving Multiple Vehicles with No Drinking, 1971.

Variable 8 - Reporting Department

Code	Variable	Number	% Crashes at Night
0	Ann Arbor Police	1108	20
1	Washtenaw County Sheriff	1051	22
3	Manchester	15	27
4	Saline	73	17
5	Brighton, State Police Post 12	23	22
6	Ypsilanti, State Police Post 26	737	26
7	Jackson, State Police Post 41	2	0
8	Milan	35	34
9	Other	698	19

Variable 20 - Road Surface Condition

Code	Variable	Number	% Crahses at Night
1	Dry	2309	19
2	Wet	932	23
3	Snowy or Icy	483	29
4	Other (e.g. Gravel, Dirt or Sand)	14	21
9	Missing Data	4	0

Variable 26 - Area of Vehicle #1 Hit

Code	Variable	Number	% Crahses at Night
0	Top or Rollover	121	24
1	Front	1532	22
2	Right Front	593	18
3	Right Side	193	24
4	Right Rear	127	26
5	Rear	130	24
6	Left Rear	103	19
7	Left Side	174	30
8	Left Front	568	20
9	More Than One Major Inclusive Area Damaged	201	21

TABLE E.6. (cont.)

Variable 28 - Total Number of Vehicles

Code	Variable	Number	% Crashes at Night
2	Two Vehicles Involved	3439	22
3	Three Vehicles Involved	263	22
4	Four Vehicles Involved	35	20
5	Five Vehicles Involved	4	25
8	Eight or More Vehicles Involved	1	0

Variable 29 - Total Number of Lanes

Code	Variable	Number	% Crashes at Night
2	Two Lanes	180	15
3	Three Lanes	310	20
4	Four Lanes	2883	22
5	Five Lanes	77	26
6	Six Lanes	1	0
9	Missing Data	291	20

Variable 34 - Traffic Control Present?

Code	Variable	Number	% Crashes at Night
0	No Traffic Control Present	1203	20
1	Traffic Control Not Functioning, Inadequate or Obscured	12	17
2	Stop Sign, Stop-Go Officer, R.R., and All Other	1224	21
9	Missing Data	1303	24

Variable 35 - Accident Diagram Interpretation

Code	Variable	Number	% Crashes at Night
1	Rear-End Collision	1210	22
2	Head-On Collision	213	23
3	Intersection Collision	1971	21
4	Side Swipe (Vehicles Traveling in Same Direction)	313	21

TABLE E.6. (cont.)

Variable 35 (cont.)

Code	Variable	Number	% Crashes at Night
6	Out of Control (To Right Side of Road)	10	20
7	Out of Control (To Left Side of Road)	3	33
9	Fire	22	10

Variable 36 - Road Straight or Curve

Code	Variable	Number	% Crahses at Night
1	Straight Road	3360	22
2	Curve Road	357	19
9	Missing Data	25	16

Variable 37 - Vehicle #1 Movement

Code	Variable	Number	% Crashes at Night
0	Going Straight Ahead	2521	23
1	Overtaking Another Vehicle	119	15
2	Making Right Turn	181	17
3	Making Left Turn	475	20
4	Making U-Turn	9	11
5	Slowing, Stopping or Remaining Stopped in Traffic	229	25
6	Starting in Traffic	42	14
7	Starting from Park Position	26	8
8	Backing	114	17
9	Remaining Parked (With or Without Vehicle Occupants)	26	46

Variable 38 - Vehicle #2 Movement*

Code	Variable	Number	% Crashes at Night
0	Going Straight Ahead	1943	22
1	Overtaking Another Vehicle	85	28
2	Making Right Turn	194	19
3	Making Left Turn	673	21

*For pedestrians see Washtenaw County Dictionary, 4 August 1971.

TABLE E.6. (cont.)

Variable 38 (cont.)

Code	Variable	Number	% Crahses at Night
4	Making U-Turn	18	22
5	Slowing, Stopping or Remaining Stopped in Traffic	676	21
6	Starting in Traffic	50	12
7	Start from Parked Position	18	11
8	Backing	85	15

Variable 41 - Accident Severity

Code	Variable	Number	% Crahses at Night
1	Fatal	13	53
2	Injury	1324	23
3	Property Damage	2405	20

Variable 42 - Violation Driver #1

Code	Variable	Number	% Crashes at Night
0	More Than One Violation Indicated	224	19
1	Speed Too Fast	338	23
2	Failure to Yield Right-of-Way, Failure to Stop	699	20
3	Drove Left of Center	62	27
4	Improper Overtaking	69	14
5	Followed Too Closely	256	22
6	Made Improper Turn or Failed to Signal	95	12
7	Improper Parking Location	8	25
8	Other	902	20
9	Not Known Due to Hit and Run	1089	24

Variable 43 - Driver #1 Drinking Noted

Code	Variable	Number	% Crashes at Night
2	Had Not Been Drinking	3742	21

TABLE E.6. (cont.)

Variable 46 - Sex of Driver #1

Code	Variable	Number	% Crashes at Night
1	Male	2556	23
2	Female	1168	18
9	Missing Data	18	28

Variable 51 - Type of Vehicle #1

Code	Variable	Number	% Crashes at Night
0	Full Size	3047	21
1	Intermediate	7	0
2	Compact	427	22
3	Sports Car	73	17
4	Station Bus, Carryall	1	0
5	Jeep Type	8	13
7	Unit or Straight Tractor	4	50
8	Truck Tractor (Semi)	61	11
9	Other or Not Known	114	23

Variable 149 - Speed Car #1, Bracket-A

Code	Variable	Number	% Crashes at Night
0	0 Mph.	136	35
1	1-10 Mph.	1105	16
2	11-20 Mph.	721	18
3	21-30 Mph.	849	25
4	31-40 Mph.	424	23
5	41-50 Mph.	235	28
6	51-60 Mph.	119	27
7	61-70 Mph.	98	21
8	71-80 Mph.	5	40
9	81-90 Mph.	50	30

TABLE E.6. (concl.)

Variable 157 - Age Driver #1, Bracket-B

Code	Variable	Number	% Crashes at Night
0	0-15 Yrs.	12	8
1	16 Yrs.	121	19
2	17 Yrs.	201	29
3	18-19 Yrs.	414	27
4	20-21 Yrs.	428	26
5	22-24 Yrs.	520	23
6	25-29 Yrs.	473	20
7	30-34 Yrs.	291	24
8	35-44 Yrs.	484	16
9	45-54 Yrs.	798	17

TABLE E.7. Washtenaw County Day vs. Night Crashes Involving Head-On, Side Swipe, Out-of-Control (Left or Right) Collisions with Drinking, 1971.

Variable 8 - Reporting Department

Code	Variable	Number	% Crashes at Night
0	Ann Arbor Police	106	73
1	Washtenaw County Sheriff	375	75
2	Dexter	1	100
3	Manchester	1	100
4	Saline	7	71
5	Brighton, State Police Post 12	2	100
6	Ypsilanti, State Police Post 26	135	67
8	Milan	11	72
9	Other	82	70

Variable 20 - Road Surface Condition

Code	Variable	Number	% Crashes at Night
1	Dry	480	73
2	Wet	133	71
3	Snowy or Icy	102	74
4	Other (e.g. Gravel, Dirt or Sand)	4	75
9	Missing Data	1	100

Variable 26 - Area of Vehicle #1 Hit

Code	Variable	Number	% Crashes at Night
0	Top or Rollover	196	76
1	Front	194	69
2	Right Front	90	70
3	Right Side	43	74
4	Right Rear	10	80
5	Rear	8	37
6	Left Rear	11	100
7	Left Side	43	79
8	Left Front	63	77
9	More Than One Major Inclusive Area Damaged	62	71

TABLE E.7. (cont.)

Variable 28 - Total Number of Vehicles

Code	Variable	Number	% Crashes at Night
1	One Vehicle Involved	543	73
2	Two Vehicles Involved	162	73
3	Three Vehicles Involved	12	83
4	Four Vehicles Involved	2	50
5	Five Vehicles Involved	1	100

Variable 29 - Total Number of Lanes

Code	Variable	Number	% Crashes at Night
2	Two Lanes	59	79
3	Three Lanes	18	72
4	Four Lanes	557	73
5	Five Lanes	1	100
9	Missing Data	85	67

Variable 34 - Traffic Control Present?

Code	Variable	Number	% Crashes at Night
0	No Traffic Control Present	279	74
2	Stop Sign, Stop-Go Officer, R.R., and All Other	89	72
9	Missing Data	352	73

Variable 35 - Accident Diagram Interpretation

Code	Variable	Number	% Crashes at Night
2	Head-On Collision	104	71
4	Side Swipe (Vehicles Traveling in Same Direction)	82	75
6	Out of Control (To Right Side of Road)	288	72
7	Out of Control (To Left Side of Road)	244	74
8	Rollover	2	100

TABLE E.7. (cont.)

Variable 36 - Road Straight or Curve

Code	Variable	Number	% Crashes at Night
1	Straight Road	481	72
2	Curve Road	228	76
9	Missing Data	10	50

Variable 37 - Vehicle #1 Movement

Code	Variable	Number	% Crashes at Night
0	Going Straight Ahead	581	74
1	Overtaking Another Vehicle	28	75
2	Making Right Turn	35	67
3	Making Left Turn	35	80
5	Slowing, Stopping or Remaining Stopped in Traffic	10	70
6	Starting in Traffic	1	100
7	Start from Park Position	5	20
8	Backing	5	80
9	Remaining Parked (With or Without Vehicle Occupants)	20	65

Variable 38 - Vehicle #2 Movement*

Code	Variable	Number	% Crashes at Night
0	Going Straight Ahead	100	74
1	Overtaking Another Vehicle	5	40
2	Making Right Turn	4	25
3	Making Left Turn	9	66
5	Slowing, Stopping or Remaining Stopped in Traffic	12	75
6	Starting in Traffic	1	100
7	Start from Park Position	1	100
8	Backing	2	0
9	Remaining Parked (With or Without Vehicle Occupants)	586	74

*For pedestrians see Washtenaw County Dictionary, 4 August 1971.

TABLE E.7. (cont.)

Variable 41 - Accident Severity

Code	Variable	Number	% Crashes at Night
1	Fatal	21	76
2	Injury	313	72
3	Property Damage	386	74

Variable 42 - Violation Driver #1

Code	Variable	Number	% Crashes at Night
0	More Than One Violation Indicated	102	78
1	Speed Too Fast	227	74
2	Failure to Yield Right-of-Way, Failure to Stop	17	52
3	Drove Left of Center	39	87
4	Improper Overtaking	8	50
5	Followed Too Closely	1	100
6	Made Improper Turn or Failed to Signal	4	25
7	Improper Parking Location	2	100
8	Other	229	75
9	Not Known Due to Hit and Run	91	65

Variable 43 - Driver #1 Drinking Noted

Code	Variable	Number	% Crashes at Night
1	Had Been Drinking	497	74
3	Not Known if Drinking	165	70
9	Missing Data	58	72

Variable 46 - Sex of Driver #1

Code	Variable	Number	% Crashes at Night
1	Male	554	74
2	Female	86	65
9	Missing Data	80	73

TABLE E.7. (concl.)

Variable 51 - Type of Vehicle #1

Code	Variable	Number	% Crashes at Night
0	Full Size	558	74
1	Intermediate	3	66
2	Compact	70	72
3	Sports Car	30	80
5	Jeep Type	2	50
6	Pickup or Panel	1	100
8	Truck Tractor (Semi)	5	20
9	Other or Not Known	51	64

Variable 149 - Speed Car #1, Bracket-A

Code	Variable	Number	% Crashes at Night
0	0 Mph.	19	63
1	1-10 Mph.	30	63
2	11-20 Mph.	43	60
3	21-30 Mph.	101	81
4	31-40 Mph.	129	68
5	41-50 Mph.	153	75
6	51-60 Mph.	85	76
7	61-70 Mph.	93	78
8	71-80 Mph.	17	47
9	81-90 Mph.	50	77

Variable 157 - Age of Driver #1, Bracket-B

Code	Variable	Number	% Crashes at Night
0	0-15 Yrs.	2	0
1	16 Yrs.	8	100
2	17 Yrs.	14	78
3	18-19 Yrs.	57	84
4	20-21 Yrs.	89	75
5	22-24 Yrs.	102	70
6	25-29 Yrs.	110	77
7	30-34 Yrs.	74	80
8	35-44 Yrs.	92	67
9	45-54 Yrs.	172	66

TABLE E.8. Washtenaw County Day vs. Night Crashes Involving Rear-End and Intersection Collisions with Drinking, 1971.

Variable 8 - Reporting Department

Code	Variable	Number	% Crashes at Night
0	Ann Arbor Police	144	58
1	Washtenaw County Sheriff	148	59
2	Dexter	1	0
3	Manchester	10	40
4	Saline	12	50
5	Brighton, State Police Post 12	6	83
6	Ypsilanti, State Police Post 26	164	53
8	Milan	5	60
9	Other	214	51

Variable 20 - Road Surface Condition

Code	Variable	Number	% Crashes at Night
1	Dry	483	53
2	Wet	134	59
3	Snowy or Icy	76	60
4	Other (e.g. Gravel, Dirt or Sand)	7	43
9	Missing Data	4	75

Variable 26 - Area of Vehicle #1 Hit

Code	Variable	Number	% Crashes at Night
0	Top or Rollover	36	64
1	Front	265	56
2	Right Front	90	59
3	Right Side	24	50
4	Right Rear	30	60
5	Rear	33	45
6	Left Rear	27	40
7	Left Side	31	67
8	Left Front	71	56
9	More Than One Major Inclusive Area Damaged	97	49

TABLE E.8. (cont.)

Variable 28 - Total Number of Vehicles

Code	Variable	Number	% Crashes at Night
1	One Vehicle Involved	55	65
2	Two Vehicles Involved	593	55
3	Three Vehicles Involved	47	38
4	Four Vehicles Involved	6	66
5	Five Vehicles Involved	2	100
7	Seven Vehicles Involved	1	0

Variable 29 - Total Number of Lanes

Code	Variable	Number	% Crashes at Night
2	Two Lanes	47	61
3	Three Lanes	47	42
4	Four Lanes	493	57
5	Five Lanes	5	60
9	Missing Data	112	47

Variable 34 - Traffic Control Present?

Code	Variable	Number	% Crashes at Night
0	No Traffic Control Present	338	54
2	Stop Sign, Stop-Go Officer, R.R., and All Other	153	48
9	Missing Data	213	64

Variable 35 - Accident Diagram Interpretation

Code	Variable	Number	% Crashes at Night
1	Rear-End Collision	299	56
3	Intersection Collision	366	52
9	Fire	36	61

TABLE E.8. (cont.)

Variable 36 - Road Straight or Curve

Code	Variable	Number	% Crashes at Night
1	Straight Road	621	55
2	Curve Road	67	59
9	Missing Data	16	44

Variable 37 - Vehicle #1 Movement

Code	Variable	Number	% Crashes at Night
0	Going Straight Ahead	402	61
1	Overtaking Another Vehicle	22	59
2	Making Right Turn	27	59
3	Making Left Turn	43	60
4	Making U-Turn	3	66
5	Slowing, Stopping or Remaining Stopped in Traffic	39	38
6	Starting in Traffic	6	17
7	Start from Park Position	13	23
8	Backing	56	46
9	Remaining Parked (With or Without Vehicle Occupants)	93	44

Variable 38 - Vehicle #2 Movement*

Code	Variable	Number	% Crashes at Night
0	Going Straight Ahead	229	55
1	Overtaking Another Vehicle	8	75
2	Making Right Turn	31	48
3	Making Left Turn	64	54
4	Making U-Turn	1	100
5	Slowing, Stopping or Remaining Stopped in Traffic	114	45
6	Starting in Traffic	10	70
7	Start from Park Position	2	0

*For pedestrians see Washtenaw County Dictionary, 4 August 1971.

TABLE E.8. (cont.)

Variable 38 (cont.)

Code	Variable	Number	% Crashes at Night
8	Backing	31	48
9	Remaining Parked (With or Without Vehicle Occupants)	214	62

Variable 41 - Accident Severity

Code	Variable	Number	% Crashes at Night
1	Fatal	9	55
2	Injury	220	60
3	Property Damage	475	52

Variable 42 - Violation Driver #1

Code	Variable	Number	% Crashes at Night
0	More Than One Violation Indicated	56	53
1	Speed Too Fast	85	69
2	Failure to Yield Right-of-Way, Failure to Stop	60	48
3	Drove Left of Center	16	68
4	Improper Overtaking	13	46
5	Followed Too Closely	48	35
6	Make Improper Turn, or Failed to Signal	8	64
7	Improper Parking Location	1	100
8	Other	225	58
9	Not Known Due to Hit and Run	192	51

Variable 43 - Driver #1 Drinking Noted

Code	Variable	Number	% Crashes at Night
1	Had Been Drinking	337	66
3	Not Known if Drinking	183	48
9	Missing Data	184	42

TABLE E.8. (cont.)

Variable 46 - Sex of Driver #1

Code	Variable	Number	% Crashes at Night
1	Male	423	63
2	Female	95	39
9	Missing Data	185	46

Variable 51 - Type of Vehicle #1

Code	Variable	Number	% Crashes at Night
0	Full Size	584	55
1	Intermediate	2	100
2	Compact	41	61
3	Sports Car	15	66
8	Truck Tractor (Semi)	5	20
9	Other or Not Known	57	47

Variable 149 - Speed Car #1, Bracket-A

Code	Variable	Number	% Crashes at Night
0	0 Mph.	96	47
1	1-10 Mph.	142	44
2	11-20 Mph.	89	53
3	21-30 Mph.	132	59
4	31-40 Mph.	73	65
5	41-50 Mph.	58	62
6	51-60 Mph.	26	69
7	61-70 Mph.	23	78
8	71-80 Mph.	3	0
9	81-90 Mph.	62	55

TABLE E.8. (concl.)

Variable 157 - Age of Driver #1, Bracket-B

Code	Variable	Number	% Crashes at Night
0	0-15 Yrs.	3	0
1	16 Yrs.	9	66
2	17 Yrs.	11	84
3	18-19 Yrs.	37	54
4	20-21 Yrs.	57	47
5	22-24 Yrs.	66	68
6	25-29 Yrs.	68	69
7	30-34 Yrs.	50	72
8	35-44 Yrs.	85	54
9	45-54 Yrs.	318	48