97... 5

COMPUTER SIMULATION EVALUATION OF VISIBILITY DISTANCES PROVIDED BY THREE HEADLAMP SYSTEMS (C, D, E)

Rudolf G. Mortimer and Judith M. Becker

Highway Safety Research Institute
University of Michigan
Ann Arbor, Michigan 48105

Report No. UM-HSRI-HF-TM-73-3

February 22, 1973

Ford Motor Company
Dearborn, Michigan

ABSTRACT

A computer simulation evaluation of the visibility distances provided by three headlighting systems is described. Two of the headlighting systems consisted of low, mid and high beams, and the other of low and high beams. A currently used low and high beam (type 6014) system was also evaluated, for comparison with the experimental beams. Visibility distances were derived, before and after meeting an opposing vehicle with the same headlights on a straight road for targets at the right side and center of the lane.

Low and mid beams produced greater visibility distances to the right target than in the center of the lane, whereas high beams were mostly unaffected by target location. Overall, mid beams produced about 10% greater visibility distances than the low beams. The type 6014 low beam produced equal or greater visibility than the experimental low beams, while its high beam was intermediate in effectiveness compared to the other systems.

TABLE OF CONTENTS

INTRODUCTION

Since the accident rate per mile is about three times higher in nighttime than daytime driving conditions, and because it is intuitively clear that the visibility provided to drivers on roads and highways which do not have fixed illumination is less than desirable under many conditions, efforts have been underway to improve the vehicle headlighting system. Among the more noteworthy developments in vehicle headlighting, in the United States, have been the introduction of the sealed beam lamp and the quad-headlamp system of four 5-3/4" lamps. The most recent change in vehicle headlighting has been the introduction, during the last two years, of low beam headlamps providing improved control of the distribution of light by a change in the fluting and increase in the wattage of the filaments to provide greater light intensities for the low beam.

Thus, while there has been a continuing development in vehicle headlighting systems, the need for providing improved night driving visibility is still apparent in order to allow traffic to move safely at normal highway speeds. Most recently, the results of research and development efforts have suggested that an improvement in headlighting may be feasible using conventional light sources, by introducing a third beam. Initially, this beam was intended to be used to supplement the low beam system on divided highways. Since vehicle speeds are highest on such roads, it would appear to be appropriate to first seek improvements in visibility on such roads. However, the, accident statistics indicate that those roads also provide the safest driving conditions, whereas the two-lane, rural roads pose a greater hazard and a more difficult seeing condition in night driving. Attention is now being given to means of supplementing the presently used low beam headlamp system by a mid beam that could be used, not only on divided highways, but on two lane roads as well.

When the lateral separation between opposing vehicles is small, as is the case on two lane roads, the problems associated with glare from vehicle headlamp systems become accute in terms of the disability glare effect upon the visibility distance and discomfort glare. To satisfy these requirements, the beam must be appropriately shaped to maintain sufficiently low glare values while providing sufficient additional light along the lane being traveled to provide an improvement in visibility distance.

In order to help to devise a methodology for the evaluation of headlighting systems, such that any improvements that they offer may become readily discernable, studies at HSRI have been conducted to develop a technique for the field testing of headlamp systems (Mortimer and Olson, 1973), to assess the role of a number of factors that may contribute to the misalignment of headlamps (Olson and Mortimer, 1973), and to develop a validated mathematical model which can be used to predict the visibility distances afforded by various types and combinations of headlamp beams (Mortimer and Becker, 1973).

This report briefly described the factors considered in the development of the mathematical model and the variables that it takes into consideration. The use of this model, in the form of a computer simulation of a nighttime meeting between two opposing vehicles, is demonstrated by comparison with field test data, in order to show the validity of the predictions made by the model. The computer simulation was then exercised on three headlamp systems that are under consideration for possible implementation. These systems consist of two that have three beams (low, mid, high) and one consisting of low and high beams only. The results of the computer simulation are described and comparisons are made to a conventional, 7 inch, type 6014 low and high beam headlamp system operated in the same driving conditions as used for the evaluations of the three proposed systems.

It is believed, that the computer simulation method holds considerable promise as a technique by which to determine the nature of improvements, in terms of visibility distance, that can be attained by a headlamp system; and the procedure should permit the development of improved conventional headlamp beams.

1. BRIEF DESCRIPTION OF HSRI HEADLAMP PERFORMANCE COMPUTER SIMULATION

The visibility distance simulation includes the road, two vehicles, a target, an observer, and the mathematical relations describing them and their interactions.

The road is assumed to be flat and level with a constant reflectance. The two vehicles move on parallel paths, with constant lateral and vertical separation distances, at constant speeds. The longitudinal separation distance is defined as the independent variable. Each vehicle has a specified number of headlights, up to five, located in fixed positions relative to one another and aimed at any horizontal, vertical and rotational angles. The output of each headlight is described by a bivariate table of intensity in candelas for pairs of horizontal and vertical angles. Each lamp may be switched off or on twice at specified separation distances. The headlights of the observer's vehicle contribute to veiling glare by reflecting light back off the road ahead, to account for foreground lighting and road reflectance.

The observer is assumed to have a single eye located at an arbitrary point in the main vehicle. The eye line-of-sight tracks the target. The eye can be in one of three states: "adaptation" to increasing veiling glare, "readaptation" to slowly decreasing veiling glare, and "recovery" during rapidly decreasing veiling glare. Transition from "adaptation" to "readaptation" occurs at the point of maximum veiling glare, and passage from "readaptation" to "recovery" occurs when the veiling glare calculated from the glare vehicle beams begins to fall off more rapidly than that calculated from the "recovery" equation. During "readaptation," the "recovery" equation computes veiling glare as exponentially decaying from the value at the previous point at a fixed rate, the value of which is also dependent on the previous value of veiling glare. During "recovery" the parameters are constant.

There is an observer relation among intensity needed to see the target, target distance, and glare intensity. It is assumed that target intensity is an increasing exponential in target distance with coefficients that are functions of glare. These coefficients appear to be well described by asymptotic exponential equations in glare intensity. The target is located at a fixed lateral and vertical distance from the eye, with a constant reflectance.

Fry's equation computes veiling glare from glare intensity, distance of glare source from eye, and glare angle between eye line-of-sight and line connecting eye to glare source. The path of the target through the main vehicle beam patterns is found in terms of the values of horizontal and vertical angles at specified values of the dependent variable (visibility distance) and the interpolated intensity values are stored for later use in the program. A rectangular linear interpolation on the log of the intensity of the beam pattern is used here. The same thing is done for the path of the eye through the glare vehicle beam patterns using the separation distance, to derive the intensities directed at the observers eye point from the opposing vehicle's headlamps. The veiling glare effect produced by the foreground illumination and road reflectance, for one combination of lateral and vertical target location and beam patterns, is included for distances of 25-200 feet ahead of the observer's car, with coefficients found by processing the output of a separate program.

Since the system of equations derived from all this is much too complex to be explicitly solved for visibility distance in terms of separation distance, a convergence procedure is used to find the largest target distance at which the intensity directed at the target is just equal to the intensity needed to see the target.

2. VALIDATION OF THE MODEL

The output of the computer simulation is in the form of predicted visibility distance as a function of the longitudinal distance between the observer's vehicle and an opposing vehicle equipped with the same, or other, headlamps. The validity of the model can be assessed by comparing its predictions with the mean visibility distances obtained by a sample of drivers, aged 18-60, in field tests. These tests used a specific type of target requiring a choice response from the observers, in which they had to identify the orientation of a square figure in the target with reference (left or right) to a horizontal line, both of the same reflectance.

Figure 1 shows comparisons between the computer simulation and field test for the case of a target located at the right edge of the road, for low and high beams meetings, with both vehicles equipped with 7" diameter, 6014 lamps. Target location, lateral vehicle separation, road reflectance, headlamp mounting locations, etc. used in the simulation are the same as for the field test. The field test data are for target reflectances of 12% and 26%, while the simulation used 10% and 26%. For both beams and target reflectances a respectable degree of fit between simulation and field test results are obtained.

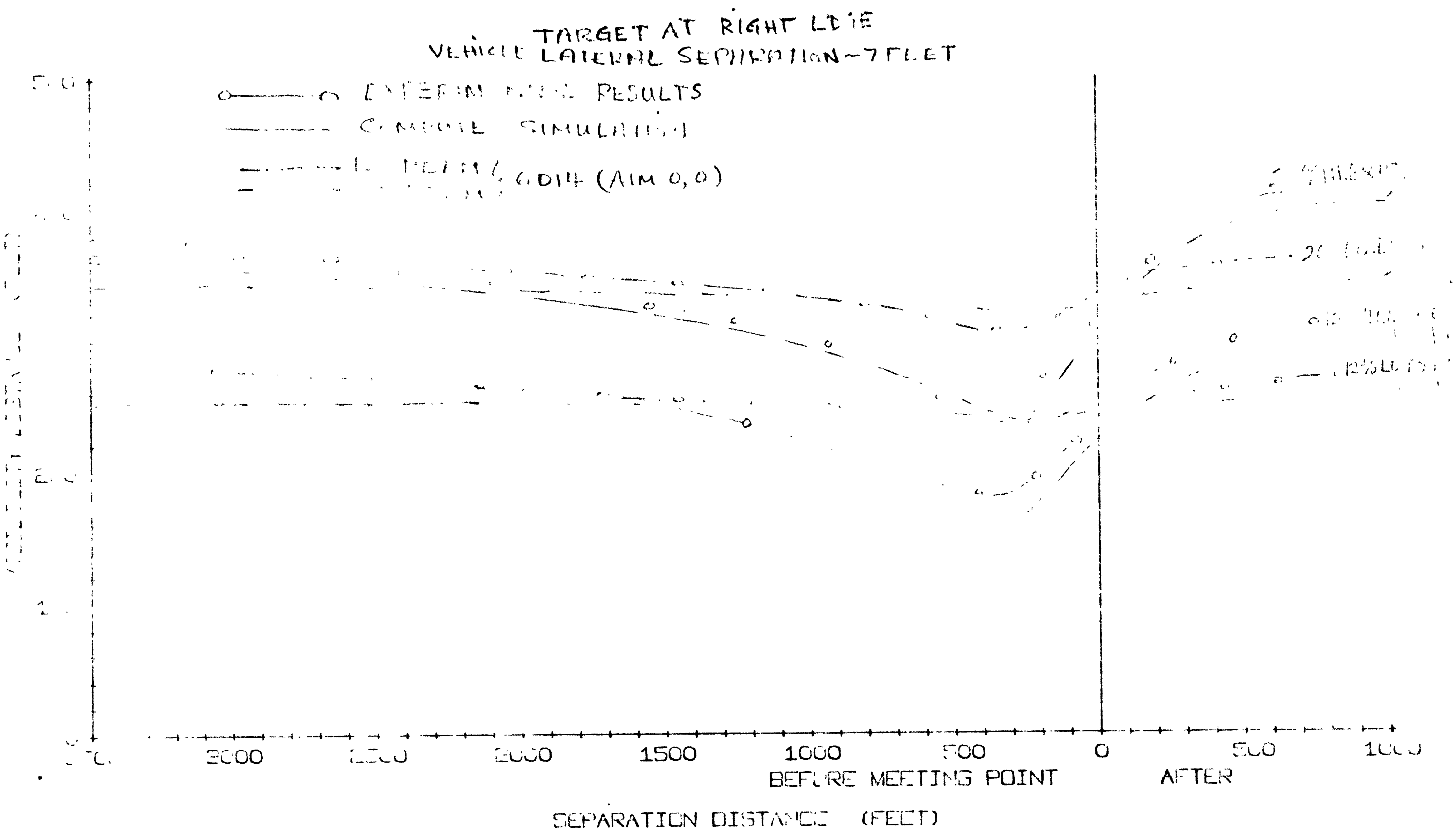


Figure 1. Comparison of experimental and computer simulation evaluations of 6014, 7" diameter, low and high beam meetings in terms of visibility distance as a function of longitudinal vehicle separation distance. Target reflectances: 12%, 26% in experiment, 10%, 26% in simulation. Road reflectance is 10%. Target at right edge of lane.

3. COMPUTER SIMULATION RESULTS FOR 6014 LOW AND HIGH BEAMS FOR COMPARISON WITH SYSTEMS C, D AND E

The results of model prediction for the 6014 low and high beams, for targets of 10% and 54% reflectance, using the same geometric, road reflectance and driver eye position conditions as used in the evaluations of the proposed systems C, D and E, to be described, are shown in Figures 2 and 3. In Figure 2 the target is positioned at the right edge of the road, and in Figure 3 it is in the center of the road lane on the projection of the long axis of the vehicle. These results can be compared with those for systems C, D and E to show the relative performance of a system presently in use.

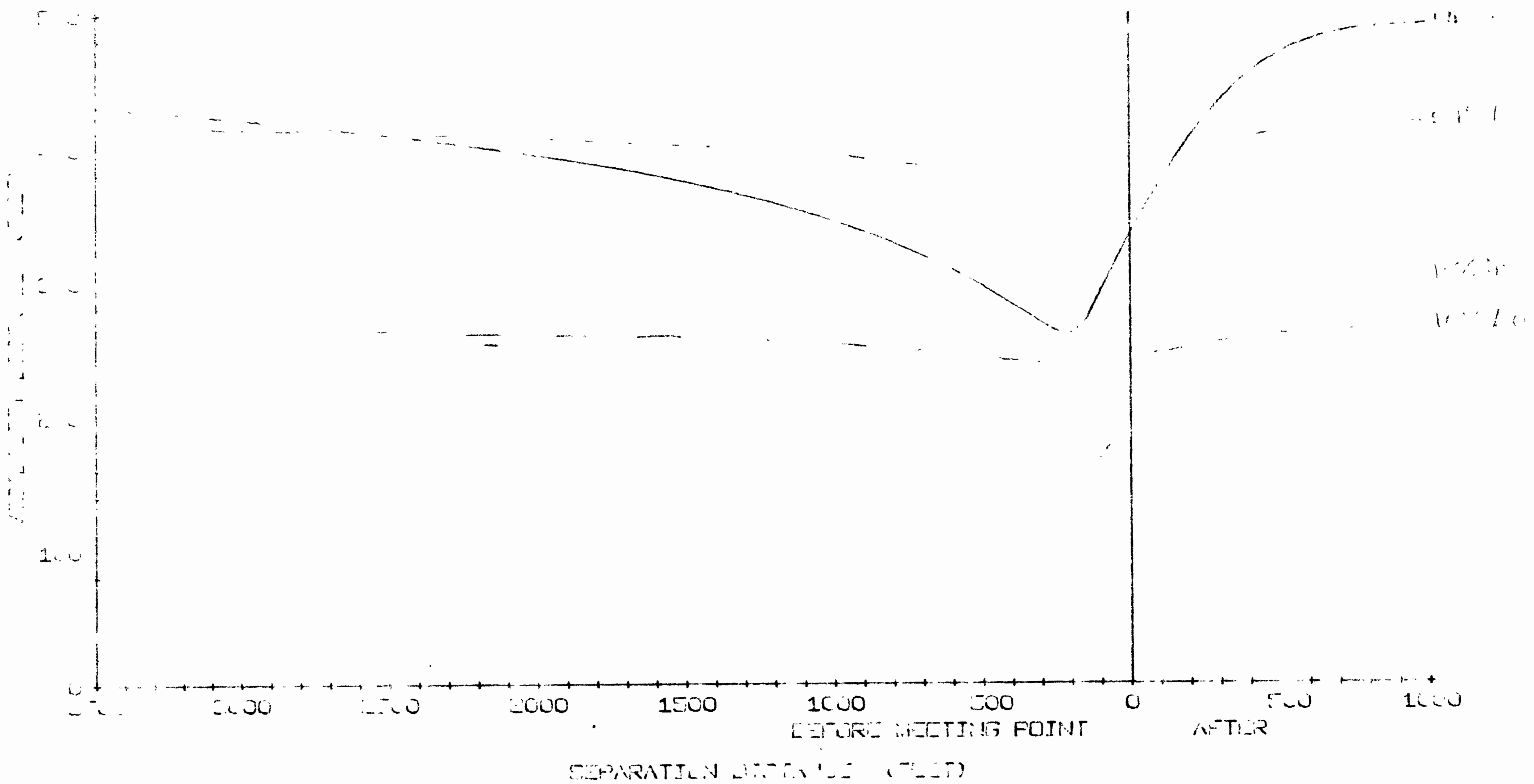


Figure 2. Computer simulation predicted visibility distances for 6014 low and high beams. Target at right edge of lane, 10% and 54% reflectances. (Other conditions the the same as for evaluations of systems C, D and E.)

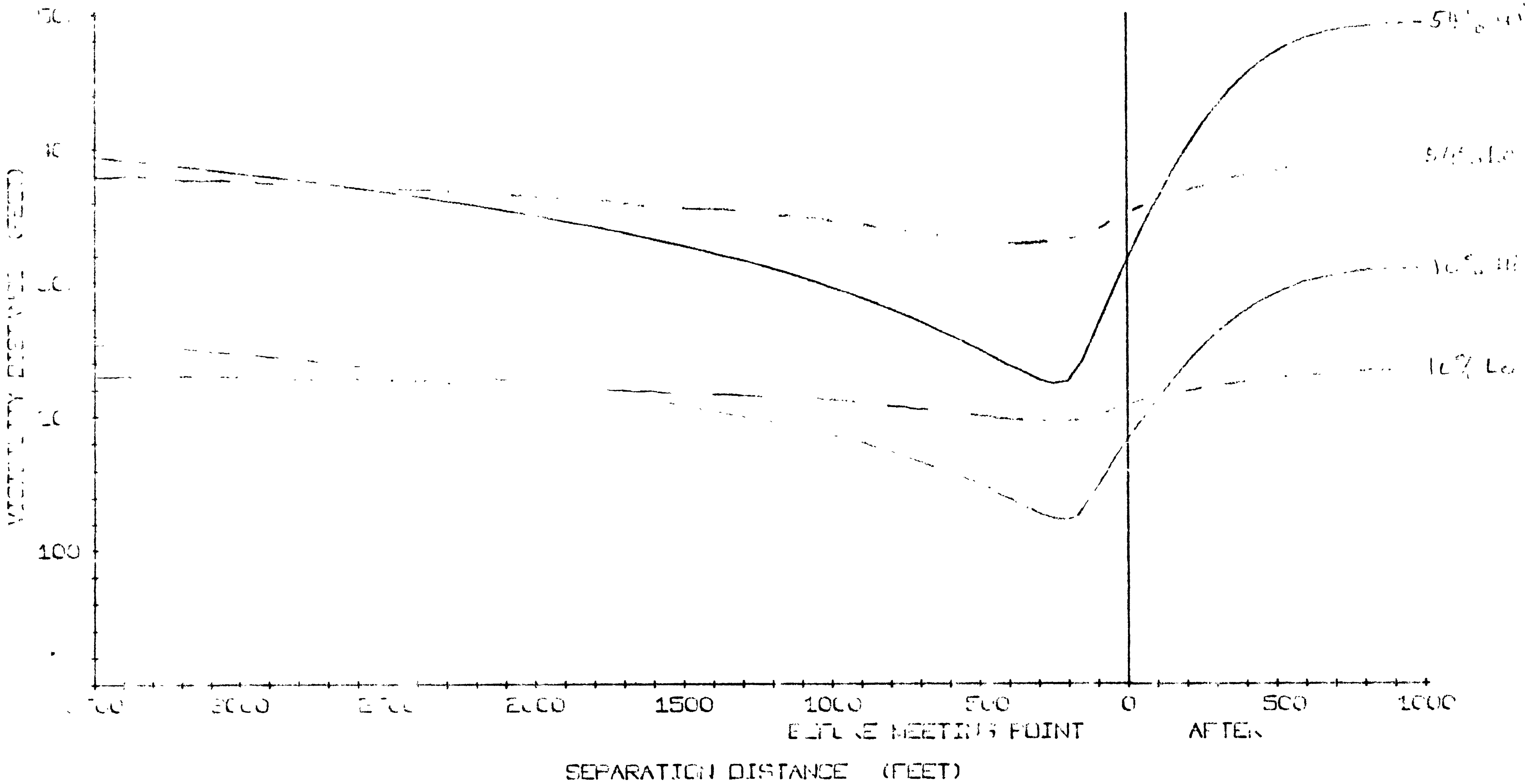


Figure 3. Computer simulation predicted visibility distances for 6014 low and high beams, target in center of lane, 10% and 54% reflectance. (Other conditions the same as for evaluations of systems C, D and E.)

4. DESCRIPTION OF SYSTEMS C, D AND E AND OTHER VARIABLES ENTERING COMPUTER SIMULATION

The three headlighting systems C, D and E are described in terms of iso-candela diagrams in Docket 69-19, Notice 3 (Federal Register, Vol. 37, #206, October 25, 1972, pp.22801-22812). The systems consist of combinations of four basic beams, for each of which the minimum and maximum proposed iso-candela values are shown in Figures 4-11.

BEAM DESCRIPTION

System C, Four Lamps.

Low beam: two type 3 on low beam

Mid beam: two type 3 on low beam + one type 4 on left side*

High beam: two type 3 on high beam, + type 4 on left side + type 5 on right side

All beams are used at 100% of indicated minimum and maximum values.

System D, Two Lamps.

Low beam: two type 3 on low beam

High beam: two type 3 on high beam,
Minimum iso-candela values 100% of type 3
Maximum iso-candela values 115% of type 3

System E, Two Lamps.

Low beam: two type 3 on low beam
Minimum iso-candela values: left lamp 80% of type 3, right lamp 100% of type 3
Maximum iso-candela values: left and right lamps at 100% of type 3

Mid beam: left lamp type 4, right lamp type 3
Minimum iso-candela values: left lamp 80% of type 4, right lamp 100% of type 3
Maximum iso-candela values: left lamp 100% of type 4, right lamp 100% of type 3

---

*As seen from driver's position.

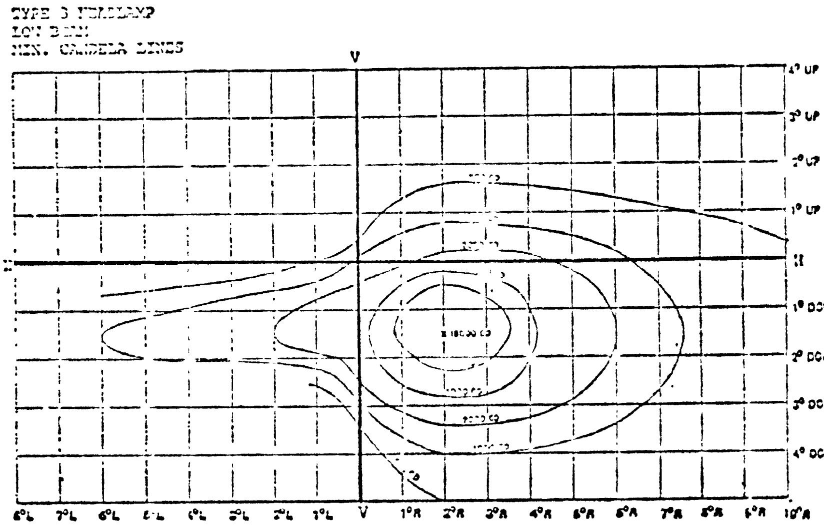


Figure 4. Type 3 headlamp low beam, minimum candela lines.

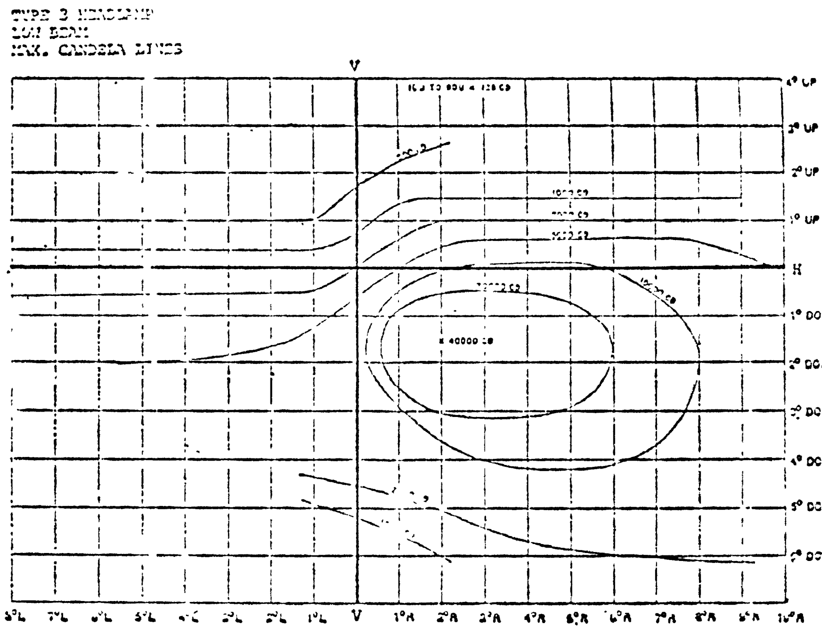


Figure 5. Type 3 headlamp low beam, maximum candela lines.

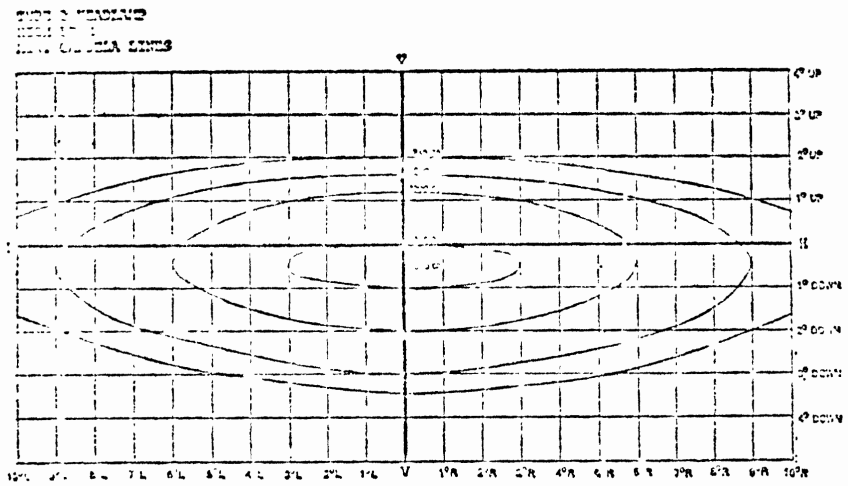


Figure 6. Type 3 headlamp high beam, minimum candela lines.

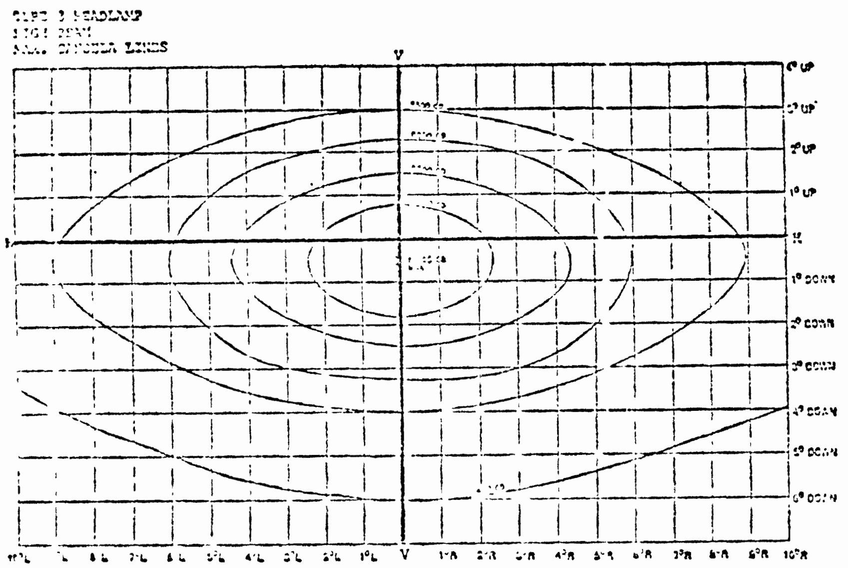


Figure 7. Type 3 headlamp high beam, maximum candela lines.

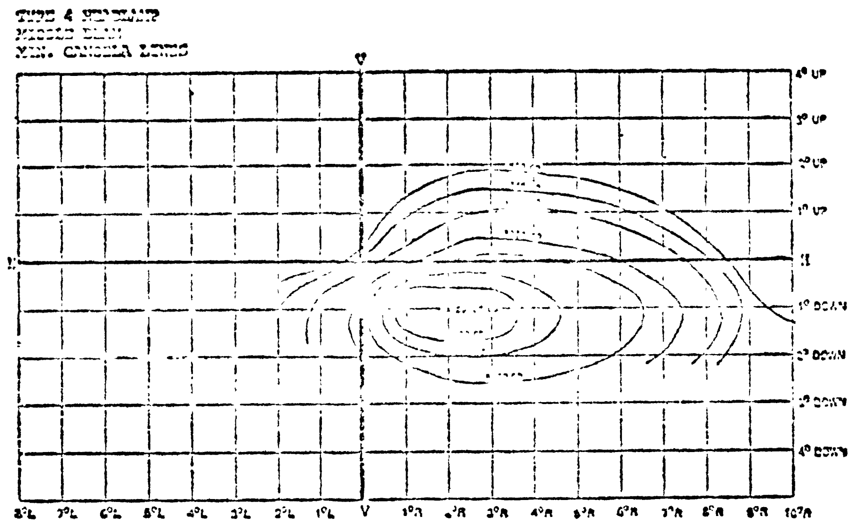


Figure 8. Type 4 headlamp middle beam, minimum candela lines.

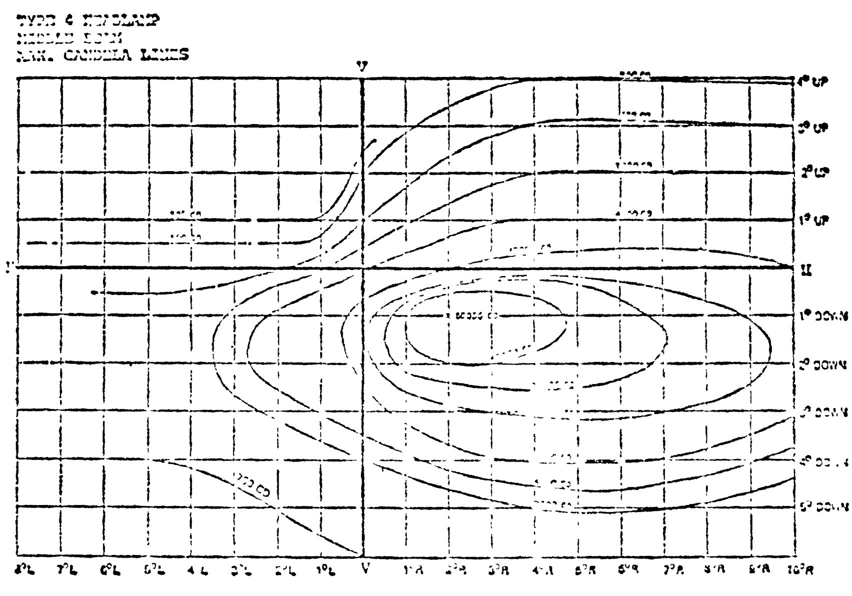


Figure 9. Type 4 headlamp middle beam, maximum candela lines.

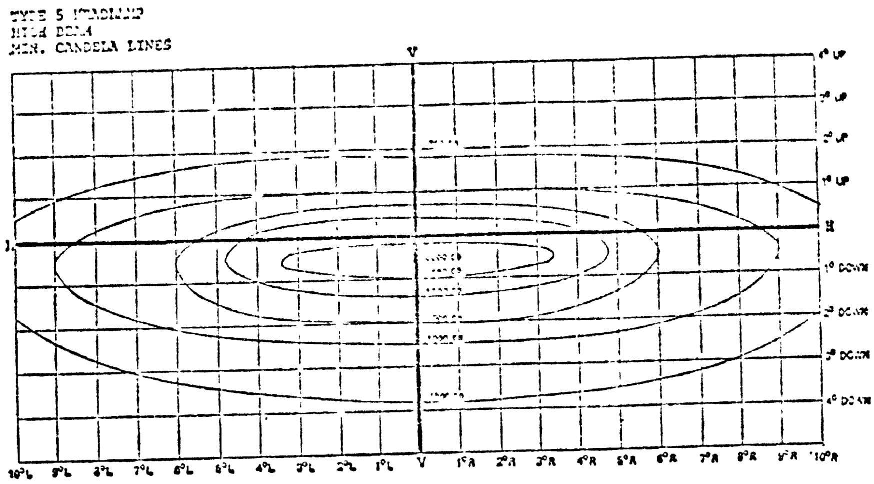


Figure 10. Type 5 headlamp high beam, minimum candela lines.

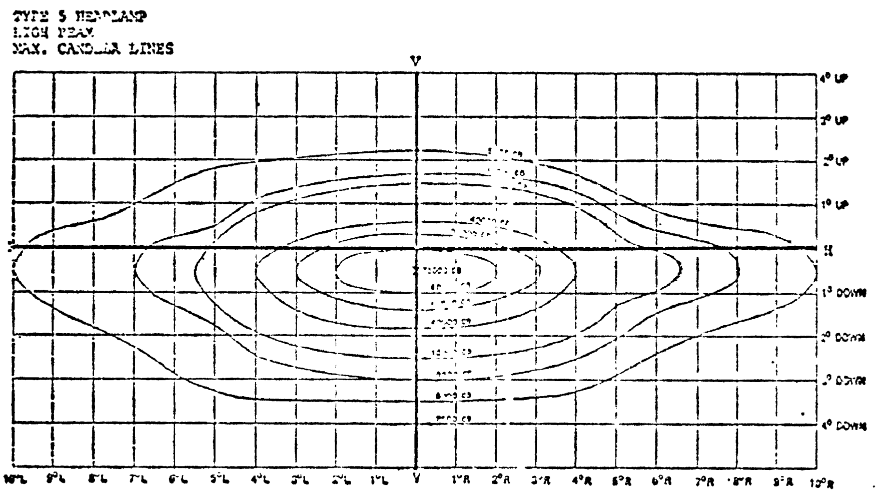
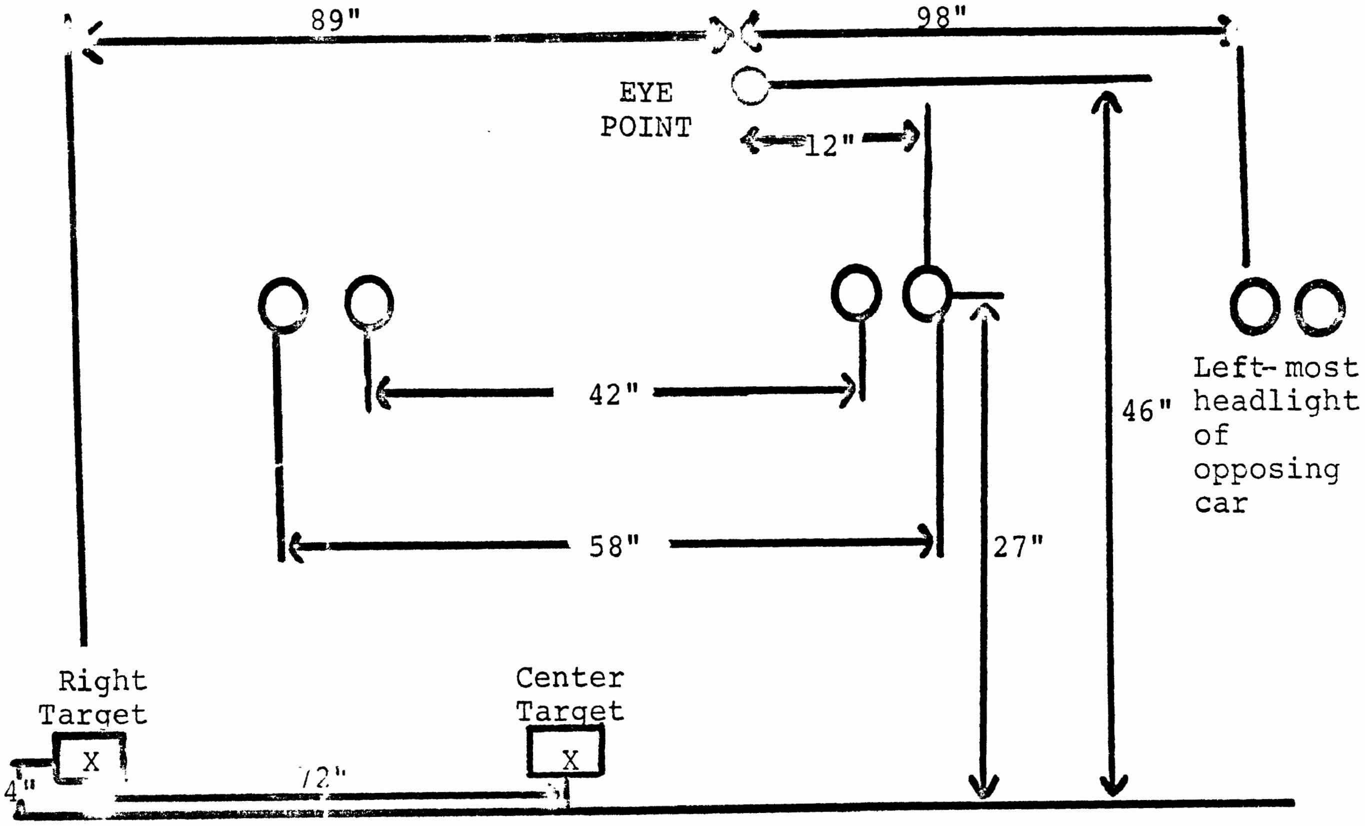


Figure 11. Type 5 headlamp high beam, maximum candela lines.

High beam: left lamp type 4, right lamp type 5
Minimum iso-candela values: left lamp 80% of type 4, right lamp 100% of type 5
Maximum iso-candela values: left lamp 100% of type 4, right lamp 100% of type 5

VALUES OF OTHER VARIABLES. The lamp mounting locations were taken from a 1972 Ford custom, four door sedan, and are shown in Figure 12. Lamp vertical height was 27 inches to centers, and the observer's eye height was 46 inches. The right side target was 89 inches to the right of the eye point and the center target was 17 inches to the right of the eye point. The left-most headlamp of the opposing car was 98 inches to the left of the eye point, to simulate a meeting with the vehicles centered in lanes 12 feet wide.

The road reflectance was taken as 10% and considered constant at all angles of incidence of the light from the headlamps of the observer's car. In the two-lamp systems, D and E, the outermost lamp locations were used.



Longitudinal distance of eye point to the lateral plane of the headlamp was 96 inches.

Figure 12. Lamp mounting and target locations with respect to observer's eye point.

5. COMPUTER SIMULATION EVALUATIONS OF SYSTEMS C, D AND E

Photographic enlargements of the iso-candela beam diagrams (Figures 4-11) were used to digitize the intensities found at half degree vertical and horizontal increments. The values shown in Tables A.1-A.8 (Appendix A) were obtained. The values were put on cards and stored in the HSRI IBM-1800 computer.

The parameter values described in the previous section were used to make simulation runs for each system operating in each of its beams. Since system C has three beams, system D has two beams and system E has three beams, a total of eight beams are involved. Each beam was run in minimum and in maximum iso-candela conditions and visibility distances for the target at the right side and in the center of the lane were obtained. This entailed a total of 32 runs. In each case the opposing vehicle was equipped with the same lamps as the observer's car.

RESULTS

An overview of Tables 1 and 2 shows that the low and mid beams produce greater visibility distances for the right side target than the center target. The high beams are only slightly affected by the target locations. This would be expected because the low and mid beams are assymetrical, placing the greatest intensities in the right lower quadrant, whereas high beams are relatively symmetrical and uniform around the central portion of the beam.

When the same beams are run at the maximum candela values and compared to visibility distances obtained for the minimum candela values, the maximum visibility distances increase (column 2, Tables 1 and 2), but the minimum visibility distances are generally lower (column 4, Tables 1 and 2), particularly for high beams.

The same columns in the Tables also show that the low beams provide lower maximum visibility distances than mid or high beams. This is to be expected since the maximum visibility distances are

TABLE 1. Maximum and Minimum Visibility Distances Obtained for Each Beam in Min. and Max. Iso-candela Conditions. Right Side, 10% Reflectance, Target.

Beam			Max. Vis. Dist (feet) (1)	Max. Vis. Dist. Ratio: Beam X / Low Min Beam X (2)	Min. Vis. Dist (feet) (3)	Min. Vis. Dist. Ratio: Beam X / Low Min Beam X (4)	Ratio: Max Vis Dist / Min Vis Dist (5)
System C	Low	Min	242	1.00	227	1.00	1.07
		Max	251	1.04	222	.98	1.13
	Mid	Min	267	1.10	252	1.11	1.06
		Max	274	1.13	244	1.07	1.12
	High	Min	295	1.22	204	.90	1.44
		Max	320	1.32	179	.79	1.79
System D	Low	Min	242	1.00	227	1.00	1.07
		Max	251	1.04	222	.98	1.13
	High	Min	243	1.00	153	.67	1.59
		Max	296	1.22	162	.71	1.83
System E	Low	Min	239	1.00	224	1.00	1.07
		Max	251	1.05	222	.99	1.13
	Mid	Min	237	.99	223	1.00	1.06
		Max	270	1.13	247	1.10	1.09
	High	Min	283	1.18	227	1.01	1.25
		Max	309	1.29	203	.91	1.52
6014	Low		267	1.00	237	1.00	1.12
	High		306	1.15	149	.62	2.05

TABLE 2. Maximum and Minimum Visibility Distances for Each Beam in Min. and Max. Iso-candela Conditions. Enter, 10% Reflectance, Target.

Beam			Max. Vis. Dist (feet) (1)	Max. Vis Dist. Ratio: Beam X / Low Min Beam X (2)	Min. Vis. Dist (feet) (3)	Min. Vis. Dist. Ratio: Beam X / Low Min Beam X (4)	Ratio: Max Vis Dist / Min Vis Dist (5)
System C	Low	Min	198	1.00	181	1.00	1.09
		Max	206	1.04	175	.97	1.18
	Mid	Min	222	1.12	199	1.10	1.12
		Max	230	1.16	192	1.06	1.19
	High	Min	293	1.48	171	.94	1.71
		Max	321	1.62	140	.77	2.29
System D	Low	Min	198	1.00	181	1.00	1.09
		Max	206	1.04	175	.97	1.18
	High	Min	249	1.26	133	.73	1.87
		Max	301	1.52	133	.73	2.26
System E	Low	Min	196	1.00	180	1.00	1.09
		Max	206	1.05	175	.97	1.18
	Mid	Min	193	.98	177	.98	1.09
		Max	225	1.15	196	1.09	1.14
	High	Min	275	1.40	199	1.11	1.38
		Max	304	1.55	165	.92	1.84
6014	Low		236	1.00	197	1.00	1.20
	High		312	1.32	124	.62	2.52

obtained after the meeting point when the effect of glare from the opposing car's headlamp had been largely removed.

By comparison, the ratios in column 4 in the Tables show that high beams generally produced lower minimum visibility distances, during the meeting than low beams. For the same comparison, the mid beams usually produced greater minimum visibility distances, since most ratios are greater than for the low beams.

Taking both the maximum and minimum visibility distances into consideration shows that, for the straight, level, two-lane road case that was simulated, the mid beams should be used throughout the meeting. It should be noted that effects due to discomfort glare are not considered in this evaluation.

In general, those beams that have relatively large maximum visibility distance: minimum visibility distance ratios are causing the decrement in visibility due to disability glare, and probably discomfort glare would be experienced by the drivers.

In this analysis the mid beams produced an increment in visibility of about 10% compared to low beams for either target location. High beams produced an increment of about 55% and 25% in maximum visibility distances, for the center and right side targets, respectively, compared to low beams.

Of the three systems, system C appeared to offer the greatest benefit in visibility distance.

For comparison with the proposed beams, the low and high beams of the conventional 6014 lamp were run under the same conditions as the other beams. The 6014 low beam provided greater maximum and greater minimum visibility than any of the other low beams, at about comparable glare levels as the low beam type 3 in maximum iso-candela conditions. The 6014 high beam produced similar maximum visibility as high beams of systems D and E, but lower than C; and lower minimum visibility than systems C, D and E. It should be noted that the 6014 lamp used in these evaluations is not necessarily representative of this type of lamp. (The photometric grids of the 6014 low and high beams are shown in Appendix B.)

The trends of visibility during the meeting and after the meeting for each beam of each system in maximum and minimum iso-candela conditions, for right and center targets, are shown in Figures 13-18. The individual plots of each beam in each condition are shown in Appendix C.

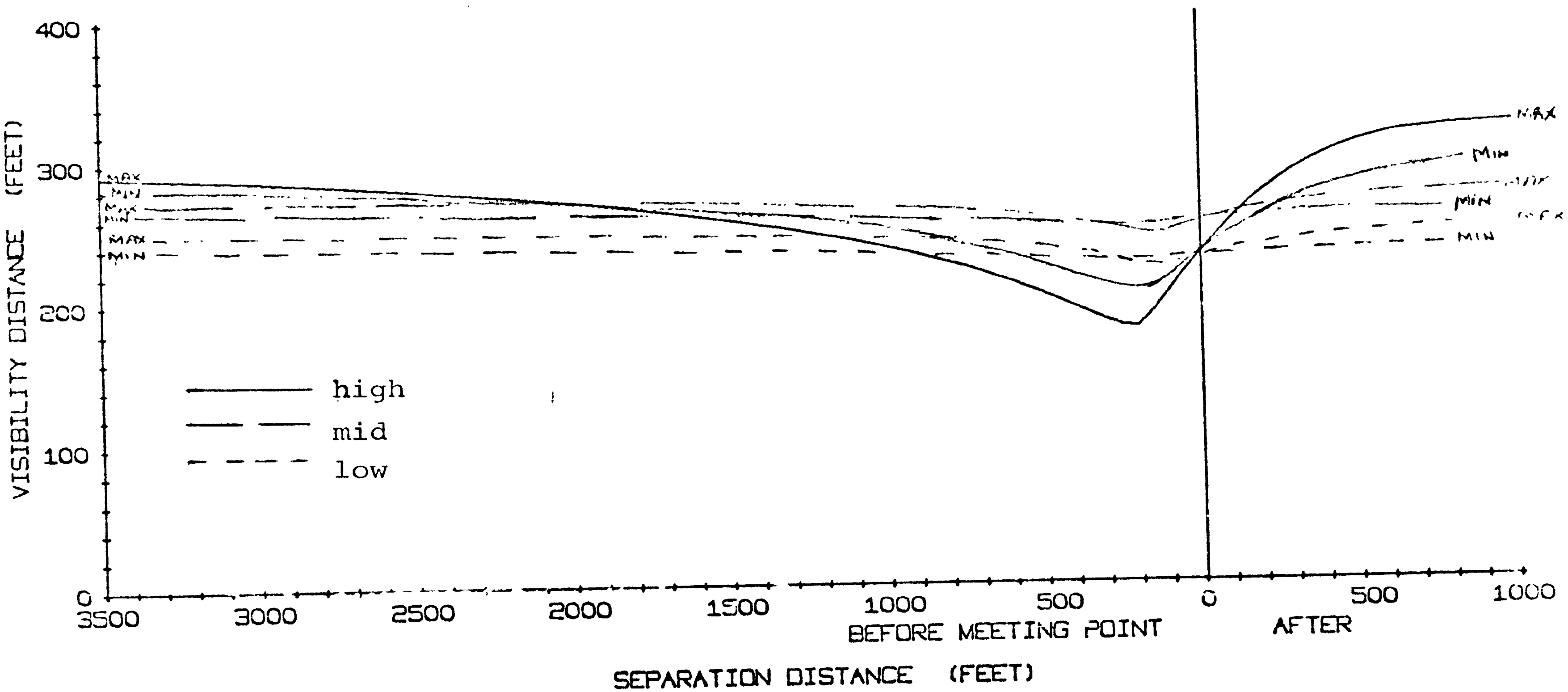


Figure 13. Computer simulation predicted visibility distances for system C low, mid and high beams, 10% reflectance target on right side.

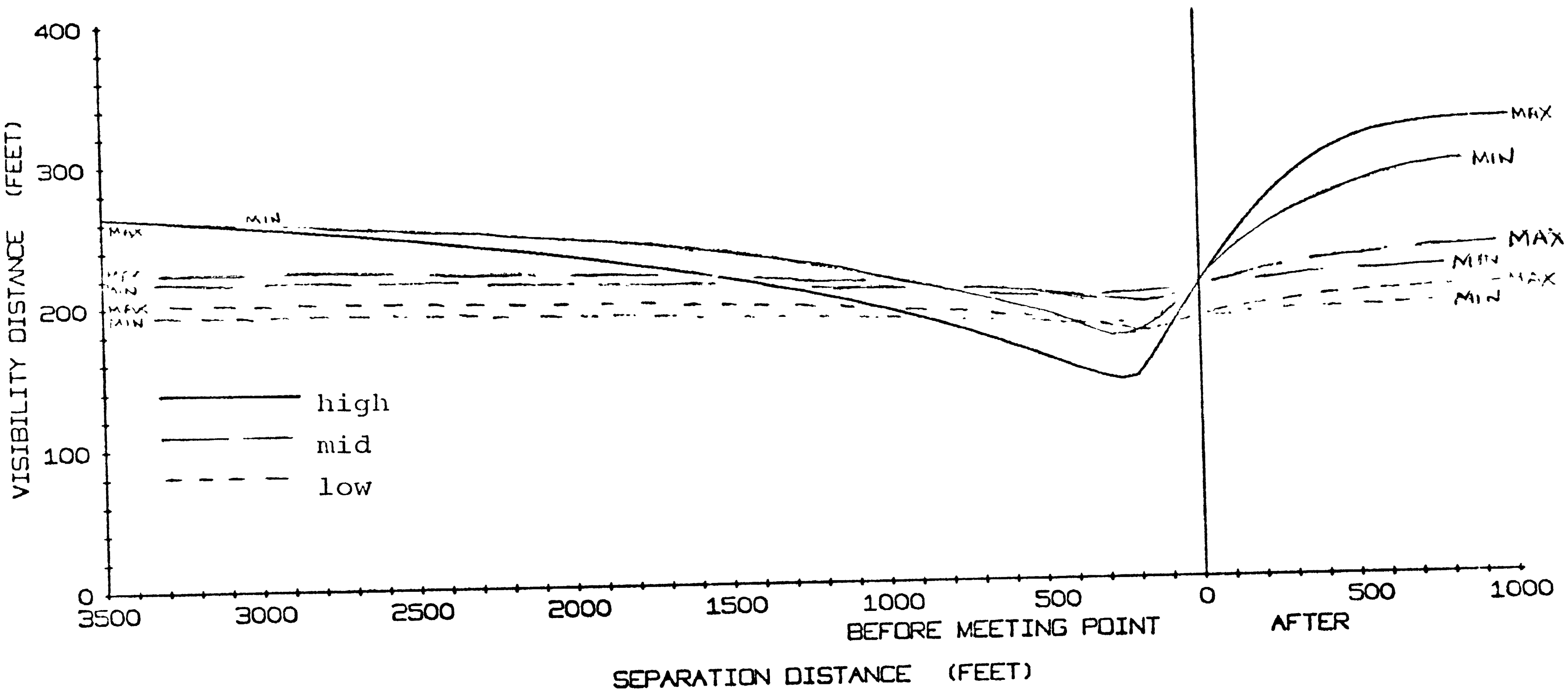


Figure 14. Computer simulation predicted visibility distances for system C low, mid and high beams, 10% reflectance target in center of lane.

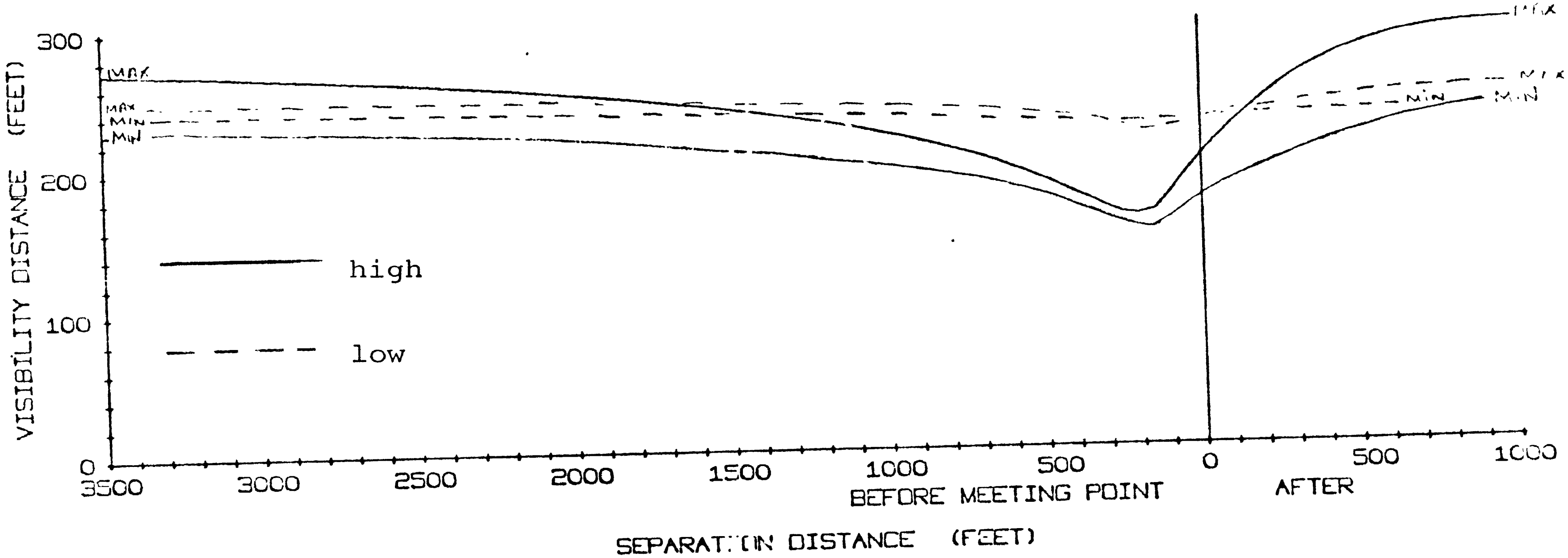


Figure 15. Computer simulation predicted visibility distances for system D low and high beams, 10% reflectance target on right side.

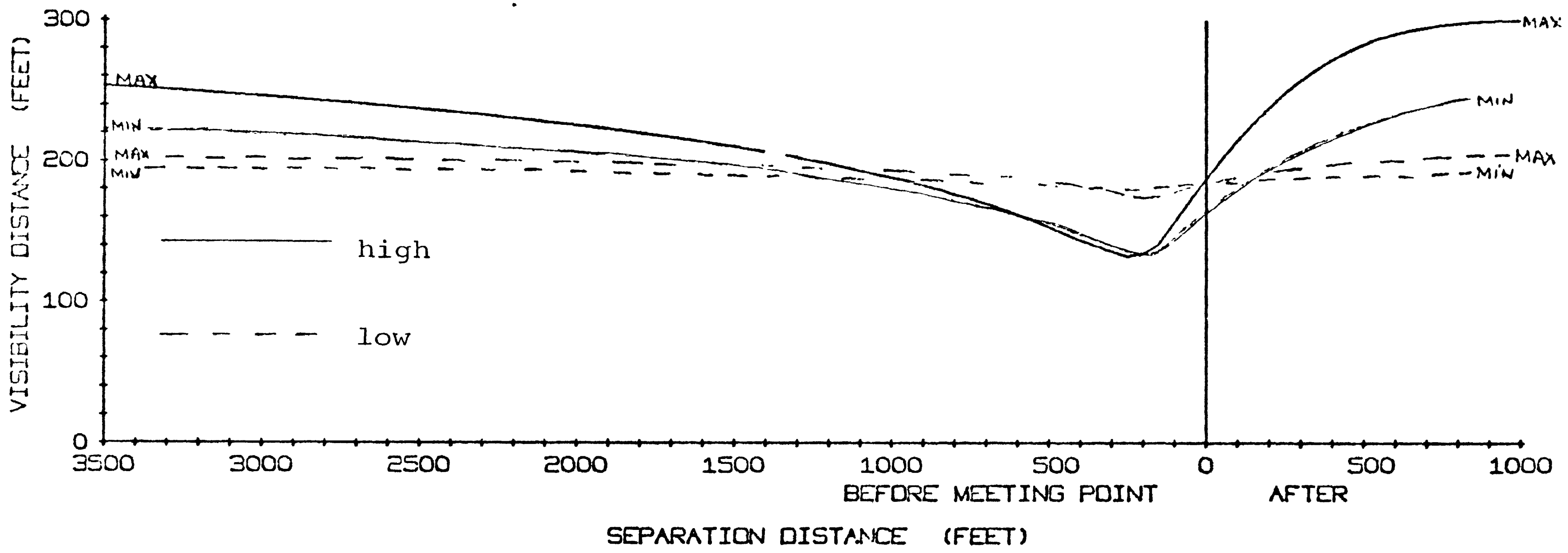


Figure 16. Computer simulation predicted visibility distances for system D low and high beams, 10% reflectance target on center of lane.

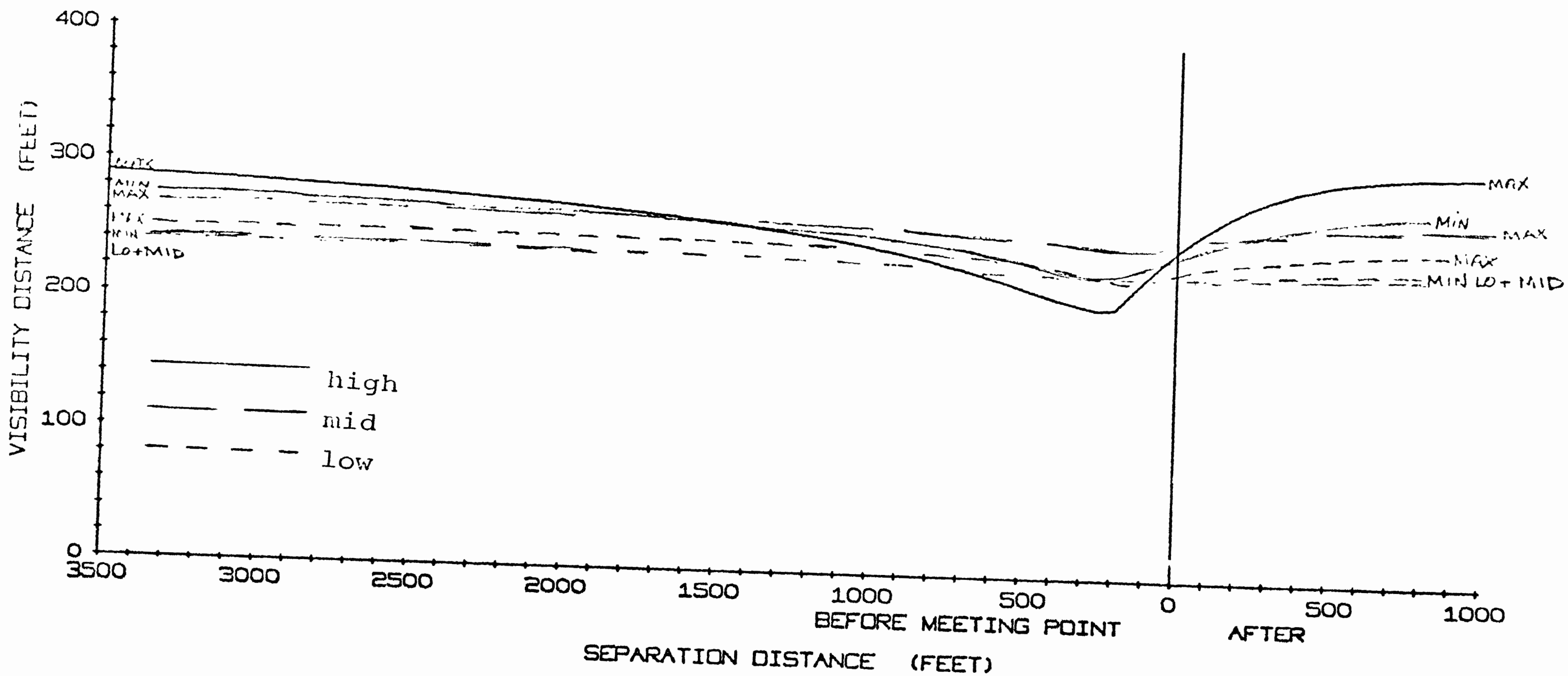


Figure 17. Computer simulation predicted visibility for system C low, mid and high beams, 10% reflectance target on right side.

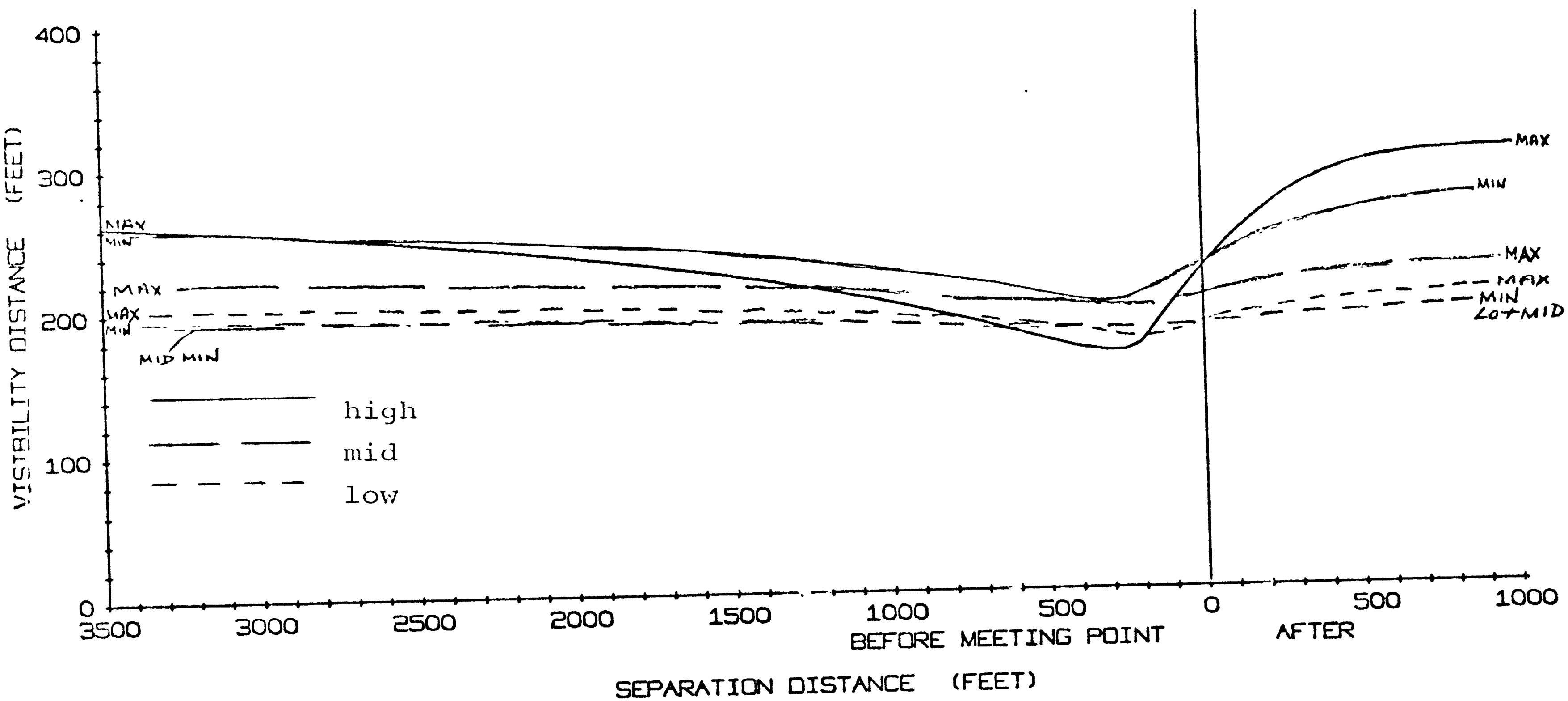


Figure 18. Computer simulation predicted visibility distances for system C low, mid and high beams, 10% reflectance target in center of lane.

REFERENCES

Mortimer, R.G. and Olson, P.L. Passenger car and truck headlighting research: development of a field testing methodology and beam pattern evaluation. Contract No. UM7102-C128, Motor Vehicle Manufacturers Association, Highway Safety Research Institute, University of Michigan, Report No. UM-HSRI-HF-73-14, (in press).

Mortimer, R.G. and Becker, J.M. Passenger car and truck headlighting research: development of a computer simulation model to predict headlamp beam performance. Contract No. UM7102-C128, Motor Vehicle Manufacturers Association, Highway Safety Research Institute, University of Michigan, Report Number UM-HSRI-HF-73-15, (in press).

Olson, P.L. and Mortimer, R.G. Passenger car and truck headlighting research: investigation of some factors affecting the aim of headlamps. Contract No. UM7204-C128, Motor Vehicle Manufacturers Association, Highway Safety Research Institute, University of Michigan, Report No. UM-HSRI-HF-73-13.

Proposed Motor Vehicle Safety Standard (Lamps, Reflector Devices and Associated Equipment). U.S. Department of Transportation, _Federal Register_, 37, No. 206, October 25, 1972.