Conspicuity of Retroreflective Signs and Devices at Night When Driving with Only One Headlamp Working

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A study was performed with a Macintosh microcomputer to analytically assess the effects of driving with only one headlamp working (driver side or passenger side, European lowbeam, American H6054 lowbeam, and American H6054 highbeam) and the effects of misaim of the one headlamp working on the conspicuity of retroreflectorized warning signs and devices of different brightnesses at night on a straight and a left-curved section of a highway. The computer model used computes all the geometric distances and angles necessary for a selected situation involving driver, vehicle, and reflectorized target, the amount of illumination returned to the driver's eyes for selected retroreflective materials, environmental and vehicle conditions, and a multiple of the visual laboratory detection threshold value. Geometric and photometric calculations were performed for a number of selected situations involving driver, vehicle, environmental conditions, retroreflective materials, and only one headlamp working with misaim. Results show that driving with only one headlamp working can have a significant detrimental effect on the visual detection distances for reflectorized targets, especially under certain headlamp misaim conditions. Therefore, it appears to be important for manufacturers to design and produce headlamp systems and headlamps with the highest possible reliability and the longest possible headlamp life (subject to economic feasibility), to have a strict law enforcement policy (encouraging immediate headlamp replacement) aimed at drivers driving vehicles at night that have only one headlamp working, and to possibly increase the minimum required brightness level of the reflective materials used for reflectorized warning signs and devices to at least partially offset the detrimental effect on visual detection distances for a driver driving with only one headlamp working.

Retroreflective signs and devices greatly aid a driver's ability to more easily detect and recognize road conditions, alignments, and hazards while driving at night. The early detection of retroreflective and nonreflective targets or obstacles while driving at night is important because it provides the driver with more time and because it is the first step of a five-step sequential driver's hazard avoidance process, as conceptualized by McGee et al. (*1*), during which the driver detects an object causing a hazardous condition, recognizes the condition, decides on a response, responds to the condition, and successfully maneuvers the vehicle to avoid the hazard. Although the process was suggested for the avoidance of an object on the highway, it might also be used to describe a driver's response to a reflective sign or device that appears in a driver's visual field at night that warns the driver of a road condition ahead, and hopefully allows the driver a close-to-maximum distance to respond to a certain potentially dangerous road condition in a near-optimal manner within the available time period.

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One factor that can affect the ability of a driver to detect reflective signs and devices at night is beam misaim. Bhise et al. (*2*) determined the effect of beam misaim on a driver's visual performance for an H4656 lowbeam using the Comprehensive Headlamp Environment Systems Simulation (CHESS) model developed at Ford Motor Company. Bhise et al. (*2*) investigated two beam misaim conditions, including random lowbeam misaim [on the basis of data from a 1971 study of lowbeam misaim by Hull (*3*)] and combinations of seven horizontal and five vertical identical passenger- and driver-side beam misaim conditions. Olson and Winkler (*4*) and Olson (*5*) have recently surveyed horizontal and vertical beam misaim variability for vehicle lowbeams. In addition, Zwahlen et al. (*6*) have systematically investigated the effect of different combinations of horizontal and vertical misaimed headlamps on the different reflectorized materials and targets, such as traffic signs, and the total reflected illumination that is returned to a driver's eyes.

Another factor that can affect the ability of a driver to detect reflective signs and devices at night is driving with only one headlamp working. Olson (*5*) found that 8 out of 964 cars (0.83 percent) had only one headlamp (lowbeam) working. This percentage does not appear to be large, but it should be noted that on the basis of the approximately 139 million cars registered in the United States in 1987 [74.6 percent of all the registered vehicles in the United States in 1987, approximately 186.1 million, were cars (*7*)], about 1.15 million cars might be expected to have only one headlamp (lowbeam) working. Zwahlen et al. (*8*) have recently examined the effects of driving with only one headlamp (for American H6054 lowbeams and American H6054 highbeams only) on the visual detection of reflectorized signs and devices of different brightnesses at night on straight and curved sections of highway. Some degradation was found in the detection distance for the situations with only one headlamp working; in most cases this degradation could have been almost totally offset by the selection of a brighter retroreflective material available on the market.

The study by Zwahlen et al. (*8*) was therefore expanded to include the effects of driving with only one headlamp for a typical European lowbeam (driver- or passenger-side headlamp working only) on the visual detection of reflectorized targets and to compare these effects with the effects of driving with only one headlamp working on the visual detection of reflectorized targets for American highbeams and lowbeams.

Another objective was to include as a reflective device in this study a raised retroreflective pavement marker. Another objective was to include the beam candlepower values for each detection distance and the observation and entrance angles for each of the reflective warning sign and device conditions. Glare effects resulting from only one working headlamp (properly or improperly aimed) on opposing traffic, and the effect glare from opposing traffic might have on a driver's detection performance while driving with only one headlamp working (either highbeam or lowbeam) are not addressed. Also, the effects of specular beam reflection off the pavement that might result in an additional small amount of illumination at the driver's eyes, especially under wet pavement conditions, are not considered.

APPROACH

The same interactive computer program (used on a Macintosh computer) that was used in two previous studies by Zwahlen et al. (*6,8*) was used to simulate and to analytically determine the detection distance of reflective targets in the driving environment. Given the specific intensity per unit area (SI) of a reflective target at given entrance, observation, presentation, and rotation angles, the computer program calculates the illumination returned to a driver's eyes from a reflective target, on the basis of the equation

$$E_{\text{eyes}} = E_{\text{ref}} * \text{SI} * C * t^{(b/100)}/b^2 \qquad (1)$$

where

- E_{ref} = illuminance produced at retroreflective target from a light source [footcandles (fc)],
- SI = specific intensity per unit area of reflector [candelas (cd) per fc/ft²],
- C = area of reflector (ft²), and
- b = direct distance from reflector to driver's eyes (ft).

E_{ref} may also be expressed as

$$E_{\text{ref}} = I * t^{(a/100)}/a^2 \qquad (2)$$

where

- I = luminous intensity of the light source (either on the driver's side or on the passenger's side) (cd),
- t = transmissivity of atmosphere per 100 ft, and
- a = direct distance from light source to reflector (ft).

The illumination that is first directed to the reflective target from either the driver- or passenger-side headlamp is then redirected to the driver's eyes and can be calculated from

$$E_{\text{eyes}} = I * \text{SI} * C * t^{(a+b)/100}/(a * b)^2 \qquad (3)$$

The computer program first has the user input the relevant geometric dimensions of the driver, vehicle, highway, and retroreflective sign or device. The program then calculates the geometric angles (such as observation angle and entrance angle) and euclidean distances from the headlamps to the reflective device and from the reflective device to the driver's eyes at user-specified rectilinear distances. The user then enters the headlamp beam aims, beam and retroreflector efficiency factors, windshield transmission factor, and environmental conditions and selects the appropriate headlamp and retroreflector data files. Illumination levels at the driver's eyes caused by the driver-side headlamp, passenger-side headlamp, and both headlamps, if desired, are then calculated by the program, which also selects the illumination threshold value for a 98 percent probability of detection of a white point source, based on a user-selected background luminance value [from laboratory data by Blackwell in the *IES Lighting Handbook* (*9*, pp. 3–24, Figure 3–46]. This illumination threshold applies only to point sources, but the program automatically adjusts for sources which are too large to be considered point sources using size factor values from the *IES Lighting Handbook* (*9*, pp. 3–25, Figure 3–49). The obtained illumination values and the adjusted threshold values are used to calculate multiple of threshold (MOT) values so that the small illumination values in footcandles at a driver's eyes can be compared on a one-to-one basis with visual backgrounds having different luminance levels. The MOT is defined as the number of times the illumination level that is returned to a driver's eyes from the reflector is above the illumination threshold for a 98 percent probability of detection of a white point source against a uniform background in the laboratory. The program then provides the reflector and beam angles, beam candlepower values, illumination at the reflector and at the driver's eyes causd either by the driver-side beam, passenger-side beam, or both beams together, along with the MOT values for the selected set of distances ahead of the vehicle.

A representative MOT criterion value must be selected for the detection of reflectorized signs and devices in the driving environment. Most published visual detection threshold values were obtained in the laboratory against uniform backgrounds with subjects who were alerted, highly motivated, and had a low information processing work load. These laboratory threshold values are most likely unsatisfactory for the detection of targets in the driving environment where the background may contain numerous light sources, the driver may be unaware of the presence and location of certain upcoming reflective targets, and the information work load may be relatively high. A criterion MOT value of 60 (17.1×10^{-8} fc or 1.84 km-candles) was chosen for the detection of all reflectorized signs and devices in this study except for the raised pavement markers that were assigned a criterion MOT value of 30 (8.55×10^{-8} fc or 0.92 km-candles). The use of an MOT value of 60 for the detection of a white license plate (6 × 12 in.) was primarily influenced by a desire to use as few as possible different MOT values and to be able to compare the performance of the selected signs and devices on a one-to-one basis (at MOT = 60). A good argument could probably be advanced for requiring a higher conspicuity level for the detection of license plates under automobile illumination at night and for an MOT value around or exceeding 100, which would result in shorter detection distances. Both the 60 and 30 MOT values fit within the human brilliancy ratings of faint (0.9 km-candles) and weak (4 km-candles) according to Breckenridge and Douglas (*10*). The MOT value of 60 was used for the fourth post delineator ahead of the car by Zwahlen et al. (*11*) in optimizing the spacing of post delineators. The MOT value of 30 was used for the fourth raised reflective pavement marker ahead of the car by Zwahlen et al. (*12*) for optimizing the spacing of raised reflective pavement markers. According to CIE Publication 73 (*13*) on the visibility distance of raised pavement markers, it was experimentally found over a group of subjects that the threshold illuminance for observations in practice was 34.7 (ranging from 25.0 to 43.1) times greater than the laboratory-based illumination threshold level for a point source, on the basis of laboratory data from Blackwell in the *IES Lighting Handbook* (*9*, p. 3–24, Figure 3–46).

The vehicle-driver dimensions that were used in this study are for a 50 percent person in a typical large car. The distance from the longitudinal vertical center plane of the car to the driver's sagittal plane, while in the driver position, was 15 in., the horizontal distance from the headlamps to the driver's eyes was 91 in., the subject eye height was 44 in. above the ground, the horizontal distance from the center of the front of the car to either the driver-side or passenger-side headlamp was 26.7 in., and the vertical distance from the center of the headlamps to the ground was 26.5 in. It is also assumed that the car is driven in the center of a 12-ft-wide right-hand lane of a two-lane highway, the beam efficiency is 90 percent, the windshield transmittance is 0.9, the atmospheric transmissivity is 0.99 per 100 ft (clear), and the background luminance is 0.01 fL.

The reflective targets included a warning sign located either on the right or left side of the highway, an overhead guide sign, a post-mounted reflective sheeting patch (flexible post delineator) on the right side of the highway, a reflectorized license plate located either on the left or right side of the highway, and a raised reflective pavement marker located in the center of the highway. Sections 2E–2 and 2E–4 of the *Ohio Manual of Uniform Traffic Control Devices* (OMUTCD) (*14*) state that warning signs should be placed a minimum of 12 ft from the edge of the highway and that the bottom of the sign should be at least 5 ft above the near pavement edge on rural roads and at least 6 ft above the near pavement edge on expressways and freeways. The yellow warning sign was assumed to be 30 × 30 in., the corner of the sign nearest the highway was assumed to be 12 ft from the edge of the highway, and the bottom of the sign was assumed to be 6 ft above the nearest edge of the highway. Section 2E–4 of the OMUTCD (*14*) states that overhead guide signs should provide a vertical clearance of not less than 17 ft unless a lesser clearance is used for the design of other structures, so the overhead sign was assumed to be 12 ft wide, 9 ft tall, and centered in the driver's lane with a vertical clearance of 17 ft. Sections 4B–3 and 4B–5 of the OMUTCD (*14*) state that the top of the retroreflecting patch of the post delineator should be placed 4 ft, plus or minus 1 in., above the near pavement edge, that all delineators should be between 2 ft and 12 ft 6 in. from the pavement edge, and that the reflective patch (white or silver) should have minimum dimensions of 3 × 6 in. The center of the reflective patch (assumed to have the rectangular dimensions of 3 in. wide × 6 in. tall) was assumed to be 12 ft to the right and 48 in. above the right pavement edge, which is 3 in. higher than a correctly installed reflective patch. A random survey of 20 late-model vehicles indicated that the center of the rear license plate was located an average of 2.1 ft above the ground, so it was assumed that the license plate [white, 23.5 cd/fc at 0.2 degrees (deg) observation angle, −4 deg entrance angle] was 2.1 ft above either the right or left edge line and that it was 6 in. high × 12 in. wide. The raised reflective pavement marker was a Stimsonite RRPM 33 (white, 4.53 cd/fc at 0.2 deg observation angle, −4 deg entrance angle) assumed to be located in the center of a two-lane highway.

All reflective materials were assumed to operate with only 90 percent efficiency because of wear and tear and dirt accumulation. The specific intensity per unit area of the yellow reflective material was assumed to be 60 percent of the specific intensity per unit area of clean, new white material [values between 59.6 and 62.5 percent are given by the Ohio Department of Transportation (*15*,p.528)] and 90 percent efficient (of overall reflectivity 54 percent). The specific intensity per unit area of the green reflective material was assumed to be 15 percent of the specific intensity per unit area of clean, new white material and 90 percent efficient (of overall reflectivity 13.5 percent).

Olson and Winkler (*4*) and Olson (*5*) included data for the horizontal and vertical averages and standard deviations for the misaim of lowbeams from a sample of 964 vehicles. The data were obtained at gas stations using mechanical aimers that were capable of measuring the misaim of the beams up to ±10 in. at 25 ft (about ±1.9 deg) in both directions. Because the measurements were taken after the drivers completed refueling, it was suggested that the standard deviation for the vertical aim be increased from 0.9 to 1.0 deg as an allowance for this bias. The original lowbeam misaim data (on a computer tape) mentioned by Olson and Winkler (*4*) was obtained from NHTSA and further analyzed on a computer to provide additional results on the lowbeam misaim data. The results reported by Zwahlen et al. (*8*) indicated that the lowbeam misaims could be assumed to be normally distributed in the vertical direction both for the driver- and passenger-side lowbeams, but that the lowbeam misaims for the horizontal direction both for the driver- and passenger-side lowbeams were not normally distributed (on the basis of a chi-squared test at the 0.01 level). There was practically no correlation between the vertical and horizontal misaim of the driver-side lowbeam ($R^2 = 0.002$) or between the vertical and horizontal misaim of the passenger-side lowbeam ($R^2 = 0$). Further, there was a fairly significant relationship between the vertical driver-side beam misaim and the vertical passenger-side beam misaim ($R^2 = 0.39$), whereas there was no such relationship for the horizontal beam misaims ($R^2 = 0.03$).

The five sets of beam misaim angles selected and used for both the passenger- and driver-side headlamps were used by Zwahlen et al. (*8*). One set of beam misaim angles chosen (for the nearly-properly-aimed beam) was 0.15 deg below the correct aim position and 0 deg in the horizontal direction (the correct aim position would be 0 deg horizontally and 0 deg vertically), which was close to the average overall beam misaim given by Olson and Winkler (*4*). The other four beam misaim angles were obtained by adding and subtracting 1.1 deg in the vertical direction and 0.9 deg in the horizontal direction from the nearly-properly-aimed beam position just mentioned. These four values are close to the standard deviations given by Olson and Winkler (*4*); however, small adjustment values were added to account for increased vertical variation that might be present for cars that had not just refueled and the small increased variability that would have resulted had the mechanical aimers been able to measure beam misaims of greater than 10 in. at 25 ft. Zwahlen et al. (*8*) has shown that if the four lowbeam misaim points were connected to form a rectangle, the rectangle would encompass 63.3 percent of the misaim points for the driver-side lowbeam and 64.7 percent of the misaim points for the passenger-side lowbeam. A circle through these four points would encompass 75.3 percent of the misaim points for the driver-side lowbeam and 75.1 percent of the misaim points for the passenger-side lowbeam.

Using the assumptions chosen, the computer program determined detection distances for the identical five passenger-side and five driver-side American lowbeam misaims. The identical five passenger-side and five driver-side beam misaim points used for the American lowbeams were also used for the American highbeam misaim points and the European lowbeam misaim points because no beam misaim data were available for these two types of headlamps. The beam patterns for these headlamps (European lowbeams, driver side and passenger side, which were obtained from Ford Motor Company, and the American lowbeam and highbeam) are shown in Figures 1 and 2. Other variables considered were the three levels of reflectivity for the signs (prismatic sheeting material with a specific intensity per unit area of 1,080 cd/fc/ft^2 at a 0.2-deg observation angle and a −4-deg entrance angle, encapsulated lens sheeting material with a specific intensity per unit area of 309 cd/fc/ft^2, and enclosed or embedded lens sheeting material with a specific intensity per unit area of 105 cd/fc/ft^2. These values were all from individual data matrices for the different reflective materials that had been empirically measured using different observation angle and entrance angle combinations and for two roadway geometries [straight highway or a 2,000-ft-radius (2.9-deg) left curve].

RESULTS

Figure 3 shows a log-log coordinate graph of the observation angles versus the target distance for the reflective warning signs and devices for only the driver-side headlamp working or only the passenger-side headlamp working that were calculated using the computer program. All the lines in this graph are straight lines. For only the driver-side headlamp working, the observation angles are slightly and consistently smaller than those for only the passenger-side headlamp working. Figure 4 shows a log-log coordinate graph of the entrance

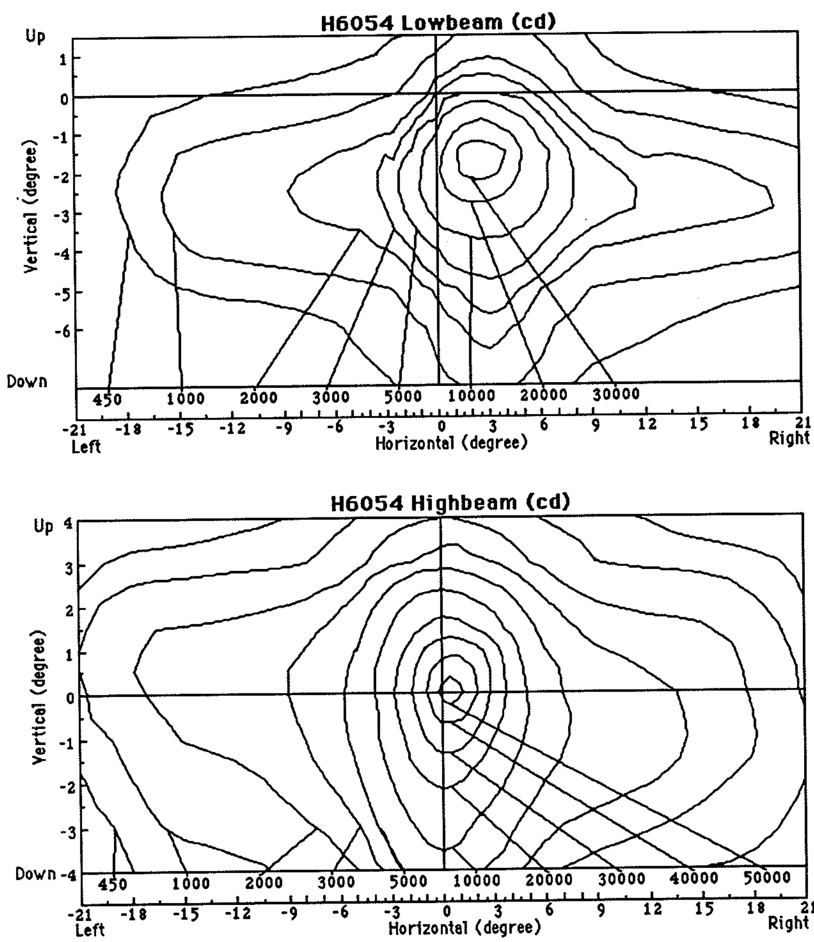

FIGURE 1 Isocandela plots for H6054 lowbeam and H6054 highbeam, based on beam candlepower data file in the computer program and plotted by the computer program.

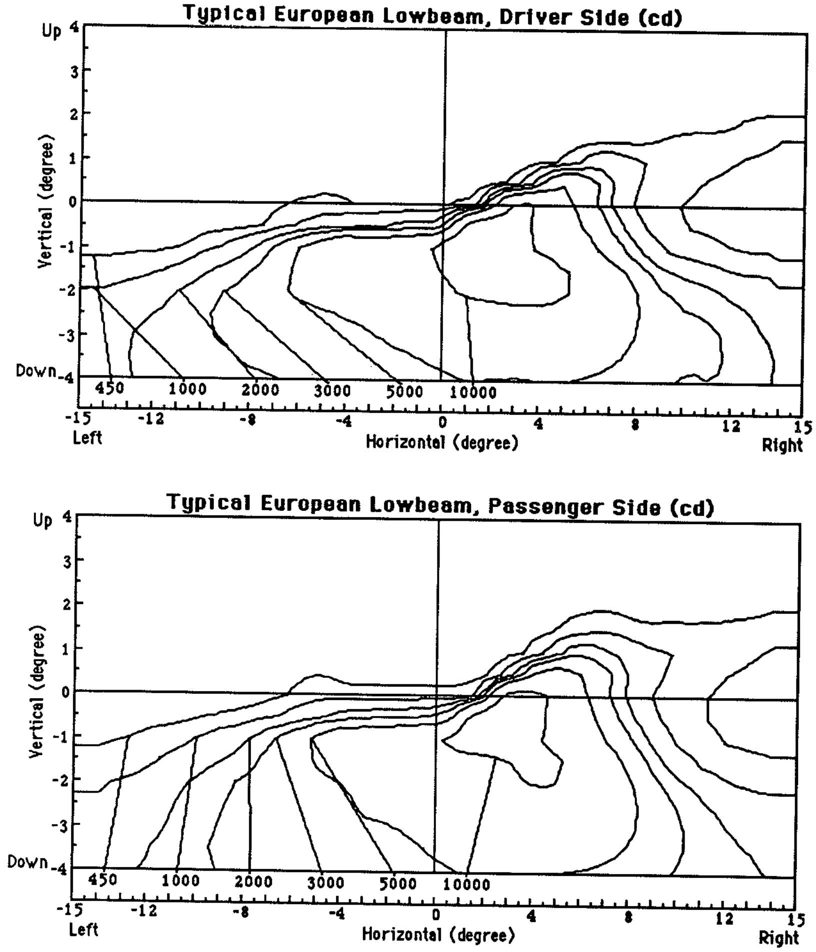

FIGURE 2 Isocandela plots for typical European driver-side and passenger-side lowbeam, based on beam candlepower data file in the computer program (data from Ford Motor Company) and plotted by the computer program.

angles versus the target distance for the reflective warning signs and devices for only the driver-side headlamp working or only the passenger-side headlamp working. All lines in this log-log presentation except the ones for the left curves are straight. The entrance angles for only the driver-side beam working and only the passenger-side beam working are different except for the overhead guide sign situation, and the curves for the entrance angles are not close together for the different reflective warning sign and device situations.

Tables 1–6 show the detection distances for 60 or 30 MOTs, percentages, and beam candlepower values aimed at the reflective warning signs and devices on a straight, or straight and curved, level two-lane highway, for two or three reflective material brightness levels, for two or three beam types (the three types of beams consisting of European lowbeam, American lowbeam, and American highbeam), with only one (misaimed or nearly properly aimed) headlamp working versus two headlamps working that are nearly properly aimed. The percentages in parentheses after the detection distances (in feet) are obtained by dividing the detection distance for each beam aim condition by the detection distance obtained for a pair of nearly-properly-aimed beams, so that any beam aim that has a percentage value of less than 100 percent has a shorter detection distance than that of two headlamps nearly properly aimed, and any beam aim that has a percentage value greater than 100 percent has a greater detection distance than that of two headlamps nearly properly aimed.

The detection distances, percentages, and beam candlepower values for warning signs placed on the right and left side (Tables 1 and 2, respectively) and for overhead guide signs placed above (Table 3) a straight highway indicate that for only one working European lowbeam and one working American lowbeam, the detection distances are always lower than that for a pair of nearly-properly-aimed lowbeams when the headlamp is aimed 0.15 deg or more below the correct aim position (either for only the driver-side beam working or only the passenger-side beam working). When the American lowbeam headlamp is aimed 0.90 deg to the right and 0.95 deg above the correct aim position in Tables 2 and 3, almost all of the detection distances are also lower than that for a pair of nearly-properly-aimed headlamps. Also, the detection distances for only one American highbeam working are always lower than that for a pair of nearly-properly-aimed highbeams.

Tables 1–3 also indicate that the longest detection distances are obtained when the beam is aimed at 0.9 deg to the left

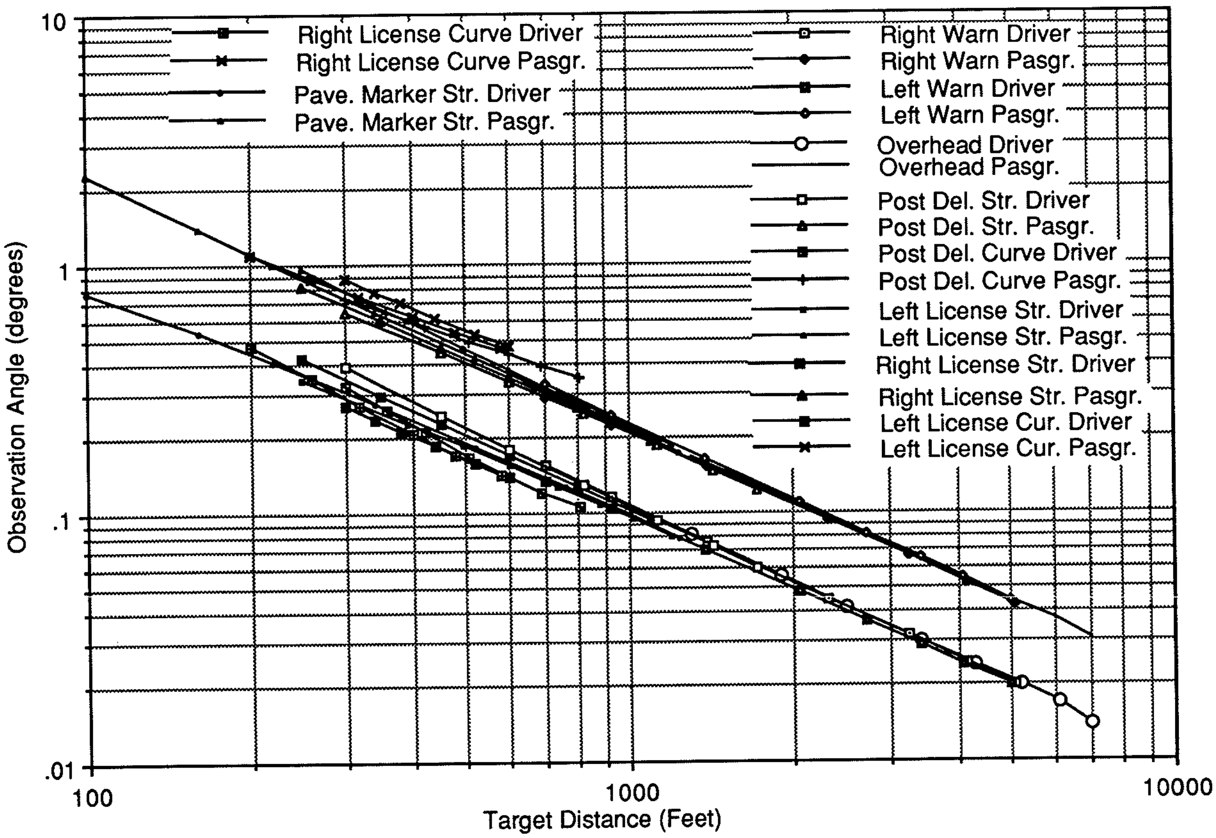

FIGURE 3 Observation angles as function of target distance for different reflectorized warning signs and devices for the situations investigated.

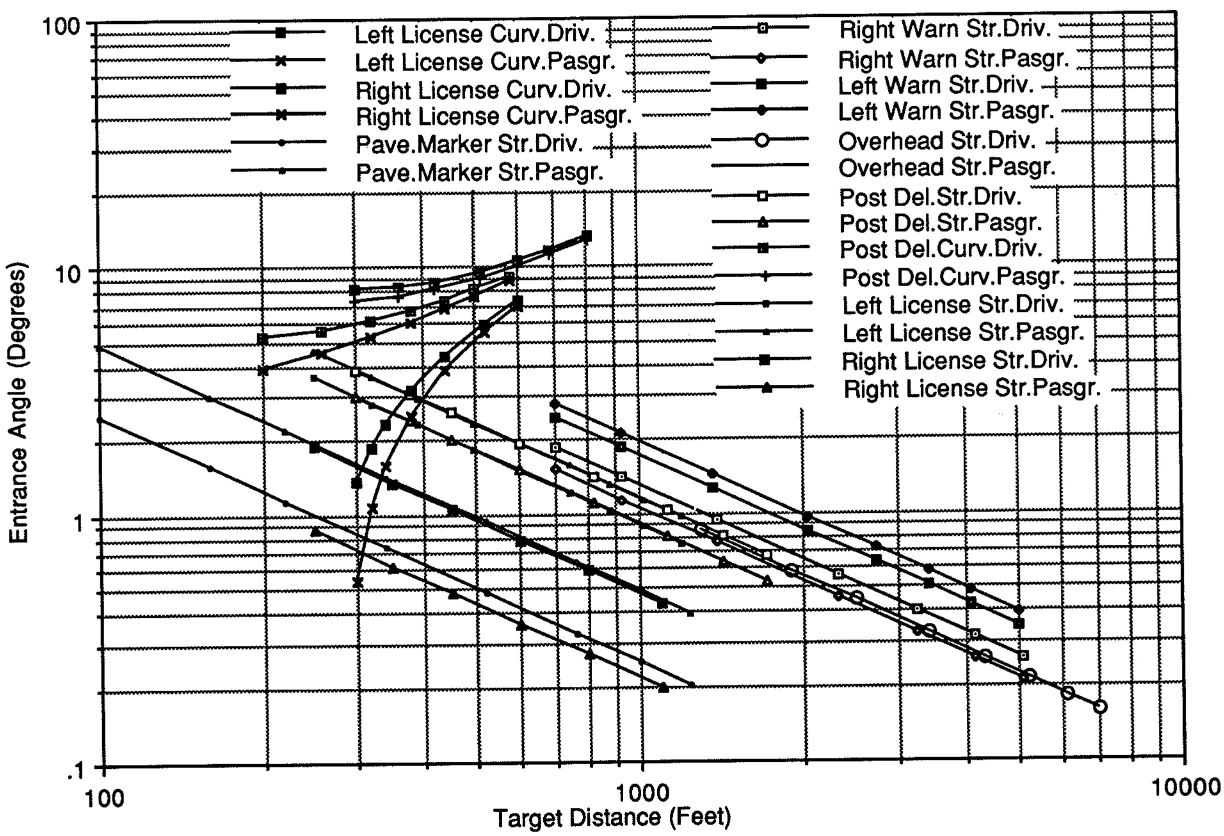

FIGURE 4 Entrance angles as function of target distance for different reflectorized warning signs and devices for the situations investigated.

TABLE 1 DETECTION DISTANCES (ft), PERCENTAGES, AND BEAM CANDLEPOWER VALUES FOR WARNING SIGNS PLACED ON THE RIGHT SIDE OF A STRAIGHT, LEVEL, TWO-LANE HIGHWAY, FOR THREE MATERIALS, THREE BEAM TYPES, AND ONLY ONE WORKING HEADLAMP, MISAIMED AND NEARLY PROPERLY AIMED, VERSUS TWO HEADLAMPS, NEARLY PROPERLY AIMED

Misaim	Reflector Material	Distance & Beam cp	European Lowbeam Straight, Level Road		H6054 Lowbeam Straight, Level Road		H6054 Highbeam Straight, Level Road	
			Driver Side	Pasgr.Side	Driver Side	Pasgr. Side	Driver Side	Pasgr. Side
● H .9° V .95°	Pris.	Dist.	3393 (192)	3250 (181)	3562 (132)	3546 (131)	4048 (80)	4054 (80)
		cp	15173	11618	19018	18644	35161	35413
	Enca	Dist.	2591 (195)	2457 (185)	2728 (133)	2714 (132)	3108 (80)	3115 (80)
		cp	15129	11726	19110	18626	35146	35473
	Encl.	Dist.	2048 (201)	1948 (192)	2157 (134)	2143 (133)	2461 (79)	2467 (79)
		cp	15141	11945	19198	18594	35138	35546
H .9° ● V .95°	Pris.	Dist.	2927 (166)	2879 (163)	2819 (104)	2792 (103)	4030 (80)	4019 (80)
		cp	7512	6967	6337	6080	34402	33947
	Enca	Dist.	2237 (168)	2163 (163)	2138 (104)	2121 (103)	3112 (80)	3101 (79)
		cp	7678	6575	6308	6062	35320	34801
	Encl.	Dist.	1767 (174)	1680 (165)	1678 (104)	1661 (103)	2474 (80)	2469 (79)
		cp	7749	6132	6162	5900	36052	35696
H 0° V .15°	Pris.	Dist.	1478 (84)	1538 (87)	2331 (86)	2311 (85)	4383 (87)	4377 (87)
		cp	333	398	2666	2574	51686	51332
	Enca	Dist.	1117 (84)	1148 (86)	1774 (86)	1753 (85)	3377 (87)	3371 (86)
		cp	316	368	2689	2553	51755	51316
	Encl.	Dist.	859 (84)	820 (87)	1394 (86)	1376 (85)	2677 (86)	2672 (86)
		cp	286	332	2675	2519	51773	51249
V 1.25° ● H .9°	Pris.	Dist.	1224 (69)	1304 (74)	1942 (72)	1932 (71)	3820 (76)	3827 (76)
		cp	147	186	1159	1132	26599	26861
	Enca	Dist.	958 (72)	976 (73)	1466 (71)	1457 (71)	2900 (74)	3009 (77)
		cp	153	182	1139	1110	25466	25969
	Encl.	Dist.	771 (76)	770 (76)	1144 (71)	1138 (71)	2266 (73)	2275 (73)
		cp	159	184	1134	1096	24141	24603
V 1.25° H .9° ●	Pris.	Dist.	1233 (70)	1331(75)	1786 (66)	1774 (66)	3794 (75)	3784 (75)
		cp	150	205	793	769	25816	25490
	Enca	Dist.	944 (71)	985 (74)	1347 (66)	1336 (65)	2905 (74)	2896 (74)
		cp	144	195	805	775	25684	25319
	Encl.	Dist.	751 (74)	767 (75)	1073 (67)	1062 (66)	2290 (74)	2283 (74)
		cp	137	184	810	780	25406	25041
Two Lamps Nearly Prop. Aimed	Pris.	Dist.	1768 (100%)		2704 (100%)		5039 (100%)	
	Enca	Dist.	1239 (100%)		2056 (100%)		3902 (100%)	
	Encl.	Dist.	1017 (100%)		1612 (100%)		3106 (100%)	

and 0.95 deg above the correct aim position for the European and American lowbeams and when the beam is in the nearly-properly-aimed position for the American highbeam. The shortest detection distances for these tables for the European lowbeam and American highbeam are obtained when the beam is either 0.9 deg to the right or left and 1.25 deg below the correctly aimed position. The shortest detection distances for the American lowbeam are obtained when the beam is 0.9 deg to the right and 1.25 deg below the correctly aimed position.

Figure 5 shows the maximum, minimum, and nearly-properly-aimed detection distances for the conditions of only one headlamp working and the detection distances for two headlamps nearly properly aimed that were presented in Tables 1–3. From Tables 1–3 and Figure 5, the detection distances for only the passenger-side headlamp working for the European lowbeam are usually greater than those for only the driver-side headlamp working (excluding the longer detection distances). The differences between these detection distances are large for some beam misaims. The detection distances of only the driver-side headlamp working for the American lowbeam and highbeam are usually greater (the differences being slight) than those of only the passenger-side headlamp working. From Tables 1–3 and Figure 5, prismatic reflective sheeting material gives the longest detection distances and the enclosed or embedded reflective sheeting material gives the shortest. The detection distances for the American lowbeam

TABLE 2 DETECTION DISTANCES (ft), PERCENTAGES, AND BEAM CANDLEPOWER VALUES FOR WARNING SIGNS PLACED ON THE LEFT SIDE OF A STRAIGHT, LEVEL, TWO-LANE HIGHWAY, FOR THREE MATERIALS, THREE BEAM TYPES, AND ONLY ONE WORKING HEADLAMP, MISAIMED AND NEARLY PROPERLY AIMED, VERSUS TWO HEADLAMPS, NEARLY PROPERLY AIMED

Misaim	Reflector Material	Distance & Beam cp	European Lowbeam Straight, Level Road		H6054 Lowbeam Straight, Level Road		H6054 Highbeam Straight, Level Road	
			Driver Side	Pasgr.Side	Driver Side	Pasgr. Side	Driver Side	Pasgr. Side
● H .9° V .95°	Pris.	Dist.	3256(185)	2956(168)	3223(136)	3159(134)	4090(83)	4089(83)
		cp	12417	7912	11905	10819	36866	36832
	Enca	Dist.	2398(181)	2174(164)	2315(134)	2196(127)	3149(83)	3148(83)
		cp	10661	6775	9046	7262	37143	37099
	Encl.	Dist.	1792(179)	1679(167)	1679(129)	1660(127)	2493(84)	2492(84)
		cp	8425	6143	6229	5932	37461	37408
H .9° ● V .95°	Pris.	Dist.	2816(160)	2838(161)	2324(98)	2298(97)	3887(79)	3871(79)
		cp	6354	6554	2635	2517	28915	28379
	Enca	Dist.	2109(159)	2124(161)	1710(99)	1685(98)	2962(78)	2943(78)
		cp	5832	6015	2291	2144	28003	27227
	Encl.	Dist.	1606(160)	1627(163)	1289(99)	1269(97)	2317(78)	2295(77)
		cp	5173	5433	1932	1777	26806	25760
H0° V .15°	Pris.	Dist.	1451(82)	1544(88)	1999(84)	1968(83)	4265(87)	4251(86)
		cp	311	405	1340	1241	45187	44459
	Enca	Dist.	1092(83)	1151(87)	1452(84)	1435(83)	3253(86)	3240(86)
		cp	289	380	1121	1056	43525	42613
	Encl.	Dist.	845(84)	881(88)	1111(85)	1098(84)	2554(85)	2538(85)
		cp	268	354	971	933	42709	40853
V 1.25° ● H .9°	Pris.	Dist.	1243(71)	1338(76)	1797(76)	1784(75)	3862(79)	3861(79)
		cp	155	210	819	792	28072	28038
	Enca	Dist.	959(72)	988(75)	1324(77)	1303(76)	2946(78)	2945(78)
		cp	156	208	732	690	27383	27345
	Encl.	Dist.	768(77)	771(77)	1001(77)	974(75)	2313(78)	2312(78)
		cp	159	207	630	574	26618	26575
V 1.25° H .9° ●	Pris.	Dist.	1209(73)	1342(76)	1588(67)	1576(67)	3653(74)	3638(74)
		cp	177	214	475	458	21494	21059
	Enca	Dist.	971(73)	985(74)	1167(68)	1159(67)	2756(73)	2737(72)
		cp	171	205	424	411	20158	19517
	Encl.	Dist.	769(77)	759(76)	915(70)	876(67)	2136(72)	2114(71)
		cp	162	193	390	370	18543	17729
Two Lamps Nearly Prop. Aimed	Pris.	Dist.	1759 (100%)		2366 (100%)		4918 (100%)	
	Enca	Dist.	1323 (100%)		1724 (100%)		3780 (100%)	
	Encl.	Dist.	1001 (100%)		1304 (100%)		2979 (100%)	

are longer than those for the European lowbeam. Further, the detection distances for the same misaim conditions and the same reflective material for the American highbeam are longer than all of the detection distances for the typical European and the American lowbeams. Figure 5 also shows decision sight distance (DSD), which ranges from 875 to 1,150 ft for a selected design speed of 55 mph [interpolated from DSD values for design speeds of 50 and 60 mph given by McGee et al. (*1*)] and stopping sight distance (SSD), which is 412.5 ft for a design speed of 55 mph [interpolated from SSD values for design speeds of 50 and 60 mph given by AASHTO (*16*)]. The DSD is defined as the distance required for a driver to detect a hazard in a cluttered roadway environment, recognize its threat potential, select an appropriate speed and path, and safely perform the necessary avoidance maneuver. The SSD is defined as the distance traversed by a vehicle from the instant a driver sights an object for which a stop is necessary until the vehicle is stopped. The DSD and SSD are well known and well used distance concepts within a driver safety context and were selected to demonstrate how the observed detection distances relate to driver safety. Other similar distance concepts may be shorter than the DSD and SSD and possibly more relevant within the sign detection, sign recognition, and driver safety context. Such distances should certainly be considered along with the DSD and SSD provided they have been published and found valid, appropriate, and reliable in care-

TABLE 3 DETECTION DISTANCES (ft), PERCENTAGES, AND BEAM CANDLEPOWER VALUES FOR OVERHEAD GUIDE SIGN ABOVE A STRAIGHT, LEVEL HIGHWAY, FOR TWO MATERIALS, THREE BEAM TYPES, AND ONLY ONE WORKING HEADLAMP, MISAIMED AND NEARLY PROPERLY AIMED, VERSUS TWO HEADLAMPS, PROPERLY AIMED

Misaim	Reflector Material	Distance & Beam cp	European Lowbeam Straight, Level Road		H6054 Lowbeam Straight, Level Road		H 6054 Highbeam Straight, Level Road	
			Driver Side	Pasgr.Side	Driver Side	Pasgr. Side	Driver Side	Pasgr. Side
● H .9° V .95°	Pris.	Dist.	4591 (182)	4255 (169)	4713 (131)	4688 (131)	5627 (84)	5629 (84)
		cp	12980	8718	14801	14409	37880	37956
	Enca	Dist.	3566 (182)	3272 (167)	3650 (132)	3624 (131)	4451 (84)	4453 (84)
		cp	12227	7822	13774	13312	38639	38733
H .9° ● V .95°	Pris.	Dist.	3735 (148)	3594 (143)	3609 (100)	3575 (100)	5510 (82)	5499 (82)
		cp	4444	4654	3740	3555	33902	33571
	Enca	Dist.	2711 (138)	2825 (144)	2744 (99)	2711 (98)	4361 (82)	4350 (82)
		cp	2970	3689	3146	2949	34602	34176
H 0° ● V .15°	Pris.	Dist.	2128 (84)	2252 (89)	3118 (87)	3098 (86)	5887 (88)	5880 (88)
		cp	235	320	1379	1684	48194	47868
	Enca	Dist.	1659 (85)	1759 (90)	2400 (87)	2385 (86)	4631 (88)	4624 (88)
		cp	215	296	1592	1530	47387	47010
V 1.25° ● H .9°	Pris.	Dist.	1905 (76)	1992 (79)	2737 (76)	2725 (76)	5168 (77)	5171 (77)
		cp	129	170	886	866	24110	24203
	Enca	Dist.	1505 (77)	1573 (80)	2135 (77)	2124 (77)	4017 (76)	4021 (76)
		cp	123	160	835	811	22675	22802
V 1.25° H .9° ●	Pris.	Dist.	1939 (77)	2052 (81)	2530 (70)	2515 (70)	5061 (76)	5051 (75)
		cp	142	195	587	569	21634	21416
	Enca	Dist.	1529 (78)	1607 (82)	1973 (71)	1960 (71)	3942 (74)	3932 (74)
		cp	134	187	555	532	20606	20346
Two Lamps Nearly Prop. Aimed	Pris.	Dist.	2521 (100%)		3592 (100%)		6692 (100%)	
		cp	235	320	1379	1684	48194	47868
	Enca	Dist.	1962 (100%)		2767 (100%)		5292 (100%)	
		cp	215	296	1592	1530	47387	47010

+ - Correct aim of headlamp ● - Actual aim of headlamp

Dist. - Distance(ft.) from the object to the driver for an illuminance of 60 MOT at driver's eyes.

(%) - Percentage of the distance for one headlamp working only when compared to the distance for two nearly properly aimed headlamps.

cp - Candlepower (Candelas) of the headlamp for given beam angles.

Pris. - Prismatic sheeting material.

Enca.-Encapsulated lens sheeting material.

fully designed and executed field studies. In Figure 5, only the minimum or shorter detection distances for the warning signs on the left and right side of the road using encapsulated lens and enclosed lens reflective sheeting when seen with the European lowbeam and the minimum or shorter detection distances for a warning sign on the left side of the road using enclosed lens reflective sheeting when seen with the American lowbeam are below or within the range of the DSD for 55 mph and no detection distances fall below the SSD for 55 mph.

For post delineators on the right side of a straight and left-curve highway presented in Table 4, the detection distances for only one misaimed beam working are always lower than that for a pair of nearly-properly-aimed beams when the European lowbeam and American lowbeam on a straight highway are 0.15 deg or more below the correctly aimed position. For only the American passenger side lowbeam working on a left-curve section, the beam misaim detection distances are always lower than that for a pair of nearly-properly-aimed lowbeams. The longest detection distances are obtained when the beam is aimed at 0.9 deg to the left and 0.95 deg above the correct aim position for all three beam conditions (European lowbeam on straight road and American lowbeam on straight and left-curved road). The shortest detection distances are obtained when the beam is aimed 0.9 deg to the right and 1.25 deg below the correctly aimed position for all three beam conditions. The detection distances for only the driver-side beam working are always longer than those for only the passenger-

TABLE 4 DETECTION DISTANCES (ft), PERCENTAGES, AND BEAM CANDLEPOWER VALUES FOR POST DELINEATORS ON RIGHT SIDE OF STRAIGHT AND CURVED, LEVEL, TWO-LANE HIGHWAY, FOR TWO MATERIALS, TWO BEAM TYPES, AND ONLY ONE WORKING HEADLAMP, MISAIMED AND NEARLY PROPERLY AIMED, VERSUS TWO HEADLAMPS, NEARLY PROPERLY AIMED

Misaim	Reflector Material	Distance & Beam cp	European Lowbeam Straight, Level Road		H6054 Lowbeam Straight, Level Road		H6054 Lowbeam Left Curve, Level Road	
			Driver Side	Pasgr.Side	Driver Side	Pasgr. Side	Driver Side	Pasgr. Side
● H .9° V .95°	Pris.	Dist.	1588 (184)	1531 (178)	1710 (132)	1697 (131)	793 (106)	716 (96)
		cp	15199	12516	21074	20461	984	1032
	Enca	Dist.	1181 (163)	1154 (160)	1285 (132)	1277 (131)	646 (109)	541 (91)
		cp	14663	12856	21460	20819	1148	1283
H .9° ● V .95°	Pris.	Dist.	1458 (169)	1356 (157)	1359 (105)	1338 (104)	782 (105)	702 (94)
		cp	10180	7463	7765	7275	901	943
	Enca	Dist.	1125 (156)	992 (137)	1071 (110)	998 (103)	621 (105)	515 (87)
		cp	11121	7283	9739	7728	1027	1124
H 0° ● V .15°	Pris.	Dist.	791 (92)	679 (79)	1114 (86)	1094 (85)	689 (92)	594 (80)
		cp	705	487	3365	3128	485	538
	Enca	Dist.	688 (95)	560 (77)	840 (86)	796 (82)	547 (92)	426 (72)
		cp	1065	644	3511	3287	606	705
V 1.25° ● H .9°	Pris.	Dist.	579 (67)	539 (61)	891 (69)	866 (67)	586 (78)	488 (65)
		cp	190	224	1313	1261	230	318
	Enca	Dist.	398 (55)	380 (53)	669 (69)	607 (62)	481 (81)	366 (62)
		cp	199	261	1349	1303	367	473
V 1.25° H .9° ●	Pris.	Dist.	555 (64)	478 (55)	824 (64)	785 (61)	546 (73)	444 (59)
		cp	147	192	937	890	167	242
	Enca	Dist.	385 (53)	343 (47)	625 (64)	556 (57)	458 (77)	319 (54)
		cp	154	184	1025	954	266	403
Two Lamps Nearly Prop. Aimed	Pris.	Dist.	862 (100%)		1291 (100%)		747 (100%)	
		cp	705	487	3365	3128	485	538
	Enca	Dist.	723 (100%)		972 (100%)		592 (100%)	
		cp	1065	644	3511	3287	606	705

—|— - Correct aim of headlamp ● - Actual aim of headlamp
Dist. - Distance(ft.) from the object to the driver for an illuminance of 60 MOT at driver's eyes.
(%) - Percentage of the distance for one headlamp working only when compared to the distance for two nearly properly aimed headlamps.
cp - Candlepower (Candelas) of the headlamp for given beam angles.
Pris. -Prismatic sheeting material.
Enca.-Encapsulated lens sheeting material.

side beam working for the three-beam conditions. The differences in the detection distances between only the driver-side and only the passenger-side headlamp working are small for the straight section of highway but may be large for the American lowbeam on the left-curved section of highway. Either for only the driver-side or only the passenger-side headlamp working, the detection distances for prismatic reflective sheeting are longer than those for enclosed lens reflective sheeting for all beam misaims.

For the license plates on the right and left sides of a two-lane highway presented in Table 5, the detection distances for only one working headlamp for the three beam conditions are usually lower than that for a pair of nearly-properly-aimed beams when the beam misaims are 0.15 deg or more below the correctly aimed position. For the passenger-side American lowbeam working only for a left-curve section of road, the detection distances are always lower than that for a pair of nearly-properly-aimed beams. The longest detection distances are obtained when the beam is aimed at 0.9 deg to the left and 0.95 deg above the correctly aimed position for all three beam conditions. The shortest detection distances are usually obtained for 0.9 deg to the right and 1.25 deg below the correctly aimed position. The detection distances for only the driver-side beam working are longer than those for only the passenger-side beam working for the three beam conditions. The differences between the detection distances for only the driver-side and only the passenger-side beam working were found to be large. For the American lowbeam and highbeam,

TABLE 5 DETECTION DISTANCES (ft), PERCENTAGES, AND BEAM CANDLEPOWER VALUES FOR LICENSE PLATES ON RIGHT AND LEFT SIDES OF STRAIGHT AND CURVED SECTIONS OF LEVEL TWO-LANE HIGHWAY, FOR TWO BEAM TYPES, AND ONLY ONE WORKING HEADLAMP, MISAIMED AND NEARLY PROPERLY AIMED, VERSUS TWO HEADLAMPS, NEARLY PROPERLY AIMED

Misaim	Reflector Material	Distance & Beam cp	European Lowbeam Straight, Level Road		H6054 Lowbeam Straight, Level Road		H6054 Lowbeam Left Curve, Level Road	
			Driver Side	Pasgr. Side	Driver Side	Pasgr. Side	Driver Side	Pasgr. Side
● H.9° V.95°	Left	Dist.	1031 (207)	893 (180)	1170 (137)	1124 (132)	588 (108)	496 (91)
		cp	12364	8320	10322	8459	1091	1128
	Right	Dist.	1091 (209)	994 (190)	950 (143)	868 (131)	560 (109)	450 (88)
		cp	15789	12220	21384	20057	1321	1493
H.9° ● V.95°	Left	Dist.	918 (185)	874 (176)	916 (108)	852 (100)	568 (105)	475 (87)
		cp	7652	7567	2651	2230	995	1029
	Right	Dist.	971 (186)	897 (172)	683 (103)	585 (88)	551 (107)	435 (85)
		cp	8685	8270	8219	7113	1162	1291
H0° V.15°	Left	Dist.	446 (90)	370 (74)	749 (88)	680 (80)	500 (92)	397 (73)
		cp	377	475	1291	1103	525	542
	Right	Dist.	478 (92)	389 (75)	581 (87)	463 (70)	474 (92)	355 (69)
		cp	473	491	3491	3041	676	754
V 1.25° ● H.9°	Left	Dist.	378 (76)	290 (58)	597 (70)	535 (63)	438 (81)	343 (63)
		cp	190	236	799	677	134	139
	Right	Dist.	370 (71)	297 (57)	523 (79)	375 (56)	368 (72)	243 (47)
		cp	180	215	1360	1322	449	607
V 1.25° H.9° ●	Left	Dist.	378 (76)	277 (56)	550 (65)	470 (55)	398 (73)	315 (58)
		cp	187	183	496	425	82	78
	Right	Dist.	361 (69)	298 (57)	469 (71)	313 (47)	315 (61)	212 (41)
		cp	169	233	935	876	387	468
Two Lamps Nearly Prop. Aimed	Left	Dist.	497 (100%)		851 (100%)		543 (100%)	
		cp	377	475	1291	1103	525	542
	Right	Dist.	522 (100%)		665 (100%)		514 (100%)	
		cp	473	491	3491	3041	676	754

—|— - Correct aim of headlamp ● -Actual aim of headlamp
Dist. - Distance(ft.) from the object to the driver for an illuminance of 60 MOT at driver's eyes.
(%) - Percentage of the distance for one headlamp working only when compared to the distance for two nearly properly aimed headlamps.
cp - Candlepower (Candelas) of the headlamp for given beam angles.
Right - License plate located above right edge line.
Left - License plate located above left edge line.

the detection distances for license plates on the left edge line of the road are longer than those on the right edge line; for the European lowbeam the opposite is usually true.

For the raised reflective pavement markers on the centerline of a two-lane highway presented in Table 6, the detection distances for only one working misaimed beam are always lower than that for a pair of nearly-properly-aimed beams for all three beam types (European lowbeam and American lowbeam and highbeam), except the European and American lowbeams for only the driver-side headlamp working, which are 0.95 deg above the correctly aimed position. The longest detection distances are obtained when the beam is aimed at 0.9 deg to the left and 0.95 deg above the correctly aimed position both for the European lowbeam and the American lowbeam, and at the nearly-properly-aimed beam position for the American highbeam. The shortest detection distances for the European lowbeam are obtained when it is aimed 1.25 deg below the correctly aimed position, and for the American lowbeam and highbeam when they are 0.9 deg to the right and 1.25 deg below the correctly aimed position. The detection distances for only the driver-side beam working are longer than those for only the passenger-side beam working, and the difference between the detection distances is large.

Figure 6 shows the maximum, minimum, and nearly-properly-aimed detection distances for the condition of only one headlamp working and the detection distances for two headlamps nearly properly aimed that were presented in Tables 4–6. From Figure 6, for the post delineator the prismatic reflective sheeting produces longer detection distances than the encapsulated reflective sheeting for all three beam con-

TABLE 6 DETECTION DISTANCES (ft), PERCENTAGES, AND BEAM CANDLEPOWER VALUES FOR RAISED REFLECTIVE PAVEMENT MARKER ON CENTERLINE OF STRAIGHT, LEVEL, TWO-LANE HIGHWAY, FOR THREE BEAM TYPES, ONLY ONE WORKING HEADLAMP, MISAIMED AND NEARLY PROPERLY AIMED, VERSUS TWO HEADLAMPS, NEARLY PROPERLY AIMED

Misaim	Distance cp of Beam	European Lowbeam Straight, Level Road		H6054 Lowbeam Straight, Level Road		H6054 Highbeam Straight, Level Road	
		Driver Side	Pasgr.Side	Driver Side	Pasgr. Side	Driver Side	Pasgr. Side
● H.9° V.95°	Dist.	915 (209)	401 (92)	946 (160)	576 (97)	1114 (79)	987 (70)
	cp	15440	7972	17689	12734	33680	33812
H.9° ● V.95°	Dist.	784 (179)	369 (84)	685 (116)	204 (35)	1071(76)	907 (64)
	cp	8643	7236	5143	2668	28703	26493
H0° V.15°	Dist.	423 (97)	199 (45)	548 (93)	155 (26)	1230 (87)	1093 (77)
	cp	1037	3047	2393	1610	50222	46688
V 1.25° ●H.9°	Dist.	196 (45)	111 (25)	443 (75)	131 (22)	1107 (78)	981 (70)
	cp	248	575	1205	875	32891	33195
V 1.25° H.9° ●	Dist.	199 (45)	111 (25)	376 (64)	123 (21)	1052 (75)	883 (63)
	cp	259	572	770	733	26892	24678
Two Lamps Nearly Prop. Aimed	Dist.	438 (100%)		591(100%)		1411(100%)	
	cp	1037	3047	2393	1610	50222	46688

—|— - Correct aim of headlamp ● - Actual aim of headlamp

Dist. - Distance(ft.) from the object to the driver for an illuminance of 30 MOT at driver's eyes.

(%) - Percentage of the distance for one headlamp working only when compared to the distance for two nearly properly aimed headlamps.

cp - Candlepower (Candelas) of the Headlamp for given beam angles

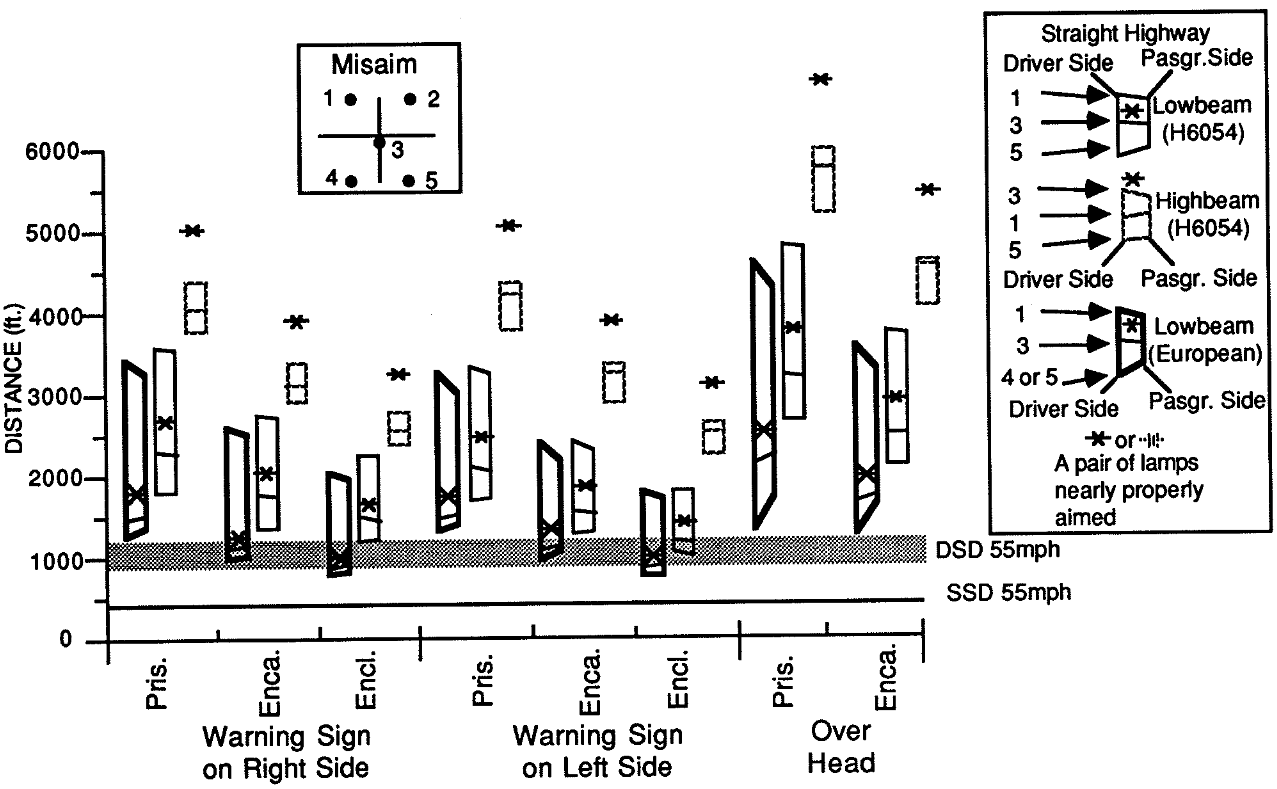

FIGURE 5 Maximum, minimum, and nearly-properly-aimed beam detection distances for only one headlamp working for the right and left warning sign and the overhead guide sign, three retroreflective sheeting materials (prismatic, encapsulated lens, and enclosed and embedded lens), for the H6054 highbeam, H6054 lowbeam, and the typical European lowbeam, on a straight section of highway.

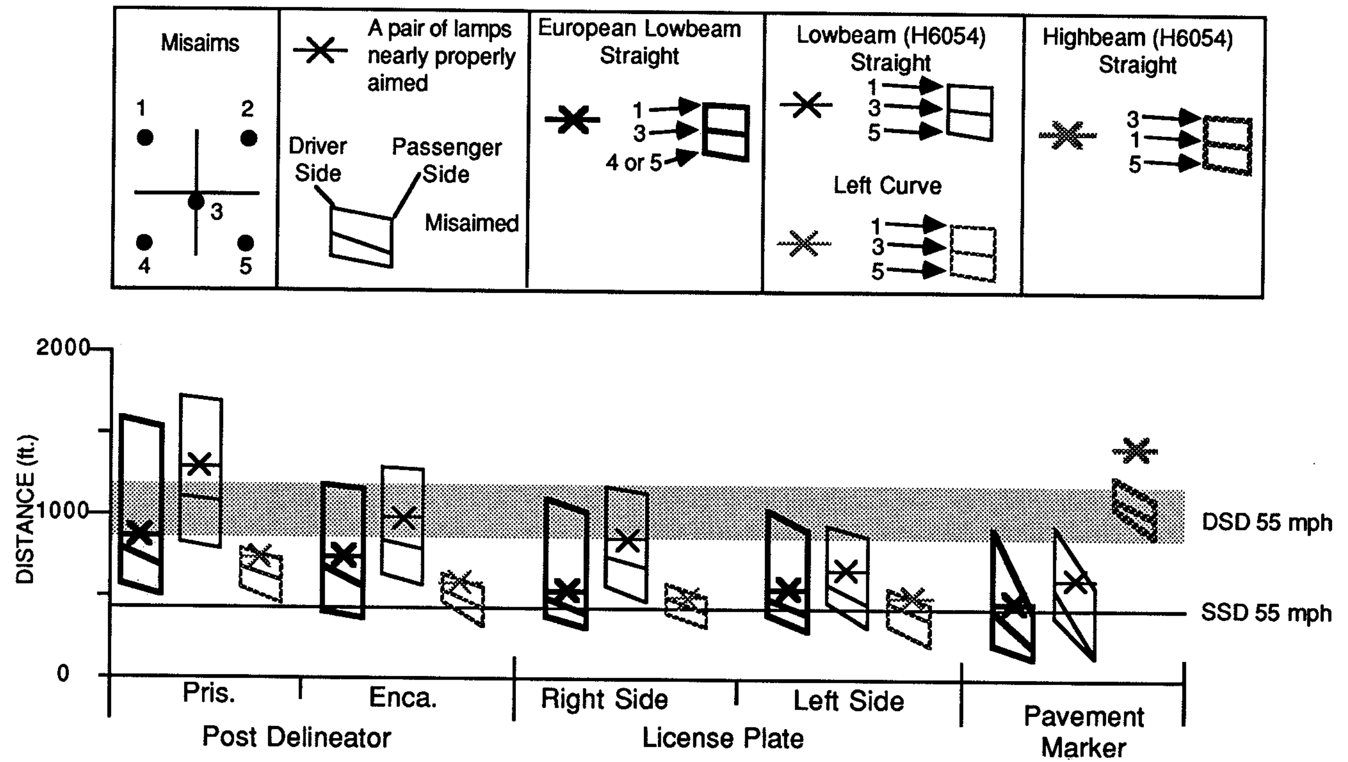

FIGURE 6 Maximum, minimum, and nearly-properly-aimed beam detection distances for only one headlamp working for a post delineator, license plate, and raised pavement marker (STMSONITE 33), for different retroreflective materials (prismatic and encapsulated lens for post delineator), and three beam types (H6054 highbeam and lowbeam and typical European lowbeam), on straight and left-curved sections of highway.

ditions. The license plate on the right side of the highway produces longer detection distances than the license plate on the left side of the highway for all three beam conditions. Further, Figure 6 shows that the American lowbeam on a straight section of road always produces equal or longer detection distances than the European lowbeam for the post delineator, license plate, and raised pavement marker.

Figure 6 also shows that only the longer detection distances for post delineators exceed the DSD at 55 mph, and that most of the misaim condition detection distances for the post delineators, license plates, and pavement markers are between the DSD and SSD ranges at 55 mph. For most misaim conditions of the license plate and pavement marker situations as well as for the detection distances for the American lowbeam on a left-curve section of highway and the European lowbeam on a straight section of highway, the minimum detection distances are below the minimum SSD at 55 mph.

In Tables 1–6, increases in the beam candlepower values are much more noticeable than increases in detection distances because detection distance is a function of the log of the beam candlepower value.

CONCLUSIONS

As reported by Zwahlen et al. (*8*) for the situation of only one headlamp working for American lowbeam and highbeam, there was similar degradation in the detection distances for the European lowbeam. Although the detection distance for only one European lowbeam working (misaimed 0.9 deg left and 0.95 deg above the correct aim) for a straight section of the highway was also longer than the distance obtained from the pair of nearly-properly-aimed lowbeam headlamps, the detection distances for most of the situations with only one lowbeam working were shorter than the detection distances for the two headlamps that are nearly properly aimed, especially for a left-curve section of the highway, and for the enclosed or embedded lens sheeting material. The detection distances for only the driver-side headlamp working versus only the passenger-side headlamp working do not appear to be much different for the warning and overhead guide signs for the American lowbeam and highbeam, but there appear to be large differences when compared with the European lowbeams. There are some differences between detection distances for only the driver-side and only the passenger-side beam working for the post delineator and license plate (for straight and curved section of highway) and the raised pavement markers for all three beam types (European lowbeam and American lowbeam and highbeam). Overall, the American lowbeam produces longer detection distances than does the European lowbeam. For beam misaims for only the driver-side or only the passenger-side beam working, for either the same reflective material or the same side of the road (left or right), the beam candlepower values are also larger for longer detection distances. The increases in the detection distances are not as large as the increases in the beam candlepower values by far. From the detection distance and DSD point of view, the situation with only one lowbeam headlamp working is not safe enough (under some misaim conditions) for the warning sign with enclosed lens sheeting material when using the European and American lowbeam and for the warning sign with the encapsulated lens sheeting when using the European lowbeam, and the situation with only one lowbeam headlamp working appears inadequate from a safety point of view (DSD and SSD) for the post delineator on the left-curve section of the highway, for the license plate on either the left or right side of the road for both the European and American lowbeam, and for the pavement marker both for the European and American lowbeam.

From Figures 5 and 6, the prismatic reflective sheeting material produces longer detection distances than the other reflective sheeting materials, which suggests that the detrimental effect of only one headlamp working (nearly properly aimed or misaimed) on the detection distance of reflectorized targets could be almost totally offset by the use of a brighter reflective material. However, Sivak and Olson (*17*) have discussed a number of studies that have shown that legibility is generally an inverted U-shaped function of luminance. Zwahlen et al. (*18*), though, have concluded that based on the averages of the recognition distances for correct responses and the number of correct and incorrect recognition responses, the use of highly reflective sheeting materials, such as prismatic reflective sheeting material, combined with fairly high beam illumination conditions have only had a small and practically negligible effect on shape recognition. Therefore, in the design of reflective warning signs and devices the use of brighter reflective sheeting materials (prismatic or encapsulated lens sheeting material) may be justifiable, because their use will likely offset the detrimental effect of driving with only one beam working (nearly properly aimed or misaimed) on the detection distance while causing only a slight and practically negligible negative effect on recognition distance under close to maximum beam illumination conditions.

Manufacturers should design and produce headlamp systems and headlamps with the highest possible reliability and longest possible headlamp life (subject to economic feasibility), and a strict law enforcement policy (encouraging immediate headlamp replacement) should be aimed at drivers driving vehicles at night having only one headlamp working. Further, the minimum required brightness level of the reflective materials used for reflectorized warning signs and devices should be raised.

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