AN EVALUATION OF RETROREFLECTIVE SIGNING MATERIALS UNDER THE 3-BEAM HEAD-LAMP SYSTEM

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The purpose of the study described in this paper is to measure the comparative brightness of contemporary traffic signing materials under both the conventional 2-beam and the proposed 3-beam head-lamp systems. Because most traffic signs are retroreflective, sign brightness is highly dependent on the illuminance supplied by head lamps. A systematic evaluation performed by the authors led to a general understanding of sign luminances for conventional 2-beam performance for Interstate Highway System signs. The design experiment was developed to evaluate the relative change in sign luminance should the 3-beam system be standardized. Photometrically selected 2- and 3-beam head-lamp sets were obtained from 2 lamp manufacturers, installed in standard-size passenger cars, and aligned. Night luminance measurements were made of retroreflective sign materials by using a telephotometer installed at driver eye position. Luminance measurements were taken at 7 distances from the traveled lane on a uniformly graded tangent section of test road. The proposed low beam is not different from the current low beam. The sign luminance under the proposed mid beam is approximately 4 times greater than it is under the low beam. The high beam provides substantially more light, and sign luminance under the proposed high beam is approximately 2 times greater than it is under the current high beam.

•NIGHT traffic sign effectiveness has been dealt with in numerous studies (1, 2, 3, 4), sign luminance values have been evaluated by Allen et al. (5), and desirable levels have been suggested, particularly for guide signs. We have extensively inventoried guide sign luminance (6) and reported on typical reflective sign luminance. Our field work reported luminance levels generally from 1 or 2 ft-L (3.4 or 6.8 cd/m^2) on the low beam for shoulder-mounted guide-sign legend materials. The output on high beam was approximately 6 to 8 times greater than these values. For overhead signs, the luminance change was about 1 to 15 ft-L (3.4 to 51 cd/m^2) for the 2-beam modes. Improved and more efficient reflective materials produce 2- to 3-fold improvements, but similar improvements are obviously possible with a change of head-lamp output. Simple alteration of the beam pattern, such as that which occurs with misaimed head lamps, can significantly alter sign luminance. Redistribution or increase of light output by the lamp manufacturer also can significantly alter sign luminance.

As we reported earlier, sign luminance determinations can be calculated, and relative notions of sign brightness can be assessed. To determine carefully the numerous variables, one must have a rather detailed knowledge of the specific luminance characteristics of the retroreflective materials obtained by the techniques outlined in procurement documents (7). The divergence angle (subtended by the head lamps, the sign, and the reflected light beam at the observer) must be known. This angle undergoes significant change as the motorist approaches the sign. The angle increases substantially as sign reading distances shorten, and this greatly influences the resulting lu-

Publication of this paper sponsored by Committee on Visibility.

minance. The greater lateral distance of the right head lamp increases the divergence angle, which reduces the luminance contribution from this source to approximately half that of the left lamp at distances beyond 150 ft (46 m). This is significant in the proposed mid-beam mode of the 3-beam system, for an added lamp is used on the left, ahead of the driver's position. Changes in divergence angle necessitate separate calculation of the luminance for each head lamp and each divergence angle.

Illuminance depends on the alignment of the sign with the head-lamp beam, and its determination requires the location of the reflective device in the appropriate area of the head-lamp isocandle diagram for both high and low beams and for typical conditions of highway alignment. Calculation for each lamp, change in sign position, and distance is required. Luminance values then are obtained by applying the inverse square law. However, voltage variation, lamp misalignment, and changes in car loading contribute to variation in illuminance, providing results that are frequently inconsistent with observed luminance values. Sign luminance is highly dependent on head-lamp output, beam distribution, and lamp proximity to the driver's eyes.

The need for brighter and better vehicle front-lighting systems has been well documented by Schwab and Hemion (8). The system currently in use in the United States has been standardized substantially since 1939, and, according to Meese (9), has undergone 2 significant and 2 minor changes. A system to provide 3 head-lamp beams for better night visibility has been proposed as the standard for the near future (10).

Adler and Lunenfeld (11) recently studied the proposed 3-beam head-lamp system as it relates to visibility distance, glare in rear view mirrors, and proper aiming requirements. Their study involved using a series of vehicles equipped with different configurations of 3-beam systems (2-3-4, 2-3-3, and 2-3-2 configurations). The identification indicates the number of lamps lighted for low-, mid-, and high-beam modes. In the 2-3-4 configuration, the 2 outside low-beam lamps are lighted in the low-beam mode. In the mid-beam mode, 3 lamps (the 2 low-beam lamps and the left inboard head lamp or mid-beam lamp) are lighted. In the high-beam mode, all 4 lamps (the high-beam elements in the low-beam lamps, the mid-beam lamp, and the special high-beam lamp) are lighted. The 2-3-4 system was selected as the best of the 3 systems tested because it resulted in the longest seeing distance and the most tolerable glare of the systems tested under all circumstances of opposed and unopposed conditions.

Although the visibility distance of a 16-in. (40.6-cm) square gray panel with 8 percent reflectivity was studied, no effort was made to determine the effects of the 3-beam system on retroreflective signing materials. The purpose of the study described in this paper was to measure the conventional types of retroreflective materials used for traffic control signs by using the recommended 2-3-4 beam system and the current conventional 2-beam 4-lamp system as a control.

Our rather elaborate, earlier field study (6) was, in part, purposely replicated. The study described in this paper was conducted in a location where the field conditions for proper positioning of test panels could be made better without disrupting normal traffic operations. This was done by employing instruments for direct luminance measurement at the driver eye position for conventional automobiles.

SIGNING MATERIALS

The signing materials studied are representative of materials employed for traffic control signs, overhead and shoulder-mounted guide signs, and standard shoulder-mounted, regulatory and warning signs. The materials conformed to all known purchase specification provisions promulgated by the states and the federal government. The materials studied and their various colors are described by the data given in Table 1.

PHOTOMETRIC INSTRUMENTATION

Luminance measurements were made with a Gamma Scientific, Inc., Model 2000 telephotometer. This instrument is suited for making such measurements because it has

a transistorized photomultiplier and electrometer amplifier; an independent, battery-powered supply; 2 min (0.033 deg) of angle sensing probe (acceptance angle); a measurement span from 0.001 to 35,000 ft-L (0.0034 to 119 000 cd/m^2); photopic color correction; and internal standardization and calibration. At the beginning and end of the tests, the instrument was calibrated with a National Bureau of Standards standard source. Over a number of tests, it averaged ±2.5 percent.

Although 5 acceptance angles are available with the instrument, the 2-min (0.033-deg) acceptance angle was chosen because it approximates, as well as the instrument permits, the acuity level for acceptable driver eyesight. As Connolly (12) pointed out in his review of visual examination practices for drivers, the licensing of motorists to a 20/40 acuity standard is common and a 2-min (0.033-deg) resolution is equivalent. The instrument was mounted on a tripod above the back of the driver's seat at driver eye position. Instrumentation thus closely approximated the normal driver's eyes for acuity, color response, divergence angle, and vehicle geometrics.

STUDY SITE

The study site used was a recently completed demonstration-research road near Hastings, Minnesota. The 2,200-ft (670-m) road was designed and constructed to represent a 1-way portion of an Interstate roadway. The facility is a straight section with a uniform +0.4 percent grade. Measurements were made from 1,500, 1,200, 900, 600, 450, 300, and 150 ft (457, 366, 274, 183, 137, 91, and 46 m) to correspond to our earlier work. Permanent reference markers were located on posts adjacent to the roadway. The distances surveyed provide one with a thorough knowledge of sign performance from the far to near distances at increments where performance changes are of interest, particularly throughout the useful legibility range.

POSITION OF SAMPLE PANELS

The sample panels were positioned as shown in Figure 1. Shoulder-mounted guide signs are 45 ft (13.7 m) to the right of the lane and 10 ft (3 m) above the elevation of the pavement; overhead guide signs are 21.5 ft (6.5 m) above the crown of the roadway and centered over the right lane; shoulder-mounted regulatory, warning, and advisory signs are 8 ft (2.4 m) above and 13.5 ft (4.1 m) to the right of the right-lane edge. These locations represent the center of typical signs and fall within the recommended placement as specified in the Manual on Uniform Traffic Control Devices for Streets and Highways (13).

HEAD LAMPS

The head lamps used in the study were supplied by 2 manufacturers. The lamps conformed to the proposed recommended standard for photometrics. The head lamps were the standard 2-beam lamps (types 4000 and 4001) and the proposed 3-beam lamps.

Special aiming and installation instructions were requested from the lamp manufacturers and the lamps were installed according to them. Although the final federal docket had not been released, we did not expect that the aiming specifications we used would deviate significantly from the current Society of Automotive Engineers (SAE) standard J599C (14) for high and low beams and SAE standard J582A for the mid beam. The lamps used in the 3-beam head lamps were type 2 in the high-low beam, type 4 in the mid beam, and type 5 in the high beam. The configuration conforms to the 2-3-4 beam configuration recommended by Adler and Lunenfeld (11).

Table 1. Retroreflective signing materials by color and specific luminance.

Material Code	Description	Color	Specific Luminance[a] (unit of area for each cd/ft-c)
A	Encapsulated-lens reflective sheeting	Silver white	250 ft^2
B	Encapsulated-lens reflective sheeting	Yellow	170 ft^2
C	Encapsulated-lens reflective sheeting	Orange	70 ft^2
D	Encapsulated-lens reflective sheeting	Red	35 ft^2
E	Encapsulated-lens reflective sheeting	Green	30 ft^2
F	Encapsulated-lens reflective sheeting	Blue	20 ft^2
G	Enclosed-lens reflective sheeting	Silver white	80 ft^2
H	Enclosed-lens reflective sheeting	Yellow	50 ft^2
I	Enclosed-lens reflective sheeting	Orange	25 ft^2
J	Enclosed-lens reflective sheeting	Red	14.5 ft^2
K	Enclosed-lens reflective sheeting	Green	9 ft^2
L	Enclosed-lens reflective sheeting	Blue	4 ft^2
M	Cube-corner reflective sheeting	Silver white	1,000 ft^2
N	Cube-corner reflector button	Clear, in white metal frames	15 $in.^2$[b]

Note: 1 ft-c = 10.76 lx, 1 ft^2 = 0.093 m^2, 1 $in.^2$ = 6.45 cm^2.

[a]At 0.2 deg divergence and -4 deg incidence. [b]At 0.1 deg divergence and 0 deg incidence.

Figure 1. Positions for 3 classes of signs.

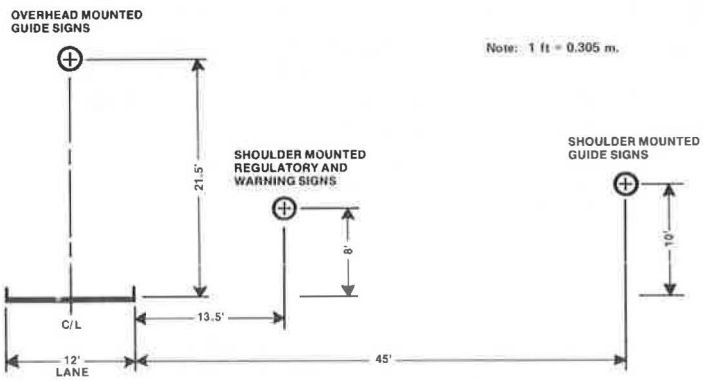

Table 2. Average night luminance of signing materials on overhead sign.

Distance (ft)	Beam	Luminance (ft-L) Code A Material 3 Beams	Code A Material 2 Beams	Code B Material 3 Beams	Code B Material 2 Beams	Code E Material 3 Beams	Code E Material 2 Beams	Code G Material 3 Beams	Code G Material 2 Beams	Code M Material 3 Beams	Code M Material 2 Beams	Code N Material 3 Beams	Code N Material 2 Beams
1,500	Low	0.3	0.3	0.2	0.2	0.04	0.04	0.1	0.1	1.3	1.3	0.3	0.3
	Mid	1.8		1.2		0.3		0.6		9.4		1.3	
	High	9.9	4.8	3.7	4.1	1.0	1.1	3.0	3.2	54	20.4	8.2	4.8
1,200	Low	0.4	0.4	0.3	0.3	0.09	0.09	0.2	0.2	1.9	1.9	0.4	0.4
	Mid	2.6		1.6		0.6		1.4		16.7		2.6	
	High	12.1	10.8	5.4	4.3	1.6	1.7	5.2	3.3	72.1	34	12.9	7.6
900	Low	0.6	0.6	0.4	0.4	0.1	0.1	0.3	0.3	2.6	2.6	0.6	0.6
	Mid	2.6		2.0		0.6		1.4		14		2.7	
	High	17.0	12.6	7.9	5.8	1.0	1.9	7.4	5.0	111.1	55.6	16.4	10.4
600	Low	0.7	0.7	0.4	0.4	0.1	0.1	0.4	0.4	2.9	2.9	0.7	0.7
	Mid	2.3		1.6		0.5		1.4		15.2		2.9	
	High	20.2	15.3	12.6	8.8	4.0	2.5	10.0	7.0	114.3	91.0	18.7	12.2
450	Low	0.7	0.7	0.5	0.5	0.1	0.1	0.4	0.4	2.9	2.9	0.7	0.7
	Mid	2.1		1.2		0.4		1.1		9.9		2.2	
	High	16.7	12.6	10.0	7.4	2.9	2.1	8.3	6.4	72	54.7	17.2	11.3
300	Low	0.6	0.6	0.3	0.3	0.1	0.1	0.4	0.4	2.2	2.2	0.5	0.5
	Mid	1.3		0.7		0.4		0.8		5.0		1.6	
	High	6.6	4.8	4.6	3.5	1.4	0.9	5.2	3.4	25.9	17.6	7.6	4.8
150	Low	0.2	0.2	0.1	0.1	0.05	0.05	0.3	0.3	0.3	0.3	0.2	0.2
	Mid	0.3		0.2		0.09		0.5		0.6		0.2	
	High	0.6	0.4	0.4	0.3	0.2	0.1	1.0	0.7	1.2	0.9	0.7	0.2

Note: 1 ft = 0.305 m. 1 ft-L = 3.4 cd/m^2.

TEST VEHICLE

Full-size, standard station wagons were used throughout the study. Three out of the 4 vehicles had tinted glass, which corresponds to the distribution of vehicles with tinted glass in the normal vehicle population. The gas tank was filled, and then the 3-beam lamps were aligned according to the recommendations supplied by the lamp manufacturer. Before readings were made, the windshield (inside and outside) and head-lamp surfaces were cleaned. The vehicle voltage output was checked, and the engine was kept running throughout the tests to keep voltage constant.

VEHICLE-ROADWAY ALIGNMENT

The test vehicle employed the right traveled lane and was 2 ft (0.61 m) from the right edge in the normal wheel-path area. Station marks were placed on the roadway surface at intervals of 1,500, 1,200, 900, 600, 450, 300, and 150 ft (457, 366, 274, 183, 137, 91, and 46 m) from the test panel surfaces. The left vehicle wheels were aligned with the longitudinal marks so that the vehicle was parallel with the roadway at each station. In this manner, vehicle position was maintained for the several nights over which measurements were taken.

RESULTS

Results were obtained for each of the head-lamp sets for both conventional 2-beam and proposed 3-beam systems. Tables 2, 3, and 4 and Figures 2, 3, and 4 permit direct comparison of traffic sign luminance values for current signing materials for the 7 distances under both the conventional and proposed headlighting systems. The arrangement of the tables permits direct comparison of the 2- and 3-beam system at each distance.

DISCUSSION OF RESULTS

Low Beam

The proposed low beam is not different from the current low beam. Current low beam output is a design compromise between tolerable glare on rural 2-lane roads for oncoming drivers and maximum forward vision. As a result, the low beam of the proposed 3-beam system is unchanged. Values given compare relatively well with values obtained in our earlier study of sign luminance for the shoulder-mounted regulatory sign (6). Variation of values from the earlier study is most likely attributable to differences in head-lamp aim, which we believe to be the most critical single variable.

Mid Beam

The proposed mid beam is intended for use on divided highways where opposing traffic is separated and resultant glare would be tolerable. The mid beam offers significantly improved sign luminance over the current or proposed low beam. The data given in Table 5 show the luminance improvement on overhead expressway signs with use of the mid beam. The improvement averages 4.5 times the low-beam values. The improvement is quite significant, and if motorists use the mid beam rather than the low beam, which is now generally used, a real contribution to sign luminance is possible.

For shoulder-mounted guide signs, the improvement is less marked. The improvement averages 2.5 times the low-beam values, but the improvement diminishes at distances of less than 600 ft (183 m). The mid beam offers little improvement at 300 ft

Table 3. Average night luminance of signing materials on shoulder-mounted guide signs.

Distance (ft)	Beam	Luminance (ft-L) Code A Material 3 Beams	Code A Material 2 Beams	Code E Material 3 Beams	Code E Material 2 Beams	Code F Material 3 Beams	Code F Material 2 Beams	Code G Material 3 Beams	Code G Material 2 Beams	Code M Material 3 Beams	Code M Material 2 Beams	Code N Material 3 Beams	Code N Material 2 Beams
1,500	Low	1.5	1.5	0.3	0.3	0.3	0.3	0.9	0.9	6.2	6.2	1.7	1.7
	Mid	5.0		0.9		1.1		2.9		42.8		6.6	
	High	9.3	2.4	1.3	0.9	2.4	2.3	4.1	2.2	57.8	15.1	11.7	3.3
1,200	Low	2.3	2.3	0.5	0.5	0.5	0.5	1.3	1.3	10.2	10.2	2.3	2.3
	Mid	6.2		1.2		1.5		3.5		40.4		7.9	
	High	11.6	4.5	1.8	1.9	2.7	2.7	5.0	4.0	71	28	14.2	7.6
900	Low	4.1	4.1	0.8	0.8	0.9	0.9	2.3	2.3	17.6	17.6	4.4	4.4
	Mid	7.7		1.4		2.2		4.5		50.8		10.1	
	High	17	7.1	2.6	2.3	3.5	2.4	7.6	4.6	109	47.3	22.5	9.8
600	Low	7.0	7.0	1.2	1.2	1.2	1.2	4.0	4.0	38.1	38.1	3.4	3.4
	Mid	7.6		1.4		1.2		4.8		56		6.6	
	High	13	10	2.0	2.0	2.0	2.8	7.0	5.2	77	58	8.2	11.3
450	Low	4.7	4.7	0.4	0.4	0.4	0.4	1.2	1.2	16.1	16.1	2.4	2.4
	Mid	4.7		0.7		0.7		2.7		28.6		4.2	
	High	7.7	8.0	1.2	1.4	1.2	1.2	4.1	4.1	40	38.5	6.6	6.1
300	Low	1.0	1.0	0.1	0.1	0.2	0.2	0.8	0.8	4.0	4.0	1.2	1.2
	Mid	1.3		0.2		0.2		1.0		7.3		1.4	
	High	4.1	3.8	0.8	0.8	0.7	0.7	2.9	2.7	18.8	13.3	4.6	3.2
150	Low	0.5	0.5	0.1	0.1	0.07	0.07	0.7	0.7	1.1	1.1	0.2	0.2
	Mid	0.5		0.1		0.07		0.8		1.2		0.4	
	High	0.8	1.6	0.2	0.4	0.2	0.3	1.4	1.6	2.6	4.3	1.3	1.7

Note: 1 ft = 0.305 m. 1 ft-L = 3.4 cd/m².

Table 4. Average night luminance of signing materials on shoulder-mounted, regulatory and warning signs.

Distance (ft)	Beam	Luminance (ft-L) Code A Material 3 Beams	Code A Material 2 Beams	Code B Material 3 Beams	Code B Material 2 Beams	Code C Material 3 Beams	Code C Material 2 Beams	Code D Material 3 Beams	Code D Material 2 Beams	Code E Material 3 Beams	Code E Material 2 Beams	Code F Material 3 Beams	Code F Material 2 Beams
1,500	Low	0.9	0.9	0.5	0.5	0.3	0.3	0.2	0.2	0.2	0.2	0.09	0.09
	Mid	6.2		3.0		1.5		0.7		1.3		0.2	
	High	7.9	5.2	7.7	3.9	3.9	2.1	2.1	1.4	2.3	1.6	0.5	0.4
1,200	Low	1.6	1.6	1.1	1.1	0.5	0.5	0.3	0.3	0.3	0.3	0.1	0.1
	Mid	8.2		4.8		2.3	2.3	1.5		1.6		0.4	
	High	18.2	13.1	11.4	5.3	5.5	2.8	3.4	3.0	3.0	4.5	0.8	0.9
900	Low	3.1	3.1	1.9	1.9	1.0	1.0	0.6	0.6	0.8	0.8	0.1	0.1
	Mid	10.5		6.1		3.0		1.8		2.0		0.5	
	High	28.7	19.6	17.8	9.7	8.4	4.6	4.4	3.9	5.0	4.9	1.4	1.3
600	Low	5.4	5.4	3.4	3.4	1.7	1.7	1.0	1.0	1.1	1.1	0.4	0.4
	Mid	16.7		10.1		5.1		2.8		3.5		1.1	
	High	46.4	30.4	26.9	16.9	12.0	8.0	7.0	4.9	8.3	5.7	2.3	1.6
450	Low	5.3	5.3	3.1	3.1	1.5	1.5	1.0	1.0	1.0	1.0	0.3	0.3
	Mid	13.0		7.7		3.3		2.6		2.9		1.0	
	High	48.6	27.8	27.8	15.4	12.8	6.7	8.3	4.8	8.9	4.8	3.1	1.7
300	Low	2.4	2.4	1.4	1.4	0.7	0.7	0.5	0.5	0.5	0.5	0.3	0.3
	Mid	5.3		2.8		1.2		1.3		1.3		0.6	
	High	18.4	12.6	10.3	7.1	4.4	3.5	4.1	2.7	3.6	2.6	1.7	1.5
150	Low	0.7	0.7	0.5	0.5	0.2	0.2	0.1	0.1	0.2	0.2	0.1	0.1
	Mid	0.9		0.6		0.3		0.2		0.2		0.1	
	High	2.1	1.1	1.6	1.2	0.7	0.6	0.7	0.6	0.8	0.7	0.7	0.6

Distance (ft)	Beam	Luminance (ft-L) Code G Material 3 Beams	Code G Material 2 Beams	Code H Material 3 Beams	Code H Material 2 Beams	Code I Material 3 Beams	Code I Material 2 Beams	Code J Material 3 Beams	Code J Material 2 Beams	Code K Material 3 Beams	Code K Material 2 Beams	Code M Material 3 Beams	Code M Material 2 Beams
1,500	Low	0.5	0.5	0.2	0.2	0.1	0.1	0.09	0.09	0.1	0.12	3.2	3.2
	Mid	2.1		1.4		0.6		0.3		0.4		31.4	
	High	4.6	2.4	2.9	1.4	1.4	0.5	0.5	0.5	0.8	0.85	58	23.5
1,200	Low	0.7	0.7	0.5	0.5	0.2	0.2	0.1	0.1	0.2	0.25	5.6	5.6
	Mid	3.2		2.1		1.1		0.4		0.6		41.6	
	High	6.6	4.8	4.2	3.2	2.2	1.7	0.8	1.2	1.1	1.7	77.2	46.5
900	Low	1.4	1.4	0.9	0.9	0.6	0.6	0.1	0.1	0.3	0.3	10.8	10.8
	Mid	4.6		2.9		1.7		0.5		1.0		53.5	
	High	12	6.4	7.4	4.2	4.1	2.2	1.3	1.2	1.9	1.7	121.5	66
600	Low	2.4	2.4	1.6	1.6	1.1	1.1	0.3	0.3	0.6	0.6	23.2	23.2
	Mid	7.6		4.8		3.5		0.9		1.8		122.4	
	High	17.7	11.8	10.3	7.3	8.0	5.0	1.7	1.6	3.8	2.5	241.9	155
450	Low	2.5	2.5	1.5	1.5	1.6	1.6	0.3	0.3	0.8	0.8	20.5	20.5
	Mid	6.1		3.4		3.6		0.7		1.6		72.8	
	High	19	10.2	10.4	6.0	10.6	5.6	1.4	1.4	4.7	2.2	202	122
300	Low	1.5	1.5	0.9	0.9	1.1	1.1	0.2	0.2	0.5	0.5	10.1	10.1
	Mid	3.1		1.7		2.7		0.4		1.0		20.8	
	High	8.8	6.9	5.4	4.0	7.4	4.8	0.9	0.8	2.5	2.2	84.5	50.5
150	Low	0.8	0.8	0.5	0.5	0.4	0.4	0.09	0.09	0.2	0.2	1.6	1.6
	Mid	1.0		0.6		0.5		0.1		0.2		2.1	
	High	2.9	2.4	1.9	1.6	1.7	1.5	0.6	0.5	0.8	0.8	5.6	4.6

Note: 1 ft = 0.305 m. 1 ft-L = 3.4 cd/m².

Figure 2. Night luminance of silver encapsulated lens materials on mounted regulatory signs.

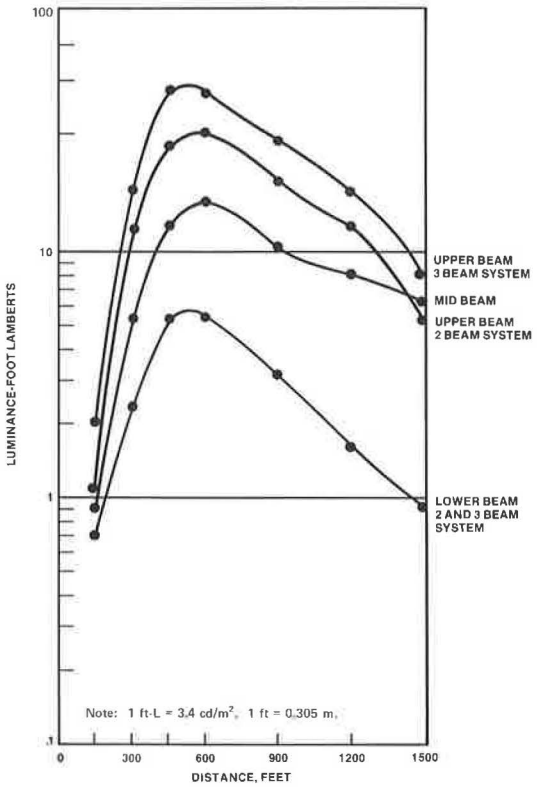

Figure 3. Night luminance of silver encapsulated lens materials on mounted guide signs.

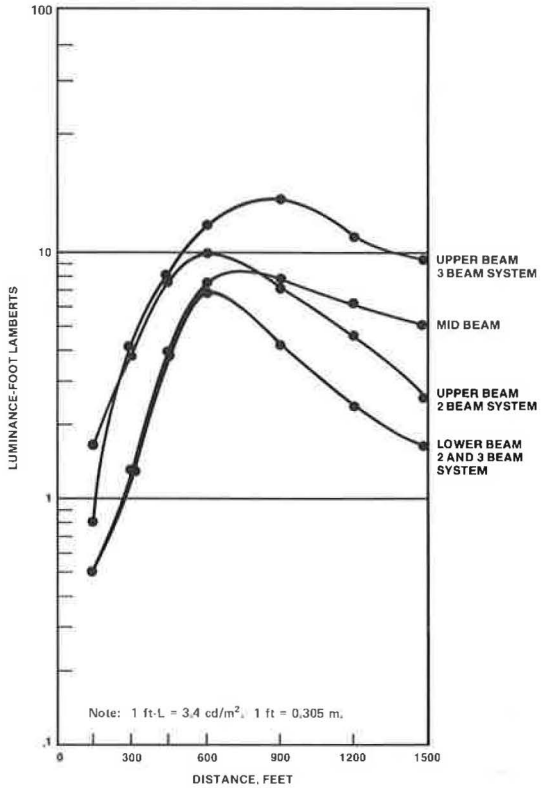

Figure 4. Night luminance of silver encapsulated lens materials on overhead guide signs.

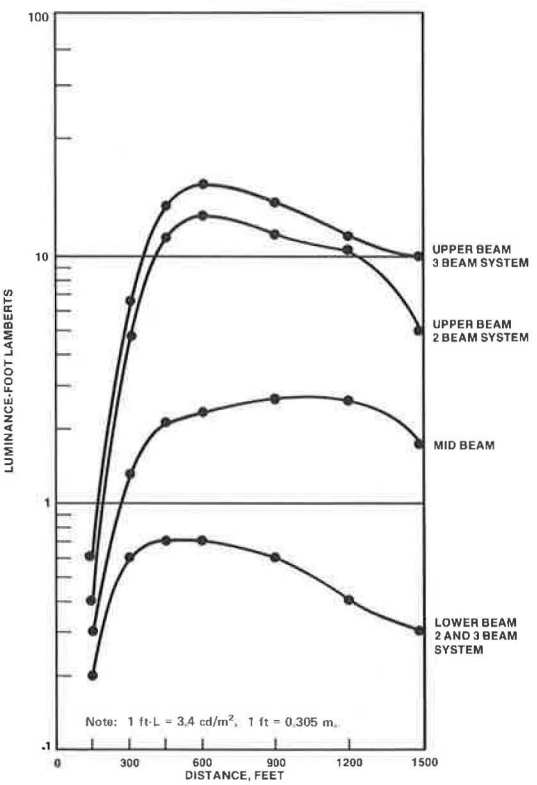

Table 5. Luminance ratios.

Distance (ft)	Comparison	Overhead Guide	Shoulder Regulatory	Shoulder Guide
1,500	3-beam mid to 3-beam low	6.57	7.72	5.43
	3-beam high to 3-beam mid	5.47	1.89	1.46
	3-beam high to 2-beam high	2.08	2.12	3.30
1,200	3-beam mid to 3-beam low	7.73	6.06	3.55
	3-beam high to 3-beam mid	4.29	1.99	1.75
	3-beam high to 2-beam high	1.77	1.52	2.18
900	3-beam mid to 3-beam low	5.04	4.79	2.55
	3-beam high to 3-beam mid	6.91	2.07	2.12
	3-beam high to 2-beam high	1.76	1.70	2.21
600	3-beam mid to 3-beam low	4.57	4.27	1.41
	3-beam high to 3-beam mid	7.53	2.14	1.41
	3-beam high to 2-beam high	1.31	1.54	1.22
450	3-beam mid to 3-beam low	3.20	3.02	1.65
	3-beam high to 3-beam mid	7.51	3.01	2.80
	3-beam high to 2-beam high	1.34	1.71	1.03
300	3-beam mid to 3-beam low	2.40	2.10	1.56
	3-beam high to 3-beam mid	5.25	3.60	2.80
	3-beam high to 2-beam high	1.47	1.53	1.30
150	3-beam mid to 3-beam low	1.68	1.22	1.15
	3-beam high to 3-beam mid	2.13	2.68	2.12
	3-beam high to 2-beam high	1.55	1.11	0.65
Average	3-beam mid to 3-beam low	4.46	4.17	2.47
	3-beam high to 3-beam mid	5.58	2.48	1.87
	3-beam high to 2-beam high	1.61	1.60	1.70

Note: 1 ft = 0.305 m.

(91 m) and closer because of the wide offset for the position of this sign. The mid beam essentially illuminates the lane ahead and is not aligned for wide offsets.

The shoulder-mounted, regulatory- and warning-sign position is in favorable alignment for the mid-beam mode, and this accounts for the 4.2-times improvement of mid beams over low beams.

High Beam

For overhead signs, luminance under the proposed high beam is approximately 5 times better than luminance under the mid beam for distances of 1,500 to 300 ft (457 to 91 m). For shoulder-mounted guide signs, luminance under the high beam is generally 1.9 times better than it is under the mid beam. For the shoulder-mounted regulatory signs, luminance under the proposed high beam averages 2.5 times brighter than the luminance under the mid beam.

The proposed high beam provides approximately 1.5 times the light output of the conventional high beam. By comparison, sign luminances for overhead, shoulder-mounted guide, and shoulder-mounted regulatory signs are 1.6, 1.6, and 1.7 times brighter respectively for the proposed lamps.

Ratios expressing improvements in sign luminance are given for each distance and sign position in Table 5.

CONCLUSIONS

The mid beam of the proposed 3-beam head-lamp system should at least double the sign luminances of the low beam. The proposed high beam is 1.5 times better than the current high beam. The most impressive improvement possible is shown in a comparison of the proposed high beam to either low or mid beams. Although there is little doubt that these improvements are possible, motorists must break long-standing habits of using low beams for almost all night driving on freeways and a high proportion of night driving on 2-lane rural roads.

ACKNOWLEDGMENT

We wish to acknowledge the helpful assistance provided by both the Wagner Electric Company and General Electric Company, particularly the valuable guidance supplied by Paul E. Westlake of the Miniature Lamp Department, General Electric Company.

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DISCUSSION

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The relevance of the paper arises from the consideration of signing materials and the effect of head-lamp illumination on the luminance of these materials at typical highway installation locations. In this respect, the paper draws attention to the need to evaluate the effectiveness of head-lamp systems with respect to the driver information needs from signs in addition to the commonly reported evaluation of roadway obstacle detection.

With respect to the signing materials at the different locations, the tabulated data given in Tables 2, 3, and 4 permit the reader to make some assessment of the relative performance of the materials and the contrast arising from the different combinations of signing materials used in a highway sign.

The ratios of the luminances for 2 different materials for a given lighting system are in general agreement with the specific luminance ratios obtained from Table 1; the variations of the ratios for the different lighting systems are typically less than 50 percent of the average. Thus, for intercomparison of signing materials, the use of the luminance data reported has some significance.

However, for the luminance levels themselves and their comparison for evaluation of head-lamp systems, the processing of the results leading to Table 5 and the experimental procedure followed leave something to be desired.

With regard to the manner in which the results are processed and their effect on statistical interpretations, we may note that the luminance values for code M material in Tables 2, 3, and 4 are approximately equal to the sum of the luminances of all other materials. Table 5 has been derived from these tables by taking the ratio of the average luminances of all materials for the different lighting systems. Clearly, the values obtained are substantially biased toward the values for code M material. A more adequate statistical method would be to take the averages of the luminance ratios. In following this procedure, one clearly minimizes the dependence of the results on code M material as seen by the data given in Table 6 for the ratio of 3-beam mid to 3-beam low.

Our table clearly indicates that a more adequate statistical interpretation than the one followed by Woltman and Youngblood leads to results that differ by as much as 40 percent.

With regard to the experimental procedure followed by Woltman and Youngblood leading to the comparison of different headlight systems, certain comments are in order. Woltman and Youngblood have noted in their introduction the effect of beam pattern, output, and head-lamp aim on illuminance and luminance, and, furthermore, they have considered the other factors required for calculations. Nevertheless, they proceeded to carry out a small-sample experiment for which none of the photometric operating

Table 6. Luminance ratios for 3-beam mid to 3-beam low.

Material Code	Shoulder-Mounted Regulatory Signs				Overhead Signs			
	600 ft	900 ft	1,200 ft	1,500 ft	600 ft	900 ft	1,200 ft	1,500 ft
A	3.1	3.4	5.1	6.9	5.0	4.3	6.5	6.0
B	3.0	3.2	4.4	6.0	4.0	5.0	5.3	6.0
C	3.0	3.0	4.6	5.0	—	—	—	—
D	2.8	3.0	5.0	3.5	—	—	—	—
E	3.2	3.5	5.3	6.5	5.0	6.0	6.7	7.5
F	2.75	5	4.0	2.2	—	—	—	—
G	3.2	3.3	4.6	4.2	3.5	4.7	7.0	6.0
H	3.0	3.2	4.2	7.0	—	—	—	—
I	3.2	2.8	5.5	6.0	—	—	—	—
J	3.0	5	4.0	3.3	—	—	—	—
K	3.0	3.3	3.0	4.0	—	—	—	—
M	5.3	4.95	7.4	9.8	5.2	5.4	8.8	7.2
N	—	—	—	—	4.1	4.5	6.5	4.3
Average	3.2	3.6	4.8	5.4	4.5	5	6.8	6.2
Average excluding M	3.0	3.5	4.5	5.0	4.3	4.9	6.4	6
Woltman and Youngblood average	4.27	4.79	6.06	7.72	4.57	5.04	7.73	6.57

Note: 1 ft = 0.305 m.

Figure 5. Isocandela maps for (a) SAE low beam type 4000 and (b) SAE middle beam type 4.

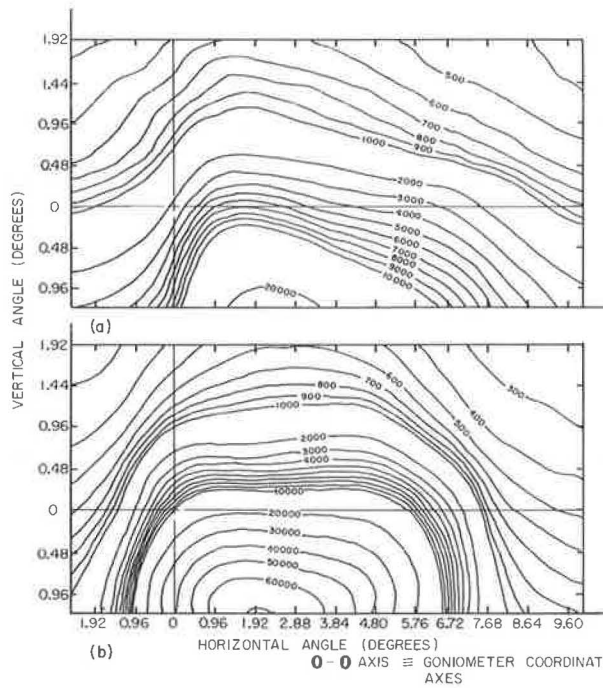


Figure 6. Ratio map for middle and low beams photometrically aimed according to SAE J582A and SAE J579B.

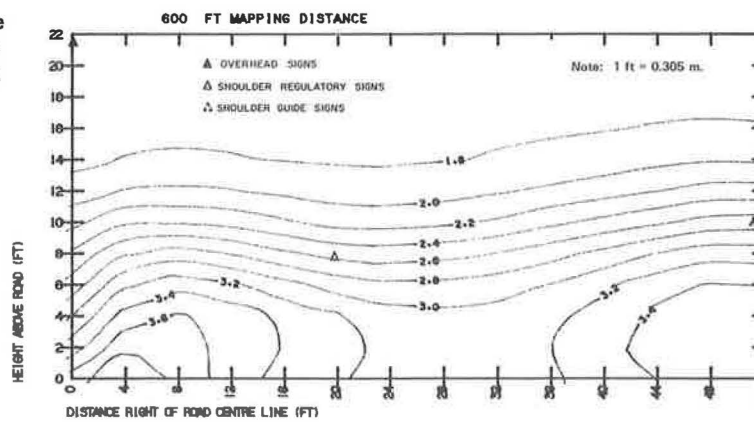
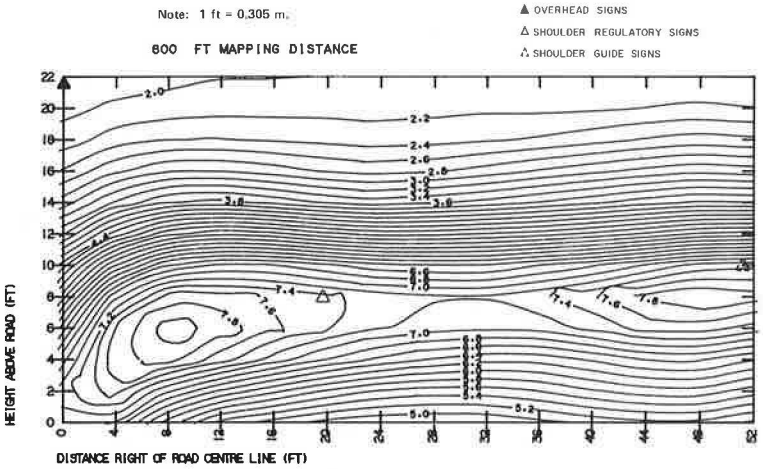


Figure 7. Ratio map for 0.5-deg vertical increase of mid-beam aim.



point conditions has been described and for which no range of values with respect to the averages reported in Tables 2, 3, and 4 has been given. One is left with the impression that in some way a small experiment is better than calculations based on laboratory data and that somehow the averages of the experimental results have significance with respect to population characteristics. However, one must treat the results obtained in this fashion with extreme care in the general case. More specifically, the results of the Woltman and Youngblood experiment will be highly sensitive to lamp photometrics and aim, vehicle pitch, voltage variations, vehicle-roadway alignment, variations due to windshield transmission factors, and possible statistical analysis of samples that are not equally weighted.

For example, the results relative to between-sample variations and sampling procedures appear to indicate that the low-beam values for the 3-beam system (Tables 2, 3, and 4) possibly were taken from the low-beam values for the 2-beam system. This inference is indicated by an inconsistency in Table 5. For the shoulder-mounted guide sign at 150, 300, and 450 ft (46, 91, and 137 m), a ratio for 3-beam mid to 3-beam low of significantly less than 1 is obtained. By definition, on a single vehicle, regardless of the operating point conditions (aim, pitch, voltage, and the like), the ratio always must be greater than (or equal to) 1. A clarification concerning this point is needed. Woltman and Youngblood, therefore, would clearly enhance the relevance of their results by indicating the operating point conditions for their experiment and the sampling procedures. However, the most important factor relevant to the head-lamp comparison question within a given sampling procedure is the problem of aim and head-lamp photometrics.

It is well known that the SAE specified tolerances on head-lamp photometrics, aim, and aiming procedures can lead to large variations in operational output. The aiming problem has been studied by several researchers, particularly Walker (15).

To provide some assessment of the aiming question itself for a comparison of a mid-beam mode with a low-beam mode, one must know the isocandela maps for the lamps used (Figures 5, 6, and 7).

An important aspect of a research program on automobile headlighting currently under way at the National Research Council of Canada is the head-lamp photometric-scene luminance intercomparison of systems performance (16). Here, it has been found that, for a typical SAE low beam, vertical aim changes of ±0.25 deg lead to changes in illuminance on the order of 250 percent in the region studied by Woltman and Youngblood. Because of the steeper gradient of the mid-beam mode, an equivalent change in mid-beam aim leads to variations of about 300 percent in illuminance in the same region. In both cases, the 0.25-deg changes in aim are within SAE tolerances.

Therefore, knowledge of the photometric operating point conditions and quality control procedures are necessary for interpreting field experiments.

A similar conclusion may be noted from the work of Adler and Lunenfeld (17) where the difference between the minimum and maximum candela lines employed for their studies is seen to be as high as 500 percent for both low- and mid-beam systems.

Having taken into consideration all the previously mentioned factors, one can expect a large range of variation of head-lamp system illumination at the highway sign locations. Therefore, in comparing head-lamp systems, particularly for small-sample-size field experiments, it is important to have measured values of the system output in the zone of the visual task, if one is to be able to assess whether the output of a system is a high or low value within system tolerance. This need and detailing of conditions have been previously commented upon by Meese and Westlake for the obstacle detection task (18).

Woltman and Youngblood can give an indication of the variations involved in their method by tabulating the average luminance values and the range observed within their sample. Also, because of the fundamental problem of aim and head-lamp photometrics, the aiming procedure followed should be specified. However, the problem of large variation in illuminance previously mentioned remains because it is intimately related to the tolerance range in current state-of-the-art specifications and procedures.

Our comments should not only be considered as an attempt to constructively criticize the experiments but also as a necessary complement to the data for use by the reader. Because of the large range of variance, statistically significant results from field experiments require a much larger sample than that presented in this paper. We feel that, because of the quality control problems and the sampling requirements inherent in this type of experiment, validated computer calculations based on large samples of head-lamp laboratory measured data together with head-lamp aiming criteria, will be more advantageous and less expensive for determining head-lamp system population performance statistics for intercomparison and evaluations.

In closing, we stress that the paper draws attention to the fact that improvement to be gained from a mid beam in the zone of the highway signs is very sensitive to aim. This is due to current aiming procedures for this type of head lamp. To improve visibility for drivers in the zone studied by Woltman and Youngblood, one might consider aiming the mid beam higher. Because this would increase rearview mirror glare for the preceding vehicles, the mid beam would be used as an intermediate driving beam to be dimmed in the following and 2-lane-meeting modes.

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AUTHORS' CLOSURE

We are delighted to have precipitated the comments by Ayad, Pinkney, and Harrison and are most appreciative of their study of our paper. Our purpose is well served if interest can be developed in the assessment of traffic sign performance instead of the visibility tests employing low-reflectance targets in the lane ahead, which is the usual head-lamp test. All too frequently, significant proposals to alter head lamps fail to

assess impact on traffic signing, and careful study of these changes generally is ignored in most evaluations.

Most discussions of either head lamps or signing materials deal either with idealized cases such as the optically correct head-lamp, or with specification luminance factors of the reflective materials in which minimum luminance values are employed. In any case, real life deals with average systems that can be wide of the mark or well above the minimums.

The discussants point out that the inclusion of luminance values for code M material in Table 5 biases the average values in favor of the code M materials. It does. The sole purpose in averaging the values is to broaden the data base for purposes of comparing the ratios. It seems quite appropriate and valid if used in this manner. However, the method suggested by the discussants is quite appropriate statistically.

As we explained, photometrically selected head lamps to meet the proposed SAE J582A standard, were provided by 2 different manufacturers and were aimed by employing the visual aim screen recommended by SAE J599C for high and low beams and SAE J582A for the mid beam. The visual aim system is believed most reliable of the systems outlined by the SAE and was recommended by the lamp manufacturers. The reflective materials chosen were representative of average production materials and, as such, are above the minimum photometric values of the customary specification. At the specific divergence and incidence values listed, only the single values are shown although both of these angles change as a sign is approached, subtly at first and with increasing magnitude at short range. Thus the total effect of specific luminance is highly variable depending on the vehicle, position of the sign laterally and vertically, and change in distance and variation from the minimum photometric value specified.

The operating points (aim, pitch, voltage, and the like) have been questioned. The voltage at the head lamps was checked by using a Hewlett Packard 970A Digital Probe Multimeter and was found to range from 13.5 to 13.9 for all vehicles used in the test, when measured at high idle speeds. The vehicle's gas tanks were filled, head lamps were aimed and then positioned on the uniformly graded roadway in the normal wheel-path position. The positioning was felt to be representative of what a driver would experience if he or she were driving the roadway under normal driving conditions.

No efforts were made to make a "sterile" lab environment because we wished to study the effects of the 3-beam system as a driver would observe them under normal roadway conditions. The vehicle alignment was maintained by using a spotting target and the internal crosshairs in the telephotometer. Windshield transmission factors were given consideration. A 70 to 30 percent mix of tinted to nontinted windshields exists in the normal vehicle population, and the same ratio was used for the vehicles in the study.

A point that should be made is that the experiment is hardly a "small-sample" experiment. The ratios for beam comparisons (Table 5) are the average results of 24 luminance values for each distance and sign position. The averages for all distances (Table 5) come from 168 of these measurements. Altogether, more than 600 measurements make up the results. Such measurements made with normal lights and reflective materials on a straight tangent roadway section constructed for this specific purpose are, in our experience, a more reliable and satisfactory method of assessment. But it does require considerable facilities and labor.

The ratios of values given in Table 5 should be equal to or greater than 1. We have reviewed the original data sheets and have determined that some data were misentered, which resulted in the observation noted by the discussants. Proper values are now provided in Tables 3, 4, and 5 in the text. We appreciate and are grateful to the discussants for calling attention to this matter.

The discussants' point that ratios between head-lamp performance can be compared more readily by computer preparation may be valid for incident illumination, but this point does not account for the fact that the mid-beam mode places particular emphasis on the left head-lamp divergence angles, which are approximately half the divergence angle of the right lamps. Therefore, illuminance from the left side in the mid-beam mode also is coupled with the smaller divergence angle that provides higher specific luminance than if this luminance were shared equally with the right lamp. A computer

comparison that fails to account for this complex relationship cannot properly evaluate it. Indeed, the only realistic method for doing so is the system employing a telephotometer at driver eye position.

Although we agree that the use of a photometric scene-luminance intercomparison of head-lamp system performance may be desirable for head-lamp comparisons, it does not lead to an accurate assessment of sign luminance as seen by the driver.

Because of all the variables outlined in this and earlier papers and because of the inverse relationship between divergence angle and reflective efficiency, we feel that direct luminance measurements are preferable, particularly when reflective sign luminance values are desirable.

A general method of determining the luminance of reflectorized materials for various positions, distances, and roadway alignments has been described by Straub and Allen (1). This procedure was used by King and Lunenfeld (4) through the use of computational programs to develop a series of luminance-versus-distance curves for various roadway, sign, head-lamp-aim, voltage, and vehicle conditions. A comparison of this technique and their field observation shows that observed-to-theoretical values range from 0.46 to 0.60 for 80 percent of their situations. We also have noted a similar relationship in other unpublished works.

It is for this reason that we feel that actual field measurements in which a sensitive instrument such as a telephotometer is used yield results that are closer to what the motorist sees under normal driving situations. This method allows for reasonably accurate, rapid assessment of luminance at the point of the visual task.