

Proposal for Standard U.S. Headlamp Beam Pattern for Evaluation of Retroreflection

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Confusion arises among researchers and designers when different headlamp output data files are used to produce luminance profiles of retroreflective sheeting. It is proposed that a standard U.S. headlamp data file be established to reduce confusion and improve communication among researchers in the area of retroreflective materials. A composite 15th percentile headlamp data file for calculating luminance values for which 85 percent of sampled headlamps produce equal or greater luminance is offered. The calculation of luminance depends on headlamp performance and retroreflector characteristics. Use of this 15th percentile headlamp is justified by comparison of luminance values calculated for enclosed lens sheeting for various headlamp data files. This reference headlamp is intended as a standard for retroreflective material research. It is not intended to be a design target for the development or testing of new headlamps. The headlamp data file is available on request.

Retroreflective materials in traffic control devices, pavement markings, and personal safety clothing provide drivers with information about the roadway environment. These materials return light from a vehicle's headlamps to the driver's eyes in a specific direction. Several researchers have used luminance as a tool to assess sign performance and pavement marking and pedestrian visibility (1-3). Luminance measurements may also be used to compare headlamp performance across a set of lamps by using a constant retroreflective target. Luminance profiles allow a glimpse of the dynamic performance of retroreflective materials by displaying the amount of light reaching a driver at different distances. The calculation of luminance depends on retroreflector characteristics and headlamp performance.

When different headlamp data files are used in luminance calculations by different laboratories, it is difficult for researchers to compare luminance profiles of various retroreflective materials. We propose that a standard data file for U.S. headlamps be established to reduce this confusion and improve communication among researchers in this area. We offer a composite 15th percentile headlamp data file for calculating luminance values for which 85 percent of sampled headlamps produce equal or greater luminance.

In their recommendations for minimum sign retroreflectivity, Paniati and Mace (3) use a composite headlamp. This composite is based on the median value of a sample of new headlamps. As such only 50 percent of the sampled headlamps will give calculated luminance values of equal or greater amplitude. If the luminance distribution as a function of headlamp type is sufficiently narrow, this choice is valid. If the luminance spread is greater than 2 to 1 however, Jenkins and Gennaoui (2) propose a better engineering choice. They suggest a headlamp for which more than 80 percent of sampled vehicles would produce equal or greater luminances. In addition to this problem of variability in headlamps, many vehicles on

the road are older and may have dirty, misaligned, or missing headlamps. These anomalous situations are not considered here. The data given here are further idealized in that no atmospheric or windshield loss was included in the analysis and all headlamps analyzed were new. The use of a 15th percentile instead of a 50th percentile headlamp gives a minimum realistic safety factor in attempting to accommodate all vehicles on the road.

METHODOLOGY

We used a combination of computer modeling and actual photometric measurements to evaluate different individual and composite headlamps. Our computer model (4) calculates geometry for left and right headlights for a specified roadway, sign position, and range of distances. The model takes as input headlamp information in the form of candela values at 1,701 measurement points. Data concerning headlamp placement on the vehicle, driver eye position within the vehicle, sign material type, and sign position on the road are also included. The model outputs the presentation, observation, entrance, and orientation angles for each headlamp for a specified set of distances. The amount of illumination (in lux) reaching the sign from each headlamp at each distance is also provided.

Input Variables

Signing Material

To simplify the analysis a single sheeting material was studied. The material, white enclosed lens retroreflective sheeting, had a coefficient of retroreflection at a 0.2-degree observation angle and a -4-degree entrance angle of 112 cd/lx/m². As such this material is representative of a typical new sheeting sample. This Type I sheeting is commonly used internationally for all types of signing.

Roadway, Vehicle Type, and Position of Signs

Roadway length is defined as the centerline distance from the viewer to the target sign, where the viewer's eye position is calculated as a single point at the bridge of the nose. A straight roadway of 457 m (1,500 ft) long with a 3.7-m (12-ft) lane width was chosen. This represents a common situation and provides for analysis over a wide range of viewing angles. A Ford Taurus with a driver viewer approaches the sign positions down the center of this lane. The headlamp and viewer positions are specified in the *x*, *y*, and *z* coordinates with a point of origin on the ground below the front center of the car. The headlamps are 0.61 m to the left or right of

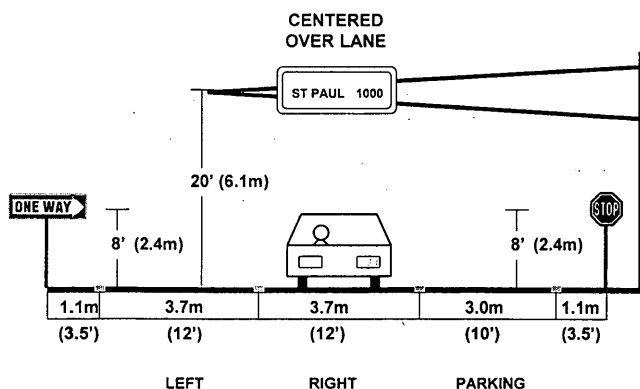


FIGURE 1 Specifications for roadway and sign positions.

center and 0.68 m off the ground. The pitch and roll points of the vehicle are 2.20 m back and 0.68 m up, respectively. The viewer's eye is positioned 2.08 m behind the front, 0.41 m to the left, and 1.16 m above the ground.

Luminance values were calculated for the geometric center of right shoulder, overhead, and left shoulder sign positions. Figure 1 specifies the positions of the three signs. The exact locations of the signs are not critical to the analysis. These three sign positions give a very wide luminance range.

Headlamps

Recently, the University of Michigan Transportation Research Institute (UMTRI) released headlamp output data for a sample consisting of 43 new U.S. headlamps (5). Twenty-six of these headlamps were measured for an earlier NHTSA study. Each file contains 1,701 test points that result from a 21×81 matrix of candela values ranging from -20 to $+20$ horizontal degrees and -5 to $+5$ vertical degrees at 0.5 -degree intervals. For the UMTRI data, candela values varied as much as 53 to 1 at some test points. Also, at most test points the distribution of values across headlamps was not Gaussian.

We analyzed 42 of these headlamp files. These headlamps are identified by an arbitrary number; all manufacturer-specific information remains anonymous. In addition, three composite headlamps were included in the analysis: the median (50th percentile) of the UMTRI data, the 15th percentile of the UMTRI data, and the median from the NHTSA data set of 26 headlamps. This latter composite is called CARTS50 because it is used in the CARTS model of sign visibility (3).

The 15th percentile composite headlamp files were derived by using the statistically derived percentile for each of the available 1,701 test points. The natural logarithm of the candela values was taken, and test points corresponding to those in J579 DEC84 of SAE (6) were tested for normality. The conversion to logarithmic values successfully produced Gaussian distributions at these test points. The 15th percentile headlamp file was statistically derived from the $\log(\text{candela})$ distributions by taking the mean value at each test point and adding 1.04 standard deviation units (7). These log values were then converted back to raw candela values by taking the antilog of the statistically derived values. This composite headlamp meets the J579 DEC84 test point specifications of SAE (6) as shown in Table 1.

TABLE 1 SAE J579 Photometric Test Points from HS-34 and (Proposed) 15th Percentile Headlamp Value

Degrees		Candelas		Proposed Headlamp
Vertical	Horizontal	Maximum	Minimum	
1.0 up	1.5 left	700		366
0.5 up	1.5 left	1000		471
0.5 up	1.5 left	2500		1259
1.5 up	1.0 right	1400		386
0.5 up	1.0 right	2700		801
0.5 down	1.5 right	20000	8000	10210
1.0 down	6.0 left		750	1126
1.5 down	2.0 right		15000	18446
1.5 down	9.0 left		750	1360
1.5 down	9.0 right		750	2506
2.0 down	15.0 left		700	893
2.0 down	15.0 right		700	1703
4.0 down	4.0 right	12500		2778

Note: A tolerance of ± 0.25 deg is allowed at any test point.

Luminance Calculation

On the basis of these input variables, intrinsic photometric angle sets were calculated for the left and right headlamps for vehicle to sign distances ranging from 30- to 457-m (100- to 1,500-ft) intervals. The computed photometric angles were duplicated on a photometric range where the enclosed lens sheeting was measured at each angle set to determine the retroreflectance (R_A) for each viewing distance. By using the headlamp data (cd), illumination (lx) at the sign center at each distance was calculated separately for the left

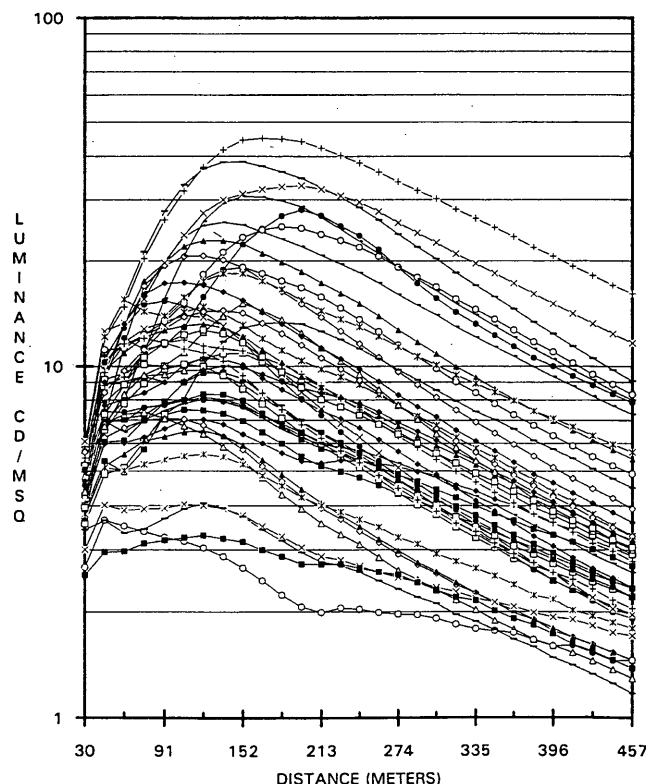


FIGURE 2 Luminance profiles for 42 UMTRI headlamps for right shoulder signs.

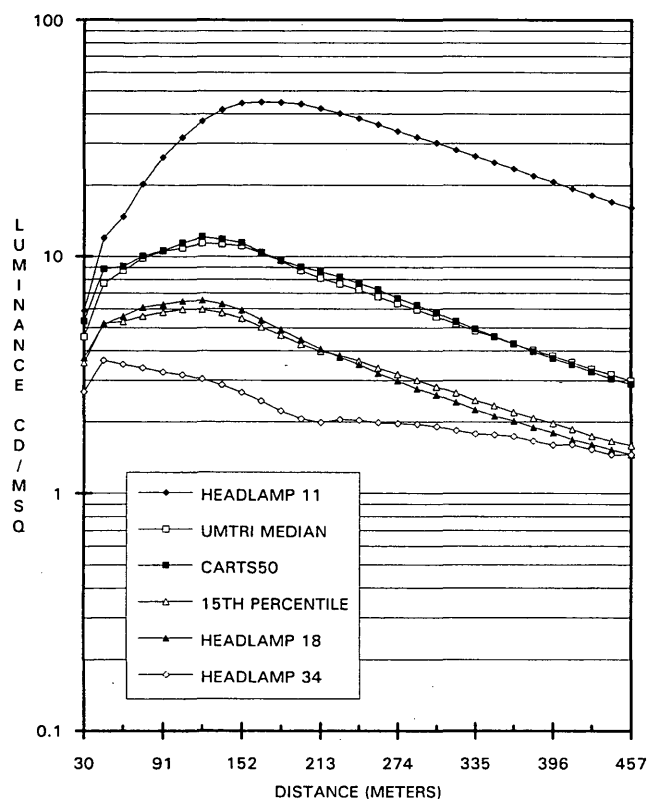


FIGURE 3 Luminance profiles for lowest, highest, and composite headlamps for right shoulder signs. Headlamp 18 matches closely the performance of the 15th percentile composite.

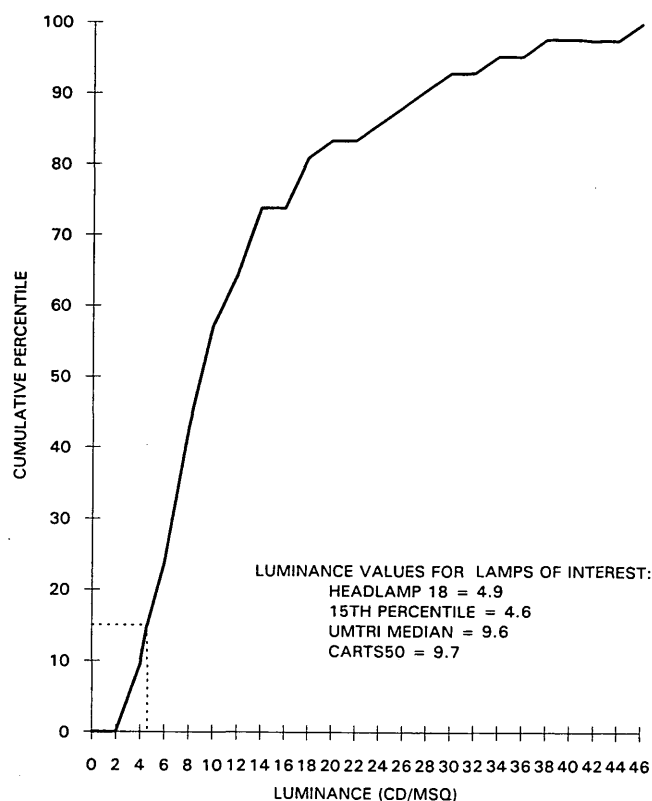


FIGURE 5 Cumulative percentile luminance distribution for 42 headlamps for right shoulder signs at a viewing distance of 183 m (600 ft). Luminance values for critical lamps are provided for reference.

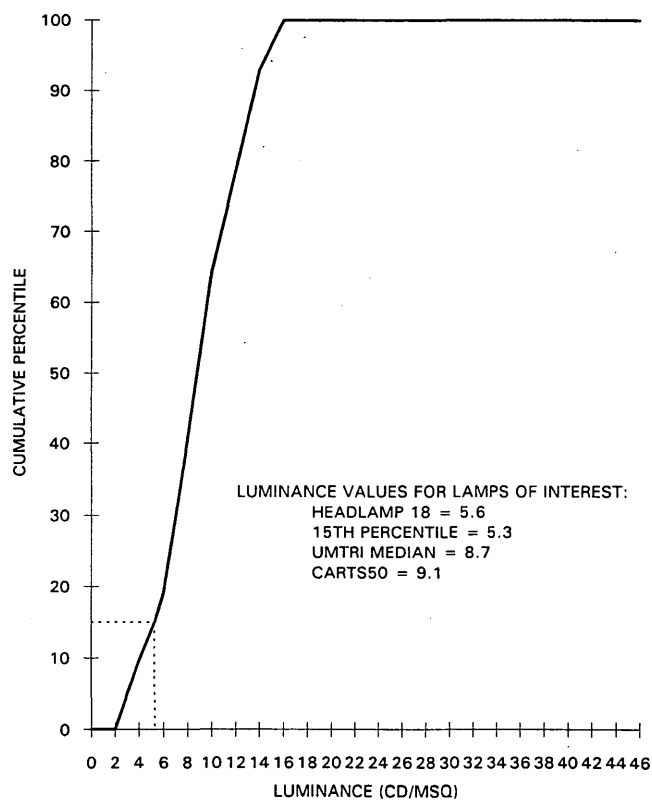


FIGURE 4 Cumulative percentile luminance distribution for 42 headlamps for right shoulder signs at a viewing distance of 61 m (200 ft). Luminance values for critical lamps are provided for reference. Note the 15th percentile value of 5.3 cd/m² falls on the 15 percent value.

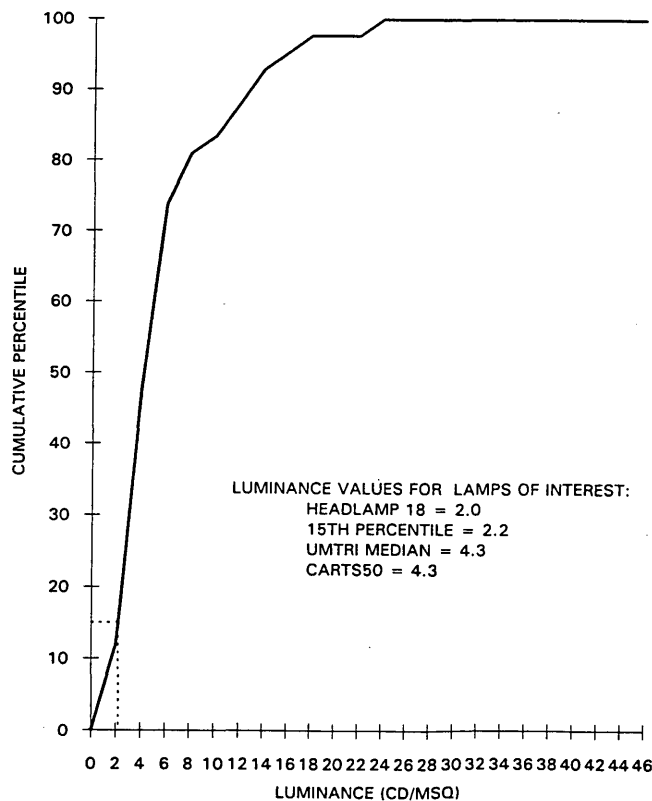


FIGURE 6 Cumulative percentile luminance distribution for 42 headlamps for right shoulder signs at a viewing distance of 365 m (1,200 ft). Luminance values for critical lamps are provided for reference.

and right headlamps. The measured R_A (cd/lx/m^2) values were then multiplied by the calculated illumination (lx) to give luminance values (cd/m^2) for the left and right headlamps. Finally, the luminance values for the left and right headlamps were summed to give the total luminance at the sign center.

RESULTS AND ANALYSIS

Luminance Curves

Figure 2 shows the luminance curves for all 42 UMTRI headlamps for the right shoulder sign. The spread in performance is surprising. Figure 3 shows the luminance curves for six selected headlamps. These six headlamps were selected for comparison because they represented the minimum (Headlamp 34), maximum (Headlamp 11), the three composite beams, and Headlamp 18, which produced luminance similar to that of the 15th percentile headlamp. Note that the CARTS50 and UMTRI median headlamps are very close to each other in performance. Figures 4, 5, and 6 show the luminance distributions plotted as cumulative percentiles at 61, 183, and 365 m (200, 600, and 1,200 ft), respectively. These figures show that at these important viewing distances the 15th percentile headlamp gives a luminance value for which approximately 85 percent of the headlamps have an equal or greater value.

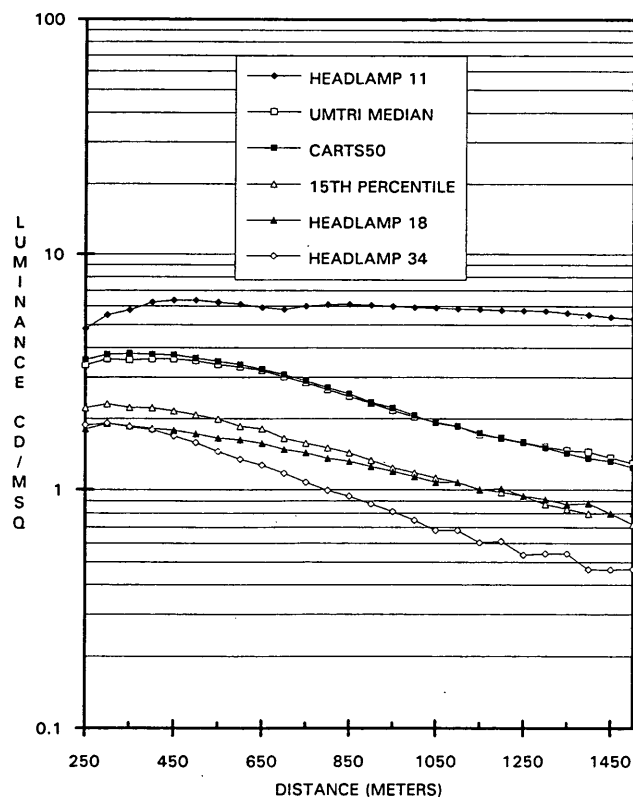


FIGURE 7 Overhead sign luminance profiles for lowest, highest, and composite headlamps. Headlamp 18 matches closely the performance of the 15th percentile composite.

Data for the overhead and left shoulder signs are presented in an abbreviated form to save space. The overall spread of the 42 headlamps and their cumulative luminance distributions for overhead and left shoulder signs were similar to those for the right shoulder sign. Figure 7 shows the luminance curves of the six selected headlamps for an overhead sign. Comparing the plot in Figure 7 with that in Figure 3 shows that the overhead sign appears approximately five to six times dimmer to the driver than the right shoulder sign. Figure 8 shows the plot for the six selected headlamps for a left shoulder sign. From Figure 8 the brightness of the left shoulder sign is seen to be comparable to that of the overhead sign, although the distribution width of these curves appears to be slightly narrower.

Headlamp Isocandela Plots

Figures 9 to 14 show isocandela plots for the six selected headlamps for which luminance curves were given in Figures 3, 7, and 8. In these figures the horizontal scale differs from the vertical scale by a factor of about 2 to make the figures more easily readable. Also on these plots the lines show the angular location for the right (R) and left (L) headlamps for the three sign locations. The overhead sign locators terminate at 76 m (250 ft) since these lines would extend beyond the figure's border. The peak candela value of the data set is given along the right side of the plot. The CARTS50 and UMTRI (Figures 9 and 10, respectively) isocandela plots are nearly identi-

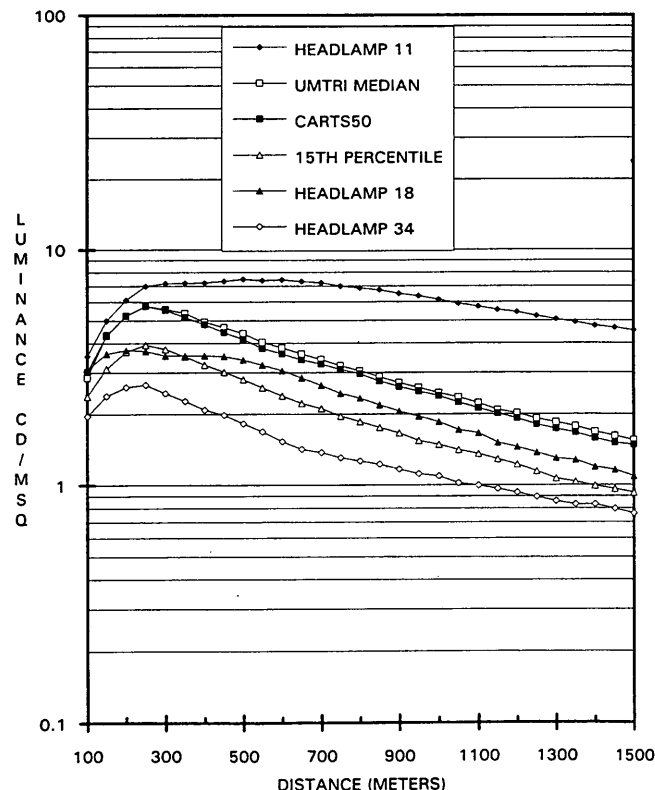


FIGURE 8 Left shoulder sign luminance profiles for lowest, highest, and composite headlamps. Headlamp 18 matches closely the performance of the 15th percentile composite.

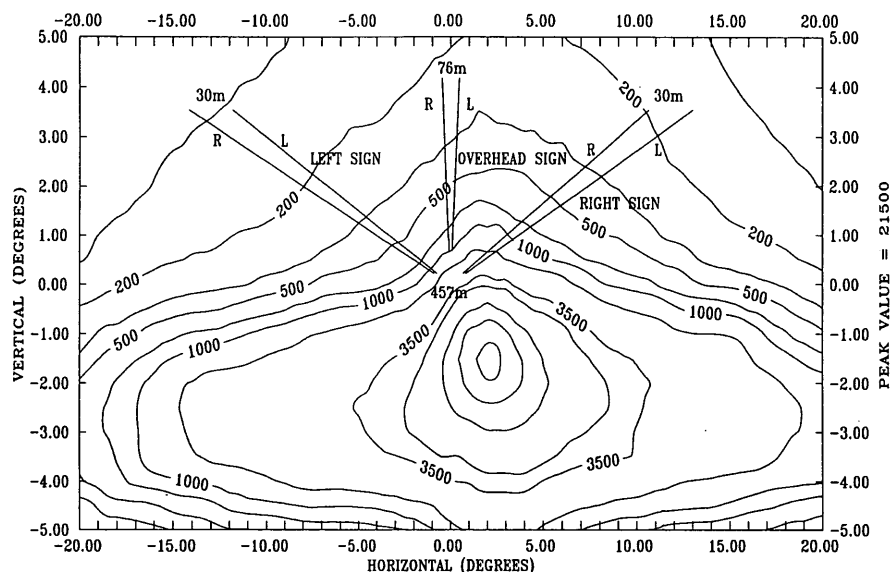


FIGURE 9 Headlamp isocandela plot for CARTS50 headlamp.

cal, which is not surprising considering that the CARTS50 data are a subset of the newer UMTRI data. Headlamp 11 (Figure 11) provides high sign luminance because it has a large peak value and the light distribution is quite broad. Headlamp 34 (Figure 12) on the other hand has a lower peak value. More important, this headlamp has an extremely sharp cutoff leading to low sign illumination. The 15th percentile headlamp and Headlamp 18 (Figures 13 and 14, respectively) have isocandela plots that are clearly different. Yet the luminance curves calculated with each headlamp are quite similar. This discrepancy highlights the importance of examining luminance curves to evaluate headlamps instead of relying solely on isocandela plots. Different intensity patterns can deliver very similar luminances to the driver.

CONCLUSIONS

It is difficult to know precisely how the headlamp population examined in the present study relates to the headlamp population of vehicles on U.S. highways. All new U.S. headlamps presumably meet SAE specifications. Furthermore, it is reasonable to assume that manufacturers of headlamps will not manufacture a certain headlamp type unless the sales of that headlamp are large enough to be profitable. This means that one could expect any of the headlamps investigated in the present study to represent those used on a significant population of vehicles on the road.

An important aspect of this investigation is the finding that the performance range of U.S. headlamps is surprisingly broad, so that

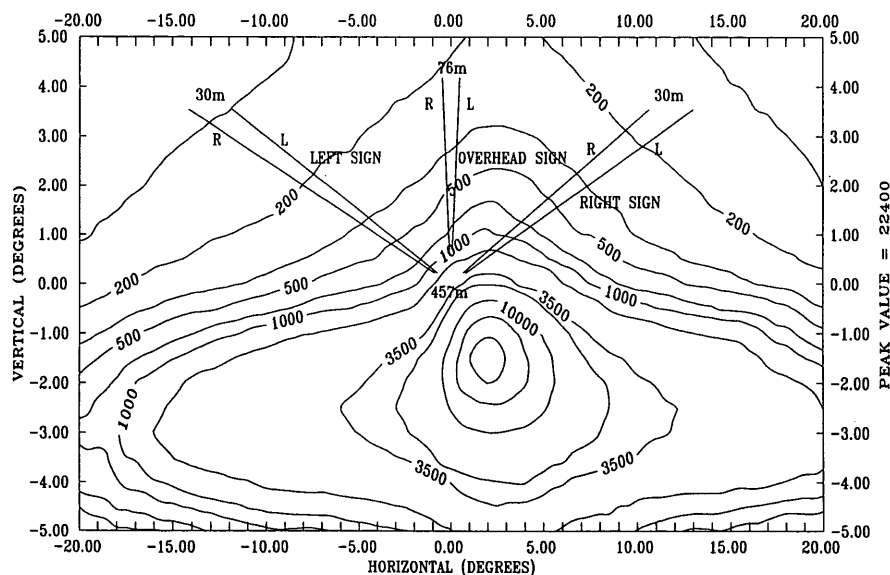


FIGURE 10 Headlamp isocandela plot for UMTRI median headlamp.

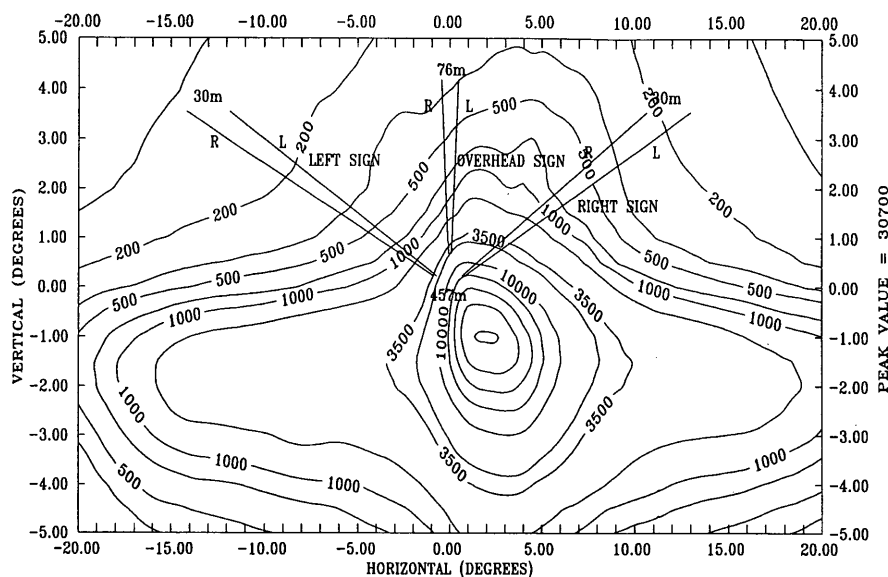


FIGURE 11 Headlamp isocandela plot for Headlamp 11, which gave the highest sign luminance.

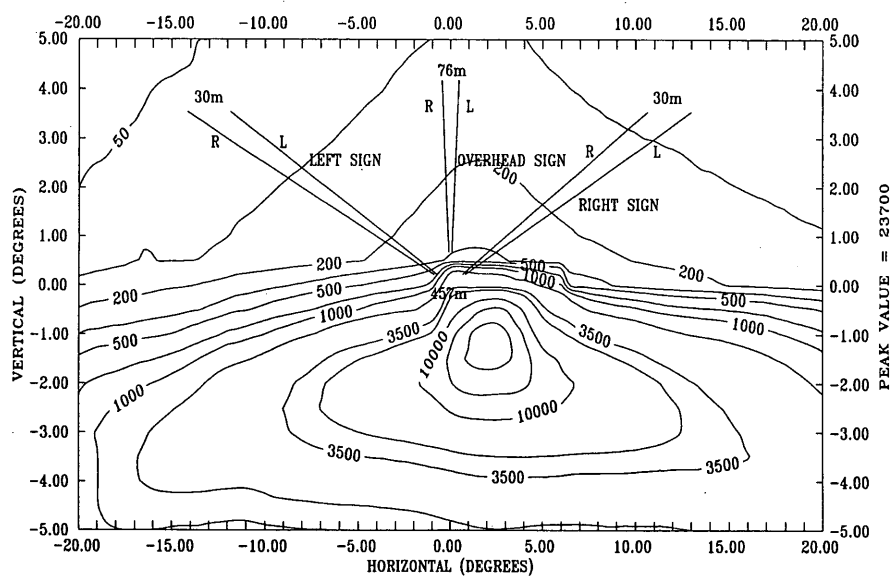


FIGURE 12 Headlamp isocandela plot for Headlamp 34, which gave the lowest sign luminance.

luminance values calculated with a median headlamp file can be 5 to 6 times greater than those of the poorest performing headlamps. This is a cause for concern. The 15th percentile headlamp on the other hand gives luminance values roughly twice those of the poorest-performing headlamp.

Finally, when assessing the performances of signs and other retroreflective materials from a moving vehicle, it is important to know the characteristics of the headlamps used. Ideally, one could measure the isocandela characteristics of the headlamp and rank the

performance of the chosen headlamp by calculating luminance and comparing it with the plots given in this paper. A headlamp set meeting the 15th percentile criterion as defined here would be our preference for most research needs. Headlamps at either extreme of the performance range should be avoided. Furthermore, we believe that use of a 50th percentile headlamp significantly overestimates the luminance received by the majority of drivers.

We propose that researchers interested in visibility issues adopt a standard headlamp data file. Those wishing to verify our results

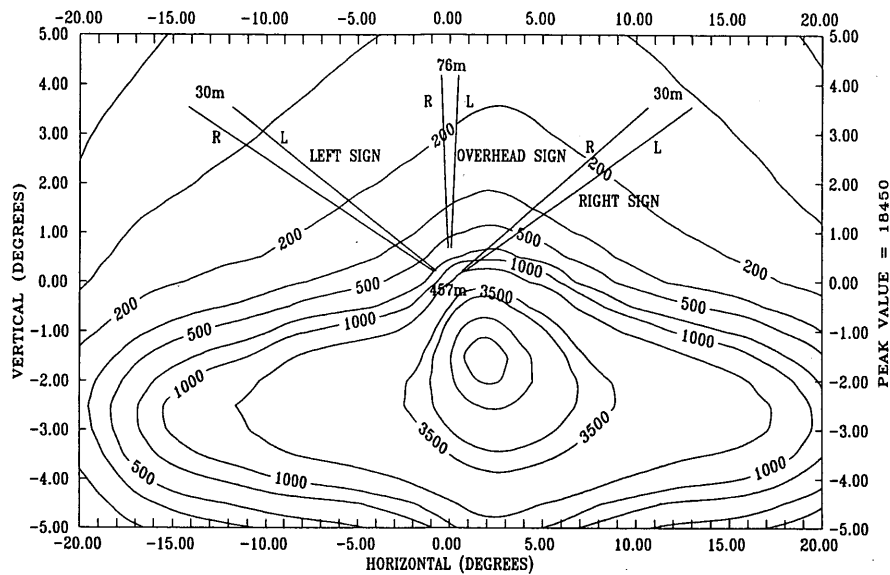


FIGURE 13 Headlamp isocandela plot for the 15th percentile headlamp.

will find the photometric angles defined in Figure 1 of Federal Test Method Standard 370 (8). Table 2 provides the headlamp coordinates for a right shoulder sign.

The data presented here show that the 15th percentile composite performs nearly identically to an actual headlamp. The composite was created from a broad range of headlamps on the road today. For this reason the shape of the isocandela plot is smoother and overall more representative of all headlamp types than a single, actual headlamp. The 15th percentile headlamp provides an adequate safety factor above the median composite typically used. For these reasons we suggest that this 15th percentile composite be

considered a standard for retroreflective material research. It is not, however, implied to be a target specification for new headlamp designers.

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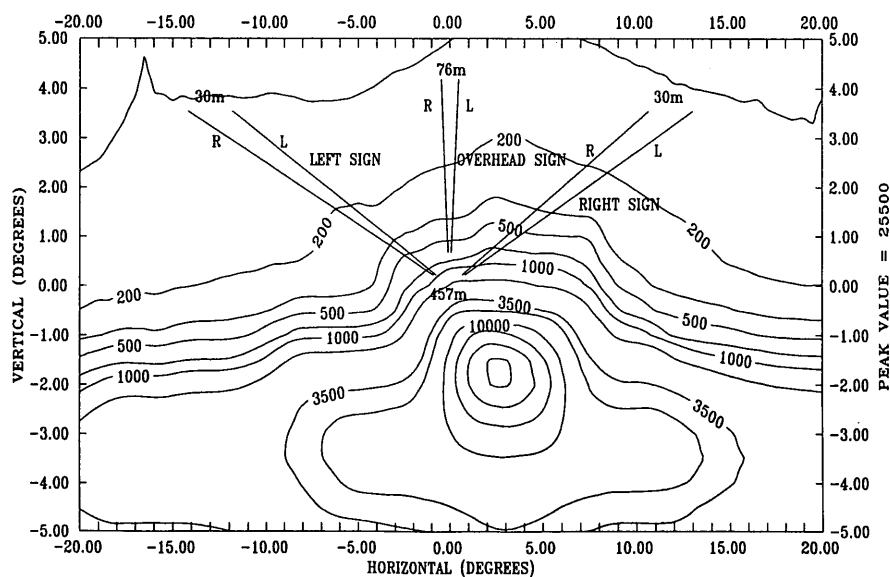


FIGURE 14 Headlamp isocandela plot for Headlamp 18, which gave a luminance performance similar to that of the 15th percentile headlamp.

TABLE 2 Positions and Angles for Viewer and Right Shoulder Sign

Viewer Distance		Left or Right	Degrees					
Meters	Feet		Observation	Entrance	Presentation	Orientation	Headlamp	Headlamp
		Headlamp	Angle	Angle	Angle	Angle	Horizontal	Vertical
457.2	1500	left	0.07	0.87	47.43	104.65	0.82	0.22
457.2	1500	right	0.17	0.69	137.77	108.69	0.67	0.22
426.7	1400	left	0.09	0.94	47.26	104.65	0.88	0.24
426.7	1400	right	0.18	0.74	137.71	108.69	0.72	0.24
396.2	1300	left	0.09	1.01	47.07	104.65	0.95	0.26
396.2	1300	right	0.2	0.8	137.65	108.69	0.78	0.26
365.8	1200	left	0.1	1.09	46.84	104.65	1.03	0.28
365.8	1200	right	0.21	0.86	137.57	108.69	0.84	0.28
335.3	1100	left	0.11	1.19	46.58	104.65	1.13	0.3
335.3	1100	right	0.23	0.94	137.48	108.69	0.92	0.3
304.8	1000	left	0.12	1.31	46.27	104.65	1.24	0.33
304.8	1000	right	0.25	1.04	137.37	108.69	1.01	0.33
274.3	900	left	0.13	1.46	45.89	104.65	1.38	0.37
274.3	900	right	0.28	1.15	137.24	108.69	1.12	0.37
243.8	800	left	0.15	1.64	45.42	104.65	1.55	0.42
243.8	800	right	0.32	1.3	137.07	108.69	1.26	0.42
213.4	700	left	0.17	1.88	44.83	104.65	1.78	0.48
213.4	700	right	0.36	1.48	136.85	108.69	1.45	0.48
182.9	600	left	0.2	2.2	44.05	104.65	2.08	0.56
182.9	600	right	0.42	1.73	136.56	108.69	1.69	0.56
152.4	500	left	0.25	2.64	43	104.65	2.5	0.67
152.4	500	right	0.49	2.09	136.14	108.69	2.03	0.67
121.9	400	left	0.32	3.31	41.5	104.65	3.13	0.84
121.9	400	right	0.61	2.62	135.49	108.69	2.55	0.84
91.44	300	left	0.45	4.44	39.17	104.65	4.19	1.13
91.44	300	right	0.8	3.51	134.35	108.69	3.42	1.13
60.96	200	left	0.73	6.73	35.09	104.65	6.35	1.71
60.96	200	right	1.14	5.32	131.88	108.69	5.18	1.71
30.48	100	left	1.87	13.8	26.44	104.65	12.99	3.54
30.48	100	right	1.99	10.97	122.59	108.69	10.64	3.54

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