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16. Abstract

This study was designed to provide photometric information for very high angles for a sample of U.S. low beams of recent vintage. The sample included 24 pairs of left and right lamps for 1999 and 2000 model year vehicles. The lamps were photometered in 0.2° steps from 10° up to 90° up, and from 60° left to 60° right. The report documents both the median and maximum luminous intensities at each test point. The utility of the present data is discussed in relation to retroreflective traffic signs, and veiling luminance in adverse weather such as fog.

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headlighting, low beams, high angles, inclement weather, fog, traffic signs, retroreflective signs, veiling luminance	Unlimited

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Contents

Introduction

The information about headlamp illumination at high angles is important for assessing two aspects related to nighttime driving: visibility of overhead retroreflective traffic signs at near distances, and veiling luminance caused by scatter in inclement weather such as fog. Despite the importance of such photometric information, the publicly available data do not extend to high enough angles. For example, the most extensive database on current low beams (Schoettle et al., 2001) contains information only up to 10° up. The current study was designed to fill this information gap, by documenting illumination up to 90° from a relatively large sample of U.S. low beams.

Method

Lamp sample and photometry

The photometry of 48 low beams (24 pairs of left and right lamps) was provided to us by a single vehicle manufacturer. The lamps were originally selected by the vehicle manufacturer as lamps that were likely to have relatively large amounts of stray light at high angles. This judgment was based on visual inspection of the lamps (not on the photometry).

The lamps were designed for 24 different vehicles (model years 1999 and 2000). There were 22 pairs of lamps (92%) with complex-reflector optics, and 2 pairs of lamps (8 %) with lens optics. The breakdown of the sample by bulb type is shown in Table 1.

The photometry was performed from 10° up to 90° up, and from 60° left to 60° right, all in 0.2° steps. The measurements were made at 12.8 V.

Table 1
The breakdown of the lamps by bulb type.

Bulb type	Number of pairs	Percentage of the sample
9007 (HB5)	8	33.3
9006 (HB4)	8	33.3
9003 (HB2)	7	29.2
H1	1	4.2

Results

We found systematic differences between the light output of left and right lamps. Consequently, we will present data for left and right lamps separately, as well as data that combine, for each vehicle, the output from the two lamps. (The combined set disregards the fact that the lamps are separated laterally. Consequently, this combined information should be used only for long viewing distances, where the lamp separation is very small relative to the viewing distance. On the other hand, at near viewing distances the error introduced by lamp separation can be substantial.)

Figures 1 and 2 present the isointensity diagrams corresponding to the median luminous intensities for the left lamps and right lamps, respectively. Figure 3 contains the analogous data for the sums of the intensities for the two lamps. As is evident from Figures 1 and 2, the two sets of lamps show patterns that tend to be symmetrical reversals of each other. This symmetry is especially evident for illumination between 10° up and 60° up. Here, the left lamps have the lowest intensities at the right side of the beam pattern, while the right lamps have the lowest intensities at the left side of the beam pattern. Because of this symmetry between the outputs of the left and right lamps, it is not surprising that the combined isointensity diagram (Figure 3) is itself symmetrical.

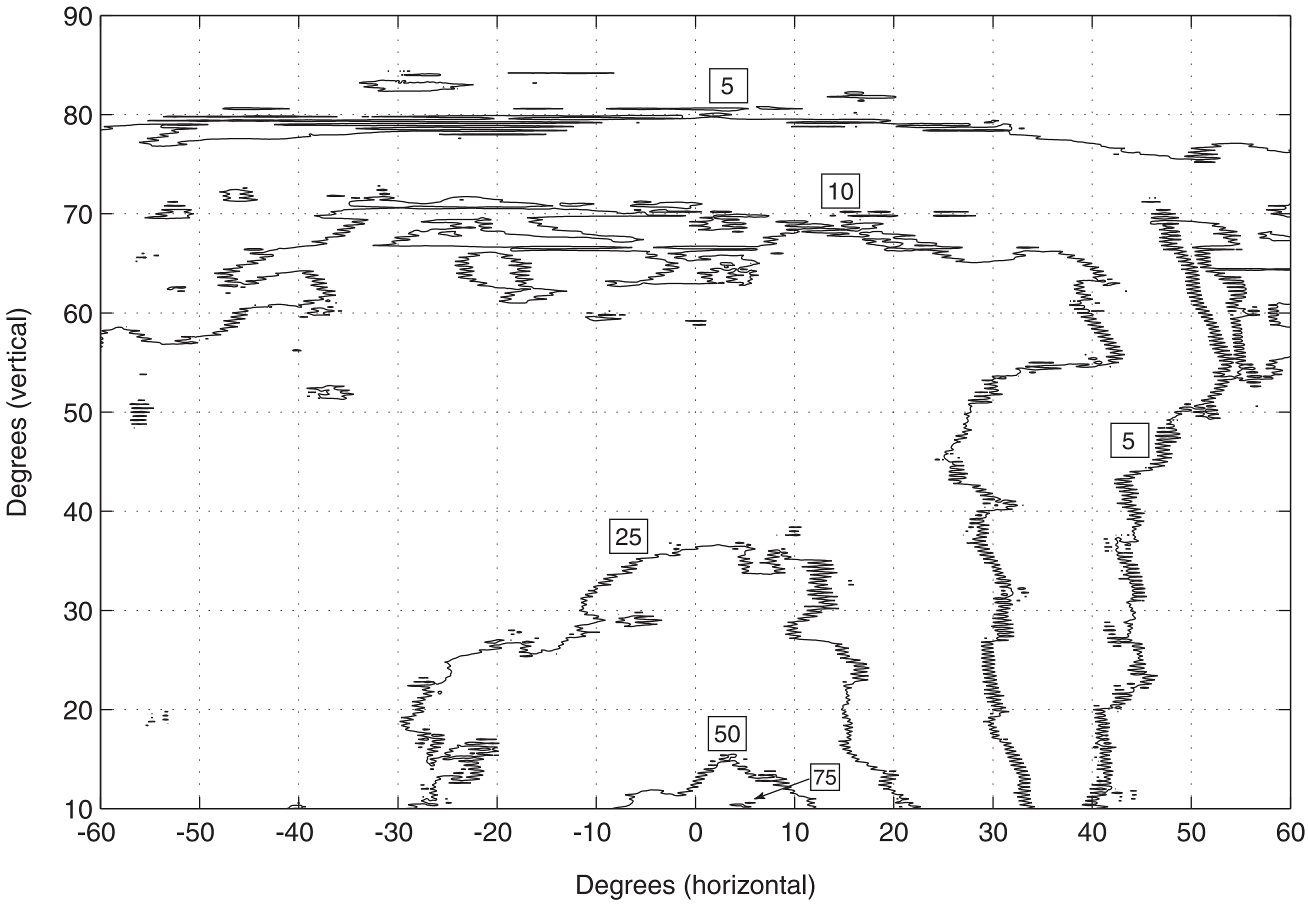

Figure 1. Isointensity diagrams (in cd) corresponding to the medians of the luminous intensities for the left lamps.

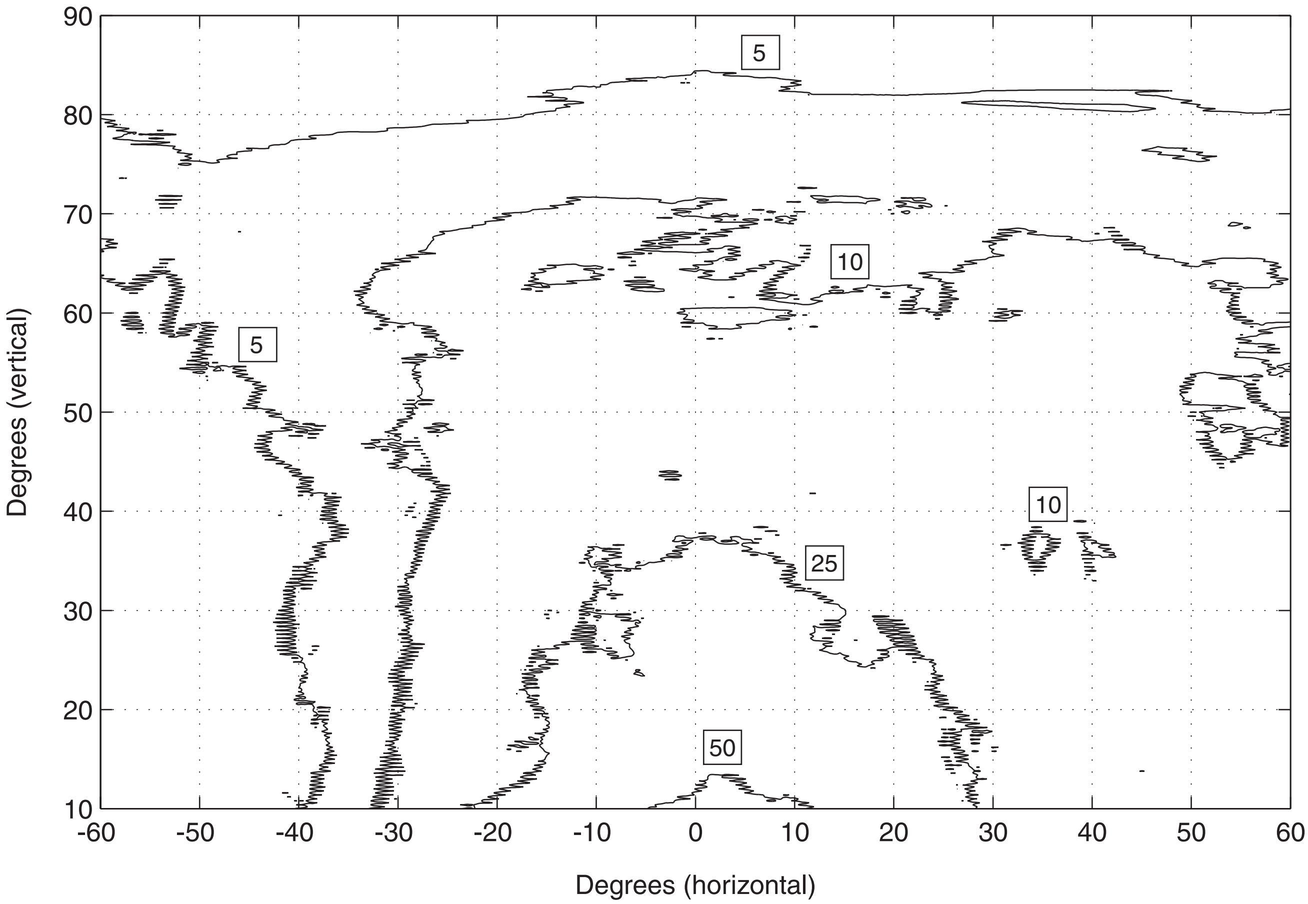

Figure 2. Isointensity diagrams (in cd) corresponding to the medians of the luminous intensities for the right lamps.

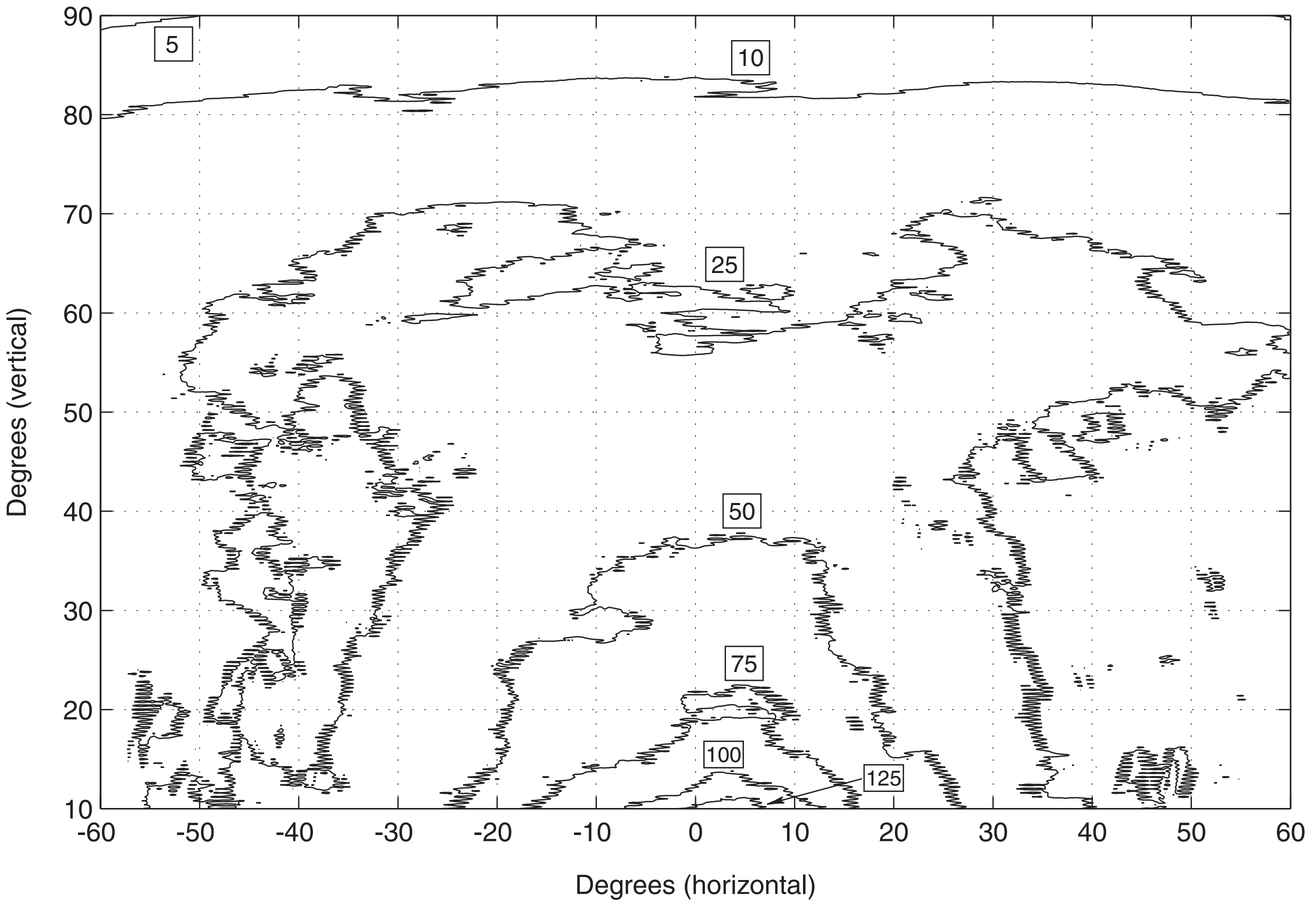

Figure 3. Isointensity diagrams (in cd) corresponding to the medians of the combined luminous intensities for the pairs of left and right lamps.

Tables 2 through 4 list the numerical values of the median luminous intensities. The horizontal steps in these tables are 1° between 0° and 10°, and 5° between 10° and 60° (left and right). The vertical steps are 5° throughout.

To provide an indication of the extent and the magnitude of unwanted high-intensity spots or streaks, Figure 4 presents isointensity curves corresponding to the maximum values at each test point for the left lamps. The analogous information for the right lamps is presented in Figure 5.

Table 2
Medians of the luminous intensities for the left lamps.

	60 L	55 L	50 L	45 L	40 L	35 L	30 L	25 L	20 L	15 L	10 L	9 L	8 L	7 L	6 L	5 L	4 L	3 L	2 L	1 L	0
90 U	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
85 U	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
80 U	3	4	4	5	4	4	4	4	5	4	4	4	5	5	5	5	5	5	5	5	5
75 U	6	7	7	7	7	7	7	8	8	8	7	7	7	7	7	7	7	7	7	8	8
70 U	8	10	9	9	9	11	17	15	13	11	10	10	10	10	10	10	8	8	8	9	9
65 U	8	10	9	10	11	12	13	12	9	11	11	12	12	11	11	11	11	10	10	10	10
60 U	8	9	9	10	10	11	13	12	11	11	10	10	11	11	12	12	12	12	12	12	12
55 U	11	12	13	13	13	15	14	14	13	14	14	14	14	14	13	13	13	16	14	14	15
50 U	13	10	17	15	15	10	11	14	16	14	15	17	17	16	16	17	16	18	18	17	15
45 U	12	11	14	18	15	13	13	14	15	16	16	17	18	18	18	18	18	19	19	20	19
40 U	17	13	19	19	16	13	12	13	16	17	17	18	18	18	17	18	17	17	17	17	18
35 U	19	18	16	20	16	15	15	16	19	18	20	21	22	22	24	25	26	27	26	28	30
30 U	16	18	17	17	15	16	16	18	19	20	27	27	26	26	27	27	26	26	27	28	30
25 U	18	19	14	18	15	17	18	24	28	26	29	31	32	31	30	31	32	32	30	30	30
20 U	13	24	16	17	15	18	22	28	28	30	33	33	33	33	34	35	35	36	38	38	37
15 U	14	20	19	20	17	21	20	25	25	32	38	38	39	40	39	39	39	41	42	42	45
10 U	14	20	20	21	25	22	23	26	33	44	46	48	51	52	55	58	58	60	61	65	70

Table 2 (cont.)

	1 R	2 R	3 R	4 R	5 R	6 R	7 R	8 R	9 R	10 R	15 R	20 R	25 R	30 R	35 R	40 R	45 R	50 R	55 R	60 R
90 U	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
85 U	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3
80 U	5	5	5	5	5	5	4	4	4	4	5	5	5	5	4	4	4	4	4	4
75 U	8	8	8	9	9	9	9	9	7	7	7	6	6	7	7	7	7	6	6	6
70 U	9	9	10	10	10	10	10	9	9	9	8	8	8	7	6	5	5	6	6	5
65 U	10	10	11	10	10	10	10	11	11	11	12	11	12	10	11	10	7	5	6	7
60 U	12	13	14	13	14	13	13	13	13	12	12	13	12	15	14	10	8	5	5	5
55 U	16	16	15	13	13	13	13	14	15	16	16	13	11	11	10	10	8	6	5	4
50 U	15	16	16	17	17	17	17	16	16	14	14	13	12	9	8	8	6	5	4	3
45 U	19	20	20	19	18	18	16	16	16	16	14	13	10	8	8	6	6	4	3	2
40 U	17	17	17	17	17	18	19	21	21	21	16	10	12	10	8	6	5	3	3	2
35 U	28	27	27	25	24	23	23	25	26	26	23	16	14	11	8	7	4	4	3	2
30 U	30	31	31	31	30	30	29	27	26	25	19	15	13	10	7	6	4	3	2	1
25 U	32	33	33	32	31	30	30	29	29	28	26	19	13	10	8	6	5	3	2	1
20 U	35	35	37	38	36	36	35	34	32	32	24	17	13	10	7	5	4	2	2	1
15 U	47	49	51	49	50	49	48	46	43	41	29	21	17	12	8	6	4	3	2	1
10 U	71	74	73	74	72	67	61	61	60	59	36	28	21	14	8	5	4	3	2	1

Table 3
Medians of the luminous intensities for the right lamps.

	60 L	55 L	50 L	45 L	40 L	35 L	30 L	25 L	20 L	15 L	10 L	9 L	8 L	7 L	6 L	5 L	4 L	3 L	2 L	1 L	0
90 U	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4
85 U	3	3	3	4	4	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5	5
80 U	4	4	4	4	4	4	4	4	4	6	7	7	7	7	7	7	7	7	7	7	7
75 U	5	5	5	5	6	6	7	7	7	7	7	7	7	8	8	8	8	8	8	8	8
70 U	6	6	5	6	6	8	8	8	10	11	12	13	12	11	11	10	10	10	10	10	10
65 U	6	5	5	6	7	8	11	13	12	12	11	11	10	12	12	12	13	13	13	13	13
60 U	4	5	5	6	8	10	11	12	14	13	13	13	13	13	12	12	12	11	10	10	9
55 U	4	4	5	5	7	8	10	10	14	12	15	15	15	14	14	14	13	13	13	12	12
50 U	2	4	4	5	5	6	10	11	15	13	16	15	15	14	15	15	14	15	16	17	16
45 U	2	3	3	4	5	8	10	12	12	16	17	17	18	18	19	19	20	22	22	22	22
40 U	2	2	3	4	5	6	9	12	14	15	19	21	21	20	20	19	21	21	20	20	21
35 U	2	2	3	4	4	6	8	11	13	19	25	26	25	24	25	25	24	25	26	26	27
30 U	2	2	3	3	6	6	10	12	16	25	25	25	27	26	26	26	28	29	29	30	30
25 U	1	2	3	4	5	6	7	14	17	25	28	27	26	25	27	28	28	28	29	29	29
20 U	1	2	3	4	5	7	10	15	21	26	28	29	30	31	32	34	35	34	33	33	33
15 U	1	2	3	3	5	6	9	15	23	25	32	33	33	34	35	35	35	37	39	40	41
10 U	1	2	3	4	5	7	15	24	34	39	44	45	47	47	48	50	52	55	59	61	63

Table 3 (cont.)

	1 R	2 R	3 R	4 R	5 R	6 R	7 R	8 R	9 R	10 R	15 R	20 R	25 R	30 R	35 R	40 R	45 R	50 R	55 R	60 R
90 U	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3
85 U	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
80 U	7	7	7	7	6	6	6	6	6	6	6	6	6	6	6	6	5	6	5	6
75 U	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	7	7	6	5	6
70 U	10	10	10	10	10	10	10	10	10	10	9	10	9	8	9	8	7	9	9	9
65 U	12	9	9	9	10	10	10	10	11	9	9	8	8	11	12	13	12	10	11	10
60 U	9	9	9	9	9	9	9	10	10	11	12	11	11	10	11	11	12	12	10	8
55 U	12	12	13	13	13	13	13	13	13	13	12	12	14	14	13	11	12	11	11	10
50 U	16	16	14	14	14	14	15	16	16	16	16	16	14	15	15	13	13	10	10	10
45 U	22	19	19	17	16	18	20	20	20	21	19	15	14	13	14	13	15	14	10	10
40 U	19	18	18	18	17	18	20	20	21	23	17	14	14	12	12	12	14	15	13	12
35 U	27	28	27	26	28	27	27	26	25	24	21	14	14	12	11	13	12	16	14	12
30 U	28	28	28	28	30	31	33	32	30	29	25	18	18	14	12	14	13	15	17	13
25 U	30	30	30	31	33	34	33	32	31	31	25	28	22	17	16	13	12	13	16	13
20 U	35	35	36	37	37	37	36	36	34	32	29	27	25	21	16	12	16	15	18	17
15 U	43	43	42	41	40	39	39	39	40	39	36	30	28	24	17	16	21	19	17	17
10 U	64	63	63	64	60	58	57	57	55	53	40	34	32	23	20	18	19	18	16	13

Table 4
Medians of the combined luminous intensities for the pairs of left and right lamps.

	60 L	55 L	50 L	45 L	40 L	35 L	30 L	25 L	20 L	15 L	10 L	9 L	8 L	7 L	6 L	5 L	4 L	3 L	2 L	1 L	0
90 U	4	4	5	5	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
85 U	8	8	8	8	8	8	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
80 U	10	11	11	11	11	11	10	10	13	14	15	15	15	15	15	14	14	14	14	14	13
75 U	15	14	15	15	15	15	15	16	16	17	17	17	16	16	17	17	18	19	19	20	20
70 U	16	19	18	17	17	20	24	27	29	27	25	25	25	24	23	22	22	21	22	22	22
65 U	17	15	14	18	25	26	28	30	29	24	22	24	26	24	22	24	25	25	23	22	22
60 U	20	15	23	27	34	28	28	27	29	33	30	29	28	28	28	29	27	24	24	23	22
55 U	18	19	26	31	28	26	34	31	33	31	31	30	29	28	28	29	29	29	29	30	29
50 U	20	19	25	27	24	24	31	30	31	30	33	32	32	33	32	33	32	33	33	33	32
45 U	14	18	25	26	22	24	26	26	29	34	35	35	34	34	35	38	39	41	43	43	40
40 U	19	19	24	25	23	22	26	28	31	36	38	38	37	37	37	37	38	36	37	38	38
35 U	22	21	20	26	23	23	25	26	36	43	47	48	50	53	53	52	51	52	56	59	59
30 U	18	21	21	22	26	23	28	31	41	45	48	50	49	51	53	53	53	53	55	57	60
25 U	18	21	19	25	23	24	34	38	50	54	59	59	59	58	56	56	58	59	57	56	58
20 U	15	27	23	24	22	25	39	45	49	57	62	63	66	68	70	72	72	71	71	75	75
15 U	15	25	22	26	23	27	38	39	47	61	67	69	71	72	72	75	75	77	78	79	84
10 U	15	26	26	26	28	33	43	51	67	83	93	96	98	100	100	107	111	115	125	128	132

Table 4 (cont.)

	1 R	2 R	3 R	4 R	5 R	6 R	7 R	8 R	9 R	10 R	15 R	20 R	25 R	30 R	35 R	40 R	45 R	50 R	55 R	60 R
90 U	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	5	5
85 U	9	9	9	9	8	8	8	8	8	8	8	8	8	8	8	8	8	7	8	7
80 U	13	13	13	12	12	12	12	12	12	12	12	13	13	12	12	12	11	13	12	11
75 U	20	20	20	19	19	19	20	20	20	21	16	16	18	17	17	16	16	14	14	17
70 U	21	21	21	22	22	21	21	21	21	22	22	23	25	23	22	19	19	21	22	21
65 U	21	20	20	19	19	19	20	20	21	21	24	23	23	29	31	27	26	22	20	22
60 U	22	22	23	24	24	24	24	24	25	24	23	25	28	28	31	31	27	22	19	21
55 U	28	28	28	26	27	29	30	31	31	32	30	28	29	31	33	31	41	28	26	29
50 U	31	32	31	32	32	32	32	33	34	33	33	31	30	27	26	24	24	23	21	19
45 U	40	41	41	38	36	35	35	36	38	39	36	28	28	22	27	24	22	22	21	17
40 U	36	35	35	35	34	37	37	38	39	38	36	27	27	23	24	19	21	20	18	17
35 U	57	57	54	54	52	54	54	54	53	52	47	37	29	26	23	21	19	23	21	18
30 U	60	60	59	58	60	61	60	58	55	54	46	39	31	27	21	21	20	24	20	16
25 U	61	63	66	68	67	68	67	66	62	59	51	47	38	30	23	22	20	21	23	15
20 U	73	73	73	74	75	76	75	75	72	68	53	47	40	31	23	20	21	23	21	18
15 U	89	93	93	91	91	88	86	84	82	78	68	53	49	37	27	24	28	23	22	20
10 U	138	146	147	140	135	127	118	115	113	113	78	62	57	37	27	22	25	20	19	15

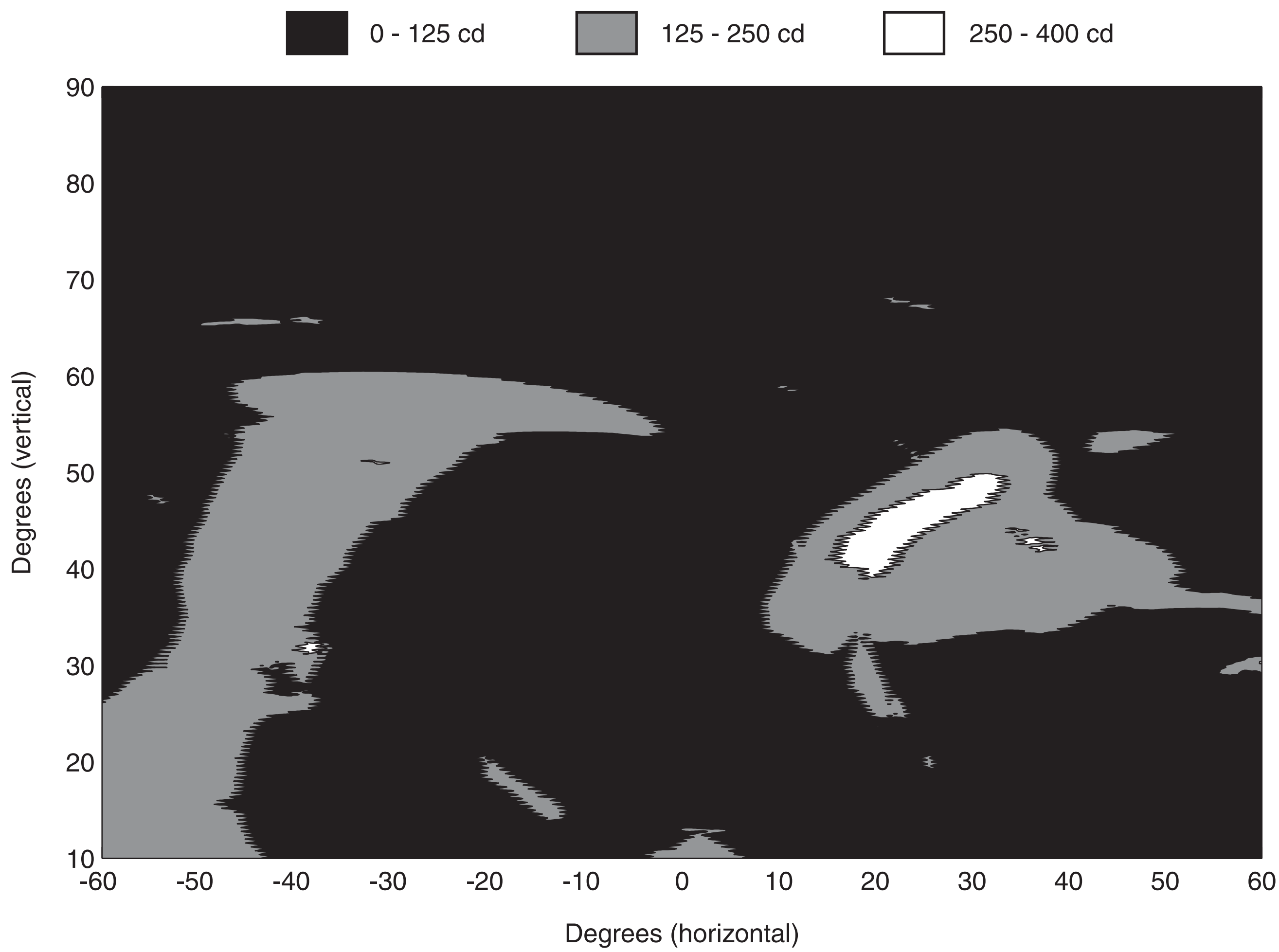

Figure 4. Isointensity diagrams (in cd) corresponding to the maxima of the luminous intensities for the left lamps.

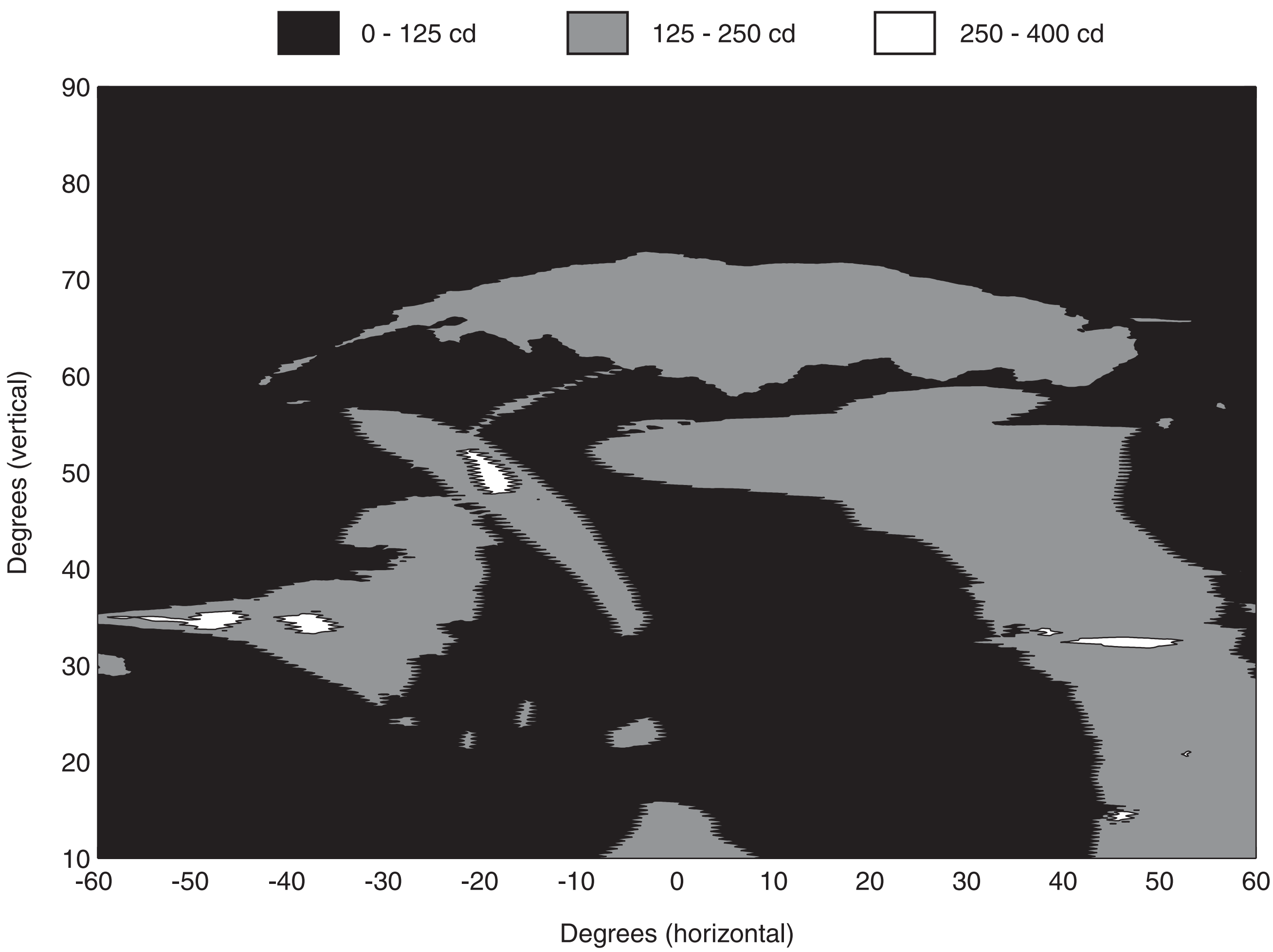

Figure 5. Isointensity diagrams (in cd) corresponding to the maxima of the luminous intensities for the right lamps.

Discussion

Headlamp illumination for retroreflective traffic signs

In contrast to self-illuminated signs (with active light sources), retroreflective signs rely on the illumination from the driver's headlamps. Retroreflective signs reflect light back towards the source of illumination in a narrow cone, with the highest intensity near the center of the cone along the axis of illumination. Consequently, the observation angle—the angle formed by the light source, traffic sign, and driver eyes—is an important factor in determining the amount of light that reaches the driver. The effect of the observation angle depends on the type of the retroreflective material. For example, for a typical encapsulated sign, the relative reflectance at 0.9° drops to about 8% of the reflectance at 0.1° (Sivak et al., 1991). For a car driver at long viewing distances, this concentration of the return near the path of origin is almost ideal, because the observation angles are small. For example, for an overhead sign at 6.1 m (Sivak et al., 1991), a driver eye height of 1.11 m (Sivak et al., 1996), and a headlamp mounting height of 0.66 m (Schoettle et al., 2002), the observation angle at 250 m is 0.12° for the left lamp and 0.25° for the right lamp. On the other hand, at near distances the observation angle becomes relatively large. For example, for the same situation, but with the sign at 25 m, the observation angle is 2.00° for the left lamp and 2.86° for the right lamp. Consequently, it is important to keep in mind that the light emitted in the direction of the sign needs to be corrected for the effect of the observation angle (and other relevant angles, such as the entrance angle) to determine the efficacy of the illumination. This is especially the case for near viewing distance. (For truck drivers, the observation angles are greater at all viewing distances because of the greater vertical separation between the driver eyes and the headlamps [Sivak et al., 1991].)

In addition to the increased observation angle, there are two other factors that limit the relevance of very high angles for use on retroreflective traffic signs. One of these factors is the physical obstruction to the direct line of sight provided by the vehicle roof. This factor varies widely from vehicle to vehicle, and it also depends on the stature and the seating position of the driver. As a result, the location of the edge of the vehicle roof can vary from just a few degrees up to several tens of degrees up.

The other limiting factor is the nonzero duration required for processing of the information contained in the sign. In other words, the driver needs to be at a certain minimum distance from a sign to be able to use the information contained in it. This minimum distance, in turn, determines (for a particular sign position) the maximum useful up angle of headlamp illumination. Let's consider a situation that is likely to produce a realistic maximum up angle for our prototypical situation with a sign at a mounting height of 6.1 m, driver eye height of 1.11 s, and a headlamp mounting height of 0.66 m: very fast information-processing time (1 s) and very slow speed (50 km). The resultant up angle is about 16° with respect to the driver eyes. With respect to the headlamps (which are located further ahead and lower), the corresponding angle is about 18°. These considerations imply that headlamp illumination above about 20° is not relevant for retroreflective traffic signs.

Headlamp illumination as a source of veiling luminance in adverse weather

The primary concern with light at high angles has been situations with fog and snow. The reason for this concern is that fog and snow particles reflect light and thus become luminous. Therefore, these particles can be a source of veiling luminance, making it more difficult to see the road and objects on the road. Kosmatka (1987) has shown that the relative glare effects of illumination at large up angles (30° to 40° up) in fog are two orders of magnitude greater than the effects of illumination near the horizontal. This is largely a consequence of greater illumination of the fog near the source of illumination, and the fact that on a level line of sight, a driver's gaze will intersect with high-angle light much closer to the lamp than it will intersect with low-angle light. (However, the greater illumination of the intervening fog at high angles is counteracted by the shorter visual path through fog.)

SAE Recommended Practice J1383 (SAE, 1996) specifies that lamps be designed to meet a maximum of 125 cd between 10° to 90° up and between 45° left to 45° right, but allows a performance maximum of 438 cd (0.7 lux at 25 m), as long as the extent of the maximum does not exceed 2° conical angle. The information in Figures 4 and 5 indicate that values above125 cd are not limited to any particular small area of the beam pattern, and that none of the values exceed 438 cd. (Importantly, there is no information in these figures on the size of the hot spots in beam patterns of *individual* lamps. They show combined maxima from the sample of lamps as a whole.)

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