UMTRI-2002-14

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Report No. UMTRI-2002-14
June 2002

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UMTRI-2002-14		

4. Title and Subtitle	5. Report Date
Performance of the First Generation of HID Headlamps in the U.S.	June 2002
	6. Performing Organization Code: 302753

7. Author(s)	8. Performing Organization Report No.
Sivak, M., Flannagan, M.J., Schoettle, B., and Nakata, Y.	UMTRI-2002-14

9. Performing Organization Name and Address	10. Work Unit no. (TRAIS)
The University of Michigan Transportation Research Institute 2901 Baxter Road Ann Arbor, Michigan 48109-2150 U.S.A.	11. Contract or Grant No.

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
The University of Michigan Industry Affiliation Program for Human Factors in Transportation Safety	14. Sponsoring Agency Code

15. Supplementary Notes

The Affiliation Program currently includes Adac Plastics, AGC America, Autoliv, Automotive Lighting, Avery Dennison, BMW, DaimlerChrysler, Denso, Donnelly, Fiat, Ford, GE, Gentex, GM NAO Safety Center, Guardian Industries, Guide Corporation, Hella, Ichikoh Industries, Koito Manufacturing, Labsphere division of X-Rite, Lang-Mekra North America, LumiLeds, Magna International, Mitsubishi Motors, North American Lighting, OSRAM Sylvania, Pennzoil-Quaker State, Philips Lighting, PPG Industries, Reflexite, Renault, Schefenacker International, Stanley Electric, Toyota Technical Center U.S.A., Valeo, Vidrio Plano, Visteon, Yorka, 3M Personal Safety Products, and 3M Traffic Control Materials.

Information about the Affiliation Program is available at: http://www.umich.edu/~industry

16. Abstract

This analytical study compared the median beam pattern of a sample of 19 HID low beams manufactured for model year 2000 vehicles sold in the U.S. with a market-weighted median beam pattern of tungsten-halogen lamps for vehicles of the same model year.

The results indicate that the HID lamps tended to provide wider beam patterns than did the tungsten-halogen lamps, which, in turn, should improve the visibility of pedestrians on curves and may make the lane-maintenance task less demanding. On right curves, there was an increase in glare illumination towards oncoming drivers, while on left curves there was a decrease in glare illumination.

On straight roads, the HID lamps produced more illumination for pedestrians and road delineation on the left side of the road. This was also the case for the right side of the road, but only for the projector HID lamps; the nonprojector HID lamps produced less illumination at the relevant locations than did the tungsten-halogen lamps. Finally, on straight roads HID lamps produced less glare for oncoming drivers than did the tungsten-halogen lamps. The results for traffic-sign illumination varied with the location of the sign.

HID lamps produce more light than do tungsten-halogen lamps. Consequently, they hold great promise for improving the nighttime safety of driving by improving the low-beam light distribution. The present analysis indicates that this promise has already been partially met in the first generation of HID lamps on vehicles in the U.S.

17. Key Words	18. Distribution Statement
headlighting, headlamps, low beams, passing beams, visibility, glare, U.S., pedestrians, road delineation, traffic signs, HID, high-intensity discharge	Unlimited

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
None	None	26	

Acknowledgments

Appreciation is extended to the members of the University of Michigan Industry Affiliation Program for Human Factors in Transportation Safety for support of this research. The current members of the Program are:

Adac Plastics
AGC America
Autoliv
Automotive Lighting
Avery Dennison
BMW
DaimlerChrysler
Denso
Donnelly
Fiat
Ford
GE
Gentex
GM NAO Safety Center
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Hella
Ichikoh Industries
Koito Manufacturing
Labsphere division of X-Rite
Lang-Mekra North America
LumiLeds
Magna International
Mitsubishi Motors
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Schefenacker International
Stanley Electric
Toyota Technical Center U.S.A.
Valeo
Vidrio Plano
Visteon
Yorka
3M Personal Safety Products
3M Traffic Control Materials

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Introduction

HID (high-intensity discharge) headlamps are beginning to make inroads on vehicles sold in the U.S. In comparison with tungsten-halogen headlamps, they produce more light per unit of energy and have longer life. Furthermore, because they produce more total light, they have the potential to provide more useful illumination for the driver.

From the safety point of view, there are two general areas in the beam pattern of low beam headlamps that could use more illumination: the central part of the beam pattern just below the horizontal (for visibility of distant objects on straight roads), and the peripheral parts of the beam pattern below horizontal (for visibility of objects and the road on curves and at intersections). Providing more illumination in the central part of the beam pattern just below the horizontal is challenging to achieve because of the intensity limitations at adjacent glare test points and the consequent steep intensity gradients in this part of the beam pattern. However, the periphery of the beam pattern does not have the constraints imposed by adjacent glare test points. Thus, it is likely that a substantial portion of the extra available light in HID lamps will be directed to the periphery, resulting in wider beam patterns. In turn, wider low beams will increase the visibility of objects on curves and intersections, and might make lane maintenance less demanding (Sivak, Flannagan, Schoettle, and Mefford, 2002).

The present study was designed to evaluate the first generation of HID low beams on vehicles in the U.S. by comparing them to current tungsten-halogen low beams. The analyses involved photometric and functional comparisons of the respective beam patterns.

Method

General approach

We evaluated the beam patterns of the HID and tungsten-halogen lamps by considering three performance aspects of the headlamps: visibility of pedestrians and road delineation, glare towards an oncoming driver, and visibility of retroreflective traffic signs. Each performance aspect was evaluated by calculating the total illuminance from the left and right headlamps at several points in space representing the locations of pedestrians and road delineation, the eyes of an oncoming driver, and retroreflective signs. Both straight roads and constant-radii curves were considered.

The following assumptions were made:

- lane width = 3.7 m
- driver eye height = 1.11 m (Sivak et al., 1996)
- driver lateral distance from the lane centerline: 1.85 m (Sivak et al., 1996)
- vehicle lane position = center
- headlamp mounting height = 0.66 m (Schoettle, Sivak, and Nakata, 2002)
- headlamp separation = 1.20 m (Schoettle, Sivak, and Nakata, 2002)
- critical part of a pedestrian = feet (thus, the visibility of pedestrians and road delineation were modeled by the illuminance at the same points on the road surface)

Table 1 shows the lateral and vertical positions for the investigated performance aspects. Table 2 lists the distances (the longitudinal positions) that were considered for each performance aspect.

Table 1
The lateral and vertical positions representing the evaluated performance aspects.

Performance aspects	Lateral distance from the vehicle centerline (m)	Vertical distance from the ground (m)
Visibility of a pedestrian at the right edge line and visibility of the right edge line	+1.85	0
Visibility of a pedestrian at the left edge line and visibility of the left edge line	-5.55	0
Glare directed towards an oncoming driver	-3.35	1.11
Visibility of a right, shoulder-mounted retroreflective traffic sign	+6.15	2.10
Visibility of a center, overhead-mounted retroreflective traffic sign	0	6.10
Visibility of a left, shoulder-mounted retroreflective traffic sign	-9.85	2.10

Table 2
The distances considered in evaluating the performance aspects.

Performance aspect	Straight road	Curves	
		80-m radius (low speed)	240-m radius (high speed)
Visibility of a pedestrian at the right edge line and visibility of the right edge line	20 – 120 m	20 – 60 m	40 – 120 m
Visibility of a pedestrian at the left edge line and visibility of the left edge	20 – 120 m		
Glare directed towards an oncoming driver	20 – 120 m	20 – 60 m	40 – 120 m
Visibility of retroreflective traffic signs	50 – 150 m		

Lamp samples

The HID sample consisted of 19 low beams produced by 5 lighting companies. All lamps were for model year 2000 vehicles, and they were designed for various models produced by 7 vehicle manufacturers for sale in the U.S. The sample included 9 projector lamps and 10 nonprojector lamps. The photometry of each of the 19 lamps was provided to us by a single vehicle manufacturer. The present analysis involved using the (unweighted) median values of each point in the intensity matrix.

The HID photometry data were compared to the market-weighted median data for the 2000 model year vehicles in the U.S. obtained by Schoettle, Sivak, and Flannagan (2001). The raw information for the market-weighted medians in Schoettle et al. consisted of intensity matrices for tungsten-halogen lamps on the 20 best-selling vehicles. All 20 were nonprojector lamps.

The photometry was performed at 12.8 V.

Results

Differences in the beam patterns

Table 3 lists the median (50th percentile) luminous intensities for the HID and tungsten-halogen lamps. Figure 1 presents the isocandela diagrams corresponding to the median luminous intensities for the HID and tungsten-halogen lamps.

For each lamp type, we estimated the luminous flux in the area from 45° left to 45° right, and from 5° down to 7° up by summing up the luminous intensities that were available in 0.5° steps. The ratio of these sums was 2.07, indicating that in this part of the beam pattern the luminous flux provided by the HID lamps was 207% of the flux from the tungsten-halogen lamps. As is evident from Table 3 and Figure 1, the HID lamps produced more light in all parts of the beam pattern except for a central area near the horizontal, and an area above the horizontal in the far left periphery. Figure 2 highlights the differences between the two sets of intensities for the central part of the beam pattern from 7° left to 7° right, and from 5° down to 7° up.

Figure 3 presents the difference in the combined illuminance on the road surface from two median HID lamps and two median tungsten-halogen lamps, mounted at the mean locations for cars currently being sold in the U.S. (Schoettle et al., 2002). As is evident from Figure 3, the HID lamps delivered more spread illumination (both at near and far distances), and more foreground illumination. The tungsten-halogen lamps provided more illumination in a narrow cone straight ahead starting at about 50 m.

Table 3

Luminous intensities (cd) for the samples representing the low-beam headlamps on model year 2000 vehicles in the U.S. The top entry in each cell is the median value for the HID sample, and the bottom entry is the median value for the tungsten-halogen sample. (Test voltage 12.8 V.)

	45L	40L	35L	30L	25L	20L	15L	10L	9L	8L	7L	6L	5L	4.5L	4L	3.5L	3L	2.5L	2L	1.5L	1L	0.5L	0
7U	13	17	24	31	37	40	59	67	68	70	73	76	80	82	84	84	86	90	91	92	93	94	95
	32	22	19	35	30	34	44	59	65	66	67	69	70	66	66	67	68	69	69	69	70	71	74
6.5U	13	17	24	31	37	41	63	70	72	75	78	81	83	86	88	90	91	95	99	99	99	100	101
	34	22	19	23	30	35	45	66	69	72	72	74	72	72	72	71	71	73	73	73	75	78	80
6U	12	17	25	31	36	42	64	78	80	83	84	87	89	91	95	96	100	105	108	107	106	106	106
	30	23	20	23	31	37	49	69	71	75	78	79	80	79	79	79	79	79	81	84	85	87	90
5.5U	12	17	25	31	37	47	64	82	83	86	89	93	95	97	99	101	103	106	110	110	111	114	116
	32	25	21	24	33	40	52	73	77	82	83	84	83	83	84	86	86	88	90	93	96	97	99
5U	13	17	27	36	45	55	70	87	91	95	98	104	103	104	106	109	111	111	113	115	115	120	126
	38	27	21	27	40	43	56	78	80	84	88	87	89	89	90	90	93	96	101	103	106	106	107
4.5U	13	17	30	39	47	59	76	92	97	102	107	111	112	112	112	112	113	114	115	119	123	126	130
	36	28	22	31	45	47	62	87	89	89	94	94	95	95	96	99	102	105	111	114	117	120	121
4U	13	18	29	40	51	63	82	100	99	108	119	123	123	123	121	121	123	122	123	126	130	134	136
	32	29	22	39	47	51	67	95	98	99	102	98	102	105	108	111	115	119	123	129	131	136	137
3.5U	13	18	30	44	58	67	90	115	118	123	126	129	134	136	137	140	142	145	148	152	155	159	162
	30	29	23	43	54	56	73	102	107	110	104	109	115	118	122	125	130	133	141	147	150	159	163
3U	13	20	30	48	65	70	94	129	134	136	139	140	148	151	152	154	157	161	167	172	175	176	178
	28	27	25	43	56	64	81	114	119	123	119	125	131	141	149	148	151	156	167	174	176	182	195
2.5U	14	21	33	51	69	76	107	132	136	137	145	146	151	154	156	160	163	166	168	172	176	180	184
	28	28	30	44	61	76	88	115	126	136	139	146	155	162	174	190	200	206	222	235	241	253	259
2U	14	23	34	58	75	85	109	137	139	139	151	153	161	166	171	174	167	167	172	177	182	185	191
	33	29	36	45	65	83	101	132	150	165	185	186	200	208	227	235	237	241	253	264	276	295	311
1.5U	15	24	32	58	75	95	117	148	153	156	168	177	186	188	190	188	186	193	200	204	208	221	234
	39	29	41	50	69	97	121	193	212	225	234	253	263	269	276	285	293	296	307	322	343	361	393
1U	15	24	35	63	74	102	131	163	171	176	204	209	217	217	220	224	227	233	244	245	246	256	286
	34	30	43	55	72	107	161	246	262	280	290	304	325	338	350	364	375	390	402	448	475	504	517
0.5U	17	26	35	72	85	122	162	203	217	239	264	279	290	293	295	300	305	317	329	341	353	389	425
	26	31	40	60	85	146	250	345	390	409	442	451	471	477	484	505	543	586	666	707	777	887	1149
0	18	28	46	80	111	193	266	312	331	368	380	391	433	465	486	529	553	571	587	598	605	669	754
	18	33	34	68	101	188	457	563	642	633	711	736	779	787	846	905	941	1023	1156	1267	1500	1900	2386
0.5D	28	45	60	114	201	441	680	1308	1476	1804	2090	2268	2490	2603	2715	2774	2832	2815	2798	2899	3000	3371	3742
	10	20	30	60	119	266	717	988	1110	1268	1646	1674	1633	1753	1876	1899	1896	1935	2305	2674	2960	4482	6110
1D	46	66	83	188	358	1094	1821	4042	4502	5776	6695	7274	7454	7785	8004	8246	8591	8894	9167	9528	10131	10521	11803
	9	20	30	100	190	454	1324	2201	2546	2821	3124	3289	3420	3540	3690	3930	4298	5126	5691	6012	6405	8154	10861
1.5D	60	91	112	306	798	2167	4183	7769	8910	9853	10823	11958	12387	12835	13283	13666	14049	14625	15200	16118	17036	18650	20265
	10	20	30	118	271	631	1614	3018	3532	3908	4120	4315	4640	4850	5094	5610	6049	6796	7023	7690	8668	10730	14562
2D	71	110	141	402	1188	2804	5690	10133	10875	11738	12877	13673	14865	15210	15568	15613	15951	16816	17610	18452	20098	21372	22123
	10	20	30	132	325	730	1833	3306	3759	4272	4520	4689	4978	5290	5619	6239	6663	7230	7780	8690	10000	11590	13424
2.5D	75	103	154	535	1302	2931	6181	10108	10969	12027	13145	13881	14913	15219	15526	15889	16252	16407	16563	17048	17534	18322	19111
	10	20	30	174	424	809	2083	3519	3939	4243	4290	4504	4798	5053	5522	5900	6460	7186	7698	8358	9221	10191	10691
3D	78	96	177	600	1390	3196	5736	9537	10595	11359	12403	13081	13839	13773	13917	14165	14267	14255	14537	14446	14583	14861	15035
	10	30	38	194	489	729	2152	3112	3356	3663	3999	4128	4535	4789	5045	5351	5967	5950	6028	6235	6928	7297	7828
3.5D	75	93	194	741	1515	3208	5495	8537	9374	10075	10943	11711	11920	12017	12114	12233	12352	12280	12208	12121	12035	11965	11895
	14	32	30	226	569	863	1961	2880	3083	3375	3573	3783	4012	4119	4321	4696	5229	5581	5632	5754	5864	6002	6156
4D	73	87	203	728	1587	3096	5237	7524	8264	8807	9528	10176	10075	10361	10241	10489	10615	10511	10306	10220	9952	9801	9326
	17	29	41	240	626	1024	1684	2543	2619	2749	2893	3018	3139	3291	3549	3671	3827	4058	4296	4566	4765	4856	4970
4.5D	74	88	179	675	1383	2791	4553	6649	7248	7785	8056	8505	8582	8701	8821	8752	8684	8567	8450	8401	8352	8212	8072
	18	32	60	221	574	1034	1465	2034	2034	2078	2129	2231	2452	2641	2655	2816	2843	3111	3147	3293	3483	3617	3770
5D	72	87	151	586	1179	2657	4058	5864	6088	6400	6715	6908	7106	7227	7165	7049	6906	6941	6999	7098	7191	7276	7261
	17	30	49	192	506	708	1197	1624	1708	1777	1763	1860	1997	2041	2061	2079	2116	2147	2186	2428	2676	2668	2678

Table 3 (continued)
The unshaded cells represent the areas where the HID lamps produced more luminous intensity, while the shaded cells represent the areas where the tungsten-halogen lamps produced more luminous intensity.

	0.5R	1R	1.5R	2R	2.5R	3R	3.5R	4R	4.5R	5R	6R	7R	8R	9R	10R	15R	20R	25R	30R	35R	40R	45R
7U	97	98	94	91	92	91	89	88	88	89	85	86	87	87	86	76	60	47	51	46	39	33
	76	78	80	82	83	84	84	83	80	76	71	67	65	62	59	45	38	27	21	9	5	4
6.5U	102	103	102	100	100	100	98	97	96	96	95	94	94	92	92	84	68	55	54	51	42	36
	82	84	86	88	89	88	88	88	89	84	77	71	70	68	66	50	44	29	21	10	5	4
6U	109	112	111	109	109	107	105	105	105	104	104	100	97	96	96	85	70	57	60	57	50	37
	88	90	95	96	96	94	93	91	89	88	82	77	76	74	71	53	46	29	20	10	7	4
5.5U	119	122	123	123	122	121	119	117	116	115	114	107	104	103	102	87	72	60	62	61	52	39
	101	103	104	105	105	104	99	98	97	97	93	87	83	81	75	58	45	31	22	10	7	4
5U	131	133	139	142	141	139	135	131	128	124	121	120	117	115	111	90	77	68	68	60	57	38
	111	114	116	117	118	116	116	115	115	114	108	99	96	91	85	63	49	36	24	10	6	4
4.5U	134	139	141	144	145	146	145	145	143	141	137	132	127	122	118	92	83	73	73	63	58	39
	123	127	130	131	133	131	130	129	128	126	122	120	116	102	100	71	54	38	28	11	7	4
4U	143	150	149	148	148	152	157	160	165	170	163	147	137	132	128	95	86	76	78	66	57	40
	142	148	152	152	153	152	153	151	149	145	140	135	128	121	116	80	60	41	30	13	7	5
3.5U	166	171	174	177	179	182	180	179	178	176	170	162	152	145	140	104	94	79	88	68	59	42
	166	173	179	178	177	176	176	175	175	176	164	154	142	133	132	90	68	43	30	14	9	3
3U	186	192	196	195	200	205	197	191	189	187	181	175	168	159	150	118	125	83	94	72	61	45
	211	210	210	216	213	212	216	214	211	202	191	181	164	151	147	102	71	46	33	15	9	3
2.5U	195	207	213	220	217	215	210	204	203	201	199	189	184	186	180	138	154	91	96	73	65	48
	272	291	276	266	264	262	260	252	246	248	214	209	194	189	172	118	76	49	31	17	10	4
2U	199	212	241	252	247	255	245	235	225	222	221	208	207	217	214	155	166	101	98	75	75	48
	334	349	348	348	345	330	322	306	299	292	271	267	254	229	194	143	83	49	31	17	10	4
1.5U	254	274	288	302	309	316	314	313	326	338	331	323	322	321	312	182	166	123	109	81	81	53
	415	431	437	446	460	462	440	435	397	385	360	333	304	265	231	162	101	66	40	18	11	6
1U	323	344	355	366	408	451	496	552	563	563	578	580	574	569	523	327	193	146	129	93	95	57
	544	557	576	613	622	614	598	587	567	540	493	439	373	323	309	212	153	106	50	24	10	4
0.5U	500	574	742	909	1164	1419	1604	1790	1904	2019	1992	2227	1651	1393	1213	490	268	183	160	106	115	64
	1159	1252	1341	1318	1293	1235	1144	1117	1153	1123	811	662	581	488	460	297	259	135	57	25	9	3
0	980	1343	2080	3257	4493	5261	5457	5859	6147	6191	5713	4468	3177	2550	2245	965	456	284	218	138	128	73
	3216	3779	4467	4822	5031	4461	4250	3730	3342	3101	2237	1387	1066	885	810	540	334	170	73	23	5	4
0.5D	6029	8316	11281	14247	14988	15728	15308	14889	13841	12793	10832	9269	7473	6184	5277	2445	1080	567	350	161	138	91
	8551	11684	13537	14732	14581	14402	13526	12236	10484	7555	4530	2820	2274	1750	1650	893	506	250	78	13	5	5
1D	15045	20263	23879	25253	24914	24196	22983	21866	19646	17779	15194	14109	11932	9675	8934	4582	2035	1100	576	216	132	109
	13838	17669	20182	21175	22212	21940	20972	17946	14595	12377	7401	5329	4209	3270	2861	1424	671	313	101	10	5	5
1.5D	23034	25802	26913	28024	26927	25830	24356	22881	21260	19640	16790	15071	13729	12014	10813	6580	3052	1564	751	258	152	109
	19466	21013	21891	22104	24440	25548	24337	20711	15902	13545	10362	6070	5030	4189	3864	2307	1083	336	135	10	5	5
2D	23245	25911	25943	26241	25668	24879	23841	22420	21020	20084	18302	16389	14957	13963	12580	7690	3704	1931	823	305	182	102
	15997	16438	16623	18140	20509	21122	20840	19582	16688	14459	10660	7813	6259	5297	4803	3024	1256	409	179	17	5	5
2.5D	19989	20868	21237	21607	20687	19767	19286	18805	18136	17467	16095	15207	13556	12358	11526	7181	4063	2165	929	297	182	101
	11514	12203	12616	13535	15018	14444	13597	13152	12506	11796	9778	7218	6019	5642	5337	3423	1388	529	219	20	5	5
3D	15648	15635	15967	15676	15378	15164	14834	14474	14321	14162	13828	12846	12543	10985	10190	6434	4207	2072	985	300	176	114
	8524	8823	9151	9170	8883	8698	8500	8359	8347	8341	7040	6355	6000	5619	4970	3098	1419	741	243	26	5	5
3.5D	12149	12403	12799	13195	12860	12525	12209	11894	11710	11526	11310	11372	10834	10162	9191	6010	4072	1927	938	304	177	90
	6318	6419	6557	6674	6603	6621	6570	6581	6566	6325	6155	5631	5289	5039	4789	2804	1395	767	295	28	5	3
4D	9138	9081	9500	9828	9678	9045	8725	8639	8968	9331	9444	9572	9436	9085	8129	5237	3588	1850	904	295	168	68
	5151	5163	5141	5087	5010	5009	4991	4999	4894	4817	4711	4436	4254	4183	3913	2419	1474	973	290	30	5	2
4.5D	7973	7874	7854	7833	7759	7686	7512	7338	7358	7379	7609	7835	8001	7738	7149	4890	3251	1803	887	295	148	80
	3798	3617	3584	3529	3553	3595	3695	3759	3740	3668	3477	3442	3356	3369	3273	2004	1303	869	313	34	10	2
5D	7226	7043	7076	6864	6858	6845	6751	6662	6543	6442	6238	6311	6490	6070	5958	4328	3109	1831	859	307	130	52
	2875	2705	2569	2617	2636	2645	2649	2641	2657	2645	2641	2559	2523	2559	2632	1721	930	621	209	33	9	3

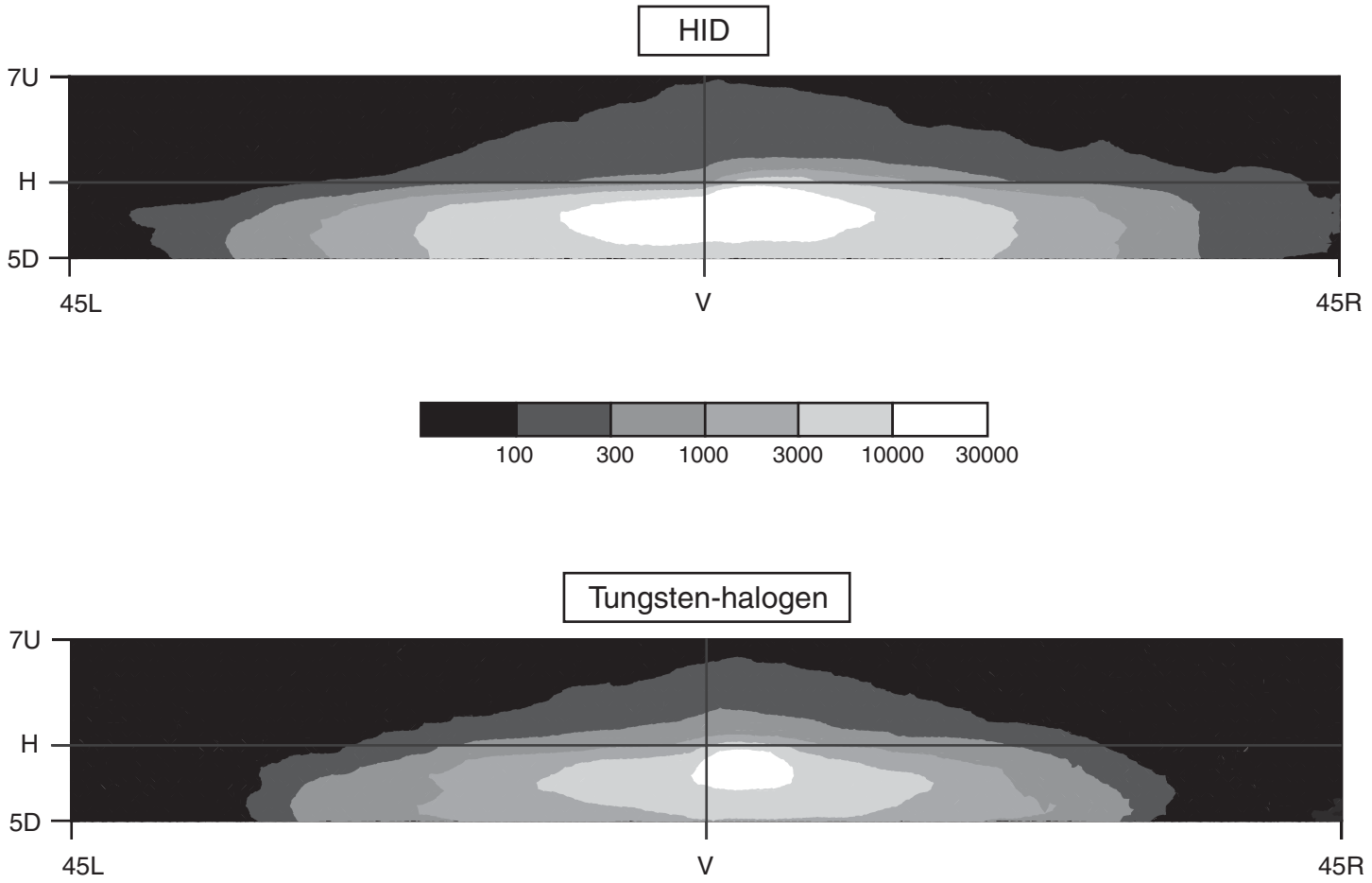


Figure 1. Isocandela diagram of the median luminous intensities for the HID lamps (top panel) and for the tungsten-halogen lamps (bottom panel).

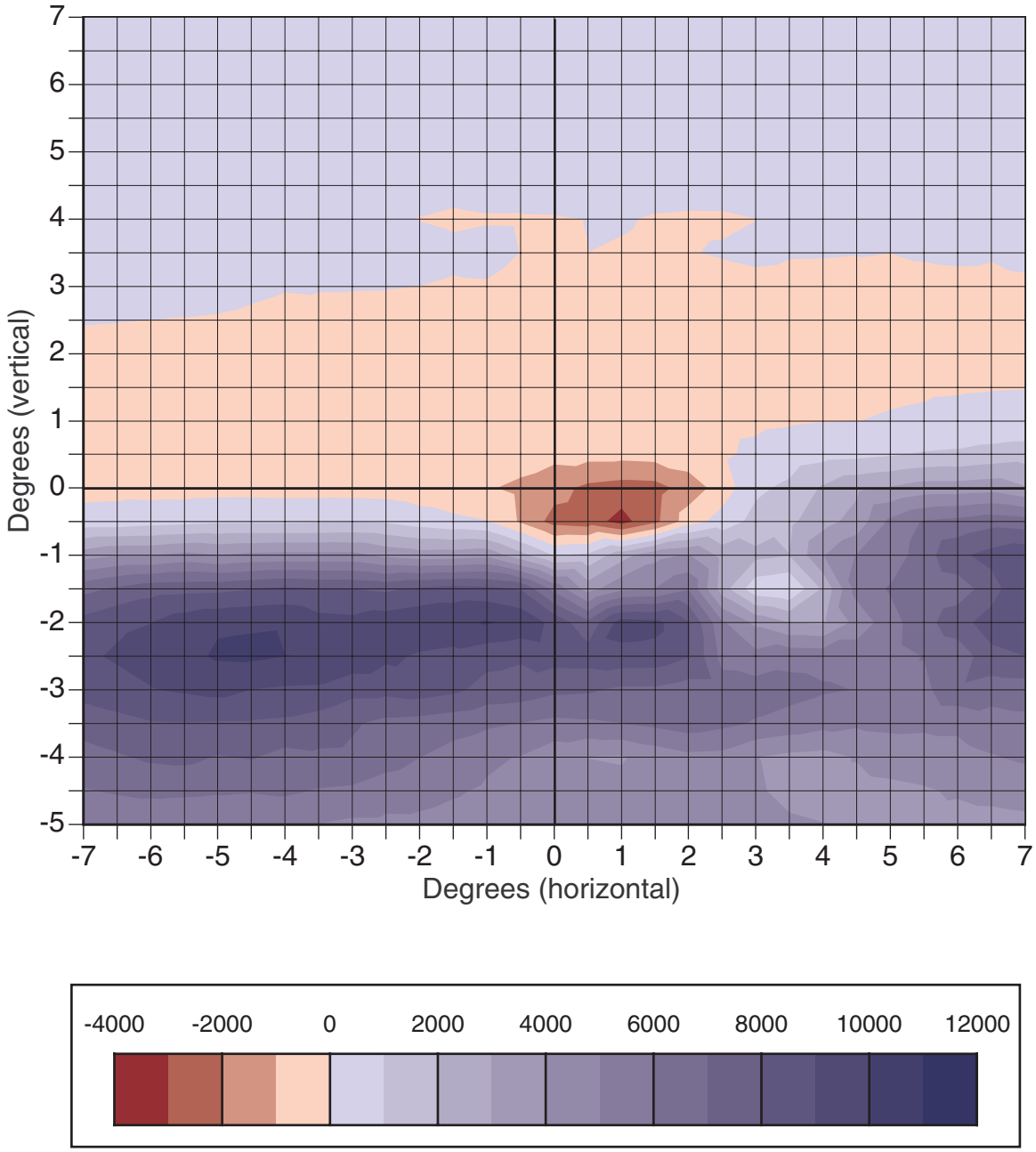


Figure 2. Differences between the median HID and the median tungsten-halogen luminous intensities in the central part of the two beam patterns. The blue colors indicate the areas where the HID intensities are greater than the tungsten-halogen intensities. Conversely, the red colors indicate the areas where the tungsten-halogen intensities are greater than the HID intensities.

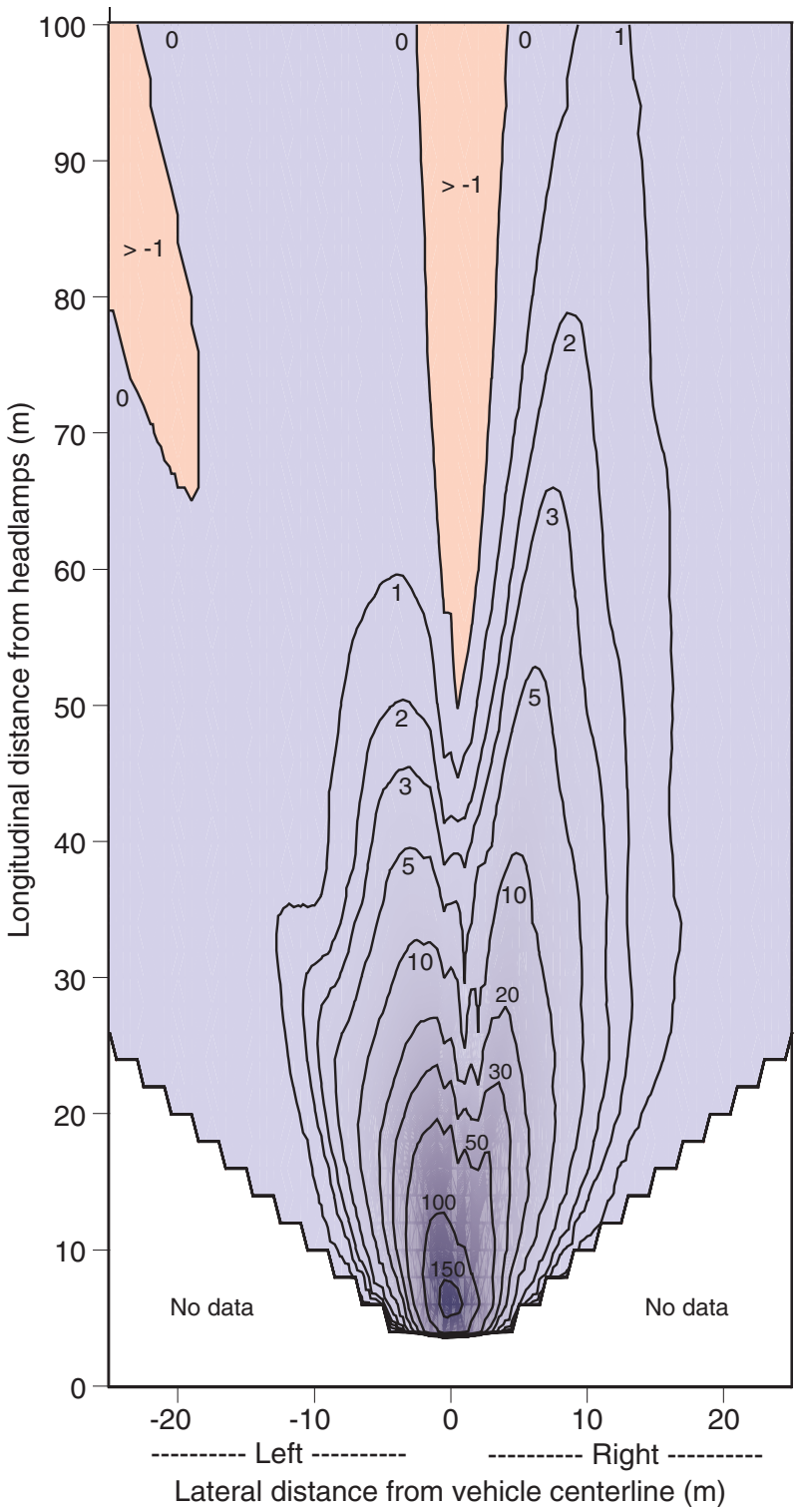


Figure 3. The difference in the combined illuminance (in vertical lux) on the road surface from two HID lamps and two tungsten-halogen lamps. The positive values favor HID lamps, while the negative values favor tungsten-halogen lamps. (Headlamp mounting height: 0.66 m, headlamp separation: 1.20 m.)

Visibility of pedestrians and road marking on straight roads

Figures 4 and 5 present the combined illuminance from two HID lamps and two tungsten-halogen lamps on the surface of a straight road as an index of visibility of pedestrians and road delineation. Figure 4 is for the illuminance at the right edge line of the lane of travel, while Figure 5 is for the left edge line of the left adjacent lane.

On the right side (see Figure 4), the HID lamps provided more illuminance at distances up to about 60 m, while the tungsten-halogen lamps provided more illuminance at longer distances. On the left side (see Figure 5), the HID lamps delivered more illuminance at all distances tested, with the difference being especially pronounced at near distances.

Figure 6 examines the situation for the right side in more detail, by comparing the performance of the tungsten-halogen lamps to the projector HID lamps (with steeper vertical gradients) and the nonprojector HID lamps (with less steep vertical gradients). At these locations, which are strongly affected by the vertical gradients between upper (glare) and lower (seeing) parts of the beam pattern, the comparison between HID and tungsten-halogen lamps was different for projector and nonprojector HID lamps. The data in Figure 6 indicate that, at all distances tested, the projector HID lamps consistently provided more illuminance, while the nonprojector lamps did so only at shorter distances.

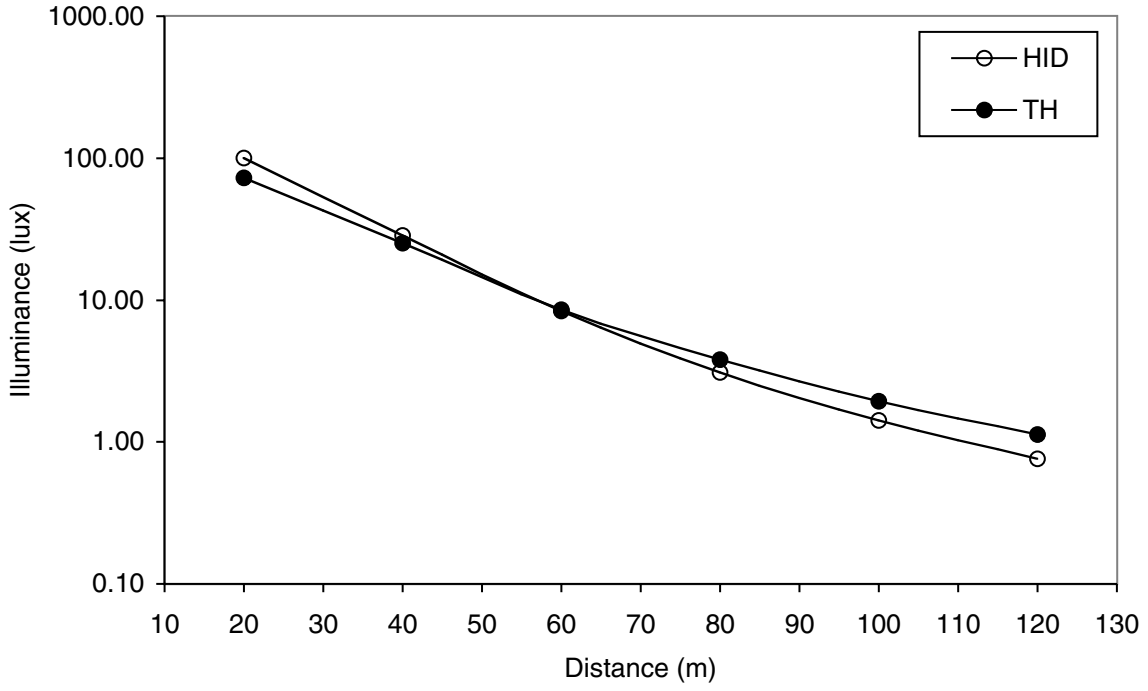


Figure 4. The combined illuminance from the left and right lamps on the right edge line of the lane of travel on a straight road (HID = high-intensity discharge, TH = tungsten halogen).

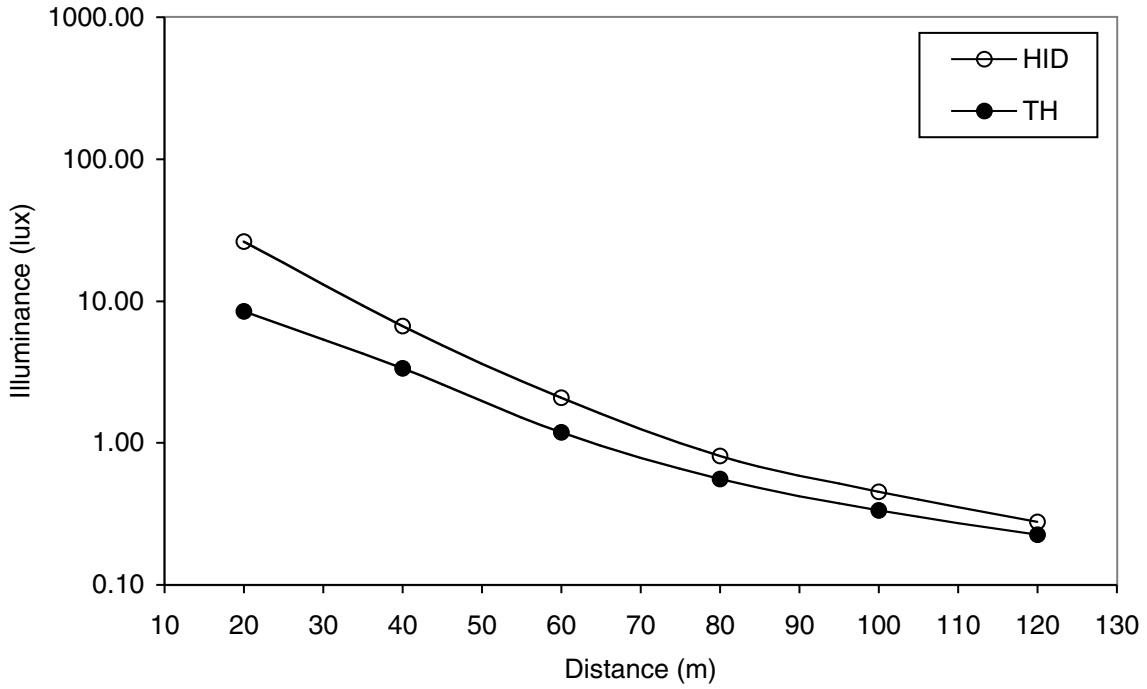


Figure 5. The combined illuminance from the left and right lamps on the left edge line of the left adjacent lane on a straight road.

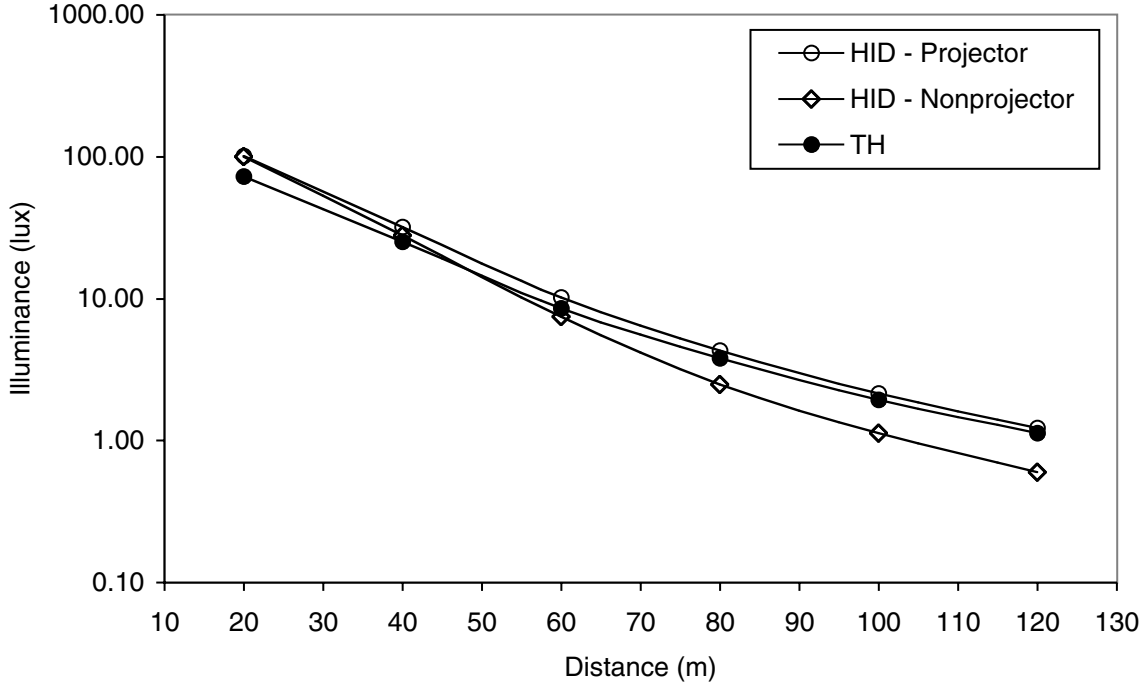


Figure 6. The combined illuminance from the left and right lamps on the right edge line of the lane of travel on a straight road by the type of HID lamp. (Compare with Figure 4.)

Glare on straight roads

At all intervehicular distances, the illuminance from the HID lamps was less than the illuminance from the tungsten-halogen lamps (see Figure 7).

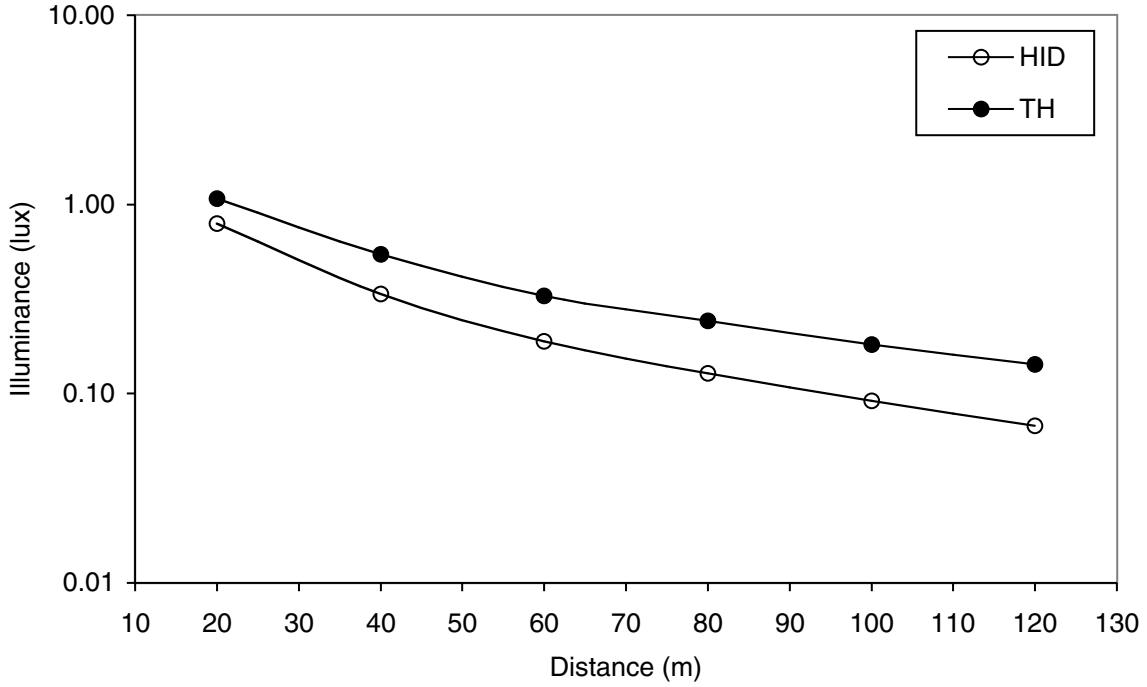


Figure 7. The combined illuminance from the left and right lamps reaching the eyes of an oncoming driver in the left adjacent lane on a straight road.

Visibility of pedestrians and road marking on curves

The illuminances from the two types of lamps for the visibility of pedestrians and road markings on short-radius (80-m) curves are compared in Figure 8 for a right curve, and in Figure 9 for a left curve. Analogous comparisons on long-radius (240-m) curves are shown in Figures 10 and 11. In virtually all combinations of radius of curve, direction of curve, and distance, the HID lamps provided substantially more illuminance than did the tungsten-halogen lamps.

Glare on curves

The illuminances at the eyes of an oncoming driver are compared in Figures 12 through 15 for all combinations of radius and direction of curve. For both left curves, the HID lamps provided less illuminance than did the tungsten-halogen lamps, with the difference especially pronounced on the longer-radius curve. For both right curves, the HID lamps produced more illuminance at all but the shortest distances tested (at 20 m for the 80-m-radius curve, and at 40 m for the 240-m-radius curve). The differences between the lamp types were greater for the longer-radius curves.

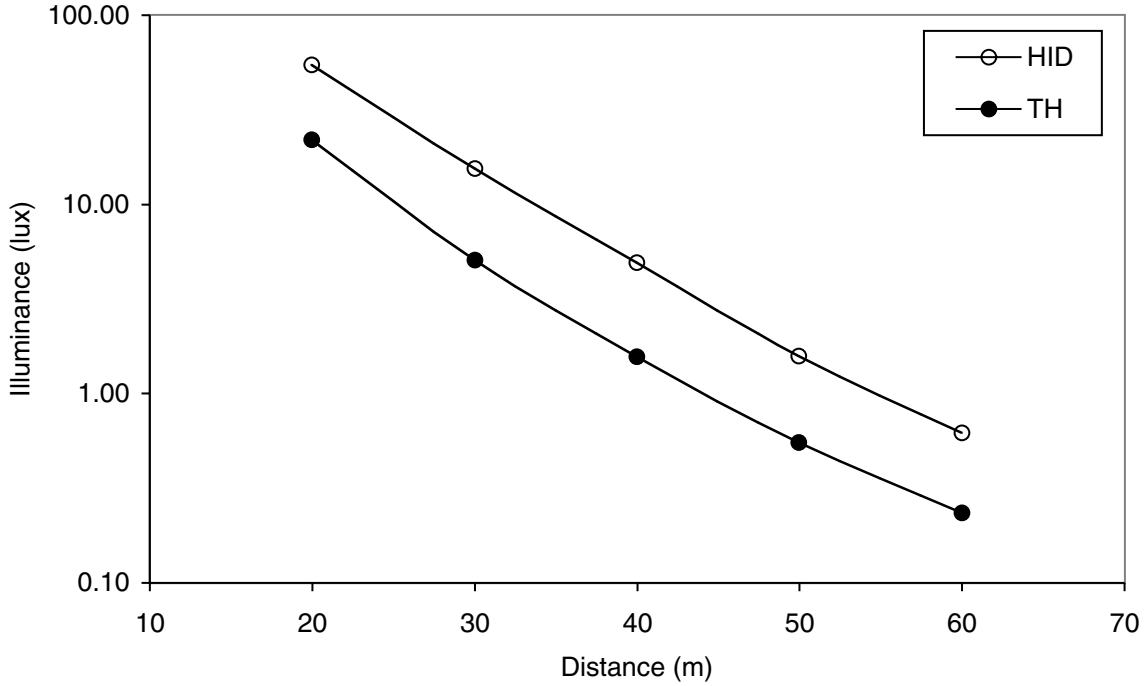


Figure 8. The combined illuminance from the left and right lamps on the right edge line of the lane of travel on a right curve with a radius of 80 m.

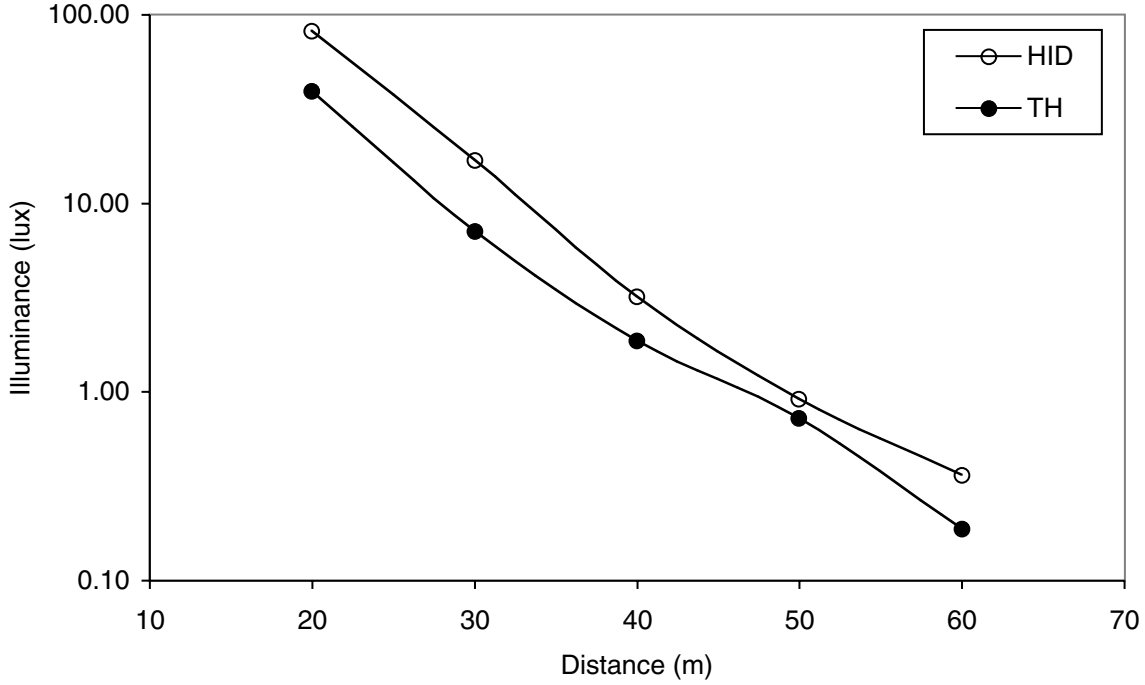


Figure 9. The combined illuminance from the left and right lamps on the right edge line of the lane of travel on a left curve with a radius of 80 m.

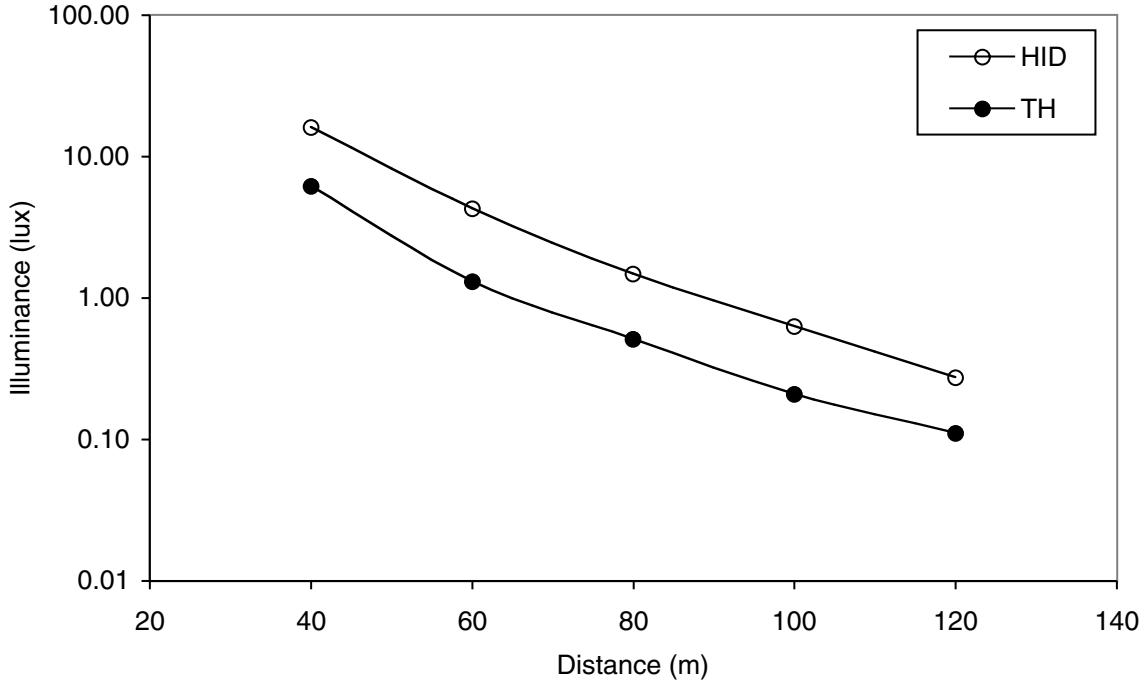


Figure 10. The combined illuminance from the left and right lamps on the right edge line of the lane of travel on a right curve with a radius of 240 m.

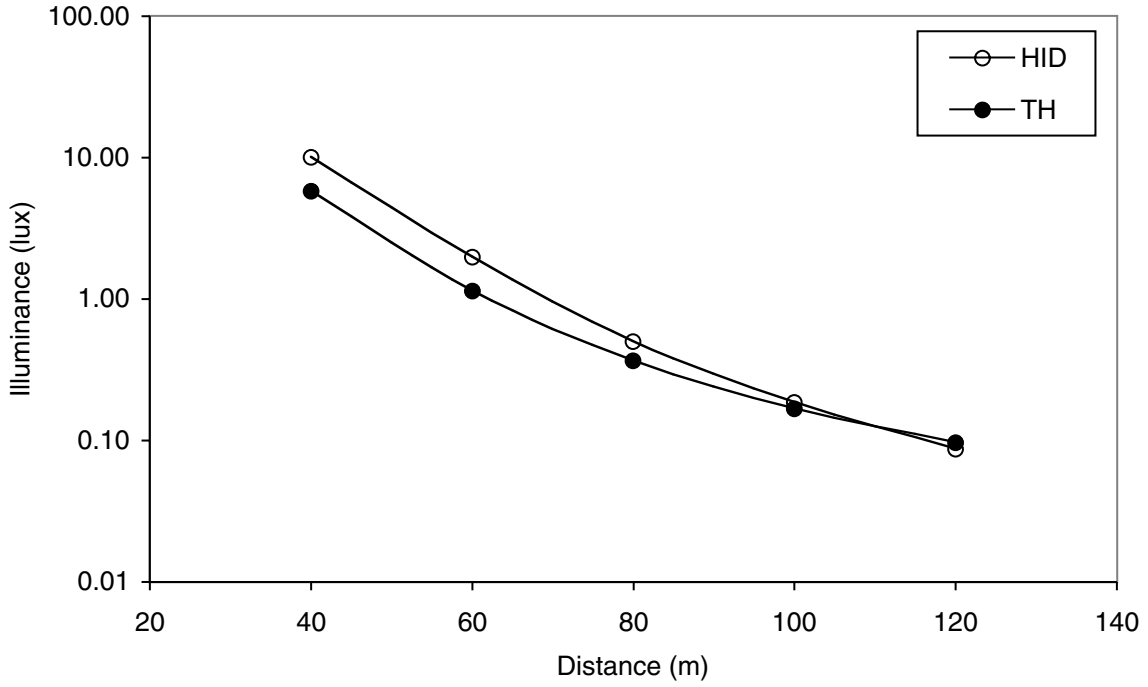


Figure 11. The combined illuminance from the left and right lamps on the right edge line of the lane of travel on a left curve with a radius of 240 m.

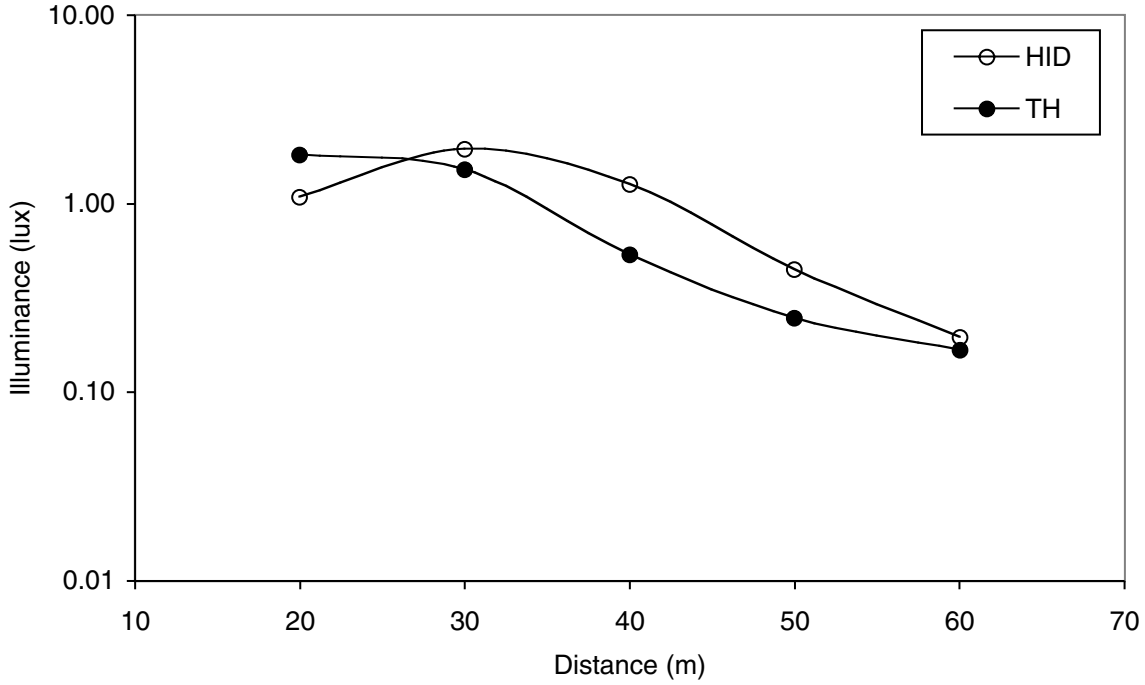


Figure 12. The combined illuminance from the left and right lamps reaching the eyes of an oncoming driver on a right curve with a radius of 80 m.

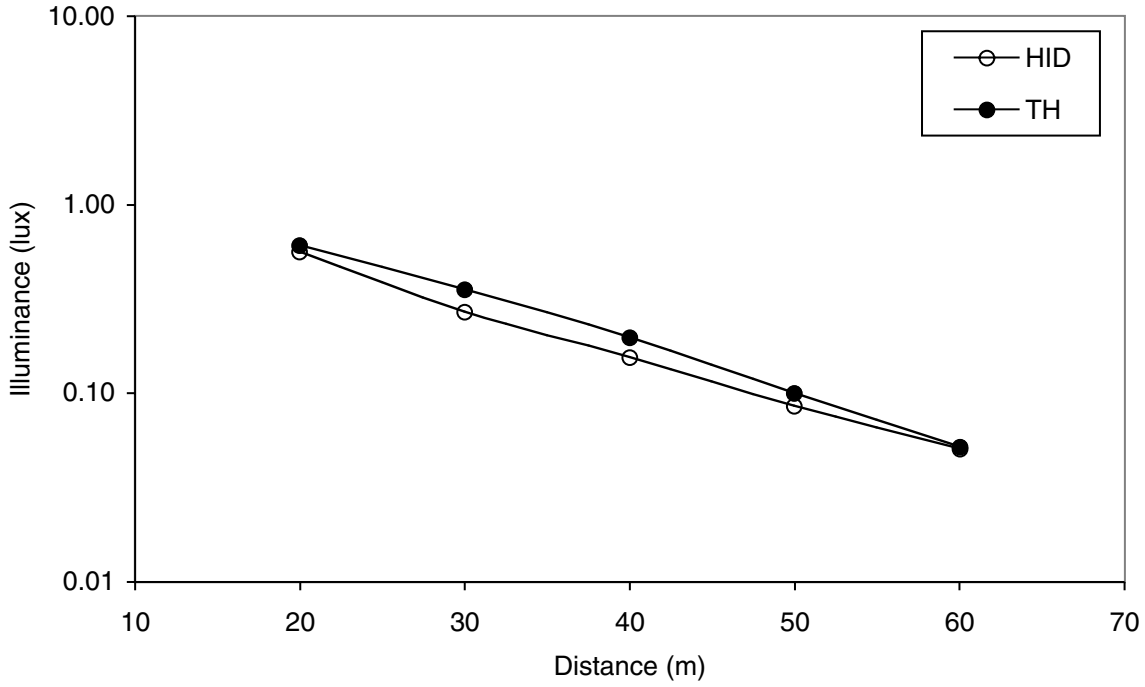


Figure 13. The combined illuminance from the left and right lamps reaching the eyes of an oncoming driver on a left curve with a radius of 80 m.

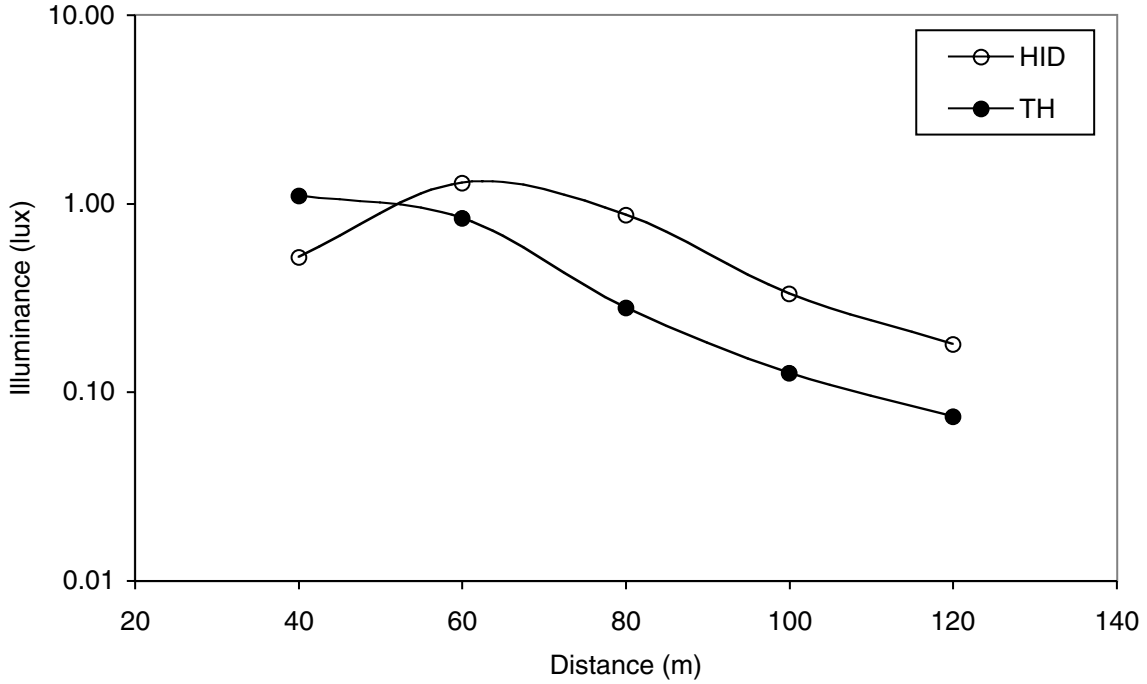


Figure 14. The combined illuminance from the left and right lamps reaching the eyes of an oncoming driver on a right curve with a radius of 240 m.

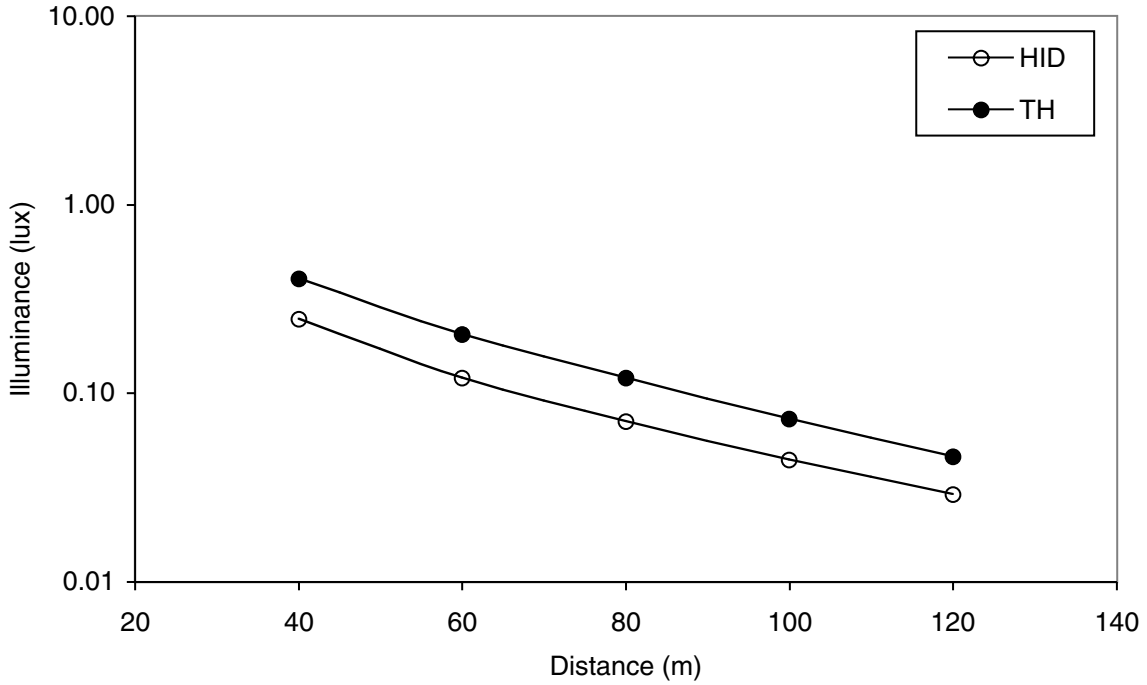


Figure 15. The combined illuminance from the left and right lamps reaching the eyes of an oncoming driver on a left curve with a radius of 240 m.

Visibility of retroreflective traffic signs on straight roads

The illuminance on a right, shoulder-mounted sign (see Figure 16) was approximately the same for the two headlamp types. For a center, overhead-mounted sign (see Figure 17), the HID lamps provided more illuminance than did the tungsten-halogen lamps at near distances, while the situation was reversed at longer distances. Finally, for a left, shoulder-mounted sign (see Figure 18), at all tested distances the illuminance was greater from the tungsten-halogen lamps than from the HID lamps.

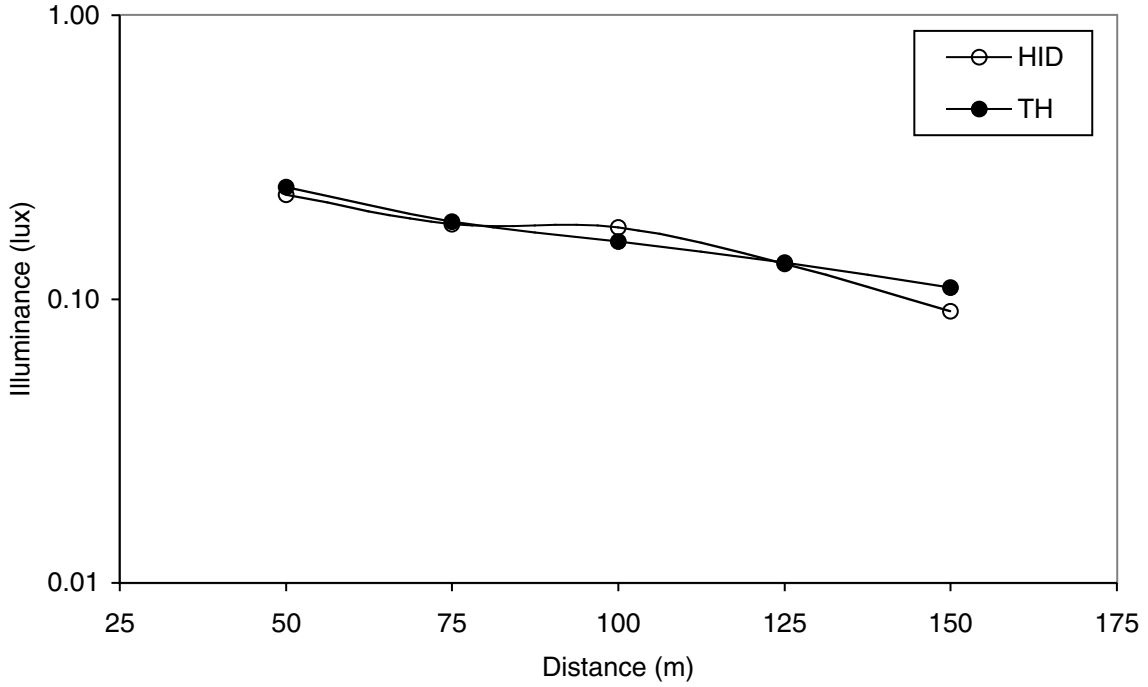
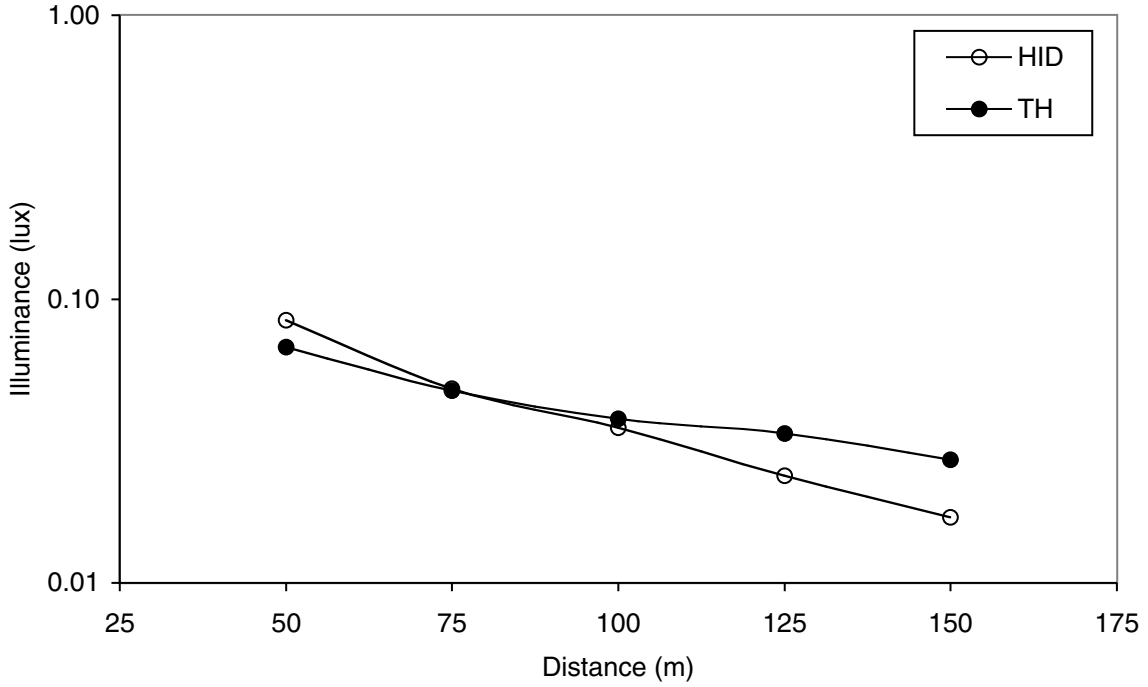


Figure 16. The combined illuminance from the left and right lamps on the right, shoulder-mounted sign on a straight road.



Figures 17. The combined illuminance from the left and right lamps on the center, overhead-mounted sign on a straight road.

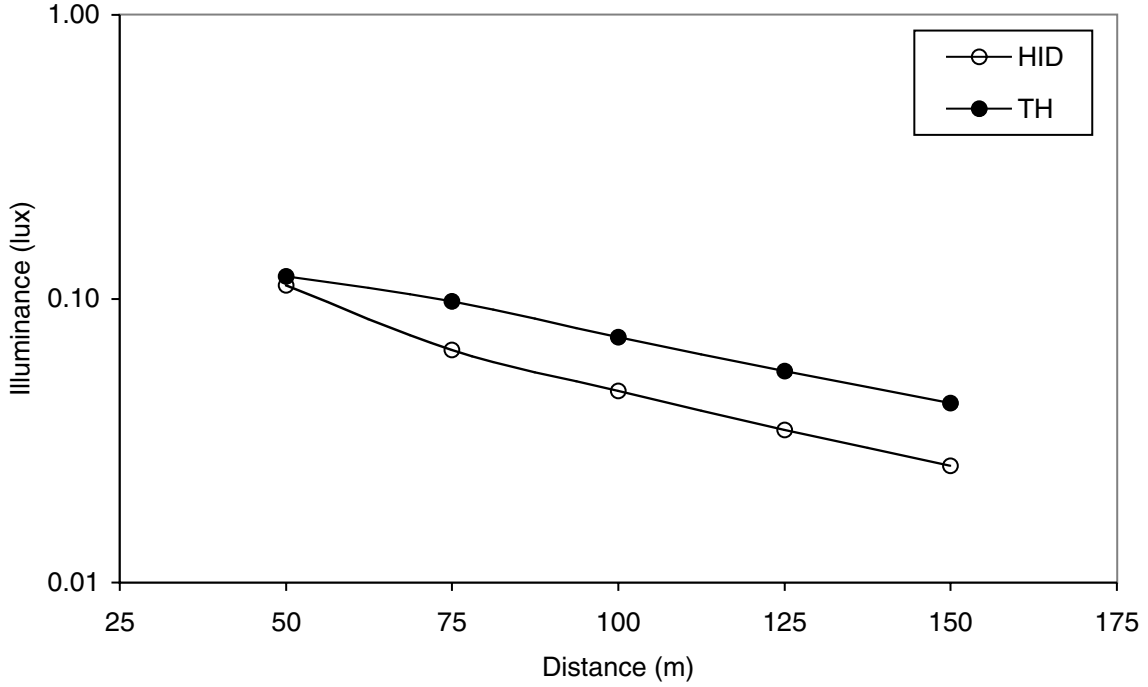


Figure 18. The combined illuminance from the left and right lamps on the left, shoulder-mounted sign on a straight road.

Discussion

The first generation of HID low beams in the U.S., in comparison to the tungsten-halogen lamps of the same vintage, delivered a wider beam pattern, more foreground illumination, and more illumination at relatively large up angles. Furthermore, the projector HID lamps provided more light in the central part of the beam pattern just below the horizontal, although that was not the case for the nonprojector HID lamps.

Specific analyses of the illuminance at the right edge line of the lane of travel on curves of two radii (80 m and 240 m) indicate a substantial advantage of HID lamps for both right and left curves. This difference should result in improved visibility on curves of pedestrians and other relevant objects with HID lamps. Furthermore, more light on road delineation with HID lamps may make lane maintenance less demanding (Sivak, Flannagan, Schoettle, and Mefford, 2002).

On the left curves, the increased seeing illuminance with HID lamps was accompanied with *less* glare illuminance towards oncoming drivers—the best of both worlds. However, on right curves there was an increase in glare with HID lamps.

On straight roads, the projector HID lamps delivered more illuminance for pedestrians and road delineation on the right side of the road, but the opposite was the case at longer distances for the nonprojector HID lamps. HID lamps as a group delivered more illuminance for the left-side pedestrians and road delineation on straight roads, and this is predicted to lead to better visibility of left-side pedestrians and delineation.

The illuminance for retroreflective traffic signs was evaluated at three sign positions on a straight roadway: right, shoulder-mounted; center, overhead-mounted; and left, shoulder-mounted. The two types of lamps produced similar illuminances at the right sign throughout the range of distances tested. At the center sign, near distances favored the HID lamps, while the situation was reversed at longer distances. Finally, for the left sign, the illuminances from the HID lamps were consistently less than those from the tungsten-halogen lamps.

Conclusions and Recommendations

HID lamps produce more light than do tungsten-halogen lamps. Consequently, they hold great promise for improving the nighttime safety of driving by improving the low-beam light distribution. The present analysis indicates that this promise has already been partially met in the first generation of HID lamps on vehicles in the U.S. Specifically, the HID lamps tended to provide wider beam patterns than did the tungsten-halogen lamps, which, in turn, should improve the visibility of pedestrians on curves and may make the lane-maintenance task less demanding. On right curves, there was an increase in glare illumination towards oncoming drivers, while on left curves there was a decrease in glare illumination.

On straight roads, the HID lamps produced more illumination for pedestrians and road delineation on the left side of the road. This was also the case for the right side of the road, but only for projector HID lamps; the nonprojector lamps produced less illumination than did the tungsten-halogen lamps. Finally, on straight roads HID lamps produced less glare for oncoming drivers than did the tungsten-halogen lamps.

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