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**A MARKET-WEIGHTED DESCRIPTION OF  
TUNGSTEN-HALOGEN AND LED  
LOW-BEAM HEADLIGHTING PATTERNS IN  
THE U.S.**

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A MARKET-WEIGHTED DESCRIPTION OF TUNGSTEN-HALOGEN AND LED  
LOW-BEAM HEADLIGHTING PATTERNS IN THE U.S.

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16. Abstract  <p>This report provides photometric information for low-beam headlamps on current U.S. light vehicles. Tungsten-halogen (TH) and LED lamps are included. The summaries presented here were based on photometric data provided by three vehicle manufacturers. The sample included data for 62 TH headlamps (in 31 left-right pairs) and 48 LED headlamps (in 24 left-right pairs). Collectively, the lamps are used on 45 vehicle models, which accounted for 36% of U.S. light-vehicle sales in 2018.</p> <p>The photometric information for each lamp was weighted by the sales figure for the corresponding vehicle. The results are presented in tabular form for the 25th-percentile, 50th-percentile (median), and 75th-percentile luminous intensities (from 25° left to 25° right, and from 5° down to 7° up). The results are also presented in graphical form as isocandela diagrams (from 25° left to 25° right, and from 5° down to 10° up).</p>			
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## Contents

Acknowledgments.....	ii
Introduction.....	1
Method.....	3
Approach.....	3
Photometry.....	3
Sample.....	3
Results.....	5
Summary and Discussion.....	12
References.....	13

## **Introduction**

This study is a continuation in a series of reports that document the market-weighted headlamp photometry for vehicles in the U.S. and Europe (see Sivak, Flannagan, Kojima, & Traube, 1997; Sivak, Flannagan, & Schoettle, 2000; Schoettle, Sivak, & Flannagan, 2001; Schoettle, Sivak, Flannagan, & Kosmatka, 2003; Schoettle, Sivak, Flannagan, & Kosmatka, 2004; and Schoettle & Flannagan, 2011). The present study was designed to update the market-weighted database of current U.S. low-beam headlamps. The primary goal was to provide information about the beam patterns of LED headlamps, which are relatively new and growing in popularity. A secondary goal was to update previous data on tungsten-halogen (TH) headlamps to allow the best possible comparison between TH and LED beam patterns. The study did not include high-intensity discharge (HID) headlamps.

The photometric data used here were donated by automobile manufacturers. At several meetings of automotive lighting groups, and through various informal means of communication, UMTRI asked for information from any vehicle manufacturers that were able to provide it. Many expressed willingness to provide data, but some indicated that it might take some time to assemble the data. At the time of this report (December 2019) we have data from three manufacturers (Fiat Chrysler Automobiles, Ford Motor Company, and General Motors). We expect that more companies will provide data, and we would be interested in updating the results reported here as more data becomes available. However, we judged that the data from these three companies was reasonably representative, and so decided to publish a summary of the data that we currently have.

The use of donated data contrasts with the approach that we have taken in previous similar studies, in which we purchased lamps and photometered them without direct input from vehicle or lighting manufacturers. The reason for doing that in the past was to guarantee that the results were not affected by any possible bias. However, we have never considered it likely that there would be substantial bias, and we considered the independence of our data collection method to be insurance against what was probably a minor problem. The reason for changing our approach in the present study is the increased difficulty of independently obtaining and photometering LED lamps. Many

replacement LED lamps are substantially more expensive than typical TH lamps. Measuring LED lamps on a laboratory goniometer can also be more technically difficult than for TH lamps.

In another contrast to previous UMTRI headlighting surveys, the data presented here cannot be strictly tied to a single model year. It is likely that the majority data we received apply to 2019 vehicles (as well as to several years before and after 2019), but we did not determine whether that was true in all cases.

## Method

### Approach

The approach consisted of the following steps:

- (1) Obtain luminous-intensity matrices for a sample of lamps designed to be used on U.S. light vehicles.
- (2) Use recent (2018) sales data for the respective vehicles to derive a sales-weighted distribution of luminous intensities at each test point. This was done separately for TH and LED lamps, using the total sales data by vehicle. We did not have sales data by lamp type. The market weighting therefore should be interpreted as characterizing lamps by the type of vehicle for which were designed, not necessarily characterizing their contribution to the whole population of headlamps.
- (3) For each test point, calculate selected percentiles—25th, 50th (median), and 75th—of the sales-weighted distribution of luminous intensities.

### Photometry

We received photometric data in a wide variety of formats, with multiple combinations of horizontal and vertical angular range. We transformed all data into a common format for analysis, with the following ranges of horizontal and vertical angles (in relation to the headlamp axes): in the horizontal direction, the angles ranged from 25° left (L) to 25° right (R) in steps of 0.2°; in the vertical direction, the angles ranged from 5° down (D) to 10° up (U) in steps of 0.2°. We determined the luminous intensities at the 25th percentile, 50th percentile (median), and 75th percentile for test points in a rectangular matrix defined by the same ranges of horizontal and vertical angles but in steps of 0.5°.

### Sample

The sample consisted of 110 lamps, in 55 matched left-right pairs. There were 62 TH lamps and 48 LED lamps. Collectively, the lamps were used on 45 vehicle models, which accounted for 36% of U.S. light-vehicle sales in 2018. The 45 vehicles were as



follows (in descending order of sales): Ford F-Series, Dodge Ram, Chevrolet Silverado, Chevrolet Equinox, Ford Escape, Ford Explorer, Jeep Wrangler, Jeep Cherokee, GMC Sierra, Ford Fusion, Jeep Compass, Chevrolet Suburban, Chevrolet Traverse, Chevrolet Malibu, Chevrolet Cruze, Ford Transit, Chevrolet Colorado, Ford Edge, Chrysler Pacifica, GMC Terrain, Ford Focus, Chevrolet Express, GMC Acadia, Ford Mustang, Cadillac XT5, Chevrolet Impala, Ford Expedition, Ford Fiesta, Chevrolet Camaro, GMC Yukon, Ford Taurus, GMC Canyon, Ford Transit Connect, Lincoln MKX, Lincoln MKC, Cadillac Escalade, Ford Flex, Lincoln MKZ, Chevrolet Corvette, Chevrolet Volt, Chevrolet Bolt, Lincoln Navigator, Lincoln Continental, Ford C-Max, Lincoln MKT.

## Results

Table 1 lists the 25th-percentile, the median (50th-percentile), and the 75th-percentile luminous intensities for the TH lamps. Table 2 lists the same results for the LED lamps. Please note that, because of space limitations, the tables provide only subsets of the available data. Specifically, the horizontal steps in the tables are  $0.5^\circ$  between  $0^\circ$  and  $5^\circ$ ,  $1^\circ$  between  $5^\circ$  and  $10^\circ$ , and  $5^\circ$  between  $10^\circ$  and  $25^\circ$  (all for left or right); the vertical steps are  $0.5^\circ$  throughout, displayed from  $5^\circ$  down to  $7^\circ$  up. (The full available range is from  $10^\circ$  up to  $5^\circ$  down.)

Figures 1 and 2 present isocandela diagrams corresponding to the 25th-percentile, median (50th-percentile), and 75th-percentile luminous intensities for the TH and LED lamps, respectively.

Table 1

Luminous intensities (cd) for the sample representing the TH low-beam headlamps on current light vehicles in the U.S. The entries in each cell are (from top to bottom) the 25th percentile, the 50th percentile (median), and the 75th percentile.

	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	7	9	14	30	35	42	42	47	54	55	56	58	60	61	61	64	69	79	81
	12	21	28	50	50	53	61	72	74	75	75	76	76	78	79	82	82	85	89
	23	46	53	126	134	139	145	157	162	162	167	173	178	180	184	185	187	187	186
6.5U	8	10	16	38	43	46	53	53	57	58	59	61	63	71	78	82	83	83	85
	13	22	30	54	67	72	76	76	77	77	77	82	84	88	93	98	100	109	114
	27	48	61	134	145	138	159	166	173	177	183	189	193	197	201	199	207	208	208
6U	9	13	19	41	46	52	59	60	60	62	63	67	82	85	86	87	87	87	89
	14	24	34	67	71	76	79	79	80	84	88	91	91	99	107	117	131	140	152
	31	50	68	143	156	167	174	182	183	193	214	226	213	220	236	226	218	233	228
5.5U	10	15	22	45	52	63	66	67	67	68	68	80	86	88	91	90	91	92	93
	14	24	39	71	75	80	84	86	90	97	102	103	109	124	131	149	163	172	184
	32	55	66	152	151	179	189	210	220	221	240	246	241	253	260	253	253	259	258
5U	12	17	27	48	62	66	70	75	76	76	74	82	91	94	96	96	97	99	98
	16	28	46	74	81	93	92	97	109	113	118	122	130	131	142	156	161	171	186
	31	60	74	142	174	191	196	211	243	248	256	261	267	262	280	286	287	304	288
4.5U	14	17	27	58	66	73	82	82	82	84	85	94	99	102	104	106	108	109	109
	18	35	55	80	95	107	113	125	137	141	145	153	161	165	169	181	191	199	213
	37	64	81	164	182	201	220	243	257	260	274	277	287	290	308	318	326	340	344
4U	11	17	24	72	89	97	101	97	88	92	96	104	108	113	116	119	120	121	122
	23	41	59	90	103	124	134	150	160	171	181	184	196	210	222	225	218	228	234
	34	68	83	175	195	216	253	254	272	278	292	297	302	311	324	340	355	367	362
3.5U	16	18	23	81	103	113	117	114	113	114	124	123	128	133	135	138	140	141	142
	26	44	70	99	110	137	143	165	178	187	200	208	221	233	215	224	253	280	280
	52	73	102	188	206	227	247	270	289	298	310	318	329	334	346	360	383	399	406
3U	15	19	24	81	105	126	131	128	133	133	152	145	149	160	185	192	192	192	194
	25	51	82	105	122	140	155	178	193	202	213	232	243	232	237	245	263	304	323
	55	88	115	201	221	237	261	286	316	326	340	351	365	372	392	409	423	450	468
2.5U	20	21	24	84	108	128	141	145	158	156	171	170	174	186	184	175	182	184	190
	27	57	92	111	137	149	173	188	204	207	225	236	230	241	254	271	312	341	355
	59	104	130	214	242	264	284	309	340	356	371	394	407	428	453	467	490	516	541
2U	22	23	23	82	109	145	160	166	177	179	189	197	208	196	199	209	221	232	250
	34	60	104	132	136	163	181	193	199	225	232	238	246	260	268	289	339	369	381
	76	114	137	233	262	295	310	341	392	402	428	419	472	491	519	526	534	556	615
1.5U	24	28	23	88	110	158	172	193	204	208	218	214	221	235	248	259	268	279	302
	43	71	116	152	162	190	201	213	218	230	241	250	263	289	303	344	375	400	411
	90	148	181	263	296	317	343	377	446	460	461	486	513	526	568	582	642	637	660
1U	27	45	28	93	113	142	174	202	216	236	256	274	295	313	315	320	326	356	369
	78	96	149	186	199	228	248	280	285	284	283	298	312	344	360	404	429	450	473
	174	199	265	302	342	371	398	455	489	477	514	533	559	583	608	654	727	820	849
0.5U	38	73	50	130	143	162	196	230	280	312	349	374	400	426	451	493	538	596	612
	103	190	249	311	342	366	400	443	482	498	511	537	549	586	621	637	699	714	771
	226	330	421	436	473	519	573	656	694	752	816	841	867	916	997	1038	1105	1248	1447
0	64	230	340	548	592	668	760	920	930	981	1081	1149	1187	1230	1526	2036	2434	2812	3115
	125	371	464	672	859	1141	1207	1392	1333	1416	1518	1572	1670	1871	2176	2560	3225	3879	4834
	441	743	821	1353	1506	1710	1767	1857	1989	2097	2346	2547	2895	3434	3984	4911	5007	6818	8363
0.5D	110	491	910	1708	1856	2130	2624	3209	3551	3641	3836	4016	4328	4751	5475	6688	9660	12402	16112
	321	933	1485	2226	2686	2920	3587	4039	4551	4764	5224	5686	6294	7143	8161	9411	11373	15100	17617
	624	1241	2095	3263	3855	4790	5172	5805	6656	7070	7618	8309	9410	10907	13932	16652	18795	22563	24554
1D	153	684	1275	2899	3562	3965	4808	5407	6430	7225	8177	8659	9863	10875	12130	13948	16184	19499	24293
	460	1319	2386	3610	4370	5001	5843	6759	8054	8620	9290	9872	10390	11247	12765	15013	19890	26263	27461
	936	1590	3255	5370	5913	6675	7554	8507	10257	11027	12206	13924	15563	17829	21001	23582	27747	30121	31199
1.5D	140	634	1524	3561	4004	4765	5853	7076	8159	8895	9611	10075	10817	11909	13236	15064	17637	20430	22975
	487	1277	2331	4698	5519	6179	6929	8254	9379	10151	10946	12092	13196	13619	14219	16603	19347	22521	23834
	959	1923	4081	5848	6283	7382	8421	9664	10913	11781	12553	13773	15168	17270	19635	23400	25570	26984	28003
2D	154	589	1766	3498	3989	4854	5960	7218	8266	8954	9584	9969	10679	11348	12397	13897	14689	15559	16689
	413	1306	2412	4934	5606	6050	7219	8107	9133	9806	10353	11194	12419	13637	14480	15139	16920	19013	20320
	880	2130	3970	5533	6156	7170	8160	9610	11090	11714	12610	13279	14219	16611	18386	20193	22393	23430	24165
2.5D	143	586	1727	3360	3668	4536	5516	6565	7228	7725	8383	8815	8853	9245	9913	10349	10764	11449	12483
	523	1220	2360	4955	5780	5880	6446	7272	8413	9144	9766	10119	10974	11972	12851	13490	14469	14306	14875
	773	2026	3913	5710	6123	6918	7718	8774	10673	11538	12495	12991	13425	14972	16775	18636	19509	19831	20106
3D	123	597	1623	3329	3536	4055	4866	5449	5973	6032	6400	6376	6311	6734	7009	7251	7595	8015	8573
	580	1116	2316	4822	5192	5312	5542	6352	7342	7745	8161	8919	9790	10360	10574	10866	11290	11375	11689
	773	2001	3850	5670	6353	7002	7870	9410	10307	11230	11770	12230	12330	12920	14953	15796	16058	16284	16284
3.5D	140	561	1465	2860	3257	3632	4074	4513	4566	4605	4647	4888	5165	5354	5509	5765	5829	5861	6305
	462	998	1985	4187	4266	4421	4788	5432	6219	6655	7188	7876	8502	8470	8549	9026	9425	9577	9509
	729	1854	3810	5224	5354	5605	6140	6993	8203	8872	9398	9836	10235	10618	111452	12169	12290	12542	12752
4D	163	558	1360	2588	2824	3208	3454	3621	3628	3688	3766	4008	4188	4294	4452	4538	4614	4605	4650
	357	930	1844	3410	3479	3661	4195	4777	5204	5426	5919	6402	6854	6847	7034	7111	7366	7609	7624
	629	1597	3317	4628	5000	5180	5565	6153	6930	7419	7850	8290	8510	8759	9540	9584	9621	9909	10190
4.5D	121	513	1257	2199	2520	2682	2894	2904	2982	3063	3102	3155	3172	3356	3426	3503	3616	3622	3648
	435	771	1678	2737	2881	3130	3416	3905	4243	4530	4832	5086	5264	5422	5518	5614	5802	5761	6020
	545</																		

Table 1 (continued)

	0.5R	1R	1.5R	2R	2.5R	3R	3.5R	4R	4.5R	5R	6R	7R	8R	9R	10R	15R	20R	25R
7U	80	79	79	78	76	75	75	72	72	70	62	58	55	50	47	25	15	9
	96	103	104	109	128	126	124	116	129	115	91	72	68	61	54	35	22	14
	187	188	186	183	181	177	177	176	171	169	163	155	143	132	127	47	38	32
6.5U	85	84	84	82	81	80	78	77	74	71	68	64	60	57	51	27	15	10
	125	120	126	135	132	142	153	149	142	133	119	94	83	74	61	35	26	14
	209	208	207	202	201	200	196	192	194	188	179	167	154	144	138	51	42	34
6U	89	88	87	86	86	86	83	80	77	75	73	70	66	62	54	29	16	11
	144	151	160	169	170	175	175	170	165	153	130	123	101	86	78	42	32	16
	232	235	233	231	221	227	223	225	217	205	204	183	167	156	149	53	50	36
5.5U	92	92	91	92	91	90	87	85	83	80	79	76	73	68	58	30	16	11
	198	200	200	197	191	192	191	176	177	182	162	132	112	105	82	48	37	16
	259	263	265	262	261	251	250	243	253	248	227	205	184	171	161	60	57	38
5U	99	99	98	97	98	96	93	90	88	85	87	85	81	77	65	31	17	10
	202	202	188	205	201	186	175	184	186	194	169	156	140	118	94	52	40	17
	294	314	299	305	298	298	296	270	279	243	257	230	207	188	176	107	61	41
4.5U	110	109	108	107	106	103	100	99	97	97	101	95	89	85	72	35	18	13
	221	221	228	226	226	225	210	212	210	205	184	166	149	122	93	54	43	21
	348	354	351	343	335	332	323	313	305	299	277	262	233	209	191	110	62	43
4U	122	122	121	121	119	118	115	113	112	113	114	103	96	88	81	40	20	12
	253	259	258	260	259	254	256	235	237	223	192	168	149	124	100	60	46	23
	363	375	374	382	371	364	347	333	324	327	311	288	261	233	213	119	64	45
3.5U	141	140	140	141	140	141	137	136	133	130	127	116	106	94	88	37	23	15
	294	309	305	306	300	280	268	256	237	223	200	176	151	124	107	67	50	25
	411	405	424	418	405	387	369	357	349	346	334	317	294	262	235	126	67	46
3U	186	176	169	169	169	172	170	167	161	155	142	130	114	107	92	47	26	18
	325	333	329	320	308	296	282	270	255	234	209	180	164	129	111	76	54	30
	467	477	468	452	439	427	403	385	382	376	373	356	327	298	254	130	71	52
2.5U	198	202	206	209	215	216	217	208	198	192	173	150	138	122	101	48	29	18
	355	360	351	346	343	324	313	289	264	242	212	188	163	150	131	85	66	33
	559	568	568	551	520	483	455	444	423	412	410	378	349	305	268	144	79	64
2U	262	272	275	271	268	261	256	231	219	221	198	177	158	137	105	55	32	20
	385	384	385	375	359	345	324	299	280	277	234	215	173	151	150	92	88	47
	666	687	708	704	662	618	547	524	484	503	481	449	394	335	292	160	101	81
1.5U	311	322	316	329	336	331	314	296	271	248	209	191	170	142	120	69	38	22
	428	446	450	436	419	399	380	330	306	284	259	242	207	182	167	109	105	52
	769	795	839	803	725	642	639	568	552	568	529	453	400	346	287	174	147	173
1U	403	405	415	417	410	400	388	358	312	291	251	218	192	165	155	80	70	30
	513	551	553	534	495	461	439	402	368	361	307	275	239	220	202	148	127	100
	852	990	907	812	815	771	656	714	631	575	574	483	403	359	322	259	171	246
0.5U	630	642	658	671	673	662	640	607	556	522	482	432	398	313	297	208	172	40
	934	961	972	950	870	817	787	744	688	680	547	493	477	445	436	304	222	138
	1593	1675	1574	1415	1353	1247	1154	1110	1047	986	878	788	676	616	578	393	462	329
0	4792	5188	4949	4473	4018	3701	3332	2999	2652	2357	1783	1416	1099	862	792	416	259	63
	6075	6024	6686	7275	6403	5690	5043	4603	4255	3873	2924	2178	1875	1621	1299	806	417	215
	8519	10090	10410	10120	9372	8522	7874	8152	7650	5957	4744	4189	3510	2770	2460	1378	733	469
0.5D	18935	18759	18339	17001	15235	13593	11254	9570	8073	6733	4442	3505	2745	1895	1588	733	537	93
	20663	22797	22996	21414	19829	17250	15038	13275	11245	9458	7106	4794	4071	3294	2689	1685	806	435
	29584	30753	27727	25534	23868	23039	21128	19064	16762	13615	9592	8435	7301	5705	4585	2434	1300	811
1D	27213	26784	25774	23696	20747	17685	15581	14073	12038	10555	7148	5729	4456	3197	2880	1314	716	178
	28962	30780	30869	29050	25819	22950	20033	18183	15655	13269	9829	7219	5818	4903	4094	2034	1105	540
	32180	31755	31972	31869	30462	29012	25759	24270	20358	16747	12784	10885	9356	7997	6468	3543	1620	924
1.5D	22890	23237	21588	20101	18492	16697	14765	13495	12304	11058	8367	6488	5243	4072	3507	1625	800	221
	25650	25814	25644	24565	22858	22035	21095	19201	16503	13859	10688	8269	7154	5850	5072	2584	1273	509
	28367	28708	29118	27942	26101	24861	22809	21104	19162	18010	13786	11017	8905	7482	6524	4052	2109	1066
2D	17523	18493	17983	17310	15597	14365	13619	12637	11710	10829	8678	6534	5610	4610	3774	1694	702	239
	20912	20380	20523	20252	19963	18407	17715	16470	14521	12637	10411	8033	6745	5522	5025	2397	1364	586
	24328	24571	23953	22695	21162	19502	18778	18111	16630	15510	13360	10290	8948	7586	6540	4054	2580	1080
2.5D	13149	13451	13185	13177	13033	12144	11338	10770	10140	9488	7725	5811	4988	4424	3945	1845	707	180
	15328	16273	16083	16073	14918	13870	13276	12347	11420	10655	8561	7415	6505	5778	5039	2476	1321	624
	20416	20532	19428	18109	17928	17044	15639	15115	14474	13439	11961	9330	8093	7346	6339	4434	2506	837
3D	9368	9916	10193	9902	9558	8638	7931	7531	7372	6908	5951	4907	4358	4055	3651	1895	694	170
	12663	12971	13394	13004	12714	11545	10347	9759	9378	8616	7090	6512	5707	5008	4656	2322	1249	606
	16258	16678	15867	15970	14542	13975	13378	12786	12611	12045	10177	8566	7728	6884	5630	4286	1950	815
3.5D	6831	7014	7186	7229	7047	6748	6459	6078	5582	5310	4992	4296	3710	3553	3304	1720	698	170
	9744	10009	10091	10304	10275	9554	8807	8151	7537	7028	6017	5398	4863	4341	3969	2204	1105	516
	12841	12793	12562	12176	11532	11145	10814	10556	9933	9255	7952	7391	6783	5969	5128	3860	1619	859
4D	4736	4848	4895	4875	4693	4612	4495	4308	4130	3940	3831	3518	3223	3128	2879	1569	683	149
	7666	7852	8176	8291	8183	7904	7014	6480	5940	5566	4994	4363	3941	3820	3261	2054	993	428
	10305	10150	9980	9660	9229	8770	8594	8311	7694	7380	6613	6094	5144	4846	4492	3563	1420	686
4.5D	3751	3628	3769	3620	3595	3541	3438	3297	3210	3138	2976	2817	2702	2621	2371	1394	595	147
	5992	6139	6214	6426	6441	6113	5404	4875	4581	4437	3869	3573	3114	2887	2654	1860	897	327
	7708	7966	7801	7707	7529	7172	6880	6592	6306	6066	5757	5180	4444	4169	4059	3091	1296	672
5D	2792	2763	2823	2763	2780	2757	2615	2581	2531	2453	2363	2226	2157	2074	2010	1186	448	132
	3967	3869	4025	3826	3863	3620	3586	3435	3328	3330	3078	2816	2436	2304	2283	1649	838	303
	5627	5837	5800	5569	5518	5268	5361											

Table 2

Luminous intensities (cd) for the sample representing the LED low-beam headlamps on current light vehicles in the U.S. The entries in each cell are (from top to bottom) the 25th percentile, the 50th percentile (median), and the 75th percentile.

	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	27	29	43	64	68	70	77	80	85	82	82	84	85	95	99	98	99	101	102
	48	73	95	114	117	118	122	120	124	127	126	124	124	123	125	129	139	151	146
	88	152	221	249	252	254	260	268	275	277	281	286	292	296	298	297	294	296	297
6.5U	29	30	48	74	78	85	89	94	103	102	101	105	111	113	124	125	124	123	126
	59	78	105	117	131	130	133	137	139	138	134	134	133	135	144	147	155	164	166
	87	162	237	281	286	287	297	306	311	316	323	331	346	365	371	374	372	369	374
6U	32	31	48	94	99	104	105	115	126	127	129	129	133	135	127	133	130	135	135
	64	84	107	122	140	152	151	144	146	152	149	149	153	164	167	170	180	191	195
	107	171	251	317	323	323	328	340	345	351	358	374	397	432	448	455	466	474	478
5.5U	31	33	48	105	115	125	124	121	126	135	139	146	155	154	150	152	146	137	137
	69	90	111	128	142	170	166	164	160	163	171	176	181	187	202	205	206	216	218
	113	180	272	360	373	371	370	374	381	388	393	407	434	471	500	499	514	526	538
5U	30	33	57	119	135	140	139	139	147	149	164	174	174	165	163	166	153	152	148
	71	92	109	138	160	172	186	178	181	184	192	190	206	208	227	240	242	249	242
	119	187	308	407	422	422	424	416	421	424	429	437	455	495	538	531	541	552	569
4.5U	32	35	60	117	143	157	162	156	157	165	166	178	186	186	180	183	172	168	169
	85	97	110	151	162	173	187	191	197	212	208	204	213	225	241	262	269	270	265
	116	191	367	462	482	486	489	481	470	465	462	467	481	518	564	575	577	576	596
4U	33	40	64	119	143	158	170	180	173	175	174	188	192	197	194	198	200	200	203
	84	103	116	169	187	197	184	196	210	211	212	213	230	249	239	272	292	291	284
	127	198	459	528	558	572	586	564	536	524	520	520	524	554	589	635	629	620	629
3.5U	39	46	68	135	144	162	173	190	195	194	194	195	204	205	209	211	211	211	211
	88	110	130	181	188	207	204	211	219	217	214	218	235	264	256	292	304	308	300
	124	206	518	608	650	678	672	645	607	604	600	600	599	606	630	670	689	677	673
3U	54	47	71	131	137	156	177	185	194	194	196	204	208	216	217	212	214	214	227
	91	116	149	194	219	228	233	237	262	243	234	236	249	284	291	307	324	327	327
	153	226	545	679	722	736	705	722	698	701	684	691	707	694	685	710	745	721	719
2.5U	74	41	69	125	149	162	181	186	192	197	203	209	219	227	228	223	223	229	237
	106	121	168	202	230	243	252	268	276	276	279	275	276	299	321	336	338	337	337
	158	241	572	702	722	737	738	779	783	786	770	754	759	784	778	766	774	743	740
2U	97	46	68	128	167	163	187	200	208	211	217	226	238	237	259	251	243	250	240
	124	152	173	202	227	252	276	283	303	307	304	303	290	317	333	352	364	353	366
	164	248	546	681	705	708	729	768	801	793	792	769	786	772	772	774	775	759	747
1.5U	114	81	71	141	170	173	192	210	219	223	238	242	244	257	277	267	268	273	278
	151	175	180	207	249	273	294	299	325	324	329	338	347	359	370	391	391	401	410
	198	251	503	615	644	663	682	727	744	747	741	753	763	762	768	768	773	762	778
1U	138	177	100	156	163	191	215	225	252	258	269	275	283	299	321	324	338	344	361
	183	231	232	287	312	328	339	347	365	381	398	400	411	427	451	470	490	530	542
	334	297	469	573	597	623	653	678	708	723	732	737	755	765	769	786	801	815	839
0.5U	163	261	239	232	230	256	282	292	330	345	356	375	394	428	468	515	560	595	629
	283	348	387	442	452	480	479	504	516	512	528	546	578	607	633	673	751	891	920
	480	655	605	711	741	717	718	741	768	788	798	803	828	847	874	924	1007	1246	1258
0	267	459	461	607	648	687	741	772	797	902	961	1081	1111	1193	1360	1404	1560	1636	2170
	510	903	1163	940	930	950	910	1066	1176	1249	1399	1346	1304	1522	1642	1839	1946	2383	3822
	724	1030	1678	2167	2061	2032	2108	2089	1599	1665	1603	1724	1836	2016	2289	2705	3853	5779	6665
0.5D	519	859	1328	1904	2187	2416	2024	2278	2541	2996	3537	4354	5275	6265	7022	8037	8914	10189	11677
	712	1350	2201	4805	4545	3661	3919	5320	5777	5767	5963	6228	6964	8519	9999	10917	13364	15224	17039
	1111	1619	3124	6532	7183	7619	7830	7951	8356	9238	9667	9971	10365	11325	12717	15234	16732	21819	25549
1D	740	1440	2083	3031	3607	4181	5255	5880	6036	7103	8037	9604	11021	12385	14216	15872	17453	19789	21876
	1103	1844	3379	6875	7718	8483	9809	9664	10830	11110	11270	12031	15135	16713	18601	21509	22292	25269	27570
	1466	2728	6090	11635	13143	12501	12252	12397	15820	16090	16313	17790	19493	20673	22380	23935	27162	30476	32121
1.5D	855	1888	2531	4391	5114	5857	6607	8237	9279	9641	10317	11614	12804	13844	15282	16867	18169	19878	21562
	1363	2284	4460	7106	8243	9118	10765	10987	12144	13648	14719	15698	16761	18173	19517	20295	22342	24179	25282
	1663	2931	6600	12382	13067	14049	15644	16008	16930	18319	19300	20084	21160	22353	23647	25821	28076	29822	32292
2D	980	2050	3151	5161	5718	6270	7490	8809	9731	10285	11184	12130	12890	13700	15048	15491	16645	17736	17911
	1508	2491	4467	6952	8182	9723	11631	13599	14213	14879	15949	16730	17309	18277	19673	20771	20160	19610	20100
	1732	3317	6710	12761	13541	14071	14551	15021	16065	16640	17990	19254	20219	22437	23924	23173	23379	24838	26125
2.5D	1050	2255	3474	5367	5937	6729	7804	8803	9838	10155	10606	11211	11986	12450	12922	13400	14150	14577	14710
	1488	2568	4423	6905	8016	9961	11761	12600	13370	13509	13934	14250	14608	15530	16048	16580	17313	16820	16926
	1769	3137	6149	12193	13179	13839	15468	16310	16305	16607	16989	17306	17686	18702	20416	21166	22452	23637	24778
3D	1070	2210	3826	5818	6333	6970	7623	8392	8644	9234	9682	10003	10484	10770	11032	11003	11492	11784	11805
	1459	2589	4511	6637	7977	10069	10680	11040	11447	11670	12138	12509	12879	12981	13637	13893	14159	14150	14140
	1761	3237	5986	11370	12370	13135	14310	14700	14960	15145	15320	15480	15510	15547	16494	17349	18521	19432	20286
3.5D	1060	2170	3968	5918	6478	6430	6702	7575	7915	8038	8177	8319	8458	8853	9200	9314	9513	9583	9539
	1377	2717	4508	6680	7675	8749	9155	9281	9224	9277	9734	10298	10279	10300	10459	10685	10976	11201	11579
	1894	3587	5897	10002	10989	11478	11879	11928	12217	12571	12940	13313	13217	13264	13317	13730	14052	14710	15033
4D	1041	2021	4060	5294	5792	5577	5660	6609	6777	6851	6915	6841	6982	7408	7602	7688	7843	7932	7969
	1367	2834	4380	6211	7045	7242	7597	7751	7660	7818	8115	8444	8549	8640	8700	8701	8871	9466	9871
	1910	3361	5222	8830	9251	9370	9636	9965	9976	10056	10340	10575	10378	10417	10330	10500	10780	10798	11066
4.5D	950	1956	3734	4968	505														

Table 2 (continued)

	0.5R	1R	1.5R	2R	2.5R	3R	3.5R	4R	4.5R	5R	6R	7R	8R	9R	10R	15R	20R	25R
7U	121	120	123	117	99	101	105	105	102	99	92	85	81	84	78	45	27	18
	144	144	143	151	157	147	139	133	125	121	114	121	114	106	110	77	56	36
	310	318	319	323	323	325	321	323	324	318	289	280	281	280	285	251	142	62
6.5U	141	132	130	128	122	118	117	115	109	106	100	98	100	102	87	45	28	27
	159	157	164	170	176	170	157	155	144	147	142	141	136	125	129	82	60	37
	380	387	410	422	424	416	410	405	405	393	373	355	369	376	367	286	151	65
6U	145	139	135	133	132	134	133	132	128	125	120	120	130	122	100	50	33	28
	186	186	196	204	202	187	177	167	164	164	167	161	158	143	153	90	64	40
	489	491	497	518	554	561	563	545	540	514	496	475	522	526	504	308	150	70
5.5U	145	148	141	140	139	137	136	135	134	134	138	131	122	124	116	59	33	27
	214	212	222	229	212	202	196	182	174	178	180	175	169	167	162	94	68	45
	566	610	628	656	701	722	721	699	688	673	661	635	633	682	710	326	149	72
5U	153	164	156	154	151	149	147	146	146	148	151	161	163	164	131	63	34	33
	227	233	242	262	242	228	224	207	195	187	191	191	180	188	178	95	71	53
	602	658	729	765	813	825	807	799	764	750	764	730	742	852	794	340	158	75
4.5U	169	181	172	171	168	165	164	165	161	162	162	175	183	166	139	60	36	35
	253	256	271	274	255	240	233	214	204	202	203	206	192	192	183	103	76	60
	620	669	764	824	829	855	842	821	787	776	829	852	824	871	793	354	176	96
4U	202	200	208	206	194	187	174	173	178	172	169	172	179	164	139	66	38	43
	274	278	276	285	271	262	245	240	234	214	226	219	202	199	190	118	81	68
	655	700	778	831	856	886	888	860	822	809	843	894	975	921	755	366	200	111
3.5U	230	237	228	232	224	204	187	185	185	182	173	167	174	163	148	66	40	57
	292	293	304	304	288	271	264	261	253	243	241	225	209	208	190	123	94	75
	689	728	801	857	890	937	945	911	880	840	846	895	955	880	710	378	230	119
3U	242	250	252	244	233	197	195	189	188	186	176	172	171	173	147	65	39	69
	327	327	327	322	319	316	295	276	260	250	250	240	220	208	178	144	124	87
	723	748	818	875	912	944	967	957	924	902	878	886	926	847	686	407	241	131
2.5U	251	250	240	249	233	217	213	212	205	199	206	205	198	179	166	71	50	72
	337	337	339	346	342	328	319	286	273	270	259	248	233	220	196	162	119	106
	745	767	818	866	915	936	949	955	989	1026	1049	979	881	803	665	437	257	163
2U	268	261	267	250	246	242	234	232	224	226	218	230	218	196	162	67	82	79
	373	374	377	353	341	329	327	320	319	327	296	281	262	247	212	197	167	148
	770	793	824	873	909	904	941	1015	1068	1093	1131	1102	952	820	769	515	270	201
1.5U	284	284	290	283	279	269	257	253	248	248	248	246	216	207	163	101	132	108
	421	424	421	420	403	386	382	373	363	356	319	294	292	263	223	237	223	174
	806	839	865	900	910	949	989	1072	1106	1150	1182	1157	1033	903	828	667	349	219
1U	366	370	382	389	398	395	386	376	357	334	319	288	281	235	243	226	203	157
	549	553	538	524	483	462	441	424	395	374	405	364	353	319	306	377	311	190
	850	875	891	932	973	1027	1087	1132	1179	1210	1256	1236	1156	1009	984	773	422	324
0.5U	663	673	664	642	631	640	641	629	612	589	569	473	391	351	349	418	293	316
	935	1013	1063	1102	1093	1071	1028	1037	1000	965	966	913	902	881	927	740	452	419
	1327	1418	1571	1772	1829	1809	1779	1706	1571	1528	1483	1421	1432	1463	1588	1178	626	556
0	2377	2651	2809	2776	2674	2761	2830	2623	2222	2146	1602	1227	922	799	685	809	600	524
	4656	5601	6278	5677	5597	4087	3558	3279	3008	2701	2771	2734	2813	2627	2137	1567	934	753
	10783	11012	12101	14950	14640	14270	13584	12750	11729	10860	6272	4978	4381	4081	3572	2346	1349	831
0.5D	13087	13436	13310	13537	13042	11909	10269	8677	8077	7902	6155	3690	2692	2334	2057	1570	1038	767
	18549	20688	21670	21474	19057	17346	15941	14274	12746	10743	8704	7738	7341	6912	6226	2928	1361	882
	27929	27934	27878	28198	26853	25377	23608	21922	19358	16196	13881	13098	12224	10700	9061	4395	2003	1152
1D	23243	23100	23854	23164	20605	17720	16826	13970	12766	11980	8583	5410	4451	3997	3378	2169	1630	890
	28100	28711	27861	27171	26008	24486	22431	20471	18980	16471	11700	11240	11144	9774	8383	4632	2001	1171
	33354	32170	31200	31862	32709	30627	28455	25212	21644	19350	18090	17060	16230	14898	13101	5725	2348	1388
1.5D	22012	22311	22431	21767	20635	19203	16854	14724	12998	12070	9094	6663	5233	4800	4340	2769	1784	1015
	25427	26133	26158	25112	23894	22580	21466	20603	19561	18190	13506	11678	10606	9485	8440	4670	2338	1417
	33841	35293	36690	36563	35191	32691	30413	27276	24754	22837	19089	17330	16390	15741	14710	7486	3153	1574
2D	18101	18256	17397	18125	17574	16413	15061	13720	12568	11605	9628	7770	6140	5528	4986	3366	2012	1130
	20486	21159	21796	21918	21525	20385	19382	19220	18363	17450	14146	11391	10270	9816	9327	4678	2768	1552
	27793	30190	31437	31396	31806	30175	28674	24764	21528	20372	18082	16807	16043	15134	14030	7717	4078	1842
2.5D	14696	14655	14325	13926	13658	13418	12664	12269	11595	10968	9446	8783	6955	6047	5481	3774	2200	1180
	16969	16720	16790	17023	17520	17343	16803	16318	15935	15342	13368	10628	9246	9032	8711	5022	2508	1587
	26764	27398	27839	26669	25623	24458	23404	21610	19290	17125	15640	15034	14287	13620	12893	7388	3963	1941
3D	11710	11602	11506	11314	11171	10930	10816	10481	10217	9748	9085	8065	7057	6349	5672	4054	2290	1179
	13939	14357	14767	14720	14505	14320	13981	13740	13520	13030	11241	8980	8476	8378	8080	5061	2578	1638
	20651	20474	20386	20073	19666	19175	18807	17499	15726	14210	12810	12520	12430	12190	11740	6841	3833	1783
3.5D	9537	9468	9338	9172	9144	9078	8908	8690	8565	8432	7938	7387	6889	6524	5959	4173	2328	1160
	11925	12389	12481	12426	12330	12153	11918	11541	11473	11060	8760	8032	7643	7250	6932	4660	2445	1533
	14876	14920	15091	15197	15400	15290	14686	13519	12360	11969	11098	10870	10991	10938	10597	5836	3544	1779
4D	7980	7904	7870	7810	7740	7677	7708	7650	7498	7217	6779	6653	6168	5723	5361	4165	2270	1130
	10248	10460	10430	10210	9792	9488	9317	9330	9216	8256	7290	7039	6949	6891	6489	4405	2340	1397
	11003	11041	11261	11390	11594	11076	10494	9915	9730	9590	9563	9190	9380	9540	9333	5562	3274	1764
4.5D	6669	6732	6699	6601	6626	6579	6496	6470	6417	6174	5824	5541	5306	5188	5043	3922	2100	1082
	7918	7993	8003	7649	7449	7454	7531	7412	7069	6612	6414	6335	6218	6164	5845	4240	2278	1368
	8468	8477	8497	8418	8468	8389	8289	8188	8118	8039	7855	7872	7976	8046	7737	5026	3038	1724
5D	5319	5335	5435	5471	5513	5478	5448	5420	5313	5116	4958	4852	4802</					

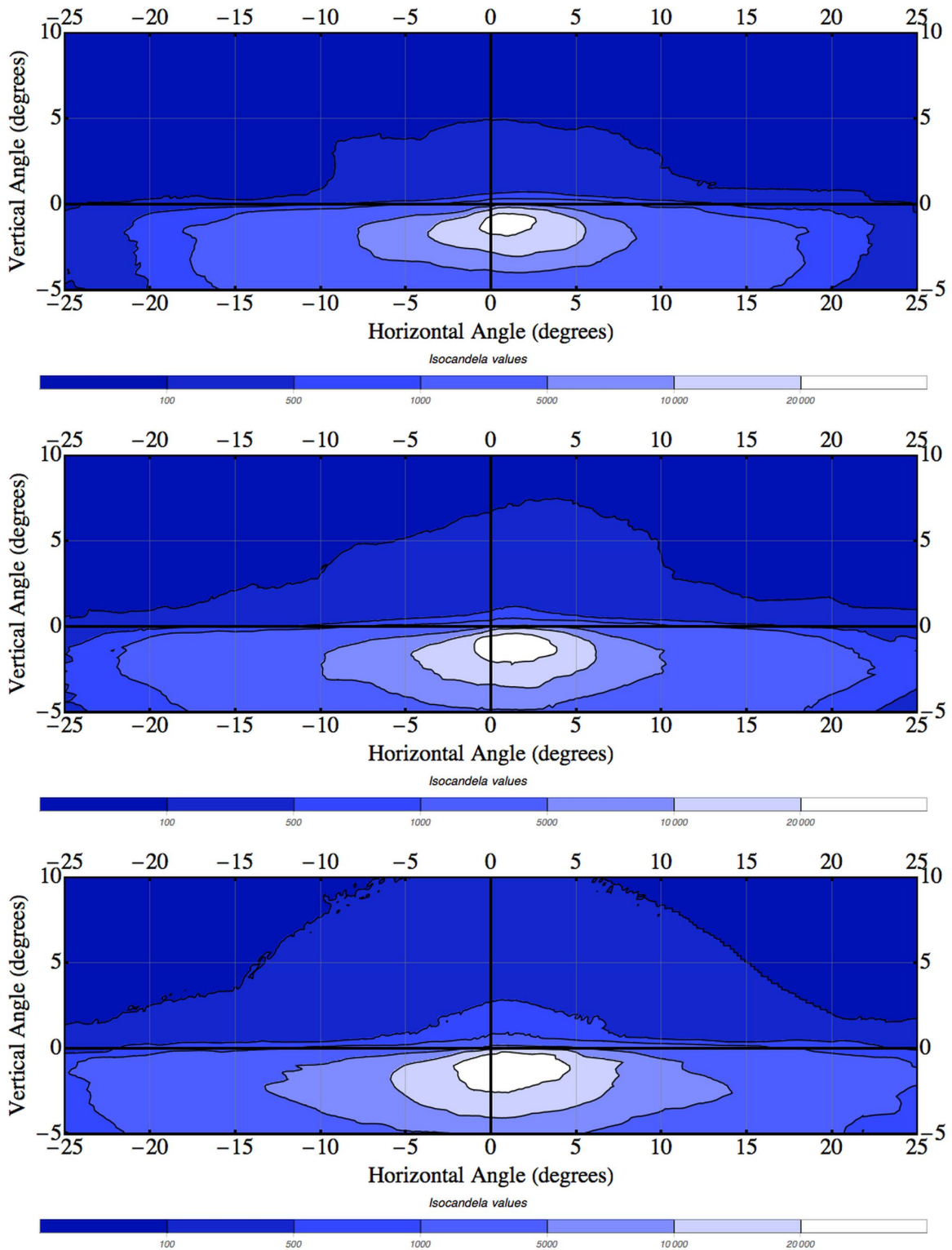


Figure 1. From top to bottom, isocandela diagrams for the 25<sup>th</sup>, 50<sup>th</sup> (median) and 75<sup>th</sup> percentiles of luminous intensity for the sales-weighted sample representing the TH low-beam headlamps on current light vehicles in the U.S.

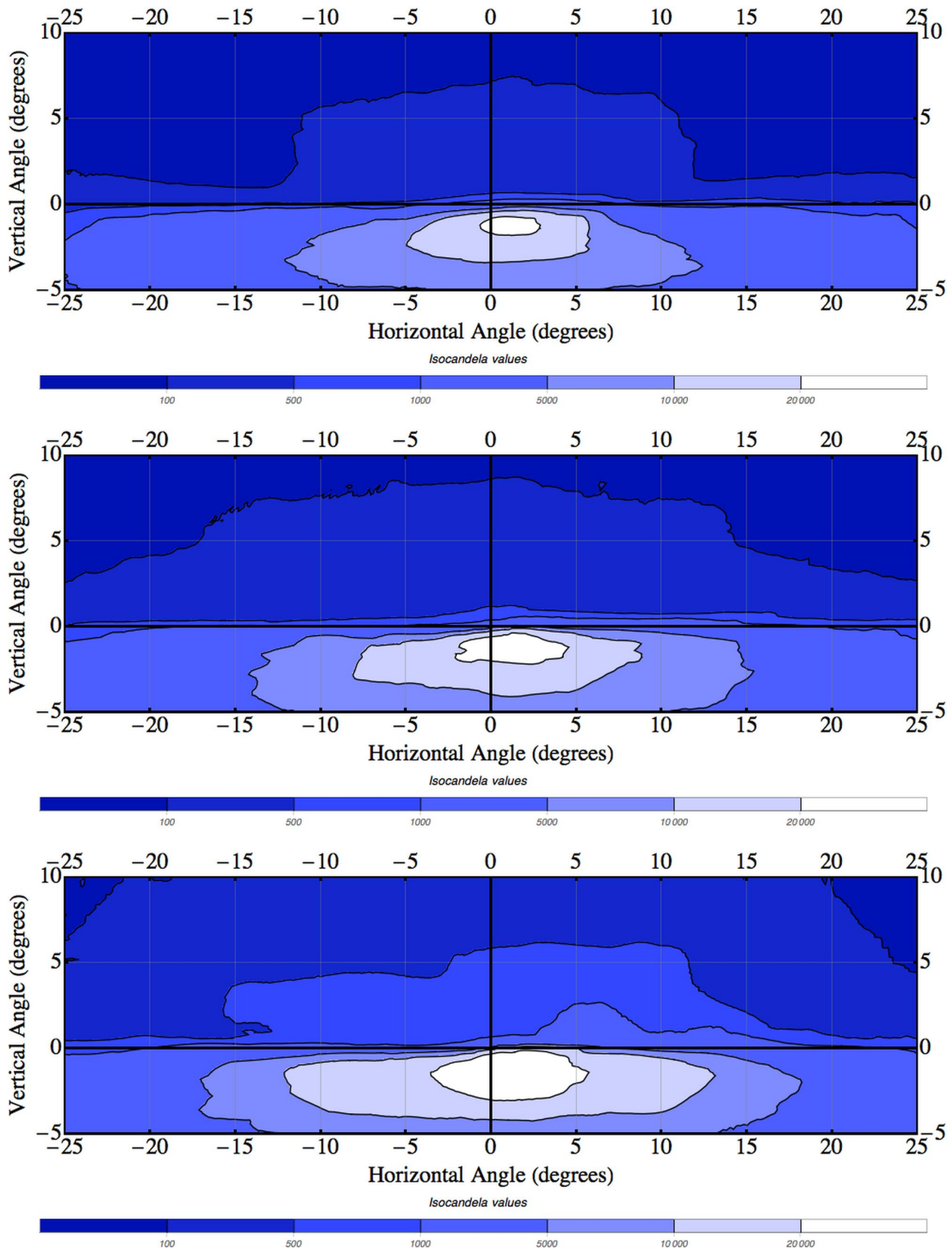


Figure 2. From top to bottom, isocandela diagrams for the 25<sup>th</sup>, 50<sup>th</sup> (median) and 75<sup>th</sup> percentiles of luminous intensity for the sales-weighted sample representing the LED low-beam headlamps on current light vehicles in the U.S.



## Summary and Discussion

The present analysis is not based on a complete census of current U.S. headlamps, but on a convenience sample of 110 headlamps (55 left-right pairs), collectively used on 45 light vehicles, and provided to us by three vehicle manufacturers. We do not have reason to believe that there are systematic differences between the lamps that were provided and those that were not. We believe that the data presented in this report provide valid estimates of the luminous intensities that can be expected at various angles with respect to the headlamp axes of TH and LED headlamps currently used in the U.S. Thus, the data could be used to calculate the expected illuminance reaching targets with known geometric relationships to the headlamps, such as traffic signs, road delineation, the eyes of oncoming drivers, and rearview mirrors on preceding vehicles.

As we pointed out in our previous market-weighted headlamp photometry studies (Sivak et al., 1997; Sivak et al., 2000; Schoettle et al., 2001; Schoettle et al., 2003; and Schoettle et al., 2004; Schoettle & Flannagan, 2011), data such as these should not be used to calculate gradients of luminous intensities for adjacent points in space (e.g., for estimating the sharpness of the cutoff that is important for visual aiming of the beam pattern). This is because the transitions from the more intense to the less intense parts of the beam pattern are not precisely in the same locations for all lamps. Consequently, although the present analysis provides valid estimates of luminous intensities for individual points, a computation of gradients between points based on the present analysis would tend to underestimate the actual gradients. This caveat applies not only to the present data, but also to any aggregate data for non-identical beam patterns.

## References

- Schoettle, B., & Flannagan, M. J. (2011). *A market-weighted description of low-beam and high-beam headlighting patterns in the U.S.: 2011* (Report No. UMTRI-2011-33). Ann Arbor: The University of Michigan Transportation Research Institute.
- Schoettle, B., Sivak, M., & Flannagan, M. J. (2001). *High-beam and low-beam headlighting patterns in the U.S. and Europe at the turn of the millennium* (Technical Report No. UMTRI-2001-19). Ann Arbor: The University of Michigan Transportation Research Institute.
- Schoettle, B., Sivak, M., Flannagan, M. J., & Kosmatka, W. J. (2003). *A market-weighted description of low-beam headlighting patterns in Europe: 2003* (Technical Report No. UMTRI-2003-37). Ann Arbor: The University of Michigan Transportation Research Institute.
- Schoettle, B., Sivak, M., Flannagan, M. J., & Kosmatka, W. J. (2004). *A market-weighted description of low-beam headlighting patterns in the U.S.: 2004* (Technical Report No. UMTRI-2004-23). Ann Arbor: The University of Michigan Transportation Research Institute.
- Schoettle, B., Sivak, M., & Nakata, Y. (2002). *The locations of signaling and lighting equipment on passenger vehicles sold in the U.S.* (Technical Report No. UMTRI-2002-8). Ann Arbor: The University of Michigan Transportation Research Institute.
- Sivak, M., Flannagan, M. J., Kojima, S., & Traube, E. C. (1997). *A market-weighted description of low-beam headlighting patterns in the U.S.* (Technical Report No. UMTRI-97-37). Ann Arbor: The University of Michigan Transportation Research Institute.
- Sivak, M., Flannagan, M. J., & Schoettle, B. (2000). *A market-weighted description of low-beam headlighting patterns in Europe* (Technical Report No. UMTRI-2000-36). Ann Arbor: The University of Michigan Transportation Research Institute.