

Evaluation of Photometric Data Files for Use in Headlamp Light Distribution

William T.C. Neale, David Hessel, James Marr
Kineticorp, LLC

ABSTRACT

Computer simulation of nighttime lighting in urban environments can be complex due to the myriad of light sources present (e.g., street lamps, building lights, signage, and vehicle headlamps). In these areas, vehicle headlamps can make a significant contribution to the lighting environment^{1,2}. This contribution may need to be incorporated into a lighting simulation to accurately calculate overall light levels and to represent how the light affects the experience and quality of the environment. Within a lighting simulation, photometric files, such as the photometric standard light data file format, are often used to simulate light sources such as street lamps and exterior building lights in nighttime environments. This paper examines the validity of using these same photometric file types for the simulation of vehicle headlamps by comparing the light distribution from actual vehicle headlamps to photometric files of these same headlamps. Light values are calculated in a simulated environment and numerically compared to light measurements taken in situ of actual headlamps. A discussion of how light distribution of a photometric file differs from light distributed by an actual headlamp assembly is included to articulate the primary differences.

INTRODUCTION

Lighting simulation for nighttime environments has increased commensurate with advances in rendering technology and the widespread inclusion of rendering engines and light models in publicly available computer modeling and animation programs. Specifically, nighttime lighting simulation benefits from two main advancements: global illumination³ and photometric light files. Global Illumination addresses the problem of how light behaves after it exits a light source and interacts with surfaces^{4,5}. By accounting for the affect of light interacting with surfaces that vary in texture, color, translucency and reflectivity, the overall impact of light in an environment becomes much more realistic than previous lighting models that did not account for propagation and bouncing of light off of surfaces. In addition to global illumination, the standardization of photometric light data also advanced light simulation since this step introduced digital data files that are specific to a particular light source, defining the lights intensity and distribution pattern. When combined, global illumination and photometric light files enable light simulation and rendering programs to generate photorealistic images that visually represent the light conditions in an environment with physically accurate light values. These results can be evaluated visually and numerically to determine the appropriateness of design decisions and compliance with light standards. Because the light simulation and rendering applications seek to evaluate accurate lighting conditions, it is relevant to include other light sources, such as vehicle headlamps, that impact both the quality and experience of the lighting environment as well as light sources that contribute to overall light levels¹. This is especially true in urban environments where there are higher densities of vehicles on the streets in closer proximity to pedestrians and buildings. Currently, light simulation programs utilize standardized photometric files for interior lighting, and exterior lighting where street lights and area lights provide much of the lighting for parking lots, security lighting, roadways, highways, illuminated signs and recreation areas. Because light simulation programs rely on photometric data files to accurately simulate these light sources, employing photometric data files to simulate vehicle headlamps is a logical step, and is the focus of this paper. To evaluate the validity of photometric files to simulate headlamp light distribution in a simulation environment, real headlamps are analyzed against the photometric files created for each headlamp. This is done numerically by

comparing luminance values of headlamps measured in situ to the photometrically generated light values in the light simulation program.

TESTING SETUP

This paper evaluates the validity of photometric files in simulating headlamp light distribution. To accomplish this, several different headlamp types were considered. The headlamps were sent to a light laboratory to have photometric files created. A test was set up to compare real-world luminance values from the headlamps to the light values obtained in the simulation program. To test the headlamps in a real world environment, a site with a typical paved roadway surface was chosen that contained no ambient lighting. In order to accommodate several basic headlamp design types, three different vehicles were used, each representing a different class of vehicle. Below is a photograph and matrix of the make and model of the vehicles used in this study and the lamp designs of each vehicle.

Vehicle Make	Model	Year	Class	Lamp Type
Toyota	Landcruiser	1994	SUV	Lens Optics
Cooper	Mini	2005	Passenger	Projector Optics
Nissan	Pickup Truck	2006	Pick-up	Reflector Optics



Figure 1

In addition to representing three different classes of vehicles, each vehicle has a different optic system. The lens optics, projector, and reflector optics headlamp designs (shown from left to right) account for the majority of vehicle headlamps used on the roads. This combination of class and optic system provides a broad range of headlamp samples suitable for this study. To measure the actual distribution from each of these vehicle headlamp types, a total of 10 calibrated grayscale cards were used, spaced at intervals from the front of each vehicle and were staggered side to side such that no calibration card cast a shadow on another. The light reflecting off of each of these cards was measured in cd/m^2 using a Minolta LS-110 luminance meter. The purpose of staggering and spacing the cards was to get the light value over a distance since the shape of the beam pattern and intensity of light for the headlamps changes as the beam spreads further from the headlamp

assembly. In order to evaluate the degree to which the photometric file is capable of representing the beam pattern and light attenuation, the light values needed to be measured at different distances. Each vehicle was parked at the same station line relative to the calibration cards and the light intensity of the headlamp distribution projected on to each card was measured using the luminance meter. A diagram of the layout for the site testing, vehicle placement and calibration card placement is shown below. The entire testing site was surveyed, including the location and orientation of each of the calibrated reflectivity cards, the station line, and the light location, so a computer generated model of the site could be built in which to test the photometric files.

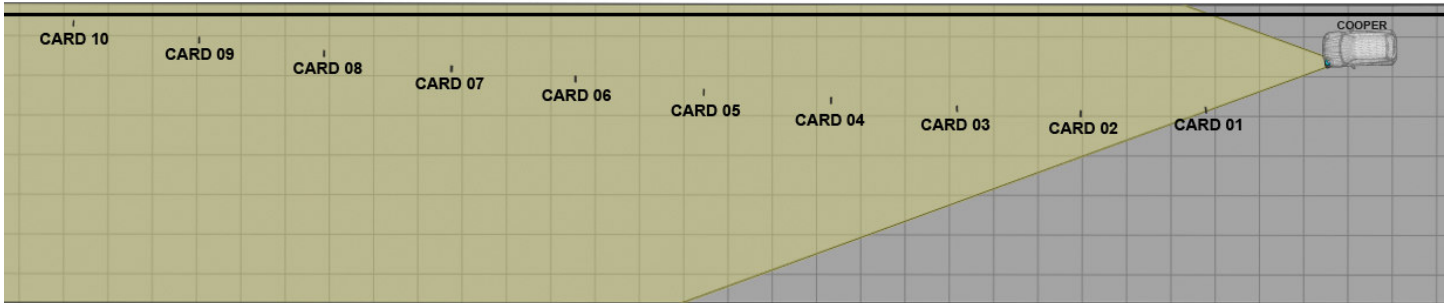


Figure 2

The reflectivity of each of the calibrated cards was also measured, so that when the photometric files were used in a computer simulation, the cards reflecting light in the simulated environment would mirror those surfaces in the real world test. The calibration cards in the real world test were measured to be 18% reflective. Below is a matrix showing the results of each vehicles headlamp light distribution measured in situ.

Landcruiser		Nissan		Mini Cooper	
card #	Luminance	card #	Luminance	card #	Luminance
1	1.06	1	0.39	1	4.3
2	1.67	2	0.51	2	3.87
3	2.2	3	0.43	3	3.87
4	1.23	4	0.15	4	1.83
5	1.45	5	0.17	5	2.03
6	0.66	6	0.12	6	1.99
7	0.41	7	0.14	7	1.17
8	0.44	8	0.24	8	2.23
9	0.29	9	0.13	9	1.37
10	0.31	10	0.18	10	1.84

Figure 3

NUMERICAL COMPARISON OF ACTUAL HEADLAMP DISTRIBUTION TO PHOTOMETRIC DATA

Photometric files for each of the three headlamps were obtained from Light Laboratory Inc, in Anaheim, California. These photometric files were simulated in Autodesk’s 3DS Max Design 2009 Exposure Technology light simulation tool. This light simulation package is widely used in light simulation environments and the accuracy of the light simulation model has been widely published and validated.⁶ To replicate the real world testing site, computer models of the calibration cards were also created, and set to reflect 18% of the light to match the reflectance of the calibrated cards used in the real world study. Since the photometric files use real world units, the calibration cards created in the simulated environment were scaled to real world units and spaced according to their locations surveyed in the real world study. Below is a rendering of the 3D environment and 3D cards used to measure the simulated light distribution.

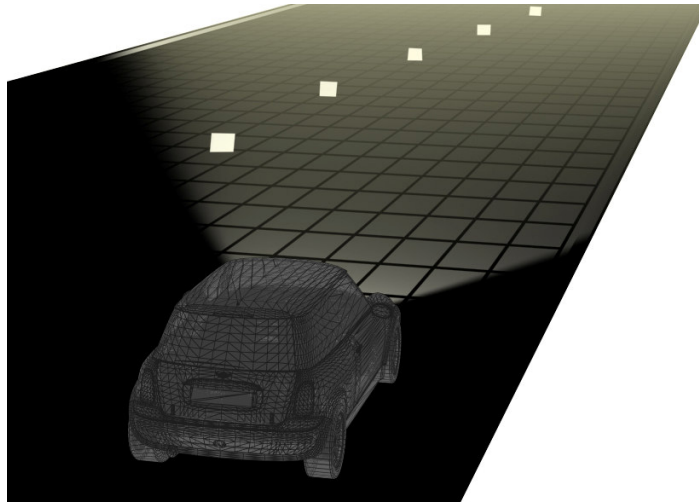
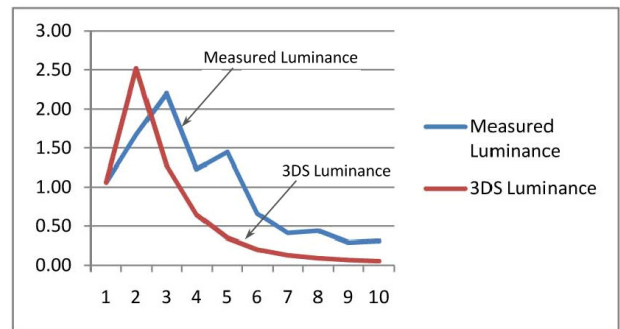


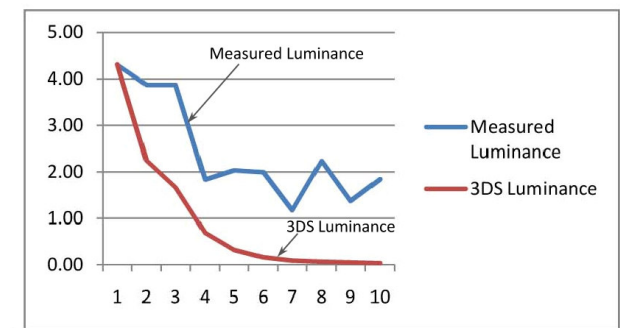
Figure 4

The position of the headlamp assembly and calibration cards in the real world test were replicated in the computer environment, and the photometric data files for the headlamps were placed in the correct location in the light environment for simulating. The photometric light files were aimed according to the survey of the actual headlamp assembly in the real world study, and projected onto the calibration cards. The light values as calculated in the simulation were recorded at the same locations on each calibration card and compared to the values obtained in situ. Graphs were made for each headlamp assembly comparing the light measurements taken in situ and those calculated in the simulated environment. Below are the graphs that result from this comparison.

Landcruiser card #	Low Beam Measured Luminance	3DS Luminance
1	1.06	1.06
2	1.67	2.52
3	2.20	1.28
4	1.23	0.64
5	1.45	0.35
6	0.66	0.20
7	0.41	0.13
8	0.44	0.09
9	0.29	0.07
10	0.31	0.05



Mini Cooper card #	Low Beam Measured Luminance	3DS Luminance
1	4.30	4.30
2	3.87	2.24
3	3.87	1.66
4	1.83	0.69
5	2.03	0.32
6	1.99	0.16
7	1.17	0.09
8	2.23	0.07
9	1.37	0.05
10	1.84	0.03



Nissan card #	Low Beam Measured Luminance	3DS Luminance
1	0.39	0.38
2	0.51	0.39
3	0.43	0.04
4	0.15	0.01
5	0.17	0.04
6	0.12	0.00
7	0.14	0.02
8	0.24	0.01
9	0.13	0.00
10	0.18	0.00

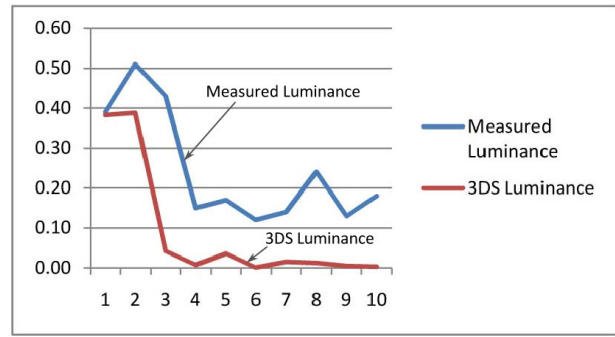


Figure 5

For each vehicle, a graph shows the luminance values for the measured luminance in blue, and the photometric simulated luminance values in red. To make an even comparison, the photometric files were scaled such that the light value at the first calibrated card matched the light value of the actual measured headlamp. Comparisons for the light values at each of the cards, both in the field and in the computer environment, are then plotted as shown in the graphs.

One difference between the field measured light values and the photometric light values as shown in Figure 5, is that the actual field measurement surface would have some reflectance associated with its material properties. The reflectance of the surface on which the field measurements were taken was measured at 6%. The computer model surface was adjusted to reflect 6% of the light from the photometric files and an analysis was performed to determine how much additional light would contribute to the overall photometric light values. The graph in Figure 6 shows the additional, though negligible, contribution from light reflecting off the surface. This contribution averages about 3% additional luminance. Appendix A lists all the values, with and without the 6% reflective surface, for each card number and for each vehicle.

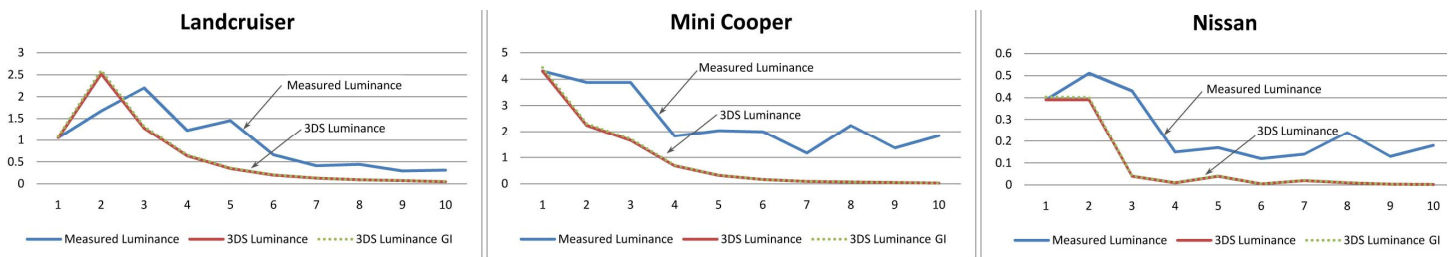


Figure 6

In general, the luminance values calculated by the photometric files have a much sharper luminance value decrease than the measured values done in the field. This sharper falloff of the photometric files is true for all three headlamp types, and their falloff is similar as well. This suggests a function in the way photometric light files are simulated, whereby the light intensity of the light in the simulated environment exemplifies an inverse square falloff as in the equation:

$$I = \frac{1}{x^2}$$

While an inverse square falloff would be true for a single point source light, because of the headlamp’s optic system, light is collected and distributed in a manner that no longer resembles a point source, but rather multiple light sources. As a result, the falloff relationship is much less than inverse square. Because the photometric files are generated directly from the headlamps themselves, the optics of the headlamps were analyzed to determine the source of this difference. The following section explains the nature of photometric files and why this pattern is created.

PHOTOMETRIC DATA FILES:

To see why there is such a difference in the light values calculated by the photometric files and those measured by actual headlamps in the field, it is relevant to examine how photometric files are created and assigned as lights in a simulation program. Standardized in the mid 1980s by IESNA, photometric data files allow for a broad use of published data, interchangeable between manufactures, designers, computer artists, and engineers⁷. Photometric light files represent the light intensity value for measured light sources and use real world units and values to enable their application in light simulation software. Photometric data files contain information in candela values that describe how light from a light source or light assembly is distributed and, because photometric data are recorded in real world units, they can be used to predict light values in a computer generated environment. Photometric data is used in light simulation programs to provide physically accurate representation of the propagation of light energy in an environment from lamps, luminaries, and other light assemblies or light sources. The light intensity distribution (or LID) of a light source or lamp assembly is measured using photometry equipment such as spectrometers or goniometers that are designed to measure light intensity at specific angles on photocells. The data collected on the cells represents the light intensity at a given angle and is presented in a digital format of values in standardized ASCII format defined by standards created by IESNA. Figure 7 ,below, is an example of the ASCII data set of a photometric file from a headlamp of a 1994 Toyota Land Cruiser.

```

IESNA:LM-43-2002
[TEST] LLI 1007-19A
[TESTLAB] LIGHT LABORATORY INC
[TESTDATE] 11/02/2007
[MANUFAC] TOYOTA
[LUMINAI] TOYOTA K210 100-73398
[LUMINAIR] 1994 TOYOTA LAND CRUISER COMPOSITE HEADLIGHT ASSEMBLY RH
[INDEX] RODZILLICATE GLASS, LOW BEAM LIGHT ONLY
[LAMPPOSITION] 0.0
[LAMPICOTT] SYLVANIA 9006 12W 55W
[OTHER] INDICATING THE CANDELA VALUES ARE ABSOLUTE AND
[INDEX] SHOULD NOT BE FACTORED FOR DIFFERENT LAMP RATINGS.
_INPRT 12VDC, 46.513W
TELEPHONE
1 1 1 23 41 1 1 .65 .5 .13
0 1 3 5 7 9 11 13 15 17 19.5 22.5 25.5 29 33 37.5 42.5 47.5 55 65 75 85 90
0 5 15 25 35 45 55 65 75 85 95 105 115 125 135 145 155 165 175 180 185 195 205 215 225 235 245 255
065 270 275 285 295 305 315 325 335 345 355 360
72 57 48 40 35 27 24 23 21 17 16 15 14 15 16 14 9 4 2 1 1 1 1 0
72 57 49 40 35 27 24 23 21 17 16 15 14 15 16 14 9 4 2 1 1 1 1 0
72 57 51 42 36 29 23 20 20 16 15 15 13 12 13 15 16 12 10 4 2 1 1 1 0
72 58 53 45 45 38 31 24 21 20 17 14 13 12 12 14 14 11 4 2 1 1 1 0
72 60 55 47 41 35 27 23 20 18 15 13 12 11 10 12 12 9 3 1 1 1 0
72 62 57 49 43 37 33 29 22 19 17 14 12 12 10 9 7 5 3 1 1 1 0
72 64 56 50 45 40 36 33 30 23 19 17 16 14 12 11 9 8 7 5 3 1 1 0
72 67 60 54 49 45 41 37 33 29 22 19 17 16 14 12 11 9 8 7 5 3 1 1 0
72 70 65 59 54 49 46 43 40 36 30 23 19 16 14 11 9 8 6 4 2 2 2 0
72 73 70 65 62 59 58 57 56 47 33 22 17 14 11 9 8 7 5 3 1 1 0
72 75 75 77 72 71 69 67 66 68 58 57 56 47 33 24 19 16 12 10 9 7 11 2 2 2 0
72 77 80 83 80 81 79 78 77 79 81 68 45 33 24 19 16 12 10 9 7 11 2 2 2 0
72 81 88 95 103 106 107 112 112 112 118 121 98 66 58 90 42 24 17 10 7 2 2 2 0
72 85 100 117 136 150 158 173 199 221 274 1008 1517 248 64 31 21 12 6 4 1 1 1 0
72 90 109 144 184 209 251 320 541 1616 2955 2261 714 130 58 31 21 12 6 4 1 1 1 0
72 96 118 176 244 347 483 751 1299 221 274 1008 1517 248 64 31 21 12 6 4 1 1 1 0
72 94 120 209 312 601 924 8871 4503 1459 331 143 89 84 58 26 20 11 8 5 4 1 1 0
72 95 142 223 363 1145 15837 9072 2824 880 324 144 79 56 34 26 23 14 10 6 6 2 2 2 0
72 96 151 235 402 2277 10629 5862 1874 725 430 232 159 97 58 34 20 15 8 8 3 3 1 0
72 98 155 236 401 2043 8532 3370 893 346 193 123 78 58 50 31 12 15 17 8 8 3 3 1 0
72 98 155 235 382 1684 5192 2721 743 252 148 86 87 40 11 22 12 12 16 7 7 7 7 0
72 98 155 227 357 1782 4072 2601 735 223 120 69 49 35 27 20 11 11 11 6 6 3 3 1 0
72 97 146 211 359 649 2618 1048 969 326 105 58 40 28 23 16 13 9 9 4 4 2 2 0
72 95 124 194 246 348 1499 1063 1873 548 104 69 37 28 20 17 10 9 8 4 4 2 2 0
72 93 121 175 319 449 1776 2161 1141 300 70 30 27 22 17 9 8 5 3 3 3 1 0
72 89 108 150 174 156 152 319 1020 1122 300 70 30 27 22 17 9 8 5 3 3 3 1 0
72 94 97 122 243 109 72 67 57 77 34 27 15 10 9 7 6 4 2 2 2 2 0
72 79 88 103 110 103 74 55 46 38 33 27 28 27 15 10 9 8 5 4 2 2 0
72 75 82 89 88 76 51 43 35 32 26 23 23 23 19 12 10 9 8 5 4 2 2 0
72 71 74 75 68 55 40 35 30 27 26 23 17 10 9 8 7 6 5 4 2 2 0
72 69 70 68 60 50 37 32 31 26 23 18 12 10 9 8 7 6 5 4 2 2 0
72 67 66 62 52 44 36 32 29 26 27 20 12 10 9 8 7 6 5 4 2 2 0
72 61 59 45 39 34 28 28 24 24 20 14 11 9 8 8 7 6 5 4 2 2 0
72 59 50 42 37 31 28 24 20 18 16 14 11 9 8 8 7 6 5 4 2 2 0
72 58 48 41 35 26 24 23 21 19 16 14 12 10 8 7 6 5 4 2 2 0
72 57 47 41 35 26 24 23 21 20 17 14 13 10 8 7 6 5 4 2 2 0
72 56 47 41 33 24 23 21 19 16 14 13 10 9 8 7 6 5 4 2 2 0
72 56 47 39 33 26 23 21 20 18 12 16 14 13 13 13 6 4 4 2 1 1 0
72 56 48 40 37 24 24 23 21 17 16 17 14 15 15 15 4 2 1 1 1 0
72 57 48 40 35 27 24 23 21 17 16 17 14 15 15 14 9 4 2 1 1 1 0

```

Figure 7

The first string of data describes the light type and specifications for how measurements were taken. Below this list is a matrix of numbers on two axes that represent the intensity values of the light at different angles. One axis is horizontal, the other is vertical, and the combined data set creates a matrix of light intensity distribution that characterizes light measured in essentially all directions. Each number represents an actual measured candela value for that horizontal and vertical angle. The larger the number, the higher the light intensity file. Thus the photometric file, when viewed as a set of numbers, actually manifests the shape of the beam visually. The regions of the file with higher candela value also have larger numbers, and areas with lower candela value have smaller numbers, giving a visual impression of the shape of the light intensity through the matrix of numbers. As in the image above, then, the hot spot of the light is near the center of the file where the numbers are largest and, therefore, brightest, and stretches horizontally, slowly dissipating light energy towards the corners. Photometric files also come in other formats such as LTLI or CIBSE, each file named so because of the region the standard was created. In North America the IES digital data file format is the standard file format for light intensity measurements, and can be used to simulate light distribution and intensity in many publicly available computer modeling and animation programs that model light behavior. This is particularly useful in

nighttime computer environments where the computer light models can visually represent how light behaves according to the intensity and light distribution as defined by the IES digital file format. Its wide availability, measurements in real world units, and standard formatting make the IES file both practical and accurate for users analyzing or visualizing nighttime light conditions. However, as will be discussed, because of the way light values are measured for headlamps, and how this data is converted to a photometric file, a 3D visualization program that simulates light using the photometric file for a headlamp will not get accurate light values. Figure 8 schematically demonstrates how light intensity data is collected on a photocell that is situated a set distance from a light source mounted on a typical goniometer.

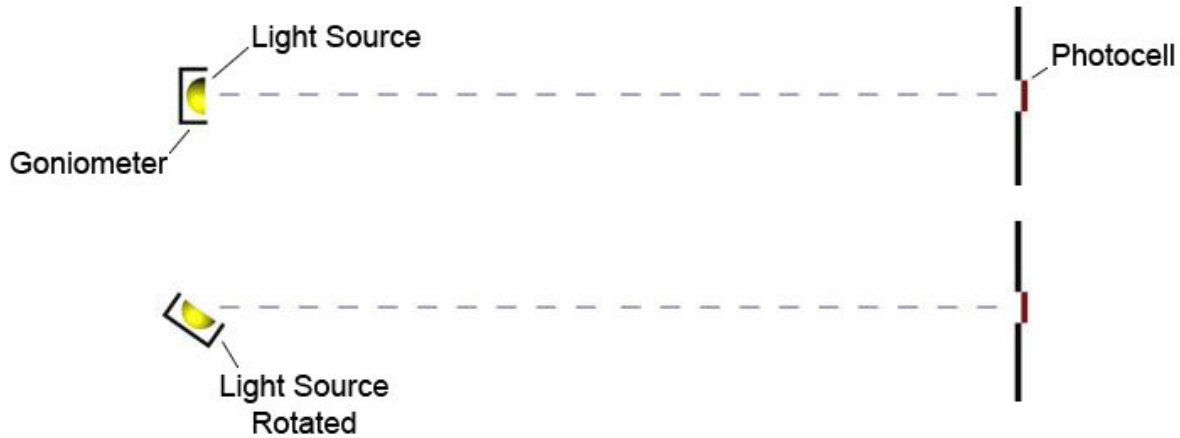


Figure 8

A photocell records the light intensity from the light source in candela, and the angle relative to the lamp. To get light values from different angles of the lamp, the lamp is rotated slightly in both horizontal and vertical axis, and another recording is taken on the photocell that reflects the light intensity emitted from the light positioned at this new angle. The result is a web of photometric data representing the light intensity for multiple angles of light emitting from the light source. However, because of the way headlamp optics work, and because of the way that simulation programs interpret and utilize photometric file formats, the simulated light only partially represents the headlamp properly.

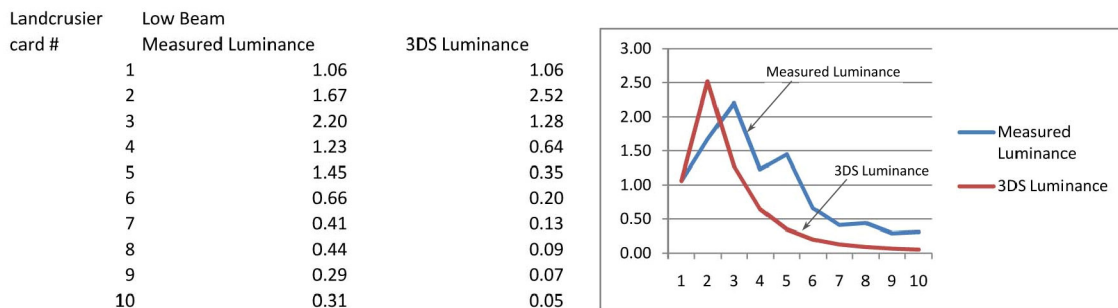


Figure 9

The graph in Figure 9 compares photometric light values to actual measured light values. The graph shows that not only do the intensity values not match; the rate of falloff for the photometric file is more rapid than the actual headlamp. This is due to the point of convergence being located too far forward than the actual headlamp, as illustrated in Figure 10, below. Because the light is being spread sooner by the photometric file, the intensity values falloff quicker as well. At greater distances, such as 250', the light from both the photometric file and the actual headlamp is so low that the intensity level approaches zero, and therefore converge together again on the graph

Figure 10 illustrates how headlamp optics collect and distribute light that cannot be properly represented in photometric files, showing the convergence of two different light rays. One of the light rays, shown in blue, converges to where the light source is actually located, the other beam shown in red, converges where light being emitted from the headlamp would converge because of the optics. In short, rays from the actual light source do not converge to the same location as the light that is actually emitted from the headlamp because of the manner in which parabolic reflectors in the lamp collect and distribute light. The parabolic shape of the headlamp collects light and distributes light in this manner, such that the location of the actual light bulb is different than the location of the convergence of the light rays that are distributed out from the headlamp. In fact, the parabolic reflectors have many surfaces of different size and angle that create multiple convergence points for the light rays that are emitted from the headlamp. This complex shape of the reflector creates the necessary beam pattern that one sees on the roadway and provides sufficient light power to the headlamps to illuminate objects ahead of the vehicle, while reducing the amount of glare that may be discomforting or distracting to oncoming traffic⁸. But because the photometric data matrix assumes that all the light is being emitted from the same point, it cannot account for the difference in convergence of the light rays it measures. The photometric file assumes a single convergence of light, and hence will produce erroneous spreading of light intensity. This difference in light spread is shown in figure 10, below, notated as a change in θ .

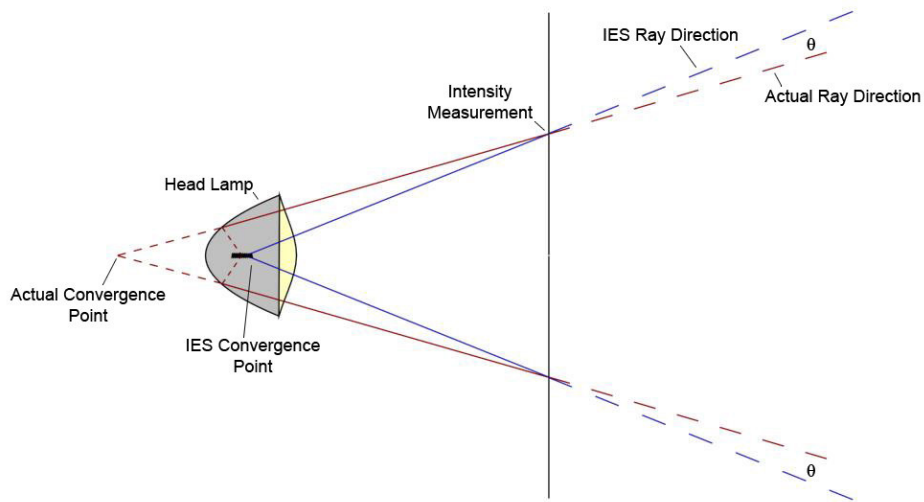


Figure 10

To further understand why converging light to a single point, as in a photometric file, creates erroneous light distributions for a headlamp, the illustration above shows that the angle of light being distributed by the photometric convergence point has a much wider spread than the actual convergence point. This means that there would be a greater diffusion of light in a shorter distance than the light emitted by the actual headlamp. In other words, light would always register a higher intensity value closer to the headlamp and a sharper fall off than what a real headlamp would register, particularly for a headlamp. This is an important distinction, since it is the focusing of light in the distance by a headlamp that creates the hotspot critical for illumination of objects at night.⁹ In an actual headlamp, the reflector optics would have multiple points of convergence as represented in Figure 11 below. In short, an actual headlamp projects light as if there are multiple light sources at work.

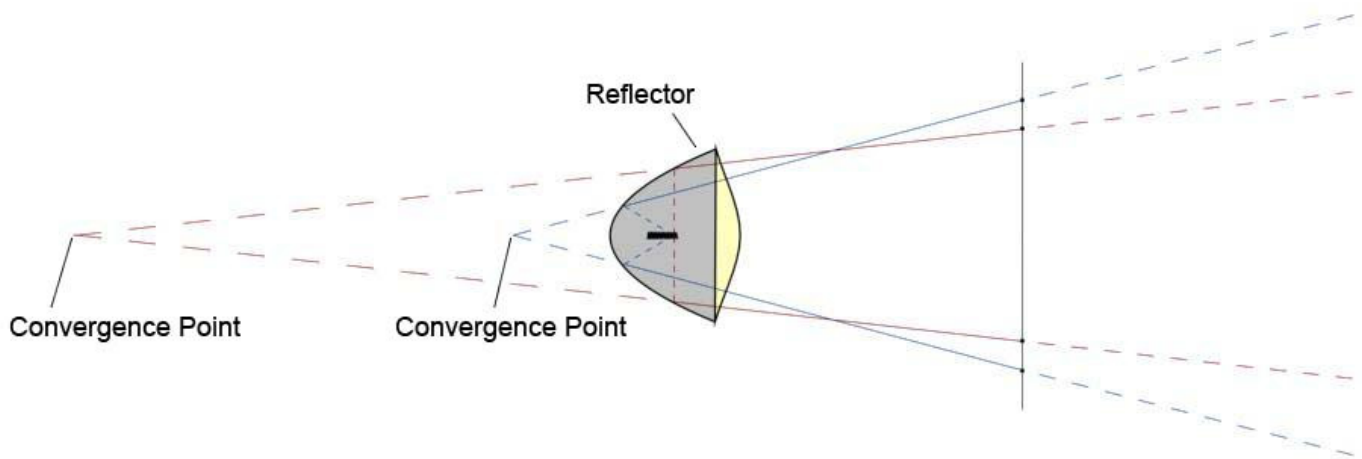


Figure 11

The effect seen in Figure 11 above is caused by reflector optics that collect light and distribute it in such a way that the resulting beam pattern can be described as if created by multiple light sources.

Photometric files are assigned to only one light in a simulation program, hence the single convergence problem. As a single light source, the physical properties defined by the light simulation application create intensity values that misrepresent the actual headlamp. Light simulation programs create photometric lights with physically-based intensity values and a falloff described with the following inverse equation:

$$I = \frac{1}{x^2}$$

This means that as the light is distributed to an area, its falloff reduces inversely proportional to the distance the surface is away from the light. Photometric files are assigned to a single light, and always attenuate at an inverse-square falloff rate. Photometric simulations rely on real world units in a scene, forcing the light source in the computer model to project light values as defined in the photometric file from a single point, at an inverse square falloff. This equation, while appropriate to define the behavior of light in a simulation program, becomes problematic when used to define light sources with single convergence points. The photometric simulated light will always start off too intense and falloff too quickly relative to an actual headlamp. The intensity value of a light at the position of the light source rather than at the position of convergence and, therefore, a higher intensity light than an actual headlamp, can be described in the following equation:

$$L_2 = \frac{I_2}{(D_1 + D_2)^2}$$

Where I_2 is the intensity value at 1 meter from the point of convergence, D_1 is the distance from the light source's location, and D_2 is the distance between the light source location and the point of convergence. Due to the increased falloff of the photometric file, the difference between the photometric light and the actual headlamp can be determined by subtracting the light intensity of the photometric file from the actual headlamp.

COMPARISON OF ACTUAL HEADLAMP BEAM SHAPE TO PHOTOMETRY BEAM SHAPE

In addition to the difference in intensity levels of the actual headlamp versus the photometric file, there is a difference in the shape or beam pattern between the actual headlamp's hotspot and the hotspot created by the photometric file. The source of the error still lies in the fact that the parabolic reflectors distribute light in a manner that cannot be captured and represented in a photometric file. To illustrate how the beam pattern changes in an actual headlamp, Figure 12, below, shows, from a top view, how light is focused in front of the lens to form a hotspot.

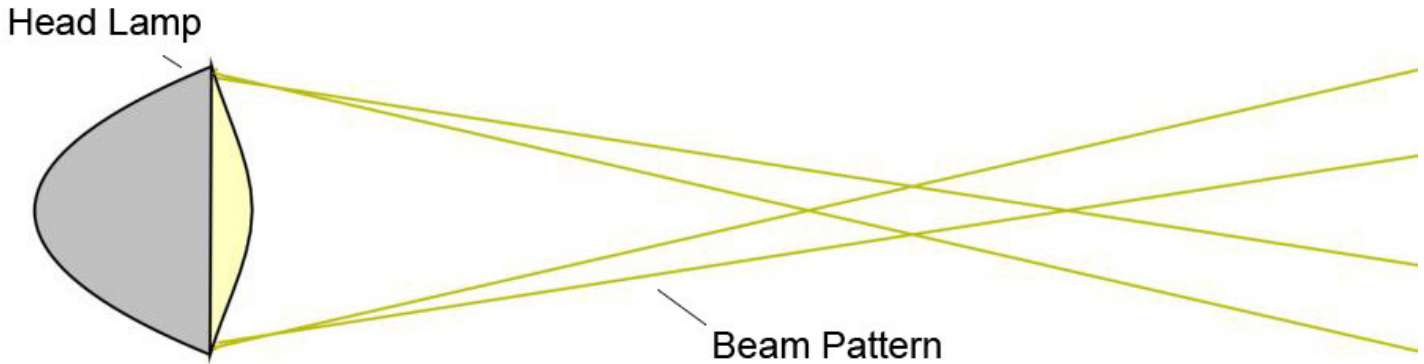


Figure 12

Light is collected on the left and right sides of the parabolic reflector since this allows for the most efficient concentration of light in the reflector. Where the beam from both sides of the reflector comes together is where the majority of light is concentrated to form the hotspot. This occurs at some distance out from the front of the light, but, most importantly, it occurs from the crossing of two light beams, i.e. one light beam coming from each side of the lamp. Because this hotspot is generated from two focused light beams as the distance from the headlamp increases, the shape of the hotspot will also change. This pattern cannot be represented in a photometric file, since the photometric file assigns the beam formation to one light beam rather than two.

To demonstrate the phenomenon, a sealed beam, lens optics, headlamp is used, and portions of the light have been masked off to show how different parts of the headlamp area can contribute a different portion and shape to the total beam pattern. Different quadrants are masked to record the contribution from any one of the quadrants making the beam pattern. Figure 13, below, is a photo showing how the sealed beam headlamp is masked to separate the hotspot contribution from each side of the headlamp.

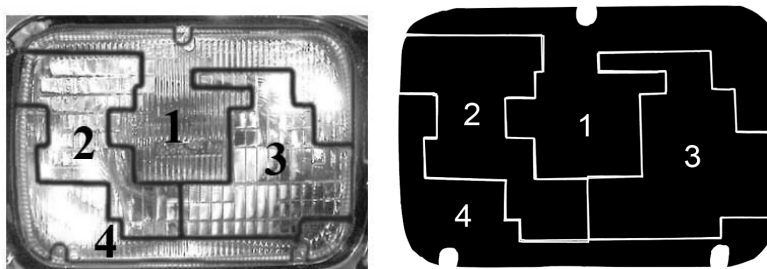


Figure 13

On the left shows the actual headlamp, with outlines of the quadrants that make up the total beam pattern. Quadrants 2 and 3 are specifically the focused hotspot, while 1 and 4 act more to diffuse light over a wider area for more general illumination. The image on the right shows the masks themselves, slightly separated for

clarity, that were used to mask each corresponding quadrant on the headlamp. With the quadrants masked, photos were taken in an unlit room to capture the contribution from each quadrant. This is shown below in Figure 14

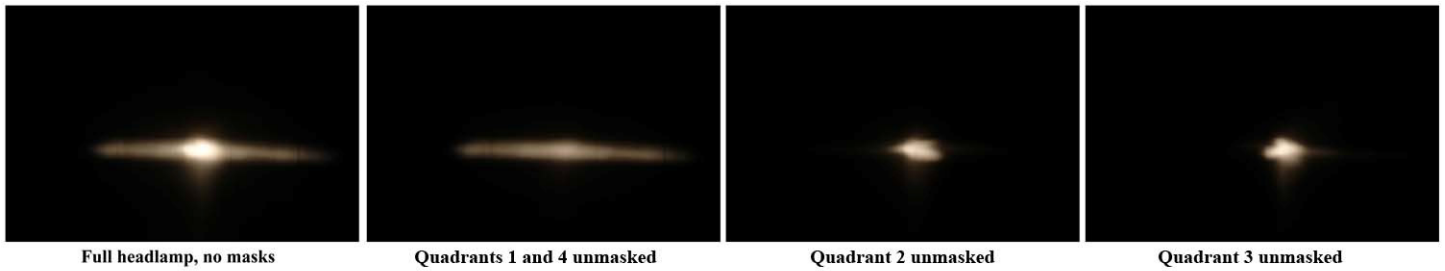


Figure 14

Quadrants 2 and 3 contribute an almost equal amount of light intensity and beam pattern to the hotspot, yet this comes from each side of the headlamp. Because this beam pattern is formed from two sides of the headlamp, the hotspot shape changes over distance since the beam pattern would criss-cross at some distance out from the headlamp. This crossing of the two hotspots is shown in Figure 15, where the actual change in position of each headlamp hotspot from quadrants 2 and 3 were recorded and measured.

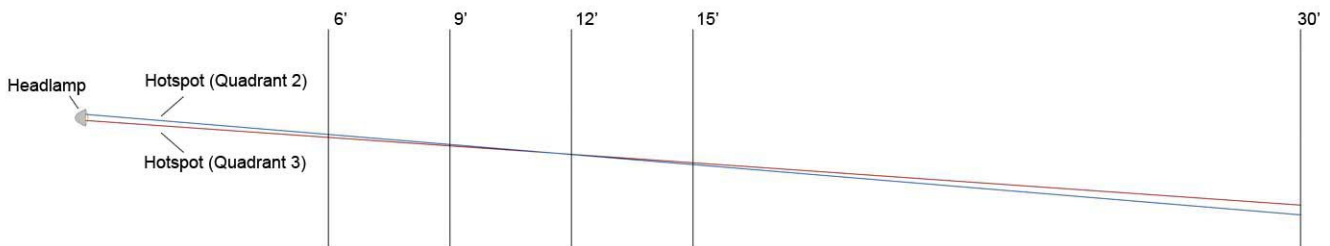


Figure 15

As a comparison, the hotspot from the photometric file does not change its shape in the same manner as the actual headlamp. This is illustrated in the images and analysis in Figure 16 below.

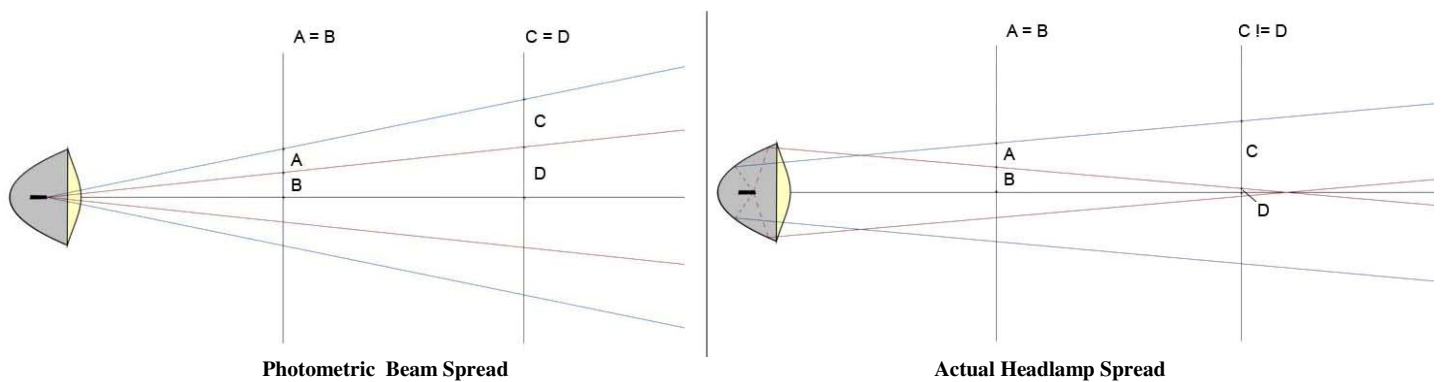


Figure 16

In Figure 16, the headlamp distribution on the left demonstrates the beam spread from a photometric file. Because of the single light object that the photometric file is assigned to, the light pattern is emitted such that

the beam pattern is accurate at the location marked A&B on both the photometric and actual light spread. Because this shape is created from a single light source, however, and not the reflection from optics in the actual light source, the light beam pattern does not change accurately as shown in the beam pattern on the right, where the actual beam pattern would converge at some distance out from the light. This convergence is not represented in a photometric file.

CONCLUSION

In this study, lens optics, projector and reflector optics headlamps were evaluated, though other headlamp types, such as HID, and Mini-projector are somewhat different and could also be evaluated. Regardless of the lamp type, however, the general criteria for headlamps is similar in a way that make headlamps unique in how light is collected and distributed. The behavior and pattern of light distribution from an actual headlamp are fundamentally different than the behavior of light emitted by a photometric file of a headlamp in a simulation program. This is because headlamps contain sophisticated optics that result in a headlamp assembly projecting light more like several light sources rather than one. The design of this optics system in headlamps renders a photometric data file of the headlamp inadequate in representing light intensity and distribution in a simulation environment. While photometric light files are accurate for some types of light sources and luminaries, the photometric file does not represent the complex reflector and lens assemblies of the headlamp that collect and distribute headlamp light such that the projection of the light changes over distance. Headlamps are not static lights like a street lamps or building, since the vehicles move within the environment. Also, the stringent design requirements for headlamps to both illuminate objects ahead for better visibility while reducing glare for oncoming traffic⁹ result in extremely complex optics. The beam formation of a headlamp may not occur until 30'-50' from the headlamp itself and this beam pattern is a central light contributing component of the headlamp for far field distances. The reflectors and lenses of headlamps direct the light from the light source to achieve a hotspot in the distance by focusing light from both horizontal sides of the headlamp. Because these two beams are crossing in the distance, it is not possible for a photometric file to record the direction the light is crossing, and how this crossing affects the hotspot close or farther away from the headlamp. While photometric files are inadequate in capturing the complex light collection and distribution of a headlamp, it is still possible to simulate headlamp illumination by creating a light source in the 3D visualization program that accounts for the multiple convergence of each individual headlamp design. The concept behind using multiple light sources is that a headlamp beam pattern can be separated into multiple light emitting areas that each contributes some part to the whole of the beam pattern. Figure 12 shows the analysis of a sealed beam headlamp visually demonstrating how the optics of the headlamp collect the light into individual quadrants that emit light through quadrants to form a complete pattern. While sealed beam headlamps are still widely used in the trucking industry for replacement parts, their use in the passenger car industry has been replaced by the lamp types that have been evaluated in the paper. As Figure 12 shows, the flutes in the sealed beam are shaped differently to create a different part of the beam pattern. When these individual flute patterns are masked off, their individual contribution to the overall beam pattern can be analyzed, and a simulated light that only accounts for this quadrant's light pattern can be created as shown in Figure 8.

Because the headlamp can be divided into discrete quadrants, it can also be analyzed in discrete parts. One way to capture how the optics of the headlamp create discrete light patterns that contribute to the whole beam pattern, is to individually photograph each light section, as shown in figure 13. With photographs that map the individual light patterns, these maps can be assigned to light sources in a light simulation and visualization program. The light sources will project light through the projection maps and as a cluster, will collectively create the entire beam pattern that is the same as the actual headlamp. Figure 17 is an image that represents the concept of a multiple light cluster.

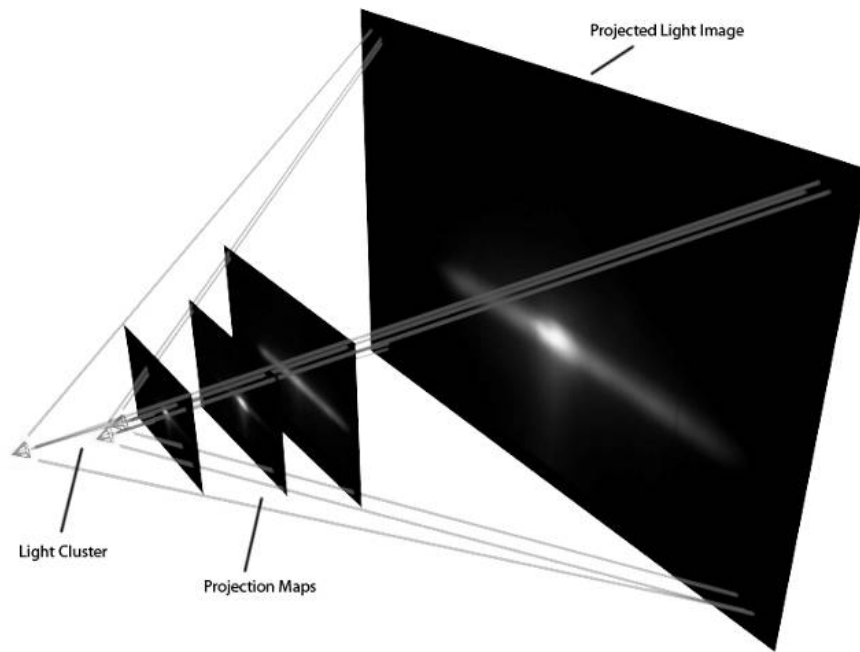


Figure 17

In the image above, digital map projections that capture the light created by each individual part of the headlamp optics are assigned to individual light sources. Each light then projects light through the map to complete the full beam pattern. For more in depth discussion of the light cluster method see the SAE publication “Simulating Headlamp Illumination Using Photometric Light Clusters,” Society of Automotive Engineers, Paper Number 2009-01-0110”.

Appendix A

Landcruzier		Low Beam		
Card #	3DS Luminance	3DS Luminance GI	Difference	average
1	1.06	1.09	3.00%	
2	2.52	2.60	3.10%	
3	1.28	1.32	2.80%	
4	0.64	0.66	2.60%	
5	0.35	0.36	2.90%	
6	0.20	0.21	2.70%	
7	0.13	0.13	2.50%	
8	0.09	0.09	2.40%	
9	0.07	0.07	2.00%	
10	0.05	0.05	2.10%	2.61%
Mini Cooper		Low Beam		
Card #	3DS Luminance	3DS Luminance GI		average
1	4.30	4.44	3.20%	
2	2.24	2.31	3.10%	
3	1.66	1.71	3.00%	
4	0.69	0.71	2.80%	
5	0.32	0.33	2.60%	
6	0.16	0.16	2.90%	
7	0.09	0.09	2.60%	
8	0.07	0.07	2.40%	
9	0.05	0.05	2.20%	
10	0.03	0.03	2.30%	2.71%
Nissan		Low Beam		
Card #	3DS Luminance	3DS Luminance GI		average
1	0.39	0.40	3.20%	
2	0.39	0.40	2.90%	
3	0.04	0.04	2.90%	
4	0.01	0.01	2.70%	
5	0.04	0.04	2.60%	
6	0.00	0.00	2.80%	
7	0.02	0.02	2.50%	
8	0.01	0.01	2.30%	
9	0.00	0.00	2.10%	
10	0.00	0.00	2.10%	2.61%

-
- ¹ A Bacelar, "The Contribution of Vehicle Lights in Urban and Peripheral Urban Environments", *Lighting Res. Technology* Vol 36,1 (2004) pp. 69-78
- ² Narisada, K., Schrbuder D., "Light Pollution Handbook", Springer Norwell, MA,2004, page 49-50.
- ³ J. Kajiya, "The Rendering Equation" ACM 0-89791-162 Volume 20, Number 4, 1996
- ⁴ Larson, Gary, Shakespeare, Rob, "Rendering with Radiance" Morgan Kaufman, San Francisco, California, 1997 p. 6
- ⁵ Gallardo, Arnold, "3D Lighting History, Concepts, and Techniques". Charles River Medi Inc, Rockland Massachusetts, Page 112
- ⁶ Reinhart, C., "Experimental Validation of Autodesk 3DS Max, Design 2009 and Daysim 3.0". National Research Council Canada, Harvard University GSD, 2009
- ⁷ IES Publication LM-63-1986, "IES Recommended Standard File Format for Electronic Transfer of Photometric Data and Related Information, Subcommittee on Photometry of the IESNA Computer Committee, September 12th, 2002
- ⁸ Sanders, Mark S., and McCormick, Ernest J., "Human Factors in Engineering and Design". 7th Edition, McGrall Hill New York, New York, 1993
- ⁹ Olson, Paul L., and Farber, Eugene, "Forensic Aspects of Driver Perception and Response". 2nd Edition, Boston, MA: Lawyers & Judges Company, Incorporated, 2003