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Photometric Indicators of Headlamp Performance

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16. Abstract

The visibility of an object is largely determined by the relative contrast between the object and its background. Thus, it might be assumed that without consideration of environmental conditions surrounding a target illuminated by a headlamp, target visibility may not be accurately assessed. That is, methods that consider only illuminance characteristics of headlamps (e.g., distribution and intensity of light) may assess headlamp performance differently from methods that include roadway and viewing conditions in the appraisal.

In this report, headlamp performance ratings are first generated using CHESS, a software application that determines visibility by simulating headlamp illumination, roadway, and target characteristics, using target contrast. The CHESS ratings were then compared with ratings obtained by two alternative illuminance-based ratings methods. The first method, the lux-area method, computes road area at or above an established lux threshold. The second method, the distant-light method, computes the average lux level within a predefined forward road area centered on the midline of the vehicle. Twenty-two tungsten halogen (TH) headlamps were evaluated using each method and their performance ratings were compared with the CHESS ratings. The simple illuminance-based measures were found to be closely correlated with the CHESS ratings. The distant-light method produced the highest correlations.

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Introduction

There have been a variety of approaches to the evaluation of automotive headlighting. In most, safety plays a prominent role in the evaluation, although glare, aesthetics, and customer opinion are often addressed as well. Safety is assessed by determining whether a forward lighting system successfully renders important roadway objects sufficiently visible to allow safe transit in darkness. This, in turn, requires identification of which items on the roadway are important, under what background luminance conditions are they observed, and when a driver needs to become aware of them to ensure safe passage. There are no simple answers to any of these questions. Each spawns a myriad of other questions: What is the relative safety importance of detecting pedestrians, animals, signs, objects, and other vehicles in the roadway? What are adequate luminance contrast levels for detection? What are the reflectance levels of common roadside targets? How are targets distributed about the roadway? What are background luminance levels at night? How do these levels change with driver approach? How is the responsiveness of a driver affected by expectation? How should travel speed be factored into the safety equation? And so on.

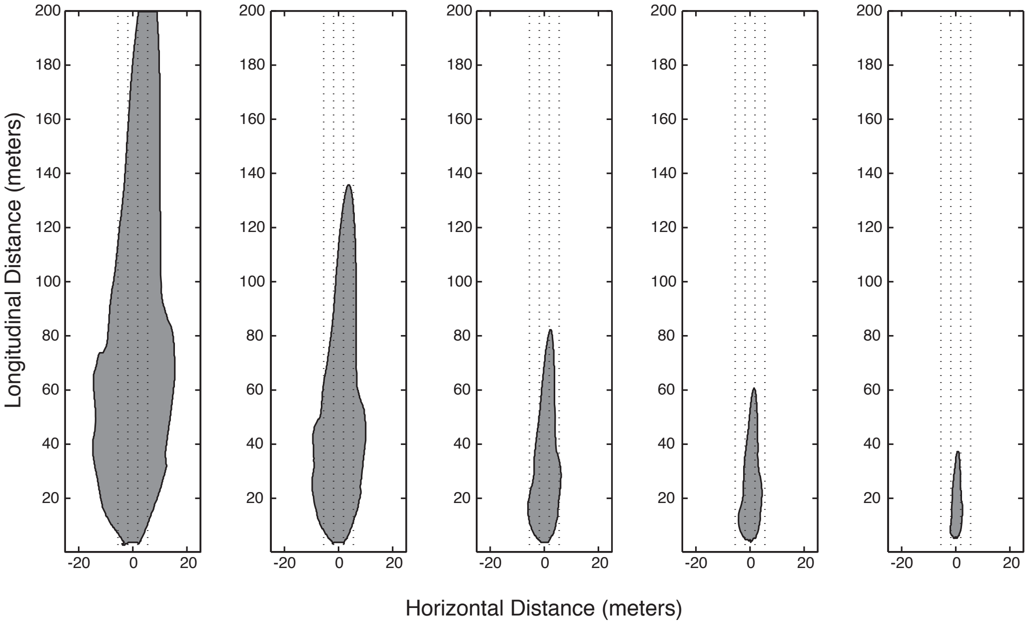
Perhaps the most ambitious attempt to simultaneously address as many of these questions as possible was Ford Motor Company's Comprehensive Headlamp Environment Systems Simulation (CHESS) (Bhise et al., 1977). With an input beam pattern and lamp configuration, CHESS computes a measure of driver performance by simulating drives through a variety of test routes, tabulating the proportion of total distance in which the seeing distance to pedestrians, road delineation, and levels of discomfort glare to other drivers is judged acceptable. The routes included environmental factors like pavement, pedestrian, and lane-delineation reflectance, road geometry, illumination and glare effects from fixed lighting, and traffic and pedestrian densities. Pedestrian characteristics included walking speed, clothing reflectance, and size. Vehicle characteristics included explicit modeling of mounting height and beam pattern. Driver characteristics included age, reaction time, alertness, glare sensitivity, and detection threshold. The CHESS model calculates an overall figure of merit (FOM) for all conditions, sub-scales for pedestrians and lane-delineation detection in both opposed and unopposed conditions, and a subscale for the percent of distance in which opposing drivers experience discomfort glare from headlamps under evaluation.

This report investigates whether headlamp evaluations based entirely on photometric output (i.e., without benefit of a driver visibility model) can approximately duplicate evaluations rendered by CHESS. Such a possibility is conceivable if the relationship between a headlamp beam pattern and a driver's ability to see a target is more or less direct. In the end, the multitude of simulated roadway environment factors, driver characteristics, and levels of traffic and pedestrian density simulated in CHESS may converge on an average roadway configuration that may be directly related to photometric output. Because the greatest light-related safety concern is pedestrian visibility (Sullivan & Flannagan, 2001), this report concentrates on CHESS's subscale for unopposed pedestrians. Two photometric beam-pattern evaluation methods will be compared with the CHESS ratings for unopposed pedestrians: a lux-area method, and a distant-light method.

Lux-Area Evaluation Method

The lux-area method rates a headlamp beam pattern based on the total roadway area at or above an established lux level threshold. It should be noted that this method is entirely blind to the shape and distribution of light on the roadway and assumes a beam-pattern that complies with Federal Motor Vehicle Safety Standard 108 (FMVSS 108) requirements. The method computes the proportion of a 50-by-200 meter forward roadway section that exceeds a given threshold. Examples of this calculation are shown in Table 1 for a sample beam pattern at 5 different lux level thresholds.

Table 1.
Sample results of lux-area headlamp evaluation method.

<table>
<tr><th>Threshold (Lux)</th><th>1</th><th>3</th><th>10</th><th>20</th><th>50</th></tr>
<tr><td>Bird-eye view</td><td colspan="5">
</td></tr>
<tr><td>Rating</td><td>35.2%</td><td>15.0%</td><td>5.5%</td><td>2.9%</td><td>1.0%</td></tr>
</table>

Distant-Light Evaluation Method

This evaluation method rates the light falling onto a section of the roadway that likely has the most significant influence on safety—a distant-light region. This area extends from 15 to 200 meters forward of the vehicle, and laterally 3 lane widths (approximately 11 meters) wide, centered on the vehicle. This nominal width is also extended by 2 additional degrees of visual angle to include recommendations from international lighting experts (Sivak & Flannagan, 1993). An example of the distant-light region is shown in Figure 1 in light gray. A lamp rating is determined from the average vertical illuminance found in this region.

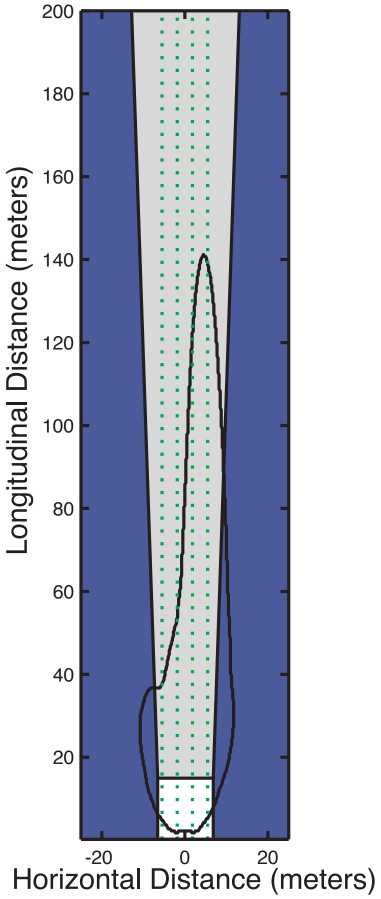


Figure 1. A prototypical roadway divided into regions with a low-beam pattern superimposed. The center gray area (the inverted trapezoid) identifies the distant-light region.

Besides the restriction of scoring to only the light that falls within the distant-light region, a maximum illuminance level is also used to establish a maximum amount of credit a lamp can be given for a level of illumination. If a maximum illuminance of 10 lux is applied, areas that exceed this level are credited for 10 lux. One consequence of such a limit is that the high levels of illuminance that fall near the vehicle are given no more credit than lower levels that fall farther away. As the maximum level is raised, areas of higher illuminance (which are normally closer) will contribute more to a vehicle's rating. This is illustrated in Figures 2 through 4. In Figure 2, the illuminance level of a beam pattern is shown as a function of the distance from a vehicle for a slice of roadway extending along the centerline of the vehicle from the front of the vehicle to a point 200 meters down the roadway.

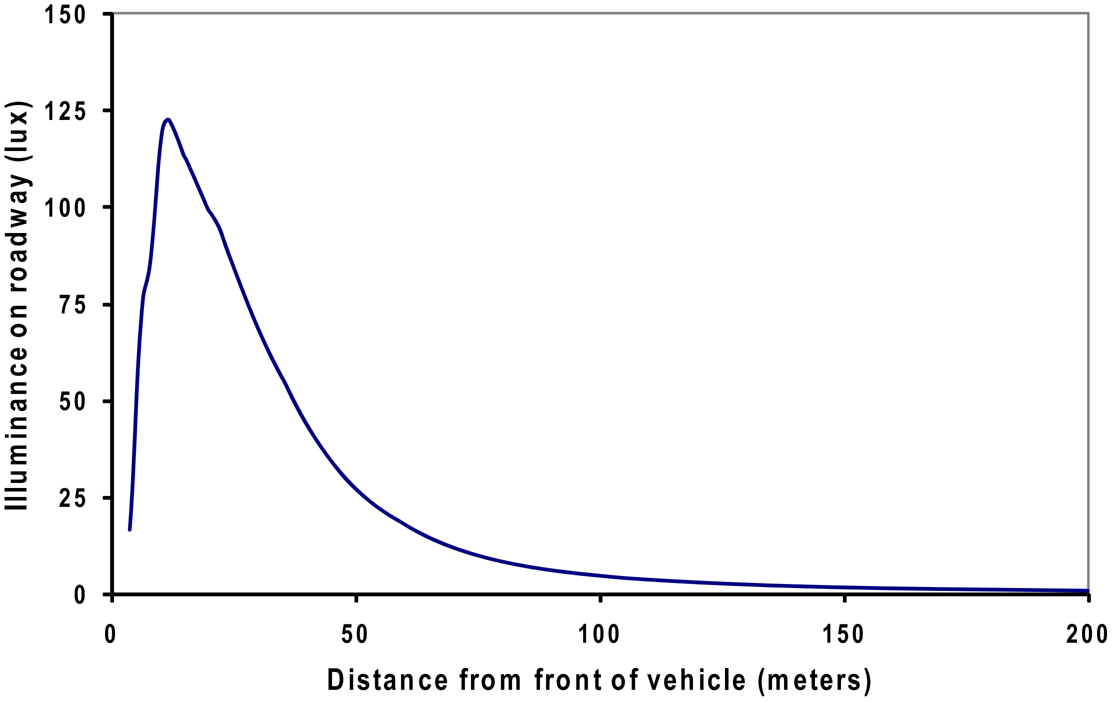


Figure 2. Example of the decline in illuminance level of roadway as distance increases from the front of a vehicle.

Figure 3 shows the illuminance (in gray) that contributes to the lamp rating when the maximum lux level is 10. All of the illuminance levels within about 75 meters of the vehicle are considered to have the same effect because they are all above the 10-lux maximum. If the maximum credited luminance is raised to 50 lux (shown in Figure 4), the nearer, higher light levels are permitted to contribute more to the overall rating.

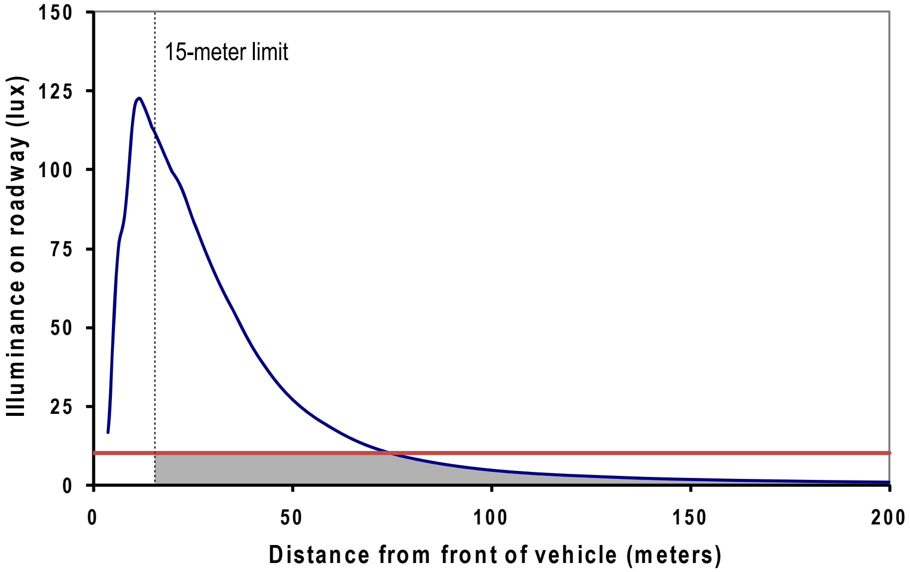


Figure 3. Example of how the use of a maximum lux level of 10 alters the relative effect of near and far light along the roadway.

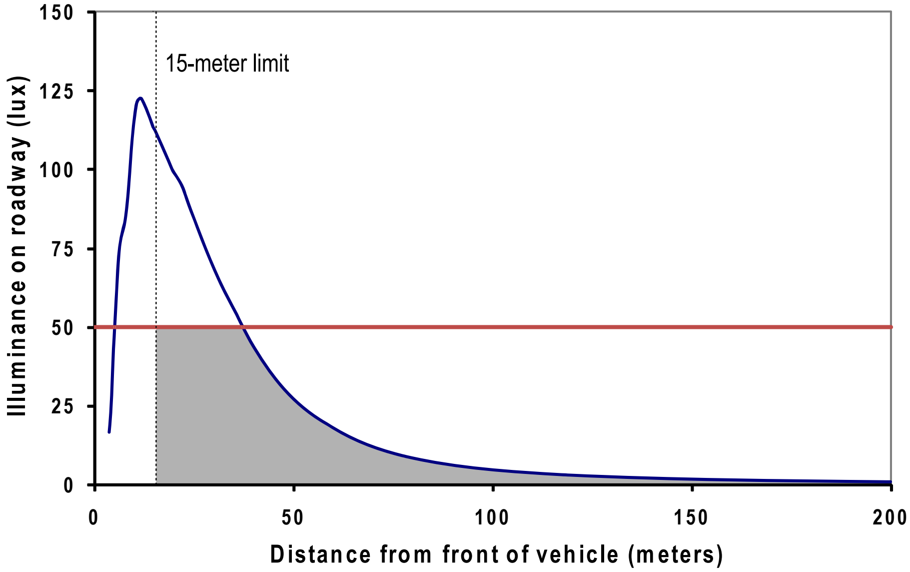


Figure 4. Example of how raising the maximum lux level to 50 increases the relative effect of light nearer to the front of the vehicle.

The final distant-light rating is calculated as the average lux level observed within the distant-light region. (Note also that as the maximum lux level increases, the resulting rating also increases.)

An example of how ratings can be influenced by changes in the maximum lux level is shown in Figure 5 by comparing Lamp 1, which distributes more light down the roadway, to Lamp 2, which strongly illuminates the area near the vehicle. In the figure, the relative magnitude of the ratings for two lamps changes as the maximum lux level is increased. At low lux levels, the far area contributes more to the rating, and Lamp 1 is rated higher than Lamp 2—the bright areas in the beam pattern of Lamp 2 are given no more weight than the dimmer areas. The rating is largely determined by the area covered by lower lux levels. In contrast, at high maximum lux levels, the bright areas in Lamp 2 exert a greater influence on the rating so that Lamp 2 is rated higher than Lamp 1.

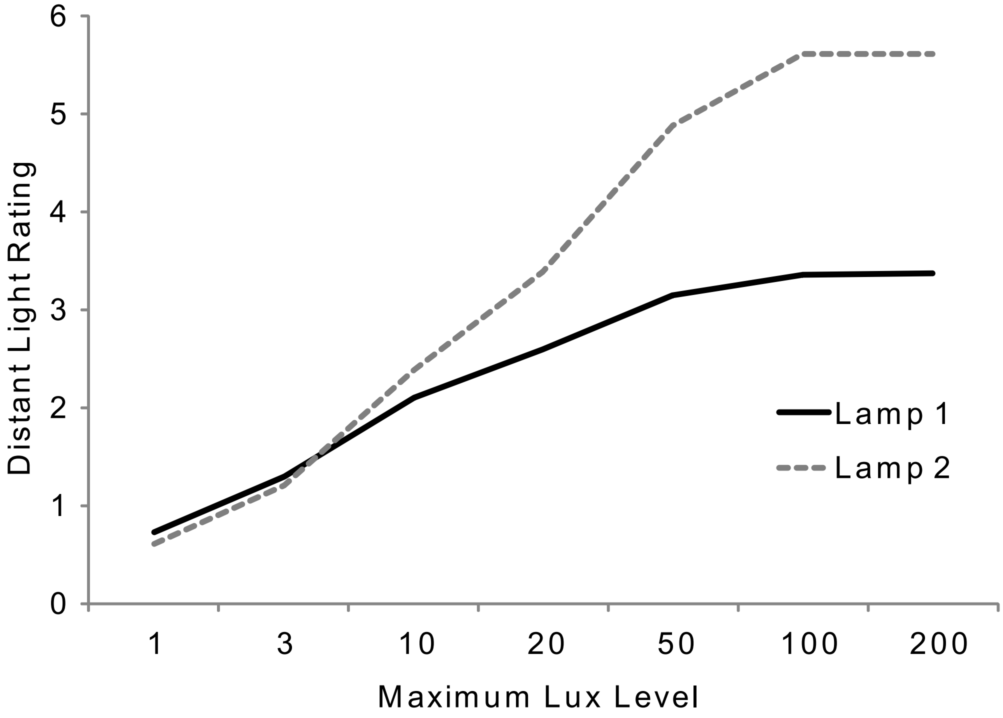


Figure 5. Example of how two lamp ratings are influenced by the maximum lux level parameter.

Comparison of Photometric Rating Methods to CHESS

Ratings using the lux-area and the distant-light algorithms were compared with the unopposed pedestrian visibility ratings produced by CHESS. This was done by examining how well the CHESS ratings of 22 tungsten halogen (TH) low-beam headlamps correlated with each of the two photometric ratings methods. The lamps were selected from a sample of 2004 top-selling vehicles summarized in a previous report (Schoettle, Sivak, Flannagan, & Kosmatka, 2004).

Each rating system was evaluated using illuminance levels measured at the surface of the roadway and at 0.25 meters above the roadway, approximately the height of a pedestrian's shin. Lux-area ratings were calculated using illuminance threshold levels of 1, 3, 10, 20, 50, 100, and 200 lux; distant-light ratings were also calculated using maximum illuminance levels of 1, 3, 10, 20, 50, 100, and 200 lux.

The correlations between the CHESS and the lux-area ratings are shown in Table 2. In the table, the correlation coefficient, *r*, is given for each lux level and target height. Overall, the correlations are quite high, suggesting a substantial correspondence between the CHESS ratings and the lux-area method. As the lux level increases beyond 20, the correlation with the CHESS ratings declines. Perhaps this is because the resulting area becomes smaller and smaller, representing only the "hottest" spots of the beam pattern which may have less relevance in the CHESS ratings.

Table 2.
Correlation coefficients obtained from correlations between CHESS unopposed pedestrian visibility rating and the lux-area rating. Bold gray cells identify the highest correlation in each row.

	Lux Level						
Target Height	**1**	**3**	**10**	**20**	**50**	**100**	**200**
0	0.849	**0.887**	0.858	0.767	0.529	-0.096	-
.25	0.793	0.849	**0.895**	0.887	0.755	0.601	0.239

Correlation between the CHESS ratings and the distant-light ratings are shown in Table 3. The observed correlations are generally higher than those observed in the lux-area ratings in Table 2. Furthermore, the maximum lux parameter in the distant light rating appears to enhance the correlation as it is increased relative to the lux parameter of the lux-area rating. Of course, the parameter functions differently in each method. In the lux-area method, higher levels of the parameter progressively exclude lower light levels from having any influence on the calculation; whereas in the distant-light method, higher values of the parameter increase the influence of brighter light without completely excluding dimmer light.

Table 3.
Correlation coefficients obtained from correlations between CHESS unopposed pedestrian visibility rating and the distant-light rating. Bold grey cells identify the highest correlation in each row.

	Maximum Lux						
Target Height	**1**	**3**	**10**	**20**	**50**	**100**	**200**
0	0.726	0.805	0.906	0.950	**0.964**	0.948	0.942
.25	0.664	0.737	0.828	0.879	0.922	0.937	**0.942**

Conclusions

The two photometric evaluation methods examined in this report produced ratings that were well correlated with the ratings produced by CHESS, a method based on visibility modeling and roadway simulation. Thus, it appears that, for many purposes, simple illuminance-based methods may adequately approximate more complex visibility-based evaluation methods. Note that the accuracy and precision obtained using a driver visibility model that incorporates detailed information about target and background luminance, driver factors (e.g., age, travel speed, reaction time), and roadway characteristics to assess the visibility of a target in an individual roadway encounter may not always be matched by simple photometric methods. However, it is plausible that when the visibility measures of targets under a variety of roadway encounters are aggregated, as they are in CHESS's roadway simulations, the resulting assessment of headlamp performance closely reflects the photometric characteristics of the headlamp. Although, in principle, the more elaborate approach used by CHESS can only do better than simpler photometric evaluations, it may be difficult in practice to demonstrate that CHESS is in fact more valid given how similar the two approaches appear to be.

The lux-area results in this study indicate that, if CHESS is provisionally accepted as a standard for validity, the customary approach of portraying headlighting systems in terms of isolux contours on the roadway (using a level of about 3 lux) is reasonably good. The distant-light results indicate that some improvement is possible even with relatively simple photometric methods. Finally, CHESS itself may offer even better prediction of headlighting performance, although careful consideration of validity may be necessary to establish that it is truly an improvement over photometric methods.

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