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**POTENTIAL VISIBILITY GAINS ON  
STRAIGHT AND CURVED ROADS  
FROM PROPORTIONAL INCREASES IN  
CURRENT LOW-BEAM INTENSITIES**

**Michael Sivak  
Brandon Schoettle  
Takako Minoda  
Michael J. Flannagan**

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Michael Sivak  
Brandon Schoettle  
Takako Minoda  
Michael J. Flannagan

The University of Michigan  
Transportation Research Institute  
Ann Arbor, Michigan 48109-2150  
U.S.A.

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## **Introduction**

Traditional tungsten-halogen low-beam headlamps do not provide sufficient visibility in many driving situations. In other words, drivers frequently overdrive the reach of their low beams. For example, Perel, Olson, Sivak, and Medlin (1983) estimated that low-beam visibility distances to unexpected low-contrast objects are shorter than the corresponding stopping distances for speeds above about 70 km/hr. This state of affairs is primarily a consequence of competing requirements for visibility and glare protection.

This research was designed to address the following question: What is the gain in visibility if we were to increase the luminous intensity of each point of a given beam pattern by a constant proportion? In our calculations, we used a market-weighted U.S. low-beam pattern, and multiplied each value in the candela matrix by a constant. Visibility changes were estimated by changes in the reach of the 3-lux line (the approximate dark bound of civil twilight). The visibility changes that resulted from changes to the low-beam pattern were compared to the visibility changes corresponding to a shift from low beams to high beams. Although a uniform proportional increase throughout the low-beam pattern may not be the most practical way to improve headlamp performance, the resulting changes provide an enhanced baseline against which to compare other potential improvements in low-beam visibility, including more localized changes in static beam patterns and adaptive headlighting systems.

## Method

### General approach

In our simulations of the visibility benefits of proportional increases in the output of low-beam headlamps, we used a straight roadway and two different fixed-radius curved roadways (representing two different speed scenarios), and applied beam patterns of different luminous intensities. Of interest was the amount of the combined illuminance on a vertical surface from the left and right lamps at a height of 0.25 m above the road surface (corresponding, for example, to the lower portion of the legs of a pedestrian). The dependent variable was the maximum distance at which this illumination reached 3 lux. Three lateral positions were considered: the right and left edgelines of the lane of travel, and the left edgeline of the left adjacent lane. (These three positions will be referred to in the remainder of this report as right, center, and left, respectively.) The width of each lane was set at 3.7 m.

Figure 1 presents an illustration of the basic approach. It shows a bird's-eye view of a two-lane roadway. Superimposed on the roadway scene is the 3-lux line (derived by combining the illuminance from both headlamps) at 0.25 m above the roadway. Of interest were the distances of the intercepts of the 3-lux line with the planes of the three edgelines 0.25 m above the roadway.

### Beam patterns

We used twelve different beam patterns in our analysis. The baseline beam pattern was the median market-weighted model year 2004 U.S. tungsten-halogen low-beam pattern from Schoettle, Sivak, Flannagan, and Kosmatka (2004). Ten derived beam patterns were obtained by multiplying each point in the baseline beam pattern by a constant that ranged from 1.1 to 2.0, in increments of 0.1. Finally, for comparison, we also used the median market-weighted model year 2001 U.S. high-beam pattern from Schoettle, Sivak, and Flannagan (2001).

For the eleven low beams, the headlamp mounting height was set at 0.66 m, and lamp separation at 1.20 m. The corresponding values for the high beams were 0.65 m and 1.04 m, respectively (Schoettle, Sivak, and Nakata, 2002).



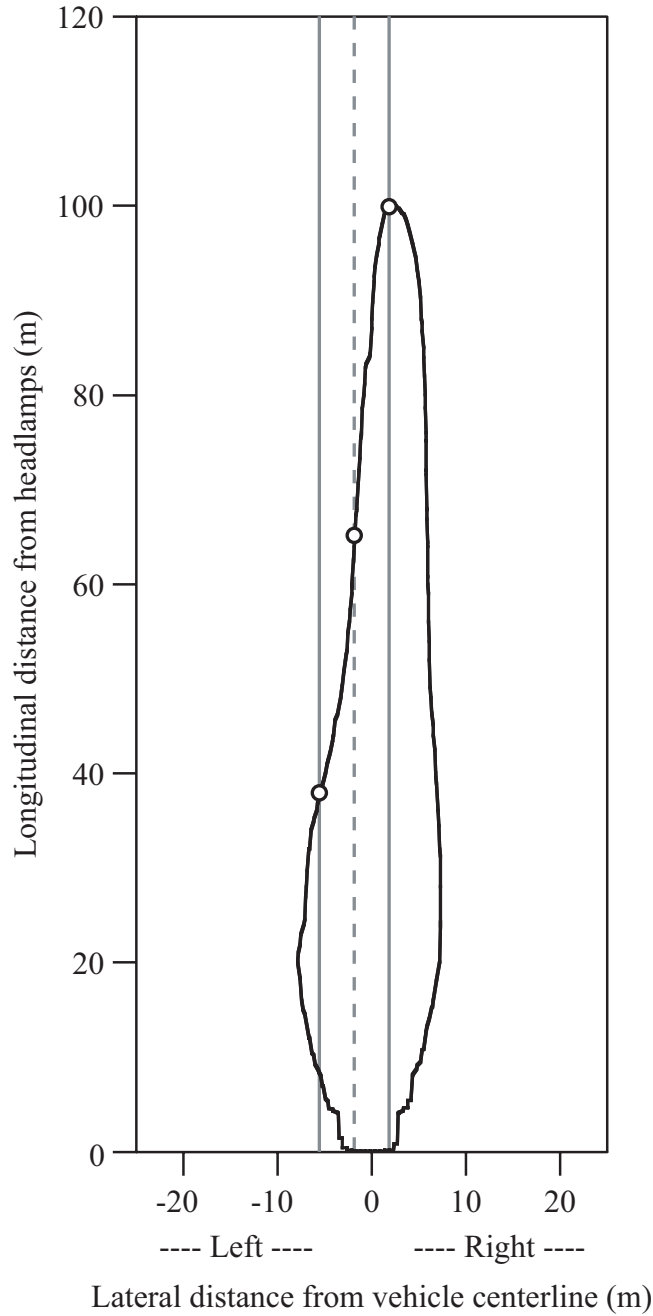


Figure 1. A schematic diagram of the three edgelines of a two-lane roadway, along with a superimposed 3-lux isoilluminance line at a height of 0.25 m above the roadway. (The vehicle was centered in the right lane.)

### Roadway scenarios

We used five roadway scenarios: straight roadway, and left and right curves with a constant radius of either 80 m (low speed) or 240 m (high speed).

## Results

Figure 2 shows the basic results for the straight roadway. This figure shows the changes in the distance of the 3-lux line as a function of the multiplier of the baseline low-beam pattern. The distances are normalized in such a way that the distance for the baseline low-beam pattern (i.e., a multiplier of 1) is set to 1. For comparison, the corresponding results for the high beam are also included. The analogous results for the curves are shown in Figure 3 (left curves) and Figure 4 (right curves).

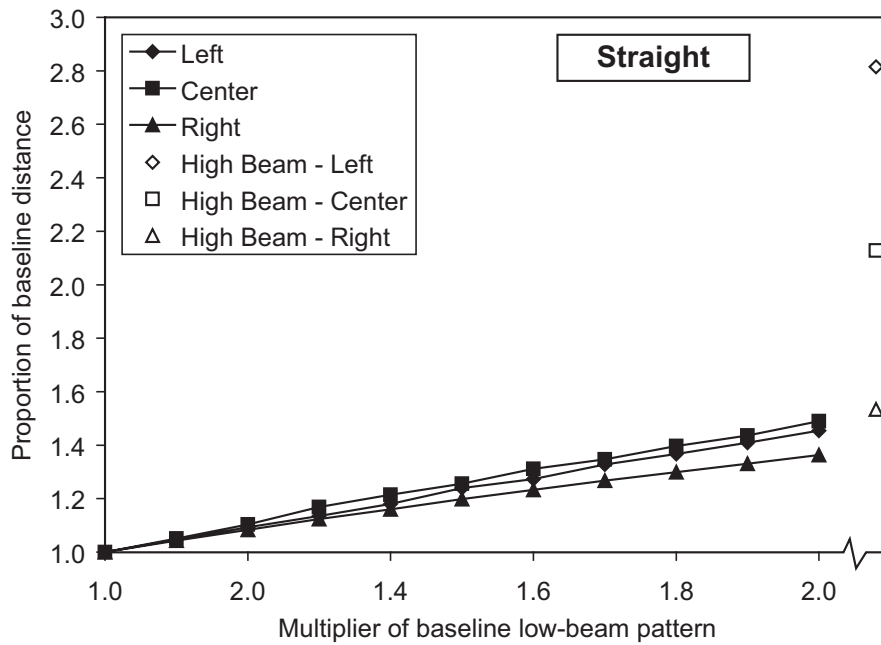


Figure 2. Changes in the distance of the 3-lux line at 0.25 m above the roadway as a function of the multiplier of the baseline low-beam pattern for straight roadway. (The distance for the baseline low-beam pattern is set to 1.)

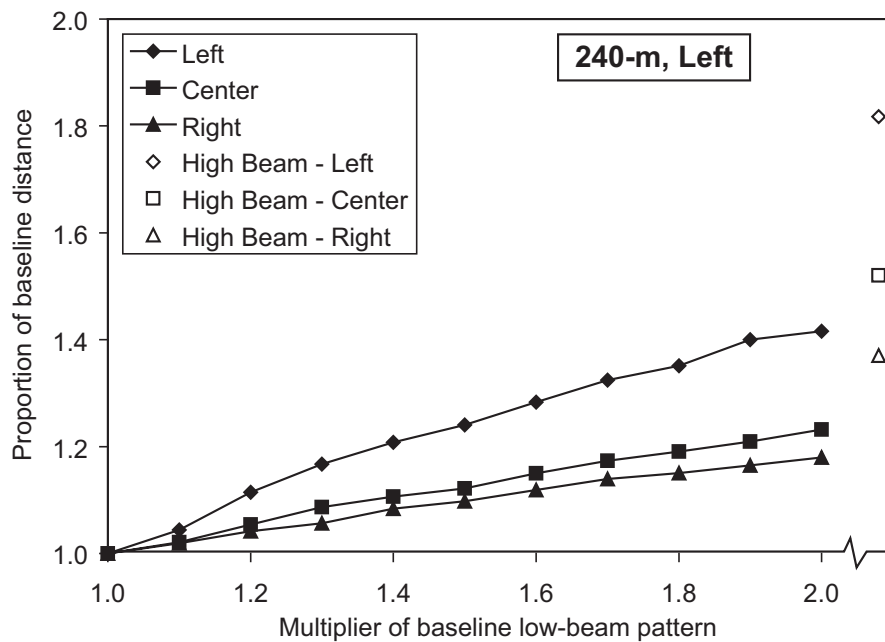
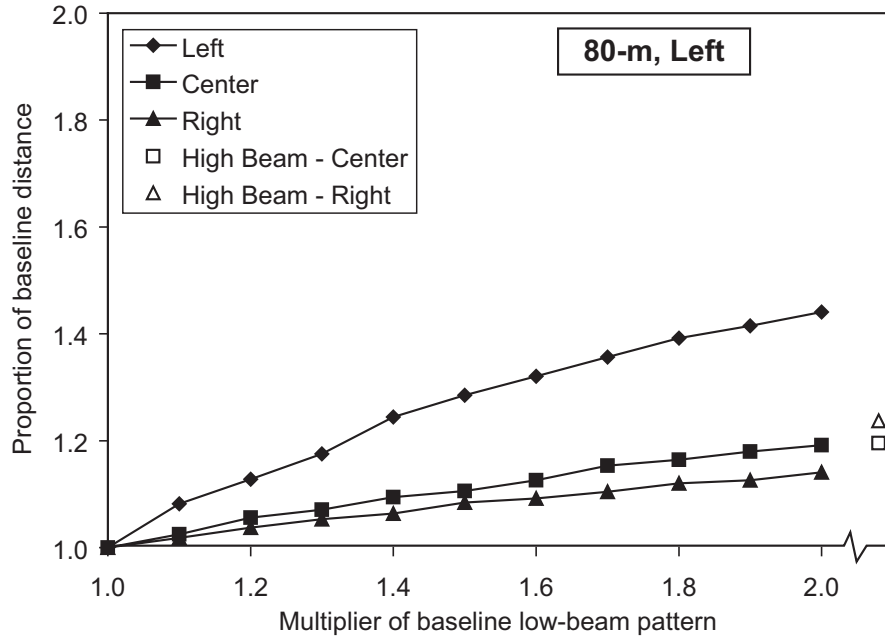


Figure 3. Changes in the distance of the 3-lux line at 0.25 m above the roadway as a function of the multiplier of the baseline low-beam pattern for the 80-m radius left curve (top panel) and for the 240-m radius left curve (bottom panel). Note that for the 80-m radius left curve, the 3-lux line for the high beam never reached the left edgeline. (The distance for the baseline low-beam pattern is set to 1.)

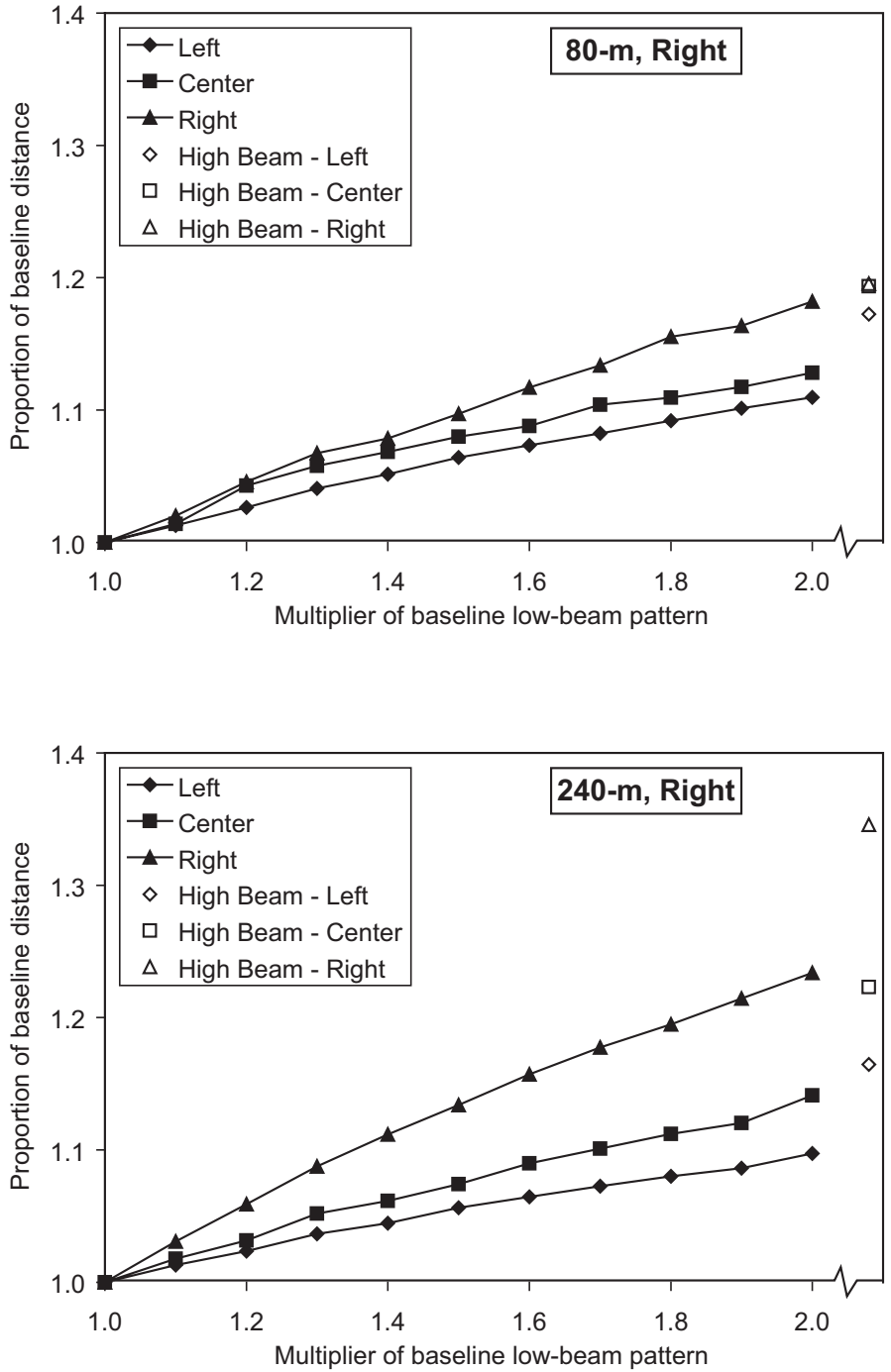


Figure 4. Changes in the distance of the 3-lux line at 0.25 m above the roadway as a function of the multiplier of the baseline low-beam pattern for the 80-m radius right curve (top panel) and for the 240-m radius right curve (bottom panel). (The distance for the baseline low-beam pattern is set to 1.)

Table 1 presents the main findings in a tabular form. It lists the distances of the 3-lux line as a function of the multiplier of the baseline low-beam pattern for three particular multipliers (1.2, 1.5, and 2.0), as well as for the high-beam pattern.

Table 1  
Proportional changes in the distance of the 3-lux line for three selected multipliers of the baseline low-beam pattern and for the high-beam pattern.

| Roadway           | Edgeline | Multiplier of the baseline low-beam pattern |      |      | High beam |
|-------------------|----------|---|------|------|-----------|
|                   |          | 1.2   | 1.5  | 2.0  |           |
| Straight          | Left     | 1.09  | 1.24 | 1.45 | 2.82      |
|                   | Center   | 1.10  | 1.26 | 1.49 | 2.13      |
|                   | Right    | 1.08  | 1.20 | 1.36 | 1.53      |
| 80-m left curve   | Left     | 1.13  | 1.28 | 1.44 | †         |
|                   | Center   | 1.06  | 1.11 | 1.19 | 1.20      |
|                   | Right    | 1.04  | 1.08 | 1.14 | 1.24      |
| 240-m left curve  | Left     | 1.11  | 1.24 | 1.42 | 1.82      |
|                   | Center   | 1.05  | 1.12 | 1.23 | 1.52      |
|                   | Right    | 1.04  | 1.10 | 1.18 | 1.37      |
| 80-m right curve  | Left     | 1.03  | 1.06 | 1.11 | 1.17      |
|                   | Center   | 1.04  | 1.08 | 1.13 | 1.19      |
|                   | Right    | 1.05  | 1.10 | 1.18 | 1.20      |
| 240-m right curve | Left     | 1.02  | 1.06 | 1.10 | 1.16      |
|                   | Center   | 1.03  | 1.07 | 1.14 | 1.22      |
|                   | Right    | 1.06  | 1.13 | 1.23 | 1.35      |

† The 3-lux line for the high beam never reached the left edgeline for this scenario.

## Discussion

### Main results

Visibility gain from a proportional increase in headlamp illumination throughout the beam pattern depends on the photometric distribution in the relevant part of the beam pattern. The increases in visibility (evaluated by the reach of the 3-lux line 0.25 m above the roadway) were greatest when considering the left edgeline of the left adjacent lane, followed by the left and right edgelines of the lane of travel. Furthermore, the increases in visibility were greatest on a straight road, followed by left and right curves.

On a straight roadway, a 20% increase in the overall headlamp illumination resulted in 8 to 10% increases in the reach of the 3-lux line (depending on the lateral position of interest). The corresponding visibility gains for a 50% increase in headlamp illumination ranged from 20% to 26%—qualifying for substantial gains (approximately 25%).

Visibility gains on curves were generally smaller. Comparable gains were achieved only for the left edgeline on the left curves. For example, for a 50% increase in headlamp illumination, the gains for all other scenarios ranges from 6% to 13%.

In summary, substantial gains in visibility (of about 25%) can be achieved on straight roadways by an increase of about 50% in the overall intensity of low beams. On curves, obtaining a substantial gain in visibility in several lateral positions would require significantly greater increase in light output.

### Isoilluminance line as an index of visibility

Using the reach of an isoilluminance line as an index of nighttime visibility has been proposed in several past studies (e.g., Owens and Francis, 1989; Andre and Owens, 2001; Flannagan and Sivak, 2005). Although it is probably adequate for the relative performance issues of concern in the current analyses, this approach provides a simplification for a complex interplay of several relevant parameters. For example, an overall increase in beam-pattern illumination will influence the adaptation level, and this is not taken into account when considering illuminance only. Also, the illuminance

criterion does not consider target size. The extent to which the omitted considerations are important should be investigated in the future.

### **High beams versus low beams**

Although high-beams produce greater peak luminous intensity than do low beams, their beam patterns are narrower (Schoettle, Sivak, and Flannagan, 2001). Consequently, it is not surprising that the visibility advantage of high beams over low beams with increased intensities was greatest on the straight-road scenario.

### **Implications for adaptive curve lighting**

Adaptive curve lighting involves turning the beam pattern into the curve (Sivak, Schoettle, Flannagan, and Minoda, 2004). The present results indicate that even a substantial increase in light output of current low beams leads to only a modest increase of visibility on curves. Consequently, the present findings provide indirect support for the use of adaptive lighting to substantially improve the visibility on curves.

### **Glare considerations**

Proportional increase in the output of low beams would increase the glare illumination for the oncoming drivers. Glare has two different aspects: disability (effects on visual performance), and discomfort (effects on comfort). A recent study found that, when both the seeing light and glare light are increased by the same proportion, more light is always better in terms of visibility (Flannagan, Sivak, Traube, and Kojima, 1996). Thus, disability glare should not be of concern if both the seeing and glare illumination are increased in tandem. Discomfort glare, on the other hand, would increase (Flannagan et al., 1996).

Consequently, implementation of any proportional increase in low-beam output depends on the tradeoff between improved visibility and worsened discomfort. The resolution of this tradeoff, however, is not a technical issue, but a matter of policy.

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