UMTRI-2000-1

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Report No. UMTRI-2000-1
January 2000

**Technical Report Documentation Page**


| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| UMTRI-2000-1 | | |
| 4. Title and Subtitle<br>A First Look at Visually Aimable and Harmonized Low-Beam Headlamps | | 5. Report Date<br>January 2000<br>6. Performing Organization Code<br>302753 |
| 7. Author(s)<br>Sivak, M., Flannagan, M.J., and Miyokawa, T. | | 8. Performing Organization Report No.<br>UMTRI-2000-1 |
| 9. Performing Organization Name and Address<br>The University of Michigan<br>Transportation Research Institute<br>2901 Baxter Road<br>Ann Arbor, Michigan 48109-2150 U.S.A. | | 10. Work Unit no. (TRAIS)<br>11. Contract or Grant No. |
| 12. Sponsoring Agency Name and Address<br>The University of Michigan<br>Industry Affiliation Program for<br>Human Factors in Transportation Safety | | 13. Type of Report and Period Covered<br>14. Sponsoring Agency Code |

15. Supplementary Notes

The Affiliation Program currently includes Adac Plastics, AGC America, Automotive Lighting, BMW, Britax International, Corning, DaimlerChrysler, Denso, Donnelly, Federal-Mogul Lighting Products, Ford, GE, GM NAO Safety Center, Guardian Industries, Guide Corporation, Hella, Ichikoh Industries, Koito Manufacturing, LESCOA, Libbey-Owens-Ford, LumiLeds, Magna International, North American Lighting, OSRAM Sylvania, Philips Lighting, PPG Industries, Reflexite, Reitter & Schefenacker, Stanley Electric, Stimsonite, TEXTRON Automotive, Valeo, Visteon, Yorka, 3M Personal Safety Products, and 3M Traffic Control Materials.
Information about the Affiliation Program is available at: http://www.umich.edu/~industry/


16. Abstract


This analytical study evaluated the performance of 40 first-generation low-beam headlamps that were either visually/optically aimable (VOA) or that met the GTB harmonized beam pattern, by comparing these low beams to conventional U.S., European, and Japanese low beams. The following aspects of headlamp performance were considered: visibility of pedestrians, visibility of pavement delineation, visibility of retroreflective traffic signs, visibility of vehicle rear reflex reflectors, visibility of targets near the road expansion point, glare directed towards oncoming drivers, glare directed towards rearview mirrors of preceding drivers, glare reflected from wet pavement towards oncoming drivers, and foreground illumination. For each performance aspect, typical geometric situations (points in space) were specified in terms of longitudinal, lateral, and vertical positions, and the corresponding visual angles from each of the two headlamps were calculated. The effects of the novel low beams were quantified by calculating the percent changes in luminous intensity directed from both lamps towards the points in space representing the performance aspects. The results are presented separately for the VOA lamps that are aimable on the left side (VOL lamps) and the right side (VOR lamps), as well as for the harmonized lamps. The present results could be used by lamp designers to maximize the advantages of the future versions of these novel low beams, while minimizing their disadvantages.



| 17. Key Words | 18. Distribution Statement |
|---|---|
| low beams, headlamps, nighttime, visibility, glare, aiming, harmonization, illumination, visual/optical | Unlimited |

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

## ACKNOWLEDGMENTS

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

Adac Plastics
AGC America
Automotive Lighting
BMW
Britax International
Corning
DaimlerChrysler
Denso
Donnelly
Federal-Mogul Lighting Products
Ford
GE
GM NAO Safety Center
Guardian Industries
Guide Corporation
Hella
Ichikoh Industries
Koito Manufacturing
LESCOA
Libbey-Owens-Ford
LumiLeds
Magna International
North American Lighting
OSRAM Sylvania
Philips Lighting
PPG Industries
Reflexite
Reitter & Schefenacker
Stanley Electric
Stimsonite
TEXTRON Automotive
Valeo
Visteon
Yorka
3M Personal Safety Products
3M Traffic Control Materials

# CONTENTS

# INTRODUCTION

Recently there were two major developments in standards for vehicle low-beam headlighting. In one of these developments, the U.S. government (FMVSS, 1997) introduced an option of having lamps labeled as visually/optically aimable (VOA). To be so labeled, the vertical gradient of the light output needs to meet certain minimum requirements, either to the left of the vertical (VOL) or to the right of the vertical (VOR). Although both VOL and VOR lamps have steeper vertical gradients than conventional U.S. lamps, the VOL lamps are conceptually similar to standard European lamps, while VOR lamps are more akin to the conventional U.S. lamps. In the second development, there has been major progress in worldwide harmonization of the low-beam pattern. GTB, an international group of lighting experts, reached an agreement in 1999 that is a compromise between North American emphasis on visibility and European concern with glare (GTB, 1999). This harmonized low-beam pattern is based on four test points recommended by Sivak and Flannagan (1993) as the starting point for agreement.

This report presents an assessment of 40 lamps that meet the VOA requirements or the GTB harmonized requirements. Because of the recentness of these developments, this is a first look at the advantages and disadvantages of real lamps meeting these two sets of requirements. The lamps were evaluated in terms of their light output towards several critical points in space that represent a variety of visibility and glare functions. The analysis involved comparisons of light output from these lamps to light output from conventional U.S. lamps from the late 1990s, and from European and Japanese lamps from the mid 1980s.

# METHOD

## Approach

The basic approach involved calculating the percent differences between conventional low beams and the novel low beams in luminous intensity directed from both headlamps towards points in space that represent major performance aspects of the beam pattern. We used the same approach as Sivak, Flannagan, and Miyokawa (1998).

## Changes that might matter

Human visual sensitivity is more closely related to percent changes in illumination than to absolute changes. For example, to detect a change in the intensity of a stimulus, the intensity needs to be increased by about 25% regardless of the baseline value (e.g., Huey, Decker, and Lyons, 1994; Sayer, Flannagan, Sivak, Kojima, and Flannagan, 1997). Thus, 25% is frequently used as an approximate benchmark for whether a change matters. Following this logic, we computed the percent changes from the baseline of the current light output to either the VOL, VOR, or harmonized lamps, to identify changes that might matter.

## Major performance aspects of low-beam headlamps

The following performance aspects were considered: visibility of pedestrians, visibility of road delineation, visibility of retroreflective traffic signs, visibility of reflex reflectors, visibility of targets near the road expansion point, glare directed towards oncoming drivers, glare directed towards rearview mirrors of preceding vehicles, glare reflected from wet pavement towards oncoming drivers, and foreground illumination. For each of the performance aspects, a typical geometric situation was specified in terms of longitudinal, lateral, and vertical positions (see Table 1), and the corresponding visual angles from each of the two headlamps were calculated (see Table 2).

Table 1
Positions of representative locations of the performance aspects, where *x* is the longitudinal distance from the headlamps, *y* is the lateral distance from the vehicle centerline, and *z* is the vertical distance from the ground. (All distances are in meters.)

| Performance aspect | $x$ | $y$ | $z$ |
|---|---|---|---|
| Visibility of a right pedestrian and road delineation at 100 m | 100 | 1.85 | 0 |
| Visibility of a right pedestrian and road delineation at 50 m | 50 | 1.85 | 0 |
| Visibility of a left pedestrian and road delineation at 100 m | 100 | -5.55 | 0 |
| Visibility of a left pedestrian and road delineation at 50 m | 50 | -5.55 | 0 |
| Visibility of a retroreflective sign; right shoulder at 150 m | 150 | 6.15 | 2.10 |
| Visibility of a retroreflective sign; center overhead at 150 m | 150 | 0 | 6.10 |
| Visibility of a retroreflective sign; left shoulder at 150 m | 150 | -9.85 | 2.10 |
| Visibility of a vehicle rear reflex reflector; right side at 20 m | 20 | 0.60 | 0.75 |
| Visibility of a vehicle rear reflex reflector; left side at 20 m | 20 | -0.60 | 0.75 |
| Visibility of a target near the road expansion point | $\infty$ | 0 | 0.62 |
| Glare towards an oncoming driver at 50 m | 50 | -3.35 | 1.11 |
| Glare towards a left mirror in the right adjacent lane at 20 m | 20 | 2.83 | 0.98 |
| Glare towards a center mirror in the same lane at 20 m | 20 | 0 | 1.24 |
| Glare towards a right mirror in the left adjacent lane at 20 m | 20 | -2.83 | 0.98 |
| Glare from wet pavement towards an oncoming driver at 50 m | 17.9 | -1.20 | 0 |
| Foreground illumination at 15 m | 15 | 0 | 0 |

Table 2
Angles (in degrees) of the representative locations for the performance aspects, with respect to each of the two headlamps.

| Performance aspect | Left lamp | Right lamp |
|---|---|---|
| Visibility of a right pedestrian and road delineation at 100 m | 1.4R, 0.4D | 0.7R, 0.4D |
| Visibility of a right pedestrian and road delineation at 50 m | 2.8R, 0.7D | 1.5R, 0.7D |
| Visibility of a left pedestrian and road delineation at 100 m | 2.9L, 0.4D | 3.5L, 0.4D |
| Visibility of a left pedestrian and road delineation at 50 m | 5.7L, 0.7D | 7.0L, 0.7D |
| Visibility of a retroreflective sign; right shoulder at 150 m | 2.6R, 0.6U | 2.1R, 0.6U |
| Visibility of a retroreflective sign; center overhead at 150 m | 0.2R, 2.1U | 0.2L, 2.1U |
| Visibility of a retroreflective sign; left shoulder at 150 m | 3.5L, 0.6U | 4.0L, 0.6U |
| Visibility of a vehicle rear reflex reflector; right side at 20 m | 3.3R, 0.4U | 0.1R, 0.4U |
| Visibility of a vehicle rear reflex reflector; left side at 20 m | 0.1L, 0.4U | 3.3L, 0.4U |
| Visibility of a target near the road expansion point | 0, 0 | 0, 0 |
| Glare towards an oncoming driver at 50 m | 3.2L, 0.6U | 4.5L, 0.6U |
| Glare towards a left mirror in the right adjacent lane at 20 m | 9.6R, 1.0U | 6.5R, 1.0U |
| Glare towards a center mirror in the same lane at 20 m | 1.6R, 1.8U | 1.6L, 1.8U |
| Glare towards a right mirror in the left adjacent lane at 20 m | 6.5L, 1.0U | 9.6L, 1.0U |
| Glare from wet pavement towards an oncoming driver at 50 m | 3.2L, 2.0D | 4.5L, 2.0D |
| Foreground illumination at 15 m | 2.1R, 2.4D | 2.1L, 2.4D |

**Visibility of pedestrians.** Pedestrians walking on the right edge line and on the left edge line of the left adjacent lane were considered. In these and all subsequent analyses the lane width was set at 3.7 m. Two distances were included (assuming two different approaching speeds): 100 m and 50 m. Feet were selected as the relevant location on the pedestrians (i.e., vertical position was set at 0 m above the roadway).

**Visibility of road delineation.** Two distances were selected for road delineation: 100 m and 50 m. Both the right edge line and the left edge line of the adjacent lane were included. (The delineation locations and pedestrian locations were identical.)

**Visibility of retroreflective traffic signs.** Three locations of retroreflective traffic signs were included: right shoulder-mounted, center overhead, and left shoulder-mounted—all at 150 m.

**Visibility of reflex reflectors on the rear of vehicles.** Both left and right reflectors were included, at a separation of 1.2 m. The mounting height chosen (0.75 m) is approximately the mean found in an informal survey of 61 cars, light trucks, and vans belonging to the staff of UMTRI (Sivak, Flannagan, and Miyokawa, 1998). The separation chosen corresponds to the mean value from that survey.

**Visibility of targets near the road expansion point.** The longitudinal distance here is infinity, the lateral offset is zero, and the vertical height is the same as that of the lamps. (For practical purposes, the lateral and vertical locations are arbitrary.)

**Glare directed towards oncoming drivers.** The oncoming driver was assumed to be in the left adjacent lane at a distance of 50 m. The oncoming driver's eye location was selected based on the market-weighted data in Sivak, Flannagan, Budnik, Flannagan, and Kojima (1996).

**Glare directed towards rearview mirrors of preceding cars.** All three mirrors were considered. For the center mirror, the preceding car was in the same lane. For the left mirror, the preceding car was in the right adjacent lane, while for the right mirror, it was in the left adjacent lane. The distance between the headlamps and the mirrors was set at 20 m. The mounting position of the mirrors was based on a late-model sedan.

**Glare reflected from wet pavement towards oncoming drivers.** The oncoming driver was assumed to be in the left adjacent lane at a distance of 50 m. The corresponding location on the pavement was calculated by assuming that the angle of reflection is equal to the angle of incidence.

**Foreground illumination.** The selected point corresponds to the pavement 15 m ahead and at the centerline of the vehicle.

## A simplifying assumption

An explicit assumption was made that a given amount of luminous intensity is equally effective whether it originated from the left lamp or the right lamp. This assumption is valid for diffusely reflecting materials. However, because the driver is not seated at the centerline of the vehicle, this assumption is not strictly correct when dealing with retroreflective materials (e.g., retroreflective traffic signs or vehicle reflex reflectors). Because of the offset of the driver toward the left side of the vehicle (for right-hand traffic), the observation angle (the angle between the headlamp, the retroreflective material, and the driver eye point) is smaller for the left lamp than for the right lamp. Consequently, a given amount of luminous intensity directed towards retroreflective objects is more effective if it originates from the left lamp than from the right lamp, because more light will be reflected back to the driver's eyes from the incident illumination that originated from the left lamp.

## LAMP SAMPLES

### VOA and harmonized lamps

Candela matrices of light output were obtained from 40 lamps that were produced by 8 different lamp manufacturers from North America, Europe, and Japan. Each of the lamps met either the VOA requirements or the GTB harmonized requirements (or both). Table 3 shows the requirements met by the lamps and the type of the light source. The 40 lamps were manufactured for 24 different vehicles. (There were 13 pairs of left and right lamps manufactured for 13 different vehicles, and 14 additional lamps manufactured for 11 different vehicles.)

Table 3
The breakdown of lamps by the requirements met and by the type of the light source.

| Light source | Visually/optically aimable (VOA) | | Harmonized | Total |
|---|---|---|---|---|
| | VOL | VOR | | |
| 9006 | 14 | 10 | 3 | 26* |
| 9007 | 0 | 5 | 2 | 7 |
| H4 | 2 | 0 | 0 | 2 |
| H7 | 1 | 0 | 0 | 1 |
| HID | 4 | 0 | 0 | 4 |
| Total | 21 | 15 | 5 | 40* |

*One lamp met both the VOL and harmonized requirements.

The photometry for 37 lamps was provided to us by the lamp manufacturers themselves, in response to our request for VOA lamps. Three additional lamps were purchased by us as VOA lamps, and they were photometered especially for this study.

The examined portion of the photometry matrices extended from 20° left to 20° right, and from 5° down to 5° up, all in 0.5° steps. The photometry was performed at 12.8 V. The analysis to follow uses the corresponding mean data.

**VOA requirements.** The compliance with the requirements for visually aimable lamps was not independently verified. Instead, we relied on the lamp manufacturers to assure that the lamps indeed met these requirements.

**Harmonized requirements.** The GTB harmonized low-beam requirements (GTB, 1999) are listed in Table 4. The photometry of each of the 40 lamps in Table 1 was compared against all but four requirements (see Table 4). (These four requirements dealt with light at 7° up and above, and our photometry matrix did not extend that far up.) Furthermore, the harmonized requirements allow a 0.25° reaim, which was not taken into account.

As indicated in Table 1, five of the tested lamps met the harmonized requirements. It is important to keep in mind that none of these five lamps were specifically designed to meet the harmonized requirements; they just happened to meet them. Had the designers explicitly tried to comply with these requirements, they might have come up with lamps having different beam patterns. Consequently, the present sample of lamps that met the harmonized requirements might not be representative of what lamps would be like, should they be designed with those requirements in mind.

Table 4
Photometric requirements of the GTB harmonized low beam (GTB, 1999).

| Test region | Angle (°) | | Luminous intensity (cd) | |
|---|---|---|---|---|
| | Vertical | Horizontal | Minimum | Maximum |
| Point 1 | 0.6D | 1.3R | 10,000 | |
| Point 2 | 0.86D | 0 | 4,500 | |
| Point 3 | 0.86D | 3.5L | 1,800 | 12,000 |
| Point 4 | 0.5U | 1.5L | | 840 |
| Point 5 | 0.5D | 4R | 5,000 | |
| Point 6 | 2D | 15L & 15R | 1,000 | |
| Point 7 | 4D | 20L & 20R | 300 | |
| Point 8 | 0 | 0 | | 1,800 |
| Point 9 | 0.5U | 2R | 600 | 2,500 |
| Line 10 | 4D | 4L to 4R | | < 30% of maximum and < 10,000 |
| Line 11 | 2D | 9L to 9R | 1,250 | |
| Line 12* | 7U | 10L to 10R | | 250, but 750 if within 2° cone |
| Line 13* | 10U | 10L to 10R | | 125, but 500 if within 2° cone |
| Line 14* | 10U to 90U | 0 | | 125, but 500 if within 2° cone |
| Point 15 | 4U | 8L | 77 | 840 |
| Point 16 | 4U | 0 | 77 | 840 |
| Point 17 | 4U | 8R | 77 | 840 |
| Point 18 | 2U | 4L | 155 | 840 |
| Point 19 | 2U | 0 | 155 | 840 |
| Point 20 | 2U | 4R | 155 | 840 |
| Point 21 | 0 | 8L | 77 | - |
| Point 22 | 0 | 4L | 155 | 840 |
| Zone 1 | 1U,8L-4U,8L-4U,8R-2U,8R-1.5U,6R-1.5U,1.5R-0,1L-0,4L-1U,8L | | | 840 |
| Zone 2 | > 4U to < 10U | 10L to 10R | | 250, but 750 if within 2° cone |
| Zone 3* | 10U to 90U | 10L to 10R | | 125, but 500 if within 2° cone |

*Not verified in the present study.

### Conventional U.S. lamps

To represent conventional U.S. low beams, we used the market-weighted data from Sivak, Flannagan, Kojima, and Traube (1997). That study photometered 35 low beams that were manufactured for use on 45% of all cars, light trucks, SUVs, and vans sold in the U.S. for model year 1997. The photometric information for each lamp was weighted by the 1997 sales figures for the corresponding vehicle. In the present analysis, we used the market-weighted median data for all vehicles from that study.

### Conventional European and Japanese lamps

The photometric information for these lamps was obtained in the mid 1980s by the Japan Automobile Research Institute, and the data were published by Sivak, Flannagan, and Sato (1993). The European sample included 37 lamps. The original Japanese sample included 48 lamps with a European-type beam pattern (the so-called ECE-J lamps) and 22 lamps with a U.S.-type beam pattern (the so-called SAE-J lamps). However, because currently most of the lamps in Japan are ECE-J lamps, only those lamps were included in the present analysis.

As with the VOA lamps, the photometric information for each lamp consisted of a candela matrix (in 0.5° steps). All lamps were measured at 12.8 V. To facilitate comparisons across jurisdictions, the candela matrices of lamps manufactured for left-hand traffic were converted to right-hand traffic. The European and Japanese lamps (that were used for the present analysis) were measured by using a standard bulb. The analysis used the corresponding median data.

# RESULTS

The basic results are shown in Tables 5 through 7. The entries in these tables are percent changes from conventional U.S., European, and Japanese low beams to either VOL, VOR, or harmonized low beams.

Table 5
Comparisons of the VOL lamps with conventional U.S., European, and Japanese lamps.
The entries are percent changes of the combined illumination from the left and right lamps.
Positive values indicate that the VOL lamps direct more light.

| Performance aspect | Conventional lamps | | |
|---|---|---|---|
| | U.S. | European | Japanese |
| Visibility of a right pedestrian and road delineation at 100 m | -22 | 69 | 158 |
| Visibility of a right pedestrian and road delineation at 50 m | -7 | 49 | 72 |
| Visibility of a left pedestrian and road delineation at 100 m | -20 | 33 | 45 |
| Visibility of a left pedestrian and road delineation at 50 m | 47 | 34 | 52 |
| Visibility of a retroreflective sign; right shoulder at 150 m | -53 | 141 | 99 |
| Visibility of a retroreflective sign; center overhead at 150 m | -28 | 49 | 35 |
| Visibility of a retroreflective sign; left shoulder at 150 m | -42 | 8 | -1 |
| Visibility of a vehicle rear reflex reflector; right side at 20 m | -34 | 41 | 53 |
| Visibility of a vehicle rear reflex reflector; left side at 20 m | -51 | 49 | 20 |
| Visibility of a target near the road expansion point | -46 | 134 | 73 |
| Glare towards an oncoming driver at 50 m | -43 | 10 | -1 |
| Glare towards a left mirror in the right adjacent lane at 20 m | -11 | -38 | -34 |
| Glare towards a center mirror in the same lane at 20 m | -37 | 39 | 24 |
| Glare towards a right mirror in the left adjacent lane at 20 m | -12 | 16 | 17 |
| Glare from wet pavement towards an oncoming driver at 50 m | 83 | 65 | 72 |
| Foreground illumination at 15 m | 9 | 62 | 69 |

Table 6
Comparisons of the VOR lamps with conventional U.S., European, and Japanese lamps.
The entries are percent changes of the combined illumination from the left and right lamps.
Positive values indicate that the VOR lamps direct more light.

| Performance aspect | Conventional lamps | | |
|---|---|---|---|
| | U.S. | European | Japanese |
| Visibility of a right pedestrian and road delineation at 100 m | 11 | 142 | 269 |
| Visibility of a right pedestrian and road delineation at 50 m | 11 | 78 | 106 |
| Visibility of a left pedestrian and road delineation at 100 m | 20 | 98 | 116 |
| Visibility of a left pedestrian and road delineation at 50 m | 45 | 32 | 50 |
| Visibility of a retroreflective sign; right shoulder at 150 m | -38 | 219 | 163 |
| Visibility of a retroreflective sign; center overhead at 150 m | -18 | 68 | 52 |
| Visibility of a retroreflective sign; left shoulder at 150 m | 4 | 93 | 77 |
| Visibility of a vehicle rear reflex reflector; right side at 20 m | -18 | 75 | 91 |
| Visibility of a vehicle rear reflex reflector; left side at 20 m | -3 | 196 | 140 |
| Visibility of a target near the road expansion point | 16 | 399 | 270 |
| Glare towards an oncoming driver at 50 m | 1 | 95 | 77 |
| Glare towards a left mirror in the right adjacent lane at 20 m | -29 | -51 | -48 |
| Glare towards a center mirror in the same lane at 20 m | -22 | 74 | 55 |
| Glare towards a right mirror in the left adjacent lane at 20 m | 14 | 51 | 52 |
| Glare from wet pavement towards an oncoming driver at 50 m | 68 | 51 | 58 |
| Foreground illumination at 15 m | 13 | 68 | 76 |

Table 7
Comparisons of the harmonized lamps with conventional U.S., European, and Japanese lamps. The entries are percent changes of the combined illumination from the left and right lamps. Positive values indicate that the harmonized lamps direct more light.

| Performance aspect | Conventional lamps | | |
|---|---|---|---|
| | U.S. | European | Japanese |
| Visibility of a right pedestrian and road delineation at 100 m | -18 | 78 | 172 |
| Visibility of a right pedestrian and road delineation at 50 m | 1 | 62 | 88 |
| Visibility of a left pedestrian and road delineation at 100 m | -23 | 27 | 39 |
| Visibility of a left pedestrian and road delineation at 50 m | 33 | 21 | 38 |
| Visibility of a retroreflective sign; right shoulder at 150 m | -53 | 141 | 98 |
| Visibility of a retroreflective sign; center overhead at 150 m | -33 | 39 | 26 |
| Visibility of a retroreflective sign; left shoulder at 150 m | -22 | 45 | 33 |
| Visibility of a vehicle rear reflex reflector; right side at 20 m | -49 | 8 | 18 |
| Visibility of a vehicle rear reflex reflector; left side at 20 m | -47 | 60 | 30 |
| Visibility of a target near the road expansion point | -58 | 82 | 34 |
| Glare towards an oncoming driver at 50 m | -24 | 47 | 33 |
| Glare towards a left mirror in the right adjacent lane at 20 m | -39 | -57 | -55 |
| Glare towards a center mirror in the same lane at 20 m | -38 | 38 | 22 |
| Glare towards a right mirror in the left adjacent lane at 20 m | 6 | 40 | 41 |
| Glare from wet pavement towards an oncoming driver at 50 m | 98 | 78 | 86 |
| Foreground illumination at 15 m | 30 | 93 | 101 |

The data in Tables 5 through 7 indicate the following changes in luminous intensity that were greater than 25%. (Because the comparisons to the conventional European and Japanese lamps proved to be similar, these two sets of lamps are treated here together. However, where differences do exist, they are pointed out. Also, for brevity, instead of "pedestrian/delineation" only "pedestrian" is being used here.)

**VOL versus conventional U.S. lamps**

- more light for a left pedestrian at 50 m
- less light for traffic signs at all three locations
- less light for vehicle reflex reflectors
- less light for targets near the road expansion point
- less direct glare
- less indirect glare via a center mirror in the same lane
- more indirect glare via wet pavement

**VOL versus conventional European and Japanese lamps**

- more light for pedestrians at all four locations
- more light for traffic signs on the right shoulder and center overhead
- more light for both vehicle reflex reflectors (except for a left reflector in relation to the Japanese lamps)
- more light for targets near the road expansion point
- no change in direct glare for incoming drivers
- less indirect glare via a left mirror in the right adjacent lane
- more indirect light via a center mirror in the same lane (in relation to the European lamps only)
- more indirect glare via wet pavement
- more foreground illumination

**VOR versus conventional U.S. lamps**

- more light for a left pedestrian at 50 m
- less light for traffic signs on the right shoulder
- less indirect glare via a left mirror in the right adjacent lane
- more indirect glare via wet pavement

**VOR versus conventional European and Japanese lamps**

- more light for pedestrians at all four locations
- more light for traffic signs at all three locations
- more light for vehicle reflex reflectors
- more light for targets near the road expansion point
- more direct glare for oncoming drivers
- less indirect glare via a left mirror in the right adjacent lane
- more indirect glare via a center mirror in the same lane, and a right mirror in the left adjacent lane
- more indirect glare via wet pavement
- more foreground illumination

**Harmonized versus conventional U.S. lamps**

- more light for a left pedestrian at 50 m
- less light for traffic signs on the right shoulder and center overhead
- less light for vehicle reflex reflectors
- less light for targets near the road expansion point
- less indirect glare via a left mirror in the right adjacent lane, and a center mirror in the same lane
- more indirect glare via wet pavement
- more foreground illumination

**Harmonized versus conventional European and Japanese lamps**

- more light for pedestrians at all four locations (except for a left pedestrian at 50 m in relation to the European lamps)
- more light for traffic signs at all three locations
- more light for a left vehicle reflex reflector
- more light for targets near the road expansion point
- more direct glare for oncoming drivers
- less indirect glare via a left mirror in the right adjacent lane
- more indirect glare via a center mirror in the same lane (in relation to the European lamps only), and via a right mirror in the left adjacent lane
- more indirect glare via wet pavement
- more foreground illumination

# DISCUSSION

## Lamp samples

The study used a reasonably large sample of VOA lamps: 21 VOL lamps and 15 VOR lamps. Thus, the performance trends observed in this study are likely to be indicative of current VOA lamps. On the other hand, the sample of lamps that met the GTB harmonized beam was rather small (5 lamps), and these lamps were not designed with the harmonized beam pattern in mind. Consequently, it is unclear how well these lamps would represent lamps that would be designed to conform to the harmonized requirements.

## Comparisons to the conventional U.S. lamps

In relation to the conventional U.S. lamps, the VOA and harmonized lamps would be expected to provide *more* light on the left side of the beam pattern. That proved to be the case: there was more light from the VOL, VOR, and harmonized lamps for the visibility of pedestrians and road delineation at a near distance (50 m). However, a consequence of more light in this area is more reflected light from wet pavement towards oncoming traffic.

On the other hand, the VOA and harmonized lamps would be expected to provide *less* seeing light for traffic signs, vehicle reflex reflectors, and targets near the road expansion point, and *less* glare light for oncoming drivers and for preceding drivers via rearview mirrors. Although these patterns were generally present for the VOL and harmonized lamps, they were generally absent for the VOR lamps. Specifically, for the VOR lamps there was decrease in light for traffic signs at only one of the three tested sign locations, no decrease in light for reflex reflectors or for targets near the road expansion point, no decrease in glare for oncoming drivers, and decrease in rearview mirror glare at only one of the three tested mirror positions.

The harmonized lamps, but not the VOR or VOL lamps, provided more foreground illumination, as measured on the pavement 15 m in front of the vehicle.

## Comparisons to the conventional European and Japanese lamps

A comparison of the VOA and harmonized lamps to the conventional European and Japanese lamps provides a different picture. Predictably, there were three general trends: First, the novel lamps provided more seeing light, be it for pedestrians, road delineation, traffic signs, vehicle reflex reflectors, or targets near the road expansion point. Second, the novel lamps tended to provide more glare light, be it direct glare or indirect glare (via rearview mirrors or wet pavement). (However, there were two major exceptions to these trends: The VOL lamps did not provide substantially more light on the left side of the beam pattern than did the conventional European and Japanese lamps. Consequently, the VOL lamps provided no increase in light for signs on the left shoulder, no increase in glare for oncoming drivers, and no increase in glare via a right mirror in the left adjacent lane. Also, the harmonized lamps provided less indirect glare from a left mirror in the right adjacent lane.) Third, the novel lamps provided more foreground illumination.

### The utility of the present findings

The purpose of this study was to provide an indication of the changes in performance with the first generation of the VOA lamps, and lamps that meet the GTB harmonized beam. Because it is early in the production of such lamps, the present results could be used by lamp designers to maximize the advantages of the future versions of these novel low beams, while minimizing their disadvantages.

## REFERENCES


FMVSS (Federal Motor Vehicle Safety Standards). (1997). Standard No. 108: Lamps, reflective devices, and associated equipment. In *Code of Federal Regulations, [Title] 49, Part 571*. Washington, D.C. Office of the Federal Register.

GTB (Groupe de Travail Bruxelles 1952). (1999). *Rationale of harmonized dipped (low) beam pattern* (Report No. C.E.-3160). Geneva, Switzerland: GTB.

Huey, R., Decker, D., and Lyons, R. (1994). *Driver perception of just-noticeable differences of automotive signal lamp intensities* (Report No. DOT HS 808 209). Washington, D.C.: National Highway Traffic Safety Administration.

Sayer, J.R., Flannagan, M.J., Sivak, M., Kojima, S., and Flannagan, C.C. (1997). *Just noticeable differences for low-beam headlamp intensities* (Report No. UMTRI-97-4). Ann Arbor: The University of Michigan Transportation Research Institute.

Sivak, M. and Flannagan, M.J. (1993). *Partial harmonization of international standards for low-beam headlighting patterns* (Report No. UMTRI-93-11). Ann Arbor: The University of Michigan Transportation Research Institute.

Sivak, M., Flannagan, M.J., Budnik, E.A., Flannagan, C.C., and Kojima, S. (1996). *The locations of headlamps and driver eye positions in vehicles sold in the U.S.* (Report No. UMTRI-96-36). Ann Arbor: The University of Michigan Transportation Research Institute.

Sivak, M., Flannagan, M.J., Kojima, S., and Traube, E.C. (1997). *A market-weighted description of low-beam headlighting patterns in the U.S.* (Report No. UMTRI-97-37). Ann Arbor: The University of Michigan Transportation Research Institute.

Sivak, M., Flannagan, M.J., and Miyokawa, T. (1998). *Quantitative comparisons of factors influencing the performance of low-beam headlamps* (Report No. UMTRI-98-42). Ann Arbor: The University of Michigan Transportation Research Institute.

Sivak, M., Flannagan, M.J., and Sato, T. (1993). *Light output of U.S., European, and Japanese low-beam headlamps* (Report No. UMTRI-93-26). Ann Arbor: The University of Michigan Transportation Research Institute.