UMTRI-2005-25

REARVIEW MIRROR GLARE WITH VARYING VEHICLE GEOMETRIES

Michael J. Flannagan

September 2005

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Michael J. Flannagan

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

Report No. UMTRI-2005-25
September 2005

Technical Report Documentation Page

1. Report No. UMTRI-2005-25	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Rearview Mirror Glare with Varying Vehicle Geometries		5. Report Date September 2005 6. Performing Organization Code 302753
7. Author(s) Flannagan, M.J.		8. Performing Organization Report No. UMTRI-2005-25
9. Performing Organization Name and Address The University of Michigan Transportation Research Institute 2901 Baxter Road Ann Arbor, Michigan 48109-2150 U.S.A.		10. Work Unit no. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address The University of Michigan Industry Affiliation Program for Human Factors in Transportation Safety		13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplementary Notes

The Affiliation Program currently includes Autoliv, Avery Dennison, Bendix, BMW, Bosch, Com-Corp Industries, DaimlerChrysler, DBM Reflex, Decoma Autosystems, Denso, Federal-Mogul, Ford, GE, General Motors, Gentex, Grote Industries, Guide Corporation, Hella, Honda, Ichikoh Industries, Koito Manufacturing, Lang-Mekra North America, Magna Donnelly, Muth, Nissan, North American Lighting, OLSA, OSRAM Sylvania, Philips Lighting, PPG Industries, Renault, Schefenacker International, Sisecam, SL Corporation, Solutia Performance Films, Stanley Electric, Toyoda Gosei North America, Toyota Technical Center USA, Truck-Lite, Valeo, Visteon, 3M Personal Safety Products, and 3M Traffic Safety Systems.
Information about the Affiliation Program is available at: http://www.umich.edu/~industry/

16. Abstract

The potential glare from rearview mirrors was quantified in simulated encounters using data on the locations of mirrors and headlamps, and on the photometric output of low-beam headlamps. This was done for two classes of vehicles (passenger cars, and light trucks and vans [LTVs]) in the roles of the vehicle subject to the glare and the vehicle producing the glare.

The results indicate that, in many encounters with glare vehicles to the rear, there will be a substantial disparity in glare, both among vehicles of different classes and among different mirror locations on a single vehicle. The main reason for this is the strong role of mirror height in determining how much a mirror is exposed to the lower, and therefore stronger, portion of a low-beam light pattern. There is substantially greater potential for high glare values on the mirrors of passenger cars versus LTVs. and on the driver-side mirror versus the center rearview mirror on all vehicles. With upward misaim of headlamps, these disparities are increased, as is the absolute level of potential glare. The relatively low potential for glare on the center mirrors of LTVs will often be compounded by the low transmittance of privacy glass on those vehicles.

The present results have implications for where glare light should be sensed in order to control automatic anti-glare mirrors. However, specific recommendations should incorporate two additional considerations: (1) the geometry of a given vehicle, including the actual heights of the rearview mirrors and how the potential fields of view of those mirrors are affected by opaque parts of the vehicle, and (2) quantification of the exposure to glare that vehicles experience in actual traffic, including the frequencies at which glare vehicles are encountered in the fields of view of the individual mirrors.

17. Key Words rearview mirrors, glare, headlamps, passenger cars, light trucks, vans, antiglare mirrors, vehicle geometry		18. Distribution Statement Unlimited	
19. Security Classification (of this report) None	20. Security Classification (of this page) None	21. No. of Pages 19	22. Price

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:

Autoliv
Avery Dennison
Bendix
BMW
Bosch
Com-Corp Industries
DaimlerChrysler
DBM Reflex
Decoma Autosystems
Denso
Federal-Mogul
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Truck-Lite
Valeo
Visteon
3M Personal Safety Products
3M Traffic Safety Systems

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INTRODUCTION

Glare from headlamps reflected in rearview mirrors is different in several ways from glare caused by oncoming vehicles. As pointed out by Olson and Sivak (1984), glare from rearview mirrors is compounded because headlamps are often visible in more than one mirror, and because exposure to glare from rearview mirrors is often of much longer duration. The difference in duration is due to the fact that a following vehicle, unlike an oncoming vehicle, may remain in the same relative position for a long time. However, the problem of rearview mirror glare is in some ways more tractable than the problem of oncoming glare. Several options are available to reduce mirror glare while still allowing a driver to see adequately in the rearview mirror. Prism mirrors, which can be switched between reflectance of about 80% and 4%, have been widely used for many years. Electronic, variable reflectance mirrors are now also widely available. In order to make the best use of such countermeasures, it is useful to know how the geometry of a vehicle and the locations of the mirrors affect the amount of glare to which each mirror will be exposed. This report outlines the major differences in the glare levels that can be expected on the mirrors of different vehicle classes (passenger cars versus light trucks and vans [LTVs]) and on different mirrors of a single vehicle.

The geometry that must be considered to analyze glare from rearview mirrors is somewhat more complicated than the corresponding geometry for oncoming glare. In the case of oncoming glare, only one vantage point is of concern—the actual location of the driver's eyes. In contrast, for rearview-mirror glare, the virtual eye points of the driver in the individual mirrors must be considered. This distinction is particularly important because the locations of the mirrors (and therefore the virtual eye points of the driver) are both higher and lower than the driver's actual eye point. This fact, combined with the strong vertical gradients in the light from low-beam headlamps (e.g., Sivak, Flannagan, & Sato, 1993), means that glare from rearview mirrors will tend to be both more intense (for lower-mounted mirrors) and less intense (for higher-mounted mirrors) than oncoming glare. (For present purposes, the consequences of the horizontal difference in vantage points between the right and left eyes are small and can be neglected.) An example of the importance of vantage-point height can be seen in the Society of Automotive Engineers report on headlamp mounting height (SAE, 2002). In that report, the recommended maximum mounting height for headlamps (850 mm at the center of the lamp) is based on consideration of glare light impinging on driver-side rearview mirrors.

Several aspects of vehicle geometry, including the differences in mirror locations within a single vehicle and the differences in size and configuration between vehicle types, affect the glare levels that rearview mirrors are exposed to. In this report, data from previous UMTRI reports on mirror locations, headlamp locations, and headlamp photometry are combined to determine the relative importance of such differences.

METHOD

Data from a number of previous UMTRI reports were used to characterize the geometries of a variety of simulated encounters between a subject vehicle and a rearward glare vehicle on a straight, level, multilane road. The simulations were performed for two classes of vehicles: (1) passenger cars, and (2) light trucks and vans (LTVs). The glare sources were recent U.S. low-beam headlamps. The primary dependent variable was the illuminance produced by headlamps at the driver's virtual eye points corresponding to the various rearview mirrors.

Headlamp photometry

The representation of light output from headlamps was the median photometry for low-beam headlamps on U.S. passenger vehicles (including passenger cars and LTVs) of the 2004 model year as reported by Schoettle, Sivak, Flannagan, and Kosmatka (2004). For angular locations near the center of the beam pattern, which include most of the locations of interest in the simulations performed in the present study, candela values in that report were given at half-degree increments. In the simulations, candela values for angles in between were obtained by interpolation.

Vehicle geometry

The locations of rearview mirrors were taken from two recent surveys of rearview mirrors on passenger cars (Reed, Lehto, & Flannagan, 2000) and LTVs (Reed, Ebert, & Flannagan, 2001). Headlamp locations on the same two classes of vehicles were taken from Schoettle, Sivak, and Nakata (2002).

Driver behavior and vehicle separation

Data from an extensive study of naturalistic driving with instrumented vehicles were used to determine the range of typical following distances in moving traffic. At speeds above 40 miles per hour, the average following distance was 34.0 m behind light trucks and 39.6 m behind passenger cars (Sayer, Mefford, & Huang, 2000). In the simulations, 30 m was used as the primary value for the separation between the mirrors of the subject vehicle (i.e., the forward vehicle) and the headlamps of the rearward glare vehicle. This separation is therefore toward the low end of the range of conditions that drivers typically encounter in moving traffic.

Procedure

The geometric information about locations of headlamps and rearview mirrors was combined with the photometric information about the output of low-beam headlamps to derive the illuminance produced by the headlamps at the driver's virtual eye points corresponding to various rearview mirrors. The virtual eye points are simply the images of the driver's eyes as they would be seen reflected in the mirrors. As an approximation, these points can be thought of as the locations of the mirrors themselves, although they are actually located short distances behind the reflective surfaces of the mirrors. In all cases, the small differences in horizontal location between the right and left eyes were neglected, and the midpoint between the eyes was used as a single nominal eye point.

The angular locations of the driver's mirror eye points relative to the headlamps were determined and the corresponding candela values were derived by interpolation within the values for the headlamps as given in Schoettle et al. (2004). Illuminance values were then determined by applying the inverse-square law for the distances between the lamps and the eye points. This was done for left and right headlamps individually, although the results reported here are all for the combined output of left-right pairs of lamps.

Except as discussed below, the glare values reported here do not take into account mirror reflectance, window transmittance, possible obstruction by opaque parts of the vehicle, or the possibility that certain headlamps would not be visible to the driver because the aiming of a particular mirror would exclude them from the field of view of that mirror.

RESULTS AND DISCUSSION

Results are reported first for the effects of vehicle class, mirror location, and lane position at the standard distance of 30 m. The more general effect of distance is then illustrated for selected cases, and the effects of headlamp misaim are examined.

Effects of vehicle class, mirror location, and lane position

Table 1 shows the effect of vehicle type on glare values on the center rearview mirror for cases in which the glare vehicle is in the lane directly behind the subject vehicle. The glare values range from 0.91 lux to 3.20 lux, depending on the classes of both the subject vehicle and the glare vehicle. As expected from the vertical gradients of low beams, the glare is greater when the lamps are higher (as they are on LTVs versus passenger cars) and when the mirrors are lower (as they are on passenger cars versus LTVs).

Table 2 shows the glare values for the driver-side rearview mirror under the same conditions. All values are substantially higher than for the center mirror, consistent with the vertical gradients of the low beams.

Table 3 shows the glare values for the passenger-side mirror. All values are substantially higher than those in Table 1 for the center mirror, and even higher than the values for the driver-side mirror in Table 2. This is because, in addition to the strong vertical gradients, low beams also typically have horizontal gradients in this region that involve more light toward the right. However, two special circumstances apply to the passenger-side mirror that do not apply to the other two mirrors: the passenger-side mirror is almost always convex, and it is at a greater angle from the driver's forward line of sight. Both of these circumstances result in glare from the passenger-side mirror having less effect than glare from the other two mirrors.

Models are available in the literature to provide estimates for how much difference can be expected between the effects of glare from passenger-side mirrors and the effects of glare from the other mirrors. The effect of convexity varies with radius of curvature and vehicle geometry, but Platzer (1995) estimated that for a typical passenger car situation, the convexity reduced glare by a factor of about 0.15. Reed et al. (2000) provide information about mirror locations, indicating that both the driver-side and center rearview mirrors are typically about 45 degrees from the driver's forward line of sight, while the passenger-side mirror is substantially further out, at about 65 degrees. The greater eccentricity of the passenger-side mirror reduces both the subjective and objective effects of glare. The subjective effects (discomfort glare) can be predicted approximately by the de Boer equation (Schmidt-Clausen & Bindels, 1974). The objective effects (disability glare) can be predicted approximately by the equivalent veiling luminance (CIE, 1981). For an increase in eccentricity from 45 to 65 degrees, the decrease in discomfort glare is predicted to be equivalent to a reduction in illuminance by a factor of 0.84. The corresponding decrease in objective effects is predicted to be equivalent to a reduction in illuminance by a factor of 0.29. Combining these estimates with Platzer's value for the effect of convexity leads to estimated reductions in passenger-side glare effects by factors of 0.15 x 0.84 = 0.13 and 0.15 x 0.29 = 0.04 for the subjective and objective effects, respectively. Therefore, even considering that passenger-side mirrors may be exposed to greater glare than mirrors in the other two positions, the effects of glare from passenger-side mirrors can be expected to be relatively minor.

Table 1. Glare illuminance (lux) for the center rearview mirror with the glare vehicle in the same lane as the subject vehicle.

		Glare vehicle	
		Car	LTV
Subject vehicle	Car	1.33	3.20
	LTV	0.91	1.18

Table 2. Glare illuminance (lux) for the driver-side rearview mirror with the glare vehicle in the same lane as the subject vehicle.

		Glare vehicle	
		Car	LTV
Subject vehicle	Car	2.44	7.25
	LTV	1.17	2.28

Table 3. Glare illuminance (lux) for the passenger-side rearview mirror with the glare vehicle in the same lane as the subject vehicle.

		Glare vehicle	
		Car	LTV
Subject vehicle	Car	5.05	16.81
	LTV	1.33	4.50

Table 4 shows the ratios between the glare levels for the center mirror, from Table 1, and the glare levels for the driver-side mirror, from Table 2. The discrepancy between the two mirror locations is correlated with the absolute glare values, being highest (a factor of 2.27) for the case of a passenger car as the subject vehicle and an LTV as the glare vehicle.

Table 4. Ratios between glare illuminance (driver-side over center rearview mirror) with the glare vehicle in the same lane as the subject vehicle.

		Glare vehicle	
		Car	LTV
Subject vehicle	Car	1.83	2.27
	LTV	1.29	1.93

In most traffic situations, the glare levels observed at the center mirror will be substantially lower than the glare levels observed at the driver-side mirror. In the case of LTVs, this difference will often be compounded by the use of privacy glass for the rear window (but not for the side window through which the driver-side mirror is viewed). Data for rear-window transmittance were sampled in a survey of the 20 best selling U.S. vehicles in 1999 (Sayer, Mefford, & Huang, 2000). For passenger cars, which are subject to the federal standards for minimum transmittance, the mean transmittance, measured normal to the glass surface, was 77.2%. For LTVs with privacy glass, the corresponding mean value was 18.0%. The reduction in glare attributable to privacy glass rather than ordinary glass can therefore be estimated as a factor of 18.0 / 77.2 = 0.23. For example, the estimate in Table 4 that the glare from passenger car headlamps on the driver-side mirror of LTVs is about 2.27 times greater than the glare on the center mirror can be adjusted for the lower glass transmittance that applies to the center mirror of a vehicle with privacy glass: 2.27 / 0.23 = 9.87. Thus, the glare exposure of the driver-side mirror is estimated to be about 10 times greater than that of the center mirror.

The glare values in Tables 1, 2, and 3 range from 0.91 to 16.81 lux. There is no simple criterion to use in judging at what level glare becomes a problem. However, that level is probably somewhere in the range of these values. For example, Olson and Sivak (1984) found that the level of rearview mirror glare that evoked a response at the midpoint on the de Boer scale of discomfort glare (corresponding to a verbal anchor of “just admissible” glare) was 3 to 6 lux, depending of duration of the glare stimulus. Because the lux values in this report do not take into account window transmittance, these candidate criterion values should be adjusted for transmittance. However, they are only approximate in any case.

Table 5 shows the same conditions as in Table 1, but for the glare vehicle one lane to the left of the subject vehicle. All glare values for the center rearview mirror are somewhat lower when the glare vehicle is one lane to the left rather than in the same lane as the subject vehicle. Corresponding results for the driver-side mirror are shown in Table 6. In contrast to the center mirror, the glare values for the driver-side mirror are all slightly higher with the glare vehicle one lane to the left. As a consequence of these opposite effects, the discrepancies in glare values between the driver-side mirror and the center mirror (shown in Table 7) are even higher when the glare vehicle is one lane to the left. As in Table 3, the larger discrepancies occur with the higher absolute glare values.

Figure 1 highlights the relative magnitudes of the effects of mirror locations and lane positions on potential glare. The values in this figure are the overall means from Tables 1, 2, 5, and 6. Driver-side rearview mirrors are subject to considerably more glare than center rearview mirrors, and this is true for glare vehicles in either the same lane or one lane to the left.

Table 5. Glare illuminance (lux) for the center rearview mirror with the glare vehicle one lane to the left of the subject vehicle.

		Glare vehicle	
		Car	LTV
Subject vehicle	Car	1.03	1.59
	LTV	0.75	0.96

Table 6. Glare illuminance (lux) for the driver-side rearview mirror with the glare vehicle one lane to the left of the subject vehicle.

		Glare vehicle	
		Car	LTV
Subject vehicle	Car	2.50	8.36
	LTV	1.18	2.65

Table 7. Ratios between glare illuminance (driver-side over center rearview mirror) with the glare vehicle one lane to the left of the subject vehicle.

		Glare vehicle	
		Car	LTV
Subject vehicle	Car	2.43	5.26
	LTV	1.57	2.76

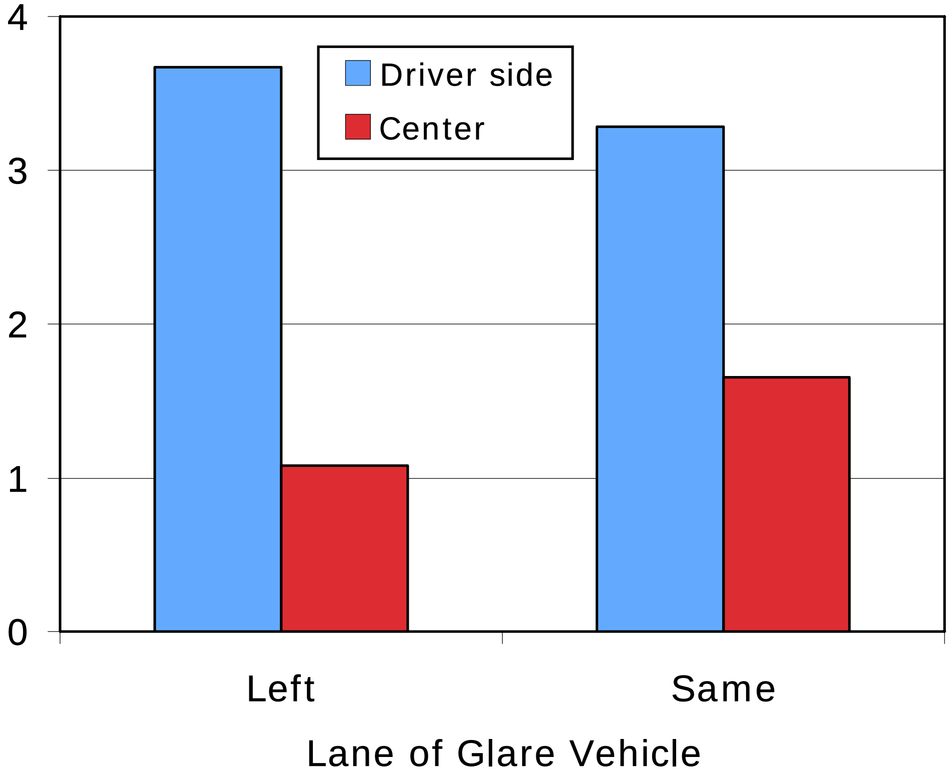

Figure 1. The relative consequences for rearview mirror glare of the location of the mirror on the subject vehicle and lane location of the glare vehicle.

Effects of distance

Figure 2 shows the effect of distance (from the glare headlamps to the mirror) on glare exposure in two cases: (1) glare from a passenger car in the same lane as the subject vehicle on the center mirror of an LTV, and (2) glare from an LTV one lane to the left of the subject vehicle on the driver-side mirror of a passenger car. These two cases were chosen to illustrate the largest difference in glare based on vehicle class, mirror location, and lane position. When the values of these variables associated with less glare are chosen (the lower function in Figure 2), glare is never very high, and falls off rapidly with greater distance. When the values associated with more glare are chosen (the upper function in Figure 2), glare is high over a wide range of separations. The main reason for the lack of substantial change with distance is that, at greater distances, which would normally be associated with lower glare because of the inverse-square law, the angular location of the mirror is closer to the high-intensity zone near the center of the headlamp beam pattern. The effects of the inverse-square law and the shift to higher intensity parts of the beam pattern roughly compensate for each other over this range.

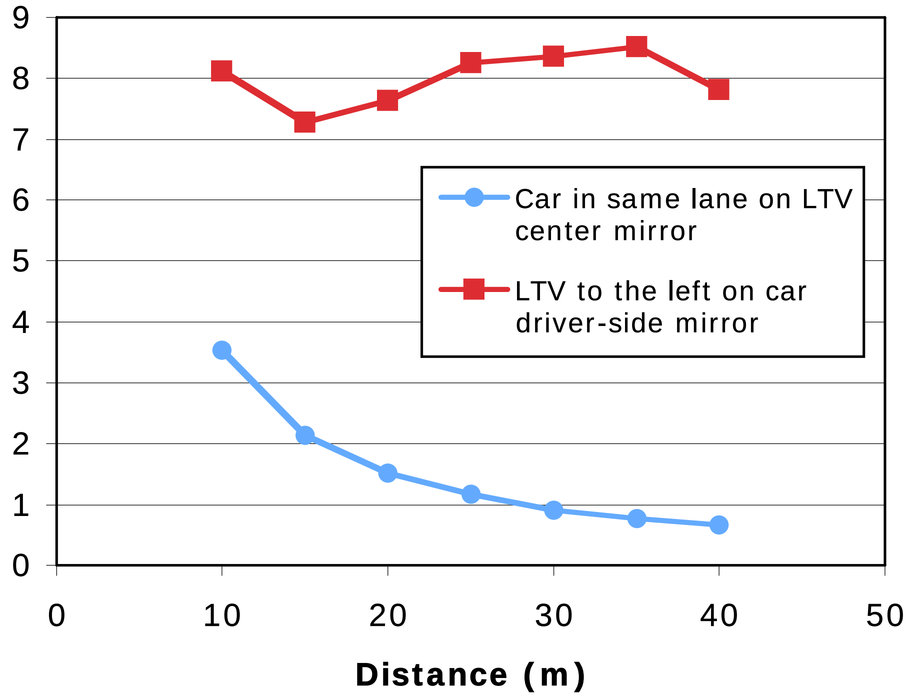

Figure 2. Glare as a function of distance for two cases (glare from a passenger car in the same lane on the center mirror of an LTV, and glare from an LTV one lane to the left on the driver-side mirror of a passenger car).

Consequences of headlamp misaim

Copenhaver and Jones (1992) found the standard deviation of vertical aim for the headlamps of vehicles in use to be about 0.65 degrees. Table 8 shows glare values that would be produced by lamps misaimed up by one standard deviation (0.65 degrees) on the center rearview mirror, for cases in which the glare vehicle is one lane to the left of the subject vehicle. The glare values range from 0.99 lux to 3.15 lux, depending on the classes of both the subject vehicle and the glare vehicle. Comparison to the values in Table 1 indicates that the misaim produces only slightly higher glare (or even a slight reduction, from 3.20 to 3.15 lux, in the case of an LTV glare vehicle and a passenger car subject vehicle). In contrast, as shown in Table 9, the corresponding values for the driver-side rearview mirror under the same conditions are substantially higher with upward misaim. As a consequence of this contrast, the disparities between glare on the driver-side mirror and the center mirror for upward misaim, shown in Table 10, are much higher than the corresponding values for nominal aim, shown in Table 4.

In terms of absolute values, even with misaim the glare levels on the center mirror are only moderate, generally lower than the criterion values of 3 and 6 lux identified by Olson and Sivak (1984). Especially for LTVs as subject vehicles, the center mirror is not exposed to high glare levels, and for LTVs with privacy glass these levels would be reduced even further. For example, using the factor of 0.23 discussed above for privacy glass, the value for the center mirror of an LTV exposed to glare from an LTV would be 1.40 x 0.23 = 0.32 lux. The resulting discrepancy between the center and driver-side mirrors would be 10.29 / 0.32 = 32.2 times more glare on the driver-side mirror.

Table 8. Glare illuminance (lux) for the center rearview mirror with the glare vehicle one lane to the left of the subject vehicle, with headlamps aimed 0.65 degrees up.

		Glare vehicle	
		Car	LTV
Subject vehicle	Car	1.92	3.15
	LTV	0.99	1.40

Table 9. Glare illuminance (lux) for the driver-side rearview mirror with the glare vehicle one lane to the left of the subject vehicle, with headlamps aimed 0.65 degrees up.

		Glare vehicle	
		Car	LTV
Subject vehicle	Car	8.32	51.60
	LTV	3.85	10.29

Table 10. Ratios between glare illuminance (driver-side over center rearview mirror) with the glare vehicle one lane to the left of the subject vehicle, with headlamps aimed 0.65 degrees up.

		Glare vehicle	
		Car	LTV
Subject vehicle	Car	4.32	16.38
	LTV	3.88	7.36

The general form of the photometric consequences of misaim for discrepancies in glare between driver-side and center mirrors can be understood by considering the location of the strong cutoff line that often exists in low-beam light patterns. As a simple case, consider one particular type of headlamps: visual/optical aim headlamps with the defined cutoff on the right side of the beam pattern (designated VOR lamps). In Federal Motor Vehicle Safety Standard (FMVSS) 108, the aim of the cutoff line for these lamps for photometry is specified to be at the "HH line" (i.e., level). Consequently, at nominal aim the cutoff of these lamps on the road would be aimed at the horizon.

A simplified simulation of the effects of misaim was run to determine how often the cutoff line would fall above the location of the driver-side mirror and below the location of the center mirror. Although headlamps vary in the sharpness of their gradients, this situation will always produce substantially higher light levels on the driver-side mirror than on the center mirror. The most critical values are the heights of the headlamps and the mirrors. Those values are summarized in Table 11. The values for headlamp height are from Schoettle et al. (2002); the values for mirror heights on passenger cars are from Reed et al. (2000); and the values for mirror heights on LTVs are from Reed et al. (2001). All heights are from the center of the lamp or mirror to the ground. The standard deviation of headlamp vertical aim used in the simulation was 0.65 degrees (Copenhaver & Jones, 1992).

Table 11. The heights (m) of headlamps and rearview mirrors (at the center) for passenger cars and LTVs.

	Car	LTV
Headlamps	0.66	0.89
Driver-side mirror	0.94	1.18
Center mirror	1.19	1.48

Figures 3 and 4 show the proportion of cases in which the cutoff line lies somewhere between the heights of the driver-side and center mirrors as a function of the distance between the headlamps and the mirrors. Figure 3 shows results for encounters between LTVs as the subject vehicles and passenger cars as the rearward glare vehicles. The maximum proportion is greatest in Figure 4, which shows the results for encounters between passenger cars as the subject vehicles and LTVs as the rearward glare vehicles. Therefore, the number of occasions in which there is a high discrepancy between glare on the driver-side mirror and the center mirror is expected to be greatest for passenger cars as subject vehicles, particularly when the glare vehicles are LTVs. Also, as is evident in Figure 4, in those cases the discrepancies will tend to occur at short distances, at which the absolute glare levels are likely to be high.

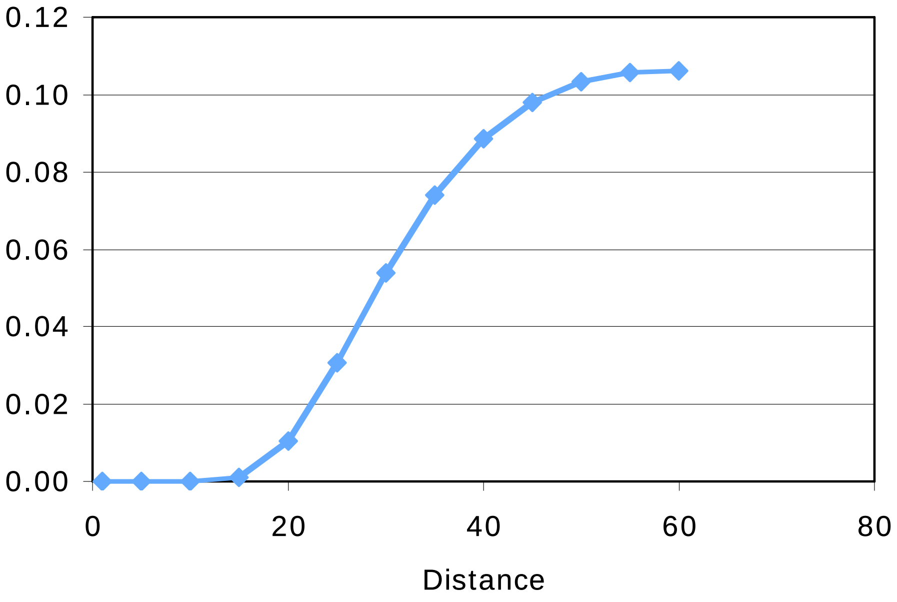

Figure 3. The estimated proportion of passenger-car headlamps with cutoffs between the heights of the driver-side and center rearview mirrors of LTVs, as a function of distance.

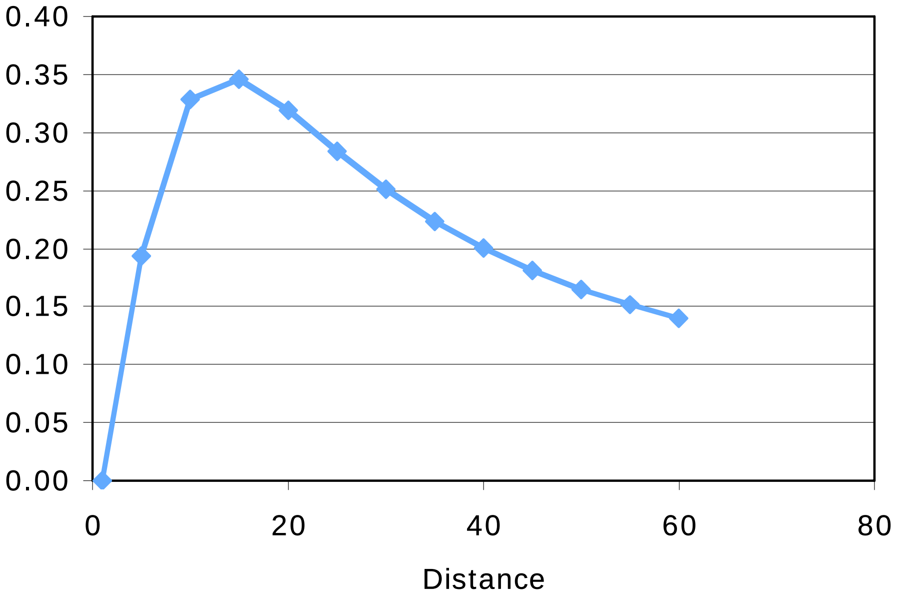

Figure 4. The estimated proportion of LTV headlamps with cutoffs between the heights of the driver-side and center rearview mirrors of passenger cars, as a function of distance.

SUMMARY AND CONCLUSIONS

The results reported here indicate that in many encounters with glare vehicles to the rear, there will be a substantial disparity in glare, both among vehicles of different classes and among different mirror locations on a single vehicle. The main reason for this is the strong role of mirror height in determining how much a mirror is exposed to the lower, and therefore stronger, portion of a low-beam light pattern. There is substantially greater potential for high glare values on the mirrors of passenger cars versus LTVs, and on the driver-side mirror versus the center rearview mirror on all vehicles. These disparities hold for a range of lateral and longitudinal separations of the subject vehicle and glare vehicle. Glare levels are roughly equal for glare vehicles in the same lane as the subject vehicle and glare vehicles one lane to the left. Greater longitudinal separation generally corresponds to lower glare, but the effect of distance can be different depending on the relative heights of the headlamps and mirrors. With upward misaim of headlamps, the disparities are increased, as is the absolute level of potential glare. The relatively low potential for glare on the center mirrors of LTVs will often be compounded by the low transmittance of privacy glass on those vehicles.

The present results have implications for how to control glare from rearview mirrors. For LTVs, the overall exposure to rearview mirror glare will be lower, and the need to control it may therefore also be lower than for passenger cars. Given the potential for strong disparities between glare on different mirrors of the same vehicle, it is important to consider where glare light should be sensed in order to control automatic anti-glare mirrors. There will be a substantial number of circumstances in which the center mirror (where sensors are conventionally located) is subject to much lower glare levels than the driver-side mirror. Multiple sensors would be one obvious, but potentially expensive, way to address this issue. However, it may also be possible to achieve effective control by assuming a certain ratio between glare levels on different mirrors.

In addition to the characteristics of glare described in this report, recommendations about how best to control mirror glare on specific vehicles should incorporate two additional considerations: (1) the geometry of a given vehicle, including the actual heights of the rearview mirrors and how the potential fields of view of those mirrors are affected by opaque parts of the vehicle, and (2) quantification of the exposure to glare that vehicles experience in actual traffic, including the frequencies at which glare vehicles are encountered in the fields of view of the individual mirrors. For any particular vehicle—for which the heights of the rearview mirrors will be known exactly—it would be possible to make more specific predictions than the generic ones given here about the disparities in glare that will likely occur between the driver-side and center mirrors. The disparities between mirrors described here assume that a particular glare vehicle is visible in both mirrors. For example, a glare vehicle in the same lane and at a short distance may not be visible in the driver-side mirror, thus effectively reducing the glare value in the driver-side mirror to zero. The extent to which these circumstances occur can be determined for individual vehicles, based on the fields of view that can be obtained from the various mirrors without being blocked by opaque parts of the vehicle. Quantitative estimates of the characteristics of actual traffic that may affect glare should be combined with the potential glare values estimated in this report. Examples include the circumstances that vehicles typically encounter in terms of density of surrounding vehicles, travel on single-lane versus multilane roads, and the distribution of lane positions that vehicles can be expected to occupy on multilane roads.

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