QUANTIFYING THE BENEFITS OF VARIABLE REFLECTANCE REARVIEW MIRRORS

Michael J. Flannagan
Michael Sivak

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

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16. Abstract

We collected photometric data on the simultaneous levels of rearview mirror glare and luminance of the forward scene, in order to characterize the night driving environment for rearview mirrors. An instrumented vehicle was used to collect photometric data for each combination of three road types (urban, expressway, and rural) with two pavement conditions (dry and wet). We then used these data to quantify the benefits of variable-reflectance rearview mirrors relative to (1) fixed-reflectance mirrors, and (2) two-level prism mirrors. The performance of the various types of mirrors was quantified in terms of a figure of merit. The figure of merit is simply the percentage of the time that all of three mirror-performance measures are met: (1) discomfort glare, (2) forward visibility, and (3) rearward visibility.

Results of the model indicate that variable reflectance mirrors offer substantial improvements, both as replacements for prism mirrors in the center mirror position and as replacements for fixed reflectance driver-side mirrors. The advantages are present in approximately equal magnitudes for most combinations of road type and pavement condition.

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Contents

Introduction

There is nothing good about glare from rearview mirrors. Strong headlamp illumination from the rear hurts a driver in three ways: it causes discomfort, it produces a veiling luminance that makes it harder to see things ahead of the vehicle, and (also via a veiling luminance) it makes it harder to see things in the rearview mirror. A tradeoff exists among those problems, such that reduced vision in the rearview mirror can be traded against the other two. Because of this tradeoff, when a substantial amount of glare is present a decision must be made about what combination of problems to accept. Variable reflectance rearview mirrors, most notably electrochromic mirrors, provide new and better options for this dilemma. By variable reflectance, we mean any technology that allows reflectivity to be varied continuously over a reasonably wide range. At the level of abstraction of the modeling that we describe here, the results should generalize to any such mirror.

In the past, the problem of headlamp glare reflected from rearview mirrors has been addressed primarily by using two-position, prism mirrors. These mirrors have two reflective surfaces, with reflectivities of about 80 percent and 4 percent. The low-reflectivity surface provides adequate protection from glare in many situations (thus increasing the visibility of forward stimuli as well as driver comfort), but it provides reduced visibility of stimuli seen through the mirror.

It can be argued on a priori logical grounds that certain variable reflectance rearview mirrors offer performance that is no worse than, and probably considerably better than, prism mirrors. Prism mirrors typically provide reflectivity levels of 80 percent and 4 percent. If the range of a variable reflectance mirror includes those values, it could be operated so as to simulate the performance of a prism mirror—providing only those two values. But the flexibility of a variable reflectance mirror offers the possibility of choosing, for any set of lighting conditions, the reflectivity level that provides the optimal tradeoff between visibility of objects in the mirror and protection from rearview-mirror glare, whether that level is 80 percent, 4 percent, or any other level within the mirror's range. Given that the performance of variable reflectance mirrors is better than prism mirrors, how much better is it? That is the central question in this study.

Our approach has been to attempt to construct a comprehensive model for the effect of mirror reflectivity on the overall performance of rearview mirror systems, on a smaller scale than but similar in general form to the CHESS model of headlighting (Bhise, Matle, & Hoffmeister, 1984; Bhise et al., 1977). The rearview mirror problem is fundamentally much simpler than the problem of headlighting because it involves the selection of a single parameter—reflectivity. (Although this could be expanded somewhat to consider separate reflectivities for individual mirrors, as indeed we will do here.) The fundamental design problem in headlighting, on the other hand, can be thought of, on an abstract level, as the much larger problem of determining all the values in the candela matrix that characterizes a headlamp beam pattern.

In spite of the relative simplicity of the rearview mirror problem, the construction of a comprehensive model is an ambitious undertaking, given the state of the art in modeling of visual processes. Perhaps the most difficult issue in modeling the performance of rearview mirrors (or any rear vision system) is characterizing what people need to see to the rear, and how well they need to see it (Flannagan & Sivak, 1993; Flannagan, Sivak, Battle, Sato, & Traube, 1993). Because it is important that drivers accept and feel comfortable with vehicle systems, it is also important to consider the related issues of what people *think* they need to see, and even perhaps what they merely want to see. A substantial number of drivers report that they do not use the glare protection afforded by the low-reflectivity setting of prism mirrors because they cannot see well enough to the rear with that setting (Flannagan & Sivak, 1990). A paradox arises because this is inconsistent with what appears to be a plausible argument: the low setting of prism mirrors should provide adequate vision to the rear because, first, only moving objects need to be seen (all other objects are receding and will never encounter or be encountered by the driver in question), and second, all moving objects (vehicles) are marked by a variety of lamps, especially headlamps, that are luminous enough to remain visible even in mirrors with reflectivity considerably below the 4-percent low reflectivity setting of prism mirrors.

Various proposals can be made to resolve this paradox. Perhaps drivers do need to see some low-luminance objects, such as the side panels of vehicles in adjacent lanes that are in positions such that their lamps are not in the field of view of a rearview mirror. Perhaps they need to see lane markings to the rear to provide the context with which to judge the locations and paths of overtaking vehicles. Perhaps they want to be able to see empty pavement, rather than merely noting the absence of vehicle lamps, as a positive indication that no vehicle is present.

In developing the CHESS model of headlamp performance, visual performance was modeled by defining the stimuli that a driver needs to see (pedestrians and pavement markings at distances adequate for given speeds) and then performing extensive photometry to determine realistic distributions of luminances for the critical stimuli (Bhise et al., 1977). Even if we had complete knowledge of what people need to see in rearview mirrors, the second part of that project—characterizing the critical stimuli photometrically—would present problems. The lighting circumstances for forward vision are relatively simple. For rearward vision, especially when glare sources are present, stimuli are often characterized by negative contrast. Furthermore, useful information is often in the form of very high luminance areas of specular reflection from pavement or vehicles.

In the present report we describe proposed solutions to this and other problems that have to be solved to allow quantitative modeling of rearview mirror performance. We outline a model that is fully specified although highly provisional, and then apply it to characterize the benefits that variable reflectance rearview mirrors provide for handling the tradeoff required by the presence of glare. We also present a new set of photometric data that characterize simultaneously the rearview mirror glare levels and forward luminances that drivers are commonly exposed to. Using that set of data, we make preliminary quantitative estimates of the performance of three systems: (1) an interior prism mirror combined with a fixed reflectivity driver-side mirror, (2) an interior variable reflectance mirror combined with a fixed reflectivity driver-side mirror, and (3) variable reflectance mirrors in both the interior and driver-side positions.

Photometry

Method

We collected data on the simultaneous levels of glare illuminance from rearview mirrors and forward pavement luminance that drivers experience in actual driving. The data were obtained with an instrumented car (a 1993 midsize sedan), which was driven in and around Ann Arbor, Michigan on trips that were planned to cover a variety of road types and weather conditions.

Illumination of the driver's eye position by rearward light sources was estimated by measuring illumination of the interior rearview mirror position by light coming through the rear window. Because the field of view of the interior rearview mirror was nearly coincident with the field of view provided by the rear window, the measured illumination gives a reasonable estimate of the illumination that would have been measured at the location of the eye itself, coming from the rearview mirror. This neglects the effect of the additional distance from the mirror to the eye that the light would have traveled, but that effect is small for most source-to-mirror distances. For example, assuming a distance from the mirror to the eye of 0.45 m and a distance from the source to the meter of 30 m, the light at the eye would have been reduced by a factor of 0.97 from what was measured at the mirror. We have not corrected for this because the distances of the light sources that were measured varied over a large range. We do not have information about the distances to, or number of, light sources for the individual illuminance measurements.

Illuminance of the center rearview mirror position was measured by a Minolta T-1 illuminance meter, fitted with a standard cosine receptor. The meter has a nominal sensitivity limit of 0.01 lx. It was installed inside a set of baffles that blocked light that did not come through the back window of the car, but that did permit light coming through the back window to reach the meter. Readings thus include the effects of the rear window glass. The rear window was cleaned before taking data, and there was no active precipitation during data collection.

The luminance of the pavement in front of the vehicle, as viewed from approximately the driver's eye position, was measured with a Minolta LS-100 luminance meter with a 1-degree field of view and a nominal sensitivity limit of 0.001 cd/m^2. The meter was positioned so that the far edge of the field of view was aligned with a point on level pavement 50 m in front of the driver's eye position, and directly ahead of the driver. The patch of pavement measured by the luminance meter extended from that point toward the vehicle for about 21.7 m, with a maximum width of 0.7 m, as is shown in Figure 1. This area contains the mean visual fixation point for drivers on straight roads using U.S. low beam headlamps as measured by Graf and Krebs (1976).

The luminance meter was mounted in the front passenger seat, as show in Figure 2. It was turned slightly to the left (about 1 degree) so that it was aimed at the pavement directly in front of the driver. It was aimed through the windshield, with approximately the same line of sight as the driver, except for being displaced laterally to the passenger seat. The front window was cleaned before taking data, and, as mentioned above, there was no active precipitation during data collection.

Data were obtained on three separate nights, beginning at least an hour after sunset. Because data were collected in Michigan (at approximately 42 degrees north latitude) in December, this was early enough in the evening that there was often still heavy traffic. The planned course included urban streets with large amounts of fixed lighting, expressways near Ann Arbor with heavy traffic but no fixed lighting, and a small amount of unlighted, lightly traveled rural road. The same course was driven on all three nights. On two nights the pavement was dry; on the other night it was wet from recent rain, but there was no active precipitation.

The procedure for taking data was very simple. The instrumented car was simply driven over the course with both photometers mounted in their fixed positions and taking continuous readings. Every ten seconds the readings were simultaneously recorded. The timing was automatic, and continued throughout an evening's run. Thus data were recorded during all phases of driving, including while the car was stopped at traffic lights or behind traffic, and while entering and exiting from expressways.

Table 1 gives the breakdown of mileage for the three different types of road (urban, expressway, or rural), and the number of observations taken for each type of road under each pavement condition (wet or dry). In all, 1,244 observations were collected during 156 miles of driving.

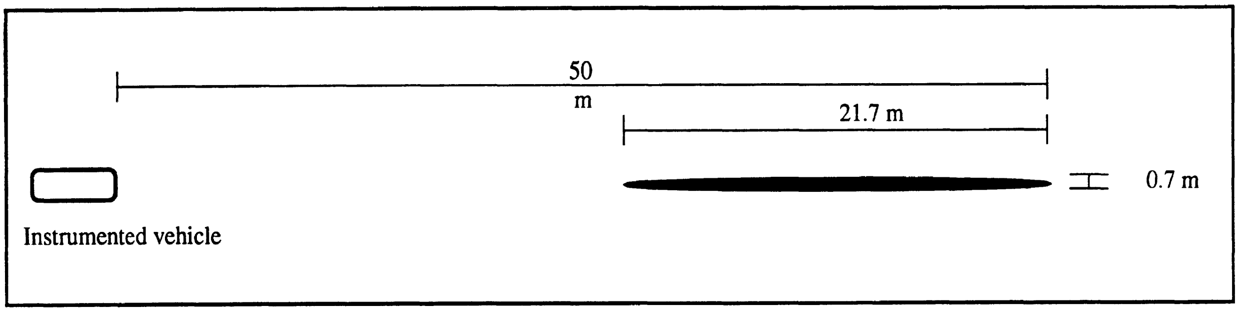

Figure 1. Plan view of the area of pavement from which luminance was measured by the spot photometer. The thin black oval is the projection of a round, 1-degree field of view directed approximately along the driver's line of sight.

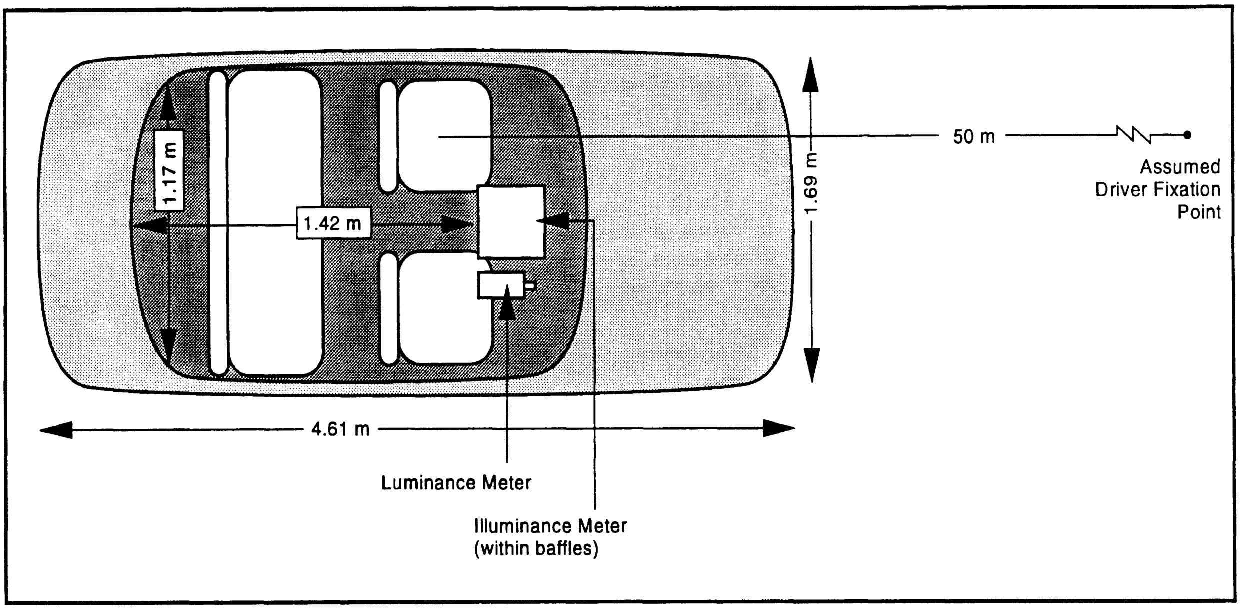

Figure 2. Plan view of the on-board photometric instrumentation.

Table 1.

Breakdown of mileage on one circuit of the test course by road type, and breakdown of the total of 1,244 photometric observations by road type and pavement condition. Each observation is a pair made up of a pavement luminance value and a rearview-mirror illuminance value.

Road type	Miles (per circuit)	Photometric observations Dry	Wet	Totals
Urban	13	383	154	537
Expressway	36	408	215	623
Rural	3	59	25	84
Totals	52	850	394	1244

Results

Distributions of the photometric variables are shown in Figures 3 through 14, broken down by road type and pavement condition. Note that the scales in those figures are logarithmic. Values for various percentiles are given in Tables 2 and 3, and medians are graphed in Figures 15 and 16, all using the same breakdown. Note that the values at percentiles are given in native units rather than logarithms. Figure 15 shows that pavement luminances were substantially higher in urban areas, which had significant amounts of fixed lighting. Also there was a tendency for pavement luminances to be lower when roads were wet. That tendency was most pronounced in unlighted rural areas. That is as expected, given that in those areas, with no fixed lighting and little traffic, most of the pavement luminance is due to the observer's own headlamps, and pavement retroreflectance is reduced when wet (Bhise et al., 1977). Figure 16 shows that mirror illuminance was highest in urban and expressway environments, and low on rural roads, as would be expected from the traffic densities in such areas. There was a tendency for glare illuminance to be higher when roads were wet. That tendency was most pronounced on urban streets, possibly due to increased specular reflection from following headlamps, or perhaps from fixed lighting (because the headlamp intensities were about equal in urban streets and expressways under dry conditions, but the increase with wet pavement was not nearly as strong on expressways).

Joint distributions of mirror illuminance and pavement luminance are shown in Figures 17 through 22, broken down by type of road and pavement condition. Correlation coefficients are shown on each figure. Correlations between pavement luminance and mirror illuminance are generally positive. (The only exception, the data for dry rural roads, has few cases.)

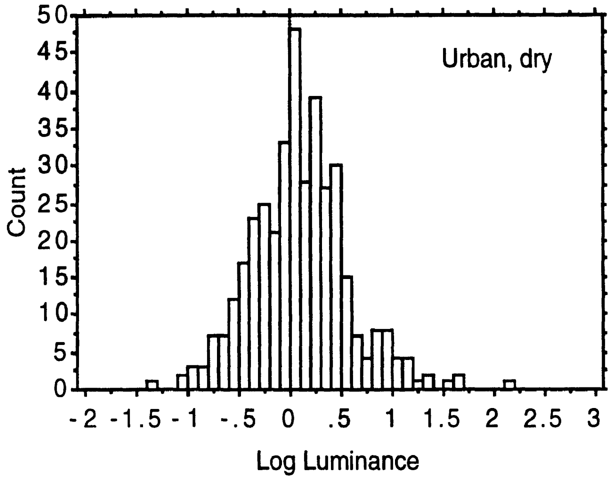

Figure 3. Log_{10} pavement luminance (cd/m^2) on dry urban streets.

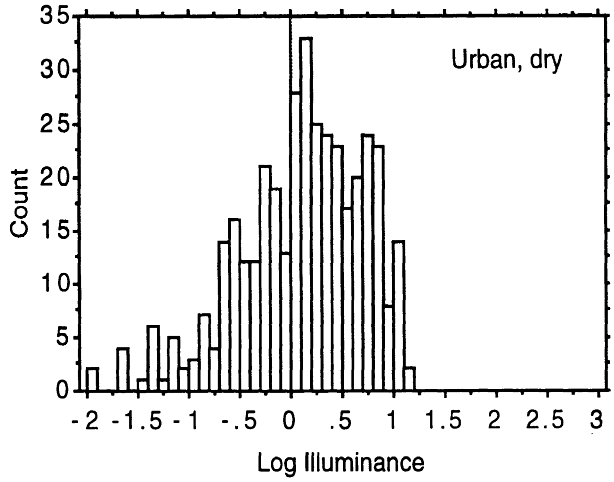

Figure 6. Log_{10} illuminance (lx) of the center rearview mirror on dry urban streets.

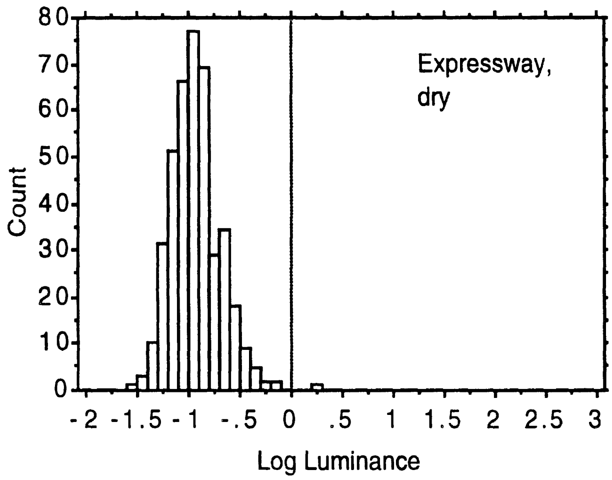

Figure 4. Log_{10} pavement luminance (cd/m^2) on dry expressways.

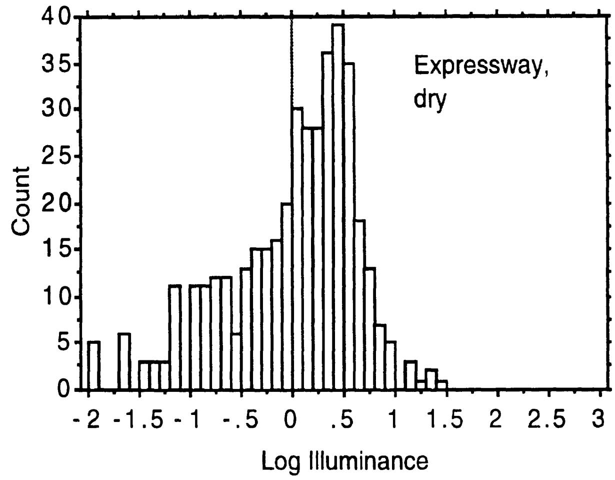

Figure 7. Log_{10} illuminance (lx) of the center rearview mirror on dry expressways.

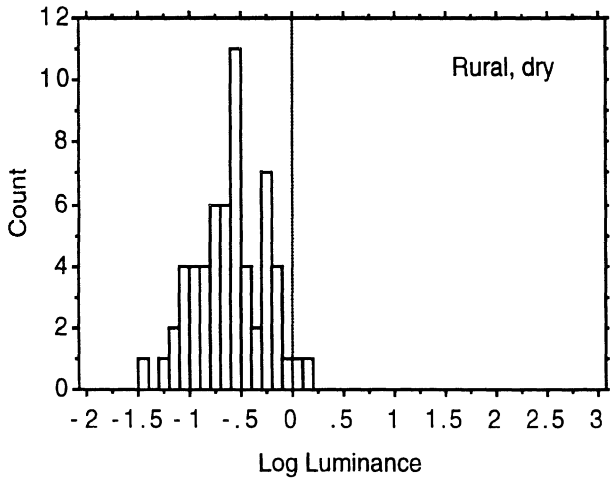

Figure 5. Log_{10} pavement luminance (cd/m^2) on dry rural roads.

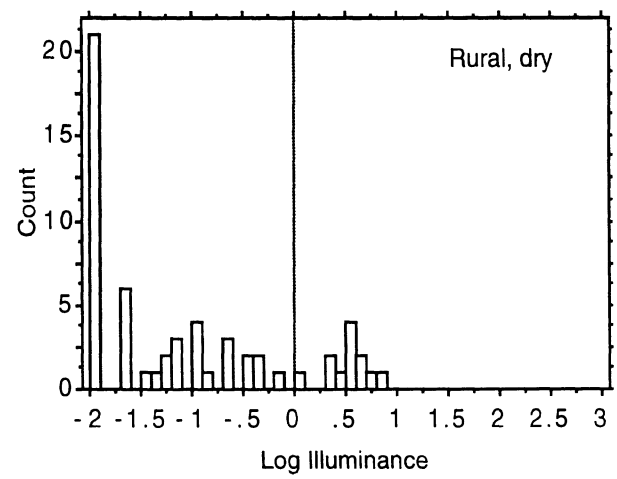

Figure 8. Log_{10} illuminance (lx) of the center rearview mirror on dry rural roads.

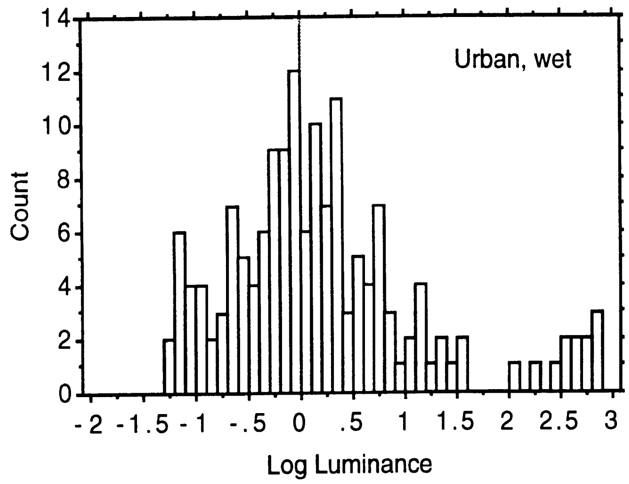

Figure 9. Log_{10} pavement luminance (cd/m^2) on wet urban streets.

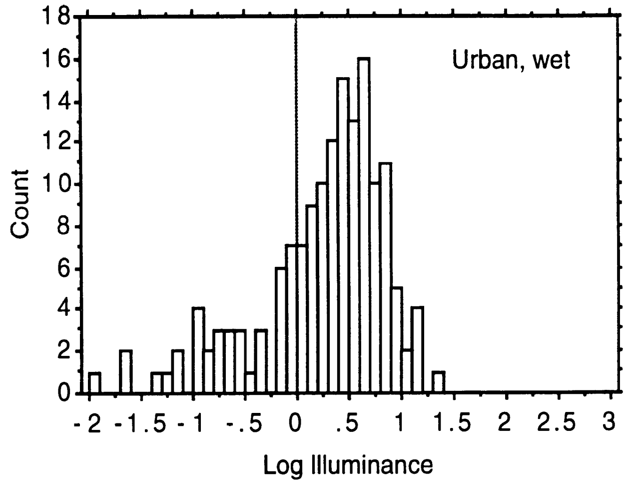

Figure 12. Log_{10} illuminance (lx) of the center rearview mirror on wet urban streets.

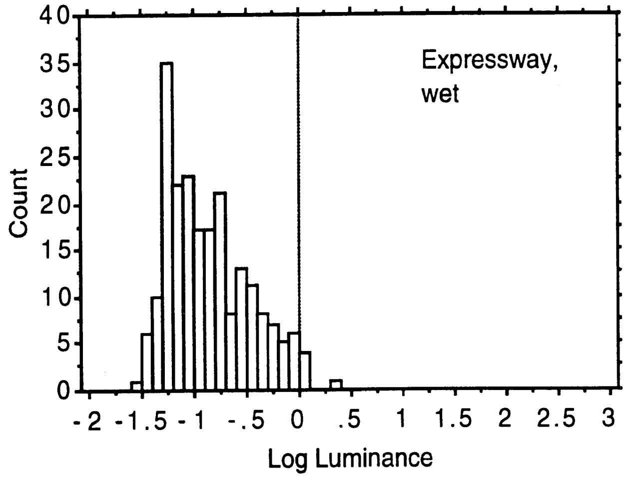

Figure 10. Log_{10} pavement luminance (cd/m^2) on wet expressways.

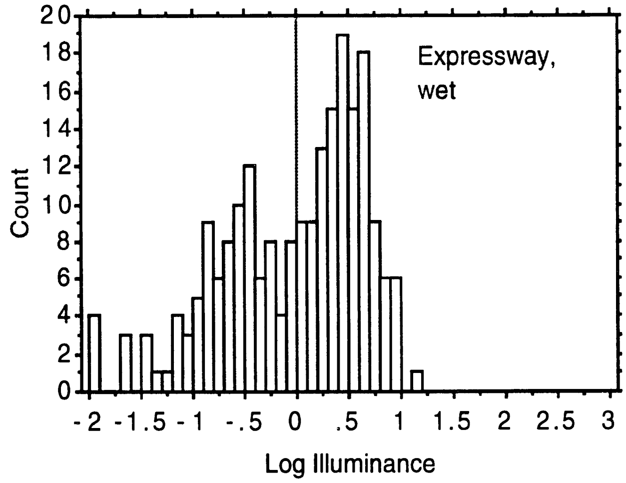

Figure 13. Log_{10} illuminance (lx) of the center rearview mirror on wet expressways.

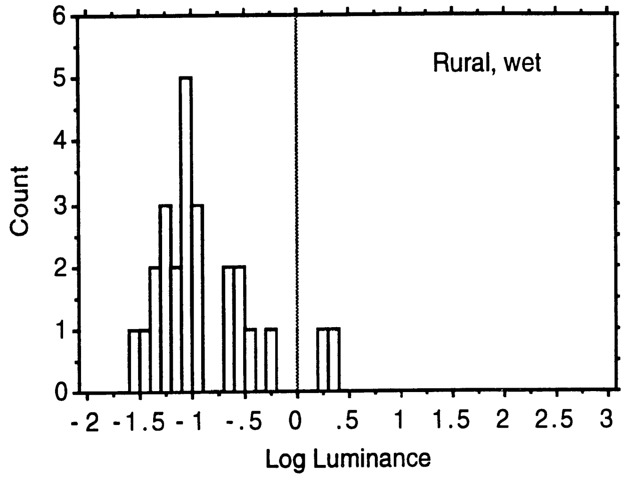

Figure 11. Log_{10} pavement luminance (cd/m^2) on wet rural roads.

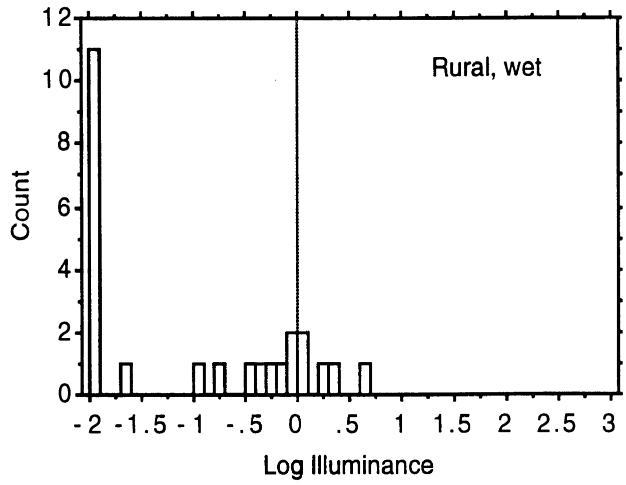

Figure 14. Log_{10} illuminance (lx) of the center rearview mirror on wet rural roads.

Table 2.
Percentiles of the luminance readings for the six combinations of pavement condition and road type (cd/m^2).

Pavement condition	Road type	Percentile				
		10th	25th	50th	75th	90th
Dry	Urban	0.316	0.501	1.175	2.291	4.385
	Expressway	0.050	0.079	0.100	0.126	0.200
	Rural	0.079	0.126	0.251	0.398	0.631
Wet	Urban	0.100	0.398	1.024	3.981	22.508
	Expressway	0.050	0.063	0.100	0.251	0.501
	Rural	0.040	0.050	0.079	0.212	0.501

Table 3.
Percentiles of the illuminance readings for the six combinations of pavement condition and road type (lx).

Pavement condition	Road type	Percentile				
		10th	25th	50th	75th	90th
Dry	Urban	0.20	0.50	1.45	3.61	6.76
	Expressway	0.10	0.40	1.43	2.79	4.34
	Rural	0.01	0.01	0.05	0.38	3.72
Wet	Urban	0.16	0.79	2.46	4.68	7.28
	Expressway	0.10	0.25	1.45	3.16	5.01
	Rural	0.01	0.01	0.10	0.79	1.62

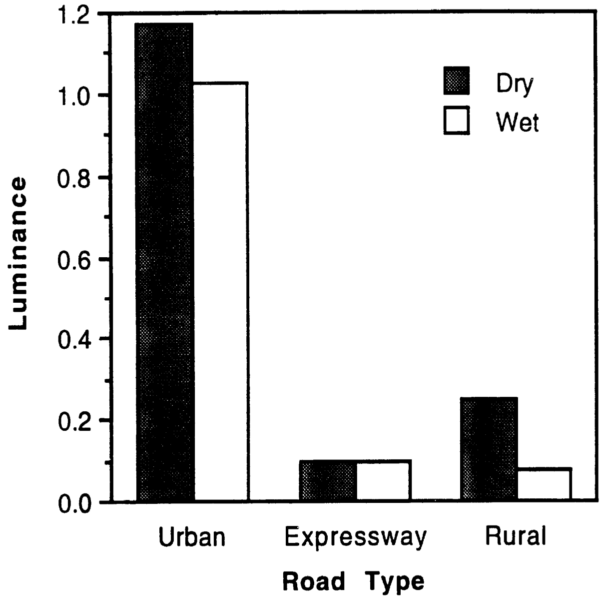

Figure 15. Median pavement luminances (cd/m^2) for the three types of road under dry and wet conditions.

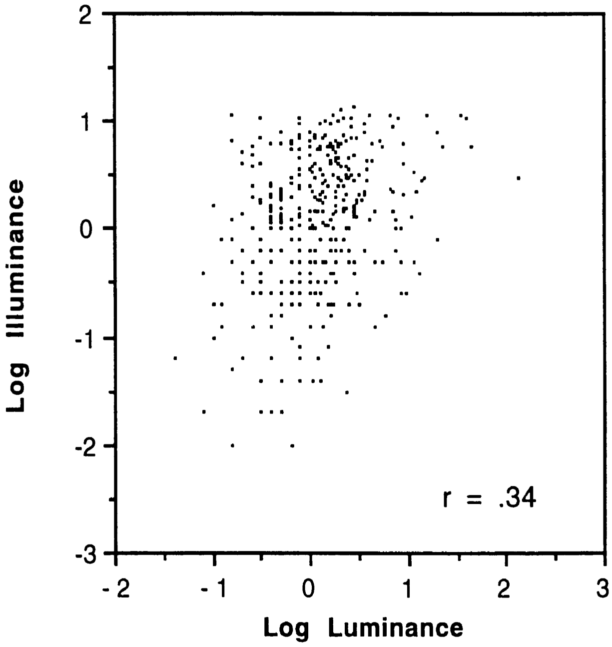

Figure 17. A scatterplot for $\log_{10}$ pavement luminance and $\log_{10}$ center rearview mirror illuminance on dry urban streets.

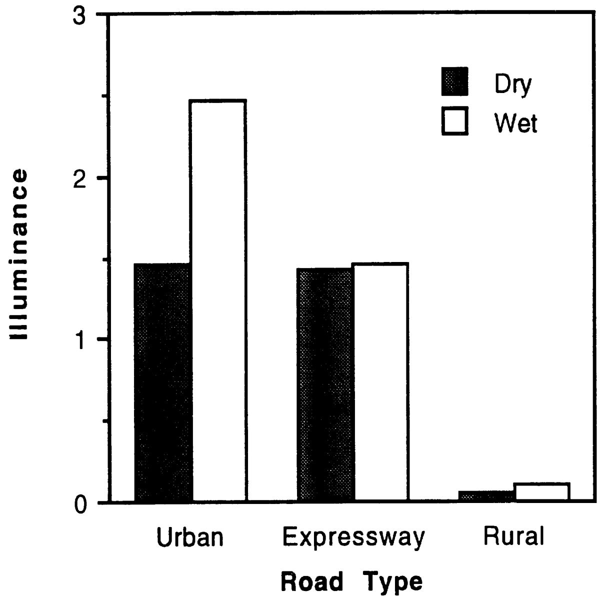

Figure 16. Median illuminances (lx) of the rearview mirror for the three types of road under dry and wet conditions.

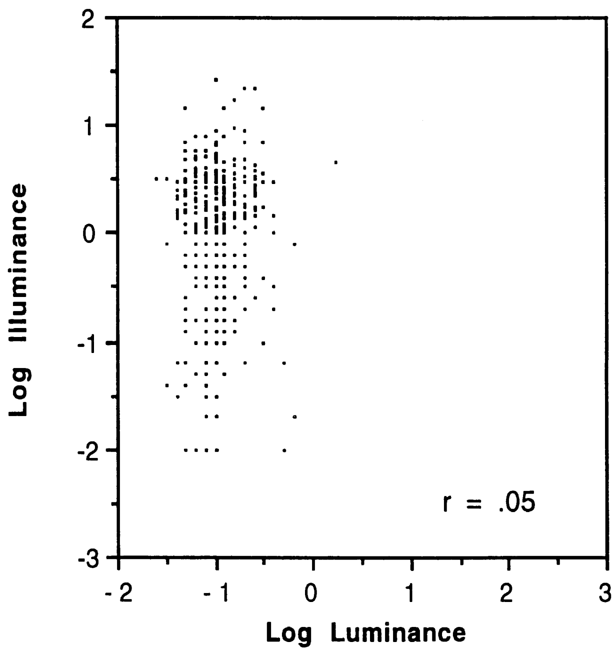

Figure 18. A scatterplot for $\log_{10}$ pavement luminance and $\log_{10}$ center rearview mirror illuminance on dry expressways.

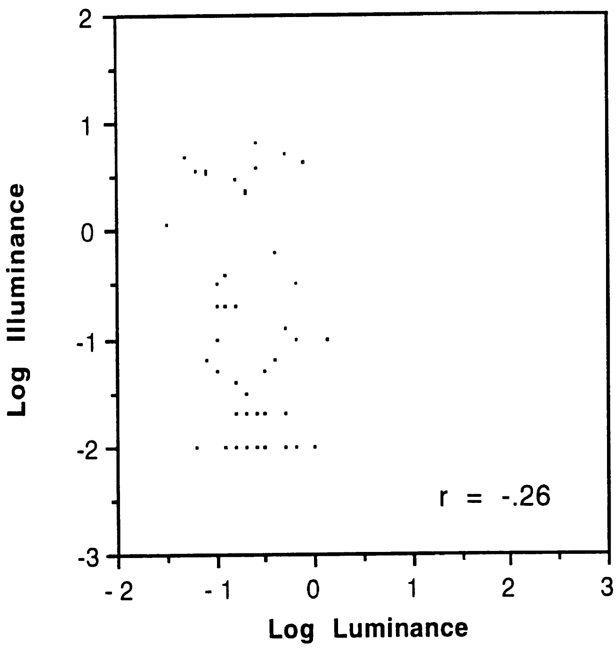

Figure 19. A scatterplot for $\log_{10}$ pavement luminance and $\log_{10}$ center rearview mirror illuminance on dry rural roads.

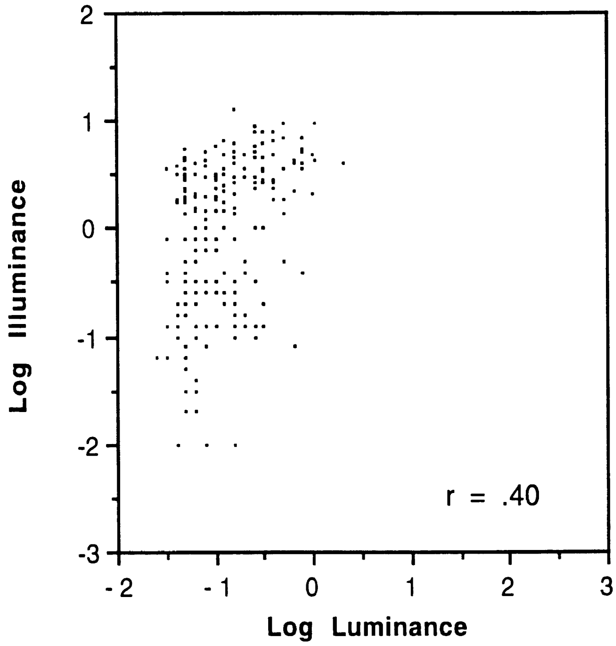

Figure 21. A scatterplot for $\log_{10}$ pavement luminance and $\log_{10}$ center rearview mirror illuminance on wet expressways.

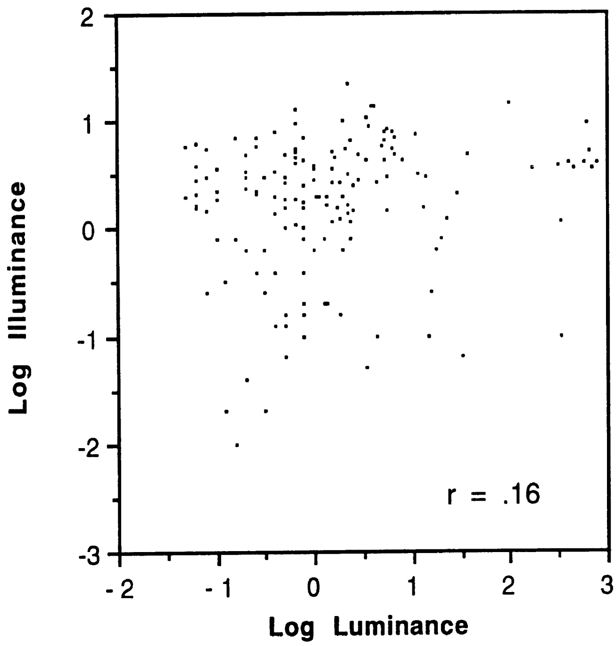

Figure 20. A scatterplot for $\log_{10}$ pavement luminance and $\log_{10}$ center rearview mirror illuminance on wet urban streets.

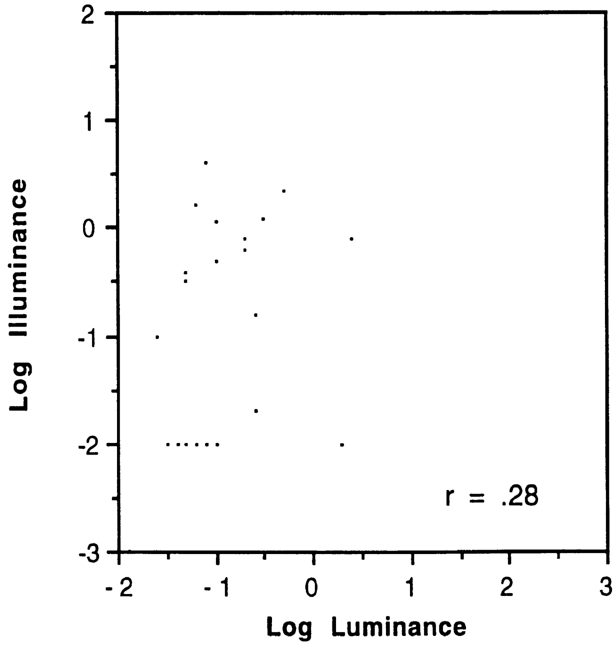

Figure 22. A scatterplot for $\log_{10}$ pavement luminance and $\log_{10}$ center rearview mirror illuminance on wet rural roads.

Vision Modeling

The model that we used to calculate figures of merit for rearview mirror systems is similar in overall structure to the CHESS model of headlighting, although much smaller in scale. Like CHESS, it involves using mathematical models to determine whether the system being evaluated (a headlamp system or a mirror system) can meet each of a set of performance criteria under lighting conditions sampled from the real world (Bhise et al., 1977). The final figure of merit for a system is the percentage of the time that all criteria are met. In our case the three requirements were that (1) discomfort glare be at or below a criterion level, (2) forward visibility be at or above a criterion level, and (3) rearward visibility be at or above a criterion level. For a representation of the variety of conditions encountered in the real world we used the 1,244 photometric situations measured by our instrumented vehicle.

We evaluated three mirror systems: (1) an interior prism mirror that can be switched between a high reflectivity level of 80 percent and a low level of 4 percent, combined with a left-side mirror with a fixed reflectivity of 50 percent; (2) an interior mirror with reflectivity that is continuously variable between 80 and 4 percent, combined with a left-side mirror with a fixed reflectivity of 50 percent; and (3) an interior mirror with reflectivity that is continuously variable between 80 and 4 percent, combined with a left-side mirror that is also continuously variable between 80 and 4 percent, with the reflectivities of the two mirrors changing in tandem.

For each pair of photometric values, the model searches for a reflectivity level at which all three criteria are met. If it finds such a level, that situation is counted a success; if not, it is counted a failure. The figure of merit is simply the percentage of successes over the set of photometrically characterized situations that is meant to represent the real world.

For a model of discomfort glare, we used the Schmidt-Clausen and Bindels model (Schmidt-Clausen & Bindels, 1974). Although we have evidence that ratings of discomfort glare from rearview mirrors deviate in systematic ways from that model (Flannagan, Sivak, & Gellatly, 1991), the deviations are relatively small. Furthermore, no model more appropriate for rearview mirrors has yet been established. Our application of the Schmidt-Clausen and Bindels model was relatively straightforward. It takes as inputs three parameters: the adaptation luminance level, the lux value for illumination of the eye by a glare source, and the angle between a glare source and the direction of gaze. If there are multiple sources of glare, values for the latter two parameters are assigned for each of them.

For the adaptation luminance level, we used the measured pavement luminance. Glare angles were the angles subtended at a typical driver's eye position between the rearview mirrors and a spot on the pavement 50 m in front of the driver. (We based the geometry used in the vision modeling on the instrumented vehicle that we used to collect the photometric field data.) The angle between the pavement location and that left-side mirror was 48 degrees, and the angle between the pavement location and the center mirror was 50 degrees. For the lux level reaching the observer's eye from the center mirror, we used the lux value measured at the mirror position, multiplied by the reflectivity level for the mirror being evaluated. We used the same value for the left-side mirror. Although we did not directly measure illumination levels at that mirror position, this approximation is supported by the data in Figure 23, which show predicted illumination levels at center and left mirror positions as functions of distance, for typical mirror and headlamp geometries. The predictions were generated using median U.S. headlamp candela matrices (Sivak, Flannagan, & Sato, 1993). The results indicate that illumination of those locations should be very similar.

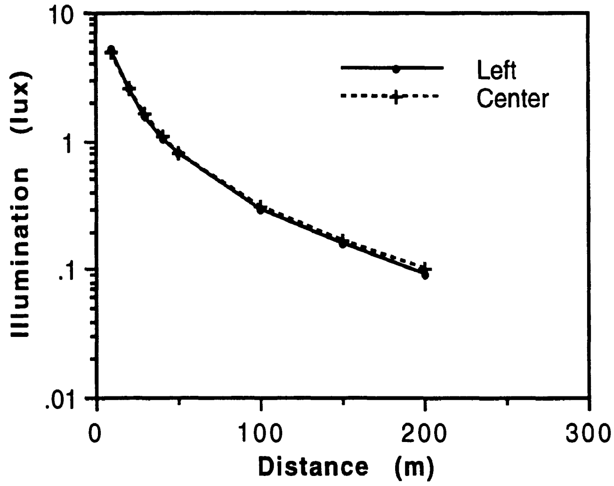

Figure 23. Illumination of the left and center mirror positions by a single vehicle with two headlamps at varying distances. See text for details.

The output of the model is a prediction for the number that someone would use to rate their feeling of discomfort if they were actually exposed to the conditions being simulated. The number is a value on the de Boer scale, a standard rating scale for discomfort from glare (de Boer, 1967). This scale goes from 1 to 9, and has verbal anchors for each of the odd numbers as follows: (1) unbearable, (3) disturbing, (5) just acceptable, (7) satisfactory, and (9) just noticeable. Our model considered the discomfort criterion to be met if the predicted de Boer number was 5 or higher.

Forward and rearward visibility were simulated using a model developed by the CIE (1981b). We followed the implementation described by Farber (1988), which we have extended to rearview mirrors (Flannagan, Sivak, & Gellatly, 1992).

Our approach to the issue of what people need to see in rearview mirrors (as well as our treatment of forward stimuli) was to assume that the visual information that is potentially useful to a driver spans a wide range of visibility, from some objects that are clearly seen to others that are less salient. This is probably a reasonable heuristic whenever an actual observer or a person modeling that observer's vision has uncertainty about what stimuli might be important for safe driving. We adopted the definition of visibility level, as the ratio of a stimulus's contrast to threshold contrast, from the CIE work (CIE, 1981b). In order to evaluate the forward and rearward visibility provided by a mirror, we then chose as criterial stimuli those that in the absence of glare would be at a moderate visibility level—just visible enough to be reliably used under the workload and visual demands of normal driving. The model then characterizes mirror performance by determining whether information at that level would remain available to an observer (although perhaps at a reduced visibility level) when glare is introduced and the mirror changes reflectivity. This is similar to the approach used by Rowland and his coworkers in evaluating the effect of rearview mirror glare on forward visibility (Rowland, Moretti, & Patton, 1981). They followed earlier work (Raine, Chatterton, & Dunn, 1975) that defined an allowable level of glare as that level that would reduce the probability of detecting a target from .99 to .90 for 95 percent of 65-year-old drivers.

We ran our model using visibility level 10. It has been estimated that stimuli at that level allow drivers to perform at about 90 percent of maximum performance levels (i.e., a reasonable minimum for reliability) under average driving conditions (CIE, 1981a).

Further parameters used in the simulation were as follows: For forward stimuli we used a background luminance of 0.01 cd/m^2, a reasonable estimate of the pavement luminance at which a pedestrian is first detected in a roadway. For rearward stimuli we used a slightly higher level, 0.1 cd/m^2, because informal photometry had indicated that was a more typical figure for pavement viewed to the rear when other traffic was present. The visual angles between the rearward stimulus and the mirrors were 89 degrees to the left-side mirror, and 9 degrees to the center of the center mirror. (The rearward stimulus was thus effectively viewed in the center mirror itself, near the edge of a mirror field of view totaling about 20 degrees horizontally.) The visual angles between the forward stimulus and the mirrors were 48 degrees to the left-side mirror and 50 degrees to the center mirror. Driver age was set at 25.

The results of our model's evaluation of the rearview mirror systems is shown in Table 4, which shows figures of merit for each of the mirror systems. Figure 24 shows the figure of merit for each mirror system with each combination of road type and pavement condition. The figure of merit is generally high in the rural environments, which mostly reflects the fact that traffic that would cause glare from the rear is less common there. Thus all visual criteria are met a higher proportion of the time because the environment is less challenging. The advantages provided by the variable reflectance mirrors are present for nearly all comparisons. The only exception is the comparison of the system with a center variable reflectance mirror to the system with both variable reflectance mirrors on dry rural roads. For that comparison, performance is equal. However the small amount of photometric data from rural roads makes all the comparisons involving rural roads tenuous.

Table 4

Figures of merit for each of three mirror systems. For mirror reflectivities, .04/.80 indicates a mirror that can be switched discretely between 4 percent and 80 percent reflectivity. The notation .04 - .80 indicates a variable reflectance mirror that can assume any reflectivity in that range.

Mirror-system reflectivities		
Left	Center	Figure of merit
.50	.04/.80	.27
.50	.04 - .80	.39
.04 - .80	.04 - .80	.50

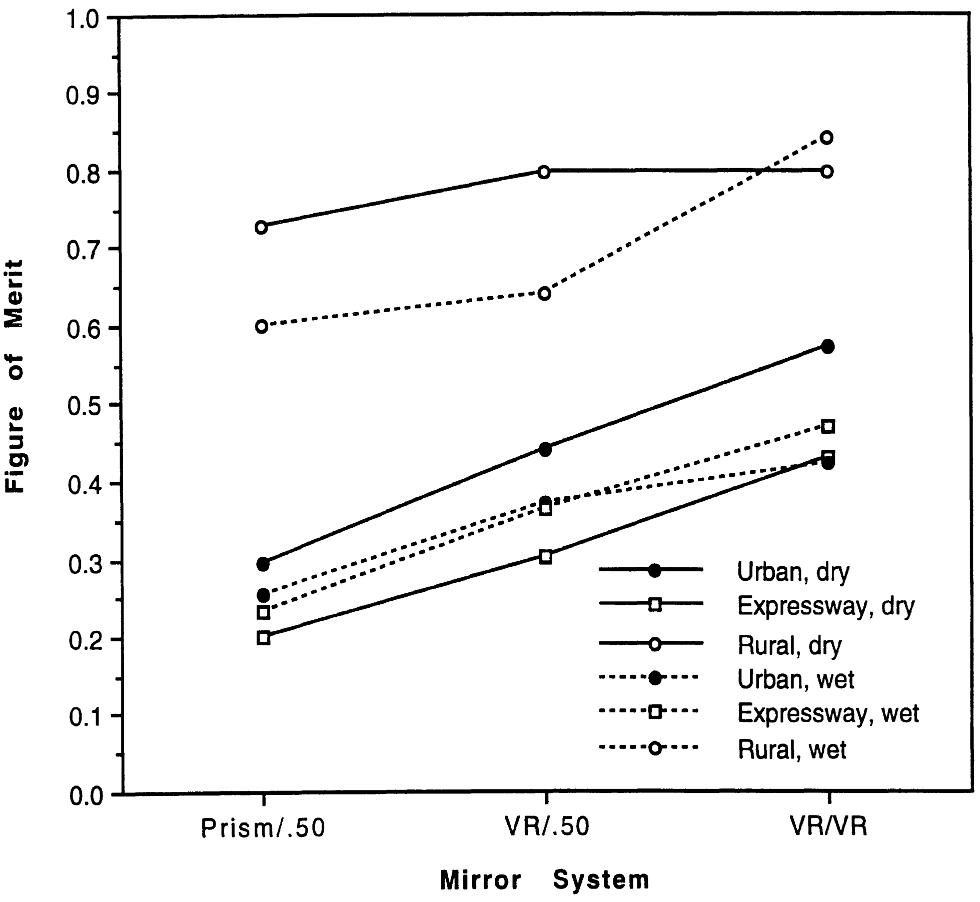

Figure 24. The figure of merit for each mirror system with each combination of road type and pavement condition. "Prism/.50" designates a mirror system with a center mirror that can change discretely between .80 and .04 reflectivity combined with a left-side mirror that is fixed at .50 reflectivity. "VR/.50" designates a mirror system that has a variable reflectance mirror in the center position, capable of changing continuously between .80 and .04 reflectivity combined with a left-side mirror that is fixed at .50 reflectivity. "VR/VR" designates a mirror system with variable reflectance mirrors that can change between .80 and .04 reflectivity in both positions.

Discussion and Conclusions

The figures of merit generated by our model indicate that variable reflectance mirrors offer significant benefits. The figure of merit, which indicates the estimated proportion of night driving situations for which discomfort and visibility criteria are all met, is greater when a system composed of an interior variable reflectance mirror and a left-side fixed reflectance mirror is compared to a system composed of an interior prism mirror and a left-side fixed reflectance mirror. It also improves when the left-side mirror is replaced by a variable reflectance mirror. These findings seem to apply in approximately the same magnitude to all road types under both dry and wet conditions.

It is not surprising that variable reflectance mirrors perform better than fixed reflectance mirrors. As we pointed out earlier, variable reflectance mirrors can only do better in this sort of evaluation. However, the model described here can provide some insights into just how and when variable reflectivity mirrors offer improvement. Furthermore, through the figure of merit it, can provide tentative quantitative evaluation of that improvement.

Our future plans include field validation of parts of this model, using a car equipped with variable reflectance mirrors in the center and left positions. Other important background issues on which further research could contribute to this modeling effort are the effects of very large angles on discomfort and disability glare (because evaluation of rearview mirrors depends critically on understanding the effects of glare sources located at large eccentricities) and the possible effects of long-term discomfort glare on objective driving performance, perhaps via fatigue or negative emotional reactions.

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