

Minimum Retroreflectance for Nighttime Visibility of Pavement Markings

J. L. ETHEN AND H. L. WOLTMAN

Many studies have addressed questions related to pavement markings; few, however, have dealt with the subject of minimum and generally acceptable retroreflectance values for nighttime visibility. Three studies that deal with this subject were found, and they agree closely on minimum and acceptable values. The question of minimum retroreflectance depends on the retroreflective quality of the painted line, the quality of headlamp illuminance, the contrast between the line and the immediately adjacent road surface, and the presence or absence of roadway lighting. Tests were conducted using markings with a broad range of retroreflectance on a level tangent roadway of weathered asphaltic concrete. A subjective system was employed for rating the lines, and the results correlated well with those of other studies. Two retroreflectance values, expressed as specific luminance in units of millicandelas per square meter per lux ($\text{mcd}/\text{m}^2/\text{lx}$) are suggested as acceptable and minimum. These values are approximately 300 and 100 $\text{mcd}/\text{m}^2/\text{lx}$, respectively. These values may be useful in establishing acceptance and service criteria for pavement markings. The availability of portable instruments such as the Ecolux, which was used in this study, permits the assessment of pavement markings for conformance to such criteria.

Numerous studies have been performed on the durability of pavement marking materials, including a study currently under way funded through the NCHRP (1). Somewhat fewer studies have dealt with nighttime performance, and fewer still with the subject of minimum and generally acceptable retroreflectance values. The subject is timely. It is the basis for a recent petition and proposed rulemaking (2) by the FHWA and is a question on which comparatively little hard information exists.

Pavement markings provide fundamental guidance for vehicle control, separation of opposing lanes of traffic, prohibition of passing maneuvers, and delineation of roadway edges. As stated in the Manual on Uniform Traffic Control Devices (MUTCD) (3), "Markings which must be visible at night shall be reflectorized unless ambient illumination assures adequate visibility." The present experiment was conducted before the previously mentioned petition and is reported on here with related studies, one of which was unknown at the outset of the experiment. This experiment deals with the visibility of pavement markings under both ambient illumination and dark conditions as cited in the MUTCD.

PREVIOUS RESEARCH

Perhaps the most comprehensive evaluation of the role of pavement markings in driver guidance is the work performed by Allen et al. (4) for the FHWA. Using a driving simulator

followed by the testing of subjects with an instrumented vehicle, basic relationships were presented that relate visibility range, stripe-to-skip length, and luminance contrast to the driver's ability to stay within his lane. These variables are expressed as a probability of lane exceedance and define line luminance primarily in terms of contrast (Delineation Contrast, C) with the adjacent road surface. This relationship is shown in Figure 1.

Allen's study suggests a minimum marking contrast of 2 and a minimum visibility distance of from 100 to 125 ft. This would result, for example with a line specific luminance of 90 $\text{mcd}/\text{m}^2/\text{lx}$, in a road specific luminance of 30 $\text{mcd}/\text{m}^2/\text{lx}$. These terms describe retroreflectance of the line and road as measured photometrically.

Availability of portable pavement photometers, such as the Ecolux, permits direct comparison measurements from laboratory to field as well as among types of materials. The Ecolux instrument is a portable photometer that measures at an entrance angle of 86.5 degrees and an observation angle of 1 degree. Readings are expressed in millicandelas per square meter per lux (specific luminance). Values from other instruments may differ due to different measuring geometries.

A study similar to the authors' is that by Serres (5). In this study an experiment developed a correlation between subjective ratings and line specific luminance. The study results were employed to develop homologation requirements for acceptance and line replacement based on retroreflectance values. The histogram from the Serres' study is reproduced as Figure 2.

The conclusion of Serres' study (5) is that line specific luminance below 150 $\text{mcd}/\text{m}^2/\text{lx}$ is unacceptable to the median viewer and that line replacement should be made at 100 $\text{mcd}/\text{m}^2/\text{lx}$.

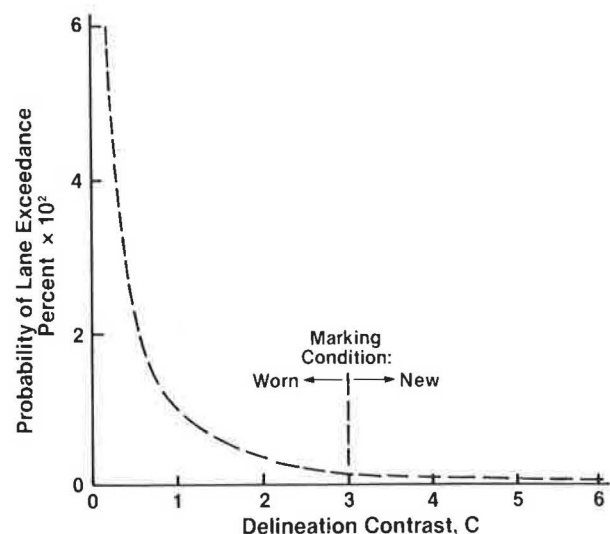


FIGURE 1 Effect of delineation contrast on the probability of lane exceedance, from Allen (4).

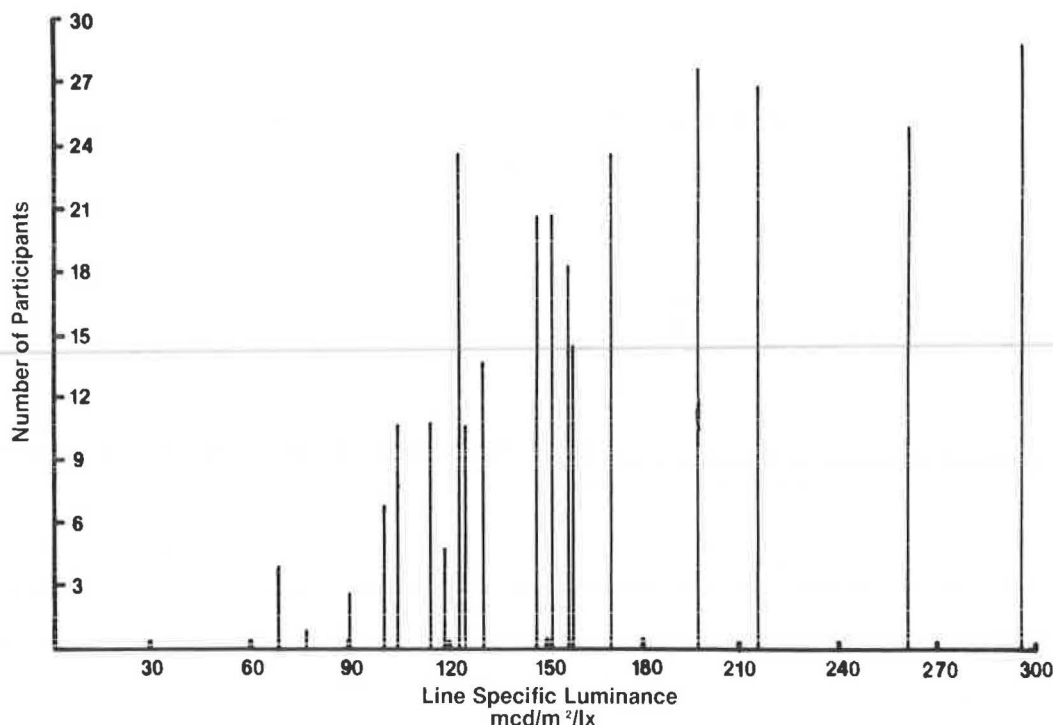


FIGURE 2 Line specific luminance versus number of just acceptable ratings, from Serres (5).

m^2/lx . It is significant that Serres employed the same type of instrument, with the same optical geometry, that was used in this study.

To make a subjective determination of minimum and optimum line luminance, two procedures appear to be possible: one in which conditions and observers are the ideal case, the other under impaired conditions. In the present test such variables as oncoming headlamp glare, roadway curvature, rainfall, misaligned headlamps, or impaired drivers were specifically avoided in the interest of obtaining a judgment of minimum and optimum line luminances under ideal (unimpaired) conditions. Additional safety factors to compensate for these effects should be considered in future work.

DESIGN OF EXPERIMENT

Pavement tapes were prepared in the laboratory using 1.5 and 1.9 refractive index glass beads coated at various concentrations to provide eight separate retroreflectance levels for testing. These levels and their order of presentation are given in Table 1.

All tape stripes were white, 4 in. x 10 ft, and placed with a 30-ft gap. Three consecutive stripes of each specific luminance were applied at the test site in the order given in Table 1. This provided eight sets of three stripes.

TEST ROAD

The test road is an asphalt-surfaced road laid out as one side of a four-lane freeway; it has two 12-ft lanes, a 10-ft paved right shoulder, and a 3-ft paved left shoulder. Edge lines were pres-

ent but were well worn and were not judged to be of significance in the evaluation of the test stripes, which were placed in the center lane line position (Figure 3).

The test road is a 2,200-ft, level, tangent section in a dark rural area; luminaires are positioned along one side. These are mounted at a 50-ft height and 250-ft spacing and are provided with 250-watt mercury-vapor lamps. Lighting, which was used in one phase of the visibility test, conforms closely to the standard for rural freeways. Each of the eight test line sets consisted of three 10-ft stripes with 30-ft spacing between stripes. A 250-ft length of roadway was employed for each of the eight test sets to ensure adequate isolation of adjacent sets. Sets were presented in the order indicated in Table 1. As subjects drove the length of the road the sets were completely presented and as subjects returned from the opposite direction the presentation appeared in reverse order.

After complete viewing in dark conditions by all subjects, the luminaires were turned on and the viewings were repeated.

TABLE 1 RETROREFLECTANCES AND ORDER OF PRESENTATION

Retroreflectance ($\text{mcd}/\text{m}^2/\text{lx}$)		Order of Presentation	
Avg	Min-Max	Run 1	Run 2
30	20–40	200	90
70	60–80	140	70
90	80–100	1700	450
140	130–150	625	30
200	180–220	30	625
450	400–500	450	1700
625	600–650	70	140
1700	1600–1800	90	200

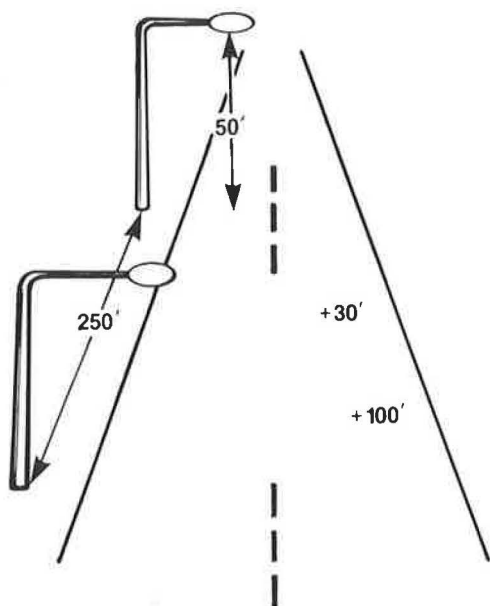


FIGURE 3 Test road layout.

PROCEDURE

On arrival, subjects were instructed to use low beams only. The widespread use of low beams is well documented and is the design illumination baseline for retroreflective traffic control materials. Headlamps were aligned and visually aimed in accordance with SAE J 599 (6) before viewings. During the viewings, one driver and one observer rode together in each car and recorded separate ratings. Vehicles were sufficiently separated so that no oncoming headlights or illumination from a following car could interfere. Subjects were instructed to view the stripes from two distances, which were marked off before each series of test stripes: 100 and 30 ft. Thus the nearest stripe in each set would be viewed from 30 ft, and the most distant stripe of the same set, when viewed from the 100-ft mark, would be observed at a distance of 190 ft. The 30- to 190-ft viewing range is substantially shorter and longer than the 100- to 125-ft distance reported as the required visibility range by Allen (4).

The subjects were instructed to rate the stripe appearance from both distances using the following subjective rating scale:

- 7 Superior,
- 6 Excellent,
- 5 Very acceptable,
- 4 Generally acceptable,
- 3 Minimum acceptable,
- 2 Unsatisfactory, and
- 1 Very poor.

A line judged very acceptable (5) is visible at from 400 to 500 ft, a requirement which satisfies the 5-sec headway requirement from Wier and McRuer (7) or the 140-m (460-ft) visibility distance for 100 km/hr speed from Blaauw and Padmos (8).

A rating of minimum acceptable (3) was defined as visibility of the farthest stripe in the set at 190 ft. If this stripe were not

visible at that distance the rating would be unsatisfactory (2) or very poor (1).

It is noted from experience that new beads-on-paint lines with specific luminance in the range of from 300 to 500 mcd/md²/lx are readily visible at from 400 to 500 ft. These would be rated very acceptable (5), comparable to the Wier and McRuer (7) and Blaauw and Padmos (8) time and distance requirements.

The number of separate observations of each line set was 32 for the dark phase and 28 for the lights-on phase.

RESULTS

The results for the viewings conducted under dark conditions are shown in Figure 4 for various retroreflectances. Results for the lighted roadway condition are shown in Figure 5. To obtain a linear regression from the response of Figure 4, a log of specific luminance versus line rating was determined and is shown in Figure 6.

The regression equation for Figure 6 is

$$\text{Line rating} = 2.88(\log \text{ of line specific luminance}) - 2.59$$

The standard deviation for rank about the regression line is 0.4450 with a correlation coefficient of $R^2 = 93$ percent. Using a standard deviation of 0.3 for predicted line rating at any one observation (largest seen), a 95 percent confidence interval of ± 1.32 is calculated for the predicted line ratings.

Levels of minimum and acceptable performance may be drawn from Figures 4 and 6. The minimum performance level, a 3 rating, corresponds to approximately 90 mcd/m²/lx. Because of instrument variability a value of 100 mcd/m²/lx is suggested as a conservative representation. The acceptable luminance would appear to be at the transition of the curve of Figure 4, corresponding to a rating of 5 or above. This is equivalent to at least 400 mcd/m²/lx or above. It should be noted that no upper luminance level was observed to be too bright or unacceptably

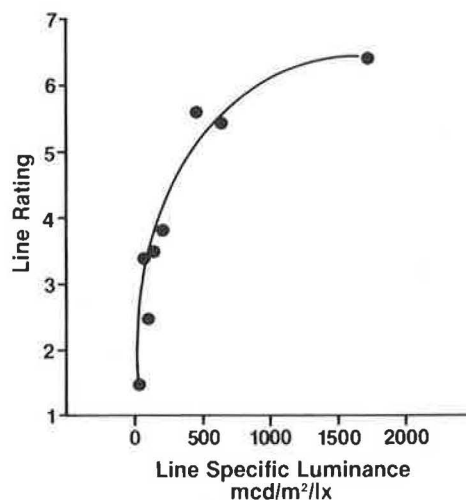


FIGURE 4 Line rating versus line reflectance, dark condition, measured with Ecolux photometer.

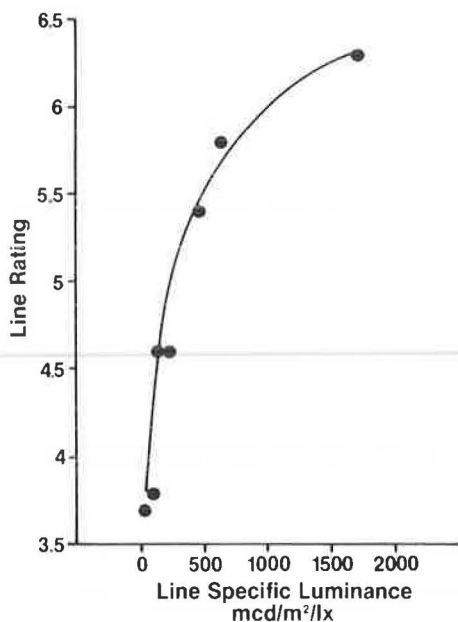


FIGURE 5 Line rating versus line reflectance, lights-on condition, measured with Ecolux photometer.

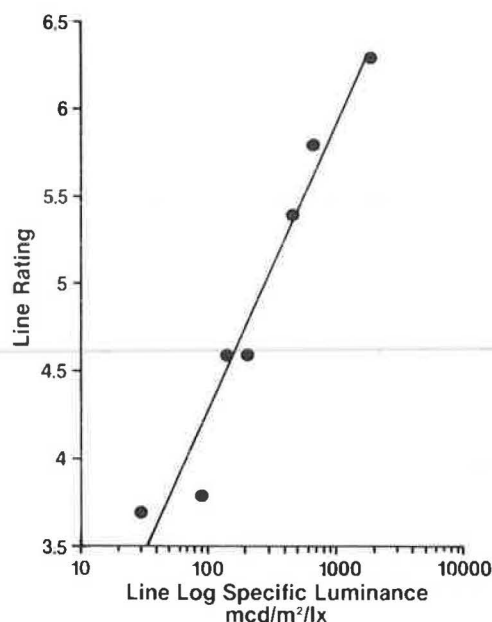


FIGURE 7 Line rating versus log of specific luminance, lights-on condition.

glaring so, in the region of line specific luminance tested (up to 1700 $\text{cd/m}^2/\text{lx}$), no upper bound was observed.

A similar linear regression is shown in Figure 7 for the lighted condition. Here the regression equation is

$$\text{Line rating} = 1.65(\log \text{ of line specific luminance}) + 0.98$$

with a standard deviation of 0.2552 and $R^2 = 93.3$ percent. The 95 percent confidence interval is ± 0.81 for the predicted line ratings.

Under the lighted condition, no unacceptable ratings were obtained. The acceptable level, corresponding to a level of 5 or above, is at least 300 $\text{mcd/m}^2/\text{lx}$. The roadway illumination was sufficient to provide adequate line luminance without the retroreflective contribution. Line luminance is a function of

sufficient roadway illumination, the diffuse reflectance (whiteness) of the line, and line retroreflectance. Both retroreflectance and luminance from diffuse reflection make up total line luminance. The minimum whiteness (Y) and retroreflectance that might be required under the lights-on condition could not be deduced from this experiment; all the lines tested had sufficient whiteness and contrast to obtain an acceptable or better rating. Lines of lesser whiteness or on roads that have lower contrast or differing illumination may not be judged acceptable under similar conditions when roadway illumination is employed. Roadway luminance and line contrast are a function of many variables including source of illumination, direction of illumination and viewing, surface texture, presence of water, and materials of construction.

The following table gives a summary of minimum and acceptable line specific luminance for dark and lighted test conditions (specific luminance in $\text{mcd/m}^2/\text{lx}$):

Rating	Roadway Conditions	
	Dark	Lighted
Minimum	100	—
Acceptable	>400	>300

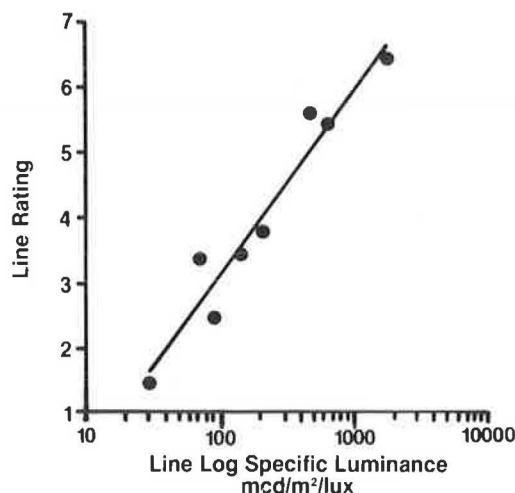


FIGURE 6 Line rating versus log of line specific luminance, dark condition.

Minimum line specific luminances are related to their contrast with the road surface itself. This implies that the values in the preceding table are valid in conjunction with the asphaltic surface of the test road (approximately 15 to 20 $\text{mcd/m}^2/\text{lx}$). Higher values might be found to be desirable under some circumstances because other road surfaces may be lighter in diffuse reflectance. Therefore it is appropriate to examine the contrast obtained by the authors in comparison with the test results of others.

Typical road specific luminances, measured with the Ecolux instrument, are 10 $\text{mcd/m}^2/\text{lx}$ for new asphalt, 15 to 20 $\text{mcd/m}^2/\text{lx}$ for weathered asphalt, and approximately 30 $\text{mcd/m}^2/\text{lx}$ for portland cement concrete; these and the resulting contrast ratios

**TABLE 2 MINIMUM LINE LUMINANCES
AND CONTRAST RATIOS FOR DARK
CONDITIONS**

	Present Authors	Allen (4)	Serres (5)
Minimum line specific luminance	100	90	100
Road luminance	20	30	—
Contrast, C	4	2	2–5

Note: Contrast, C = (Line luminance – Road luminance)
÷ Road luminance.

from the authors' study and two other studies are given in Table 2.

Serres does not report road specific luminances at test locations; she does, however, report the use of a variety of diverse road surfaces. Contrasts are thus implied from known road surfaces and the minimum line luminance reported.

CONCLUSIONS

Comparatively good agreement among the three studies was obtained for minimum specific luminance of pavement marking. These data support a minimum specific luminance level of 100 mcd/m²/lx under ideal "dark" conditions. In addition, the minimum contrast of the line with the road surface should be 3 times the road surface specific luminance, as indicated by Allen (4).

For an acceptable level under dark conditions, a specific luminance of 400 mcd/m²/lx or higher is indicated for dark roadways. For illuminated roads, line specific luminance of at least 300 mcd/m²/lx was judged acceptable and was obtained

with stripes having good whiteness (Y). Under these conditions, the level of retroreflection did not appear to be as significant as line whiteness (Y).

Given the availability of suitable instruments, progress can be made in implementing appropriate inspection policies for acceptance and replacement of these critical materials.

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