

# Luminance Measurements of Retroreflective Warning Signs at Night Using the CapCalc System

HELMUT T. ZWAHLEN, QI LI, AND JING YU

A study to measure the luminance of traffic signs at night with no appreciable glare sources within the field of view at certain distances and lateral positions ahead of a car was conducted on an unused airport runway by using CapCalc, a new photometric measuring and analysis system. Yellow warning signs for curves and turns and yellow chevron signs were placed on the right or left side of a simulated straight, level, dry, two-lane rural highway. Three different types of yellow sheeting materials (enclosed lens, encapsulated lens, and prismatic sheeting) with different reflectance values were used. The results of this study confirmed that the luminance of a reflective traffic sign observed by a driver at night illuminated by the beams of the car is not a constant but changes according to an inverted U-shaped function as the distance between the car and the traffic sign ahead is increased. The observed luminance first increases with the distance between the car and the traffic sign ahead until about 400 ft and then decreases. The highest luminance values for the different lateral positions of the signs (right or left side of the road) are quite different; however, the patterns of the luminance curves as a function of the distance for the right side and the left side traffic signs are similar. Improvements to CapCalc hardware are suggested.

Retroreflective materials are used to enable drivers to more easily detect and recognize signs, delineation elements, and other reflectorized traffic control elements at night under headlamp illumination. Early detection and recognition are important factors in a driver's hazard avoidance process (1). The process suggested for the avoidance of an object on the highway can be used to analogously describe a driver's response to a reflectorized traffic sign and other reflectorized devices that warn a driver of a potentially dangerous road condition ahead at night.

The detection and recognition distances for traffic signs and devices at night are determined by various factors, such as size, color, shape, background, weather conditions, and the luminance of the sign. The *Manual On Uniform Traffic Control Devices* (MUTCD) (2) contains specifications and recommendations for size, color, symbols used, and shape for most signs and devices in service. Another important and controllable factor for the detection or recognition distance is the luminance of a sign or a device. MUTCD indicates that the sign or device should be retroreflective or be illuminated at night. It does not contain a requirement for a minimal luminance value for a particular sign or group of signs or for a particular device or group of devices.

The luminance of a sign is determined by the retroreflectance of the material; the relative positions of the headlamps, the sign, and the driver's eyes; the intensity distribution of the headlamps; and the headlamp misaim. Woltman and Szczech (3) proposed the use of luminance as a criterion for evaluating performance of signs (instead of retroreflectance) because the luminance provides a means to more directly match driver needs. A study by Sivak and Olson in 1983 (4) determined luminance as a function of the driver needs for nighttime sign recognition, and an optimal luminance of 75 cd/m<sup>2</sup> was proposed.

Mace et al. (5) investigated the minimal luminance requirements for official highway signs in 1986. They pointed out two reasons for the lack of a standard to reflect the fundamental driver needs for luminance. The first is the absence of conclusive performance data to support a minimal luminance standard; the second is that there is no practical and reliable way of measuring luminance in the field. (The lack of the proper means of measuring luminance in the field is probably also the major reason for the absence of supporting data.)

In the field, the luminance measurement method using a traditional photometer (e.g., Pritchard photometer) is expensive, inconvenient, and slow. The smallest aperture or measuring angle for a photometer is usually 2 min of arc. For example, if a target is placed 900 ft away from the photometer, the 2 min of arc aperture is used, and only 60 percent of the total circular target area is used to measure the luminance (circular center portion of target). The diameter of the target area for a reliable measurement must be larger than 0.675 ft (8.2 in.). It is therefore difficult to measure the luminances at one or more places on a warning sign that is placed relatively far away from the photometer and that is virtually covered by a large black symbol or message. To overcome these problems and to provide faster measurements, a new photometric measuring and analysis system—CapCalc (Capture an image and Calculate photometric values)—was developed by the Canadian National Research Council (NRCC).

The primary objective of this study was to measure and analyze the luminance of traffic signs in the field under low- and high-beam illumination at night as a function of the distance between the car and sign while using and evaluating the newly developed CapCalc system. Another objective was to examine the luminance performance for signs with different sheeting materials, such as enclosed lens, encapsulated lens, and micro-prismatic sheeting, for different distances of the

signs ahead, for high and low beams, and for different lateral positions (left and right sides of the road). In addition, measurements with a Pritchard photometer were made for comparison purposes.

## EXPERIMENTAL SITE AND APPARATUS

This study was conducted on a 1,500- × 75-ft unused, level, concrete airport runway near Athens, Ohio. The stationary experimental vehicle containing the CapCalc system and the retroreflective traffic signs were arranged to simulate a two-lane rural highway (Figure 1). To reduce the experimental effort, three similar signs were spaced 300 ft apart and 16 ft away from the longitudinal center line of the experimental vehicle to the right side or 22 ft away from the longitudinal center line of the experimental vehicle to the left side. The selected lateral positions of the signs represent conditions found along two-lane rural highways. The bottoms of the signs were 6 ft above the ground. The vehicle used in this experiment was a 1981 Volkswagen Rabbit with properly aimed H6054 headlamps (12.8 to 13 V idle operating voltage, hottest point of the right and left low beams approximately 2 degrees to the right and approximately 2 degrees downward, and hottest point of the right and left high beams approximately 0 degrees vertical and 0 degrees horizontal). The car was placed at four positions 75 to 300 ft from the nearest sign, with an increment of 75 ft between each position. The longitudinal axis of the car was always parallel to the runway axis.

CapCalc, the new computer-based luminance-measuring and image analysis system used in this study, was initially developed by NRCC and is manufactured and marketed by MSR Scientific Enterprises in Ottawa, Canada. The system used in

this study consists of a V-lambda corrected solid-state video camera (Burle CCD), a minimonitor, an image processing board, and a portable personal computer with a hard disk. The system is powered by a 12 V DC/110 V, 60 Hz AC inverter that is powered by the car's electrical system (battery) while collecting the data in the field. The Burle CCD camera of the CapCalc system was placed in the driver's seat of the car in such a way that the center of the front of the lens was approximately at the position at which a driver's eyes would be. The computer and minimonitor were placed in the back seat near the passenger side door to provide easy access to the keyboard and the monitor (Figure 2).

The signs used in this study had three types of retroreflective sheeting materials. Three 30- × 30-in. yellow curve or turn warning signs with enclosed lens sheeting were used, with an average specific intensity per unit area (SIA) (SIA, 0.2 degrees observation angle and -4 degrees entrance angle) of 92.0 cd/lux/m<sup>2</sup> for Sign 1 (measured at 75, 150, 225, and 300 ft), an average SIA of 91.4 cd/lux/m<sup>2</sup> for Sign 2 (measured at 375, 450, 525, and 600 ft), and 86.0 cd/lux/m<sup>2</sup> for Sign 3 (measured at 675, 750, 825, and 900 ft). Three 36- × 30-in. yellow chevron signs with encapsulated lens sheeting were used, with an average SIA of 265.1 cd/lux/m<sup>2</sup> for Sign 1, 263.2 cd/lux/m<sup>2</sup> for Sign 2, and 279.2 cd/lux/m<sup>2</sup> for Sign 3. Three 30- × 30-in. yellow curve and turn warning signs with micro-prismatic sheeting were used, with an average SIA of 957.6 cd/lux/m<sup>2</sup> for Sign 1, 1041.2 cd/lux/m<sup>2</sup> for Sign 2, and 1053.7 cd/lux/m<sup>2</sup> for Sign 3 (Figure 3).

## MEASUREMENT METHOD

The study was conducted several nights between 7:30 and 10:00 p.m. During the measurements, the sky was clear or slightly cloudy. The concrete surface of the runway was dry.

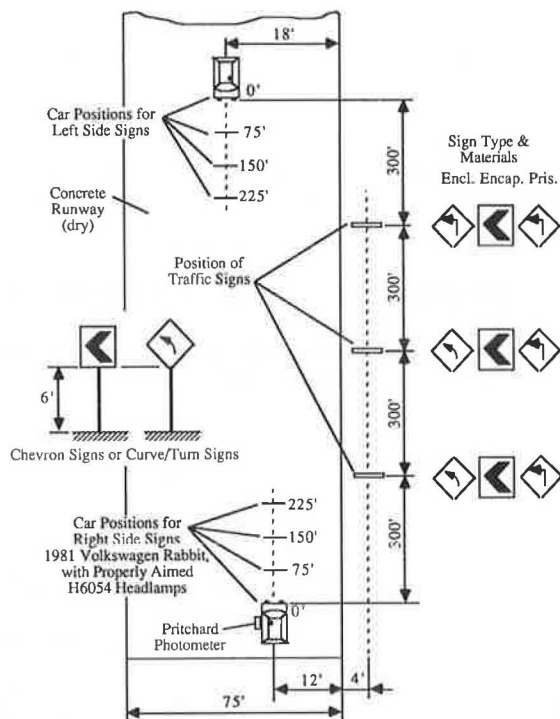


FIGURE 1 Layout of experimental site.

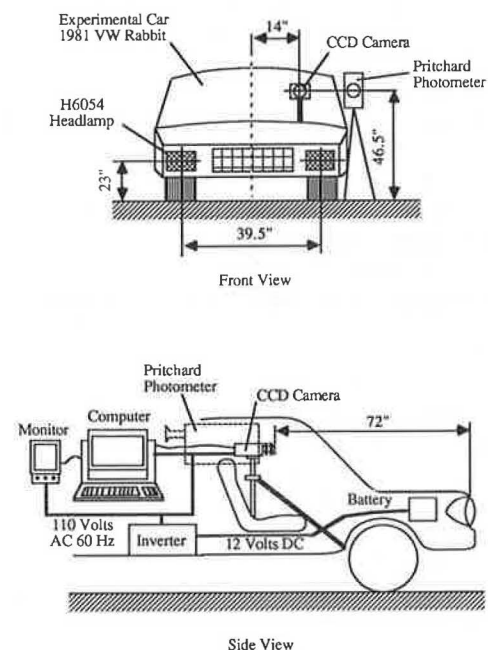
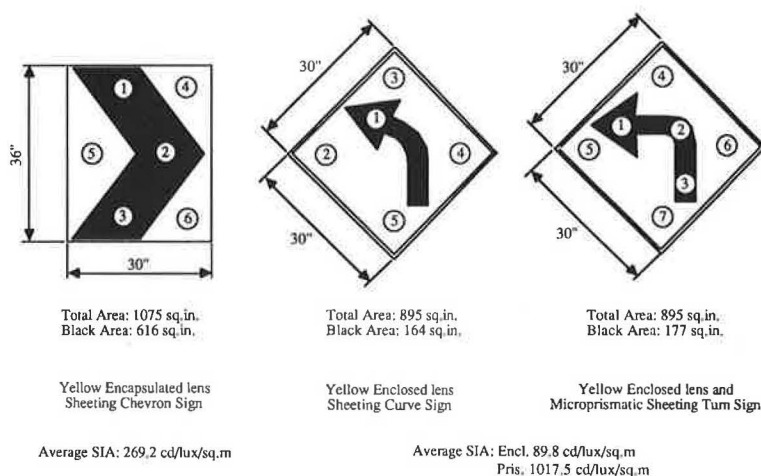


FIGURE 2 Arrangement of CapCalc system in experimental car.



**FIGURE 3** Dimensions and average SIAs of retroreflective materials of signs (circled numbers indicate approximate measurement positions for Pritchard photometer and CapCalc comparisons).

The temperature was between 36 and 43°F. Three signs with the same retroreflective sheeting material were mounted on the steel posts in such a way that the surfaces of the signs were approximately perpendicular to the longitudinal axis of the car.

Three signs were used to increase the speed of the data collection process and to minimize the movement and alignment of the experimental vehicle. CapCalc was used to measure the luminances of the entire picture containing the three signs under low- and high-beam illumination at 300, 225, 150, and 75 ft (measured from the first sign to the headlamps of the car). Using three equally spaced signs also provided luminance values for 600, 525, 450, and 375 ft and for 900, 825, 750, and 675 ft. Thus, for each reflective sheeting material, low beams or high beams, signs on the left or right side of the roadway, a set of luminance measurements for 12 sign positions (using an increment of 75 ft between each sign position) was obtained for further analysis. A zoom setting of 75 mm was used for the 300- and 225-ft measurements, (distance setting at infinity, lens 2 (LB) and 5.6 (HB) for enclosed and encapsulated lenses, lens 4 (LB) and 8 (HB) for prismatic lenses). A zoom setting of 50 mm was used for the 150-ft measurements (distance setting at infinity, lens 2.8 (LB) and 5.6 (HB) for enclosed lens, 2 (LB) and 5.6 (HB) for encapsulated lens, 5.6 (LB) and 11 (HB) for prismatic lens). A zoom setting of 30 mm was used for the 75-ft measurements (distance setting at infinity, lens 2.8 (LB) and 5.6 (HB) for enclosed lens, 2 (LB) and 4 (HB) for encapsulated lens, 5.6 (LB) and 8 (HB) for prismatic lens).

The pictures taken with CapCalc are stored as a luminance value matrix containing 245,760 pixel values (512 × 480). To obtain accurate luminance values, zeroing was performed before each measurement. Zeroing, as used here, means to have the CapCalc system take a number of black pictures and average these values to obtain an average zero, or black, level for each pixel. In this study the number was eight to obtain more stable and accurate values. With this zero level recorded, CapCalc was then instructed to take and average eight pictures of the image of interest. All images of interest can

be saved on a diskette or hard disk for further reference or for further luminance and contrast analyses.

The analysis software in the CapCalc system is menu driven and user friendly. Luminance values of reflectorized objects such as traffic signs can be obtained in three different ways. First, CapCalc can display the luminance value of any single pixel within the picture under the Relative Visual Performance (RVP) menu. The user simply selects the Luminances function from the RVP menu. After the selection a crosshair (which is movable in both directions) will appear on the image screen, the corresponding x-y pixel position and the luminance value for this pixel will be displayed on the computer screen. Second, the average luminance within a measured field can be obtained by using the CapCalc the same way as a standard photometer under the Photometry menu. In this situation the user can move a rectangular frame to define a field or area of interest. The user may relocate and resize the frame, and then get the average luminance value for the pixels contained within that frame. The last and most powerful method uses the RVP calculations under the Calculate menu. To calculate the RVP, the user first defines a frame to contain the target to be analyzed. To identify the target area and background area, the user uses the Contour function to separate the luminance values of all pixels contained in the frame into several levels or equal width frequency classes. CapCalc then uses different gray levels to display the luminances that correspond to the average luminance value for each level or frequency class. The number of contours selected depends on how easily one can separate the target area from the background area. These levels can then be combined stepwise into wider and wider frequency classes until either the whole target area or the whole background area is included. After the target area and the background area are defined, the corresponding average target luminance and the average background luminance will be shown on the screen of the computer. Unfortunately, the current CapCalc software does not provide the number of pixels that are used to calculate the average luminance of each contour frequency class, information that would be useful.

In this study, because of the interest in the average luminances of the traffic signs with different retroreflective materials, the RVP calculation option was used to successfully determine the average luminance values under low- or high-beam illumination for a warning sign placed on the right or left side of the road.

## RESULTS

Average luminance values of the signs under the H6054 low- or high-beam illumination, for signs placed on either side of the roadway are presented in Tables 1 and 2. The curves shown in Figures 4–7 plot the values given in Tables 1 and 2 as a function of the distance between the car's headlamps and the sign. To check the repeatability of the CapCalc system, the measurements for the signs placed on the right side of the roadway were measured again several days after the first

measurements were taken. Figures 4 and 6 show that the results of the repeated measurements (dotted lines) are close to the results of the first measurement, and the CapCalc system appears to produce reasonable repeatability under field conditions. A major portion of the observed differences is most likely a result of small changes in the alignment of the longitudinal car axis and small changes in the operating voltage of the electrical system of the car. The results of the first measurement also show that under low-beam illumination, the maximum luminance value occurred between 400 and 500 ft for signs on the right side of the roadway and between 300 and 600 ft for signs on the left. Under high-beam illumination, the maximum luminance value occurred at 400 ft for signs placed on the right side of the roadway and between 450 and 600 ft for signs placed on the left side.

All shapes of the curves shown in Figures 4–7 are fairly similar to the curves shown by Woltman et al. (3), but the right-hand tail of each curve for the longer distances was not

TABLE 1 AVERAGE LUMINANCE VALUES FOR SIGNS ON RIGHT SIDE OF ROADWAY UNDER LOW- AND HIGH-BEAM ILLUMINATION AS A FUNCTION OF CAR-TO-SIGN DISTANCE

Car to Sign Distance (ft)	Average Luminance Values of the Signs (cd/m <sup>2</sup> )					
	Encl.LB	Encl.HB	Enca.LB	Enca.HB	Pris.LB	Pris.HB
75	2.19	7.6	1.70	11.54	V.L.	V.L.
150	3.79	34.68	5.20	60.64	11.47	45.42
225	7.09	80.64	7.09	230.55	53.68	435.60
300	14.17	114.14	55.51	213.89	125.80	899.78
375	24.77*	119.25*	64.20*	251.55	194.51	1174.28*
450	23.73	89.76	51.33	305.47*	297.83*	1065.22
525	21.87	70.56	51.13	220.01	267.17	726.00
600	18.17	57.07	42.37	127.05	217.90	606.69
675	10.93	46.30	36.78	122.49	144.45	625.02
750	10.78	42.24	20.25	104.70	133.51	450.67
825	6.84	30.24	13.88	91.27	160.83	363.00
900	7.79	25.94	15.61	54.45	103.76	326.70
Overall Average	12.65	59.87	30.42	149.47	155.53	610.76

NOTE: Encl. = enclosed lens; Enca. = encapsulated lens; Pris. = prismatic sheeting.

\* Maximum Luminance.

V.L. Very low luminance value. It was too low for CapCalc to measure.

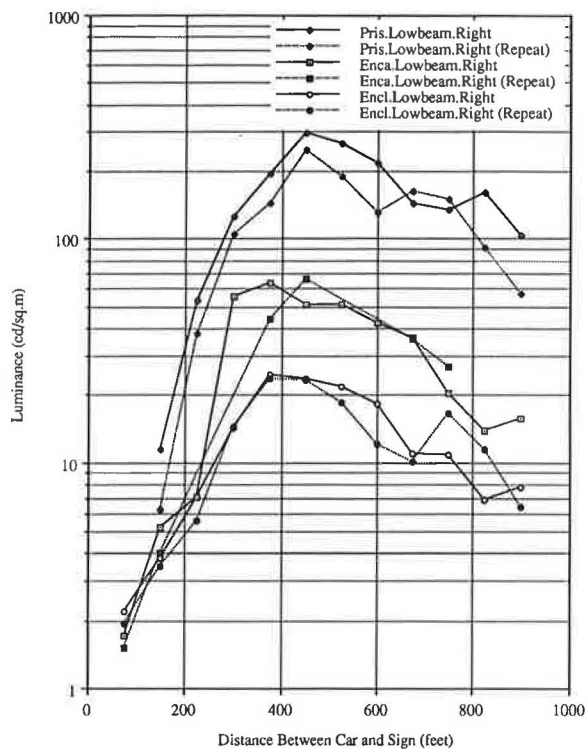
TABLE 2 AVERAGE LUMINANCE VALUES FOR SIGNS ON LEFT SIDE OF ROADWAY UNDER LOW- AND HIGH-BEAM ILLUMINATION AS A FUNCTION OF CAR-TO-SIGN DISTANCE

Car to Sign Distance (ft)	Average Luminance Value of the Signs (cd/m <sup>2</sup> )					
	Encl.LB	Encl.HB	Enca.LB	Enca.HB	Pris.LB	Pris.HB
75	0.87	7.05	0.92	7.41	V.L.	V.L.
150	1.64	24.89	2.44	31.66	4.41	45.18
225	2.93	28.56	7.11	62.26	15.04	108.90
300	4.36*	35.54	9.57*	88.20	19.14	181.44
375	4.01	33.67	8.32	72.60	22.58	242.33
450	2.51	29.04	8.64	84.42	24.89	318.37
525	3.72	36.34	9.24	119.32*	25.97	308.55
600	3.97	38.76*	9.57*	114.14	30.07*	322.56*
675	2.46	22.45	4.93	59.16	17.48	204.63
750	1.89	19.36	5.75	55.40	19.36	256.75
825	2.66	23.36	6.40	77.82	19.14	163.35
900	3.19	21.87	5.44	62.26	19.14	171.36
Overall Average	2.85	26.74	6.53	69.55	19.77	211.22

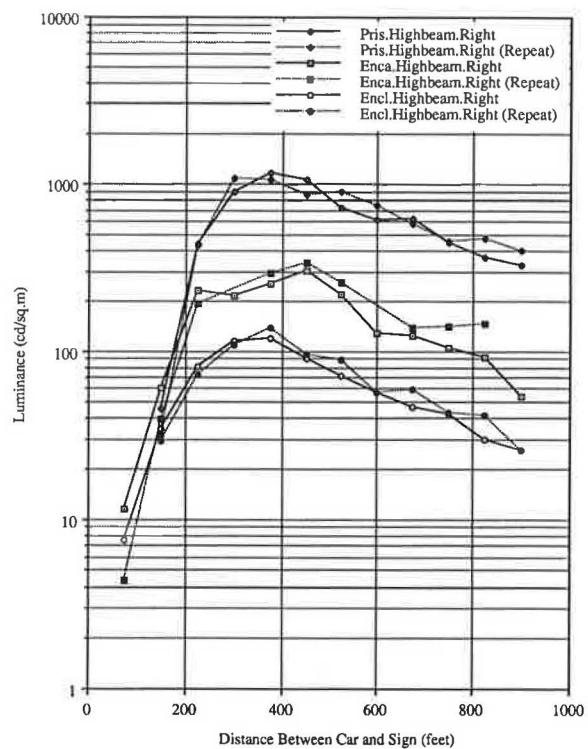
NOTE: Encl. = enclosed lens; Enca. = encapsulated lens; Pris. = prismatic sheeting.

\* Maximum luminance.

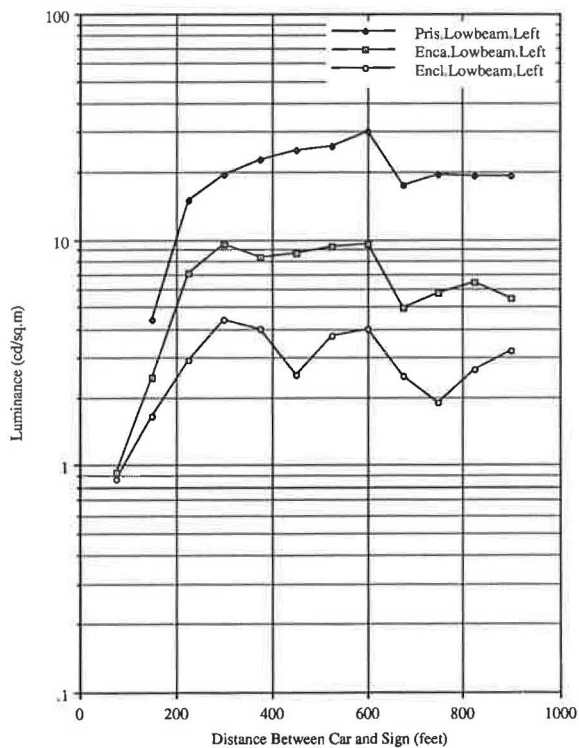
V.L. Very low luminance value. It was too low for CapCalc to measure.



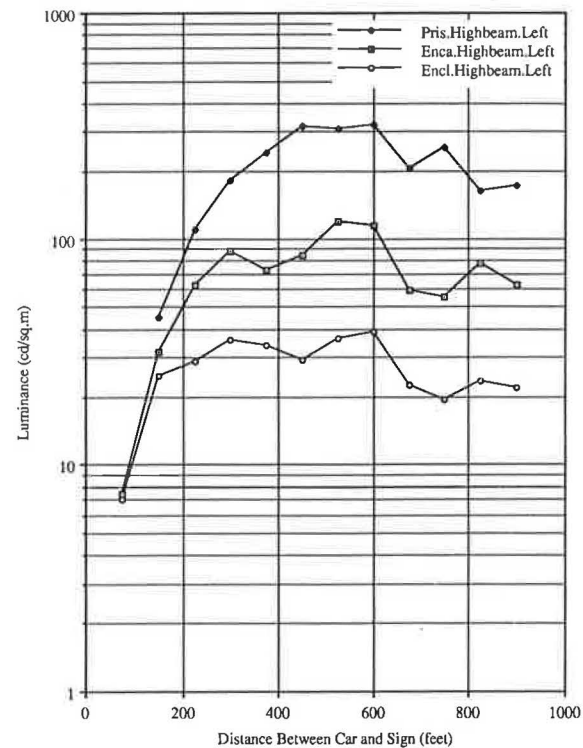
**FIGURE 4** Luminance values for retroreflective sheeting materials versus distance between car and sign for signs on right side of roadway under low-beam illumination, including repeat measurements.



**FIGURE 6** Luminance values for retroreflective sheeting materials versus distance between car and sign for signs on right side of roadway under high-beam illumination, including repeat measurements.



**FIGURE 5** Luminance values for retroreflective sheeting materials versus distance between car and sign for signs on left side of roadway under low-beam illumination.



**FIGURE 7** Luminance values for retroreflective sheeting materials versus distance between car and sign for signs on left side of roadway under high-beam illumination.



as smooth as expected. The major reason may be because in this study three similar signs were captured and measured in one CapCalc picture to reduce the number of pictures taken and to increase the speed of the data collection process. When the distance of the car to the first sign was 75 ft, to contain all the three signs within one scene, the zoom had to be set at 30 mm for signs on the right and 20 mm for signs on the left side of the roadway. The image area covered by the third sign (at 675 ft) became small and contained only 20 to 50 pixels. With such a small number of pixels, it was difficult to identify the target areas and the background areas accurately in the CapCalc pictures by using the Contour function; therefore, the calculated average luminance values for the 675, 750, 825, and 900 ft distances are not as accurate as the values for the shorter distance and show more variability.

Figures 4–7 also show differences in the luminances because of the different beam illumination and sheeting material

types. For comparison, the ratio of luminances under high-beam illumination to that under low-beam illumination for the same sheeting material and the ratio of the luminances for the different sheeting materials under the same beam illumination are shown in Tables 3 and 4 for signs placed on either side of the roadway. The average ratios (averaged over all car to sign distances) for the luminances between high- and low-beam illumination are 4.31 to 7.55 for the three types of retroreflective sheeting materials for signs on the right side of the roadway and 9.64 to 10.63 for the three types of retroreflective sheeting materials for signs on the left. The average ratio for the luminances (averaged over all distances from 75 to 900 ft) between the prismatic sheeting and the enclosed lens sheeting was 11.5 for low-beam illumination and 9.64 for high-beam illumination for signs placed on the right side of the roadway. For signs on the left side, the average ratio was 6.93 for low-beam illumination and 7.54 for high-

TABLE 3 RATIOS OF LUMINANCE VALUES FOR SIGNS ON RIGHT SIDE OF ROADWAY

Car to Sign Distance (ft.)	Ratio of HB Lumi. to LB Lumi. for the Same Retroreflective Material			Ratio of the Luminances for the Different Retroreflective Materials under the Same Beam Illumination					
	Encl. HB/LB	Enca. HB/LB	Pris. HB/LB	Enca/Encl LB	Enca/Encl HB	Pris/Encl LB	Pris/Encl HB	Pris/Enca LB	Pris/Enca HB
75	3.47	6.79	N.D.	0.78	1.52	N.D.	N.D.	N.D.	N.D.
150	9.15	11.66	3.96	1.37	1.75	3.03	1.31	2.21	0.75
225	11.37 *	32.52 *	8.11 *	1.0	2.86	7.57	5.40	7.57	1.89
300	8.06	3.85	7.15	3.92 *	1.87	8.88	7.88	2.27	4.21
375	4.81	3.92	6.04	2.59	2.11	7.85	9.85	3.03	4.67
450	3.78	5.95	3.58	2.16	3.40 *	12.55	11.87	5.80	3.49
525	3.23	4.30	2.72	2.34	3.12	12.22	10.29	5.23	3.30
600	3.14	3.00	2.78	2.33	2.23	11.99	10.63	5.14	4.78
675	4.24	3.33	4.33	3.37	2.65	13.22	13.50 *	3.93	5.10
750	3.92	5.17	3.38	1.88	2.48	12.38	10.67	6.59	4.30
825	4.42	6.58	2.26	2.03	3.02	23.51 *	12.00	11.59 *	3.98
900	3.33	3.49	3.15	2.0	2.10	13.32	12.59	6.65	6.00 *
Average	5.17	7.55	4.31	2.15	2.43	11.5	9.64	5.46	3.86

NOTE: Encl. = enclosed lens; Enca. = encapsulated lens; Pris. = prismatic sheeting.

\* Maximum ratio

N.D. No data

TABLE 4 RATIOS OF LUMINANCE VALUES FOR SIGNS ON LEFT SIDE OF ROADWAY

Car to Sign Distance (ft.)	Ratio of HB Lumi. to LB Lumi. for the Same Retroreflective Material			Ratio of the Luminances for the Different Retroreflective Materials under the Same Beam Illumination					
	Encl. HB/LB	Enca. HB/LB	Pris. HB/LB	Enca/Encl LB	Enca/Encl HB	Pris/Encl LB	Pris/Encl HB	Pris/Enca LB	Pris/Enca HB
75	8.10	8.05	N.D.	1.06	1.05	N.D.	N.D.	N.D.	N.D.
150	15.18*	12.98*	10.24	1.49	1.27	2.69	1.82	1.81	1.43
225	9.75	8.76	7.24	2.43	2.18	5.13	3.81	2.12	1.75
300	8.15	9.22	9.35	2.19	2.48	4.45	5.11	2.03	2.06
375	8.40	8.73	10.73	2.07	2.16	5.63	7.20	2.71	3.34
450	11.57	9.77	12.79	3.44*	2.91	9.92	10.96	2.88	3.77
525	9.77	12.91	11.88	2.48	3.28	6.98	8.49	2.81	2.59
600	9.76	11.93	10.73	2.41	2.94	7.57	8.32	3.14	2.83
675	9.13	12.00	11.71	2.00	2.64	7.11	9.11	3.55*	3.46
750	10.24	9.63	13.26*	3.04	2.86	10.24*	13.26*	3.37	4.63*
825	8.78	12.16	8.53	2.41	3.33*	7.20	6.99	2.99	2.10
900	6.86	11.44	8.95	1.71	2.85	6.00	7.84	3.52	2.75
Average	9.64	10.63	10.49	2.23	2.50	6.93	7.54	2.81	2.79

NOTE: Encl. = enclosed lens; Enca. = encapsulated lens; Pris. = prismatic sheeting.

\* Maximum ratio

N.D. No data

beam illumination. The average ratio for the luminances between the prismatic sheeting and the encapsulated lens sheeting for signs on the right side of the roadway was 5.46 for low-beam illumination and 3.86 for high-beam illumination. For signs on the left side of the roadway the ratio was 2.81 for low-beam illumination and 2.79 for high-beam illumination. The average ratio for the luminances between the encapsulated lens sheeting and enclosed lens sheeting for signs on the right side of the roadway was 2.15 for low-beam illumination and 2.43 for high-beam illumination. For signs on the left side of the roadway the ratio was 2.23 for low-beam illumination and 2.50 for high-beam illumination.

Under low-beam illumination for signs placed from 75 to 900 ft on the right side of the roadway the average luminance values were about 4.44 to 7.87 ( $12.65/2.85 = 4.44$ ,  $30.42/6.53 = 4.66$ ,  $155.53/19.77 = 7.87$ ) times higher than that for signs correspondingly placed on the left side of the roadway. Under high-beam illumination for signs placed from 75 to 900 ft on the right side of the roadway the average luminance values were about 2.15 to 2.89 ( $59.87/26.74 = 2.24$ ,  $149.47/69.55 = 2.15$ ,  $610.76/211.22 = 2.89$ ) times higher than that for signs correspondingly placed on the left side of the roadway.

Another important feature shown in Figures 4–7 is the substantial increase of the luminance values (for the shorter distances between the car and sign) for the prismatic sheeting material, which is much steeper than that for the enclosed lens sheeting material or the encapsulated lens sheeting material. For example, for signs with prismatic sheeting material on the right side of the roadway under low-beam illumination, the maximum luminance value occurring at 450 ft ( $297.83 \text{ cd/m}^2$ ) was 26 times higher than the luminance value at 150 ft ( $11.47 \text{ cd/m}^2$ ). The corresponding increase in luminance was only 6.5 times for the enclosed lens sheeting material. (The maximum value,  $24.77 \text{ cd/m}^2$ , occurred at 375 ft; the luminance value at 150 ft was  $3.79 \text{ cd/m}^2$ .) The corresponding increase in luminance was 12.3 times for the encapsulated lens sheeting material. (The maximum value,  $64.20 \text{ cd/m}^2$ , occurred at 375 ft; the luminance value at 150 ft was  $5.20 \text{ cd/m}^2$ .)

To check the validity of the CapCalc measurements, a Pritchard photometer was used to measure the luminance values of the signs when the second set of CapCalc measurements were made. Because the size of the Pritchard photometer is too big to fit easily inside the car so that the lens position coincided with driver's eye position, the photometer was placed outside the car (Figures 1 and 2) as close to the driver's eye position as possible. The distances between the Pritchard photometer and the traffic sign were 225 or 300 ft. Some Pritchard photometer measurements were made using the photopic filter (to compare with CapCalc, which also has a photopic filter) and some using the scotopic filter, because night driving might involve luminance conditions that require photopic, mesopic, and possibly even scotopic vision. Table 5 presents the comparison of the luminance values measured by the Pritchard photometer and the second set of corresponding measurements made using the CapCalc system. The locations on the sign for the Pritchard measurements are shown in Figure 3. The Pritchard photometer provides in some cases both photopic and scotopic measurements; however, for comparison with the CapCalc measurements only the photopic measure-

TABLE 5 COMPARISON OF AVERAGE LUMINANCE VALUES MEASURED WITH PRITCHARD PHOTOMETER AND CAPCALC

T.o.W. Sign	S. Material	C-S Distance	M Position	Lowbeam			Highbeam			No. of Pixels	
				Pritchard		CapCalc	Pritchard		CapCalc	Covered and Angles	
				Scoto. Filter	Photo. Filter	Photo. Filter	Scoto. Filter	Photo. Filter	Photo. Filter	by Pritchard Circle	by CapCalc Rectangle
Curve Warning	Enclosed Lens	300 feet	1	N.M.	0.17	0.90	N.M.	1.07	7.46	10	81
			2	N.M.	17.96	14.43	N.M.	110.20	109.68		
			3	N.M.	14.88	10.95	N.M.	113.86	111.30		
			4	N.M.	18.31	16.05	N.M.	111.69	112.11		
			5	N.M.	24.76	23.56	N.M.	109.52	118.51		
Chevron Warning	Encapsulated Lens	225 feet	1	2.11	2.05	1.61	21.60	16.91	7.21	60	120
			2	0.09	0.09	0.27	0.63	0.43	2.03		
			3	0.08	0.07	0.22	0.73	0.45	1.95		
			4	13.75	20.35	18.38	168.67	228.06	226.89		
			5	10.34	19.86	14.78	140.69	251.13	202.17		
Turn Warning	Microprismatic	225 feet	1	0.15	0.13	0.97	1.77	1.55	11.50	10	81
			2	0.25	0.20	N.M.	2.84	1.80	N.M.		
			3	0.22	0.21	N.M.	1.18	1.46	N.M.		
			4	18.11	26.39	24.99	259.11	438.53	386.82		
			5	27.15	41.32	40.04	309.03	553.98	524.95		
			6	23.92	38.52	35.33	223.83	435.44	418.95	2' Circle	5.53' V 6.77' H
			7	40.04	72.97	60.19	294.75	508.99	531.88		

NOTE: Luminance values are in candelas per square meter.

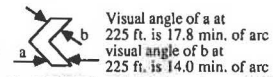
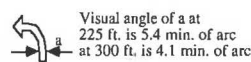
T.o.W. Sign = Type of Warning Sign S. Material = Sheeting Material

C-S. Distance = Car - Sign Distance M. Position = Measurement Position

Scoto. = Scotopic Photo. = Photopic N.M. = Not Measured.

■ M. Position in black area

□ M. Position in yellow area



\* Smallest possible rectangle provided by CapCalc Luminance Function contains 9 x 9 pixels (or roughly 4.75' V x 5.70' H visual angle for a zoom setting of 75 mm).

ments should be used. The CapCalc measurements for the positions within the yellow reflective sheeting area are close and slightly lower than the corresponding Pritchard photopic measurements (Table 5). Note that the photopic CapCalc averages are based on somewhat larger areas than the Pritchard photopic values, which may be the reason for the few and rather small differences in the opposite direction (see the last two columns in Table 5). In addition, the idling car engine produced small vibrations that were conducted through the car and seat to the CapCalc camera, which could have produced some slight measurement errors. In general one would expect somewhat lower CapCalc values as a result of transmission losses caused by the windshield of the vehicle. Most CapCalc measurements for the positions within the black arrow or the black chevron area are higher than the corresponding Pritchard photopic measurements. This is most likely a result of the radiating edge effect of the yellow area, because a larger region of the black area was used for the CapCalc analysis when compared with the actual area covered by the aperture of the Pritchard. In this study, the selected CapCalc areas for each black measurement position almost included the whole area of the black arrow to fit the minimum 9- x 9-pixel rectangle inside the black area and to obtain average luminance values using the CapCalc luminance measurement function. In general the luminance values for the yellow area measured with the scotopic filter of the Pritchard photometer were somewhat lower than the corresponding values using the photopic filter.

## CONCLUSIONS

This study demonstrated that obtaining luminance measurements of reflectorized traffic signs from a stationary vehicle under static conditions in the field at night with no appreciable glare sources within the field of view is feasible using the CapCalc system. Further, the use of CapCalc for data collection and subsequent analysis in terms of luminance values is fairly easy and straightforward. Comparisons between two sets of CapCalc measurements and between the photopic Pritchard and the CapCalc measurements show that the CapCalc system appears to provide satisfactory accuracy and repeatability for luminance measurements of traffic signs at night in the field. For field application the digitized pictures can be saved for further analysis and future reference. Multiple signs in a row can be captured using a single picture in order to speed up the data collection process and reduce the storage requirement. However, the luminance values of signs placed far away in multiple sign pictures may not be accurate or reliable and may include considerable variability because a relatively low number of pixels cover such a sign. To obtain the most accurate luminance values with the CapCalc system installed in a car it is recommended that the objects of interest always be placed as close to the center of the screen as possible and be as large as possible and that the engine is turned off (provide power for headlamps using another vehicle or power source) and the vehicle does not vibrate.

Although CapCalc was used successfully in this study, several improvements are necessary for the system to meet the wide range of night driving and signing conditions. These improvements include better measurement sensitivity and accuracy in the low luminance range (between 1 cd/m<sup>2</sup> and values close to 0 cd/m<sup>2</sup>), a more powerful tele-objective lens (much greater than 75 mm focal length) to capture the luminance values of signs farther away more accurately (more pixels on the signs), an increase in the number of gray levels from 256 (8 bits) to a larger number such as 4,096 (12 bits), as well as some minor modifications to improve the usefulness and the statistical capabilities of the analysis software. On a more general visibility note, this study confirms that the luminance performance of retroreflective traffic signs at night

depends on many factors, such as the retroreflectance of the materials used, the distance between the car and the sign, the lateral position of the sign with respect to the car, and the beam illumination. Signs placed on the left side of the roadway have considerably lower luminance values when compared with the luminance values for signs placed correspondingly on the right side of the roadway, especially when the low beams are used. It would appear that the prismatic sheeting material might be the most viable option to increase the luminance values for signs placed on the left side of the roadway under low-beam conditions. Further, if one would want to use the retroreflectance of the sheeting material instead of the luminance to match driver needs and to specify a minimum acceptable retroreflectance value, it would appear that a single minimum acceptable retroreflectance value would not be a feasible, efficient, or desirable alternative. At least two different minimum acceptable retroreflectance values for side-mounted traffic signs (not overhead signs) should be used depending on whether a retroreflective traffic sign such as a yellow warning sign is placed on the right side or on the left side of the roadway.

## REFERENCES

1. H. W. McGee, W. Moore, B. G. Knapp, and J. H. Sanders. *Decision Sight Distance for Highway Design and Traffic Control Requirements*. Report FHWA-RD-78-78. FHWA, U.S. Department of Transportation, Feb. 1978.
2. *Manual on Uniform Traffic Control Devices*. FHWA, U.S. Department of Transportation, 1988 edition.
3. H. L. Woltman and T. J. Szczech. Sign Luminance as a Methodology for Matching Driver Needs, Roadway Variables, and Signing Materials. In *Transportation Research Record 1213*, TRB, National Research Council, Washington, D.C., 1989, pp. 21-26.
4. M. Sivak and P. L. Olson. *Optimal and Replacement Luminances of Traffic Signs: A Review of Applied Legibility Research*. UMTRI 83-43. Transportation Research Institute, University of Michigan, Ann Arbor, Dec. 1983.
5. D. J. Mace, R. S. Hostetter, L. E. Pollack, and W. D. Zweig. *Minimal Luminance Requirement for Official Highway Signs*. Report FHWA/RD-86/150, Executive Summary. Office of Safety and Traffic Operations Research and Development, FHWA, U.S. Department of Transportation, May 1986.