Evaluation of Proposed Minimum Retroreflectivity Requirements for Traffic Signs

CLETUS R. MERCIER, CHARLES GOODSPEED, CAROLE J. SIMMONS, AND JEFFREY F. PANIATI

An FHWA study was recently completed as part of its retroreflectivity research program; the goal was to determine minimum retroreflectivity requirements for traffic signs. Results were summarized in tables providing recommended minimum R_a values for warning, regulatory, and guide signs, with the tables designed to provide a framework of minimum retroreflectivity requirements for field implementation. However, the level of accommodation could only be estimated in the range of 75 to 85 percent. The study measured luminance threshold for traffic signs. Subjects in a darkened laboratory viewed a series of scaled traffic signs. Simulated viewing distance was the "minimum required visibility distance," that is, the minimum distance that would allow a driver sufficient time to respond safely to the sign. Sign luminance was increased in steps until the subject was able to correctly recognize it. Data scatter plots showed an increased need for sign luminance with subject age. To specify the percent accommodated for the driving population, laboratory data were extrapolated statistically. For each sign, the mean and variance for the subjects tested were used to generate model data points, and percentiles were determined using U.S. driving population age distribution data. Analysis showed that 85 percent or more of all drivers (98 to 100 percent for most signs) would be accommodated by the level of retroreflectivity recommended for nearly all signs tested. Results indicate that minimum retroreflectivity table values are fairly conservative, allowing a margin for safety.

This paper is based on a study completed as part of the FHWA retroreflectivity research program. The program has two primary goals: (a) to define minimum nighttime visibility requirements for traffic control devices, and (b) to develop measurement devices and computer management tools necessary to effectively implement these requirements.

Two separate studies were directed toward the first goal. The first of these was the development of a computer model designed to define minimum retroreflective values for in-service traffic signs. The second study, described in this paper, is an evaluation of the proposed values.

Current national guidelines relating to traffic sign nighttime visibility are limited to the stipulation in the Manual on Uniform Traffic Control Devices for Streets and Highways (*1*) that all warning and regulatory signs be illuminated or reflectorized to show the same color and shape by day or night. No objective measures are stated that can be used to determine end-of-sign service life, when it needs replacement.

C. R. Mercier, Department of Engineering, Iowa State University, Ames, Iowa 50011. C. Goodspeed, SAIC, 6300 Georgetown Pike, McLean, Va. 22101-2296. C. J. Simmons and J. F. Paniati, Turner-Fairbank Highway Research Center, 6300 Georgetown Pike, McLean, Va. 22101-2296.

SUPPLY AND DEMAND

Visibility of retroreflective traffic signs can be examined on the basis of supply and demand. Retroreflective materials included in sign manufacture combine with light received from vehicle headlights to "supply" a given level of luminance, reflected back to the driver. This provides a "lighted" sign, which is easier for vehicle drivers to see and read at night.

The demand side is associated with driver needs to gain access to information provided by the sign at a particular distance to take timely and proper action. When sign luminance falls below that demanded by the driver because of inadequate retroreflectance, the sign should be replaced. The study goal was to define a "threshold" level of sign retroreflectivity, when supply satisfies demand. One of the main problems is that demand varies according to the vision characteristics of the driver. Part of the driving population, aware of their nighttime visibility problems, compensate by either avoidance of nighttime driving, by driving only on familiar streets at night, or by driving at slower speeds to have enough time to react to traffic sign messages and to unexpected situations.

The challenge of determining threshold levels that are suitable for a high percentage (for example, 90 percent) of the driving population remains a policy decision because it is not economically feasible to select threshold levels that will serve all drivers. This study will help in the decision-making process by providing minimum retroreflective values needed to accommodate varying percentages of the driving population. If the threshold is not high enough to serve the selected population, then minimum retroreflectivity values must be changed.

However, the wide range of visual, cognitive, and psychomotor capabilities among drivers complicates the problem of determining the percentage of driving population served. Also, there is substantial complexity in relationships among driver, vehicle, signs, and the roadway.

COMPUTER MODEL

A 1993 FHWA study by Paniati and Mace (*2*) addressed the first of the two goals described earlier. The research developed minimum retroreflectivity requirements for warning, regulatory, and guide signs. Researchers utilized a mathematical model to study the complex relationships between the driver, the vehicle, the signs, and the roadway. The model produced is called Computer Analysis of the Retroreflectance of Traffic Signs (CARTS). The model's theoretical construct is based on two validated theoretical models and one submodel developed expressly for CARTS.

The fundamental basis for CARTS is the concept of minimum required visibility distance (MRVD). The MRVD is the shortest distance at which a sign must be visible to enable a driver to respond safely and appropriately. MRVD includes the distance required for a driver to detect the presence of a sign, recognize the message, decide on a proper action (if necessary), and make the appropriate maneuver (if necessary) before the sign moves out of the driver's vision. For a selected sign, CARTS calculates the required MRVD, determines the luminance required at the MRVD, and then converts this luminance to a minimum required retroreflectivity value. The model allows the user to vary numerous parameters, including the type, size, and location of the sign; the headlamp design and driver position; the driver age and visual characteristics; the roadway design; and the traffic volume. Details of the CARTS model are provided in the Minimum Visibility Requirements for Traffic Signs project report.

Paniati and Mace (*2*) used the CARTS model in their research to identify the critical variables affecting sign retroreflectivity and to provide insight into the levels of retroreflectivity that are required for meeting driver needs. The result of this work was a set of minimum retroreflectivity requirement tables (see Table 1). The tables were designed to provide a framework for field implementation of research results. Paniati and Mace estimated that values provided in the tables would accommodate at least 75 to 85 percent of all drivers, but for various reasons (described in the project report) they were unable to provide a more definitive estimate. This paper describes a second research project, conducted to more fully study the levels of driver accommodation.

STUDY PROBLEM

Resulting minimum retroreflectivity values derived from CARTS seem consistent with experimental values derived from other studies but need to be specifically validated in the context of their intended use. The validation problem was further complicated by the variability of driver nighttime vision exacerbated by accelerated deterioration of contrast sensitivity loss experienced by some older drivers. A lack of significant correlation between age and contrast sensitivity loss provides another variable important in the validation study. This lack of correlation provided the rationale for two elements of this study. It was hypothesized that age-related deterioration in vision contrast sensitivity is the proximate cause for nighttime visibility problems experienced by some older drivers. This

TABLE 1 Summary of Minimum Retroreflectivity Guidelines for Signs Covered in the Study (*2*)

Legend Color: Black	**Background Color: Yellow or Orange**			
Sign Size		**>=48 in[1]**	**36 in[1]**	**<= 30 in[1]**
Legend	Material Type	Minimum retroreflectivity values[2]		
Bold Symbol	All	15	20	25
Fine Symbol and Word	I	20	30	45
	II	25	40	60
	III	30	50	80
	IV, VII	40	70	120

Legend Color: White	**Background Color: Red**											
Traffic Speed	**45 mph or greater**						**40 mph or less**					
Sign Size	>= 48 in		36 in		<= 30 in		>= 48 in		36 in		<= 30 in	
	W[2]	R[2]	W[2]	R[2]	W[2]	R[2]	W[2]	R[2]	W[2]	R[2]	W[2]	R[2]
All Signs	50	10	60	12	70	14	30	6	35	7	40	8

Legend Color: Black and/or Black and Red		**Background Color: White**					
Traffic Speed		**45 mph or greater**			**40 mph or less**		
Sign Size		>= 48 in	30-36 in	<= 24 in	>= 48 in	30-36 in	<= 24 in
	Material						
Grnd Mntd	I	20	35	50	15	20	35
	II	25	45	70	20	30	55
	III	30	60	90	25	45	75
	IV, VII	40	80	120	35	60	100
Over-head Mntd	I				40	50	100
	II				50	75	135
	III				65	115	185
	IV, VII				90	150	250

Legend Color: White	**Background: Green**			
Traffic Speed	**45 mph or greater**		**40 mph or less**	
Color	White[2]	Green[2]	White[2]	Green[2]
Grnd Mntd	35	7	25	5
Ov'hd Mntd	110	22	80	16

[1]1 in = 25.4 mm
[2]Shown below are minimum reflectivity values for the material and color indicated, in cd/lux/m^2.
1 mph (mile per hour) = 1.6 kph (kilometers per hour)

translates to a need for higher retroreflectivity values to be able to read traffic sign messages.

Therefore, the population of participants recruited was weighted to include a significant number of drivers aged 65 and older—ages at which a higher incidence of vision with diminished contrast sensitivity would be expected. Second, data were collected on high and low luminance vision contrast sensitivity for all subjects for later analysis.

The experimental design includes a simulation designed to approximate CARTS reference conditions described earlier, used to generate traffic sign minimum retroreflectivity requirements incorporated in the tables. Analysis of data collected from this study was directed toward the evaluation of these minimum retroreflectivity values.

RESEARCH METHODOLOGY

A luminance threshold experiment was conducted in which subjects in a darkened laboratory viewed a series of signs at corresponding MRVDs. Test conditions simulated CARTS reference conditions. Luminance provided for each sign was increased in steps until the subject was able to correctly read or recognize the sign. The luminance level when the subject correctly recognized the sign was recorded as the "threshold" value.

Sign luminance was controlled by varying the illuminance level on the sign. The light source used to illuminate the signs was placed at a 45 degree angle from perpendicular, such that sign luminance in the direction of the subjects did not utilize the retroreflective properties of the signing material. To compare the experimental data with the candidate guideline values in the Minimum Retroreflectivity Requirements for Traffic Signs report, guideline R_a values were converted to luminances using the CARTS model. A detailed account of the experimental methods and results follows.

Experimental Setup

The experiment was conducted in the Photometric and Visibility Laboratory at the Turner-Fairbank Highway Research Center. The main part of the laboratory consists of a single, windowless room, measuring 4.3 m (14 ft) by 36.6 m (120 ft) in length. All interior surfaces (walls, ceiling, and floor) are black to minimize light reflection and allow better control of light levels. The laboratory was darkened to a level of approximately .01 cd/m^2, to simulate a nighttime rural highway environment.

A total of 25 signs were selected as representative of the regulatory, warning, and guide signs included in the candidate guideline tables. These comprised thirteen yellow diamond warning signs (nine with symbol legends, four with word legends), three white-on-red regulatory signs and two white-on-green guide signs. Five of the signs were fabricated and tested in two different sizes to evaluate the effect of sign size on required retroreflectivity.

Signs were tested at distances corresponding to the MRVDs for two speeds: 88 kph (55 mph) and 48 kph (30 mph). Because a maximum sight distance of less than 36.6 m (120 ft) was available in the laboratory, it was not possible to model driving conditions at full scale. Instead, signs were scaled using available laboratory distance and the calculated MRVD for each sign tested. For example, if a sign's MRVD was 62.2 m (204 ft), the sign was fabricated at 0.5 scale and shown at 31.1 m (102 ft). (In most cases, signs were scaled at half size.) Tables 2 and 3 provide a complete listing of

TABLE 2 Description of Stimuli Tested in Phase 1

SIGN	MUTCD Code	Actual Size (m)	Scaled Size (m)	MRVD @ 48 km/h (m)*	MRVD @ 88 km/h (m)*
Right Curve	W1-2R	.762	.381	50.3	61.3
Right Intersection	W2-2	.762 .914	.381 .457	50.3 50.6	61.3 61.9
Narrow Bridge	W5-2	.762	.381	50.3	61.3
Right Lane Ends	W2-2	.762 .914	.381 .457	50.3 50.6	61.3 61.9
Bicycle Crossing	W11-1	.762	.381 .457	50.3 50.6	61.3 61.9
Pedestrian Crossing	W11-2	.762	.381	50.3	61.3
Do Not Pass	R4-1	.61	.305	49.7	61
Keep Right	R4-7	.61 .762	.318 .356	56.4	61
No Right Turn	R3-1	.61	.305	50.6	61 73.2
One Way	R6-1	.914	.457	50.6	61.9
Stop	R1-1	.914	.152 .33	70.4	185.3
Do Not Enter	R5-1	.762	.127 .254	46.6	185.3
Coming (destination)	D2-1	1.27	.229	51.5	62.8
Creston/Gravity (destination)	D2-2	1.524	.762	52.4	63.4

1 m = 3.28 feet

TABLE 3 Description of Stimuli Tested in Phase 2

SIGN	MUTCD Code	Actual Size (m)	Scaled Size (m)	MRVD @ 48 km/h (m)*	MRVD @ 88 km/h (m)*
Merge	W4-1	.762	.381	n/a	61.3
Deer Crossing	W11-3	.762	.381	n/a	61.3
Slippery When Wet	W8-5	.762	.381	n/a	61.3
No Passing	W14-3	1.22	.283	n/a	133.8
Narrow Bridge	W5-2	.914	.457	n/a	62.5
Flagger	W20-7a	.914	.457	n/a	61.9
Worker	W21-1a	.914	.457	n/a	61.9
Road Work 1 Mile	W21-4	.914	.457	n/a	61.9
Stop	R1-1	.762	.127	70.4	185.3
Yield	R1-2	.762	.127	70.4	185.3
Do Not Enter	R5-1	.762	.127	70.4	185.3
Speed Limit 50	R2-1	.61	.259	n/a	73.2
Reduced Speed Ahead	R2-5a	.61	.311	n/a	61
Route 40	M1-4	.61	..311	n/a	61

1 m = 3.28 feet

scaled sign sizes and viewing distances for Phases 1 and 2, respectively.

For ease of presentation, signs to be displayed were mounted on a rotating wheel approximately 2 m (6 ft) in diameter. Five signs could be placed on the wheel at one time, although one at a time would be visible.

Signs were illuminated by a Standard Illuminant A light source, positioned at a distance of 2.6 m (8.5 ft) from the sign, with an entrance angle of 45 degrees (see Figure 1). It was not possible to vary the light source intensity directly without causing color shifts. Instead, the desired illumination levels were achieved with the aid of a neutral density filter wheel with 20 neutral density settings ranging from 0.02 to 3.0. The filter settings were calibrated with an LMT 1009 luminance meter. Sign panel luminance was also measured with the light source unfiltered, for each of the sign background colors used. Exposure time for each trial was controlled by a shutter on the light source. Type 1 engineering grade sheeting was used for all signs.

The study was conducted in two phases. In Phase 1, a total of 14 different signs were tested at various size/speed combinations, for a total of 34 trials. In Phase 2, a total of 14 different signs were tested (17 trials). Three signs from Phase 1 were repeated in Phase 2 (Narrow Bridge, Stop, Do Not Enter), but only two trials were exactly replicated in the two phases [Do Not Enter, .76-m (30-in.) size, at 88 and 48 kph].

Subjects

Subjects were recruited from a list of drivers who regularly take part in various FHWA human factor studies and were paid for their participation. An attempt was made to balance each age group by gender. Subjects were required to hold a current valid driver's license. Subject age distributions for both phases of the study are shown in Table 4. All subjects were tested for static visual acuity using a

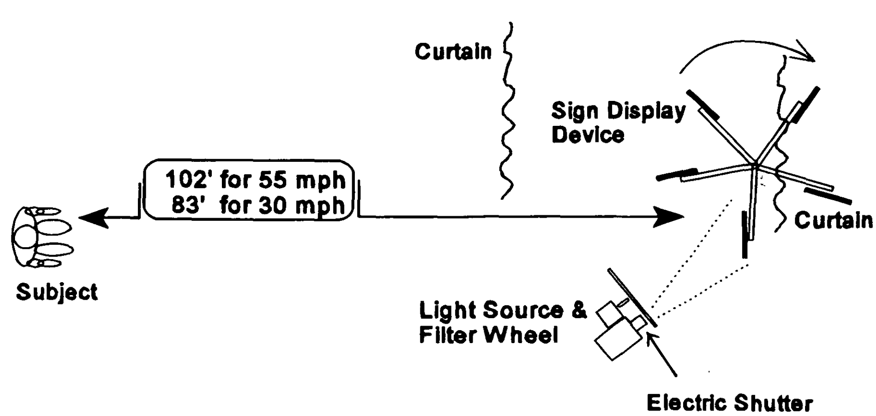

FIGURE 1 Experimental set-up.

TABLE 4 Age and Visual Acuity Data for Subjects

Ages	# of Subjects		Mean Age (S.D.)		Mean Visual Acuity (S.D.)	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
16-34	10	10	28 (3.6)	32.9 (7.4)	19.8/40 (3.4)	21.2/40 (3.9)
35-44	10	*	39 (2.7)	*	19.9/40 (2.9)	*
45-54	10	10	49 (3.1)	50.0 (3.0)	20.7/40 (1.9)	20.0/40 (1.9)
55-64	10	10	59 (2.8)	59.0 (2.7)	21.8/40 (1.9)	22.3/40 (3.2)
65-74	13	7	71 (3.5)	70.1 (3.2)	27.0/40 (5.6)	25.9/40 (4.3)
75+	10	8	8 (2.8)	77.0 (2.2)	25.9/40 (7.0)	24.6/40 (5.4)

For Phase II, there were a total of 10 subjects in the age range of 16-44.

Bosch and Lomb Orthorater and were required to have a minimum of 20/40 (Table 3). All subjects were tested for contrast sensitivity using the Vistech 6500 (*3*) test chart at high luminance (20 cd/m^2) (Figure 2). In addition, subjects in Phase 2 of the study were tested for color vision with American Optics Pseudo-isochromatic Color Plates, and their low luminance contrast sensitivity (1.85 cd/m^2) was measured at the end of the experiment while their eyes were still dark adapted.

Experimental Procedure

Subjects were seated in the darkened laboratory for 5 min to allow their eyes to dark adapt, while being instructed on the experimental task. After the adaptation period, the sign visibility data collection portion of the study commenced.

Subjects were first shown all the signs at one viewing distance, then moved to view the signs at the second distance. Half of the subjects viewed the signs from a distance of 88 kph first and half viewed the signs from a distance of 48 kph first. To minimize possible learning effects, signs were arranged so that similar signs were not shown consecutively. The sets of signs that were placed on the rotating wheel were shown in an order that was counterbalanced across subjects.

For each trial, a single sign was displayed for a 1-sec interval, and subjects were asked if they could see and describe the sign message. If the subject failed to respond correctly, the wheel was rotated to display the next sign in the set at the same illuminance. If the subject correctly identified the sign message, the filter setting was recorded and the sign was removed from the sequence. When all signs had been presented at a given illuminance level and the correctly identified signs had been removed, the illuminance level was increased by one step of the filter wheel, and the remaining signs were presented to the subject. This procedure was repeated until all of the signs in the group were correctly identified or the maximum luminance level was reached.

RESULTS AND DISCUSSION

The first step in the data analysis was the generation of scatter plots for each sign, plotting subject age (*x*-axis) versus required lumi-

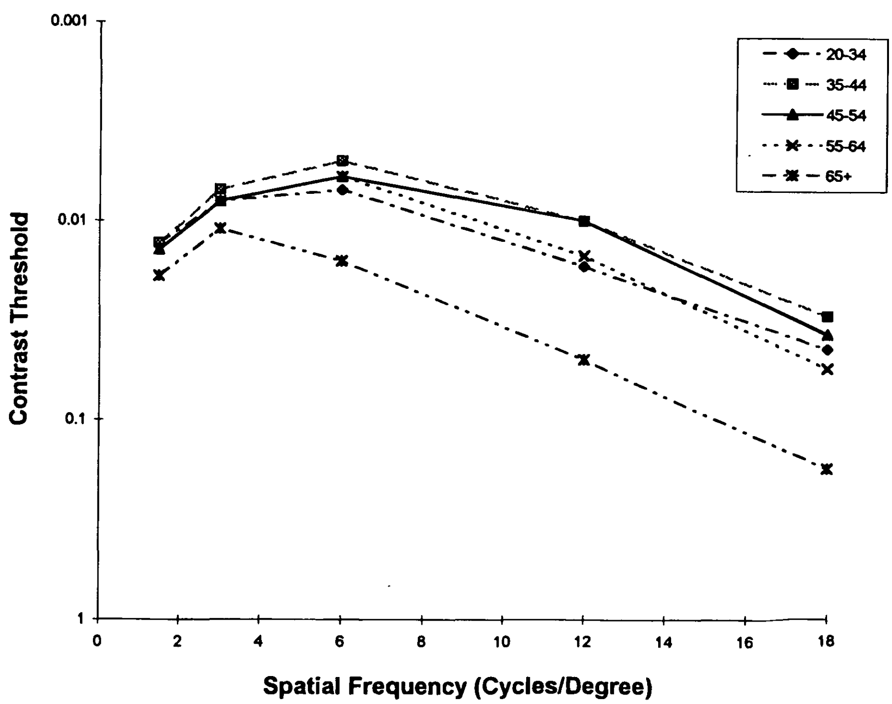

FIGURE 2 Contrast sensitivity test results for Phase I subjects (means for each group).

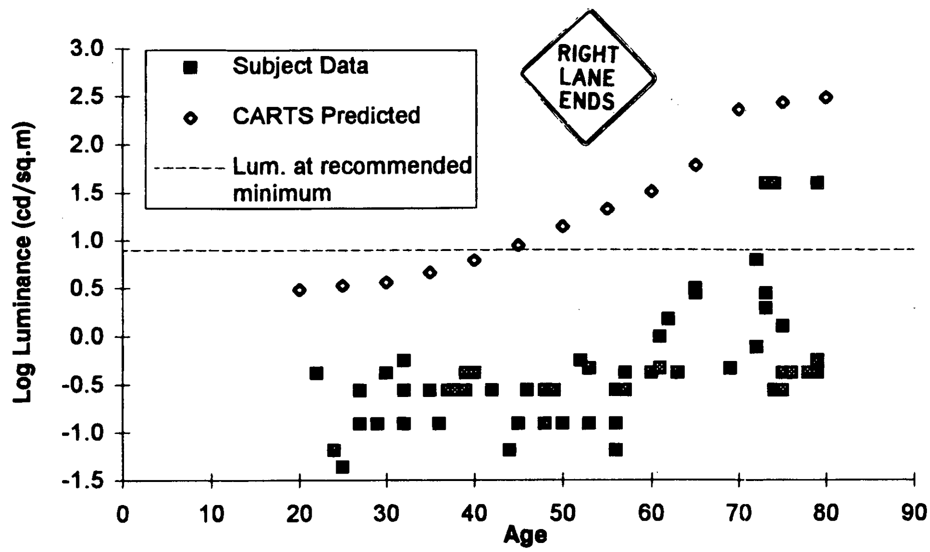

FIGURE 3 Luminance required to identify Right Lane Ends warning sign as a function of subject age (four subjects unable to read at highest luminance). Speed = 55 mph, sign width = 36 in.

nance (y-axis) for each sign tested. The full set of scatter plots are provided in the project report, but three representative plots are presented here to illustrate some of the typical features. The square data points represent the threshold luminance value for each subject.

Data for the text warning sign "right lane ends" (0.914 m, 48 kph) are shown in Figure 3. In general, older subjects required higher luminances than did the younger subjects to recognize the sign, and data variability tended to increase with age. These patterns were typical of the text warning signs tested.

Figure 4 shows data for the right turn arrow (0.72 m, 88 kph), which is typical of the bold symbol signs. Results were different from the text signs in that even older subjects were able to recognize the sign at low luminances.

Figure 5 is the scatter plot for a bicycle symbol (0.914 m, 88 kph) warning sign. This is categorized as a "fine symbol" sign and grouped with text warning signs in the Paniati and Mace tables. The plot for this sign is similar to that of text signs in that older subjects tended to require more light than did the younger subjects to recognize it. There were a number of cases in which a subject failed to correctly identify a sign even when it was shown at the highest luminance level. The number of subjects unable to read or recognize the sign is indicated on each of the scatter plots. Table 5 lists six different signs that were not recognized at the highest luminance level by five or more subjects. As can be seen, with the exception of the No Passing Zone sign, almost all of the subjects were in the 65+ age group. This points to a problem with the design of these signs that cannot be remedied by additional sign brightness. Instead, these signs need to be either redesigned or made larger to enable older drivers to resolve the level of detail needed for recognition.

Each scatter plot indicates values predicted by the CARTS model by the diamond-shaped data points. The CARTS model used was a recently modified version (July 1994) that correctly accounts for

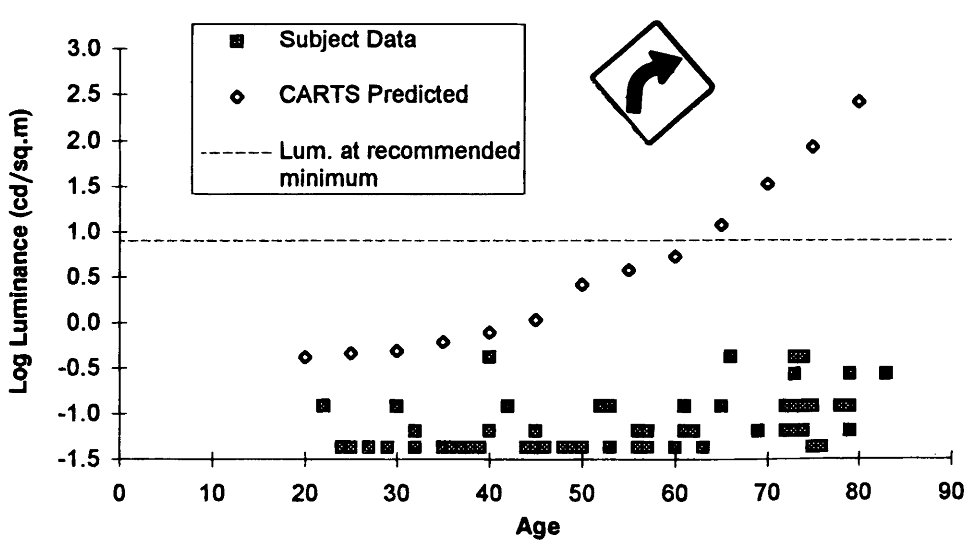

FIGURE 4 Luminance required to identify Curve symbol warning sign as a function of subject age. Speed = 55 mph, sign width = 30 in.

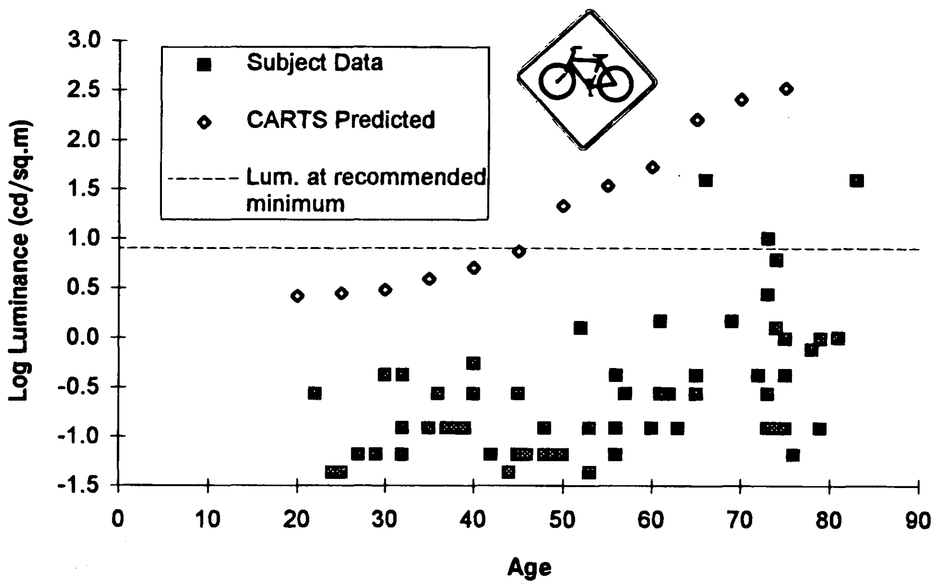

FIGURE 5 Luminance required to identify Bicycle symbol warning sign as a function of age. Speed = 55 mph, sign width = 30 in.

effects of two headlights on observation angle. All signs were assumed to follow MUTCD-specified heights and offsets. All signs were assumed to be right-mounted, with the exception of the No Passing Zone (left-mounted) and Keep Right (median placement) signs.

In most cases the experimental data fall well below the CARTS predicted values More importantly, each plot also contains a horizontal line indicating the luminance value supplied by the candidate minimum R_a recommended by Paniati and Mace. For each plot, almost all the subject data fall below this line, indicating that most subjects tested would be accommodated by the minimum R_a values.

Although the scatter plots offer qualitative evidence that most test subjects would be accommodated by the candidate guidelines, a second level of analysis was necessary to estimate percent accommodated for the driving population at large. Table 6 indicates the age distribution of the test sample versus the U.S. driving population (*4*). The test sample was not reflective of the whole driver population because older drivers were purposely oversampled for the study.

To develop an unbiased estimate, hypothetical data for each age group were generated by randomly sampling data from a normal distribution having the same mean and standard deviation as the corresponding subject age group. A total of 100 hypothetical data points were generated, with the same age distribution as that of the whole driving public. This resulted in 39 hypothetical threshold luminance values generated for the age group 16 to 34, 22 values for the 35 to 44 age group, 14 for the 45 to 54 age group, 11 for the 55 to 64 age group, and 14 for the 65 and older age group. For cases where an age group included some percentage of subjects who could not recognize the sign at maximum luminance, the number of data points generated for that age group was reduced proportionately.

TABLE 5 Stimuli That Five or More Subjects Were Unable to Recognize Even At Highest Luminance Level Tested

Sign	Size Width-m	Speed mph	Number of Subjects Tested Unable to Recognize Sign	Number of Older Subjects Unable to Recognize Sign
Narrow Bridge	.76	88	5	5
Right Lane Ends	.76	88	5	5
Do Not Enter (Phase 1)	.76	88	16	12
Corning 12 (D2-1)	1.27	88	8	8
No Passing Zone	1.22	88	22	11
Yield	.76	88	6	5
Yield	.76	48	6	6
Do Not Enter (Phase 2)	.76	88	12	8
Do Not Enter (Phase 2)	.76	48	5	4

TABLE 6 Age Distribution of Test Samples and U.S. Driving Population

Age Group	Percent of Test Sample (#/subjects)		Percent of U.S. Driving Population
	Phase I	Phase II	
16-34	15.9 (10)		39
35-44	15.9 (10)	22.2 (10)	22
45-54	15.9 (10)	22.2 (10)	14
55-64	15.9 (10)	22.2 (10)	11
65+	36.4 (10)	33.4 (15)	14
Totals	100.0 (63)	100.0 (45)	100

N for Phase I was 63 and for Phase II was 45.

This same procedure was used for each sign tested. To determine percent accommodated by candidate guideline values, the recommended R_a for a given sign was converted to a luminance value using the CARTS model. Tables 7 and 8 show the percent accommodated, that is, the percent of hypothetical data points falling below the candidate guideline luminance. As can be seen, the recommended R_a values would accommodate at least 85 percent of all drivers for all but two signs: the No Passing Zone pennant (63 percent accommodated) and the Narrow Bridge sign (65 to 67 percent at 88 kph).

The problem that subjects had with the No Passing Zone pennant was likely related to lack of familiarity. Study subjects were from Northern Virginia and do most of their driving in suburban areas where the pennant is not used. Even so, given the problems with this sign and the fact that it is left-mounted (thus receiving less light from vehicle headlamps), consideration should be given to increasing the required R_a for this sign.

It is more difficult to account for the lower percentages accommodated for the Narrow Bridge sign (at 88 kph). Values were only 65 percent accommodated for the 30-in. sign and 67 percent for the 36 in. sign. This was lower than the three-line text sign Right Lane Ends (which accommodated 90 and 92 percent for the corresponding sizes at 88 kph). Perhaps the difference was because of the word length or lack of familiarity with the sign message.

A third level of analysis was completed in which the experimental data were used to calculate the retroreflectance that would be required to accommodate three levels (67, 85, and 95 percent) of the driving population. Tables 9 and 10 contain these data. Those signs requiring more light than the recommended retroreflectance values supply are highlighted. At the 67 percent accommodated level, only one sign (Narrow Bridge, 30 in., 55 mph) requires a higher R_a than the recommended value. At the 85 percent level, only two signs would require a higher R_a than was recommended (Narrow Bridge and Deer warning signs). Finally, for 95 percent accommodation, the number of signs requiring more retroreflectance than the recommended R_a increases to 9. In addition, there were four signs for which the 95 percentile level could not be accommodated.

A subset of the preceding data was used to examine the effects of sign size and traffic speed on required retroreflectivity. These were two of the critical variables used by Paniati and Mace in constructing the framework for their minimum retroreflectivity requirement

TABLE 7 Percent Accommodated: Black-on-Yellow and Black-on-Orange Warning Signs

Sign	Sign Type		Speed/Sign Size				
			55 mph (88kph)			30 mph (48 kph)	
	Text	Symbol	1.2 m (48 in)	.92 m (36 in)	.77 m (30 in)	.92 m (36 in)	.77 m (30 in)
Right Lane Ends	x			92	90	92	93
Narrow Bridge	x			67	65		95
No Passing Zone	x		63				
Merge		x			100		
Right Curve		x			100		100
Right Intersection		x		100	100	100	100
Pedestrian Crossing		x			99		100
Bicycle Crossing		x		97	97	99	99
Deer Crossing		x			100		
Slippery When Wet		x			99		
Road Work 1 Mile	x			85			
Worker		x		91			
Flagger		x		100			

TABLE 8 Percent Accommodated for White-on-Red Regulatory Signs, Black- or Black-on-Red-on-White Regulatory and Guide Signs, and White-on-Green Signs

Sign	Speed/Sign Size			
	55 mph (88 kph)		30 mph (48 kph)	
	.92 m (36 in)	.77 m (30 in)	.92 m (36 in)	.77 m (30 in)
Yield		94		95
Do Not Enter		90		92
Stop	98	98	99	100
	.92 m (36 in)	.61 m (24 in)	.92 m (36 in)	.61 m (24 in)
One Way	94		95	
Speed Limit 50		88		
Keep Right		99		
Route Marker		99		
Reduced Speed Ahead		89		
Do Not Pass		92		
No Right Turn		95		
Corning (D2-1)	97		97	
Gravity/Creston (D2-2)	91		97	

TABLE 9 R_a Required To Accommodate 67, 85, and 95 Percent of Drivers for Black-on-Yellow or Black-on-Orange Signs

Sign	Size (m)	Speed (km/h)	Minimum R_a (Paniati and Mace)	R_a to Accommodate 67%	85%	95%
Right Lane Ends	.914	88	30	2	2	68
	.914	48	30	2	3	65
	.762	88	45	9	24	100
	.762	48	45	3	7	90
Narrow Bridge	.914	88	30	30	71	92
	.762	88	45	48	70	108
	.762	48	45	4	7	55
No Passing Zone	1.22	88	20	24	*	*
Merge	.762	88	45	<1	1.5	5.5
Right Curve	.762	88	25	<1	<1	1
	.762	48	25	<1	<1	<1
Right Intersection	.914	88	20	<1	<1	<1
	.914	48	25	<1	<1	<1
	.762	88	25	<1	<1	<1
	.762	48	25	<1	<1	<1
Pedestrian Crossing	.762	88	45	<1	<1	<1
	.762	48	45	<1	<1	2
Bicycle Crossing	.914	88	30	<1	<1	10
	.914	48	30	<1	1	8
	.762	88	30	<1	2	25
	.762	48	45	<1	2	17
Deer Crossing	.762	88	45	6	7	20
Slippery When Wet	.762	88	45	<1	2	2
Road Work 1 Mile	.914	88	30	4	27	94
Worker	.914	88	30	1	3	53
Flagger	.914	88	30	<1	<1	<1

* Indicated percentage level cannot be accommodated.

Shaded cells indicate values exceeding recommended minimums.

TABLE 10 R_a Required To Accommodate 67, 85, and 95 Percent of Drivers for Regulatory and Guide Signs

Sign	Size (m)	Speed (km/h)	Minimum R_a (Paniati and Mace)	R_a to Accommodate 67%	85%	95%
White-on-Red Regulatory						
Yield	.762	88	70	<1	2	*
	.762	48	40	<1	<1	*
Do Not Enter	.762	88	70	12	38	*
	.762	48	40	2	10	55
Stop	.914	88	60	2	7	34
	.914	48	35	<1	<1	8
	.762	88	70	6	10	26
	.762	48	20	<1	<1	<1
Black or Black-and-Red-On-White Regulatory and Guide:						
One Way	.914	88	35	2	11	43
	.914	48	20	1	5	19
Keep Right	.61	88	50	<1	<1	14
	.61	48	35	<1	<1	3
Route Marker	.61	88	50	<1	2	11
Reduced Speed Ahead	.61	88	50	11	21	*
Do Not Pass	.61	88	50	5	13	124
	.61	48	50	2	6	43
Speed Limit 50	.61	88	50	<1	9	98
No Right Turn	.61	88	50	3	4	49
	.61	48	35	<1	1	64
White-on-Green Guide Signs						
Corning 12	1.27	88	35	2	7	25
(Destination)	1.27	48	25	<1	1	16
Gravity/Creston	1.52	88	35	2	21	51
(Destination)	1.52	48	25	<1	2	18

*** Indicated percentage level cannot be accommodated.**

Shaded cells indicate values exceeding recommended minimums.

tables. Because only five signs were tested at two different sizes, no definitive conclusions could be drawn about the effect of sign size. However, as indicated in Table 11, there was a fairly consistent decrease in the required retroreflectivity values for the larger signs. This is particularly apparent for signs with text (Narrow Bridge, Right Lane Ends) and fine symbol (Bicycle) messages.

The effects of speed are also evident in the results, although less consistent than for sign size. In the minimum retroreflectivity tables developed by Paniati and Mace, speed is included as a critical variable for all sign types except for warning signs. Because warning signs involve little reading time and are placed well in advance of the hazard, speed has only a small effect on the MRVD for these signs and thus was not expected to affect the required retroreflectivity. The results for warning signs, indicated in Table 12, generally support this conclusion, with the exception of the Narrow Bridge sign. For the regulatory and guide signs, longer MRVDs are required at higher speeds; therefore, speed was expected to affect the required retroreflectivity. This is generally confirmed by data in Table 12. Study results (Table 12) can be compared with results of the Paniati and Mace study (see Table 1).

TABLE 11 Effect of Sign Size on Required Retroreflectivity

Sign (speed)	Required R_a for 95 % Accommodation .762 m Width	.914 m Width
Right Intersection (88 km/h)	<1	<1
Narrow Bridge (88 km/h)	108	92
Right Lane Ends (88 km/h)	100	68
Right Lane Ends (48 km/h)	90	65
Bicycle Crossing (88 km/h)	25	10
Bicycle Crossing (48 km/h)	17	8
Stop (88 km/h)	26	34
Stop (48 km/h)	<1	8

TABLE 12 Effect of Speed on Required Retroreflectivity for Warning Signs and on Regulatory and Guide Signs

Sign (size)	Required R_a for 95% Accommodation	
	48 km/h	88 km/h
Right Curve (.762 m)	<1	1
Right Intersection (.762 m)	<1	<1
Right Intersection (.914 m)	<1	<1
Narrow Bridge (.762 m)	55	108
Right Lane Ends (.762 m)	90	100
Right Lane Ends (.914 m)	65	68
Bicycle Crossing (.762 m)	17	25
Bicycle Crossing (.914 m)	8	10
Pedestrian Crossing (.762 m)	2	<1
Do Not Pass (.61 m)	43	124
Keep Right (.61 m)	3	14
No Right Turn (.61 m)	64	49
One Way (.914 m)	19	43
Stop (.762 m)	<1	26
Stop (.914 m)	8	34
Do Not Enter (.76 m)	46	N/A
Coming - D2-1 (1.27 m)	19	25
Gravity/Creston - D2-2 (1.52 m)	18	51

CONCLUSIONS AND RECOMMENDATIONS

Analyses of the experimental data indicate that candidate minimum R_a values from the Paniati and Mace report are sufficient to accommodate a high percentage of drivers for all but a few of the signs tested. The project report did not recommend a percentile value, although the authors were confident that the recommended tabular values would provide a "reasonable level of driver accommodation for most driving situations." In view of the analysis provided in this paper, it appears that the percent of drivers accommodated by the recommended retroreflectivity values is comfortably above the 85th percentile level. The recommended retroreflectivity values also exceed the values suggested by Sivak and Olson (*5*) or Jenkins and Gennouai (*6*).

For the bold symbol signs tested, legibility thresholds were well below the recommended minimum values. Lower minimums are not recommended, however, because even though the signs are legible at dim levels, they would not be sufficiently conspicuous. (In fact, the candidate minimum R_a values for these signs were based on conspicuity requirements rather than on legibility requirements.)

Additional research is needed on the effect of sign size on minimum retroreflectivity requirements. For the limited number of signs tested at two sizes in this study, there seems to be a fairly consistent improvement in threshold values for the larger signs. Future research should examine a wider range of signs and sizes.

Finally, as already noted, certain signs did not perform as well as most, especially for older subjects. Additional research is recommended to determine the nature of the problems with these signs (and others like them). This research should evaluate whether changes in sign design or in recommended sign size, or both, would produce the needed improvement.

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