Minimum Photometric Properties of Retroreflective Signing Materials

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Laboratory and field studies were conducted to assess the minimum luminance levels of signs that ensures that they will be detected and identified at adequate distances under nighttime driving conditions. Thirty subjects participated in the field study, driving a car on public roads and reporting when they could identify the test signs that were positioned at random points along the side of the road. Surround complexity, subject age, retroreflective efficiency, and sign color were considered. A study was also carried out to measure the effect of subject expectancy. All of the independent variables, including color, were found to have an effect on sign conspicuity. For example, sign retroreflectivity had to be increased by a factor of about 10 to achieve equivalent conspicuity when going from areas of low to high complexity and by a factor of about 3 to compensate for the effect of subject age. The colors red, orange, green, and blue had substantially greater conspicuity than did yellow with equivalent retroreflectivity. Possible reasons for the latter finding are discussed. Minimum retroreflectivity recommendations and the rationale for their development are presented for stop signs, construction area warning signs, warning signs, and overhead guide signs.

The purpose of this research was to develop information that would aid in recommending minimum candlepower values for various types of retroreflective signs in cluttered urban, suburban, and dark rural environments. The work was carried out in four stages:

1. The first stage was a laboratory study, which provided information on relationships such as sign size and the effects of borders and legends. Details about the laboratory study are contained in the project final report (*1*).
2. Stage two was a field study, which measured the distances at which subjects could identify test sign panels and their color in real-world environments.
3. Stage three was a study designed to develop a correction for the expectancy level of the subjects in the field study. Details about this investigation are contained in the project report (*1*).
4. In stage four, recommendations for minimum reflective material specifications were developed for different types of signs in three levels of environmental complexity.

FIELD STUDY OF SIGN CONSPICUITY

The field study was the primary data-gathering effort in the sign conspicuity program. Its purpose was to develop information on the relative nighttime conspicuity of signs in a real-world setting. The test was run on public roads; the subject drove. Measures were made of the distances at which subjects could distinguish and identify the color of test sign panels having different levels of retroreflective efficiency in environments of varying complexity.

Method

Independent Variables

The independent variables in the study were the retroreflective properties of the sign, sign color, surround complexity, and subject age.

Five levels of retroreflective efficiency were available in one color (yellow). These ranged from SIA 750 to SIA 16. Three of these were used in each level of surround complexity.

Yellow was the primary sign color used in the study. Some data were also taken on orange, red, green, blue, and white signs. However, these colors did not appear at all levels of surround complexity.

Three levels of surround complexity were used. These will be referred to as high-, medium-, and low-complexity areas.

Subjects were classified into two age groups: young and old. The young subjects ranged in age from 20 to 46 years, the old subjects from 58 to 75 years. There were 15 subjects in each age group, for a total of 30. All were licensed drivers and drove regularly at night.

Dependent Variable

The dependent variable was the distance at which the subject could identify the test sign and its color.

Equipment

A number of blank signs were fabricated for use in this project. Each was 30 in^2. They were faced with retroreflective material in various grades and colors.

The SIA values of the test panels were measured using an Advanced Retro Technology Model 920 Field Retroreflectometer. A minimum of five measurements were taken on each panel. Four of these were at a point about 6 in. in from each corner, and the last was approximately in the center. The value assigned to each panel was the average of the individual measurements.

Five yellow signs, with SIA values of 750, 250, 77, 40, and 16, were the basic set on which most of the data were based.

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Each subject was exposed to each of the yellow signs three times in each complexity area.

In addition, in each complexity area, subjects were exposed once to each of three other signs having colors other than yellow. It was intended to use all colors at least once and one color (green) in all three areas. Otherwise, the choice of signs in colors other than yellow in the different complexity areas was governed by the opportunity to investigate color differences with minimum differences in SIA. Where such comparisons were made, the signs appeared at the same location within a given area. Table 1 is a listing of signs assigned to the different complexity areas.

The test vehicle driven by the subjects was a 1981 full-sized station wagon. It was equipped with a distance measuring system that worked off the left front wheel, producing four counts (1.74 ft or 0.53 m per count) per revolution. The test vehicle was also provided with a precision voltage control system that kept the lamps operating at 12.8 volts throughout the test. The headlamps were number 6052 (large rectangular sealed beams, meeting FMVSS 108 requirements), mounted with their centers 30 in. above the pavement. They were aimed with calibrated mechanical aimers.

Test Areas

Three test areas represented what the investigators judged to be high, medium, and low levels of complexity. Figures 1, 2, and 3 are photographs that show representative sections of the high-, medium-, and low-complexity test areas, respectively.

In each complexity area, several sites were selected for displaying the signs. The following criteria were used:

- A minimum 1,000-ft approach of straight and flat roadway,
- A safe place to park the sign handler's car so that it would be out of the subject's sight, and
- A representative sign surround.

A number of sites were selected in each complexity area. Because no site was identical to any other, there was the

TABLE 1 LISTING OF SIGNS BY COMPLEXITY AREA

High Complexity		Medium Complexity		Low Complexity	
Color	SIA	Color	SIA	Color	SIA
Yellow	750	Yellow	250	Yellow	77
Yellow	250	Yellow	77	Yellow	40
Yellow	77	Yellow	40	Yellow	16
White	115	Red	41	Blue	11
Red	64	Orange	38	Orange	38
Green	64	Green	64	Green	15

Note: All sign panels were 30 inches square.

FIGURE 1 High-complexity area.

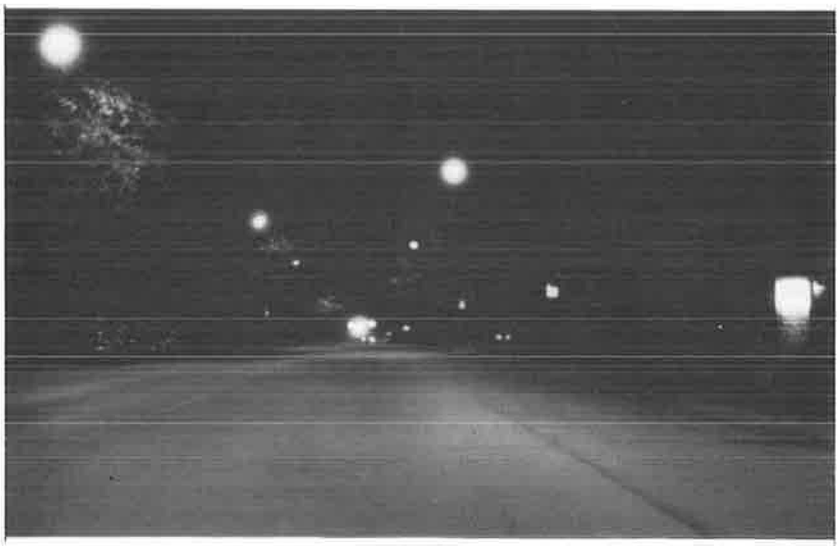

FIGURE 2 Medium-complexity area.

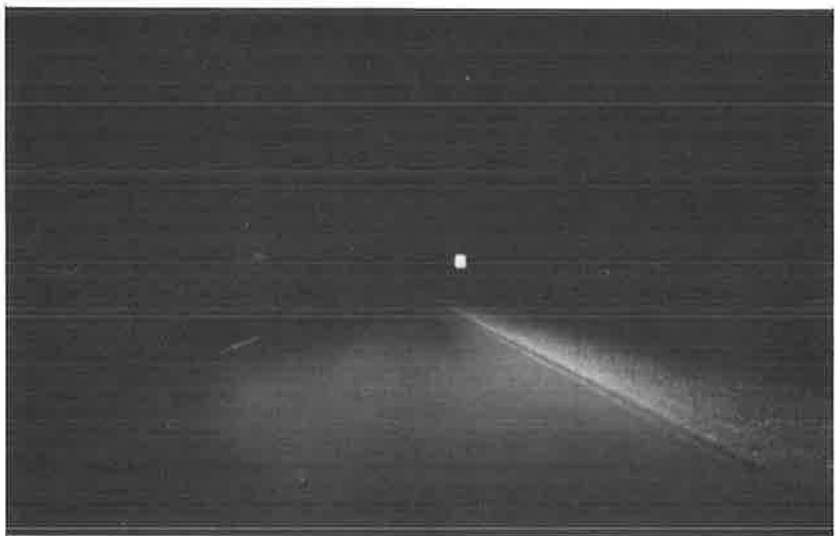

FIGURE 3 Low-complexity area.

possibility of differences between signs being confounded by differences between sites. There was no way of completely avoiding this problem. However, the following steps were taken to minimize it:

- In the preparation stage, all sites were viewed under test conditions to make sure there were no obvious problems. Some sites were eliminated in this process. Adjustments to the sign position were made at others.
- The three presentations of each sign were made at different sites, minimizing the influence of any one site on a particular sign.
- Signs that had different SIAs were presented at the same site, thus allowing an unbiased estimate of the effect of SIA. However, the extent to which this could be done was limited because the subject had to be uncertain about where signs would appear.

A comparison of mean identification distances for the same sign at different sites showed that task difficulty did vary from site to site within a given complexity area. In some cases, the differences were fairly large. Clearly, the results that will be obtained in an investigation such as this depend in part on the specific sites which the experimenter chooses. Thus, the resulting conclusions are only generally indicative of performance in different types of surroundings.

Procedure

Subjects were run individually. Each was seated in the test vehicle and told to arrange the seat and mirrors in the best position. The instructions were then read. As part of the orientation process, the subjects had the opportunity to see the six different colors of signs side by side about 300 ft away,

using the illumination from the test vehicle's headlamps. The colors were named by the experimenter at that time.

When the instructions had been read and all questions answered, the subject was instructed to drive to the starting point for the first area, following specific roads. Along the way, two yellow signs were presented. This was to ensure that the subjects understood the instructions, to allow them to become familiar with how the signs looked in the field, and to encourage them to be on the lookout for signs. No data were taken on these two presentations.

The signs were positioned by two experimental assistants, each responsible for half of the test route. The assistants drove from site to site, parked their car, selected the proper test sign, positioned themselves next to the road, and watched for the test vehicle (which was distinctively marked with two yellow lights across the roof). When the test vehicle was identified they held up the sign at head height until it passed. They then returned to their car, stored the sign, and drove to the next site.

The subjects made six passes through each area. Signs were encountered at random points on each pass and normally not at the same points on the following pass.

When the subjects detected a sign, they were required to call out, "sign." The experimenter in the back seat then started a distance counter. When the subject could identify the color of the sign, he or she called out the color. The experimenter started a second counter if the identification was correct. If not, the counter was started when the subject made the appropriate correction, and the error was noted. Both counters were stopped as the sign was passed, and the experimenter wrote down the values and reset the counters.

Interpretation of Recorded Distances

In the following analysis paradigm, five steps were assumed necessary for drivers in interacting with highway signs (*2*). These were detection, identification or recognition, decision, response, and maneuver. The subjects in this study were required to detect the test signs, identify them as test signs, and then call out, "sign." The experimenter then pressed a button to start the distance counter. With the exception of the reaction time of the experimenter in starting the counter, the values recorded in this study were assumed to correspond to identification distance, or response distance for signs leaving no choice of response to the driver (e.g., a stop sign).

A follow-up study was concerned with the development of a correction for the expectancy levels of the field study subjects. That study was conducted in such a way that it compensated for experimenter response time as well. Hence, no attempt will be made to apply such a correction to the results presented in the next section.

Results

Sign Identification Distance

A summary of the sign identification distance results is given in Table 2. The values shown in this table are mean identification distances for all 30 subjects for each color and SIA level in each complexity area. For the yellow signs only, mean identification distance varied directly with SIA and inversely with area complexity. For colors other than yellow (with the

TABLE 2 MEAN SIGN IDENTIFICATION DISTANCES FOR ALL SUBJECTS AS A FUNCTION OF SIGN COLOR AND AREA COMPLEXITY

Sign		Area Complexity		
Color	SIA	High	Medium	Low
Y	750	965		
Y	250	735	845	
Y	77	617	701	1070
Y	40		600	817
Y	16			675
W	115	457		
R	64	911		
R	40		811	
O	40		824	1062
G	64	889	844	
G	15			1039
B	11			1196

exception of white), the mean identification distances were substantially greater than for the yellow sign having the most comparable SIA. This point will be raised again later. The presentation of results begins with data obtained from the yellow signs.

Normal probability distributions of identification distances for all 30 subjects are shown in Figures 4, 5, and 6. There is one figure for each complexity area. These figures show the percentile associated with each identification distance for each sign SIA. For example, the 85th-percentile distance in the high-complexity area for the SIA 750 sign was about 500 ft. It was about 400 ft for the 250 SIA sign and about 275 ft for the 77 SIA sign.

It is evident from Figures 4 through 6, as it was in Table 2, that sign identification distance varies as a function of both SIA and surround complexity. Figure 7 shows the relationship between identification distance and surround complexity for the SIA 77 yellow sign, the only one to appear in all three complexity areas. The differences are substantial. For example, the 85th-percentile identification distances are about 275, 400, and 600 ft in the high-, medium-, and low-complexity areas, respectively.

The discussion so far has concerned data from all subjects involved in the study. This can be misleading, because performance differences between the young and older subjects were fairly large. Figure 8 illustrates this point, providing a comparison between the two age groups for the SIA 77 sign in the high- and low-complexity areas. At the 85th-percentile level, the difference in identification distance between the groups was 150 to 200 ft. To achieve performance equivalent

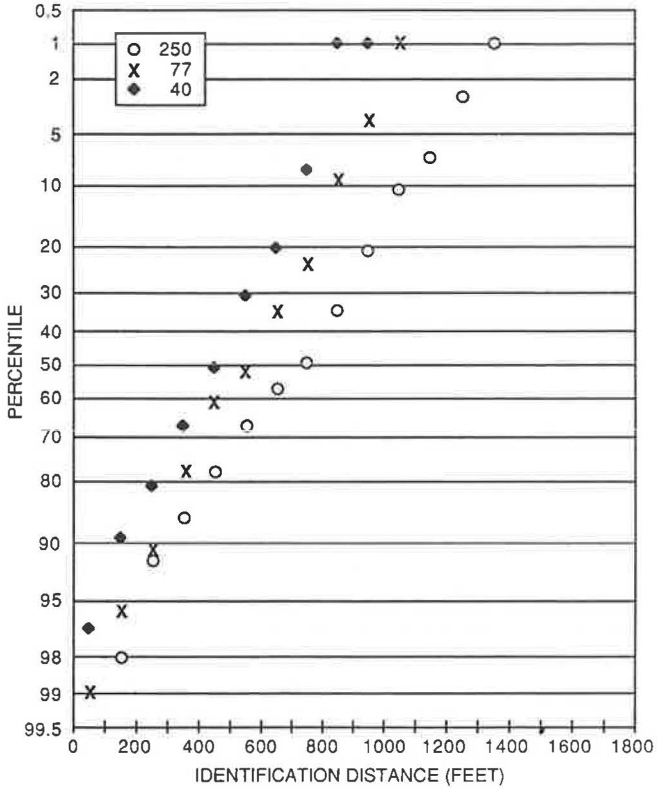

FIGURE 5 Normal probability distribution of sign identification distances in the medium-complexity area.

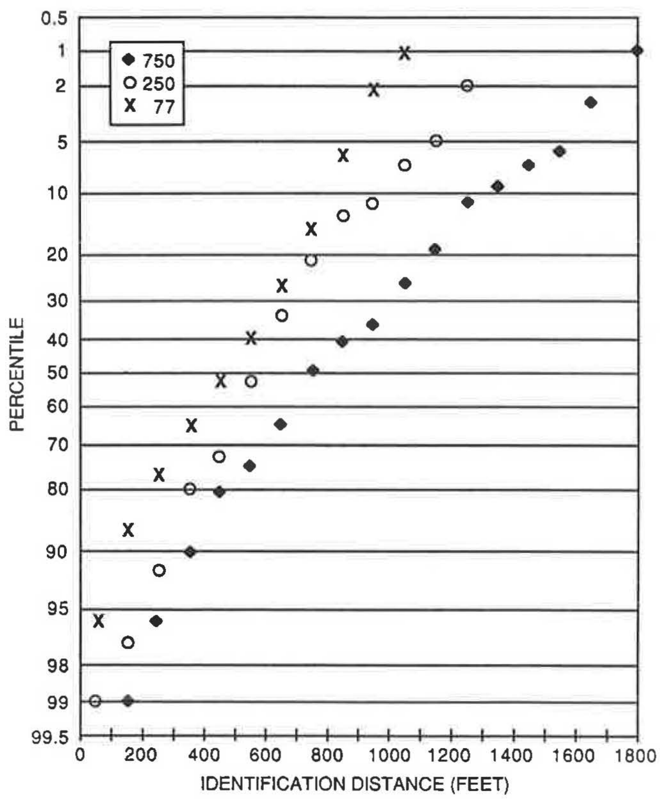

FIGURE 4 Normal probability distribution of sign identification distances in the high-complexity area.

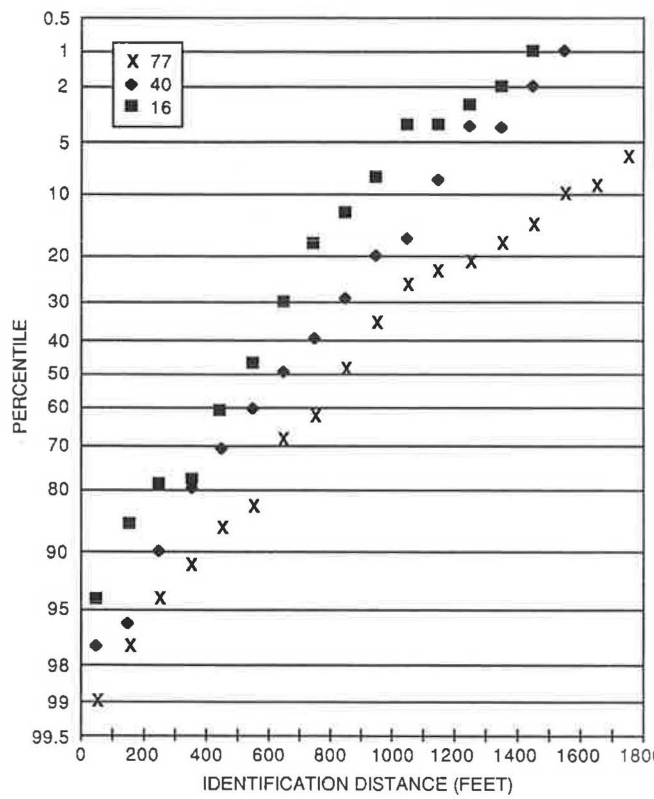

FIGURE 6 Normal probability distribution of sign identification distances in the low-complexity area.

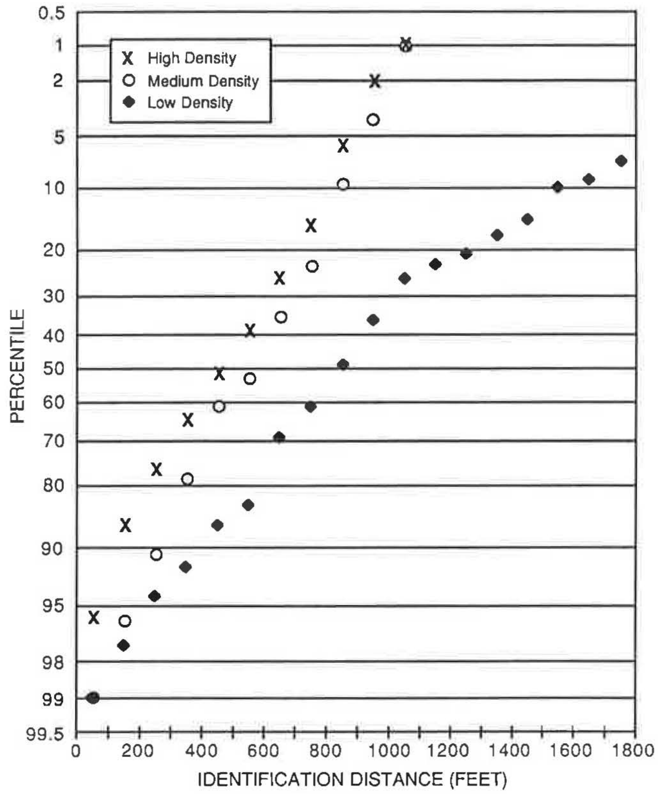

FIGURE 7 Normal probability distribution of sign identification distances for the yellow SIA 77 sign as a function of area complexity.

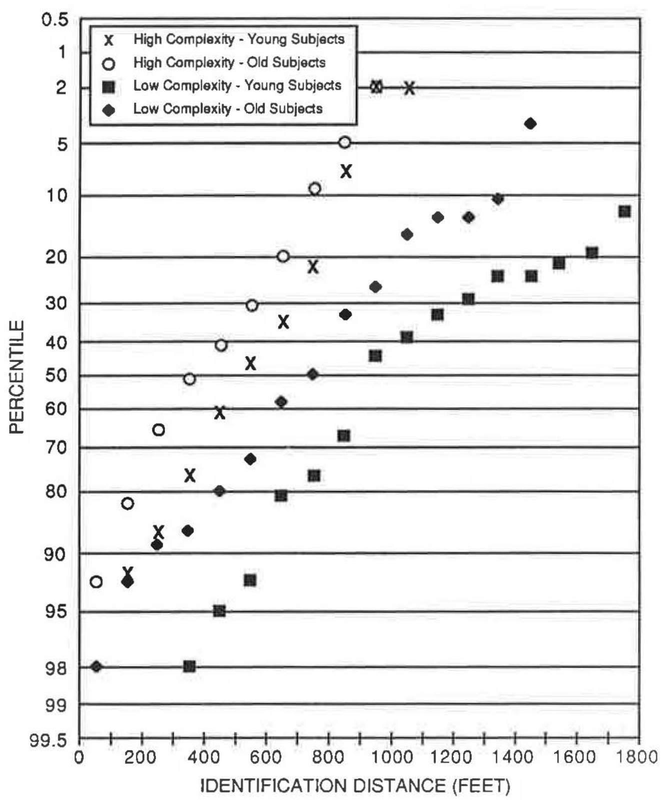

FIGURE 8 Normal probability distribution of sign identification distances for the SIA 77 sign by the young and older subjects at two levels of area complexity.

to the young subjects, the data from this study indicate that the older subjects required signs having about three times greater SIA.

Color Identification

Color identification errors were fairly common, particularly with certain signs. However, the subjects usually corrected themselves before passing the sign. Table 3 lists the percent of trials on which the subjects initially correctly identified the color as a function of the sign color, SIA, and area complexity. These data are for all 30 subjects. The yellow signs were identified correctly about 90 percent of the time by most subjects. (The yellow signs may have had an advantage in that the subjects knew that yellow would be the color most frequently used.) There is some evidence that errors were inversely related to sign brightness.

Color identification errors of the other signs were much more variable. In particular, the SIA 40 red (usual error: orange), orange (yellow), and blue (green) signs were associated with large numbers of errors. In many cases, errors involving the orange and blue signs were not corrected by the subject.

Color as a Factor in Sign Identification Distance

It was pointed out earlier that colors other than yellow were identified at substantially greater distances than were yellow signs having about the same SIA (see Table 2). An exception to this was the white sign. In the case of the white sign, it was felt that the site at which it appeared included a great deal of white in the surround, which may have affected its conspicuity. Hence, the identification distance associated with the white sign may not be representative.

A number of avenues were reviewed in trying to find some explanation for the apparent differences in conspicuity associated with color. One promising possibility is that the differences may be attributable to the same phenomenon that causes the judgments of brightness made by human observers to be influenced by hue.

There have been a number of investigations of what is usually referred to as heterochromatic brightness matching [see the work of Wyszecki (*3*)]. A typical approach to research in this subject area requires subjects to adjust the luminance of a white surface until it appears to be the same brightness as an adjacent colored surface. When the match has been made to the satisfaction of the subject, the two surfaces are photometered. If the luminance of the reference surface (white in this case) is denoted by R and the luminance of the colored test surface by T, the ratio R/T is generally greater than 1 when the subject judges the surfaces to be equally bright. The ratio increases with increasing saturation of the test surface. Interestingly, yellow is a color often cited as an exception to this rule. Experimental data show that the value of R/T typically stays close to 1 even as the saturation of a yellow surface approaches maximum.

In an effort to determine whether the phenomenon just described might account for the color results found in the field study, a laboratory color brightness investigation was conducted. This work is described in the project report. Briefly,

TABLE 3 PERCENT OF TRIALS ON WHICH THERE WERE NO COLOR IDENTIFICATION ERRORS—ALL SUBJECTS

Sign		Area Complexity		
Color	SIA	High	Medium	Low
Y	750	98		
Y	250	86	91	
Y	77	82	89	88
Y	40		90	89
Y	16			81
W	115	97		
R	64	100		
R	40		56	
O	40		47	57
G	64	96	89	
G	15			86
B	11			31

the results are in accord with those from heterochromatic brightness matching studies. However, although colors such as red, green, and blue were judged brighter than would be indicated on the basis of their photometric performance, they were not judged brighter than white or yellow from the same family of materials.

The work on brightness judgments as a function of color is suggestive and may afford a complete explanation of the results of the study. However, experimental work to date has been concerned solely with the perception of brightness. The data from the field study conducted as part of this program indicate that colors such as red, orange, green, and blue also have inherently greater conspicuity per unit SIA than does yellow (and perhaps white) in the context of road signs.

The fact that conspicuity depends to a significant degree on sign color complicates the recommendations with which this program is ultimately concerned. Unfortunately, the study was not designed to systematically evaluate color, since major effects were not anticipated. Signs having colors other than yellow were generally matched at a particular site within a given complexity area with a yellow sign having approximately the same SIA. Where these comparisons are available, it is clear that the other colored signs (with the exception of white) were identified at a much greater distance than the yellow sign. The red, blue, green, and orange signs in a given complexity area typically performed about as well as the brightest yellow sign tested, although the latter had anywhere from 2 to 10 times greater SIA.

Lacking more definitive information on the effect of color, recommendations were based on the assumption that orange, red, green, and blue have conspicuity equal to that provided by yellow in the same family of materials. This is strongly supported by the data that were collected, and, if anything, is conservative. Further work on color effects should be carried out to better define the relationship.

RECOMMENDATIONS

Background

This section presents recommendations for minimum sign SIA values based on the results of the two field studies just described. Certain assumptions were required to arrive at these recommendations. These are described as well.

In formulating these recommendations, an 85th-percentile performance level was used. There are two reasons for this. First, the 85th percentile is a common performance limit in traffic engineering. Second, the 85th percentile can be estimated with some accuracy from these data. A much higher level (e.g., 95th or 99th) is more difficult because of the limited number of measurements (maximum of 90) per condition.

A separate investigation was carried out to develop a correction for the expectancy levels of the subjects in the field study. The results suggest that the identification distances recorded in the field study must be reduced by about 40 percent to approximate normal expectancy levels.

Sign SIA, Surround Complexity, and Driver Expectancy

Figure 9 illustrates the relationship between SIA and 85th-percentile identification distance for the three levels of surround complexity and includes a correction for driver expectancy. The recommendations for minimum SIA levels for most

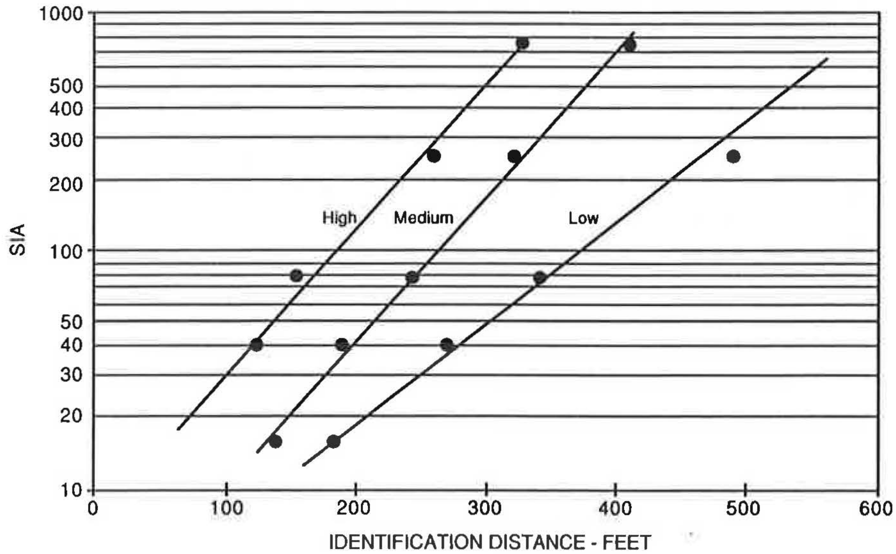

FIGURE 9 Eighty-fifth percentile yellow warning sign identification distances for three levels of area complexity, corrected for driver expectancy.

applications to be considered in this paper can be traced back to this figure.

The figure was prepared by estimating the 85th-percentile sign identification distance from the appropriate plots presented earlier (see Figure 10). The resultant values were multiplied by 0.6 to correct for driver expectancy.

Only three levels of SIA were tested in each complexity area. Estimates were made of the performance of the SIA 40 level in the high-complexity area, the SIA 750 and 16 levels in the medium-complexity area, and the SIA 250 level in the low-complexity area. This was done by comparing the performance of each of these signs with other signs in areas where they were used. For example, the identification distance of the SIA 40 sign at the 85th percentile was 75 percent and 76 percent of that of the SIA 77 sign in the medium- and low-complexity areas, respectively. Hence it was given an estimated 85th-percentile identification distance of 75 percent of that of the SIA 77 sign (122 ft) in the high-complexity area.

In the case of the high- and medium-complexity areas shown in Figure 9, the fit of these estimates to the empirical data is good, and the extrapolations are included in the visual best-fit line shown. In the case of the low-complexity area, the estimate of the 250 SIA is not as close as the others, and it was given no weight in positioning the best-fit line.

Driver Age

The large differences between the two age groups included in the study raised a question of how to weight the results for

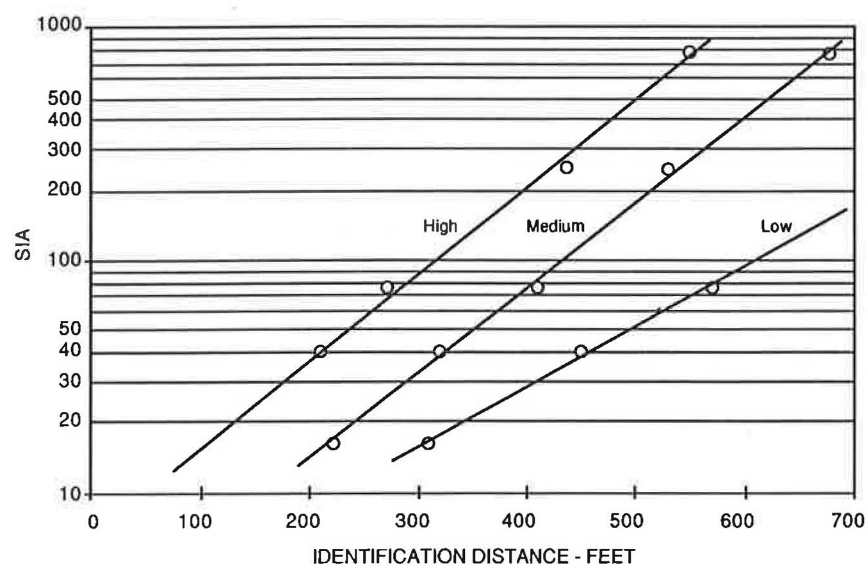

FIGURE 10 Eighty-fifth percentile yellow warning sign identification distances for three levels of area complexity, without correction for driver expectancy.

purposes of recommendations. For example, Awadallah (*4*) argues that the weighting should consider the percentage of nighttime miles driven by older individuals.

Although some information is available concerning the visual characteristics of older people, it is not clear that this includes those characteristics that determine the ability to detect and identify highway signs as night. Even if it were certain that this information was available, it seems reasonable that older persons who drive very much at night would tend to be those with better night vision. Thus there is no way at present to accurately estimate the low-luminance vision characteristics of the population of persons who drive at night. It must be remembered, too, that the age composition of the population is changing. The percentage of people 55 and over is increasing. In addition, these people are enjoying better health and have more disposable income than in the past, so they are likely to travel more. As a result of these known trends, setting standards based on current population characteristics could cause them to be outdated in the near future. It does seem clear that it would be unfair to use only the data from one of the age groups. For purposes of this paper, the recommendations were based on the combined data from the two groups.

Sign Background Color

The effect of sign color on identification distance was much greater than expected. Because of this, estimates of the effective SIA of various colors could not be made to a high level of accuracy using these data. For the purposes of this paper, it was assumed that all colors within a given family of retroreflective materials are equally effective.

In making recommendations on the basis of Figure 9, adjustments were based on relative SIAs within the family of materials. For example, the SIA of a screened red was assumed to be 21 percent of that of yellow. If Figure 9 indicates that the minimum SIA of a yellow sign for a given application should be X, then the minimum for a red sign would be $0.21(X)$.

Sign Size, Borders, and Legends

The baseline data from the field study were based on signs that are 30 in. square. Adjustments appropriate for signs that are greatly different in size (e.g., guide signs) were made as indicated by the results of the laboratory study carried out as part of this program (*1*).

Yellow, orange, and white signs use black borders and legends, which would be expected to reduce their conspicuity by reducing their apparent brightness. This effect would be most significant at longer distances, where the sign approximates a point source. The effect should be proportional to the percent of the surface area that is black. No precise data are available, but the portion of the faces of yellow, orange, and white signs that is black was estimated to range from 10 percent to 30 percent. A 15 percent figure was taken as representative. The replacement SIA value of such signs was adjusted by 15 percent to allow for this effect.

Red, green, and blue signs have white borders and legends. Nominally, these borders should prove helpful, because they increase the effective SIA for the whole sign. However, when the use of borders and legends was barred from a family of materials having higher overall SIA, the field data indicated that the benefits of the colored background outweighed the contribution of the white areas. Hence no adjustments were made to the recommendations for minimum values of red, green, and blue signs due to the effects of borders and legends.

Headlamps

The recommendations were based on the assumption of a single vehicle in the right-hand lane, using low-beam headlamps (of the type specified in FMVSS 108) in correct aim and driven at 12.8 volts. All glass was assumed to be clean and clear.

Spatial Location

Where a sign is located (to the right, left, or overhead) and how far it is from the path of travel affects the amount of illumination reaching it from an approaching vehicle's headlamps. To generalize the data from the field study to locations other than the right edge of the road, a computer model was written to calculate sign luminance. The field data could then be used to estimate minimum SIA values. The accuracy of the model was verified by a number of field photometric measurements of sign panels in various positions and at various distances.

Classes of Signs

Recommendations were based on a structure first defined by Perchonok and Pollack (*2*). These authors classified signs into four categories, based on what the driver must accomplish prior to reaching them. These categories are as follows.

- *Class I.* The driver must accomplish all critical steps (i.e., detection, recognition, decision, response, and maneuver) before reaching the sign. A stop sign is an example of a class I sign.
- *Class II.* The driver must accomplish all but the maneuver stage before reaching the sign. There are few signs in this category. Perchonok and Pollack cite the "TURN OFF 2-WAY RADIOS" sign (W22-2) as the only example in the MUTCD.
- *Class III.* The driver must detect and recognize the sign and reach a decision before reaching the sign. Response and maneuver, if any are necessary, can occur after the sign is passed. Most warning and guide signs fall into Class III.
- *Class IV.* The driver must only detect and recognize a Class IV sign. Mileposts and general service signs are examples of this category.

Recommendations for Stop Signs

Stop signs are Class I signs (i.e., the required maneuver must be completed by the time the sign is reached). In preparing

these recommendations, it was assumed (a) that the distances given in Figure 9 are equivalent to response distance in the case of a stop sign, and (b) that the driver decelerates at a mean of 0.25 g. Table 4 gives the minimum SIA recommended for stop signs not accompanied by an advance warning sign or other supplemental device, for various traffic speeds and areas of different complexity.

The values in Table 4 were derived as follows. First, red was assumed to be equal in conspicuity to yellow in the same family of materials. Then, for each stopping distance shown, Figure 9 was accessed to find the appropriate SIA for each level of area complexity. For example, for 121 ft in the high-complexity area, Figure 9 indicates an SIA of about 40. This value was multiplied by 0.21 to obtain the equivalent SIA for a screened red material, yielding an estimated minimum SIA of 8.

SIA values above 40 are not generally attainable with Type III materials in red at present. At any point in the table where the minimum recommendations cannot be met, some form of supplemental warning device (e.g., flasher or advance warning sign) should be employed.

A recent report on the conspicuity of stop signs by Morales (*5*) offers an opportunity for comparison. Morales used 10 stop signs having different retroreflective properties in a field test involving 20 subjects of various ages. The test was run on a dark, private road. The signs always appeared at the same location.

Morales's recommendations are based on what he calls "overall SIA," a measure that takes into account both the red and white areas of the sign. Using this index, a new Type II stop sign that had SIAs of 120 and 16 in the white and red areas, respectively, would have an overall SIA of 41.

Morales's recommended minimum SIA values are generally much lower than those given in Table 4 for the low-complexity area. However, if the correction for expectancy is removed from the values given in Figure 9, the values are much closer. To illustrate this point, Table 5 has been prepared. In this table, the recommended minimum SIA values given in Table

TABLE 4 RECOMMENDED MINIMUM SIA VALUES FOR A STOP SIGN

Speed (mph)	Stopping Distance @ 0.25 g (feet)	Area Complexity		
		High	Medium	Low
65	569	*	*	150
60	484	*	*	71
55	407	*	155	30
50	337	170	63	14
45	272	70	25	8
40	215	30	11	4
35	164	16	5	3
30	121	8	3	2

*Supplemental warning required.

TABLE 5 COMPARISON OF RECOMMENDED MINIMUM SIA VALUES FOR STOP SIGNS FROM TWO STUDIES

Speed (mph)	Stopping Distance @ 0.25 g (feet)	Minimum Overall SIA	
		Current Study*	Morales
65	569	46	40
60	484	29	40
55	407	17	40
50	337	11	18
45	272	8	10
40	215	6	6

*Calculated from data for low complexity area in Table 4 after removing correction for expectancy. Assumes red SIA is 13% of white SIA.

4 for the low-complexity area were recomputed without the correction for expectancy and converted to overall SIA (assuming red to be 13 percent of white). Table 5 shows the recommended minimum values for 40 and 45 mph to be very close. From 50 to 60 mph, Morales's recommended minimums are actually somewhat higher. (Note that Morales found no benefit for signs having an overall SIA greater than 40.)

Given that the two studies were conducted in different ways, the similarity shown in Table 5 is encouraging. However, it does seem clear that raw experimental data in a study such as this require an appropriate adjustment for the test subjects' expectancy level.

Recommendations for Construction Area Signs

Orange-series construction zone signs are mostly warning signs. However, some fall into Class I, in that a maneuver must be completed by the time the sign is reached. An example is a lane closure sign that is placed at the end of the available lane.

Table 6 gives the minimum recommended SIAs for such a sign as a function of area complexity and traffic volume. The latter variable assumes that it takes 8 sec to check for traffic and make the lane change maneuver in light to medium traffic, and 9.8 sec in medium to heavy traffic. These values are recommended by Perchonok and Pollack (*2*), based on a review of the literature.

The values in Table 6 were derived as follows. First, it was assumed that orange and yellow from the same family of materials have equal conspicuity. Then, for each required distance in the table, Figure 9 was used to determine the appropriate SIA for a yellow sign. For example, for 293 ft in the low-complexity area, Figure 9 indicates an SIA of 45. This value was multiplied by 0.55 to obtain the equivalent orange SIA, and the result was multiplied by 1.15 to correct for the effect of borders and legends.

An examination of Table 6 makes it clear that there are relatively few cases where a single sign will serve. These occur largely at low speeds and in areas of low complexity.

Recommendations for Warning Signs

Warning signs are Class III devices, meaning that detection, identification, and some level of decision are required before reaching the sign. Response and maneuver, if any, can take place after the sign is passed.

In developing recommendations for warning signs, a consideration was the complexity of the decision that must be made by the driver. Perchonok and Pollack (*2*) distinguish three levels of decision complexity (low, medium, and high), assigning time values of 0.5, 2.5, and 4.5 sec, respectively. Table 7, derived from Perchonok and Pollack's Table 19, shows the assignment of decision complexity (hence decision time) as a function of the area complexity and number of choices created for the driver by the warning sign.

Table 8 lists recommended minimum SIA values for yellow (warning) signs as a function of area complexity and the number of options available to the driver. The values in this table were derived as follows. First, the speed in feet per second was multiplied by the appropriate decision time to obtain a decision distance. Figure 9 was then accessed to obtain an SIA. As a final step, this value was multiplied by 1.15 to correct for the effect of borders and legends.

For orange-series signs that fall under Class III, an approximation of their minimum values can be obtained by multiplying the values in Table 8 by 0.55.

The lowest SIA listed in Table 8 is 15. This is primarily because extrapolations below 15 in Figure 9 are difficult. However, an SIA of 15 represents about 30 percent of the new minimum value of a yellow sign. By the time it reaches this level, a sign would typically present a poor appearance night and day and be a candidate for replacement in any event.

Guidelines for warning signs have been prepared by Mace et al. (*6*). They suggest that Type II yellow sheeting degraded to 36 percent of federal specifications (i.e., an SIA of about 18) would be adequate for low-complexity sites. This compares well with the values given in Table 8, except for speeds of 55 or higher in situations that present the driver with three or more choices.

At medium-complexity sites, Mace et al. suggest that an SIA of 36 may be the appropriate minimum. For many appli-

TABLE 6 RECOMMENDED MINIMUM SIA VALUES FOR A CONSTRUCTION SIGN (ORANGE) REQUIRING A LANE CHANGE

Speed (mph)	Traffic Volume							
	Light to Medium				Medium to Heavy			
	Required Distance (feet)	Area Complexity			Required Distance (feet)	Area Complexity		
		High	Medium	Low		High	Medium	Low
≥ 45		*	*	*		*	*	*
40	469	*	*	170	575	*	*	*
35	411	*	425	95	503	*	*	240
30	352	*	230	51	431	*	*	114
25	293	280	98	28	359	*	250	57

*Advance warning sign required.

TABLE 7 DECISION COMPLEXITY AS A FUNCTION OF NUMBER OF POSSIBLE CHOICES AND AREA COMPLEXITY

Area Complexity	Number of Choices		
	0–1	2–3	≥ 3
Low	Low	Low	Medium
Medium	Low	Medium	High
High	Medium	High	High

Adapted from Perchonok and Pollack, 1981.

TABLE 8 RECOMMENDED MINIMUM SIA VALUES FOR WARNING SIGNS (YELLOW) AS A FUNCTION OF AREA COMPLEXITY AND DECISION REQUIRED OF THE DRIVER

Speed (mph)	Area Complexity						
	Low		Medium			High	
	Number of Choices		Number of Choices			Number of Choices	
	0–3	3 or more	0–1	2–3	3 or more	0–1	2 or more
65	15	31	15	86	630	230	*
60	15	25	15	63	414	173	1115
55	15	21	15	52	276	144	750
50	15	17	15	38	180	110	520
45	15	15	15	29	126	80	345
40	15	15	15	23	80	63	230
35	15	15	15	17	52	52	150
30	15	15	15	15	35	38	100

*Supplementary devices required.

cations, the recommendations in Table 8 are about half that value. For more complex choice situations, their recommendation would be adequate for speeds of 50 mph or less, based on Table 8.

Mace et al. feel that Type III sheeting (SIA of about 170) may be required in high-complexity areas. This compares well with the recommendations given in Table 8 for higher speeds, when the driver has a limited number of choices to make.

Recommendations for Overhead Guide Signs

Developing recommendations for guide signs is a more complex process than for the other types of signs considered up to this point. A number of assumptions must be made. These are

- Green is equal in conspicuity to yellow in the same family of materials.
- The effect of the white border and legend on conspicuity is minimal.
- The correction for driver expectancy does not apply. It will be assumed that drivers are searching for guide signs and their expectancy is approximated by that of the subjects in this study. Figure 10 has been prepared to estimate the SIAs without the correction for expectancy incorporated into Figure 9.
- Guide signs are typically much larger than the signs used in the field study, and their larger size aids conspicuity. An estimate of this effect can be obtained from the laboratory study (*1*). Those data indicate that a multiplier of 2.4 would be appropriate.
- Because of the distributional characteristics of low-beam headlamps, the level of illumination reaching an overhead guide sign will be a great deal less than the illumination reaching the test signs at the same distances. As noted earlier, a computer model was used to estimate the illumination levels appropriate for overhead signs.
- Because of the position of overhead and many ground-mount guide signs, they are difficult to see when the car gets close to them. In addition, their luminance level begins to drop off rapidly as the car gets to within 200 to 300 ft. Therefore, it was assumed that the driver had to complete the reading task before passing 100 ft in front of the sign.
- Reading time for a guide sign depends on the number of words contained on the sign. Mitchell and Forbes (*7*) have

TABLE 9 RECOMMENDED MINIMUM SIA VALUES FOR THE GREEN BACKGROUND AREAS OF AN OVERHEAD GUIDE SIGN

Speed (mph)	Area Complexity								
	Low			Medium			High		
	Words on Sign			Words on Sign			Words on Sign		
	3	6	9	3	6	9	3	6	9
70	8	15	27	13	31	70	35	82	200
60	8	13	22	12	25	54	32	70	150
50	7	11	17	11	20	37	28	54	100
40	7	9	13	10	15	25	25	40	68
30	6	8	10	8	12	17	22	33	46

Sign is assumed to be 20 feet high and centered over a roadway 24 feet wide.

estimated this time at 3 words/sec. Thus, the tables that present minimum recommended SIAs contain headings for 3, 6, and 9 words, representing 1, 2, and 3 sec of travel time, respectively.

The recommended minimum SIAs for an overhead guide sign are presented in Table 9. These values were derived as follows. First, the illumination reaching the overhead position was calculated. This was typically found to be about 10 percent of that reaching the test signs in the field study at the same distance. Thus, to achieve the same luminance level, the material on the overhead sign would have to have 10 times the SIA. However, it was assumed that green has the same conspicuity characteristics as yellow in the same family of materials. Because green has about 23 percent of the reflectivity of yellow, the SIA value must be increased only by 2.3. The correction for size was 2.4, which nearly canceled out the correction for relative reflectivity. Thus, the values given in Figure 10 are a good estimate of the minimum SIAs for overhead signs and were used directly in making up Table 9.

An examination of Table 9 indicates that Type II materials would be appropriate on overhead guide signs only in areas of low complexity and with three or fewer words on the sign. More highly reflective materials and/or multiple signs are appropriate in most cases.

DISCUSSION OF RESULTS

This paper has described an experimental program designed to determine the minimum luminance characteristics required of reflectorized highway signs to ensure adequate conspicuity. It has also provided some example specifications based on those data.

It should be clear that this is a complex area, and one study cannot resolve all relevant questions. A comparison of these recommendations with those offered by other investigators, in particular Mace et al. and Morales, does show reasonable agreement and suggests that a time may be approaching when minimum SIA levels can be set with some confidence.

However, a number of significant questions remain. Among those that should be addressed are the effects of sign color, size, and location on conspicuity. Hopefully, significant work on these issues can be undertaken in the near future.

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