RETROREFLECTIVE REQUIREMENTS FOR TRAFFIC SIGNS -

A STOP Sign Case Study

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and Technology

Turner-Fairbank Highway
Research Center
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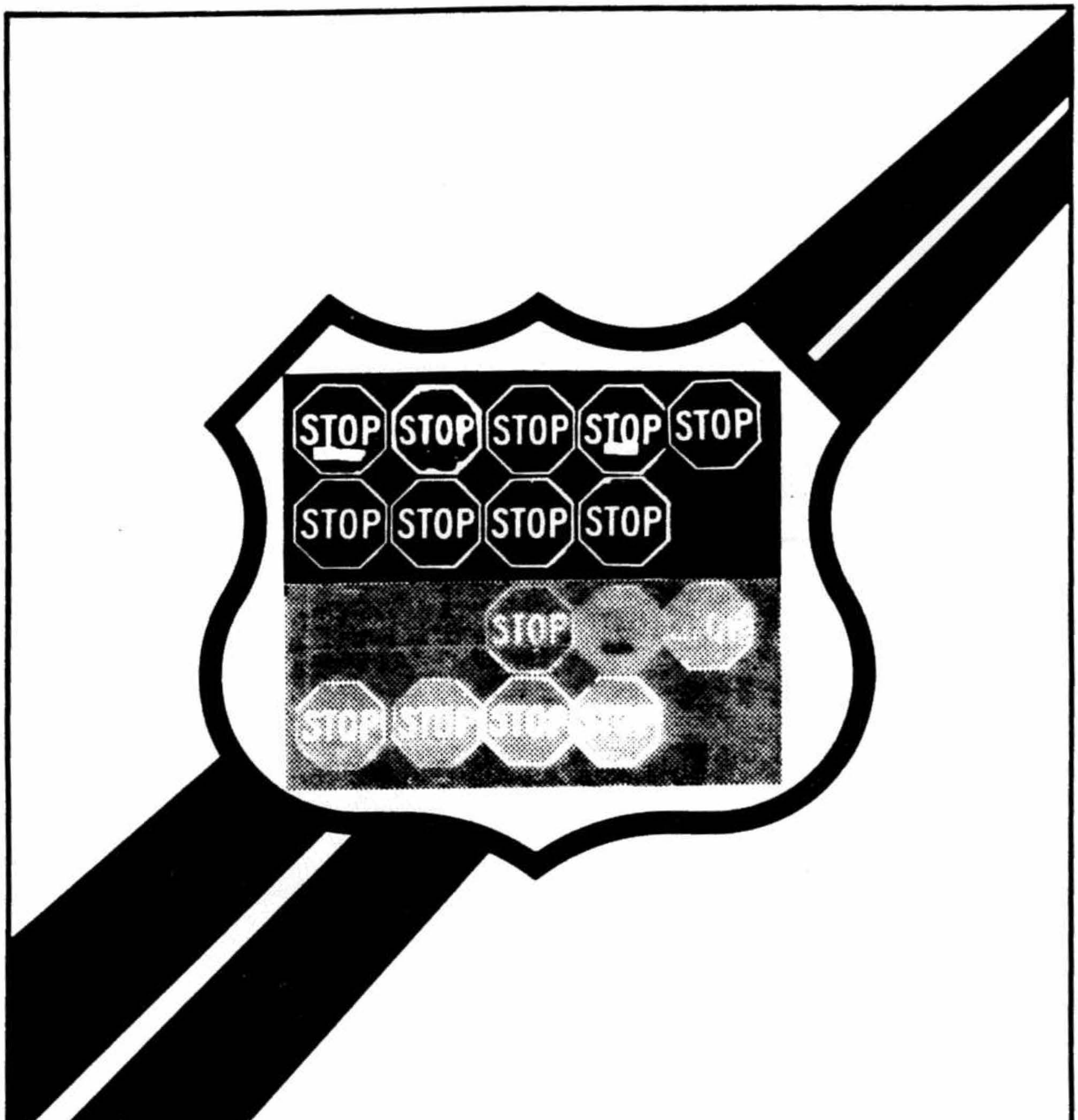

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16. Abstract

Poor sign reflectivity is a contributor to the high proportion of nighttime accidents. At night, signs must have enough brightness to allow a driver to recognize and react to the intended message of the sign in a safe manner. Failure to recognize a regulatory sign, such as a STOP sign, could result in a severe accident.

The Manual on Uniform Traffic Control Devices (MUTCD) contains no standards on minimum initial or maintained retroreflectivity for traffic signs. However, the Federal Highway Administration, through the Federal Register, is considering comments to determine whether to establish minimum retroreflectivity standards for in-service traffic signs.

This study determined the performance of STOP signs based on their retroreflective properties. Thirty-five 30-inch STOP signs, including engineering grade and high intensity, were measured in the laboratory to determine their retroreflective properties. A subset of ten signs was taken to the field to determine how far they could be recognized by paid subjects. Mathematical relationships between the various retroreflective properties and recognition distance were developed. The overall specific intensity per unit area (SIA) was found to be a good measure for estimating the recognition distance of STOP signs. By computing the minimum sign viewing distance for various approach speeds, the required integrated SIA of STOP signs was found.

Findings from this study will (1) aid in establishing minimum in-service levels of retroreflectivity for STOP signs, (2) assist field personnel to determine whether a particular STOP sign is providing the desired recognition distance or whether it should be replaced, and (3) give an insight to the feasibility of creating minimum in-service retroreflective standards for other types of traffic signs.

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INTRODUCTION

Night driving is one of the most difficult tasks a driver has to face. The proportion of fatalities occurring at night has increased to more than 60 percent over the years. This is an amazing statistic considering only 25 percent of all travel is done at night. Although a single causal factor cannot be assigned to nighttime accidents, lack of adequate visual guidance, such as poor sign condition, is a significant factor in the greater accident rate at night.

Signs must be bright enough to provide drivers with sufficient recognition distance to process and respond to the sign's intended message in a particular driving situation. Failure to recognize and react to a regulatory sign, such as a STOP sign, could result in an accident with injuries or fatalities. It is the responsibility of the traffic engineer to provide signs that can be recognized by drivers and still allow them to follow the intended command of the sign.

The Manual on Uniform Traffic Control Devices (MUTCD) presently provides that regulatory and warning signs shall be reflectorized or illuminated to show the same shape and color both by day and night. The MUTCD (1) contains standards concerning size, shape, and color, but no minimum initial or in-service retroreflective requirements for retroreflective traffic signs. Such requirements would indicate when signs should be replaced because of lack of retroreflectivity. Minimum initial retroreflective requirements for new sheeting materials do exist (2,3) but provide no differentiation based upon driver needs.

The problem has not gone unnoticed. The Federal Highway Administration (FHWA) published a notice in the Federal Register (Vol. 50, No. 81, April 26, 1985) requesting comments on the issue of standards for retroreflective illumination of traffic control devices. Comments were received in February 1986 and are being considered to determine whether standards are needed for minimum maintained retroreflective performance requirements for traffic signs and other traffic control devices.

This report describes a study on the performance of STOP signs based on their retroreflective properties. Thirty five 30-inch STOP signs, ranging from new engineering grade to color-faded used signs, were tested in the laboratory to measure their retroreflective characteristics. A set of ten signs was then taken to the field to determine their respective recognition distances at night. Mathematical relationships between reflectivity measures and recognition distance were developed using regression analysis techniques. Applying these mathematical relationships, a field procedure was developed to determine when STOP signs should be replaced because of lack of retroreflectivity as a function of the approach speed of the intersection they serve.

Findings from this study will (1) aid in establishing minimum in-service levels of retroreflectivity for STOP signs, (2) assist field personnel in determining whether a STOP sign is providing the desired recognition distance or whether it should be replaced, and (3) give an insight to the feasibility of creating minimum retroreflective standards for other types of signs.

APPROACH

The study approach was to: (1) obtain a set of 30-inch STOP signs having a wide range of retroreflective characteristics, (2) test them in the laboratory to obtain their retroreflective properties, (3) select a subset to determine their field recognition distance, (4) develop retroreflectivity versus recognition distance relationships using regression analysis techniques, (5) select which relationship is best based on its goodness of fit and other criteria, and (6) develop a procedure to determine when STOP signs should be replaced which uses the chosen relationship and is based on the approach speed of intersections.

Signs are created in various designs and shapes to serve different needs. These size and shape differences create substantial differences in the retroreflectivity needed to function properly at night. Different signs can perform adequately with different levels of retroreflectivity. STOP signs are critical signs (as opposed to a speed limit sign, for example) and must have adequate retroreflectivity at night since failure to react to their conveyed message could result in an accident with injuries or even fatalities.

If results from this study prove to be useful, similar studies could be performed to include other types of highway signs.

STUDY SAMPLE

During the summer of 1985, the District of Columbia replaced some 3,100 STOP signs. Although the average life-expectancy of a sign is 7 years, some of the signs had been in service for 20 years. Upon contacting city traffic officials, approximately 50 STOP signs were obtained. An attempt was made to obtain location and date of installation data but these records were not available.

A set of 35 STOP signs was selected for the study. Signs ranged from badly faded to good. Included in the set were a new engineering grade sign and a new high intensity sign. Two high intensity signs were included for a relative comparison. The final sign sample consisted of the following 30-inch STOP signs:

32 used engineering grade
1 new engineering grade
1 used high intensity
1 new high intensity

LABORATORY PROCEDURE

A. DEFINITIONS

Before describing the laboratory data collection procedure, defining basic photometric quantities is essential. Some of the photometric quantities defined below are used to specify the performance of retroreflective materials. They are luminance, specific intensity, specific luminance, and specific intensity per unit area.

(1) Luminous Flux is the time rate flow of light. The unit of luminous flux is the lumen (lm).

(2) Luminous Intensity, I, is defined as the solid-angular luminous flux density in a given direction. The unit used to measure luminous intensity is the candela (cd). Candlepower and luminous intensity are descriptive terms and are used in the same sense.

(3) Illuminance, E, is incident luminous flux density (the amount of light "falling" on a surface). When the unit of luminous flux is the lumen and the area is one square foot, the unit of illumination is the footcandle (fc). When the area is one square meter, the unit of illumination is the lux (lx).

(4) Luminance (Photometric Brightness), L, is the luminous intensity of a surface in a given direction per unit of projected area of the surface as viewed from that direction. When the unit of luminous flux is the lumen and the area is in square feet, the unit of luminance is the footlambert (fL). When the luminous intensity is in candelas and the area is expressed in square feet, the unit is in candelas per square foot (cd/sq ft).
Luminance, then, can be used when referring to the 'reflectivity' or 'retroreflectivity' of a surface. In common sense, brightness refers to the intensity of the "sensation" resulting from viewing surfaces from which light comes to the eye.

(5) Specific Intensity, SI, is the ratio of luminous intensity of a surface to the normal illuminance. It is expressed in candelas per footcandle (cd/fc).

(6) Specific Luminance, SL, is the ratio of the luminance of the projected surface (as seen from the observation position) to the illuminance of the surface. When the unit of luminance is candelas per square feet and the illuminance is in footcandles, the unit of specific luminance is candelas per square foot per footcandle (cd/sq ft/fc). Changes in the observation position will result in changes to the specific luminance. Specific luminance can also be used when referring to the 'reflectivity' of a surface.

(7) Specific Intensity per unit Area, SIA, is the ratio of the luminous intensity of the surface to the normal illuminance and to the area of the

retroreflective surface. It is expressed in candelas per footcandle per square foot (cd/fc/sq ft).

Although SL and SIA represent the same quantity, SIA should be used when the surface being measured has some area (like reflective sheeting on a highway sign). SL is used to measure a "point", where the area is negligible.

B. LABORATORY DESIGN

A photometric laboratory was prepared at the Turner-Fairbank Highway Research Center in McLean, Virginia. The laboratory (Figure 1) consisted of a 100-foot black tunnel, baffles, headlights, a headlight stand, sign stand, and various photometric instruments. Baffles were used to minimize light reflecting off the tunnel walls, floor, and other surfaces from illuminating the test signs.

The laboratory procedure called for illuminating the signs with automotive headlights located 100 feet away and measuring their reflective properties from a fixed observation point. Two standard, 12.8V automotive headlights, mounted on an adjustable stand, were used to illuminate the test signs. The headlights and the signs were in the same horizontal plane. Angular offsets were used to orient the headlights relative to the signs to simulate signs 7 feet high and 2 feet off the pavement's edge.

A critical variable in the laboratory setting is the observation angle, sometimes referred to as the angle of divergence. As shown in Figure 1, this is the angle between the line from the headlights to the sign and the line from the driver's eyes to the sign. This angle is greater in proportion to the vertical distance between a driver's eyes and the headlights. It also increases rapidly as the distance between the driver and the sign decreases. The distance and divergence effects partially offset each other. Small changes in the observation angle can result in large differences in the luminance (or reflectivity) measured.

A 0.2 degree observation angle was chosen for the study to be consistent with the photometric instruments being used. This angle, for the desired geometric conditions, is obtained when the distance between the headlights and the sign is 400 feet. Due to length limitations in the black tunnel, this distance was impossible to accomplish. However, the observed luminance of a surface is directly proportional to the luminance of the light striking it and this drops off in proportion to the square of the distance. Thus the total light reflected is 1/16 th of any measured amount when the distance from a given light source quadruples. Therefore, it is possible to obtain the 400-foot luminance of a sign by dividing the 100-foot readings by 16. The separation between the headlights was also reduced by 1/4 (to 12 inches) to compensate for angle variations that occur. Table 1 shows the 400-foot laboratory conditions:

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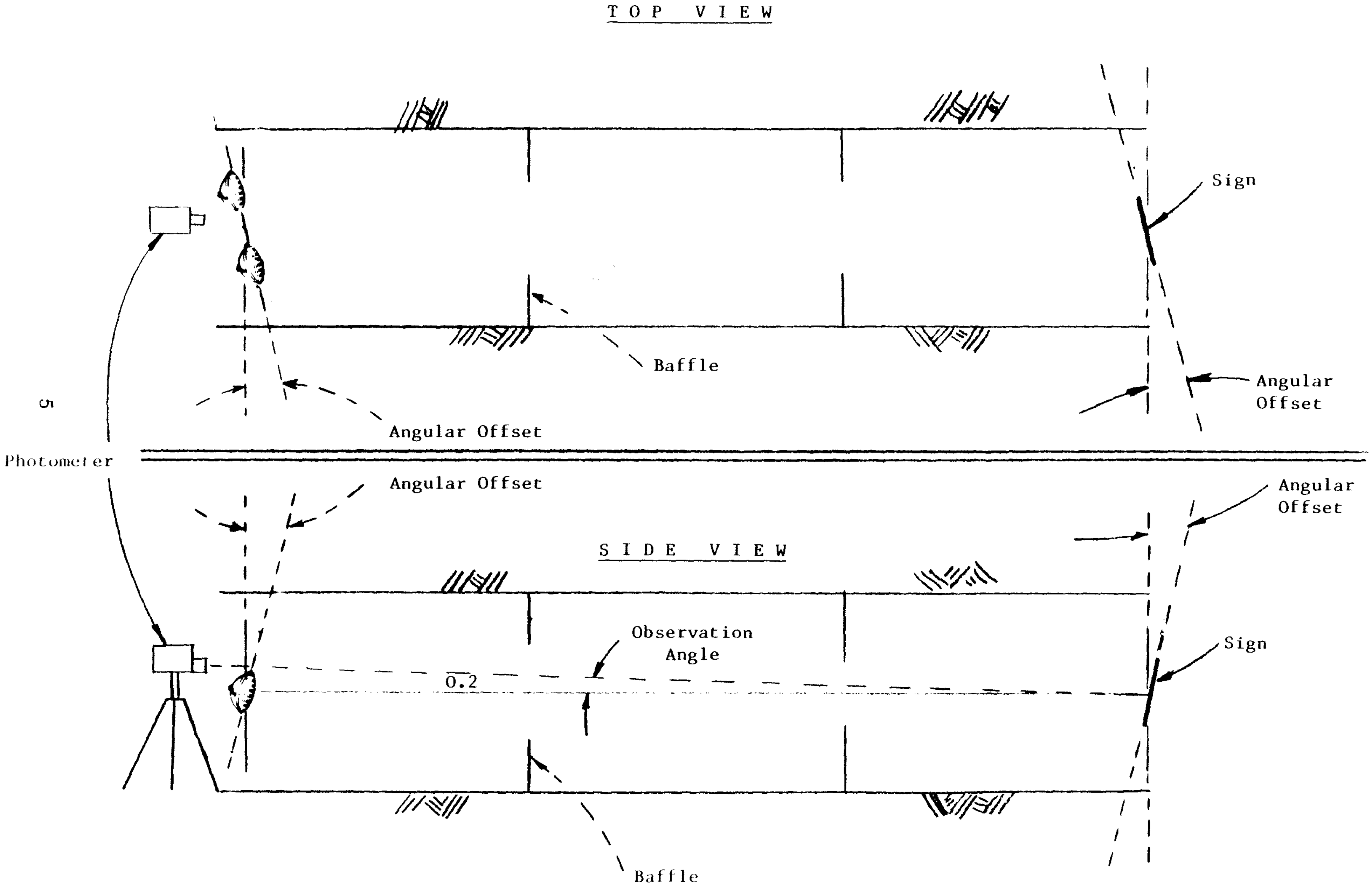


Figure 1. Laboratory Conditions

Table 1. Laboratory Conditions (400 ft)

Test distance	400 ft.**
Test surface	30 in. STOP signs
Headlight height	24 in. to center
Headlight separation	12 in. center to center
Observer's eye height	28.5 in.
Observation angle	0.2 degrees
Sign height	7 ft. to bottom of sign**
Lateral sign offset	2 ft. from pavement's edge**
Headlights (2)	Wagner H6054 (halogen)
Beam	Low beam only
Lamp voltage	12.8 V

** geometrically obtained using angular offsets as shown in Figure 1.

C. DATA COLLECTION

Once the laboratory was completed, the photometric data were collected:

(1) Illuminance, I, was measured using a Tektronix J16 Digital Photometer with a probe to measure illuminance in lux. The instrument's sensor was positioned at 7 different locations on the sign's surface and an average illuminance was obtained.

(2) Luminance, L, was measured (in footlamberts) using a Pritchard 1920 Telephotometer set at a 2-minute aperture. Eight points in the red area of the sign and eight points in the white area (letters only) were read. Since it was difficult to measure the border of the sign due to its width, its luminance was assumed to be equal to the luminance of the letters. A 'red' average and a 'white' average were obtained. These averages were weighed by the respective percent of red (76%) and white (24%) in the sign and an 'overall sign luminance' was obtained.

(3) Specific Intensity per Unit Area, SIA, was measured using a Retro-Tech 920 Meter. This gun-like instrument is calibrated for different colors and materials and is pressed against a point on the test surface. SIA is measured in candelas per footcandle per square foot. Using the same red (76%) and white (24%) areas, the averages of the eight 'red' SIA readings and eight 'white' SIA readings were weighted to obtain an 'overall sign SIA'. The Retro- Tech 920 has its own built-in light source, which strikes the test surface at a 0.2 degree observation angle, consistent with the laboratory set-up. As explained above, variations in the observation angle will result in significant variations in the measured SIA.

(4) White to red ratio, W/R, was defined as:

$$W/R = \frac{\text{White SIA}}{\text{Red SIA}}$$

The minimum recommended W/R ratio for a 0.2 degree observation angle on Type II sheeting ranges between 4.8 and 5 according to FP-85 (2).

Data obtained from the laboratory procedure are shown in Appendix A.

Figure 2 shows the sample distribution obtained from the laboratory data for the overall SIA measure. Based on this distribution, a subset of ten signs was chosen to be tested in the field. Table 2, Part A, shows the photometric data for the selected signs. Figure 3 shows 9 of the 10 selected signs, arranged in order in increasing overall SIA from left to right, during daytime and nighttime conditions. This figure clearly shows how signs seeming to be adequate during the day might not perform adequately during the night.

FIELD PROCEDURE

The purpose of the field procedure was to determine the recognition distance of the selected signs as recognized by paid subject drivers.

To understand why recognition distance was chosen as the key measure for this study, consider the components of the perception-reaction-maneuver process involving a driver approaching a traffic sign:

(1) Point of first possible detection. The driver detects an object as he/she approaches it but is not sure of what it is. The distance from this point to the object is called 'detection distance'.

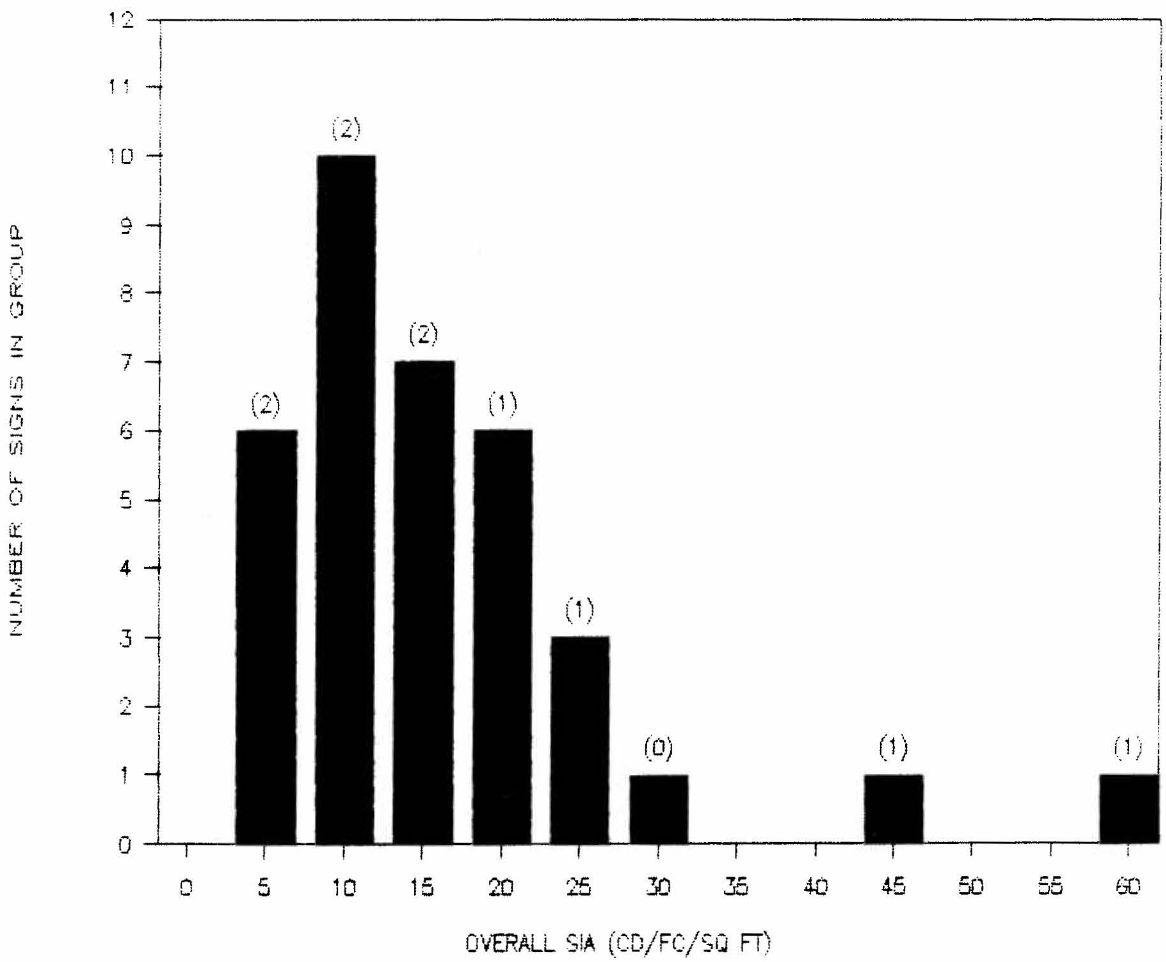
(2) Point of recognition. The driver recognizes what the object is (in the case of this study a STOP sign) and understands the meaning or command associated with it. The distance from this point to the sign is called 'recognition distance'.

(3) Point of legibility. The driver can read the words in the sign, if any. The distance from this point to the device is called 'legibility distance'. The legibility distance can be equal to the recognition distance, however, in some cases, a common shape (the STOP sign octagon, for instance) or color can transmit the intended meaning/command before the driver can actually read the words.

(4) Point of initial reaction. The driver starts to execute the command. In the case of a STOP sign, for example, this is the point where the driver releases the accelerator pressure.

(5) Point of response. The driver starts to respond to the command. In the

FIGURE 2. SAMPLE DISTRIBUTION



( ) Indicates number of signs selected for field testing

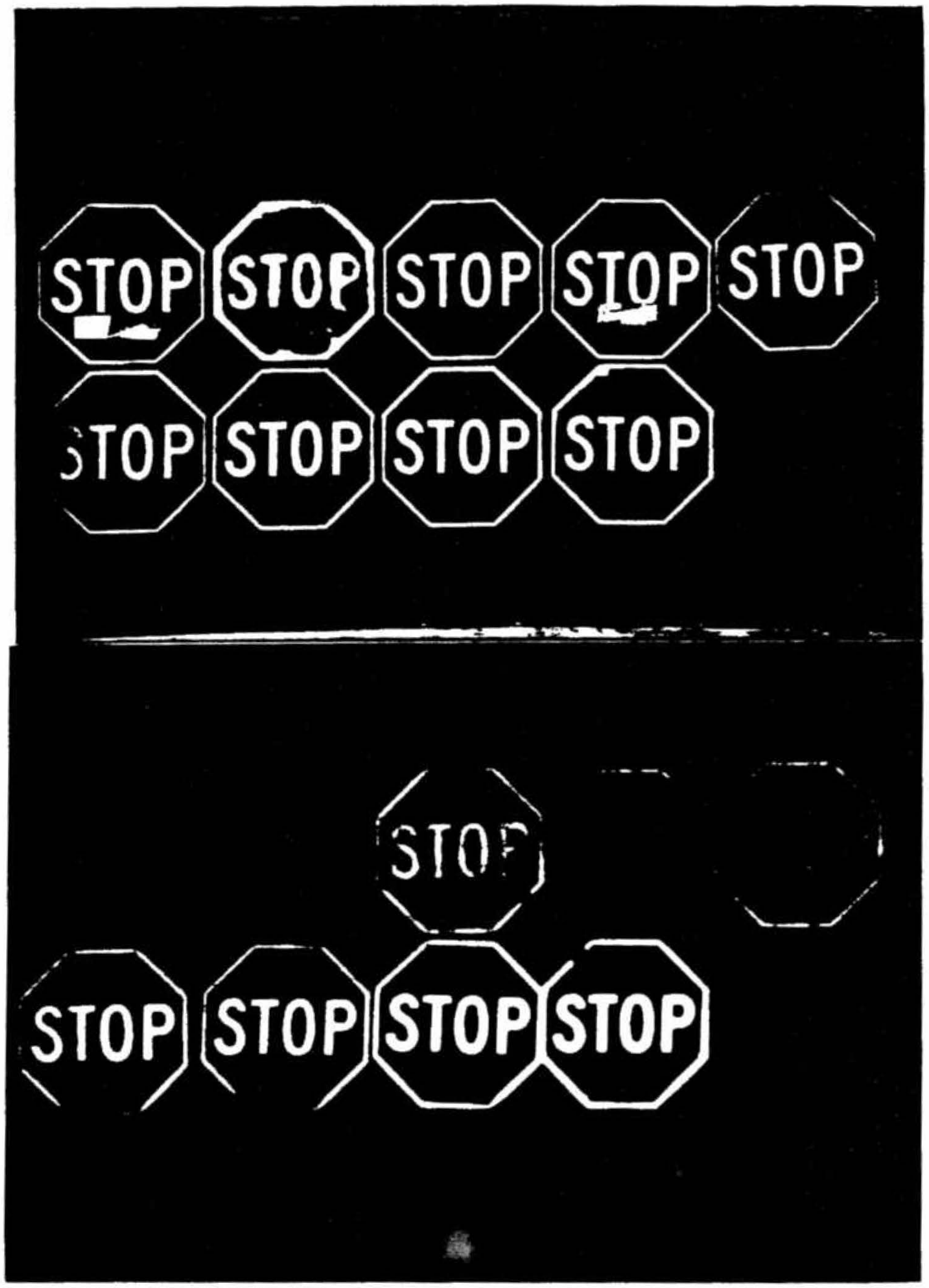
TABLE 2. COLLECTED DATA FOR SIGNS TESTED IN FIELD

PART A. LABORATORY DATA:

SIGN	LUMINANCE (CD/SQ FT) (400 FT DISTANCE) OVER-ALL	WHITE	RED	SIA (CD/SQ FT/FC) W/R RATIO	OVER-ALL	WHITE	RED
14	0.02	0.04	0.01	2.5	2.4	4.5	1.8
7	0.02	0.00	0.03	0.4	3.1	1.6	3.6
31	0.06	0.22	0.01	11.9	5.7	19	1.6
6	0.06	0.04	0.07	0.5	7.6	4.5	8.6
28	0.09	0.09	0.09	0.7	11.5	9.2	12.3
30	0.14	0.43	0.05	5.8	13.9	37.8	6.5
25	0.19	0.46	0.10	3.8	17.7	40.7	10.6
1	0.29	1.08	0.04	18.0	24.1	86.2	4.8
33	0.48	1.59	0.14	10.6	43.2	139.8	13.2
35	0.98	3.19	0.30	10.4	91.9	296.4	28.4
LOW:	0.02	0.00	0.01	0.4	2.4	1.6	1.6
HIGH:	0.98	3.19	0.30	18.0	91.9	296.4	28.4

PART B. FIELD DATA:

	SIGN RECOGNITION DISTANCE (FT)																								
NO.--)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20					
SEX--)	M	M	F	F	M	M	M	F	F	F	M	F	F	F	M	M	M	M	F	F					
AGE--)	24	59	44	22	65	50	63	59	27	26	61	23	76	38	42	30	23	31	58	30	MIN	85%	AVG	MAX	STD
SIGN NO. 14	585	210	276	470	498	220	411	360	460	517	475	290	238	435	690	243	460	570	500	710	210	250	431	710	146
7	570	170	238	565	580	240	278	360	385	534	240	320	249	470	860	445	480	785	540	560	170	240	443	860	182
31	680	415	345	490	488	400	512	470	390	585	445	360	348	620	1130	509	580	670	480	990	345	360	545	1130	198
6	728	128	247	320	272	335	460	325	300	232	550	150	170	300	1040	155	570	370	285	550	128	175	374	1040	218
28	1045	240	308	955	870	275	514	420	650	735	525	350	150	430	1500	612	725	1580	540	480	150	300	645	1580	377
30	980	545	603	980	542	430	592	470	520	602	560	440	372	750	980	805	690	630	615	900	372	467	650	980	185
25	550	575	795	965	472	525	620	320	665	668	570	520	415	980	940	796	970	640	640	1020	320	500	682	1020	201
1	850	290	376	770	745	490	648	610	580	828	785	495	378	570	1400	585	830	120	885	1200	120	350	672	1400	290
33	1140	400	560	750	985	625	795	580	745	825	1020	595	352	725	1650	935	1180	1470	790	1450	352	533	879	1650	345
35	1150	465	405	860	958	595	745	560	570	894	1010	635	512	895	1675	965	850	1210	800	1620	405	525	869	1675	338
LOW:	550	128	238	320	272	220	278	320	300	232	240	150	150	300	690	155	460	120	285	480	120	175	374	710	146
HIGH:	1150	575	795	980	985	625	795	610	745	894	1020	635	512	980	1875	965	1180	1580	885	1620	405	533	879	1675	377



@

LEGEND:

Sign No.---->	14	7	31	6	28
Overall SIA-> (cd/fc/sq ft)	(2.4)	(3.1)	(5.7)	(7.6)	(11.5)
	30	25	1	33	*
	(13.9)	(17.7)	(24.1)	(42.2)	

@ Kodak Ecktachrome 64 film, f5.6, 1 sec. exposure
* Sign No. 35 not shown

Figure 3. Field-tested Signs during Daylight and Nighttime Conditions

case of a STOP sign, it is the point where the brake is first applied.

(6) Point of maneuver. The driver fully executes the command. In the case of a STOP sign, it is the point at which the stop is made.

Of all these components, the one of interest in this study is the point of recognition. Most drivers recognize the command associated with the familiar red octagon before they are sufficiently close to read the word STOP, if they read it at all. The message is conveyed by code (color, shape, etc.), not only by legibility. A good example of this is the study done by Faber Birren in 1957 (4). In his study, a conventional STOP sign was placed in a prominent location with the letters rearranged to read TOPS. Under the assumption that the sign is recognized primarily by its shape and color, it could be expected that few drivers would note anything unusual. Of 100 drivers questioned after passing the sign, 86 percent admitted that the word TOPS had been overlooked.

Twenty paid subjects were instructed (see Appendix B) to drive down a controlled road located at the David Taylor Naval Ship Research and Development Center in Carderock, Maryland. The road was 2,000 feet long, level, totally dark and had no other traffic. Subjects were representative of the driving populations in terms of the percent of vehicles-miles driven annually. Two age groups (under 35 and over 35) were chosen. The national percent of vehicles-miles driven by these age groups represents a study sample of 9 and 11 subjects respectively. The subject sample was also chosen by gender (50%/50%) to represent the driving population.

Sign recognition distance was measured using a calibrated fifth-wheel mounted to a Ford Tempo sedan equipped with aligned Wagner H6054 low-beam headlights. Subjects were instructed to, one at a time, drive towards the signs (7 feet high, 2 feet off pavement's edge) and to say aloud when, without any doubt, a sign was recognized. The fifth-wheel counter would be immediately reset to zero by the observer seated in the passenger's seat, the subject would continue to drive up to the sign. The distance measured between the reset point and the location of the sign was defined as the sign's recognition distance. Upon passing the sign, the subject would make a 'U" turn to return to the starting position. An assistant would then replace the sign with another sign at the same location. This procedure was repeated for each of the 10 STOP signs and the 5 "dummy" signs.

The "dummy" signs were included with the STOP signs to keep subjects from being biased toward STOP signs. The dummy signs included two YIELD and three DO NOT ENTER symbolic signs. The inclusion of the dummy signs and the fact subjects were not aware the study was limited to STOP signs practically eliminated the 'guessing' factor. The sequence in which the signs were shown was randomly obtained and varied to eliminate driver practice and order effects. The subject data obtained using this procedure are shown in Table 2, Part B.

In order to give drivers an additional task and to keep them from focusing their attention on a fixed point (the expected location of a sign), the subjects were instructed to keep a constant speed of 15 miles per hour. This instruction would require looking back and forth from the speedometer of the car to the roadway, thus changing eye focus and the point of attention.

It should be noted that under average driving conditions there are countless distractions, ie. pedestrians, other traffic, and wandering eye and mind. Results from the procedure used in this study will provide recognition distances under ideal conditions, that is, a dark background on a clear night. The effects of background complexity, weather conditions, and environmental distractions are not considered in this study.

DATA ANALYSIS

The laboratory and field data were analyzed for the purpose of creating a STOP sign photometric-recognition distance model for nighttime applications. The establishment of such a model was needed as input to the development of a field procedure to assess the adequacy of STOP sign retroreflectivity.

A. PRELIMINARY ANALYSIS

A preliminary analysis and review of the data was undertaken to determine if overall consistency in the data base existed, and whether discernable differences were associated with gender or subject age.

Twenty subjects viewed ten signs in the field tests. A total of 200 recognition distances were therefore obtained. The subjects, consisting of 10 females and 10 males, had STOP sign recognition distances as shown in Table 3. A statistical review of this data using the Student-t test failed to show at 0.05 significance level any difference between the male and female observed recognition distances.

Table 3. Frequency Counts for Recognition Distance Ranges by Gender of Driver

Gender	Recognition Distances in Feet					
	<250	251-500	501-750	751-1000	>1000	Total
Male	10	22	35	18	15	100
Female	8	38	34	16	4	100

However, when the subject test scores were grouped, as shown in Table 4, by the less than and over 35 age groups, a significant difference at the 0.05 significance level was found by the Kolmogorof-Smirnof test between the two groups. STOP signs 25, 28, and 30 were determined to be the primary source of the differences between the age groups. Examination of the SIA values (see Table 2, Part A) of these three signs showed they were in the middle of the group of ten signs tested in the field.

Table 4. Frequency Counts for Recognition Distance Ranges by Driver Age

Age	Recognition Distances in Feet					
	<250	251-500	501-750	751-1000	>1000	Total
<35	5	18	36	20	11	90
>35	13	42	33	14	8	110

Graphically, the relationship between subject response, recognition distance, and SIA values is shown in Figure 4. As the overall sign SIA increases (moving to the right) the number of subjects who could recognize the sign at a longer distance increases. For example, 15 of the 20 subjects (75%) had to be within 500 feet of STOP sign 14, which had the lowest SIA value, to provide correct recognition. However, for sign 35, having the highest SIA value, only 8 of the 20 subjects (40%) had to be within 500 feet of the sign. This proportional type trend confirmed a relationship existed between the photometric characteristics of a sign and its recognition distance.

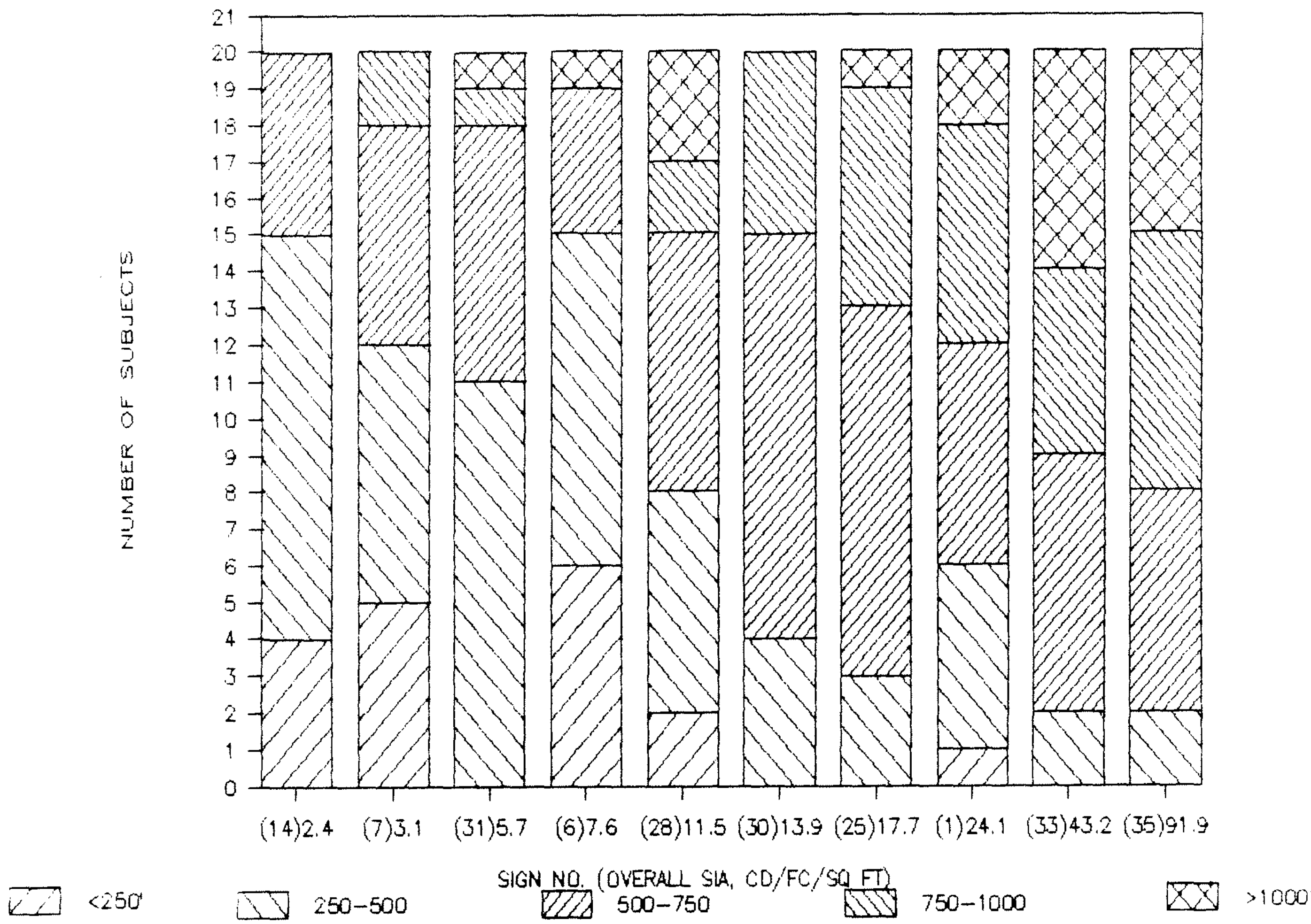
The preliminary analysis showed the data were reasonable and suitable for further use.

B. MODELING OF IN-SERVICE STOP SIGN NIGHT RECOGNITION DISTANCE

A mathematical model was sought which related both retroreflectivity values and night STOP sign recognition distance. Preliminary examination of the data suggested the Box-Hunter equation of the form $y=a[1-e^{-bx}]$ would be suitable. In this model, y is the recognition distance, x is the photometric measure (SIA, for example), a and b are regression coefficients, and e is the exponential constant 2.71828. This exponential model assumes that at zero luminance or SIA the recognition distance is

FIGURE 4. FREQUENCY COUNT OF

RECOGNITION DISTANCES BY SUBJECTS



zero, and that beyond certain distance, regardless of the photometric brightness of the sign, the sign cannot be recognized.

Non linear regression analysis techniques (5,6) were used to develop Box-Hunter models for recognition distance versus the following photometric quantities:

1. Luminance of the red
2. Luminance of the white
3. Overall sign luminance
4. SIA of the red
5. SIA of the white
6. Overall sign SIA

All 200 data points (20 subjects x 10 signs) were used to generate the a and b regression coefficients for the six mathematical models. The models generated using this procedure represent the "average" or the "50th percentile" of the 200 data points.

C. BEST MODEL SELECTION

The best of the six photometric-recognition distance models was sought to develop a field procedure. The models' statistical goodness and feasibility of field applications were the selection criteria.

Runs and Durbin Watson tests were conducted to determine the goodness of fit of the non-linear regression analysis. These tests and an F-test approximation (6) found no statistical evidence at the 0.05 significance level that any of the six models did not represent the observed data.

The residual sum of squares for each of the models was also obtained. The "overall SIA" and the "White SIA" models had the lowest residual sum of squares.

Appendix C contains these tests results, as well as the a and b coefficients generated for each model.

Based on these results, the "overall SIA" model was selected as the best model. Besides its statistical goodness, it explicitly accounts for the retroreflectivity of the entire sign and, therefore, the retroreflectivity of both the red and the white, regardless of the material (engineering grade or high intensity sheeting). In addition, it can easily be measured in the field, during daylight hours, using an instrument such as the Retro-Tech 920 which has its own light source at a constant observation angle. Determining the observation angle in the field (as it would be necessary if a luminance-based model is selected) is not necessary.

The selected photometric-recognition distance model is:

$$\text{30-inch STOP Sign Recognition Distance, in feet,} = 762(1-e^{-.19(SIA)})$$

where SIA is the overall sign SIA (.76 Red SIA + .24 White SIA), in candelas per footcandle per square foot.

As explained before, this model represents the "50th percentile" of the 200 data points analyzed. Common traffic engineering practices utilize the "85th percentile" for design purposes. To facilitate computations, the 85th percentile of the recognition distance of the 20 subjects was computed for each sign. Regression analysis was then performed on the resulting ten points to obtain the Box-Hunter 85th percentile model:

$$\text{30-inch STOP Sign Recognition Distance, in feet,} = 476(1-e^{-.15(SIA)})$$

where SIA is the overall sign SIA (.76 Red SIA + .24 White SIA), in candelas per footcandle per square foot. This model satisfies 85 percent as opposed to 50 percent of the test subjects.

Both the 50th percentile and the 85th percentile models are shown in Figure 5.

From the overall SIA model obtained for 30-inch STOP signs, data for 24-inch STOP signs can be derived under the assumption that, if the shape, color, and overall SIA of a 30-inch STOP sign is equal to those of a 24-inch STOP sign, the difference in their relative recognition distance will be directly proportional to the area of the sign. In other words, if all factors remain constant except size, recognition distance can be assumed to be directly proportional to the area of the sign (9).

The area of a 24-inch STOP sign is 64% of the area of a 30-inch sign, therefore, under the stated assumption, its recognition distance will be 64% of the distance obtained from the mathematical model. Table 5 shows the 50th and 85th percentile data for 30-inch and 24-inch STOP signs for a given overall SIA. Note that a higher than 40 overall SIA does not improve on the sign's recognition distance.

D. FIELD APPLICATION OF MODEL

The "85th percentile" overall SIA model presented in Table 5 can be adopted to a field procedure for assessing whether an in-service STOP sign has sufficient retroreflectivity or should be replaced with a new sign.

The procedure applies the standard stopping distance formula to Table 5. If the distance required by a driver to recognize the sign and come to a complete stop at a comfortable deceleration is known, then the overall SIA needed to achieve this distance can be obtained from the model selected above for a given approach speed. For example, using a 1.5 second perception-reaction time and a comfortable deceleration of 8 ft/sec/sec, for an approach speed of 35 mph (51.3 ft/sec) a minimum viewing distance of

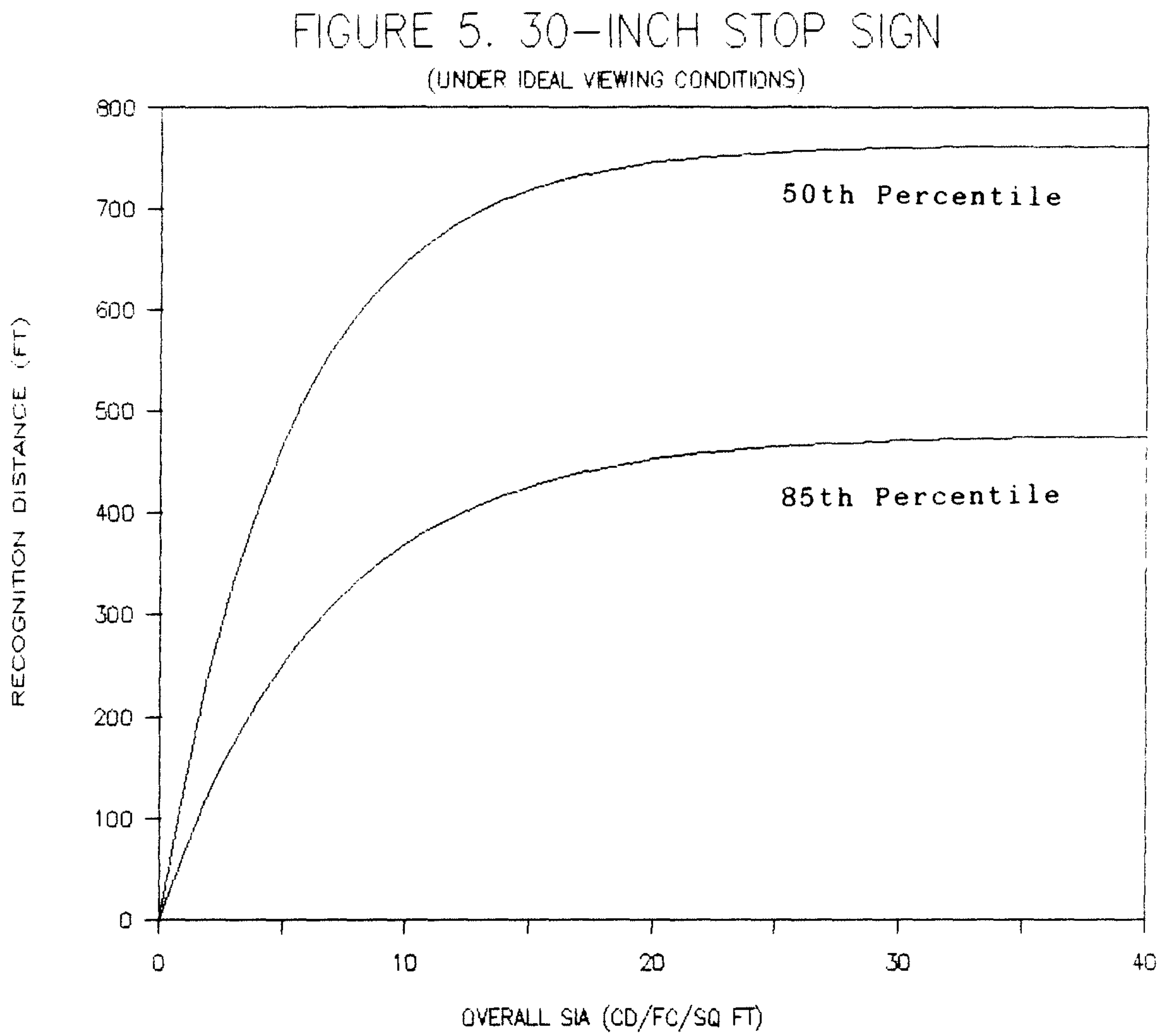


FIGURE 5. 30-INCH STOP SIGN
(UNDER IDEAL VIEWING CONDITIONS)
800
700
600
500
400
300
200
100
0
RECOGNITION DISTANCE (FT)
50th Percentile
85th Percentile
0
10
20
30
40
OVERALL SIA (CD/FC/SQ FT)

TABLE 5. STOP SIGN RECOGNITION DISTANCE VERSUS OVERALL SIA UNDER IDEAL VISIBILITY CONDITIONS (Selected Model in Tabular Form)

OVERALL SIA cd/fc/sq ft	STOP Sign Recognition Distance, FT			
	30-Inch		24-Inch	
	50th %	85th %	50th %	85th %
0	0	0	0	0
1	129	68	83	44
2	237	126	151	81
3	326	176	208	113
4	400	219	256	140
5	461	256	295	164
6	512	288	328	184
7	555	315	355	201
8	590	338	377	216
9	619	358	396	229
10	643	375	412	240
11	664	389	425	249
12	680	402	435	257
13	694	412	444	264
14	706	422	452	270
15	715	430	458	275
16	723	436	463	279
17	730	442	467	283
18	735	447	471	286
19	740	451	474	289
20	744	455	476	291
21	747	458	478	293
22	750	461	480	295
23	752	463	481	296
24	754	465	482	298
25	755	467	483	299
26	756	468	484	300
27	757	469	485	300
28	758	470	485	301
29	759	471	486	302
30	760	472	486	302
31	760	473	486	303
32	760	473	487	303
33	761	474	487	303
34	761	474	487	304
35	761	475	487	304
36	761	475	487	304
37	762	475	487	304
38	762	476	488	304
39	762	476	488	304
40	762	476	488	305

$$t(V) + (V^2/2a)$$

or

$$1.5(51.3) + (51.3^2/16) = 77 + 165 = 242 \text{ ft}$$

is needed. From Table 5, 85th percentile, the required 30-inch STOP sign overall SIA (under ideal viewing conditions) necessary to provide at least 242 feet of stopping distance is 5 candelas per foot candle per square foot. Using this procedure, the required overall SIA for various approach speeds can be obtained as shown in Table 6. For example, for an intersection with a 35 mph approach speed, a 30-inch STOP sign with a minimum overall SIA of 5 would be sufficient to accommodate the 85th percentile of the drivers. Higher values should be used to accommodate less than ideal viewing conditions.

To implement the procedure in the field, a user would perform the following steps:

1. Measure the "red SIA" and the "white SIA" of the sign, in candelas/footcandle/square foot, using a retroreflectometer such as the Retro-Tech 920.

2. Multiply the "red SIA" by .76 (or 3/4).

3. Multiply the "white SIA" by .24 (or 1/4).

4. Add the results of steps 2 and 3 together to obtain the "overall sign SIA".

5. Determine the average approach speed of the intersection.

6. Obtain the minimum "overall SIA" from the correct column in Table 6.

7. Replace the sign if the computed "overall SIA" (step 4) is less than the "overall SIA" obtained from Table 6 (step 6).

When applying this procedure the user should consider using higher values of "overall SIA" to accommodate less than ideal viewing conditions resulting from inclement weather, glare, etc. STOP AHEAD signs should be used when horizontal or vertical sight distance restrictions are present.

DISCUSSION

The recommended model and the field application procedure described herewith can be used as an <u>indicator</u> to assess the adequacy of STOP sign based on their retroreflective properties to satisfy driver needs during nighttime conditions.

The model does not indicate the adequacy of STOP signs for daytime driving

TABLE 6. REQUIRED OVERALL SIA FOR VARIOUS APPROACH SPEEDS UNDER IDEAL VISIBILITY CONDITIONS

INTERSECTION'S APPROACH SPEED		MINIMUM STOPPING DISTANCE#	MINIMUM OVERALL SIA * (CD/FC/SQ FT) 85th Percentile	
MPH	FPS	FT	30-Inch STOP	24-Inch STOP
10	15	35	1	1
15	22	63	1	2
20	29	98	2	3
25	37	139	3	4
30	44	187	4	7
35	51	242	5	11
40	59	303	7	35
45	66	371	10	40
50	73	446	18	40
55	81	528	40	40
60	88	616	40	40
65	95	711	40	40

Assumes a deceleration of 8 FT/S/S and a Perception-Reaction Time of 1.5 seconds

* Under ideal visibility conditions (does not consider weather nor other visibility reducing factors)

* STOP Sign's Overall Specific Intensity per Unit Area, in candelas per footcandle per square foot,
= [.76 X RED SIA] + [.24 X WHITE SIA]

in which, in accordance with the MUTCD, STOP signs should have white letters on a red octagonal background.

Lack of color shall not be confused with lack of retroreflectivity. For example, a high intensity sign such as the one shown in Figure 6 does not comply with the MUTCD color criteria. The red octagon has lost most of its color so it looks white with an extremely low red SIA. The white letters, however, still have a high white SIA value. This particular sign has a relatively high "overall SIA" and therefore passed the above described model. The sign, however, does not meet the MUTCD criteria because the octagon is not red and should be immediately replaced.

The model can be used effectively on those signs which meet current MUTCD color criteria but are suspect of lack of retroreflectivity. Common sense should be used in extreme cases, such as the example above, to replace obviously inadequate signs.

Consideration was given to include a second parameter, such as White to Red ratio, to screen cases such as the one described above. Previous research studies (7,8) have found the optimum W/R ratio to be between 8 and 12. Inclusion of a contrast-based parameter would not only complicate the field screening procedure but could discard hundreds of signs because they are not "legible". Internal contrast, or W/R ratio, becomes important when the sign in question must be read to be understood. In the case of the unique shape STOP sign, the sign does not have to be read to be understood and therefore, inclusion of a contrast-based screening parameter would eliminate signs which are perfectly recognizable but not legible. Legibility should not be a criteria when developing in-service retroreflective standards <u>for STOP signs.</u>

Furthermore, additional research would be needed to determine the acceptable "band" of W/R ratios. Should it be between 8 and 12 or, for example, between 3 and 25? Considering the range of W/R ratios of the field-tested signs (from 0.4 to 18.0) gives an idea of the implication of adding a second screening parameter with various "band" widths.

Determining the driver population for which to design becomes an important issue since a statistical difference was found between the over 35 and the under 35 age groups. Consideration should be given to the location dealing with. Perhaps a community of retired citizens needs a minimum overall SIA which is higher than the one needed in a college community. Designing for the worst driver would likely result in unacceptable maintenance and replacement costs. Perhaps the 85th percentile should be used.

Questions like these remain unanswered and must be considered before in-service retroreflective standards are established. This study, however, has confirmed the need for such standards. Figure 3 dramatically shows how signs that look adequate during the day literally disappear at nighttime. Results from this study will help quantify the adequacy of STOP signs for nighttime recognition. However, further research is necessary to determine minimum levels of retroreflectivity of other types of signs and to improve on ways of measuring retroreflectivity in the field.

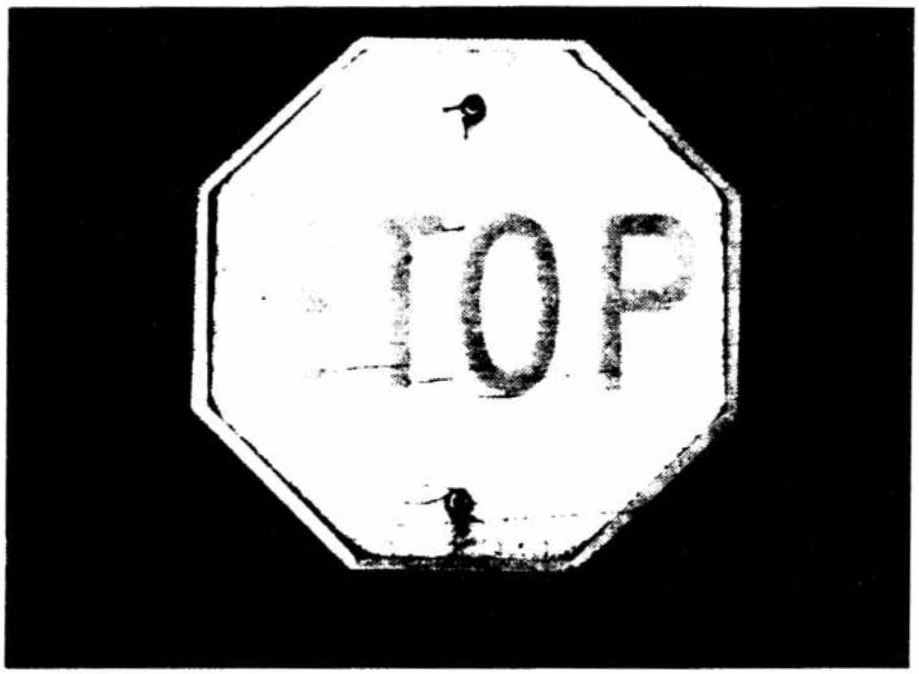


Figure 6. Red-faded STOP Sign

SUMMARY

This study has (1) found mathematical relationships between STOP sign recognition distances and its photometric characteristics, and (2) recommended the use of a recognition distance versus overall SIA model for field applications to determine when STOP signs should be replaced based on the intersection's approach speed.

Further research is necessary to determine minimum in-service levels of retroreflectivity for other types of signs and to study the feasibility of establishing standards to include in the MUTCD.

While this study has contributed to the understanding of in-service sign retroreflectivity other research is underway to further investigate the problem. FHWA is conducting research to determine the minimum distances at which signs and markings should be visible to a motorist. Based on these minimum visibility requirements, it will be possible to determine the needed retroreflectivity necessary to make a sign or marking visible at a given distance. This study is expected to be completed in late 1988.

A National Cooperative Highway Research Program (NCHRP) study will determine the feasibility of developing instrumentation suitable to rapidly measure retroreflectivity from a moving vehicle during daylight hours. This study is expected to be completed in early 1989.

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APPENDIX A: LABORATORY DATA

SIGN	LUMINANCE DATA* WHITE (cd/sq ft)	LUMINANCE DATA* RED (cd/sq ft)	LUMINANCE DATA* OVERALL (cd/sq ft)	SIA DATA WHITE/RED	SIA DATA WHITE (cd/fc/sq ft)	SIA DATA RED (cd/fc/sq ft)	SIA DATA OVERALL (cd/fc/sq ft)
1	1.08	0.01	0.29	18.2	86.2	4.8	24.1
2	0.19	0.06	0.09	2.7	13.6	5.0	7.[illegible]
3	0.73	0.04	0.20	14.9	58.3	3.9	16.9
4	0.18	0.04	0.07	3.8	15.8	4.1	[illegible]
5	0.42	0.09	0.17	3.7	38.2	10.2	1[illegible].8
6	0.01	0.07	0.06	0.5	4.5	8.6	7.[illegible]
7	0.00	0.03	0.02	0.4	1.6	3.6	[illegible].1
8	0.50	0.04	0.15	9.6	43.9	4.6	[illegible]
9	0.12	0.07	0.08	1.7	9.2	5.2	6.2
10	0.12	0.14	0.13	0.7	9.2	13.7	12.6
11	0.31	0.13	0.17	2.2	27.9	12.6	15.2
12	0.04	0.06	0.06	0.5	3.7	7.9	6.[illegible]
13	0.21	0.06	0.09	3.0	18.7	6.1	9.1
14	0.04	0.01	0.02	2.5	4.5	1.8	2.1
15	0.01	0.03	0.03	0.5	1.7	3.4	3.0
16	0.01	0.04	0.03	0.4	1.5	4.2	[illegible]
17	0.37	0.03	0.11	8.5	36.4	4.3	11.9
18	0.00	0.04	0.03	0.3	1.4	4.7	3.9
19	0.13	0.13	0.13	1.0	12.7	13.1	13.0
20	0.91	0.01	0.24	18.1	76.1	4.2	21.2
21	0.89	0.16	0.33	10.6	78.6	7.4	24.[illegible]
22	0.45	0.09	0.18	3.5	37.7	10.9	17.3
23	0.01	0.07	0.05	0.2	1.8	8.1	6.6
24	0.00	0.07	0.05	0.2	1.6	7.6	6.2
25	0.46	0.10	0.18	3.8	40.7	10.6	17.7
26	0.01	0.04	0.03	0.4	1.8	4.7	4.0
27	0.46	0.06	0.15	5.4	41.0	7.5	13.5
28	0.09	0.09	0.09	0.7	9.2	12.3	11.5
29	0.15	0.05	0.07	2.1	12.4	5.9	7.5
30	0.43	0.05	0.14	5.9	37.8	6.5	13.0
31	0.22	0.01	0.06	12.1	19.0	1.6	5.7
32	0.33	0.10	0.15	2.7	28.6	10.7	17.0
33 (1)	1.59	0.14	0.48	10.6	139.8	13.2	43.2
34 (2)	1.18	0.03	0.30	27.0	101.7	3.8	27.0
35 (3)	3.19	0.30	0.98	10.4	296.4	28.4	91.9

* Illuminance = 0.21 lux

(1) used high intensity
(2) new engineering grade
(3) new high intensity

INFORMED CONSENT

You are about to participate in an official sign recognition study being performed by the Federal Highway Administration. You will be asked to drive a vehicle in a loop and indicate when you can, without any doubt, identify which of the following signs you recognize:

STOP

YIELD

DO NOT ENTER

You must maintain a constant speed of fifteen (15) miles per hour. This is very important. You can look at the vehicle speedometer as often as you desire.

You will drive a standard automobile equipped with a calibrated wheel in the back. Backing up with this vehicle will damage this wheel. DO NOT BACK UP. You will be accompanied by a FHWA employee at all times and MUST NOT step down from the vehicle unless instructed because of security reasons. You will receive verbal instructions during the test. You will not be subject to any risks exceeding those encountered in your every day driving.

You will be paid twenty five dollars ($25.00) for your cooperation. All personal data furnished by you will remain confidential and will be used only for research purposes. Your name will not be used. The test session will take less than 1 hour. You are free to decline consent, or withdraw consent and discontinue participation in the session at any time.

The above information has been presented and understood by me, and I consent to participate as a subject.

Name______________________________

Signature ________________________ Date________________

APPENDIX C. REGRESSION ANALYSIS RESULTS
(for the "50th Percentile")

Box-Hunter Equation: $y=a[1-e^{-bx}]$

e = 2.71828

y	x	REGRESSION ANALYSIS: Coefficient a	Coefficient b	Runs Test: Runs	Runs Test: Z-Stat.	Durbin-Watson Stat.	Residual Sum of Squares (3)
30-Inch STOP Sign Recognition Distance, in feet, under ideal visibility conditions	Overall SIA (1)	762	0.19	73	-3.86	1.53	2.42
	Red SIA (1)	683	0.57	77	-3.24	1.39	2.47
	White SIA (1)	715	0.24	71	-4.17	1.47	2.41
	Overall Luminance (2)	751	2.06	77	-3.36	1.49	2.42
	Red Luminance (2)	683	11.7	77	-3.15	1.37	2.46
	White Luminance (2)	725	1.66	71	-4.25	1.27	2.43

(1) in candelas per footcandle per square foot

(2) in candelas per square foot

(3) in square feet x 10^7