proper type of grit is used. Even the best grit reduces braking distances at low temperatures only 5 to 10 percent using a lock wheel stop. For maximum effectiveness with sanders, the pumping braking technique should be used—under this condition, the best grit reduces braking distances 30 to 40 percent below the locked wheel stop, depending on whether sanders are used on the rear wheels only or on all wheels.

7. Acceleration time with an empty (15,670 lb.) four wheel drive truck through a speed range of 10 mph. on glare ice is about half that obtained with a standard truck. This indicates approximately the advantage of four wheel drive trucks over standard trucks when climbing hills on icy roads.

8. Pumping the brakes can reduce braking distances as much as 20 percent, providing the proper technique is used. Because of the increased steering control possible by pumping, this method of braking is recommended even for the inexpert driver.

9. Power Braking (applying power without accelerating with the right foot while braking with the left) can reduce braking distances about 20 percent for a truck equipped with hydraulic or electric brakes; with air brakes this technique is not effective.

10. Natural road ice may closely approach glare lake ice in slipperiness.

11. Glare ice braking distances with natural rubber tires range from about 20 to 30 percent less than with synthetic tires. Acceleration time through a speed range of 10 mph. is about 25 percent less with rubber tires than with synthetic tires.

CERTAIN STRUCTURAL COMPONENTS OF LETTERS FOR IMPROVING THE EFFICIENCY OF THE STOP SIGN[1]

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SYNOPSIS

In 1930–31 studies were carried out by the writer under the National Research Council to determine the most efficient type of license plate. The results obtained with numbers suggested a further study of letters on highway signs. In 1939 Forbes presented a paper before the Highway Research Board giving certain constants for spacing of Series B, Series D, and Series E letters used at that time on standard highway signs.

These various studies suggested the need for exploration of types, stroke, and spacing of letters and background combinations which could be made to give a greater legibility distance and efficiency than those used heretofore. Accordingly studies were begun in 1940 at Iowa State College as a cooperative study of the Committee on Motor Vision for the American Optometric Association, the Engineering Experiment Station, Iowa State College, and the Public Roads Administration, to ascertain the basic principles for improving letter designs using Forbes' formulae as a basis of departure. It became obvious that improved letters could be designed if more study were given the individual characteristics of each letter, especially in four-letter words. It was found that a stroke somewhere between 0 18 to 0.25 the width of the letter would give best results and that it would need to be proportional to the height or width It was also found that letters are crowded together much too closely for maximum efficiency. Optimal spacings were studied and optimal limits established.

[1] Study inaugurated as a cooperative project of the Committee on Motor Vision of the American Optometric Association, the Engineering Experiment Station, Iowa State College, and the Public Roads Administration.

Controlled studies of letter background combinations showed that black letters on a white background are almost invariably superior to white letters on a black background. In this connection it was shown that the fewer items on the background the higher the efficiency of the sign. Experiments were then made with signs having only STOP and designed to fit on to forms of octagonal signs in order to obtain the largest possible letters in the space available.

Since the octagonal sign has only about 81 percent of the surface of a square or diamond-shaped sign of corresponding size, some modification in symmetry makes it much easier to discriminate from a round sign and also allows for much larger letters. Samples of the new type were shown with data on the performance of each.

Some data on the relative merits of different colors of reflectorized backgrounds were presented. Laboratory studies under controlled conditions show some advantages of red background over standard yellow or white for color discrimination under low levels of illumination. This is contrary to findings on non-reflectorized painted signs since the Purkinje phenomenon causes a shift toward darker values as illumination levels drop. It was found by outdoor measurement of distance for proper form discrimination that the octagonal sign is one of the least efficient from the standpoint of shape as a warning device since the legend on the sign can actually be recognized sooner than the shape. On the other hand, square or diamond shaped signs can be perceived correctly at nearly twice the distance that their legends can be read.

Suggestions are given for considerable improvement in legibility of the letters on the sign and for the recognition value of an eight-sided sign which would incorporate the essential features of standards established but would increase the warning efficiency very noticeably.

Further study is planned using various types of reflectorized signs for outdoor experiments incorporating the essential features of improvement gleaned from results established by experiments carried out to date.

In 1932, the writer presented a study before the Highway Research Board directing attention to the need for standardization and simplification of highway signs and markers. Photographs of existing markers were shown which varied in size from a few square inches to several square feet and in legibility distance from a few feet to several hundred yards. Possible improvements in signs, based upon an unpublished study of license plates (1931) were suggested which may be summarized as follows·

1. Letters or numerals properly spaced on the background give greater legibility distance for a given size. There is a tendency to crowd too much on the background space and to introduce unnecessary items on the plates.

2. Numerals should be constructed to be easily differentiated from each other. For example, digit 9 will be confused with 6 or 8 if the segments are rounded to form a partial enclosure.

3. An optimal width of stroke seems to hold for each width-height ratio of digit or letter. Theoretically superior numerals were constructed to differentiate numbers or letters in the greatest degree possible.

By using a large number of outdoor observations and subsequent statistical analysis through zero order and multiple correlation techniques, certain factors were shown to be important in legibility of license plates in the order of the beta values as shown in Table 1. Sample digits of improved design are shown in Figure 1.

From graphic analysis it was found that a difference in reflection factor between legend and background below 45 percent lowered the efficiency considerably. It was also shown that flat finish is superior to gloss finish under various conditions of lighting and that semi-reflectorized surfaces such as those coated with aluminum paint were much superior to ordinary painted signs in low illumination.

Forbes (1939) called attention to several factors involved in the accurate perception of highway signs. Two basic factors were legibility and attention value. Legibility was divided into pure legibility and glance legibility. The attention factor was sub-divided into target value and priority value. The present studies deal primarily with pure legibility but tachistoscopic observations are being contemplated in the final stages of this investigation.

TABLE 1
FACTORS OF LEGIBILITY

Variable	Beta Value[a]	Interpretation
Width-height ratio	.3592	Block type superior
Legend-background ratio	.2435	Less legend better
Stroke width	.2407	Number strokes were too broad
Spacing of numbers	.2167	More spacing needed
Stroke-width ratio	.1942	An optimum of about .20-.25 was obtained
Wave difference	.1145	Greater difference better
Items on the plate	.0977	Fewer items best

[a] The beta is an index of the relative importance of each factor studied. It is not to be interpreted as a percentage.

block or square type numerals for license plates. He also found a stroke of $\frac{3}{8}$ in. on a numeral $1\frac{1}{2}$ in. wide to be superior to $\frac{1}{4}$-in. stroke. This agrees in general with our earlier findings. He also found digits having a width at least half the height to be superior to those of more slender characteristics.

In our laboratory, Uhlaner (1941) made a careful study of the relationships between spacings as well as height, width, and stroke. His findings were obtained from several thousand observations made on typical rounded and square type letters and words commonly used on traffic signs in which the stroke, width-height ratio, and spacings were studied.

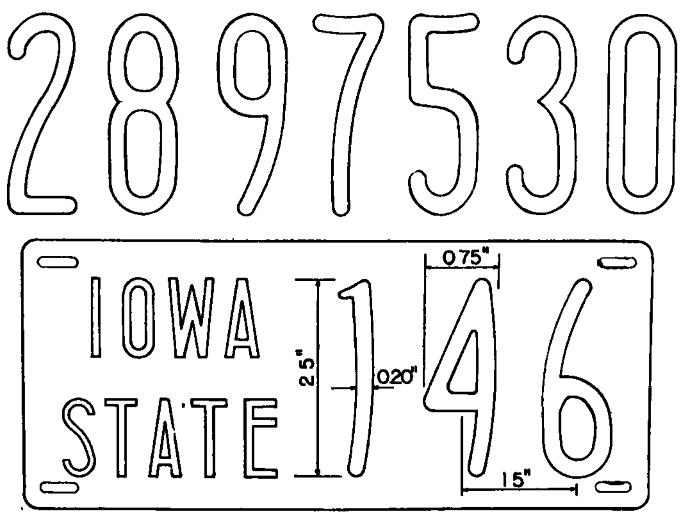

Figure 1. Modified Form of Numerals Which Increases Legibility Distance—Since the upper half of characters is of most value in such discriminations, an effort should be made to make them as distinctive as possible.

While Neal (1944) found that rounded letters are superior to block or square type letters, our first studies were conducted with block letters[2] since greater precision in construction could be obtained. Later rounded types of letters were used.

However, Aldrich (1937) reported no appreciable difference between rounded and

[2] The description of letters is sometimes misleading. Block letters are used here to indicate any rounded or square type letters with width equal to height unless qualified by further designation as square type.

Observations were made both indoors and outdoors in light varying from three to about 400 foot candles. The results for the letters selected for special study showed a stroke of 18.3 percent of the width of block letters to be best. The letters were selected on the basis of their legibility with respect to width as a percentage of letter height. Outdoor studies were made with a mean of 389 foot candles of light.

The results generally confirm those of other investigators that legibility distance increases as the width-height ratio approaches unity, or as the latter approaches a square or block design.

Next, the relation between width of letter, percentage of height and stroke was studied using the same letters. It was shown that as the letter widens in relation to its height the width of stroke must be increased. A three-axis graph was constructed to show the relationships between legibility, stroke, and relative width of letters. It is shown in Figure 2.

Further studies were made of spacing of letters in nine typical words found on highway

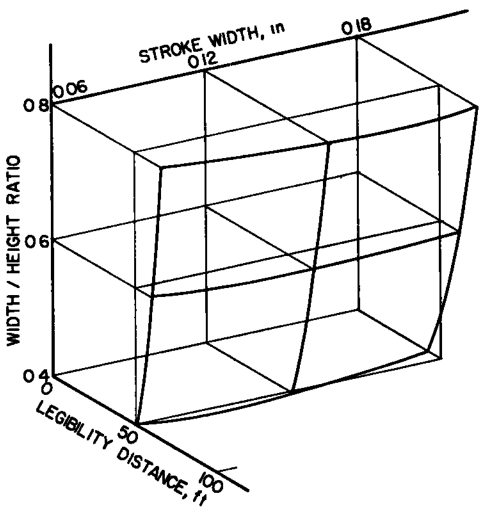

Figure 2. Three Dimensional Graph Showing Relationship between Width-Height Ratio, Stroke, and Legibility.

signs. The results indicate that wider spacings of the letters used are best and, according to Forbes (1939), specific formulations of measurements, spacing around 50 percent of the letter width showed satisfactory results. Any gains above this spacing would hardly justify the increased size required for most signs.

With this background as a basis, the present problem was set up in an attempt to develop a more efficient STOP sign than that found in common usage and to develop letter combinations which would best fit on the octagonal background.

It is reported that the evolution of shapes of signs came about in the following manner. A square sign was first used for giving information of all types to the motorist. It became necessary to differentiate between types of dangers or hazards and to specifically designate those at the side of the highway such as schools, residential districts, cattle crossings, etc., requiring caution and those on the roadway proper such as curves, dips, one way, and similar conditions requiring reduced speeds. In short to differentiate between dangers along the highway and those on the roadway proper. Consequently, it was suggested that the sign be rotated 45 degrees and a diamond-shape adopted for the latter purposes. Later, to provide for a STOP sign, the corners were clipped making it octagonal and thus reducing the area to 83 percent of its original size for perhaps the most important of all signs. For railroads the round sign was adopted which is 78 percent the area of a square sign with one side equal to the diameter of the circular railroad marker.

A number of related problems arose in connection with the present investigation which centered about the efficiency of the STOP sign with respect to target value in high and low illumination and with varying types of setting in which it is found along the highway. It was noted in the study of license plates already mentioned that with non-reflecting signs the dark oranges and reds tend to appear darker at night due to the Purkinje phenomenon, thus reducing the legend-background contrast which is very important for legibility in low level illumination. However, since white would tend to lose its target value on a white background of snow, some form of yellow seemed more desirable. The natural conclusion on a priori grounds is that lemon or light yellow would give best all around results.

Developments in reflectorization by buttons, special types of paint, indented metal, glass, or plastics and by impregnated materials has changed the original conclusions and necessitated a complete re-evaluation of the effectiveness of the STOP sign as a Gestalt or pattern, both with respect to shape and legibility of the word STOP. There are certain elements of a total pattern which affect the visual perceptibility of any object in a manner which cannot always be predicted from the elements.

From our previous studies it was considered necessary to eliminate all borders or other wording such as ARTERIAL above or below the word STOP which have almost invariably been shown to reduce the efficiency of a sign or plate. An exception may be that of reflectorizing the outline of the border which would appreciably raise the target value at night. This remains to be shown by experimental study with certain types of material, although many states are finding reflectorized borders very successful. In such case, the background color used might need be reversed. As a result of these considerations, the immediate problems set for experimental investigation may be summarized in general by the following questions

1. Do the letters S, T, O, and P differ in difficulty?

2. What size and shape of letters can be used to give the greatest efficiency for a given size of sign?

TABLE 2
STOPPING DISTANCE UNDER DIFFERENT ROAD CONDITIONS
(A composite index based on various published tables)

Speed	Dry Concrete	Ordinary Gravel	Wet Pavement	Packed Snow	Ice or Sleet
mph.	*ft.*	*ft.*	*ft.*	*ft.*	*ft.*
20	42	65	70	94	210 or more
30	84	129	140	185	415 or more
40	143	223	242	322	740 or more
50	220	339	366	490	1190 or more
60	317	486	526	700	1535 or more
70	436	670	723	970	2170 or more

3. How close can letters be spaced in a pattern and yet retain their original efficiency as isolated characters?

4. Is a dark background with light legend as satisfactory as the reverse?

5. How will reflectorization affect target value and the discrimination of the shape of the sign at night?

6. When reflectorizations are used, how will this modify the results obtained on painted signs?

7. How can the principles evolved in solutions to the above questions be utilized in practical sign construction to increase the efficiency of the STOP sign since increased speeds on the highway demand sufficient warning at danger points?

8. Are laboratory studies valid for evaluating certain factors of legibility?

Neal (1946) has suggested 10 seconds as a reasonable period of warning to a driver. Seventy and eighty mile speeds are not uncommon in the middle west. This means a minimum warning distance of more than 500 feet is necessary on dry pavement. According to Moyer (1947) and others, the distance would be much greater when traction is not good. Calculations made on this and similar existing data are shown in Table 2. A perusal of the stopping distance when traction is poor would suggest that a ten-second warning period would be hardly sufficient.

A point has been advanced by some that legend is not important since shape of the sign designates the STOP. A preliminary study of regular traffic signs used in Iowa shows that under average daylight conditions the legend on an octagonal sign can be read before the shape of the sign is discernible. On the other hand, the shape of square or of diamond signs can be recognized at nearly twice the distance the best legend on these signs can be read.

Thus, it seems that the shape of the octagonal sign is so hard to differentiate from a round one that its value as a warning signal is negligible. Consequently, a study has been set up to determine the best reflectorized colors to be used and the possibilities for changing the shape to make the sign more distinctive. Only a preliminary statement of results of experiments on shape and color will be given in this paper. The question arises as to whether or not there is justification for retaining standard octagonal shape signs since the utilization of space on a given area will depend considerably upon a satisfactory solution of this problem. Further studies are being carried out to determine the best possibilities in this direction if changes seem feasible in light in reflectorization patterns.

EXPERIMENTAL

The experimental part of this paper will be described here in outline only, as a series of eight studies, designated as Series 1 to 8, respectively. The procedures are briefly described to orient the reader. Statistical evaluations are introduced at points where they are thought to be necessary. In all regular experiments the conclusions given are based only on cases shown to be significantly different.

Series 1—Differential Perceptibility of Certain Letters

Problem—To determine the differential perceptibility of the standard Snallen letters S, T, O, and P used for visual tests under controlled conditions. These letters are square with a stroke of 20 percent the width of the letters. The criterion used for vision charts is that each member of the letter subtend an angle of 1 minute and the characters as a whole subtend an angle of 5 minutes.

Method and Procedure—Since it was desired to have the visual acuity of all observers used, those taking part in Series 1 and 2 were subjected to an additional set of observations using only the letters S, T, O, and P which were presented separately. This was done at the time the vision test was given.

Apparatus—The Clason Acuity Meter was used for testing vision as well as letter efficiency and they were thrown on the screen separately in random order. Fifty-five observers were used for evaluation, each letter being presented four times making a total of 220 observations for each of the perceptibility characters.

Results—The results are shown in Table 3 and indicate some difference in perceptibility of letters of this type when shown individually. The differences were all significant as shown by statistical techniques except in the case of O and P which was borderline.

Conclusions—It may be safely concluded that block letters of this nature are of somewhat unequal difficulty in legibility although it is not certain whether they should be constructed of different size in the word STOP. Since any variation from uniformity would complicate spacing, stroke, and other variables it was decided to use uniform size letters and subsequently make adjustments in size if necessary. It seems likely that perceptibility may be equalized by variations in shape of letters and other characteristics. The differences were calculated to be significant by standard statistical techniques.

Series 2—The Optimal Spacing of Block Letters

Problem—From data available it was deemed advisable to set up an experiment to determine, if possible, the conditions which would increase the legibility of the STOP sign in idealized form. This Series deals only with the effect of width of stroke and its relation to spacing and legibility. A preliminary check of sample letters was constructed and tested in a preliminary way. It was found that strokes above 25 percent of the width or less than 18.75 percent of the width were inferior. It was decided to investigate these two spacings using different strokes at various spacings.

Method and Procedure—Five plates with the word STOP in one-inch letters were constructed using spacings $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, 1 and $1\frac{1}{4}$ in. respectively and two widths of stroke, 0.187 and 0.250 percent of the width. Block letters were carefully drawn and inked with India ink. They were mounted on white cardboard and attached to plywood backs for use in the Stoelting Flash Card Tachistoscope (No. 11320-E) for slow-timed exposures. Twenty-three subjects were used in this Series under conditions of scotopic vision and 91 measurements were made of each stop sign keeping conditions constant. The order of presentation was rotated to offset any systematic error. A standard visual test had been given each subject as described in Series 1.

TABLE 3

EFFICIENCY OF LETTERS

(Readings from an average of 220 observation for each letter)

Sullen letters	S	T	O	P
Acuity Readings in percent	87.6	109.2	96.0	101.8

Apparatus—A dark room or test booth as described by Silver and Lauer (1941) was used to control the amount of illumination on the test object. The letters were exposed in rotating order as stated and the light controlled by a Ferree-Rand Projector, (No. 71-35-50) with mounted iris diaphragm to vary the light without affecting the wave length of impinging light. The cards were presented as desired by pushing a button to start the motor in the Stoelting Flash Card exposure device. Ten exposures are thus successively made from loading the device once, thereby saving a great deal of time. The projected light was gradually increased on each test card until the test object was just legible to the observer. He was asked to use the same criterion of discrimination for each observation and was required to make a verbal report immediately upon discrimination of the word symbols.

Results—The results of stroke-spacing relations obtained in Series 2 are shown in Table 4.

The mean light readings for the narrow stroke was 28.4 while that of the heavy stroke was 24.1 units of light. The low value means superiority of the test object. The difference was quite consistent throughout the range with one exception. While Uhlaner's results showed a difference in favor of the narrower stroke, his tests were run in light well above three foot candles and under conditions of photopic vision. As Neal (1946) suggests, "If a sign is not of sufficient importance to be

TABLE 4
RELATIONSHIPS OF STROKE AND SPACING TO LEGIBILITY

Stroke of Letters	Spacing of Letter or Word					
in.	*in.*					
	¼	½	¾	1	1¼	Mean for Stroke
	Diaphragm Readings on Ferree-Rand Projector[a]					
⅜	31.0	24.5	27.5	29.5	29.6	28.8
¼	22.0	28.5	22.0	22.0	26.0	24.1

[a] Low readings best

read by a motorist at night as well as by day, it has little place on the highway." No very significant difference in spacings were noted for maximum legibility unless it be a slight advantage at about ¾ in., for letters one inch high. No other reason than scotopic vision can be given by the writer for the results obtained from ¼-in. stroke which has usually been inferior.

Conclusion—It may be tentatively concluded that a stroke of 0.25 percent of the width of square letters is most desirable for very low levels of illumination. Since Neal (1944) found white reflectorized letters on dark background to be most effective at night this result may possibly be explained by a hilation effect on the retina, giving in reality a wider effective stroke, while the reverse would hold for black letters on a light reflectorized background.

Series 3—Optimal Background-Letter Combinations—The next step seemed to be that of checking the effects of black letters on white background against white letters on dark background with other conditions being held constant.

Problem—To test the effect of background-letter combinations with different widths of strokes and spacings under controlled conditions.

Method and Procedure—Identical sets of one-inch block letters were constructed with backgrounds reversed using spacings varying from ½ to 1¼ in. and with strokes ⅜ and ¼ in.

TABLE 5
COMPOSITE OF SPACINGS FOR TWO LEVELS OF ACUITY

A—WHITE LETTERS ON BLACK BACKGROUND
(Light units required for accurate perception-low superior)

Spacing	Acuity Above 80 Percent	Acuity 80 Percent and Below	Average for all Acuity	Acuity Ratio
in.				
¼	51.88	83.08	67.33	1.55
½	48.18	80.37	64.97	1.57
¾	47.34	66.76	57.01	1.41
1	47.19	66.49	56.84	1.40
1¼	51 46	79.54	65.50	1.52

Advantage of higher group is approximately 50 per cent

B—BLACK LETTERS ON WHITE BACKGROUND
(Light units required for accurate perception-low superior)

Spacing	Acuity Above 80 Percent	Acuity 80 Percent and Below	Average for all Acuity	Acuity Ratio
¼	43.80	63.11	53.45	1.42
½	40.54	60.01	50.28	1.49
¾	42 94	54.93	48.93	1 31
1	41.16	57.88	49.26	1.40
1¼	42 33	62 12	59.22	1.46

Advantage of higher acuity group is approximately 45 per cent

Total advantage of B over A—Approximately 20 per cent

Two different groups of observers were used, one for black letters on white background and the other for the white letters on black background. In the two sets of observations there were 91 and 56 respectively.

Apparatus—The same apparatus as described in Series 2 was used.

Results—To ascertain the possible effects of levels of visual acuity each group of subjects was divided into those above 80 percent and those below 80 percent acuity. The results of Series 2 are shown in Tables 5 and 6. It should be borne in mind that all subjects had fairly high vision and much greater differences in results would be obtained at border-line levels of vision as required for a driver's license by most states.

Conclusions—The results in general lead to the general conclusion that for low levels of illumination, or scotopic vision, wider strokes are necessary than for photopic vision. Also that the results obtained by Uhlaner and Lauer (1941) of a stroke of about 0.183 of the width for block letters, hold only at the higher levels of lighting. The superior results obtained by Neal (1944) from white reflectorized letters on black background probably are due to retinal irradiation of the luminous letters giving the effect of a broader stroke which offsets the disadvantage of white on black found in this study.

TABLE 6
COMPOSITE OF STROKE FOR TWO LEVELS OF ACUITY

Stroke	Acuity Above 80 Percent	Acuity 80 Percent and Below	Averages for all Acuity	Acuity Ratio
A—WHITE LETTERS ON BLACK BACKGROUND (Light units required for accurate perception-low superior)				
in.				
$\frac{1}{4}$–(.2500)	45.92	76 36	61.14	1 56
$\frac{3}{16}$–(.1875)	51.45	64.01	64.01	1.24
Advantage of higher acuity group approximately 35 per cent				
B—BLACK LETTERS ON WHITE BACKGROUND (Light units required for accurate perception-low superior)				
$\frac{1}{4}$–(.2500)	38.61	38.94	48.78	1.51
$\frac{3}{16}$–(.1875)	45.69	60.27	52.78	1.31
Advantage of higher acuity group approximately 40 per cent				
Total advantage of B over A approximately 25 per cent				

A random population group divided into upper and lower visual acuity will probably differ on the average about 50 percent in light requirements for equal legibility of signs at average levels. Differences of more than 100 percent may be expected at borderline levels. A typical curve is shown in Figure 3.

Black letters on white were superior in practically all combinations used, the average superiority being about 20 to 25 percent. Spacing between letters is a function of several variables but can probably range between 50 to 100 percent of letter width without doing violence to most letter combinations.

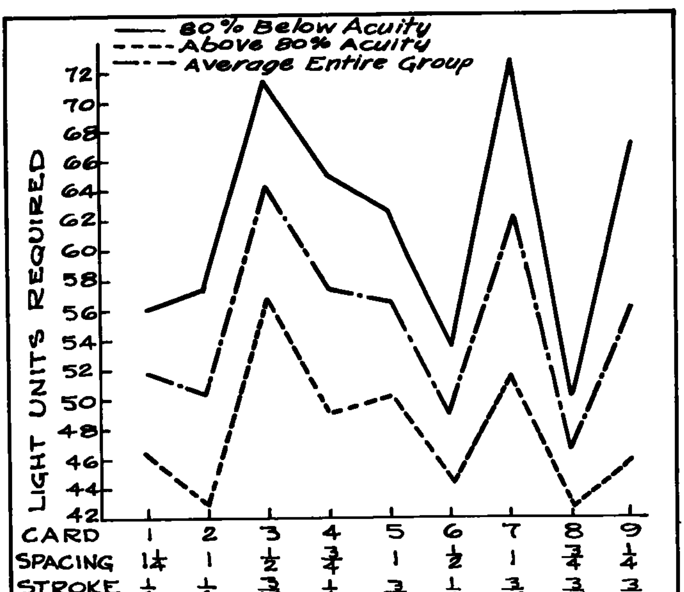

Figure 3. Group II a. Black Card—White Letters. Approximate Difference to Give Critical Ratio of 2.5 = 7.15. Difference in Threshold Levels of Certain Letter Combinations by Persons with Different Levels of Visual Acuity. This is a prime reason why acuity levels and size of lettering on signs must be considered.

Series 4—Optimal Letter Shapes—It was next deemed advisable to test out the various styles and sizes of letters to be used as a basis for the final selection of letters to be made for the word STOP in further studies.

Problem—To determine the singly exposed types of letters which give highest legibility under low levels of illumination.

Method and Procedure—The same general methods were used to separate letters of the various combinations of styles and characteristics as were made in the previous Series described. Some modifications of letters were made to test their legibility value.

Apparatus—Same as that in Series 2 and 3.

Results—The results were synthesized into a generalized STOP that seems to give the best all-around legibility. It is shown in Figure 4. Further modifications will need to

Figure 4. This figure represents an idealized type of stop sign constructed according to principles derived from the study. Slight artists modifications were made to equalize the legibility of letters in the Gestalt of the word STOP. Dimensions: 25 Percent Stroke, 25 Percent Modification on "S", "T", and "O", 50 Percent Spacing.

be made for reflectorization and fitting on to the background finally selected. The height may be increased but with diminishing returns in terms of legibility. The letters will increase in legibility distance by increasing the height. Certain minor modifications need be made in such case.

Conclusions—Rounded letters with height and width equal, having a stroke of 25 percent of the letter width, and spaced 50 percent of the width of the letter, seems to give the best legibility under conditions of low illumination. It is likely that such letters raised in height may need some special modification to fit well on the conventionally used, or some modified form of the octagon-shaped sign.

Series 5—Relative Perceptibility of Sign Shape and Color—Since an octagon-shaped sign is not easily recognized as such, there seemed to be some justification for consideration of other possibilities. Series 5 deals primarily with aspects of this problem which is presented as a preliminary investigation only.

Problem—To determine possible modifications, shapes, and colors, which will give maximum attention value and provide for maximum legibility of the legend on a STOP sign.

Method and Procedure—The first step was to study the octagonal sign and consider its possibilities. Since only 40 percent of the height of the revised sign is utilized, five possibilities for modifying the shape were considered. Two of these were modifications to form a cross, by notching the diagonal corners. One was an octagon having a height of 80 percent of the width while two were modified forms of a sign 60 percent as high as broad. Thirty-six miniature blank signs embracing nine patterns one inch across were constructed from white cardboard and three colors of Scotchlite; white, yellow, and red. These were presented individually to six trained subjects to ascertain at what point the shape and color could be perceived accurately.

The observer was shown a sample of the forms as a guide and given the following instructions: "Look ahead of you in the booth and tell me at what point you see a shape or color, of sign like those on the card." Then he was further instructed, "As soon as you see either color or shape, tell me." The light was gradually increased until a shape or color was observed. The reading was made and another form presented.

Apparatus—The apparatus is the same as that described in the previous experiments of Series 2, 3, and 4.

Results—An analysis was made of the amount of light required for accurate perception of color. In very low levels of illumination (below 0.01 to 0.40 f.c.) the yellow reflecting surfaces were difficult to discriminate from white. This fact has resulted in higher light readings for both white and yellow, than would normally result if discrimination of only white and red were made. The results are shown in Table 7. Table 8 gives the results found on form discrimination.

Conclusions—In general, it may be stated that the diamond and square are easiest to discriminate while the most difficult are the circle and octagon. As the octagonal shape is decreased in height it becomes easier to distinguish from the circle and to be identified as a characteristic shape.

Red is easiest to distinguish as a color but this experiment did not indicate clearly whether it showed up equally well at very low levels of illumination.

Series 7—Comparison of Thresholds for Visability, Color, and Shape—A short experiment was set up to determine which of four types of reflecting and plain surfaces were easiest to perceive; (a) as an object, (b) as a shape, and (c) as a color when relatively large areas were exposed, well above the angle of normal visual discrimination.

The same laboratory apparatus and technique were used as in Series 6 with shapes 5 in. across being exposed at 20 ft. and four trained subjects making a total of 78 observations. The instructions were as follows: "Take a look in the direction of the target, and as soon as you see anything appear say, 'Now' ". When this was accomplished the added instructions were given thus; "Now, tell me which you see first—shape or color." After both color and shape were correctly noted and readings recorded, the next stimulus object was presented and the same procedure followed. The series was repeated with the target holder tilted at 10 to 20 deg. backward from perpendicular. All readings were average for each factor studied for comparisons as given in Table 9.

TABLE 7
COLOR DISCRIMINATION—ALL FORMS
(Stimulus object 1 in. across at 20 ft)

	Number of Observations	Light Units Mean Values[a]
Red - Reflectorized	42	21.55
Yellow - Reflectorized	53	48.66
White - Reflectorized	66	31.68
White - Plain	53	49.94

[a] Light Units Required for Correct Discrimination of Color—Low values mean easy discrimination.

The results for this series may be considered preliminary to further tests of this nature being made out of doors. They suggest strongly that STOP signs should carry some combinations of white and red reflectorized materials since yellow does not have a low color visibility threshold. No valid conclusions can be drawn on shapes from this experiment since there were not enough forms in each category. Color vision may in some degree affect the ultimate choice of colors. The discrimination of colors seems much more critical at low levels of illumination that that required for ordinary discrimination of red and green stop lights.

TABLE 8
FORM DISCRIMINATION—ALL FORMS
(Stimulus object 1 in. across at 20 ft.)

	Number of Observations	Light Units Mean Values[a]
Diamond	12	24.42
Square	24	36.43
Circle	46	61.82
Octagon	20	63.40
80-Percent Octagon	18	41.33
60-Percent Octagon—A	18	41.33
60-Percent Octagon—B	17	34.18
Cross-Modified Octagon	23	57 91

[a] Light Units Required for Correct Discrimination Low values mean easy discrimination.

TABLE 9
THRESHOLD LEVELS FOR VISIBILITY COLOR AND SHAPE
(5-in. signs at 20 ft)

Normal Color Vision Subjects
(Three subjects—54 observations on each target)

Background	Light Units Required for Correct Discrimination		
	Visibility	Color	Shape
Yellow Reflectorized	5.5	70.0	91.0
Red Reflectorized	12.9	26.6	131.6
White Reflectorized	2 9	101.0	93.8
Stimsonite	1.9	66.5	44.6
Plated Tin	2.6	63.5	20.7
Mean	8.16	47 14	100 3

Color Blind Subject
(One Subject—24 observation on each)

Background	Visibility	Color	Shape
Yellow Reflectorized	4.8	249.0	71.0
Red Reflectorized	12.6	483.2	771.4
White Reflectorized	3.0	87.8	129.5
Stimsonite	2.0	461 2	230.2
Plated Tin	2.5	70.0	18.0
Mean	7.23	353.0	390.0

Series 8—Comparison of Laboratory and Outdoor Results on Typical Signs Used—The final series consisted of construction of model signs and a preliminary evaluation of certain experimental forms. Since the work is not completed we will merely indicate a few types of the small models to be built up in various reflectorized and painted forms according to specifications and suggestions from studies made which are to be subjected to further

analysis for more nearly complete evaluation. Some of the best designs so far devised are shown in Figure 5 and will indicate the progress that has been made so far. These basic designs can probably be greatly improved by some further modifications. It will be noted that modified forms of the octagon sign, the diamond and the square sign all have the same area. The legend on the square sign could be raised in height to increase its legibility distance somewhat. The special elongated sign at lower center represents an artists conception of balanced letters. It was not studied experimentally.

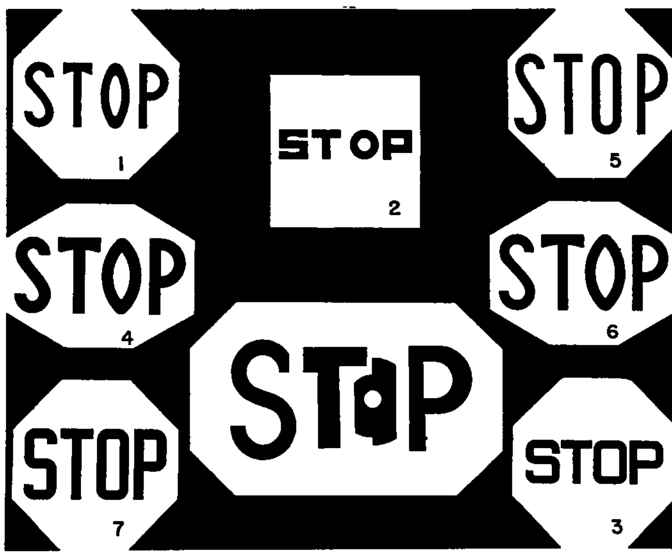

Figure 5. Types of Sign Studied—The sign at the lower left (No. 7) is a scaled reproduction from Neal of 30-in. stop signs used in Ohio. The sign at the lower right (No. 3) is a scaled reproduction of an older form of 24-in. stop sign used in Iowa. These are typical of signs being subjected to further analysis in various forms of reflectorization.

The matter of backgrounds and reflectorization for best results still remains to be solved but we expect to build further work on the principles already derived for the generalized form of the letters in STOP with modifications which are found necessary as the work progresses.

To make preliminary evaluations of the experimental forms of STOP signs shown, tests were made with the laboratory apparatus at 20 ft. and with the signs outdoors in 300 to 400 ft. candles of light on a hazy afternoon. They were set in mild shade with the surface facing the west for the outdoor runs. Both in and out observations were made and the average taken as an index. Two trained subjects were used in this study which is to be considered preliminary only.

TABLE 10

PRELIMINARY DATA ON EFFICIENCY OF SIGNS

Sign (as indicated in Fig. 5)	Average Light Units for Recognition at 20 ft.—(low best)	Rank	Average Distance Read	Rank	Combined Rank
			ft.		
1	207	2	260	4	2
2	276	6	165	7	7
3	234	4	218	6	5½
4	172	1	302	1	1
5	242	5	301	2	3
6	317	7	295	3	5½
7	215	3	249	5	4

The results are shown in Table 10 for the various forms of the STOP sign as shown in Figure 5. The shapes have the same area and are designed to give the largest letter of a given width on each sign. The two standard road signs were used although neither was of the rounded letter design.

From the results it seems that preliminary studies in the laboratory are valid enough to warrant their usage considering the advantages gained in experimental controls. Thus number 4 ranked highest in both indoor and outdoor tests, and 2 was nearly at the bottom. In no case was the placing off more than four rankings, while most were but one or two.

Some of the designs shown would be more effective if the letters were taller but they represent specimens of types to be reflectorized for further study.

GENERAL SUMMARY

Studies of the most efficient form of STOP sign were based upon previous work done by the writer and others. Beginning with evaluation of letter difficulty, stroke, width-height relation, spacing, letter formation, and fit on the conventional, as well as a modified octagonal STOP sign, the study indicates possible improvement in legibility up to 50 percent of STOP signs now found on the highways.

It was found the rounded letters are superior and that the letter T needs to be strengthened to make it equal to other letters as a part of the STOP Gestalt. Strokes of about 25 percent of the letter width were found best. Ovalizing the O seems to improve it as an individual letter as well as improving the Gestalt of the STOP sign generally.

Preliminary studies of background colors and shapes show a superiority of horizontally elongated octagonal signs for discrimination of form. As a distinctive target the reflectorized red seems to have an advantage over yellow. Earlier experiments would indicate the reverse to be true for non-reflectorized signs although this result might have been suspected on theoretical grounds.

The results show that the efficiency of standard signs now in use can be improved from 20 to 50 percent by redesign of the letters. Target value of the octagonal form, as a precautionary sign, could be much improved by a change in shape.

Probably the most effective as well as distinctive STOP sign from all points of view will be a combination of red and white reflectorized materials with a third color or material used for letterings.

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