Color and Brightness Factors in Simulated and Full-Scale Traffic Sign Visibility

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•THIS is a report of the last three experiments of a four-year study of traffic sign requirements, the objective of which was to study characteristics yielding optimum sign visibility and effectiveness. A review of earlier studies showed that much research had been on legibility but relatively little on visibility factors (1, 2). Accordingly, this project emphasized the study of factors affecting visibility and attention value. Observations were obtained from a total of 499 subjects in 13 laboratory experiments using simulated signs and highway scenes, and from an outdoor, full-scale set of observations as a check of the laboratory results.

Two previous reports described the laboratory simulation method and the results obtained. The first five experiments (4) showed that when four simulated green signs were presented briefly while the subject was engaged in an auxiliary task, overhead mounting position was favored over side mounting. To equalize this factor, later comparisons were therefore all in the overhead position. Use of blank green signs indicated an advantage for the brightest sign against night and the darkest sign against a day-snow background. Introduction of white letters on the signs modified these relationships.

Another series of experiments (5), in which size and brightness of the simulated signs were varied, showed that bright letters on the sign gave contrast effects which tended to oppose the advantage of the bright signs against the night background and to enhance the advantage of a darker sign against a day-snow background. When this effect was reduced or eliminated, the advantage of the bright signs against the night background increased.

The present report gives the results of Experiments 12, 13, and 14. Experiment 12, in which the four simulated green signs were seen against three colored backgrounds, showed contrast of sign-to-background to be important. Experiment 14 measured the effects of seven different colors of simulated signs in pairs when seen against four different colored backgrounds. Finally, Experiment 13, in which outdoor observations were made by subjects riding over a standardized course, is reported. Mathematical models based on known visual and logical relationships were tested against each set of laboratory results. A model which fitted the laboratory results best is reported, along with another which gave good correspondence with average outdoor observations. Suggestions are made as to application of the results for estimating highway sign effectiveness, although the results must be viewed as tentative until further research confirms and refines them.

RESEARCH METHODS

Laboratory Simulation Method

Previous reports have described the laboratory simulation procedure (1, 3, 4, 5). Essentially it required the subject to relight with buttons under his left hand whatever number of lights were extinguished in a matrix of small red lights. The matrix appeared

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below a projected highway scene. This auxiliary task thus "loaded the operator" to some degree and assured fixation at road level.

An appropriate highway scene was projected continuously in a darkroom laboratory from a 35-millimeter colored slide to maintain the proper visual adaptation for the day or night background being used. At unpredictable times and keyed by the response to the light matrix (the auxiliary task), a set of test signs appeared for one second on the same highway scene. The subject was asked to give his immediate reaction as to which of the four signs was seen "first and best" and which second best. He recorded his reaction by pushing one of four buttons under his right hand, then continued with the auxiliary task. From 15 to 20 subjects viewed the simulated signs against each different background, giving for Experiments 12 and 14 a total of 105 different people.

Outdoor Observation Method

Outdoor observations were made by 41 subjects, 22 under night and 19 under day conditions. Each observer rode beside the driver in a station wagon and reported all signs as soon as they were seen. The 40-mile standardized course included both city and freeway driving in and near Lansing, Michigan.

A speed and delay recorder in the car showed the position at which each sign was reported. The observer indicated a highway or an advertising sign by pushing one of two buttons which activated recording pens. Mileposts and locations of selected experimental signs were identified by the experimenter on the paper recording tape.

Approaching five multiple overhead sign locations (at freeway interchanges), the subject was instructed while the signs were not yet visible to raise a cardboard screen to cut off his view. On signal, about 200 feet from the signs, he dropped the screen and reported the sign he saw first.

ANALYSIS OF THE DATA

From the laboratory records, the number of times each sign (of the four) was "seen first" was tabulated for each subject, and the total for all subjects was converted into percent "seen first." Resulting figures were plotted.

Outdoor observation distance was measured from the paper tape and recognition distances plotted for each experimental sign. Average, 25, 50, and 75 percent values were determined.

For each sign of the installations viewed suddenly by use of the cardboard screen, the number and percent reported as "seen first" were tabulated and percents computed.

TERMINOLOGY

In dealing with stimuli for color perceptions and achromatic visual responses, terminology is sometimes confusing in spite of attempts to standardize it. One system uses the terms "hue," "chroma," and "lightness" for the three basic characteristics of colored surfaces viewed under reflected light. On the other hand, "hue," "saturation," and "brightness" may be properly used for colored light stimuli.

In our study, projection of the colored highway scenes and simulated signs on a reflective screen gave a result somewhere between that of highly reflectorized materials and ordinary surfaces seen in reflected light. Fairly good simulation of day and night viewing of signs was obtained, but terminology must be arbitrarily selected. We have used the term "brightness" throughout to indicate the "Y" or "brightness" values measured with the Spectra Pritchard photometer (which includes a correction for the average brightness sensitivity of the human eye). Similarly, we have arbitrarily used the term "brightness" for this characteristic of signs outdoors under both day and night conditions, again referring to the same photometric measurement.

EXPERIMENTS WITH COLORED BACKGROUNDS AND COLORED SIGNS

Experiments 6, 7, and 8 investigated effects of four sign sizes and four brightnesses of simulated green signs (5). Experiment 6 used white letters and arrows of the same

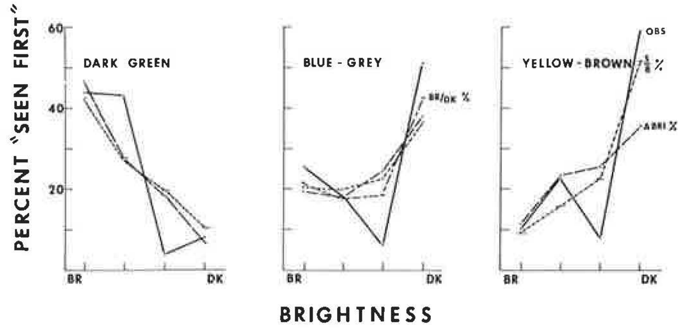
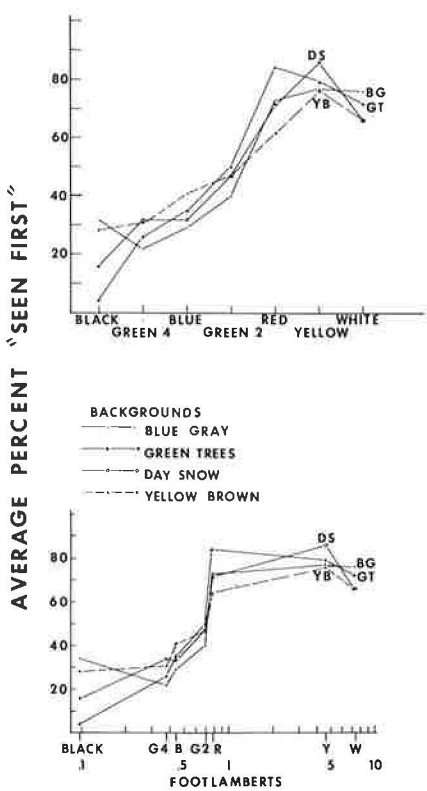


Figure 1. Results of Experiment 12—green signs and colored backgrounds (observed values shown by solid lines, calculated values by broken lines).

brightness on all signs. Experiment 7 used blank signs (no letters or arrows). Experiment 8 used letters and arrows of reduced brightness on the darkest two signs. The results showed an advantage for the bright and large blank signs against the night background and of the dark and large against day-snow. White letters and arrows contrasting with the signs enhanced the advantage of dark signs against snow and reduced the advantage of bright signs against night backgrounds.



SIMULATED SIGN COLORS PRESENTED IN PAIRS

Figure 2. Results of Experiment 14—colored signs and colored backgrounds.

Colored Backgrounds

Experiment 12 investigated the effect of seeing the four simulated green signs against three colored backgrounds. Dark green trees, a yellow-brown hill, and a blue-gray cliff were the backgrounds against which the green, blank simulated signs (of four brightnesses) were seen by the subjects. A total of 45 subjects viewed these signs while carrying on the auxiliary task as in the original procedure.

Figure 1 (solid lines) shows that the brightest sign was seen best against the green trees, the darkest against the yellow-brown hill, and there was a combination effect against the blue-gray cliff background. This last effect apparently resulted from a difference in brightness from left to right in the background scene. The other two consistently show an advantage for signs contrasting in brightness with the background.

Colored Signs and Colored Backgrounds

Experiment 14 investigated the effect of seven different colors of simulated signs seen against four different colored backgrounds (dark green trees, yellow-brown hill, blue-gray cliff, and the day-snow scenes). The signs were black, dark green (with 30 percent overlay), blue, the saturated green, a brilliant red, yellow, and white.

A total of 60 subjects, 15 for each background, saw the simulated signs in pairs and indicated which of the pair was "seen best." The pair-comparison technique in this case was effective in deriving a scale. The scale is based on the

average percent of the total observations in which each color of a pair was selected when seen against all four backgrounds.

Figure 2 shows that when the colors were arranged in general order of brightness (top figure), the brighter colors were "seen best" more frequently. When plotted against the logarithm of brightness of the simulated sign (lower figure) the average percent "seen best" increased nearly linearly with the log of brightness as might be expected if the different contrast against the four backgrounds of the seven colors averaged out. The exceptions were the red and the yellow and black signs. Here hue contrast apparently added to the effect of brightness contrast and modified the result. This was especially noticeable for the red, which was a brilliant, slightly bluish-red contrasting well with the four backgrounds when projected in the darkroom laboratory. The spread of plotted points for black and for red indicates the effect of sign-to-background contrast.

Outdoor Observations

Experiment 13 was a full-scale outdoor check series in which each subject rode in a car over a standardized course and viewed regular street and highway signs against backgrounds of sky, trees, grass, concrete bridges, buildings and other city backgrounds, and competing signs. As noted earlier, a standard route of some 40 miles included freeway driving and city driving in and around Lansing, Michigan, in about equal proportions. From a total of over 400 highway and advertising signs, 82 highway signs were used as test signs.

The subject called out each sign as soon as he noticed it, indicating color and location (right, left, or ahead), and pushed one of two buttons to indicate whether it was an advertising or a highway sign. A group of 19 subjects made day observations and 22 others made night observations.

Figure 3 shows examples of the range of distances recorded for pairs of different sizes of signs—large, medium (4 to 6 feet in height), and small. Each pair illustrates

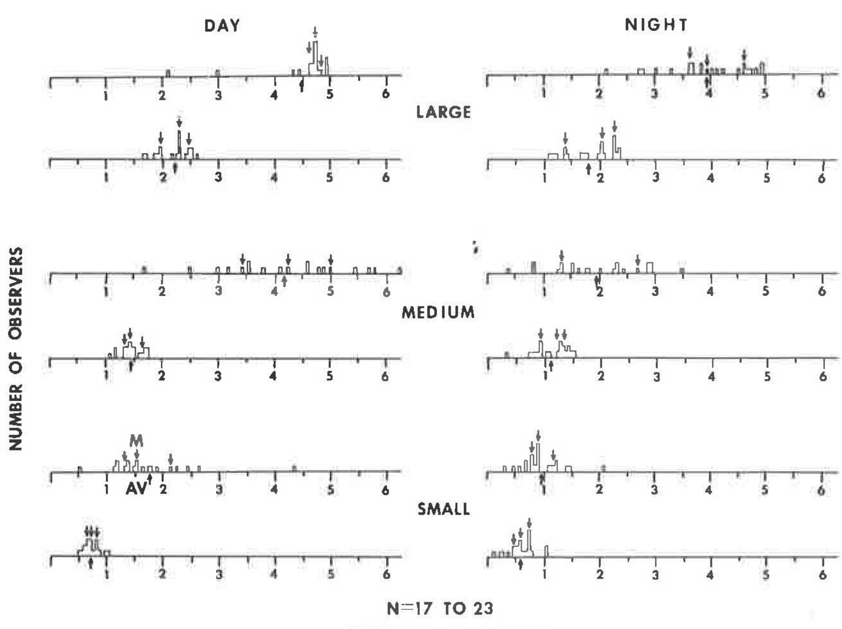


Figure 3. Results of Experiment 13—three sizes of sign with restricted and unrestricted sight distance (arrows indicate 25 and 50 percentile and arithmetic mean).

records from a sign with unrestricted sight distance and another where viewing distance was limited. Most signs were reported well beyond the legibility distance of their largest legend, but clear vision distance often limited recognition distance. Large overhead multiple installations, when viewed with sudden exposure, showed an advantage for the left-most sign in daylight and the straight-ahead sign under night conditions.

TEST OF MATHEMATICAL MODELS AGAINST OBSERVATIONS

In experiments of the type used here for measuring visibility and attention-getting characteristics, a relatively large number of factors had to be varied. But possible fatigue of the subjects and effects carrying over from one series of sign presentations to another limited the number of combinations which could be used in any one experiment. The results were in percentage form and the number of points determined was limited.

Under such circumstances, one practical method of analyzing and explaining the results is to test calculated values obtained from a mathematical model against the observed values from the series of experiments. The mathematical model must be based on proper assumptions from known characteristics of human vision with regard to color, size, and brightness and allowable logic from other known relationships. The models should fit the essential results from both the laboratory experiments and the outdoor experiment. For this purpose, laboratory Experiments 6, 7, 8, and 12 were the most clear-cut in control of conditions and independence of the observing groups and Experiment 13 represented night and day observations in the full-scale outdoor situation.

Several models based on possible assumptions using allowable logic and valid vision principles were tested. Two of these showed the best fit for laboratory results as a whole. Certain others, which showed a better fit for one experiment, but poorer ones for others, were discarded. A semilogarithmic model did not fit except in Experiment 14.

The model giving best fit for laboratory results was

$$P = \frac{BR_{SiBi} + BR_{LiSi}}{\sum_{i}^{n} \left(BR_{SB} + BR_{LS}\right)} \times AR_{LS} \times SF \times 100 \qquad (1)$$

where

P = percent "seen first"

B_B = background brightness

B_{Si} and B_{Li} = sign and letter brightness respectively for sign i

A_{Li} and A_{Si} = area of legend and of sign i

A_{Si} and A_{Si-1} = area of sign i and of next smallest sign i - 1

Brightness ratios:

$$BR_{SB} = \frac{B_S}{B_B} \text{ if } B_S > B_B$$

$$= \frac{B_B}{B_S} \text{ if } B_B > B_S$$

$$BR_{LS} = \frac{B_L}{B_S}$$

Legend to sign area ratio:

$$AR_{LS} = \frac{A_{Li}}{A_{Si}} \text{ expressed as percent of largest ratio}$$

Size factor:

$$SF_1 = \frac{A_{Si}}{A_{Si} + A_{Si-1}}$$

$$SF_2 = (1 - SF_1) \frac{A_{Si-1}}{A_{Si-1} + A_{Si-2}}$$

The model giving second best fit for laboratory results used contrast rather than brightness ratio:

Sign-to-background percent contrast

$$C_{SB} = \frac{B_S - B_B}{B_S} \times 100 \quad \text{if } B_S > B_B$$

$$= \frac{B_B - B_S}{B_B} \times 100 \quad \text{if } B_B > B_S$$

Similarly, letter-to-sign percent contrast

$$C_{LS} = \frac{B_L - B_S}{B_L} \times 100 \text{ or } \frac{B_S - B_L}{B_S} \times 100$$

Then, percent "seen first"

$$P = \frac{C_{SiBi} + C_{LiSi}}{\sum_i^n \left(C_{SB} + C_{LS}\right)} \times AR_{LS} \times SF \times 100 \tag{2}$$

The model as applied to outdoor results calculated average distance seen:

$$D = \frac{C_{SB} + C_{LS}}{2} \times ER \tag{3}$$

where ER = expected recognition distance (small dimension of sign in feet × 1200) or clear sight distance, whichever is smaller.

Best Models for Laboratory Data

Experiment 12, since it presented blank green signs against three different backgrounds, was a good test case, especially since the blue-gray background actually included two brightness values. Figure 1 shows the comparison of three calculated values against the observed data for the three different backgrounds. The values corresponding to Eq. 1 are labeled BR/DK percent. A calculation corresponding to Eq. 2 is labeled ΔBRI percent. The third calculation labeled S/B percent was similar to that for Eq. 1 except that the ratio was always sign/background. Except for the yellow-brown background, the calculated values for the two models were about equally good fits. For the yellow-brown and the dark green, the bright/dark was identical with the sign/background percent. It showed a slightly better fit than ΔBRI for the yellow-brown.

Figures 4 and 5 show that the calculated brightness ratio values from Eq. 1 fitted quite well for Experiments 6, 7, and 8. Figure 4 shows the fit obtained when size was constant (upper figures) and when brightness was constant (lower figures). Figure 5

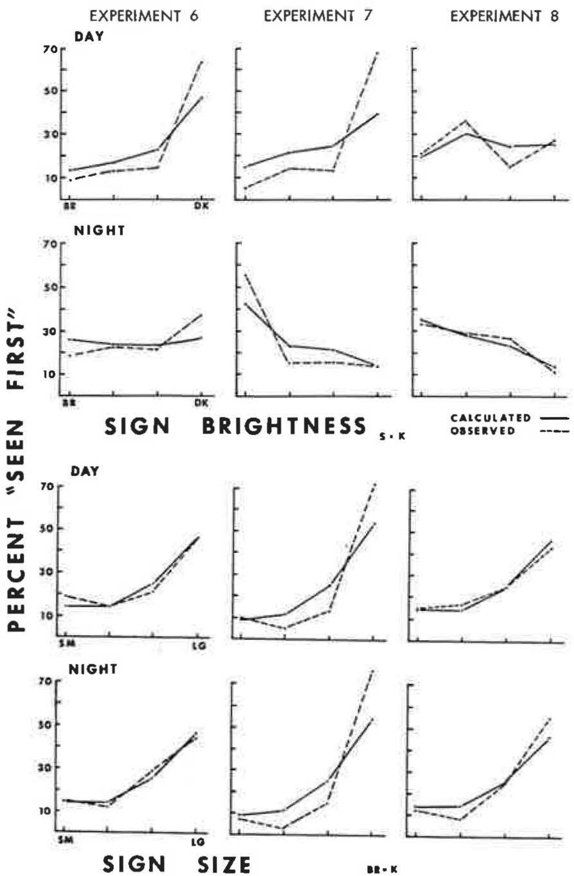


Figure 4. Calculated and observed values for size and brightness experiments (upper figures, size constant; lower figures, brightness constant).

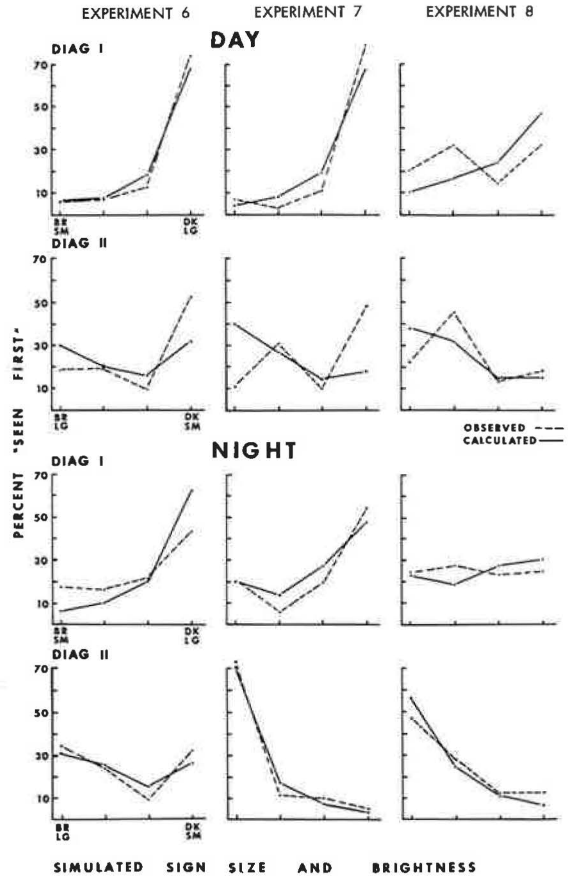


Figure 5. Calculated and observed values for diagonal 1 and diagonal 2 size and brightness experiments.

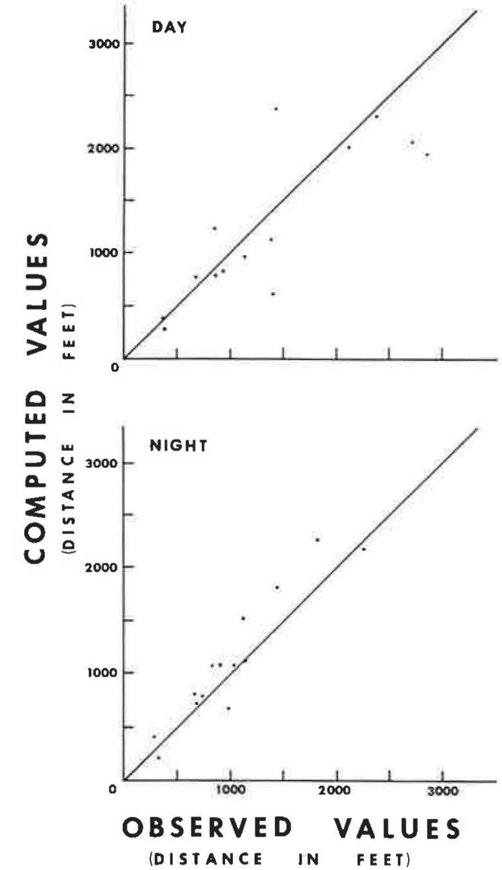


Figure 6. Experiment 13, outdoor observations—calculated and observed distances.

shows the corresponding fits for diagonal 1 (bright small to dark large) and for diagonal 2 (bright large to dark small). Reasonably good correspondence was obtained.

Model Applied to Field Results

When the field observations were compared with calculated results based on Eq. 3 (additive contrast percent times estimated recognition distance) and on the clear sight distance available, rather good correspondence was found. Figure 6 shows the calculated vs the average observed distances for night and day observations. The next-to-longest observed distance was taken as an indication of the actual amount of clear sight distance if less than the calculated expected recognition distance. Expected recognition distance was 1200 feet per foot of sign height for day conditions. This means assumption of twice the legibility distance for a letter of that height.

If the calculated values corresponded exactly to the observed values, the points would all fall on the straight line. Although they do not, they fall close enough to it to indicate rather good correspondence.

DISCUSSION

Possible Differences Between Laboratory and Full-Scale Conditions

For the outdoor observations, use of the brightness contrast percent, Eq. 3, gave distance values corresponding quite well to the observed values when clear sight distance was taken into account. The calculated brightness contrast values from Eq. 2 did not fit the laboratory data quite as well for Experiments 6, 7, and 8. They produced a somewhat lower percentage for the most frequently seen sign combination.

It is possible that the laboratory observations exaggerated somewhat the advantage of the sign "seen best." In order to obtain more observations, the observers saw the test sign series twice. In spite of the scrambling of different sign combinations, some might respond consistently to the same sign a second time. If they developed a habit of response and then responded the same way in the second series, theoretical calculations indicated this might raise their score by about 10 percent, and thus increase the score for the preferred sign. Therefore, the more conservative percent contrast is probably the better relationship of the two to use for practical application.

Implications of the Two Models

Both mathematical models must be viewed as tentative approximations pending further research. However, on the basis of Eq. 1, brightness ratios of sign-to-background and legend-to-sign are major factors in sign visibility and they are additive but modified by the proportion of the area in legend and in sign. Therefore, if sign-to-background brightness ratio becomes zero, visibility would depend on the legend-to-sign brightness ratio reduced by the relative area factor (about 0.56 in Experiment 6). With our experimental signs this would divide legend-to-sign brightness roughly by two. Where two signs are being compared, the relative size of the two signs also would play a part as indicated by the sign area ratio.

On the other hand, Eq. 2 indicates additive percent contrast of sign-to-background ratio and legend-to-sign weighted equally. These are modified by the same ratio of legend-to-sign area where two signs are compared, and by ratio of sign size (area). Here again, if sign-to-background contrast becomes zero, the remaining legend-to-sign contrast percent is reduced by one-half, and also reduced by the proportion of legend-to-sign area in different size signs.

To achieve the best visibility and at the same time not interfere with legibility, both models indicate that sign-to-background and legend-to-sign brightness ratio or contrast must be balanced. Further research is needed to determine the optimum combination of these.

The contrast percent is probably the more practical and valid of the two relationships for application to full-scale situations.

Importance of Environmental Background

It has been shown that contrast of a darker sign against a bright background is as important as contrast of a bright sign against a dark background. In many cases it would be desirable to achieve the first for day and the second for night in the same sign installation.

A study by Hanson and Woltman (6) showed the wide range of backgrounds against which highway signs are seen. Dark trees, bright sky, and highway bridges furnished 23, 19, and 16 percent of the backgrounds for traffic signs. In winter, of course, backgrounds are largely snow in many areas.

PROCEDURE FOR TRAFFIC ENGINEERING APPLICATIONS

The following is a suggested procedure for predicting sign visibility on the basis of project results.

Measure or Estimate Background, Sign and Legend Brightness

Photometric measurements can be made with the Pritchard Spectra photometer which includes a correction for average human visual sensitivity. If this is not possible or if this degree of accuracy with attendant time and cost of making such measurements is not desired, an approximation can be obtained for daylight conditions by taking colored photographs under good daylight, using Kodachrome II or an equivalent slower type of color film that gives most accurate color. For this purpose, use at least three exposures bracketing the one indicated as normal by the light meter. Then choose the projected picture that gives the most correct-appearing colors.

Use of 35-mm color slides gives better reproduction than color prints. Slides should be projected in a completely dark room with a good quality projector and white reflective screen. This will avoid poor color from stray light and from uneven or low illumination introduced by poor projectors. Photometric measurements of sign, letters, and background can be made from the projected pictures.

Calculate Percent Brightness Contrast

For day conditions use photometric data from outdoor or laboratory measurements to calculate contrast. For night sign visibility use values for different reflective and other sign materials from such studies as Straub and Allen (7, Fig. 12) and Powers (8, Fig. 8). Other studies are understood to be under way that will give actual or calculated luminance for sign materials under headlights at a given distance.

Estimate Recognizable Distance

Use the small dimension of the sign. For most conditions, assume the sign will be recognizable or visible twice as far as legibility distance of the same size letter. Therefore, use 100 feet per inch (or 1200 feet per foot) of the small dimension of the sign. This assumption will not be valid below a certain minimum brightness. On the basis of other studies (7, Fig. 21, and 9) it is suggested that, for signs less than 0.05 ft-L in maximum brightness, 400 feet per foot be used. Apply factor to estimated recognizable distance or to clear sight distance to sign, whichever is smaller.

Apply Factor To Estimate Relative Visibility

Use Eq. 2, including area and size factors where applicable, as follows:

Case 1, daylight, one sign—Relative area factor is inoperative here. Therefore, use average of contrast percents.

Case 2, daylight, two signs—Use sum of contrast factors to determine factor for each sign. If signs are of different size, apply sign area and legend area ratios. Apply factor to estimated recognizable distance as described earlier for each sign.

Case 3—For night visibility prediction use the same procedures, obtaining contrast values as suggested previously.

Results

The resulting figure gives an estimate of the distance in feet a given sign is most likely to be seen by the average driver. Comparing distance estimates for competing signs will give an estimate of relative visibility of each one relative to the others.

CONCLUSIONS

1. Average visibility and attention value of highway signs can be estimated from characteristics of legend, sign and environmental background. Visibility and the sign characteristics fundamental to its production are relative in character.
2. Relative brightness and contrast of sign-to-background and of legend-to-sign are of primary importance for visibility and attention value.
3. In visibility effects from colors, relative brightness is of most importance, but hue contrast enhances the brightness effects in some cases. However, color is important and effective in transmitting coded meanings.
4. For best visibility, a sign should be darker against a bright day background but brighter against a dark day or night background. Legend-to-sign contrast may enhance or oppose effects of sign-to-background contrast. They should be balanced to obtain best visibility (and attention value) and at the same time high legibility.
5. A formula for estimating visibility effects is suggested on an approximate basis and within limits.

RECOMMENDATIONS

1. The question of whether and how much the reduction of letter-to-sign brightness contrast impairs legibility should be investigated. Such contrast reduction may occur in using higher sign brightness to carry the important color message to the motorist.
2. A method of obtaining better color and legend effectiveness is needed for cases where a sign is darker than a bright sky background and the legend is in shadow. In such a case, the visibility and legibility of the legend is low because of relatively low legend-to-sign brightness.
3. Another study has reported that contrast of signs to environmental background varies greatly. Backgrounds should be considered in designing traffic signs.
4. Much more research is needed to confirm and refine the tentative approximate relationships reported here.

ACKNOWLEDGMENTS

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