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16. Abstract

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A laboratory study was carried out to define the effects of luminance, contrast, color, and driver visual characteristics on legibility distance. At the same time a computer model was developed which could predict the legibility distance of a sign, based on the laboratory data as well as geometric and photometric variables. A field study was then conducted in which legibility distance predicted by the model was compared with legibility distance measured on a number of real and simulated signs using a sample of normal drivers. In general, the model's predictions were within 10% of the measured legibility distances.

Data have been developed which show graphically the relationship between legibility distance and the photometric properties of background and legend materials. In general, more highly reflective backgrounds permit somewhat greater legibility distances. Perhaps more important, reflectorized backgrounds reduce the effect of changes in viewing conditions, which can be quite substantial in the case of a non-reflective background. The contrast provided by the legend is very important. The optimum choice of legend depends on the reflectivity of the background and the sign location. Luminance contrast requirements are lowest for highly reflective backgrounds and increase as background reflectivity decreases.

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ABSTRACT

The purpose of this study was to define the relationship between sign luminance and legibility in a way that would assist in selecting optimum material choices for various signing applications as well as aid in decisions concerning maintenance and replacement.

A laboratory study was carried out to define the effects of luminance, contrast, color and driver visual characteristics on legibility distance. At the same time a computer model was developed which could predict the legibility distance of a sign, based on the laboratory data as well as geometric and photometric variables. A field study was then conducted in which legibility distance predicted by the model was compared with legibility distance measured on a number of real and simulated signs using a sample of normal drivers. In general, the model's predictions were within 10% of the measured legibility distances.

Data have been developed which show graphically the relationship between legibility distance and the photometric properties of background and legend materials. In general, more highly reflective backgrounds permit somewhat greater legibility distances. Perhaps more important, reflectorized backgrounds reduce the effect of changes in viewing conditions, which can be quite substantial in the case of a non-reflective background. The contrast provided by the legend is very important. The optimum choice of legend depends on the reflectivity of the background and the sign location. Luminance contrast requirements are lowest for highly reflective backgrounds and increase as background reflectivity decreases.

SUMMARY OF FINDINGS

The purpose of this project was to develop legibility guidelines which would aid traffic engineering agencies in decisions relating to the selection, maintenance and eventual replacement of retroreflective signing materials.

There are a number of factors which enter into decisions concerning the selection of signing materials. Most of these are well known and quantified to a greater or lesser extent. Examples are: initial cost, expected life, luminance properties, and maintenance requirements. One significant factor about which not enough information is available is the relationship between luminance properties and legibility. This project was designed to provide the required information.

The guidelines developed by the project depend on the contrast direction (white or black legend). Signs with white legends shall be considered first.

For white legend signs both legend and background luminance are important. Thus, configurations where the legend is separate (not silk-screened) provide greater flexibility, and complexity. The following discussion of white legend signs is most applicable to those with separate legends. However, specific consideration shall also be given to silk-screened signs.

The results of the project indicate that any sign background material in use today, or likely to be available in the near future, can provide satisfactory legibility. Highly reflective materials have the potential (depending on the choice of legend material) of providing somewhat greater legibility distance than others, but the difference is not great (about 10%, comparing highly reflective and non-reflective options). Perhaps of greater consequence is the fact that the legibility characteristics of non-reflective and low-reflective background signs change a great deal more, depending on the headlamp beam being used or the amount of stream traffic, than do the legibility characteristics of moderately and highly reflective signs. For example, if two signs were placed side by side, one having a non-reflective and the other a highly reflective background, their legibility distances would probably not differ by more than 10% when viewed under design conditions (e.g., isolated car, low beams). However, if the approaching car were using high beams, the legibility of the two signs would change significantly, and in opposite directions. The distance at which the sign with the non-reflective background could be read would decrease (due to excessive legend luminance contrast) while the distance at which the sign with the highly reflective background could be read would increase. The legibility distance difference under these conditions could well be 30% or more.

If an agency wishes to settle on one material combination for all signing, the characteristic of background reflectivity just described is of considerable importance. Basically, it means that greater legibility distances will be achieved (on a system-wide average) through use of backgrounds having moderate to high levels of reflectivity. Alternatively, it means that the use of non-reflective backgrounds requires illumination or larger legend sizes to equal the performance of signs having at least moderate levels of reflectorization.

The most important factor affecting the legibility of white letter signs is legend luminance contrast. Having chosen a background material, the legend material must be selected with care to maximize the legibility potential of the sign. It is possible to select materials which are too reflective or not reflective enough. The luminance contrast required depends on the background luminance, being least for highly reflective backgrounds and greatest for non-reflective backgrounds. As it happens, the ratios work out to a fairly narrow selection of materials, at least for the single car, low beam condition. Thus, on overhead signs, button legends are most effective, for any background. On ground mount signs, highly reflective sheeting legends are most effective, except when the background is made of this material, in which case buttons are preferred.

Silk screened white legend signs present a special problem because high levels of contrast can only be achieved by using a less transparent ink and darkening the background. Where conspicuity is important (as it generally is, especially in red background signs) this is an undesirable trade-off. Highly reflective materials enable lower contrast ratios and brighter and more conspicuous backgrounds.

For signs having a white legend and black background or a black legend and a white, yellow or orange background, legibility is determined by the luminance of the brighter portion. For any of these combinations a luminance in the range of 1-5 ft-L (3.43-17.1 cd/m^2) is best. When such signs are positioned on or close to the road surface the use of highly reflective materials may degrade legibility to some extent. Where attention-getting properties are of prime interest such materials may still be indicated however, and the loss of legibility can easily be corrected by using a larger legend.

Differences in legibility as a function of sign color are minimal. Within a given contrast direction, it is possible to predict the relative performance of various material options equally well from the individual data on any color.

The luminance of the environment within which a sign is placed also has an effect on legibility. Barring the presence of glare sources near the sign, higher surround luminance improves legibility and reduces the effects of excessive legend luminance. Thus, the same sign could be read at a greater distance if placed in a highly illuminated urban environment rather than in a dark rural environment.

The "legibility distance" of a highway sign is determined in large part by the visual characteristics of individual drivers. It was hoped that this project could generate data which would make it possible to predict legibility distance for the general driving population. This turned out to be a complex problem. What was found was that the usual driver visual screening test is not a reliable predictor even of the ability to read road signs. Other variables, some of which have been little studied, are quite important. The net effect of these variables on the ability of the driving population to read road signs is unknown, so prediction of the legibility afforded to specified fractions of the drivers on the road is somewhat uncertain. What can be offered is a relative evaluation of various signing material options, and this is what has been provided in this report.

CHAPTER 1 - INTRODUCTION AND RESEARCH APPROACH

Statement of the Problem: The aims of this project are well described by the title: "Determine the Luminous Requirements of Retroreflective Signing Materials." Road signs, even excluding consideration of the support structure, represent a tremendous capital investment to the various jurisdictions which must erect and maintain them. It is an area where careful consideration of cost-effectiveness has the potential for substantial savings. Available materials differ widely in initial cost, durability, and maintenance problems, all of which are pertinent to a cost-effectiveness analysis. They also differ in photometric properties. There can be no question that the luminous characteristics of a sign have an effect on its legibility and, therefore, on its most important function, the transmission of information. Missing at present is the kind of data which would allow the engineer to include luminous requirements in a cost-effectiveness analysis. This project was designed to provide such data.

Background. As part of this effort a detailed review of the literature was undertaken. The review is presented as Appendix A of this report. There have been a substantial number of investigations which have attempted to relate sign luminance and legibility characteristics. Many of these studies have been carefully done and have yielded useful information. However, as pointed out in the review summary, very few studies have dealt with cases where both legend and background have significant luminance, or considered different background colors, or presented both photometric and subject response data in a way which was adequately quantitative. The two studies which do meet these criteria present somewhat different recommendations. It is apparent that further work is required before the issue can be adequately resolved.

RESEARCH APPROACH

INTRODUCTION

The aim of this investigation was to provide information relating sign luminance to legibility is such a way that the engineer could readily weigh the merits of various material combinations. Further, it should be possible to use these data without having to acquire special instruments and/or laboratory facilities or make photometric measurements in the field.

Even brief consideration of the problem posed in this study makes it apparent that there are a large number of potentially important variables. Table 1 is a listing of those variables which the authors feel are most significant.

An experimental investigation which gave reasonable consideration to all of these variables would be impractical. A great simplification could be achieved by using computer modeling techniques to calculate sign luminance given the photometric properties of the materials and specifications for variables 6 through 9 above. The idea is not new. Analytical approaches have been described by Straub and Allen (1956), Elstad, et al. (1962), and King and Lunenfeld (1971). Further, computer models have been used in a number of other situations to handle complex geometric problems with a high degree of success.

Typically, variables such as 1 through 5 have been studied in full scale outdoor simulations. While this adds to the credibility of the results, the process is slow, expensive and lacking in precise control of variables. It was decided to use a laboratory simulation instead, with a field study reserved for purposes of validation.

Finally, it was necessary to devise a format for presentation of the final results which would be useful to traffic engineers.

Laboratory Study

The laboratory study is described in detail in Appendix B. The

TABLE 1. Listing of Variables Significantly Influencing the Luminance of Retroreflective Signs

Number	Source	Description
1	Sign	Background Reflectivity
2	Sign	Legend Reflectivity
3	Sign	Background Color
4	Sign	Placement (vertical and horizontal) relative to the roadway
5	Environment	Luminance of the environment within which the sign is place (surround luminance)
6	Environment	Road alignment in the approach to the sign
7	Car	Headlight characteristics (photometry and aim) of the vehicle providing the illuminance
8	Car	Position of the car on the road (lane position and distance from the sign)
9	Observer	Observer visual characteristics

intent was to collect a substantial amount of information on the effect of variables 1 through 5 on a small sample of carefully selected subjects. To do this an apparatus was devised which was a modification of one described by Hills and Freeman (1970). This is a simple optical device which permits independent control of the background and legend luminance of a simulated sign through a broad range of values. Background and legend colors can be readily changed and both positive and negative contrasts investigated. This unit was used to measure the legibility threshold of various size Landolt "C" legends as a function of background color and background, legend and surround luminance. A glance legibility criterion was used. Three groups of subjects participated. The main group consisted of young people with normal vision. The members of the second group were also young, but had relatively poor low-contrast far acuity. The third group consisted of persons 65 years of age or older who had normal vision. The results of this investigation defined the relationship between luminance and color parameters in terms of legibility distance, and were used as inputs to the legibility distance model.

Legibility Distance Model

A more complete description of this model is provided in Appendix D.

As a means of evaluating the effectiveness of automotive headlighting systems, HSRI had developed a computer seeing distance model which performed calculations of the luminance and contrast of various roadway objects when illuminated by automobile headlamps. This model was modified to permit consideration of retroreflective signs. Then, based on the results of the laboratory study, it could calculate legibility distance.

Besides equations describing observer response characteristics, the model accepts as input parameters: photometric properties of the sign materials, sign position relative to the roadway, road alignment, vehicle position on the roadway, headlight photometry (for right and left lamps separately), and driver eye position.

The intent was to use the model as a means of developing predictive data regarding the performance of various signing materials and situations to meet the contract objectives. However, it was necessary to ascertain whether the predictions provided were realistic. In order to do this a field study was carried out.

Field Validation Study

The field validation study is described in detail in Appendix C. It was designed to verify the accuracy of the model and to determine what correction, if any, should be applied to the laboratory data to take field factors into account. Two field studies were conducted. One of these was performed on a private road, using artificial signs. The second was carried out on a local freeway, using existing guide signs. The legibility distances measured were compared with predictions provided by the model.

Development of Predictive Data

The legibility distance model was used to generate data describing the relationship between the photometric properties of various material options and legibility distance for specific signing situations. Checks were also run to determine whether other signing situations would yield different results. If they did, a complete set of predictive curves was generated for these as well.

These figure sets were prepared in a suitable format, along with instructions and illustrative examples, to provide guidance to traffic engineers in decisions concerning use of signing materials.

CHAPTER 2 - FINDINGS

LABORATORY STUDY

Introduction

The laboratory study was carried out to measure the effect of variables such as sign luminance, color, and surround luminance on the ability of subjects having different visual characteristics to detect the orientation of a standard visual acuity target.

Results

A detailed description of the study and its results is provided in Appendix B. These results are quite complex and only a brief summary will be offered here.

Sign Luminance. Both background and legend luminance are important factors in sign legibility. For signs with white legends and red, blue, or green backgrounds the following general relationships were found:

1. Increasing background luminance results in some improvements in peak legibility potential of the sign. However, the legibility actually achieved depends largely on the legend luminance.
2. Increasing background luminance increases the range of legend luminance associated with maximum legibility distance.
3. Legend luminance contrast is very important. Optimum contrast depends on background luminance, being least at the highest levels of background luminance tested and increasing substantially at lower levels of background luminance.
4. The use of highly reflective background materials makes possible somewhat greater legibility distance and allows the maximum to be maintained through a greater range of viewing conditions (e.g., high and low beams and chnages in

traffic density). As the reflectivity of the background material is decreased, the maximum potential legibility distance decreases somewhat and the range of viewing conditions associated with maximum legibility is also decreased. Thus, whether the sign is viewed with high or low beams, for example, can have a substantial effect in terms of legibility distance with non-reflective or low-reflectivity background materials (unless the sign is illuminated).

For signs having a black legend and a white, yellow, or orange background, or for signs having a white legend and a black or non-reflective background, legibility is determined by the luminance of the brighter component. For all these cases the maximum legibility occurs in a luminance range of 1-5 ft-L (3.43-17.14 cd/m^2), for a dark surround. Since the optimum luminance range is fairly narrow for such signs, they are obviously very much affected by changes in viewing conditions such as different headlamp beams.

Sign Color. Green and blue backgrounds yield about the same performance. Red, especially at lower luminance levels, seems to require more luminance contrast to achieve the same legibility as green and blue. Black backgrounds yield performance about the same as colored backgrounds at the lowest luminance levels tested. White, orange, and yellow backgrounds differ somewhat in the luminance levels required for a given level of performance. White is best in this respect, yellow poorest.

Surround Luminance. Increasing the luminance of the environment within which a sign is positioned has two major effects:

1. An increase in the distance at which the sign is legible.
2. A reduction in the detrimental effect of high legend luminance contrast. On a typical brightly lighted urban freeway, as an example, the effect of excessive luminance contrast would disappear entirely.

Subject Visual Characteristics. There are large differences in the performance of different subject groupings. Subjects classified as having poor low-contrast acuity require about ten times the legend luminance contrast to equal the performance of the visual normal group. Older subjects (65 +), although matched in terms of visual acuity with the younger subjects, perform much more poorly in general. They require substantially more luminance contrast than the young normal group and have a peak legibility distance about one-third less.

FIELD VALIDATION STUDY

Introduction

The field validation study was carried out primarily to determine whether the legibility distances predicted by the computer model could be achieved in the field. An additional aim was to measure what correction, if any, must be applied to the laboratory data to compensate for field study procedures and changes in the visual task.

Results

A detailed description of this study and its results is provided in Appendix C. There are three aspects of these results which will be briefly discussed here. These are:

Predictive Validity. In the first phase (referred to as the airport study) 48 conditions were investigated. In 26 of these the discrepancy between measured and predicted legibility distance was 5% or less. In 14 cases the discrepancy was between 5 and 10%. In 6 cases the discrepancy was between 10 and 20%. Only two cases were in error by more than 20% (maximum - 25.6%). Four of the largest errors were associated with conditions characterized by low luminance contrast, a situation where relatively minor variations from the assumed specific luminance could produce a significant change legibility distance.

In the second phase (referred to as the freeway study) 23 signs were included. In 12 cases the discrepancy between measured and predicted legibility distance was less than 10%. In 8 cases the discrepancy was between 10 and 15%. Only 3 cases were in error by more than 20% (maximum - 23.5%).

The results of this study indicate that the computer model, combined with the data from the laboratory study, has a high degree of predictive validity and should be a useful tool in evaluating the merits of various sign material options.

Comparison Between Laboratory and Field Results. The laboratory data (which represent approximately 90th percentile performance) compare well with average (approximately 50th percentile) performance in the field study. Simply stated, this means that the subjects were able to perform better in the laboratory setting. In order to prepare the results for a final presentation the distribution of data from the laboratory study must be shifted down to allow for the field effect described above. The objective is to have the mean of the laboratory data correspond to the mean of the field data.

Visual Criterion. The two field studies used different performance measures: acuity in the case of the airport study, message comprehension in the case of the freeway study. Despite this, the model predicted legibility distance about equally well in both instances. This is an important finding which indicates that the laboratory data, although based on an acuity measure, should relate well to legibility of actual sign messages.

PREDICTION OF THE LEGIBILITY DISTANCE OF HIGHWAY SIGNS

Introduction

The work reported so far has concerned the development of:

1. Basic data concerning the visual capabilities of observers with signing materials.
2. A computer model which uses the vision data, together with geometric and photometric information, to predict the distance at which highway signs will become legible.

Having demonstrated that the model is capable of predicting legibility distance with reasonable accuracy, it is necessary to exercise it in a systematic way to develop predictions for a broad spectrum of signing applications. These predictions can then be used to draw inferences concerning appropriate material use, etc.

In this section shall be presented basic predictive data for the legibility of highway signs in a variety of situations. The comparisons are presented in terms of "legibility distance." Clearly it would be desirable that this measure represent the actual capabilities of the population of motorists in this country today. Before presenting the predictive legibility distance information it is appropriate to examine the question of population visual characteristics.

Estimate of Representative Legibility Distances. Because of the potentially enormous cost implications, any investigator who makes a recommendation to significantly change present sign design specifications (especially in a way that would require larger signs) must be able to muster compelling support for his or her arguments. It would be desirable at this point to examine the available data to see if such support exists.

The results of this study indicate that young persons with normal visual acuity can record legibility distances of 55 ft/inch (6.6 m/cm) letter height or so under favorable conditions. Granting that a large fraction of the driving population is neither young nor blessed with 20/20 (6/6) vision, it would appear that a substantial correction is required in order to accommodate the visual capabilities of most if not all licensed drivers.

At the start one encounters a difference in design philosophy. On the one hand it is argued that, since it is legal for persons with visual acuity as poor as 20/40 (6/12) to drive, signs should be designed for them, not for persons with 20/20 (6/6) visual acuity. By this logic, it would appear that if 55 ft/inch (6/6 m/cm) letter height is a reasonable maximum for normal vision, half that value is required to accommodate persons with half normal acuity.

The other argument is that sign specifications should be established to cover some large fraction of the driving population (a common figure is 85%). Designing for less than everybody is regarded as acceptable practice in many fields where: (1) there is the possibility of people accommodating to the design to some extent, and (2) designing for everyone is very costly.

As it turns out, regardless of which position is favored, determination of population vision characteristics pertinent to the nighttime legibility of highway signs is an exceedingly complex problem.

Static far acuity is the usual measure discussed with reference to sign legibility. But, as a predictor of the ability to read signs at night, its value is questionable. Even the young, 20/20 (6/6) subjects involved in our laboratory study differed somewhat in the contrast required to resolve the Landolt ring legend. Older subjects with 20/20 (6/6) or better vision did much poorer in the laboratory test than did young 20/20's (6/6). It is apparent that there are other variables, aside from acuity, which are very significant in this type of visual task. The net effect of these variables is uncertain, so that the distribution in the population is not known. Thus, attempts to predict population performance in the task of interest here, based on the distribution of static far acuity scores, would be in error to an unknown degree.

With the above caution in mind, it is instructive to estimate the size of the correction required to accommodate about 85% of the population having 20/40 far acuity or better. Distributional data have been supplied by HEW (Roberts, 1964) which make such an estimate possible. Based on these data it appears that a corrective multiplier of about 0.7 would be appropriate. Using this, a legibility distance of 50 ft/inch (6 m/cm) letter height becomes 35 ft/inch (4.2 m/cm) letter height.

Clearly, on an acuity basis, present sign design standards (based on a criterion of 50 ft/inch [6 m/cm] letter height) are seriously inadequate. However, there are compensating factors which make the situation less serious than it might appear. One of these factors is the motorist, who can adapt, perhaps by driving more slowly, to be able to acquire the necessary information from signs. Another factor, sometimes overlooked, arises from the wealth of redundant information contained in a written message. Thus, it is not necessary to be able to identify each individual letter. Useful and sometimes sufficient cues are present in the length and gross shape of a word or the presence and location of key letters. It is this characteristic of written information which makes it possible to read poor handwriting and makes it difficult to perceive errors such as misspellings, reversals or missing letters (which is one reason why proofreading is a difficult job). In view of this, legibility distance estimates based on anything other than comprehension measures will be conservative. Unfortunately, it is not easy to determine how conservative because even comprehension measures derived in an experimental setting are probably based on rather conservative responses on the part of the subjects.

In sum, the authors do not believe that there exists at the present time the kind of data which will allow an accurate estimate of population legibility distance criteria. The problem is a complex one and would require considerable experimental effort to resolve.

The predictive legibility distance curves presented in this report are based on the performance of young, visually normal subjects, corrected to represent a level at which about 85% of their responses had occurred. On an absolute basis the legibility distances cited can be debated, for the reasons mentioned earlier. In the opinion of the authors they are not unreasonable, if for no better reason than they are in a range which corresponds to long accepted practice and which seems, on a basis of that experience, to "work" fairly well.

On a relative basis the curves accurately describe material performance. That is, if combination "A" is 10% better than "B," for example, it would be true regardless of what decisions might finally evolve concerning the absolute visibility distance question. Thus the engineer can use the curves as an aid to defining the relative merit of various materials for given signing problems. It must be remembered only that the legibility distance taken from the vertical axis of the curve is an approximation and not an absolute truth.

Utilization of the Predictive Legibility Distance Data

This section will provide an introduction to the major project end product, the predictive legibility distance curves. There are ten of these curves, describing various signing situations. Table 2 lists the conditions appropriate for each. Accompanying each figure is a table (Tables 3 through 12) which summarizes the data in the figure and adds information for some additional cases.

Rationale. The curves show the legibility distance (in ft/inch letter height) provided by various combinations of signing materials. The lines each represent one background material having the specific luminance indicated by the label. They range from 0.1 cd/ft-c/ft^2, representing a non-reflective surface, to 100 cd/ft-c/ft^2, a material whose reflectivity substantially exceeds any available today. The curves show the 85th percentile legibility distance provided by each background material as a function of legend specific luminance. It will be noted that each curve begins at a relatively short legibility distance with low levels of legend specific luminance, initially shows increasing legibility distance as legend specific luminance increases and, in most cases, peaks at some point and starts down again as legend specific luminance continues to increase. The tables repeat and supplement the information contained in the figures. Each cell entry represents the legibility distance (in feet/inch letter height) associated with the legend and background specific luminances indicated on the horizontal and vertical axes.

TABLE 2. List of figures describing the specific luminance requirements for highway signs for differing roadway alignments and headlamp beams.

Figure	Road Alignment	Sign Position	Headlamp Beam
1	Tangent, constant grade	Overhead, 20 feet high, centered over lane	Low
2	Tangent, constant grade	Overhead, 20 feet high, centered over lane	High
3	Tangent, constant grade	Roadside, 8 feet above pavement, 12 feet to right of edge of pavement	Low
4	Tangent, constant grade	Roadside, 8 feet above pavement, 12 feet to right of edge of pavement	High
5	2^{o} Right hand curve constant grade	Overhead, 20 feet high, centered over lane	Low
6	2^{o} Left hand curve constant grade	Overhead, 20 feet high, centered over lane	Low
7	2^{o} Right hand curve constant grade	Roadside, 8 feet above pavement, 12 feet to right of edge of pavement	Low
8	2^{o} Left hand curve constant grade	Roadside, 8 feet above pavement, 12 feet to right of edge of pavement	Low
9	Tangent, crest (A = 8%)	Overhead, 20 feet high, centered over lane	Low
10	Tangent, sag (A = 8%)	Overhead, 20 feet high, centered over lane	Low

Assumptions. The following assumptions have been made in producing these curves:

1. Roadway alignment and sign position. Both of these factors are very significant. Separate figures have been prepared for a number of typical problems.

2. Intensity of illumination. The curves assume the presence of a single vehicle on low beams. The use of high beams makes a significant difference and two figures have been prepared to illustrate this. Heavy stream traffic will also increase sign luminance (Woltman and Youngblood, 1976). The effect increases as viewing distances increase, and could result in overall luminance increases by as much as eight times. For installations where the engineer wishes to consider this effect it is necessary to increase both background and legend specific luminance levels by the multiplier considered appropriate. Further consideration will be given this point later.

3. Weather. The curves assume the weather to be clear and dry. While conditions such as fog and rain can reduce visibility significantly, it should be noted that damp pavement can result in substantial increases in sign luminance levels (Woltman and Youngblood, 1976).

4. Effective distance. The curves have been developed on a basis of legend sizes referred to in the Manual of Uniform Traffic Control Devices (up to about 18 inches (46 cm) in height). For legends much larger than 18 inches (46 cm) the reduction in overall sign luminance resulting from the greater separation between the sign and car headlamps significantly changes the predictions given in the figures and tables. As can be seen from inspection of the predictive legibility distance curves, the effect of holding luminance contrast constant and reducing overall luminance

is to reduce legibility distance fairly rapidly. Thus, if these data are used to predict the legibility of signs using legends much larger than 18 inches, the predicted legibility distances will be optimistic to an increasing degree as the legend becomes larger.

Use of the Data. Each of the figures contains three or four curves (the accompanying tables show background specific luminance at six levels). If there are three it is because the curves labeled 0.1 and 1.0 are identical. Each of the curves represent a background material (green is shown) having the indicated specific luminance. The 0.1 level is appropriate for either a colored non-reflective or black background.

While these curves are intended to represent signs with white legends, they can be used for signs with black legends as well. In the latter case the curve labeled 0.1 is used and the horizontal axis interpreted as "Background" rather than "Legend Specific Luminance." The tables consider non-reflective legends specifically, through a background specific luminance of 250 cd/ft-c/ft^2.

Specific luminance information is supplied by the manufacturers of signing materials and is based on documents such as Federal Specification L-S-300-B. Individual samples may be photometered, using approved procedures, as many highway departments do. It is very important to point out that exact specific luminance data are not necessary in order to use the predictive legibility distance curves. Although manufacturer's specifications represent minima and there are substantial variations from sample to sample, these variations are not large enough to seriously affect the predicted performance. An exception to this does occur if choices are made which have low luminance contrast. As can be seen from the predictive legibility distance curves, such combinations would have poor legibility anyway and variations from assumed specific luminance could produce relatively large errors in predicted legibility.

Manufacturer's specifications include specific luminance data for a variety of incidence and divergence angles. The engineer must first decide which are appropriate for the installation under consideration. For most large signs (e.g., freeway guide signs) the -4^{0}, 0.2^{0} specifications should be used. For some other types of problems (e.g., street signs and other small signs in urban areas) larger angles should be used. This is a matter of judgment best left to the persons directly involved.

Overhead Signs. Refer to Figure 1 and Table 3 for the examples which will now be presented. The figure shows 85th percentile legibility distances for four background materials as a function of legend specific luminance. The sign is positioned overhead on a tangent with a contrast grade and has a green background. Specific luminance values other than those shown can be approximated through interpolation.

For the situation depicted in Figure 1 a non-reflective background (specific luminance = 0.1) would enable a maximum legibility distance of about 49 ft/inch (5.88 m/cm) letter height, through use of a legend having a specific luminance of about 500. As has been reported in Appendix E, button legends have a "sheeting equivalent" specific luminance of about 600 cd/ft-c/ft^2; they could be used here. Choosing a legend material having a specific luminance in the 100-150 range would reduce legibility distances somewhat, about 10% in this case. If legends having specific luminance much greater than 500 were available these would also result in reduction in legibility.

Much the same is true for a retroreflective material having a specific luminance of 10. Using a legend having a specific luminance in the 70-100 range, as would be the case if the legend were chosen from the same family of materials as the background, would produce a legibility distance of about 43 ft/inch (5.16 m/cm) letter height. Legiblity distance can be improved to 50 ft/inch (6 m/cm) letter height by use of a legend having a specific luminance of about 500.

Thus, for this situation, in terms of legibility distance at least, there is little to choose between a non-reflective and moderately reflective background. There are, of course, a number of other factors to consider (e.g., conspicuity, color retention, cost, service life). For background materials having specific luminance greater then 10, some improvements in legibility are possible. A background in the 30-40 range would permit maximum legibility distances about 5% greater than those for the less reflective backgrounds. Although this would require legend materials having greater specific luminance than is now possible. In addition, for overhead signs at least, there would be significant benefits from the use of far more reflective background materials than are available today.

If signs with black legends are being considered, the procedure is basically the same. The 0.1 curve is used and the horizontal axis is assumed to read "background specific luminance." This process or the use of the "non-reflective" row in Table 3, indicates that a background specific luminance of about 250 would be optimum. While there is a white material close to this value, other available materials which would be used with black legends are less reflective and would yield lower legibility distances. Figure 1 illustrates an overhead situation, however, and signs of this type are more usually ground mounted, close to the road edge. Some Figures in the set (especially Figure 3) are probably more appropriate.

Other Signing Situations. The situation depicted in Figure 3 is identical in all respects to Figure 1 except the sign has been moved to a roadside position. Since this places it closer to the high-intensity portion of the low beam, the luminance levels are higher. This results in changes in contrast requirements and, for some materials, improvements in legibility distance.

Consider first the constrast requirement changes. The two less reflective backgrounds peak with legends having specific luminance in the 100-200 range. A 500 legend, which was best in the overhead situation, is now excessive and results in reduced legibility distance. A 10 background peaks with a legend of about 300, although the 500 legend which was best in the overhead situation would not produce a really significant decline in legibility. Higher luminance backgrounds require correspondingly smaller changes in legend luminance.

It will also be noted that, while the peak legibility distance for the least reflective materials (0.1 and 1.0) remains constant for the two signing situations, the 10 background increases to about 54 ft/inch (6.48 m/cm) letter height, almost a 10% improvement, for the roadside sign. This is because, at low background luminance levels, legend luminance is the only factor determining legibility. The 10 background, in the roadside position at least, has enough luminance to interact with legend luminance and produce an overall increase in legibility.

Figures 2 and 4 are included to indicate the effects of using high beams to view the same signs as depicted in Figures 1 and 3. Two points should be noted in particular:

First, the peak legibility distance changes least for the non-reflective backgrounds. The contrast requirements, however, change substantially. The result is that a non-reflective background sign designed for maximum legibility under low beam conditions will suffer a considerable loss in legibility distance if viewed with high beams. In each case shown the loss is from about 49 ft/inch (5.88 m/cm) letter height to 38 ft/inch (4.56 m/cm) letter height.

Second, more reflective backgrounds show significant increases in peak legibility distance and, while there is a drop in legend luminance requirements, it is small enough that there is still a net gain in legibility distance even if the low-beam optimum configuration is viewed with high beams.

Figures 5 through 10 depict other signing situations of general interest. They are interpreted in the same way as the first four figures which have just been discussed in some detail.

Although this project is primarily concerned with retroreflective signs it would be appropriate to say something concerning illuminated signs. Illuminating a sign poses initial cost and maintenance problems not associated with a retroreflective installation. On the other hand, there are significant advantages, one of which is that sign luminance is fairly high and uniform for all conditions. Thus legibility distance is predictable and certainly as good or better than can be obtained with any available retroreflective material. These data indicate, assuming that the background has a luminance of 1 foot Lambert (3.43 cd/m^2) or more and the legend-to-background contrast is about 10:1 or better, that a legibility distance of 60 ft/inch (7.2 m/cm) can be expected using illuminated signs.

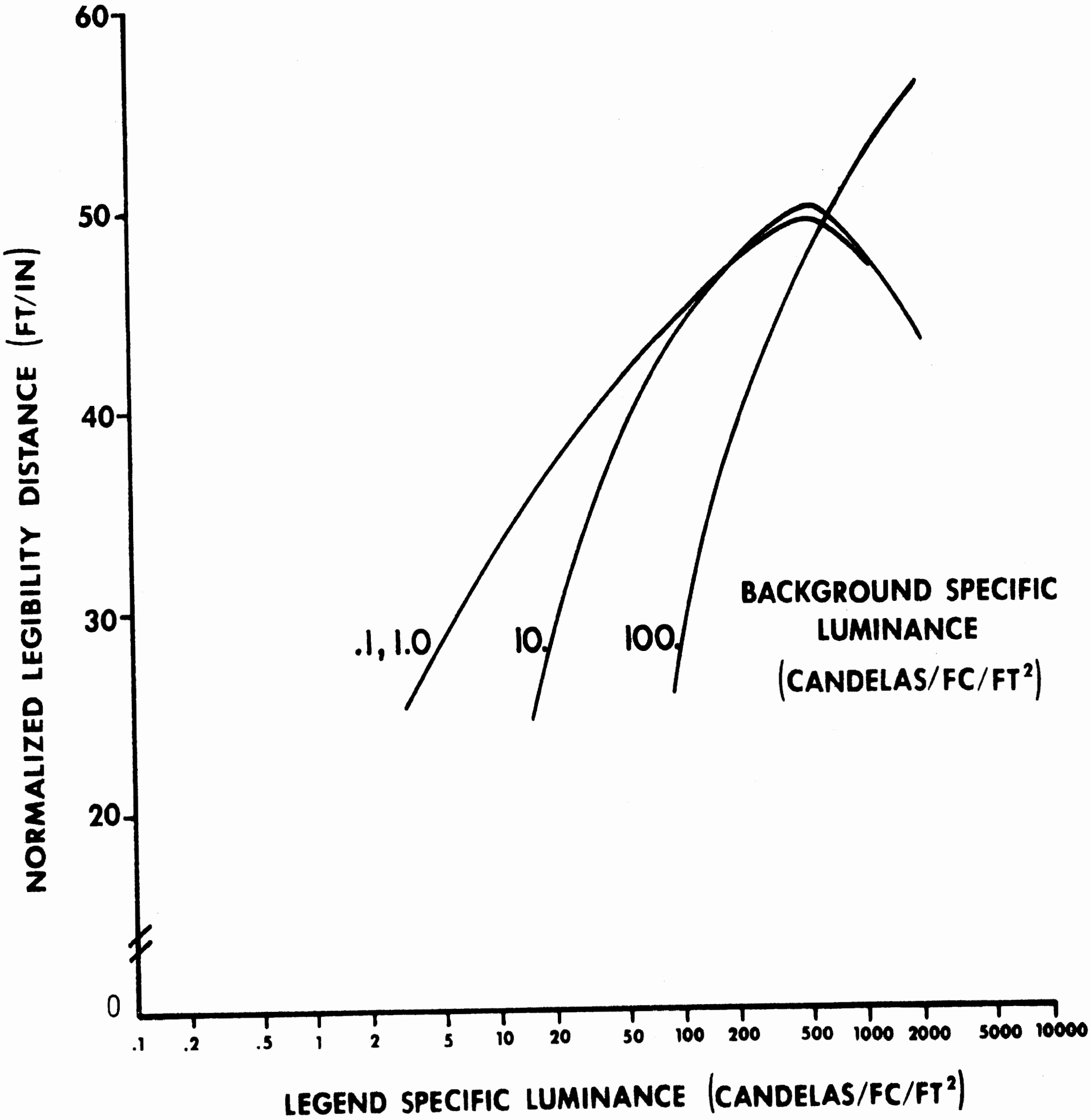

Figure 1. Legibility distance for an overhead sign; low beams; legend 20 ft. above pavement and centered over driver's lane.

TABLE 3. Legibility distance for an overhead sign; low beams; legend 20 ft. above pavement and centered over driver's lane (as described in Figure 1).

LEGEND SPECIFIC LUMINANCE (cd/ft-c/ft^2)	BACKGROUND SPECIFIC LUMINANCE (cd/ft-c/ft^2) Non-Ref.	5	10	30	50	100	150	250
Non-Reflective	--	28	33	39	42	45	47	48
10	33	28	--	--	--	--	--	--
20	38	34	30	--	--	--	--	--
40	42	40	38	28	--	--	--	--
70	43	42	42	35	33	--	--	--
100	45	44	44	39	37	--	--	--
150	47	47	47	43	42	37	--	--
250	48	48	48	46	45	41	--	--
500	49	50	50	51	51	48	--	--
1000	48	48	48	52	53	53	--	--

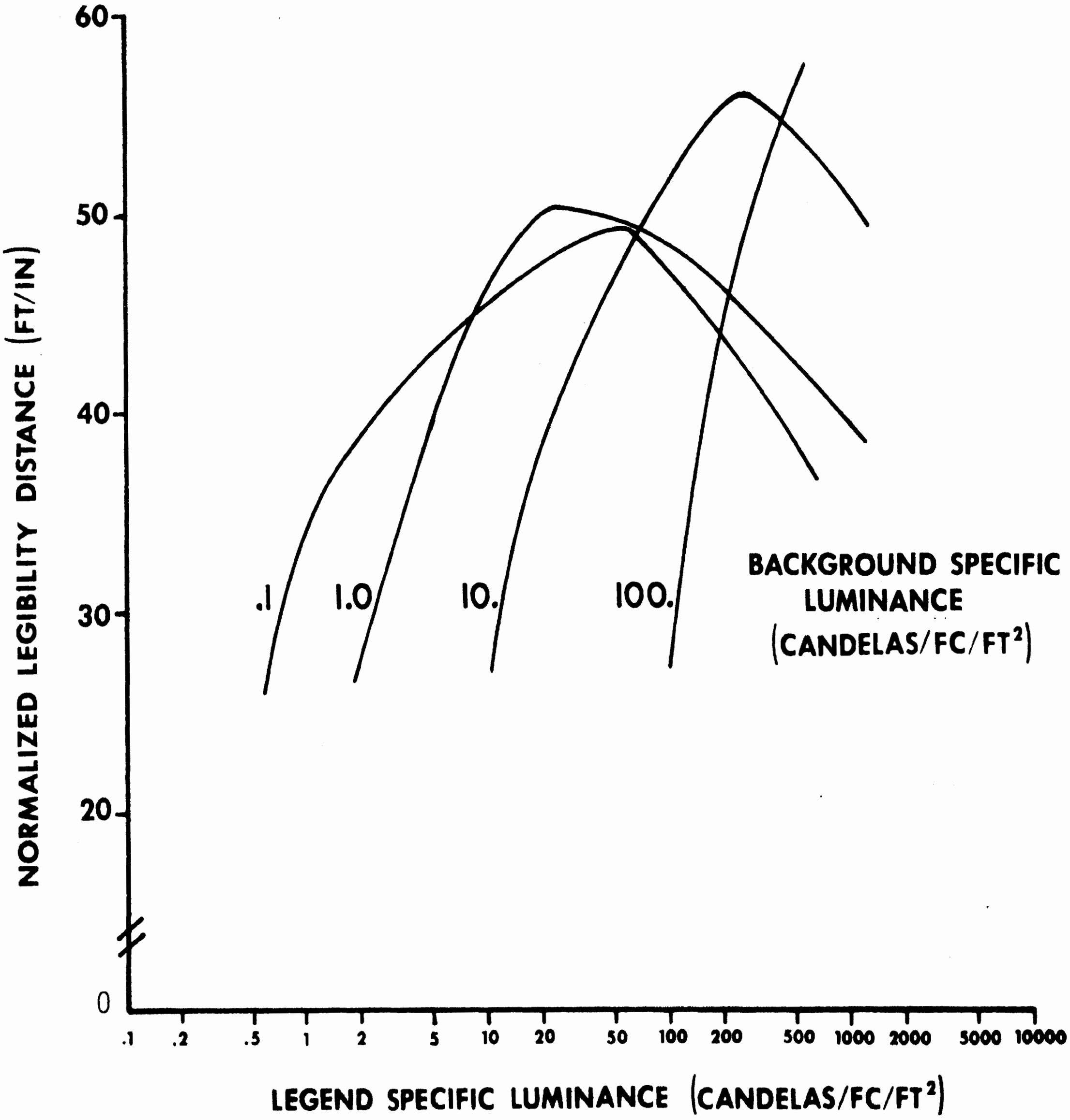

Figure 2. Legibility distance for an overhead sign; high beams; legend 20 ft. above pavement and centered over driver's lane.

TABLE 4. Legibility distance for an overhead sign; high beams; legend 20 ft. above pavement and centered over driver's lane (as described in Figure 2).

LEGEND SPECIFIC LUMINANCE ($cd/ft\text{-}c/ft^2$)	BACKGROUND SPECIFIC LUMINANCE ($cd/ft\text{-}c/ft^2$) Non-Ref.	5	10	30	50	100	150	250
Non-Reflective	--	43	46	48	49	47	44	43
10	46	37	--	--	--	--	--	--
20	48	43	39	--	--	--	--	--
40	49	50	46	33	--	--	--	--
70	48	53	50	42	35	--	--	--
100	47	55	52	45	41	--	--	--
150	44	55	54	50	47	41	--	--
250	42	53	56	54	52	53	--	--
500	38	50	54	58	59	56	--	--
1000	--	46	51	55	57	--	--	--

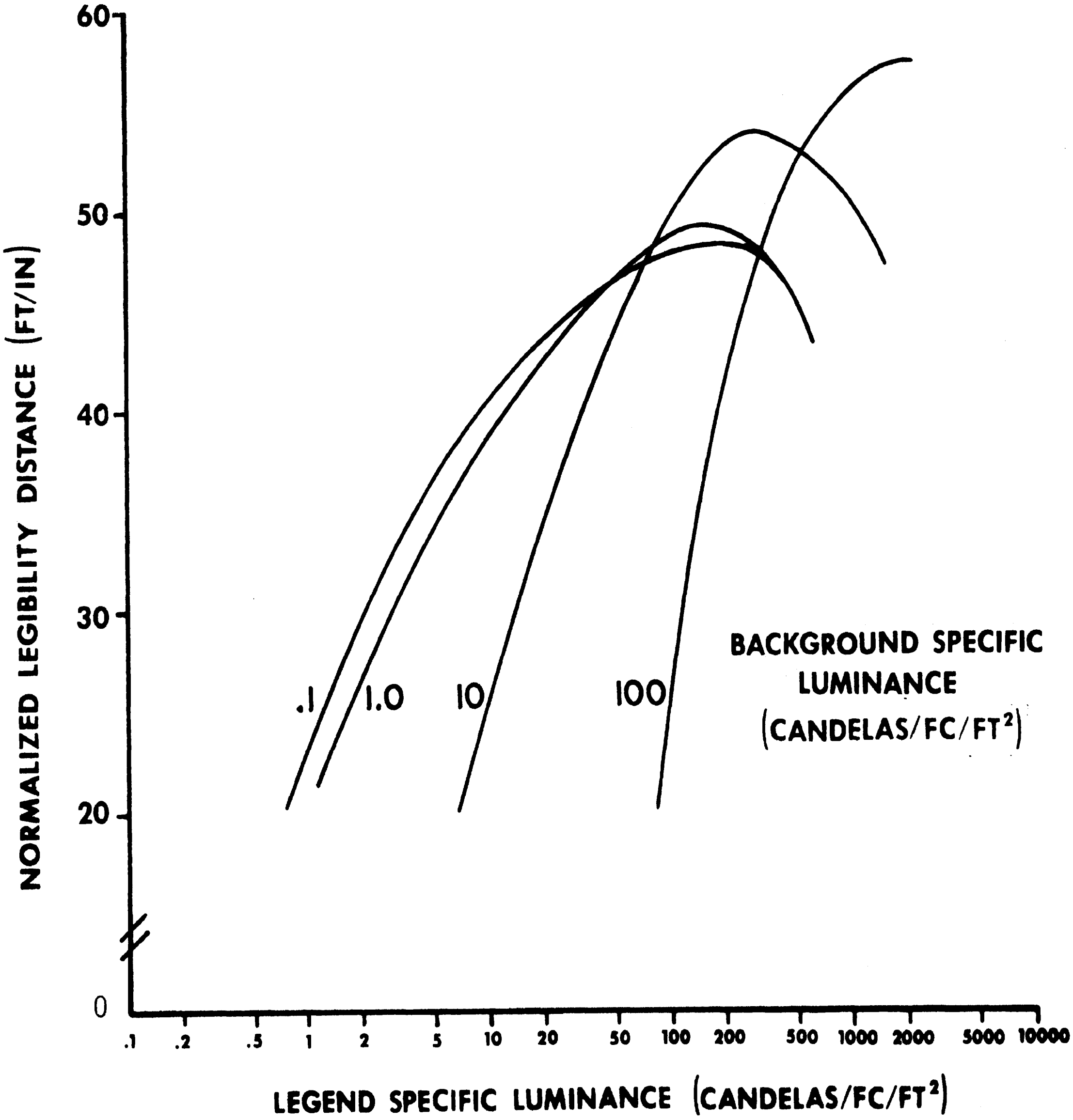

Figure 3. Legibility distance for a roadside sign; low beams, legend 12 ft. to the right of the pavement edge, 8 ft. above the pavement.

TABLE 5. Legibility distance for a roadside sign; low beams, legend 12 ft. to the right of the pavement edge, 8 ft. above the pavement (as described in Figure 3).

LEGEND SPECIFIC LUMINANCE ($cd/ft\text{-}c/ft^2$)	BACKGROUND SPECIFIC LUMINANCE ($cd/ft\text{-}c/ft^2$)							
	Non-Ref.	5	10	30	50	100	150	250
Non-Reflective	--	37	41	45	47	48	48	48
10	41	34	--	--	--	--	--	--
20	44	41	35	--	--	--	--	--
40	47	47	43	30	--	--	--	--
70	48	50	48	40	37	--	--	--
100	48	51	50	43	42	--	--	--
150	48	52	53	48	48	38	--	--
250	48	52	54	52	52	44	--	--
500	46	50	53	55	56	53	--	--
1000	--	47	50	54	56	57	--	--

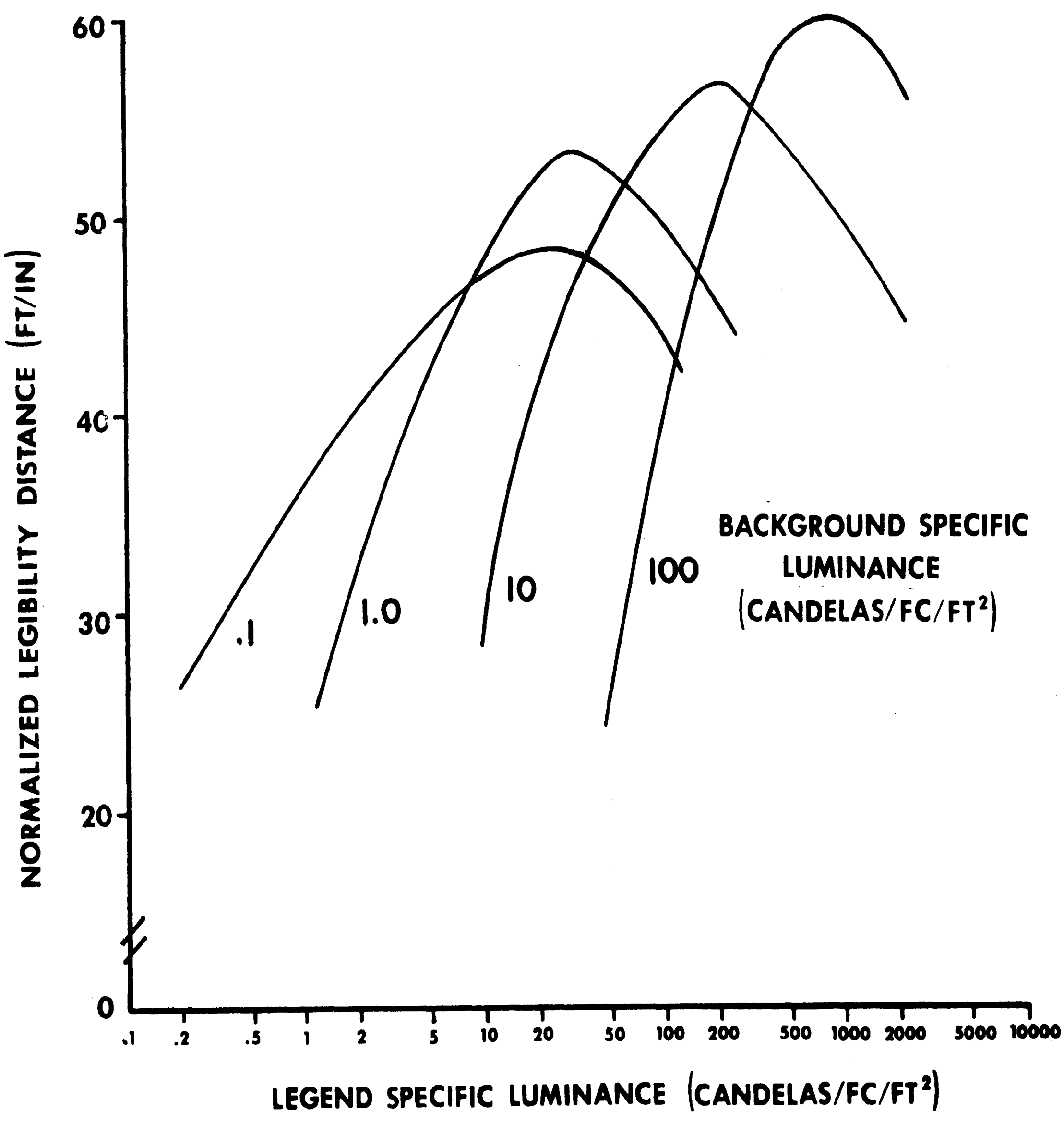

Figure 4.. Legibility distance for a roadside sign; high beams, legend 12 ft. to the right of the pavement edge, 8 ft. above the pavement.

TABLE 6. Legibility distance for a roadside sign; high beams, legend 12 ft. to the right of the pavement edge, 8 ft. above the pavement (as described in Figure 4).

LEGEND SPECIFIC LUMINANCE ($cd/ft\text{-}c/ft^2$)	BACKGROUND SPECIFIC LUMINANCE ($cd/ft\text{-}c/ft^2$)							
	Non-Ref.	5	10	30	50	100	150	250
Non-Reflective	--	44	47	48	47	43	--	--
10	47	41	--	--	--	--	--	--
20	48	48	42	--	--	--	--	--
40	47	52	49	40	--	--	--	--
70	45	53	53	48	47	--	--	--
100	43	53	54	50	49	--	--	--
150	40	54	57	54	54	48	--	--
250	--	53	57	57	57	52	--	--
500	--	49	53	58	59	59	--	--
1000	--	54	49	55	56	60	--	--

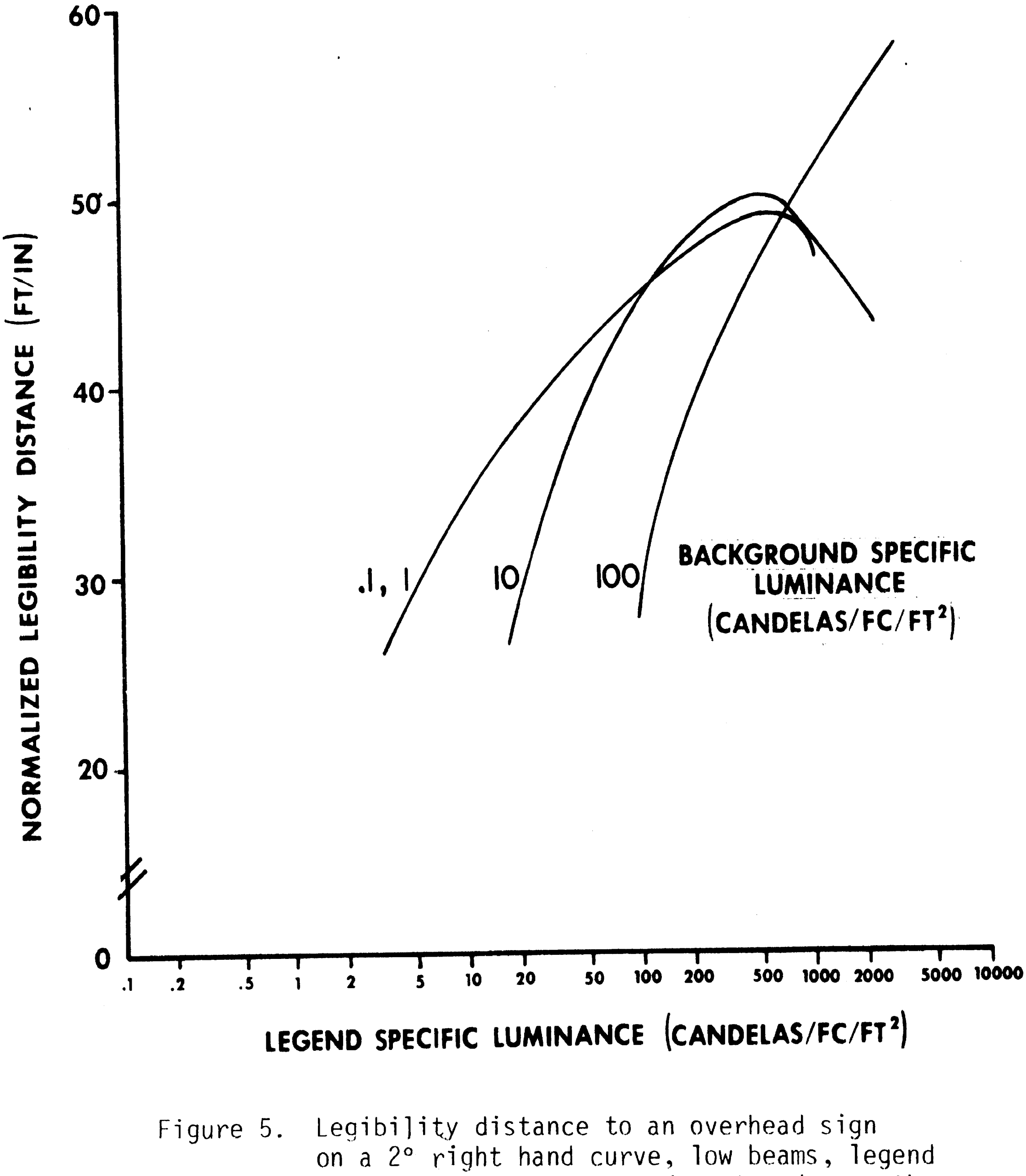

Figure 5. Legibility distance to an overhead sign on a 2° right hand curve, low beams, legend 20 ft. above pavement and centered over the driver's lane.

TABLE 7. Legibility distance to an overhead sign on a 2° right hand curve, low beams, legend 20 ft. above pavement and centered over the driver's lane (as described in Figure 5).

LEGEND SPECIFIC LUMINANCE (cd/ft-c/ft^2)	BACKGROUND SPECIFIC LUMINANCE (cd/ft-c/ft^2)							
	Non-Ref.	5	10	30	50	100	150	250
Non-Reflective	--	30	35	40	43	45	47	48
10	34	30	--	--	--	--	--	--
20	38	36	29	--	--	--	--	--
40	42	40	38	27	--	--	--	--
70	44	43	42	37	36	--	--	--
100	45	45	44	39	38	--	--	--
150	47	47	47	43	43	37	--	--
250	48	48	48	46	46	40	--	--
500	49	49	50	51	51	47	--	--
1000	48	48	47	52	53	52	--	--
2000	--	--	44	50	51	55	--	--

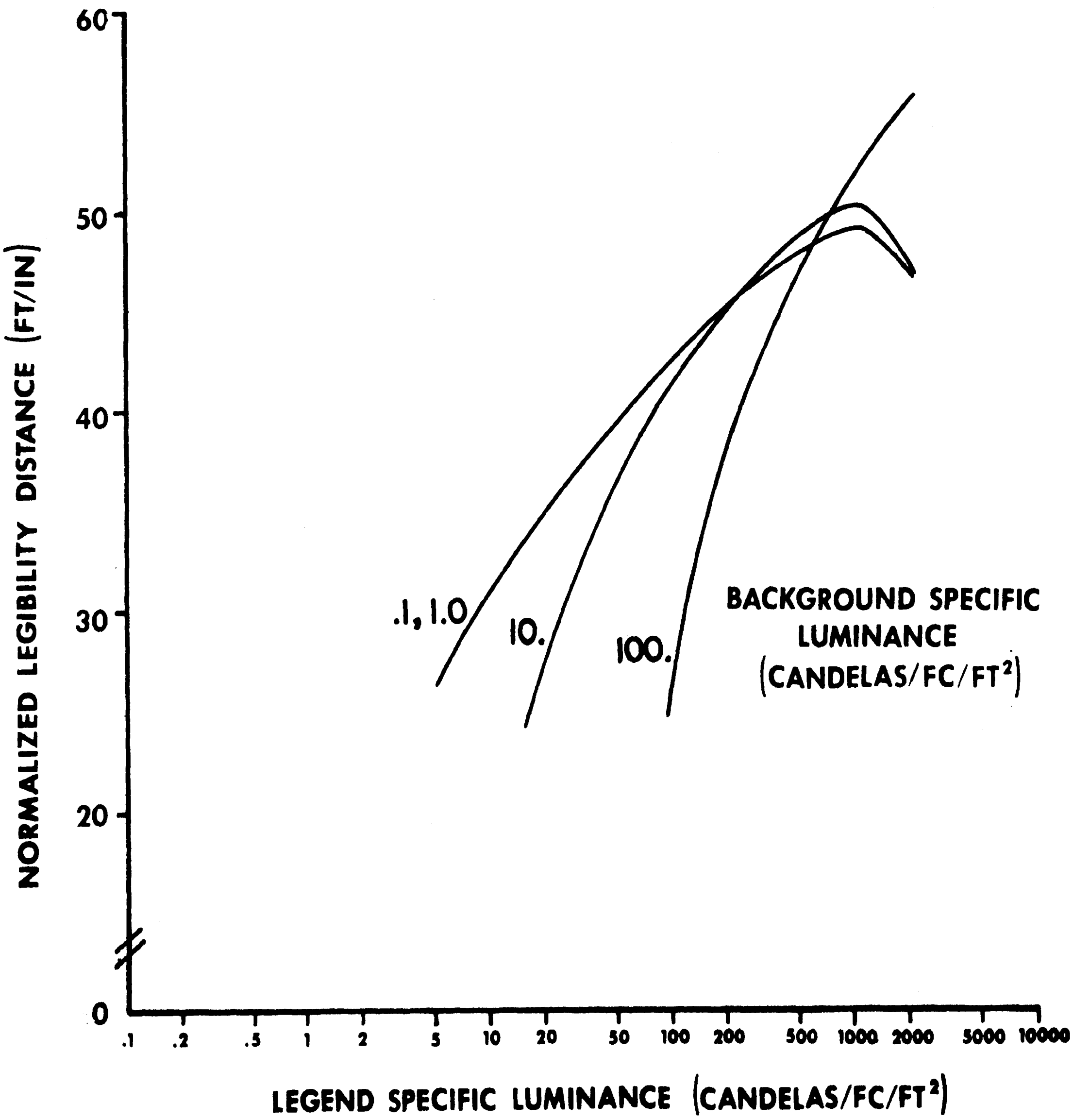

Figure 6. Legibility distance for an overhead sign on a 2° left hand curve, low beams, legend 20 ft. above the pavement and centered over the driver's lane.

TABLE 8. Legibility distance for an overhead sign on a 2^{0} left hand curve, low beams, legend 20 ft. above the pavement and centered over the driver's lane (as described in Figure 6).

LEGEND SPECIFIC LUMINANCE ($cd/ft\text{-}c/ft^2$)	BACKGROUND SPECIFIC LUMINANCE ($cd/ft\text{-}c/ft^2$)							
	Non-Ref.	5	10	30	50	100	150	250
Non-Reflective	--	26	32	37	40	43	44	46
10	32	25	--	--	--	--	--	--
20	35	32	28	--	--	--	--	--
40	39	38	36	25	--	--	--	--
70	42	42	40	33	32	--	--	--
100	43	43	42	37	37	--	--	--
150	44	44	43	42	42	36	--	--
250	46	46	46	44	44	40	--	--
500	48	48	49	49	49	47	--	--
1000	49	50	51	52	52	52	--	--
2000	47	47	47	51	52	56	--	--

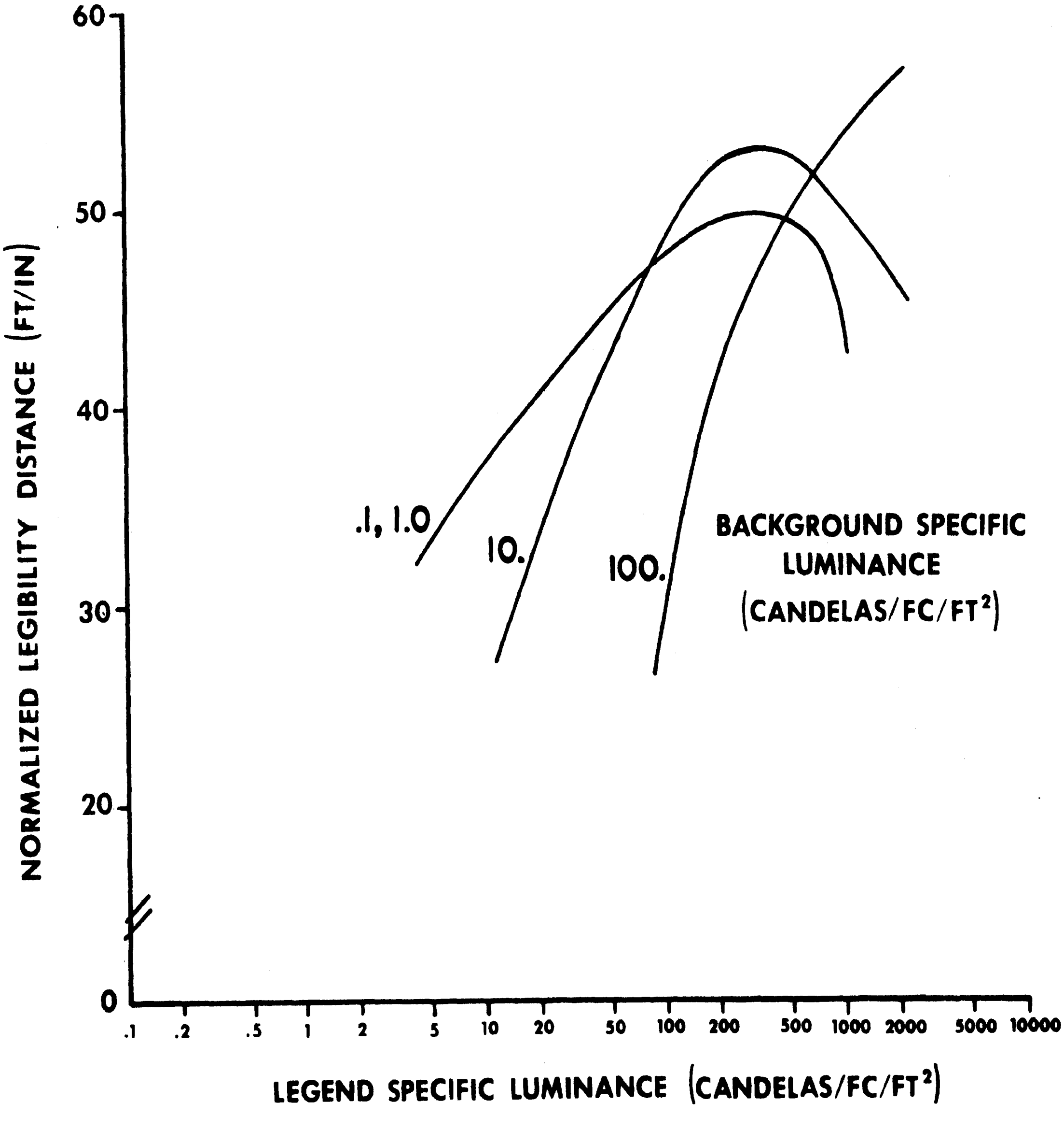

Figure 7. Legibility distance for a roadside sign; 2° right hand curve, low beams, legend 12 ft. to the right of the pavement edge, 8 ft. above the pavement.

TABLE 9. Legibility distance for a roadside sign; 2^0 right hand curve, low beams, legend 12 ft. to the right of the pavement edge, 8 ft. above the pavement (as described in Figure 7).

LEGEND SPECIFIC LUMINANCE ($cd/ft\text{-}c/ft^2$)	BACKGROUND SPECIFIC LUMINANCE ($cd/ft\text{-}c/ft^2$) Non-Ref.	5	10	30	50	100	150	250
Non-Reflective	--	33	37	42	45	48	49	49
10	37	32	--	--	--	--	--	--
20	41	38	34	--	--	--	--	--
40	44	43	42	32	--	--	--	--
70	47	48	47	38	37	--	--	--
100	48	49	49	43	42	--	--	--
150	49	51	52	47	47	40	--	--
250	49	52	53	50	50	43	--	--
500	49	51	53	53	54	50	--	--
1000	44	48	50	54	54	54	--	--
2000	--	43	46	51	52	57	--	--

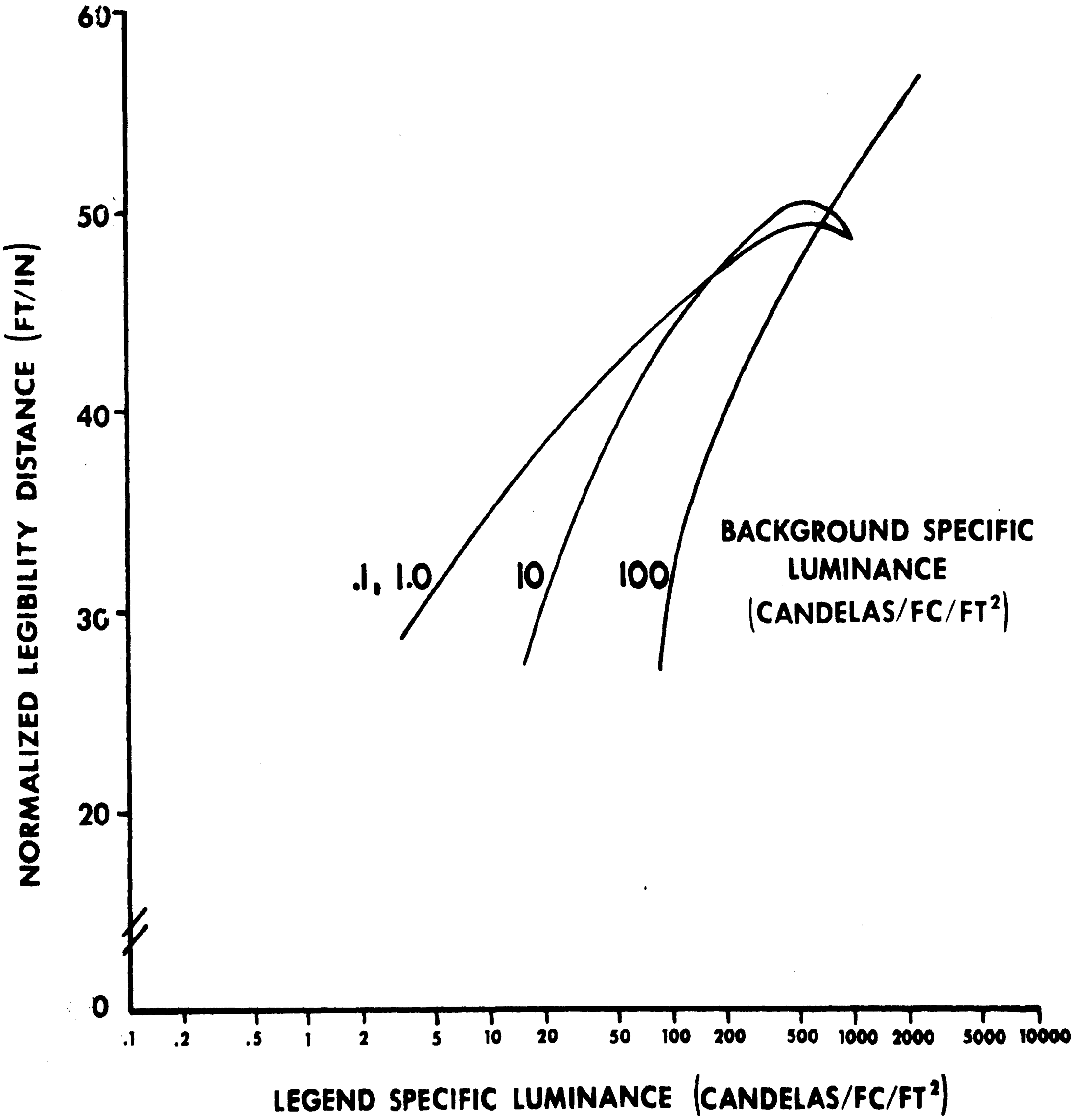

Figure 8. Legibility distance for a roadside sign; 2° left hand curve, low beams, legend 12 ft. to the right of the pavement edge, 8 ft. above the pavement.

TABLE 10. Legibility distance for a roadside sign; 2^{o} left hand curve, low beams, legend 12 ft. to the right of the pavement edge, 8 ft. above the pavement (as described in Figure 8).

LEGEND SPECIFIC LUMINANCE ($cd/ft\text{-}c/ft^2$)	BACKGROUND SPECIFIC LUMINANCE ($cd/ft\text{-}c/ft^2$) Non-Ref.	5	10	30	50	100	150	250
Non-Reflective	--	32	35	40	43	45	47	48
10	35	29	--	--	--	--	--	--
20	38	36	31	--	--	--	--	--
40	42	41	38	28	--	--	--	--
70	44	44	43	37	34	--	--	--
100	45	45	44	40	38	--	--	--
150	47	48	47	43	42	38	--	--
250	48	48	48	46	45	41	--	--
500	49	50	51	50	50	47	--	--
1000	48	48	48	52	52	52	--	--
2000	--	--	--	52	53	56	--	--

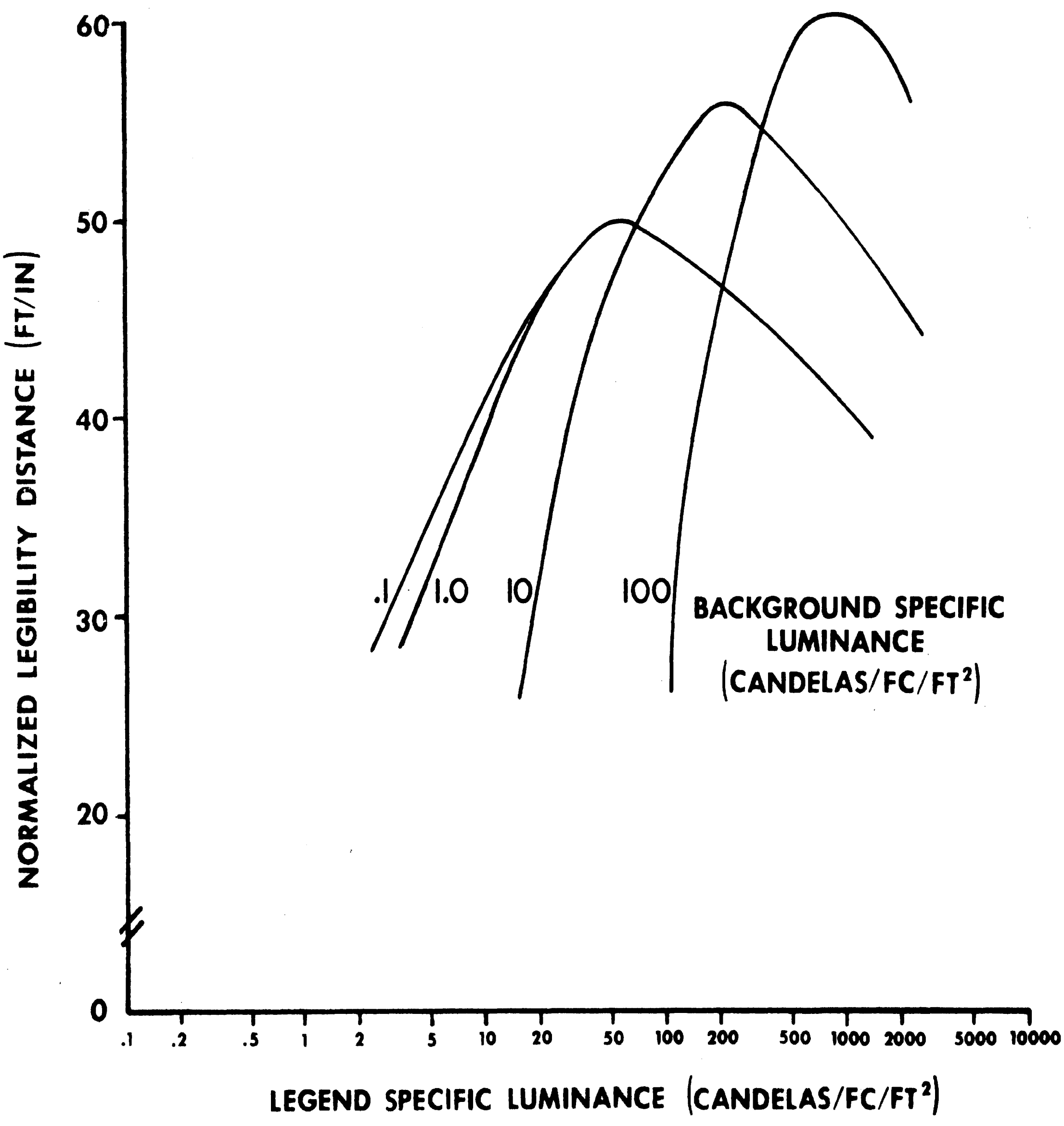

Figure 9. Legibility distance for an overhead sign on a tangent, crest (A = 8%), low beams, legend 20 ft. above pavement and centered over the driver's lane.

TABLE 11. Legibility distance for an overhead sign on a tangent, crest (A = 8%), low beams, legend 20 ft. above pavement and centered over the driver's lane (as described in Figure 9).

LEGEND SPECIFIC LUMINANCE ($cd/ft\text{-}c/ft^2$)	BACKGROUND SPECIFIC LUMINANCE ($cd/ft\text{-}c/ft^2$) Non-Ref.	5	10	30	50	100	150	250
Non-Reflective	--	35	42	48	50	49	47	46
10	42	30	--	--	--	--	--	--
20	46	42	33	--	--	--	--	--
40	49	50	45	26	--	--	--	--
70	49	53	52	43	40	--	--	--
100	48	54	53	47	45	--	--	--
150	47	53	55	53	51	42	--	--
250	46	53	56	55	54	48	--	--
500	43	50	53	58	58	59	--	--
1000	41	46	50	57	58	61	--	--
2000	--	--	45	53	55	57	--	--

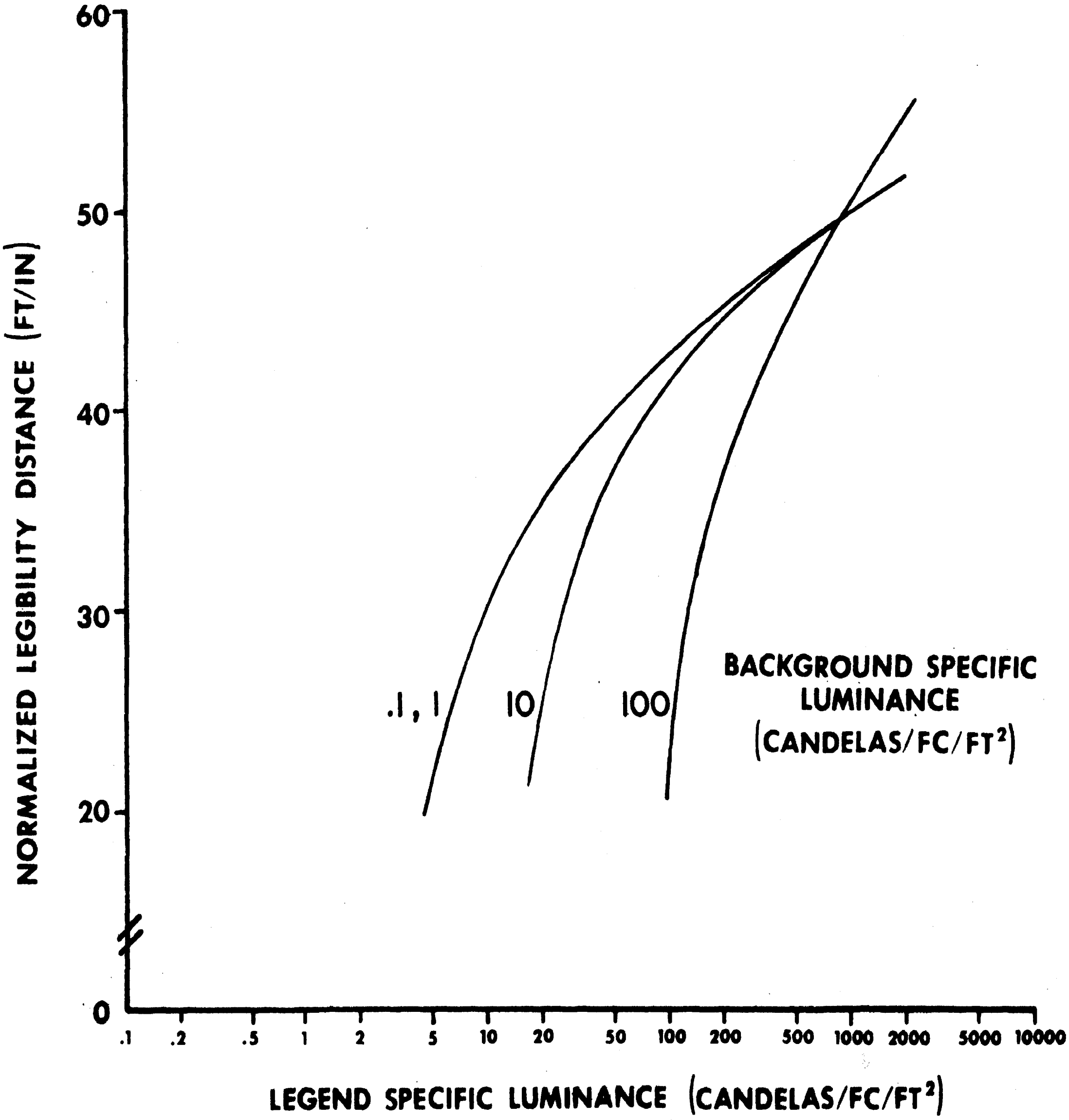

Figure 10. Legibility distance for an overhead sign for a tangent, sag (A = 8%), low beams, legend 20 ft. above pavement and centered over the driver's lane.

TABLE 12. Legibility distance for an overhead sign for a tangent, sag (A = 8%), low beams, legend 20 ft. above pavement and centered over the driver's lane (as described in Figure 10).

LEGEND SPECIFIC LUMINANCE ($cd/ft\text{-}c/ft^2$)	BACKGROUND SPECIFIC LUMINANCE ($cd/ft\text{-}c/ft^2$) Non-Ref.	5	10	30	50	100	150	250
Non-Reflective	--	22	31	38	40	43	44	46
10	31	22	--	--	--	--	--	--
20	36	32	25	--	--	--	--	--
40	40	39	36	22	--	--	--	--
70	42	41	40	33	32	--	--	--
100	43	42	42	36	35	--	--	--
150	44	43	43	40	40	34	--	--
250	46	46	46	43	43	38	--	--
500	48	48	48	47	47	45	--	--
1000	50	50	50	51	51	50	--	--
2000	52	52	52	53	54	55	--	--

CHAPTER 3

INTERPRETATION, APPRAISAL, APPLICATION

INTRODUCTION

Chapter 2 presented basic data describing the relationship between sign luminance characteristics and legibility. This chapter will provide guidelines for use of retroreflective materials based on the information presented in Chapter 2. The purpose is not only to draw inferences from the data, but to suggest various ways in which the data can be used.

THE SELECTION OF SIGNING MATERIALS

Background Materials. An inspection of individual figures in Chapter 2 might well create the impression that the background has little effect on sign legibility. Recall that each figure is for a very specific combination of circumstances in terms of position, road alignment and viewing conditions (single car, high or low beam). While the geometric factors do not change for a given sign, viewing conditions can and do, over wide ranges. In addition, it is probably impractical to custom design individual signs to the specific conditions of their setting. Thus, there are strong reasons to select signing materials which will provide good performance wherever placed and under all viewing conditions. This requires consideration of many if not all the figures in the set presented in Chapter 2. If this is done it will be seen that the background of a sign can have considerable effect on legibility.

By way of illustration, consider Table 13. The data for this table are drawn from Tables 3 through 12 in Chapter 2. Three background reflectivity levels are considered, non-reflective, 10 and 30 cd/ft-c/ft^2. These have been taken to illustrate three readily available choices in the present market. The rows of the table are drawn from each figure as labeled so that it is possible to make side by side comparisons of the legibility distances for the same background in different situations.

TABLE 13. Legibility distances (ft/inch letter height) as a function of legend specific luminance for three levels of background reflectivity in ten different signing situations.

	Legend Specific Luminance (cd/ft-c/ft^2)	FIGURE NUMBER 1 Overhead Low Beams	2 Overhead High Beams	3 Roadside Low Beams	4 Roadside High Beams	5 Overhead Right Curve Low Beams	6 Overhead Left Curve Low Beams	7 Roadside Left Curve Low Beams	8 Roadside Right Curve Low Beams	9 Overhead Crest Low Beams	10 Overhead Sag Low Beams
Non-Reflective Background	10	33	46	41	47	34	32	37	35	42	31
	20	38	48	44	48	38	35	41	38	46	36
	40	42	49	47	47	42	39	44	42	49	40
	70	43	48	48	45	44	42	47	44	49	42
	100	45	47	48	43	45	43	48	45	48	43
	150	47	44	48	40	47	44	49	47	47	44
	250	48	42	48	--	48	46	49	48	46	46
	500	49	38	46	--	49	48	49	49	43	48
	1000	48	--	--	--	48	49	44	48	41	50
Background Specific Luminance 10 cd/ft-c/ft^2	20	30	39	35	42	29	28	34	31	33	25
	40	38	46	43	49	38	36	42	38	45	36
	70	42	50	48	53	42	40	47	43	52	40
	100	44	52	50	54	44	42	49	44	53	42
	150	47	54	53	57	47	43	52	47	55	43
	250	48	56	54	57	48	46	53	48	56	46
	500	50	54	53	53	50	49	53	51	53	48
	1000	48	51	50	49	47	51	50	48	50	50
Background Specific Luminance 30 cd/ft-c/ft^2	40	28	33	30	40	27	25	32	28	26	22
	70	35	42	40	48	37	33	38	37	43	33
	100	39	45	43	50	39	37	43	40	47	36
	150	43	50	48	54	43	42	47	43	53	40
	250	46	54	52	57	46	44	50	46	55	43
	500	51	58	55	58	51	49	53	50	58	47
	1000	52	55	54	55	52	52	54	52	57	51

An inspection of Table 13 makes it apparent very quickly that the legend which produces maximum legibility is not the same for all conditions. However, the scatter is much less for the retro-reflective backgrounds. Thus, for a 30 cd/ft-c/ft^2 background, a 500 cd/ft-c/ft^2 legend is the single choice which comes closest to the maximum legibility distance in all cases. For a 10 cd/ft-c/ft^2 background, a 250 cd/ft-c/ft^2 legend seems to be the best choice, if only one legend material is to be used. However, the legibility distances tend to run 2-6% less than with the more reflective background.

If a non-reflective background is being considered, selecting a single legend material is much more difficult. A material in the 250-500 cd/ft-c/ft^2 range is best for most conditions listed, but becomes too bright, with consequent loss of legibility distance, under high beam (or heavy stream traffic) conditions. A better choice might be in the 100-150 cd/ft-c/ft^2 range, but no such materials are currently available. A material having specific luminance of about 70 cd/ft-c/ft^2 is good for conditions where the sign is highly illuminated, but significantly poorer for other conditions.

Clearly, the use of non-reflective backgrounds means that certain viewing conditions will result in significant reductions in legibility distance regardless of what legend materials are selected. Because of this characteristic, the only way to use a non-reflective background and be sure of obtaining legibility distance at least equal to that provided by reflective backgrounds under all conditions is by increasing legend size. As an example, if an overhead sign is to be placed on a tangent, constant grade and be legible at 800 feet (columns 1 and 2), this would require a 16 inch legend for the reflective signs (30 background, 500 legend and 10 background, 250 or 500 legend) and an 18 inch legend for the non-reflective sign (using a 70 or 250 legend). Use of a button legend (500 cd/ft-c/ft^2 is a good approximation) or a non-reflective background would require at least a 20 inch legend to provide 800 feet legibility because of the relatively poor performance of the combination under conditions of high illuminance (38 ft/inch letter height on high beams as compared with 49 ft/inch letter height on low beams).

The reason for the greater spread of optimums in the case of the non-reflective background lies in the fact that legibility is largely determined by luminance contrast. With a retroreflective background, luminance contrast remains constant. It is true that optimum contrast changes with luminance level, going down as luminance increases, but this is not a major effect. With a non-reflective background, contrast changes directly with illuminance (at least so far as the eye is concerned). Since the range of optimum contrast is narrow relative to the range of illuminance conditions arising from changes in headlamp beams or traffic density. there are substantial changes in the legend specific luminance associated with peak performance under different conditions.

The cautions just noted concerning the use of non-reflective backgrounds do not apply to installations in well-lighted areas since, as has been pointed out earlier, one of the effects of high surround luminance is to reduce the detrimental effect of excessive legend luminance contrast. If non-reflective backgrounds are planned for use in a well-illuminated environment, as on some urban freeways, the data describing high beam viewing conditions should be ignored and the legend specific luminance based on the low beam viewing conditions.

The discussion to this point has been largely relevant to signs with white legends. However, the problems which are associated with non-reflective backgrounds also apply to signs using black legends. Table 14 has been prepared to illustrate this point.

Table 14 is made up of the data for non-reflective legends from the four figures in Chapter 2 which pertain to roadside signs. Clearly, no background specific luminance level is associated with optimum legibility in all cases. A few special points should be noted with regard to black legend signs however:

TABLE 14. Legibility distances (ft/inch letter height) as a function of background specific luminance for signs having black legends in four different signing situations.

Background Specific Luminance ($cd/ft\text{-}c/ft^2$)	Figure Number 3 Roadside Low Beams	4 Roadside High Beams	7 Roadside Left Curve Low Beams	8 Roadside Right Curve Low Beams
5	37	44	33	32
10	41	47	37	35
30	45	48	42	40
50	47	47	45	43
100	48	43	48	45
150	48	--	49	47
250	48	--	49	48
500	46	--	49	49
1000	--	--	44	48

1. Many of these are symbol signs (especially the yellow and orange series). The legibility data developed in this study are not relevant to symbol signs. Conspicuity, which is largely determined by luminance, is very important to symbol signs.

2. Even for word signs in the yellow and orange series, conspicuity is very important. Thus, high luminance may be favored, especially since legibility can be changed in other ways (e.g., increasing legend size).

3. Many black legend signs are small and designed for relatively short legibility distances. This means that incidence and divergence angles larger than -4° and 0.2° should be considered in using the predictive legibility distance data.

Given that black legend signs force a choice between conspicuity and legibility, recommendations for materials are more difficult. In general, for yellow and orange series signs, conspicuity should be favored and highly reflective materials would have considerable merit. This would be particularly true for symbol signs, but would also apply to word signs. Legibility would be of more concern with white background signs and highly reflective materials would probably be a poor choice for signs designed to be viewed at fairly long distances in a dark surround (highway speed limit signs, for example). On the other hand, highly reflective materials would work well in an illuminated surround, or where conspicuity is judged to be very important, or where the placement of the sign indicates that relatively large incidence and divergence angles would apply.

In sum, sign backgrounds have a substantial effect on sign legibility and the choice is an important one to a traffic engineering agency. From a legibility point of view, reflectorized backgrounds are favored. Whether the moderate legibility advantages associated with highly reflective background materials are cost-beneficial requires consideration of other factors such as purchase price, effective life, etc.

Legend Materials. Legend luminance contrast is the most important factor in sign legibility. For signs in dark surrounds it is possible to have too much or too little contrast and the choice of legend is more critical. For signs in highly illuminated surrounds, the low contrast relationship is unchanged but the deleterious effect of high contrast is eliminated.

A substantial amount has already been said about legend reflectivity in the preceding section and there is no point in repeating it here. For most applications there is a substantial range of near-optimum legend specific luminances and one or more materials can be found within that range. If a single material must do for all applications, the choice is much narrower, as noted earlier.

There are some points regarding legend choices which should be noted:

1. Using legends and backgrounds from the same family of materials will produce luminance contrast below optimum. For example, for a white on green sign, a common material has a specific luminance of 10 cd/ft-c/ft^2 in green and 70 cd/ft-c/ft^2 in white (manufacturer's specifications). Referring to Table 13, such a combination would result in legibility distances 10-15% below what is possible with other legend materials.

2. The data are based on the use of manufacturer's specifications, which represent minima. Although there can be a substantial range of specific luminances from sample to sample of "identical" materials, this will not seriously affect predicted legibility distance, so long as the combinations elected are in the optimum range. However, especially in the low contrast range, chance variations in specific luminance can have a much greater effect on actual luminance contrast and, hence, on legibility

distance. This is a further reason for avoiding low contrast combinations.

3. Where a material choice is possible in the optimum range, consideration should be given to the more reflective product. It will be recalled that the data are based on young, normal subjects. Additional luminance contrast will aid older drivers and those afflicted with low contrast acuity problems.

4. If possible, the legend material should be chosen to decay more slowly than the background. This will result in an increase in legend luminance contrast as the sign ages. As has already been noted, less reflective backgrounds require more luminance contrast to achieve legibility distance comparable to highly reflective backgrounds. The loss in legibility distance normally associated with the decay of signing material can be minimized if the legend luminance contrast increases as the background becomes less reflective. This will increase the effective life of the sign.

MAINTENANCE AND REPLACEMENT OF RETROREFLECTIVE SIGNS

As it is possible to predict the legibility of new signs, it is possible to predict changes in legibility over time associated with dirt build up and/or aging effects, <u>if</u> photometric data are available.

For example, consider an overhead guide sign on a tangent, constant grade (Figure 1, Table 3). Suppose the sign uses a 10 cd/ft-c/ft^2 background and a 70 cd/ft-c/ft^2 legend in 16 inch size. The data suggest that, new, this sign would have a legibility distance of 672 feet. If photometric data indicated that, after a period of time, the specific luminance had dropped by 50%, would this indicate a need for cleaning or replacement? In Table 3, values of 5 for the background and 35 for the legend would result in an expected legibility distance of about 610 feet. Whether this 10%

reduction in legibility distance warrants cleaning, refurbishing or replacement depends on whether engineering persons involved think 610 feet adequate legibility for that situation. Presumably it would be wise to design signs with substantially more than a 10% margin of excess legibility distance.

If the same sign were to decay to the point where the specific luminances were 1/10th the new values, this would result in a legibility distance of about 480 feet. Again, whether this is satisfactory performance depends on the expectancies of the persons responsible. However, it should be noted that by the time a sign has decayed to this point, not only has legibility dropped substantially but conspicuity and the effect of color coding have been greatly reduced as well. These are additional considerations in decisions concerning the adequacy of a sign.

Unfortunately, decisions such as those outlined are complicated at this time by an almost total lack of systematic, time-related, photometric data on sign materials. It will be necessary for the interested traffic engineering agency to develop their own data. The process need not be complicated. A small sample of signs can be selected for regular photometric checks and the changes in legibility distance plotted as a function of time. These data can be used to infer to all signs in the system. There are presently available convenient and accurate instruments which make it possible to develop such a data base at low cost.

Information relating legibility to photometric characteristics is a substantial aid in decisions regarding sign cleaning, etc. However, firm decisions regarding the minimum performance level considered acceptable depend on a number of considerations. The following are offered as guidelines:

1. The minimum legibility distance can be based on consideration of the amount of time required to read the message.

Moore and Christie (1963) found reading times equal to:

$$N/3 + 2 \text{ seconds}$$

where N = the number of words on the sign.

Assuming an 85th percentile speed of 100 ft/sec, this means a sign having 6 words should have a minimum legibility distance of 400 feet. This formula indicates a minimum distance to read the sign; greater distance may be advisable if the sign is close to a maneuver point.

2. When background specific luminance reaches a level of about 1 cd/ft-c/ft^2 color definition is largely lost, especially on overhead signs with low traffic density. Poor conspicuity results as well. It is advisable to replace materials which have degraded to this extent, even if they still offer adequate legibility distance by the measure indicated in 1.

OTHER SIGN POSITIONS

The position indicated for the roadside sign in the predictive legibility distance curves (12 feet [3.7 metres] from the edge of the pavement) is fairly close to the road for large signs. Placements up to 30 feet (9.14 metres) from the edge of the pavement are common. Heights above the roadway greater than 8 feet (2.44 metres) are also encountered. Either situation would reduce the amount of illumination reaching the sign to some extent. An overhead sign represents a worst case in terms of illumination, since low beam headlamps, by design, project relatively little light above the horizontal, especially to the left and center. In the case of large freeway signs, increasing lateral offset from the 12 feet (3.7 metres) given in the curves to 30 feet (0.14 metres) would have a minor effect on sign luminance and, hence, on legibility. Increasing height above the roadway would have a greater effect. The following guidelines should be considered:

1. For lateral offsets greater than 20 feet (6 metres), the use of a more highly reflective legend material would be

beneficial, if it is still in the optimum range defined by the appropriate table in Chapter 2.

2. Any sign 15 feet (4.6 metres) or more above the road surface should be treated as an overhead sign for purposes of material selection.

CORRECTION FOR STREAM TRAFFIC EFFECTS

Youngblood and Woltman (1976) reported that, in dense traffic, sign luminance might increase by as much as eight times over a single car--low beam situation. As it happens, this is close to the change in luminance associated with switching from low to high beams. Thus, high beam data (Figure 2 and 4) can be used to approximate heavy stream traffic effects under some conditions. Note however, that this effect is most pronounced at viewing distances of 1000 feet (305 metres) or more and drops off rapidly at shorter distances. Indications are that at 600 feet (183 metres) luminance might be increased by a factor of four and the difference is negligible at 300 feet (91 metres). The effect also depends on sign position. It is maximum for overhead signs on the oberver's left and is minimal for roadside signs.

Alternatively, both legend and background specific luminance values can be increased by the multiplier judged appropriate. For example, if a sign has a background specific luminance of 10 cd/ft-c/ft^2 and a legend specific luminance of 70 cd/ft-c/ft^2 and it is thought that stream traffic conditions for the road in question might increase luminance by a factor of 4, treat the specific luminance values as 40 and 280 and consult the appropriate figure or table. Thus, if a sign such as described in Figure 1 were under consideration, single car low beam legibility would be estimated as 43 ft/inch letter height. Under stream traffic conditions legibility would be expected to increase to 46-47 ft/inch letter height. It should be noted that legibility distance will not always improve under stream traffic conditions, especially if non-reflective backgrounds are in use.

CORRECTIONS FOR BACKGROUND COLOR

The specifications provided are for white on green configurations. The results of the laboratory investigation (Appendix B) indicate that the green data apply equally well to blue backgrounds and can be used for either. The laboratory data also indicate that equivalent legibility on a red background requires about double the contrast as on a green or blue. Since red background signs are generally made by silk screening on a white material, greater contrast can only be achieved by using an ink which further reduces the luminance of the red portion. This reduces conspicuity, a poor trade-off, in the opinion of the authors. Given that conspicuity is such an important factor in red background signs, and that color and shape provide redundant information, it is felt that legibility is a minor consideration.

For signs employing non-reflective legends the data pertain to white backgrounds. A white background requires somewhat less luminance to achieve the same legibility distance as either yellow or orange (see Figure B-15). However, the differences are not such as to result in a large difference in legibility. In general, using white background data for yellow or orange signs will result in a 5-10% overestimate of legibility distance.

CHAPTER 4

CONCLUSIONS AND SUGGESTED RESEARCH

CONCLUSIONS

In reading the conclusions presented here it is necessary to understand that they are offered in the context of the present investigation. The authors recognize that legibility is determined in part by factors other than those we have included (e.g., letter size, stroke width, spacing). In our opinion these areas have been adequately convered by other researchers. Thus, a statement to the effect that such and such variable is the only factor determining legibility should be understood to mean "of those factors tested."

1. Sign legibility is determined by a variety of factors, among the most important of which are the luminance characteristics.
2. While highly reflective sign backgrounds have the potential of providing somewhat greater legibility distance than non-reflective or moderately reflective backgrounds, any background material is capable of yielding satisfactory legibility distance. The primary differences among backgrounds are in terms of conspicuity, color rendition and ability to maintain maximum legibility distance under a variety of illumination conditions.
3. For signs having white legends, legend luminance contrast is the primary factor in sign legibility. The contrast required for optimum legibility depends on background luminance. In general, the higher the background luminance, the lower the required contrast.
4. Legend luminance is the only factor determining the legibility of signs having non-reflective or black backgrounds. As a result such signs are more sensitive (as measured by changes in legibility distance) to changes in illumination.

5. Background luminance is the primary factor in legibility of signs having black legends. The high luminance levels required for conspicuity and color rendition appear to reduce legibility. For many such signs conspicuity is of primary concern and some loss of legibility can be tolerated. Where legibility is of importance, it is necessary to increase legend size and stroke width as background reflectivity increases.
6. Within a given contrast direction, the differences in legibility associated with background color are relatively small (black background excepted) and of no practical significance.
7. Increasing surround luminance results in improvements in sign legibility, regardless of the material combination used.
8. There are very substantial differences in the ability of different people to read highway signs. These differences are largely independent of their performance on a conventional test for far acuity, such as might be given during a driver's license examination.

SUGGESTED RESEARCH

Certain additional research would add significantly to the value of what has been presented here. A brief description follows:

1. The sign as a disability glare source. As indicated earlier, there would be significant legibility benefits in the use of background materials having reflectivity characteristics greater than is presently available, especially on overhead installations. The limiting factor in the development of such material is the point at which the sign becomes a disability glare source to the driver; that is, when the sign is so bright it makes it difficult to see other roadway features essential to the safe operation of the vehicle. Present materials appear not to pose such a problem and

the research reported here was primarily concerned with presently available materials.

An investigation of disability glare effects would be an appreciable undertaking, as it must consider sign luminance, surround luminance, size, color and relationship to other objects being viewed. Consideration should be given both to the case where the sign has been fixated and where it merely appears in the periphery.

2. Effect of glare sources on sign legibility. While it is true that high surround luminance levels improve sign legibility, such an environment also increases the likelihood of finding glare sources close to a sign. Research on the effect of glare sources on sign legibility would be helpful in that it could (1) form a basis for laws regarding the placement of potential glare sources such as advertising signs near a road and/or (2) provide guidelines for the luminance characteristics of signs positioned near glare sources.
3. Sign legibility for the general driving population. The difference in performance between the various groups of subjects in this investigation was much larger than anticipated. Other research has found no significant link between far acuity and collision involvement. The work reported here indicates that far acuity scores do not necessarily correlate highly with the ability to read road signs at night. Clearly, information of value could be developed in an investigation which was concerned with the determination of the visual requirements for night driving.

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APPENDIX A

REVIEW OF THE LITERATURE

REVIEW OF THE LITERATURE

INTRODUCTION

A substantial number of studies have been reported dealing with the effect of sign luminance on legibility and conspicuity. The bulk of this work has appeared in the last ten years or so, possibly as a response to the problems engineers face in having to choose from an increasing variety of materials. Some measure of the extent of this problem is provided by the results of a survey on the use of retroreflective signing materials by traffic engineering agencies conducted as part of this investigation. The details are provided in Appendix B of this report. Perhaps the most striking finding to emerge from the survey is the great variety of approaches to signing in use today. Not only do different agencies use different material combinations, but they have different policies regarding matters such as illumination, inspection, cleaning and use of restorative processes. In part these differences arise from unique local problems, (climate, budget considerations, etc.) but in part they undoubtedly reflect differences of opinion concerning the subject matter of this investigation.

This review will begin with consideration of the effect of luminance and contrast on sign legibility and will then deal with the topic of sign conspicuity. This is practical because, even though legibility and conspicuity are both influenced by the same variables, they have been treated as separate problems by investigators. Later sections of the review will deal with sign surrounds and environmental effects. (The term "background" has been used to refer to part of the sign itself and to the environment within which the sign is placed. In this report "background" shall mean that portion of the sign to which the legend is fixed and "surround" shall be used to describe the environment which forms the backdrop for the sign.)

LEGIBILITY

A number of methodological approaches have been employed by the various investigators in this problem area. However, all the studies fall into one of four general classifications. Basically, these are as follows:

1. Studies in which the participants subjectively evaluated the adequacy of various configurations.
2. Studies in which various experimental techniques are employed to obtain objective measures of the effect of different levels of luminance and contrast on legibility and/or conspicuity.
3. Studies in which sign luminance is measured under various conditions.
4. Studies in which mathematical models are used to predict sign luminance and/or legibility.

Table A-1 is a brief summary of investigations which have been concerned with the effect of sign luminance characteristics on legibility. These studies will be reviewed in greater detail in the following section.

Apparently, the first published study of sign luminance was reported by Forbes and Holmes (1939). They investigated legibility distance for black-on-white signs as a function of letter series (B and D) and letter height (6 to 24 inches [15 to 61 cm.]). Comparisons were made day and night using reflectorized and illuminated legends. The results, based on 4600 observations by 400 observers, suggested that legibility distances of 50 ft/inch (6 m/cm) letter height were appropriate for day viewing conditions and normal (20/20 [6/6]) vision. The authors state that floodlighting is desirable when the sign is viewed against a lighted surround, and reflectorized letters were found to do as well as floodlighting when the surround was dark. No specific photometric values are provided.

TABLE A-1. Summary of Studies of the Effect of Luminance and Contrast on Sign Legibility.

Author(s)	Year	Technique	Variables	Findings
Allen	1958	Field legibility measurements	Legend & background luminance, letter size, lamp beam, sign position	Best legibility at luminance of 10 ft-L. High beams almost as good as best illuminated sign, low beams were 20-30% less.
Allen & Straub	1955	Field legibility measurements	Ambient lighting, lamp beam and luminance	High ambient: legibility distance increased as lamp output & reflectivity increased. Low ambient: high beams no better than low beams on highly reflective sheeting.
		Laboratory simulation	Luminance, ambient illumination, letter series and contrast direction	Legibility increased with luminance. Low luminance better at low ambient, high luminance better at high ambient levels.
Allen et al.	1966 1967	Field legibility measurements	Luminance, ambient level, contrast, contrast direction, letter height, subject age	Best legibility at 20 ft-L for low and medium ambient. Best legibility at 200 ft-L for high ambient conditions.
Cleveland	1966	Field legibility measurements	Luminance, lamp beam and system, sign and roadway illumination	Legibility distances generally in excess of 50 ft/in. letter height. Best performance by high beams, and illumination by careful placement of roadway luminaires.
Dahlstedt	1974	Laboratory study	Contrast	Optimum luminance at about 20 ft-L. Reduction in legibility at values above and below that point.
Elstad et al.	1962	Analytical plus confirming measurements	Sign position, distance, road geometry, lamp beam	With high beams all materials are close to optimum zone (Allen, 1958). Low beams poorer.
Forbes & Holmes	1939	Field legibility measurements	Letter series and height, luminance, day and night	Legibility distance of 50 ft/in. letter height for normal vision in the day. Floodlighting desirable if surround is illuminated.
Forbes et al.	1975	Laboratory study and field validation	Luminance, color, contrast	Presents family of curves showing relationship of variables under investigation. Legibility distance increases as luminance and contrast increase through range tested.
Hicks	1974	Laboratory simulation	Luminance, lamp beam, level of alcohol	Brighter signs better. Alcohol impaired drivers required brighter signs for equivalent performance.
Hills and Freeman	1970	Laboratory study	Luminance, contrast, color	Provides family of curves showing legibility distance as a function of variables tested. Higher luminance - better performance through all levels tested.
Keese et al. Walton and Rowan	1966 1966 1967 1969	Field legibility measurements	Primarily concerned with fixed illumination, type and mounting height	Mounting height of 40 ft. for luminaires yields best legibility of signs. Signs should be placed in line with and 20-60 ft. beyond luminaires.
King and Lunenfeld	1971	Analytical	Distance, sign position, luminance, lamp beam, road geometry	Developed a model to predict legibility distance. When compared with sample of actual signs the model indicated they were often inadequate.
Powers	1965	Measured errors in driving a test course	Luminance	No significant differences among three levels of reflectorization.
Richardson	1976	Field legibility Measurements	Luminance, color, sign position, headlamp beam	No advantage to high intensity backgrounds. Unit reflector legends best. Opaque backgrounds better with low than high beams. Opposite true for reflective backgrounds.
Rizenbergs	1972	Field observations	Luminance, surround	Use of encapsulated lens materials recommended. Luminance in excess of 20 ft-L reduces legibility. Legibility affected by surround.
Rizenbergs	1974	Field observations. Lab tests	Luminance, durability, cost	Encapsulated lens materials felt to be best over life of sign.
Robertson	1974 1976	Photometry of paired signs	Sheeting materials, illuminated	Encapsulated lens sheeting as good as illuminating on straight road sections. Not as good on curves.
Rumar & Ost	1975	Field legibility measurements	Sign reflectance, headlamp beam, sign illumination, symbol dimensions, and dirt	Recommends highly reflective materials. Dirt effects minimal on illuminated signs.
Smyth	1947	Laboratory simulation	Sign luminance, surround luminance, contrast direction, headlamp glare and dirt	"Ideal" luminance 8-10 ft-L at low surround and 15-30 ft-L at high levels, maximums about 4 times higher. No important effects from glare or dirt.
Straub and Allen	1956	Analytical	Sign position, distance to vehicle, road geometry lamp beam	Presents comparisons of luminance data as a function of variables.
Swezey	1974	Laboratory study	Contrast, from 97 to 34%	Used recall criterion. Significant reductions in performance at lowest contrast level only.
Woltman and Youngblood	1975	Photometric	Lamp beam, sign material, distance, sign position	New mid beam produced luminance equal to old beam for shoulder-mounted signs. Little gain over low beam for overhead-mounted signs, however.
Woltman and Youngblood	1976	Photometric	Number of vehicles, viewing distance and pavement wetness	Stream traffic adds significantly to sign luminance, especially at longer viewing distances. Wet pavement also increases sign luminance.
Woods et al.	1970	Subjective evaluation of existing signs	Luminance, position	Signs should be illuminated. Viewed one section with new encapsulated lens material. Felt it was adequate.
Woods & Rowan	1976	Field legibility measurements	Sign reflectance, mounting height, headlamp beam, sign tilt and speed	Legibility distance less with low beams for highly reflective materials than for illuminated signs. Reflectorized signs felt adequate however.
Youngblood and Woltman	1971	Photometric survey	Distance, sign position, materials, surround, lamp beam	Illuminated legends 10 ft-L or better. High beams produced comparable results with brighter materials. Enclosed lens sheeting measured 1-10 ft-L. Low beams reduced luminance to 1 ft-L or less with all materials.

In the same year Forbes (1939) published what has become a basic paper in the field. The author discusses legibility and conspicuity (the latter is called "attention gaining characteristics" by Forbes). He points out that there are two types of legibility; pure legibility, where reading time is unlimited, and glance legibility, where reading times are short due to the need to time share with other tasks. Forbes' data indicate that legibility distances would be 10-16% less if a glance legibility criterion was used. Conspicuity is divided into target value (the quality of a sign which makes it stand out in competition with other signs and distractions) and priority value (the quality which results in one sign being read first, given equal target values). The characteristics which are associated with high target value are: color contrast, size, simplicity and contrast of layout, placement and luminance. The characteristics which are associated with high priority values are: leftmost or uppermost position, prior position on highway, and nearness of competing signs.

A laboratory investigation which attempted to set luminance specifications for road signs was conducted in England during the war years (Smyth, 1947). The signs were black on white or the reverse. Subjects viewed a simulated road scene at one of four levels of overall luminance to represent various ambient lighting conditions. A simulated sign was presented and the subjects were instructed to adjust the background or legend luminance as appropriate, using one of three criteria as follows:

Criterion "A," the minimum sign luminance at which the legend could be read at a distance of 50 ft/inch (6 m/cm) letter height. To do this, the subject observed the sign continuously until the desired legibility level was reached.

Criterion "B," the maximum luminance acceptable, determined either by the observer's sense of discomfort or by loss of surround detail behind the sign due to glare.

Criterion "C," the "ideal" luminance, determined purely by personal judgment.

In working to criteria B and C the subjects were instructed not to fixate the sign continuously; instead they were to study the simulated road scene and glance at the sign as required in order to make their judgments. Other more limited investigations were conducted in order to assess the effect of headlamps coming toward the observer and dirt obscuring the sign.

The results of the primary investigation indicate that "ideal" luminance for both positive and negative contrast directions ranges from 8-10 ft-L (27-34 cd/m^2) at the lowest surround levels investigated, up to 15-30 ft-L (51-103 cd/m^2) at the highest surround levels. Maximum acceptable luminances are appreciably higher, about four times higher on the average at the lowest surround luminances and about ten times higher at the highest surround luminances. Little effect was noted from oncoming headlights or from accumulations of dirt.

Allen and Straub (1955) have reported the results of two studies. The first was conducted in the field and measured the distance at which subjects could read series C numerals as a function of ambient luminance ("rural intensity" vs. "open road"), headlamp beam (high and low) and sign reflectivity (white paint, beads on paint, moderately reflective and highly reflective sheeting). The results showed steadily increasing legibility distance as headlamp output increased and as sign reflectivity increased for the high ambient condition. However, in the low ambient condition, high beams did not provide better legibility on any of the beaded materials and did no better than low beams on the highly reflective sheeting.

The second study was conducted in a laboratory and varied sign luminance (0.1, 1.0, 10 and 100 ft-L [0.34, 3.43, 34.3 and 343 cd/m^2] for either legend or background, depending on contrast direction) ambient illumination (0.001 and 0.1 ft-candles [0.00009 and 0.009 metre-candles] measured at the subject's eyes), letter series

(A, C and F) and contrast direction (white-on-black and reverse). A tachistoscopic presentation was used (one-second exposure) and subjects were tested to determine the smallest letters they could detect for each combination of variables.

In general it was found that legibility distance increased with sign luminance, although the increase was more marked with the series F letters for the two highest luminance levels. There were slight differences favoring white on black contrast, but only at the 1 and 10 ft-L (3.43 and 34.3 cd/m^2) levels. Ambient illumination interacted with sign luminance, the low luminance signs providing slightly better legibility distance at low ambient levels and high luminance signs producing slightly better legibility distance at high ambient levels.

In an important follow-up to the work just described, Straub and Allen (1956) provide a comprehensive review of then available retroreflective materials. Using isocandela diagrams for headlamps and photometric data for the signing materials, the authors calculated expected luminances for both high and low beams for different sign materials, locations (roadside and overhead), road geometry (straight, vertical and horizontal curves), types of headlamps (4030 and 5040 series) and extent of sign rotation. The results can be compared with equivalent sign legibility data derived from the earlier paper (Allen and Straub, 1955). These data treat luminances from 10-200 ft-L (34.2-686 cd/m^2) as optimum and indicate legend size increases which are required to achieve equivalent legibility for other luminance values. For example, the legend should be about 1.3 times larger at 1 ft-L (3.43 cd/m^2), about 2 times larger at 0.1 ft-L (0.34 cd/m^2), and about 3 times larger at 0.03 ft-L (0.103 cd/m^2).

The results of this study are very complex, but for many materials and conditions high beams produced luminances of 10 ft-L (34.3 cd/m^2) or better. Low beams produced luminances of 1.0 ft-L (3.43 cd/m^2) or better for some materials and conditions but oftentimes the predictions were as low as 0.1 ft-L (0.34 cd/m^2).

Allen (1958) has reported a field study which evaluated legibility distance as a function of legend type (moderately and highly reflective sheeting as well as reflective buttons), letter size (8, 12, 15 and 18 inches [20.3, 30.5, 38.1 and 45.7 cm]), headlamp beam, sign position (overhead and roadside) and sign luminance (0.1, 1.0, 10 and 100 ft-L [0.34, 3.43, 34.3 and 343 cd/m^2] for legend only). Series E letters were used with stroke widths increased to .20 of letter height. Results were compared with daytime visibility. Contrast direction was constant in this study (white on black).

The daytime legibility distances for all letters was 88 ft/inch letter height (10.56 m/cm). The best nighttime legibility distances for the ambient conditions tested (low surround luminance) were obtained at a legend luminance of 10 ft-L (34.3 cd/m^2) and were about 15% less than under day conditions (75 ft/inch letter height [9 m/cm]). Legibility distance using retroreflective letters was about equal to the best illuminated sign when viewed with high beams, but was 15 to 30% less with low beams.

Elstad, Fitzpatrick and Woltman (1962), using an approach similar to that of Straub and Allen (1956), employed a computer program to predict sign luminance at various distances for both high and low beams. These results are compared with the luminance recommendations of Allen (1958). The data suggest that, with high beams, luminance readings are in or close to what Allen defined as the optimum zone for much of the useful range. On the other hand, low beams produce luminance levels ranging from 70 to 90% of optimum. The luminance calculations were verified by field measurements on a sample silver-white sign.

In the same paper the authors report measurements of light falling on signs from ambient sources. In dark rural areas this illumination ranged from zero to 0.1 ft-L (0.34 cd/m^2). In an "illuminated suburban" setting, readings ranged from 0.1 to 0.4 ft-L (0.34 to 1.37 cd/m^2). A test was then conducted to see if a level of

0.1 ft-L (0.34 cd/m^2) made any difference in legibility distance. Forty-five observers participated in this test using 10 different automobiles. Legibility distance for both high and low beams were about 3% greater with the additional illumination.

A field investigation which used a count of errors in locating turn-offs as the dependent variable has been reported by Powers (1965). A total of 150 subjects participated in this test. However, errors were infrequent, totaling only 8.5% of all possible maneuvers, and there were no significant differences in the number of errors associated with any of the three levels of sign reflectorization employed.

Several studies relating to sign legibility have been performed at the Texas Transportation Institute. The most important of these, for purposes of this review, was reported by Cleveland (1966), who investigated reflective button and reflective sheeting legends placed against three types of backgrounds (opaque, and two levels of reflective sheeting). Other variables were the headlamp system (2 or 4 headlamps), headlamp beams (high or low), sign illumination and roadway illumination. The observers (students, no visual acuity noted) rode in slow-moving cars and the distance at which six-letter, pronounceable-place-name legends could be read was noted. For most conditions, the legibility distances were significantly in excess of the 50 ft/inch (6 m/cm) letter height rule of thumb. The best combinations produced legibility distances on the order of 75 ft/inch (9 m/cm) letter height, the worst about 35 ft/inch (4.2 m/cm) letter height. Performance improvements were brought about by illuminating the sign with special fixtures, by placing roadway luminaires in front, near enough to throw some light on the sign face, by using legend materials having greater reflectivity, or through use of high beams. No photometric data were provided.

Other studies reported by the Texas Transportation Institute (Keese, Cleveland and Rowan, 1966, and Walton and Rowan, 1966, 1967, 1969) were primarily concerned with roadway illumination, but considered sign legibility as a criterion. It was found that roadway illumination had a significant effect on sign legibility. A luminaire mounting height of 40 feet yielded lower sign luminance but better legibility distance, due to reduced glare. The authors recommend that signs be placed in line with luminaires and 20 to 60 feet beyond for best legibility distance.

The Texas Transportation Institute has also reported a subjective analysis of roadway problems (Woods, Rowan and Johnson, 1970) in which six individuals with varied training and experience toured a prescribed course to observe problems. In general, the team felt that signs should be illuminated, although one road section which had been signed with highly reflective sheeting material was judged adequate.

An important investigation of sign luminance levels and other factors has been reported by Allen, Smith, Janson and Dyer (1966) and by Allen, Dyer, Smith and Janson (1967). An internally illuminated sign with adjustable intensity was constructed and mounted on a truck for easy removal to the different test areas. The factors investigated were: sign luminance (0.2, 2.0, 20, 200 and 2000 ft-L [0.69, 6.86, 68.6, 686 and 6856 cd/m^2]), ambient illumination (dark road, lighted street and very bright downtown street), contrast (100% and 75%), contrast direction (white-on-black and reverse), letter height (13.3, 10 and 7 inches [33.8, 25.4 and 17.8 cm]) and subject age (18-37, 38-57, and 58 and older) with 15 subjects in each group. Far acuity scores averaged 20/20 (6/6) for each age group. The subjects were driven slowly past the sign and the distance at which they could correctly read the legends were noted.

The results indicated that about 20 ft-L (68.6 cd/m^2) was optimum for low ambient conditions and for medium ambient conditions in the absence of headlamp glare. Maximum legibility distance was measured under high ambient conditions at 200 ft-L (686 cd/m^2).

No age differences were noted overall, however the older group was poorer at low levels of sign luminance by 30 to 40%. There were no differences at higher luminance levels.

The authors recommend minimum luminance levels of 10 ft-L (34.3 cd/m^2) for dark areas, 20 ft-L (68.6 cd/m^2) for moderately lighted areas and 100 ft-L (343 cd/m^2) for well lighted areas. They also recommend that variation in luminance of different areas on the sign be kept to a minimum of 10:1. Recommendations of maximum luminance values for optimum performance are less certain, but upper limits of 30, 100 and 500 ft-L (103, 343 and 1714 cd/m^2) were suggested for each of the three ambient conditions.

The first study which attempted to systematically measure the effect of background and legend luminance as well as color on legibility distance was reported by Hills and Freeman (1970). Employing an apparatus which permitted independent adjustment of background and legend luminance, the authors measured the legend luminance necessary to produce various legibility distances as a function of background luminance and color. Background luminances ranged from less than 0.03 ft-L to about 23 ft-L (0.103 to 79 cd/m^2). Legend luminances ranged from 0.009 ft-L to about 100 ft-L (0.03 to 343 cd/m^2). Background colors employed were red, green and blue. The legends were white series C letters, selected to be the most difficult in the alphabet to discriminate. Three subjects, all of whom had at least normal far acuity, participated in the study. The subject's task was to increase legend luminance, starting from the point of subjective equality, until the legend could be read correctly. The results indicated that legibility distances of about 50 ft/inch (6 m/cm) letter height or more could be achieved at all levels of background luminance. The required contrast was much greater for low levels of background luminance than for high levels, however.

The authors investigated between-subject differences using a sample of 11 subjects at one background luminance level. The poorest far acuity score was about 20/24 (6/7.2), however. Still, the scatter in performance was substantial. (However, large differences between subjects are to be expected in studies where the subjects must decide for themselves the level of certainty at which to respond. Thus, the performance differences do not simply reflect differences in capability, but are confounded with differences in the level of confidence at which the subjects were willing to commit themselves to a choice.)

The authors state "It is clear from the results that, at night-time luminance levels encountered in highway practice, there must be some reductions in the legibility of white legends as soon as the background is changed from essentially black to any of the colors red, green and blue with appreciable background luminances." Presumably this loss is made worthwhile by improvements in conspicuity and color coding. However, the latter characteristics cannot be quantified in a way which enables a straightforward calculation of desirable background reflectance levels. Hills and Freeman assume a 10% reduction in visibility distance as the maximum acceptable and present a table, part of which is here reproduced, giving minimum legend-to-background luminance ratios.

Background Color	Minimum Luminance Ratios for 10% (Max) Reduction in Legibility	
	Legend Luminance 1 ft-L	Legend Luminance 3.4 ft-L
Red	8	10
Green	7	7
Blue	6	7

An extensive inventory of legend, background, and surround luminances for signs in use has been reported by Youngblood and Woltman (1971). The authors measured luminances at viewing distances from 150 to 1500 feet on 127 shoulder-mounted and overhead signs ranging from two to four years old. Included were three background materials (non-reflective and moderately and highly reflective sheeting materials) and four legend materials (non-reflective, buttons, and moderately and highly reflective sheeting). Measurements were taken both day and night against a wide variety of surrounds. Eleven different vehicles were used and measurements were taken through the windshield from the driver's position. Data were generally confined to straight, flat roadway sections. It was found that illuminated legends averaged 10 ft-L (34.3 cd/m^2) or more at all distances tested. The luminance of non-illuminated legends depended on sign location and headlamp beam. For overhead signs, the use of high beams produced results comparable to illuminated legends for the two more efficient legend materials (buttons and highly reflective sheeting), and between 1 and 10 ft-L (3.43 and 34.3 cd/m^2) for the other legend materials. The use of low beams on overhead signs reduced legend luminances to 1 ft-L (3.43 cd/m^2) or less for all materials. Much the same is true for shoulder-mounted signs, except that luminances were significantly higher (generally above 1 ft-L (3.43 cd/m^2) for low beams). The same pattern held for background materials, except luminances were about 10% of those measured for legends.

King and Lunenfeld (1971) have described a computer model designed to establish letter sizes for signs to meet legibility criteria. Portions of this work have been described elsewhere by Adler and Straub (1971) and by King (1970, 1971).

The authors do not report any new research but instead build upon the work of Allen, et al. (1967) to determine legibility as a function of luminance, and Mitchell and Forbes (1942) and Moore and Christie (1963) for reading times. Taking standard headlamp isocandela diagrams and manufacturer's data on signing materials, the authors developed a computer model which, given sign location, road geometry and sign materials, predicts required letter size. Computed luminance values were compared with actual measurements for one material in a validation study. The resultant correlation (0.9) indicated good validity. The predicted luminance values were about double those measured, but this would result in relatively minor differences in legibility distance.

The model was applied to 63 signs located along a 20-mile (32 km) stretch of highway. For daylight conditions, 73% of the signs were adequate. At night 65% were adequate with high beams, 51% with low beams. When considering guide signs alone, the results were worse, the figures being 71%, 56% and 37% respectively. There was no attempt to validate legibility distance data, however.

Rizenbergs (1972) has reported the results of studies conducted by the Kentucky Highway Department. This work led to the conclusion that legend luminance in excess of 20 ft-L (68.6 cd/m^2) reduces legibility distance. The author notes that sign legibility is also a function of the contrast of sign legend and background, but no specifications are given. The results of this research program, plus consideration of effective life, led to a recommendation for use of highly reflective sheeting materials.

Another study (Rizenbergs, 1974) reports field observations, laboratory tests, and evaluations which were conducted comparing moderately and highly reflective sheeting materials with regard to reflectivity, durability, and cost over the life of the materials. In this study, test signs were set up along the highway using different combinations of materials. Laboratory weatherometer tests were also conducted. The conclusions of this effort support those of the 1972 study in that highly reflective sheeting materials were felt to be best and least expensive in the long run.

Swezey (1974) has reported a study of luminance contrast. Black letters were used on a white background, the luminance of which is not given. Contrast levels varied from 97% to 34%. Two phases were employed. In the first, unspecified "highway sign materials" were used as stimuli. In Phase 2 information on point assessments for Maryland drivers' licenses were used as stimulus materials. Exposure times were controlled at either 6 or 12 seconds in Phase 1. In Phase 2 the reading directions were varied (once through only, or read as long as necessary). This study is unique in that a recall criterion was employed, the subjects being required to write down their understanding of the stimulus materials after they had been withdrawn. Both phases indicate that performance fell off significantly at the 34% contrast level. Performance did not change significantly at the higher contrast levels. The author feels that only positive contrast, such as the black on white employed in this test, should be used on highway signs.

Although it is primarily concerned with the effects of uniformity of illumination, a study reported by Dahlstedt (1974) also provides data relating to legibility as a function of overall luminance. In this study, a special sign was made using Landolt rings for legend materials. The colors and direction of contrast are not specified. The sign was installed on a darkened street and illuminated by various sources having different light distribution characteristics. The subjects were stationed at a distance from the sign so that they could just see the ring gaps. When the lights were turned on the subjects had to list the gap positions on coding sheets. Luminance values for individual Landolt rings ranged from about 1 to 100 ft-L (3.43 to 343 cd/m^2). Optimum legibility for the viewing conditions tested was found to be at about 20 ft-L (68.6 cd/m^2) with a distinct reduction in legibility distance at greater intensities.

The effect of differences in luminance within the sign were determined by the author. According to his data, internal luminance ratios of 5:1 produce an 8% decrease in legibility distance, a 10:1 ratio about 12% and a 50:1 ratio about 20%. Dahlstedt recommends that the internal contrast ratios on a sign do no exceed 6:1.

Hicks (1974) has reported an investigation of legibility distance as a function of:

1. Blood alcohol level (0%, 0.08% and 0.15%)
2. Sign reflectivity (moderately vs. highly reflective sheeting)
3. Headlamp beam (high and low)

The test signs employed series E black legends on a yellow background. The road along which they were installed was straight but had considerable vertical curvature. As a result, the luminance of the sign at the point at which it became legible could not be determined exactly. However, photometric data collected before the study started indicates that typical luminances for highly reflective materials and high beams were 8-15 ft-L (27.4-51.4 cd/m^2) and for low beams 1-5 ft-L (3.43-17.1 cd/m^2). Typical luminances for moderately reflective materials with high beams were 2-6 ft-L (6.86-20.6 cd/m^2) and 0.6-3 ft-L (2.06-10.3 cd/m^2) with low beams. For all subjects, it was determined that legibility distances increased with increasing sign background luminance.

Robertson (1974, 1976) has reported a field study comparing the luminance of illuminated and non-illuminated signs. Six overhead sign installations having two or more signs side by side were selected for study. One sign of each set was refurbished in highly reflective sheeting and not illuminated. The other sign was refurbished in moderately reflective sheeting and illuminated.

Luminance readings were made from the driver's position in eleven different vehicles using high and low beams and with and without other traffic present. The findings indicate that under many conditions the highly reflective sheeting provided luminances at least equal to and sometimes higher than the illuminated signs. However, on the curved sections, the non-illuminated signs had significantly lower luminance than the illuminated signs. In general, it was felt that until more reflective materials could be made available, non-illuminated signs should be confined to straight sections of roadway.

Woltman and Youngblood (1975) have reported an investigation of the effect of a proposed mid-beam headlamp system on the luminance of signing materials. They measured luminance as a function of headlamp beam (low, mid and new high beam) for overhead and roadside-mounted signs. The authors prepared curves showing luminance measured at the driver's eyes as a function of beam, sign material, viewing distance and lateral position of the sign. The results indicate that, for shoulder-mounted signs, the proposed mid-beam produces luminance equivalent to that produced by the present high beam. On the other hand, relatively little gain was achieved in the luminance of overhead signs through use of the mid-beam.

The same authors (Woltman and Youngblood [1976]) have reported a photometric assessment of the contribution of stream traffic to sign luminance. They also measured luminance contributed by light reflected off a wet pavement. It is evident from the results that both effects can be quite significant in terms of total sign luminance.

The effect of stream traffic increases with viewing distance. For example, in one test sixteen vehicles were used, spaced over various distances in front of the sign. Luminance measures were made from the last vehicle. When the last vehicle was 300 feet (91.4 metres) from the sign the luminance increase was negligible on an overhead sign, but at 1500 feet (457 metres) the luminance was increased by a factor of eight. This results, no doubt, from reductions in both incidence and divergence angles for sources of illumination other than one's own car at longer viewing distances.

The effect of wet pavement was most marked on overhead signs and peaked at 1200 feet (366 metres) where the increased luminance was six times greater than under dry conditions.

Recently, a comprehensive investigation of factors affecting sign legibility and conspicuity has been reported (Forbes, Saari, Greenwood, Goldblatt and Hill, 1975, Forbes, 1975, Forbes, 1976). The major part of this effort was a laboratory investigation in which slides showing several highway signs each were presented to the subjects. Luminance, background color, and contrast of legend to background were varied. Another series of blank slides was included to estimate the minimum luminance required for color discrimination.

A field study was conducted as well. In this instance, the subjects were seated in a car which was driven slowly toward a sign set up along the side of a dark road. An effort was made to alter ambient lighting conditions by placing a gray plywood panel next to the test sign and illuminating it at various levels. The visibility distances resulting from the field study were substantially greater than those from the laboratory investigation. The authors speculate that this may have come about due to the fact that the slide presentations used in the laboratory phase were relatively brief, so that the performance measured approximated "glance legibility" as described by Forbes (1939). In the field investigation, as in most other studies of this type, the subjects could fixate the sign for a period of time limited only by the duration of an experimental run.

The results of this investigation are quite complex. However, for purposes of this review, the key data are figures which describe legibility distance as a function of luminance. The figures were developed by averaging over all contrast conditions tested. The authors do not note any interaction between background luminance and required contrast. They do state that contrast beyond 5:1 resulted in little performance improvement. The average contrast represented by the figures referred to above was about 10:1. The luminance values plotted in these figures are interpreted as either legend or background, whichever is higher. On a semi-log plot these data show linear increases in legibility distance with increasing luminance through the range considered (approximately 0.3 to 50 ft-L [1.02 to 171 cd/m^2]). At the lowest luminance levels all color combinations yield about 20 ft/inch (2.4 m/cm) letter height. The plots diverge with increasing luminance. The best combination is black and white (either contrast direction), which yielded legibility distances of 60 ft/inch (7.2 m/cm) letter height at maximum luminance. White on green was about 50 ft/inch (6 m/cm) letter height at maximum, black on orange about 40 ft/inch (4.8 m/cm) letter height. Other color combinations in common use fell within the range indicated.

Like the Hills and Freeman study, these results suggest that black and white is the best combination in terms of legibility distance. Thus, preservation of color coding and high conspicuity value will result in reduced legibility distance. Unlike the Hills and Freeman study, these results show no evidence of an asymptote in performance at high luminance levels and no evidence of an interaction between required contrast and background luminance.

Further, the luminance recommendations of the two papers differ significantly. Hills and Freeman's data for black and white configurations agree well with the results of Allen, et al. (1968) in that a luminance of about 10 ft-L (34.3 cd/m^2) is optimum. Forbes indicates steadily improving performance through 50 ft-L, (171 cd/m^2) with no sign of a leveling off.

An objective comparison of legibility distances provided by moderately and highly reflective sheeting has been provided by Woods and Rowan (1976). Subjects were driven toward test signs and the distance at which they could read four-letter familiar words was measured as a function of the following variables:

1. Sign materials (highly reflective sheeting vs. moderately reflective sheeting with external illumination).
2. Mounting height (all signs were overhead, mounted at heights of (18.4, 20.3 and 22.6 feet [5.6, 6.2 and 6.9 metres] above the road).
3. Headlamp beam (high or low).
4. Angle of sign tilt from the vertical (0^o, -5^o, $+5^o$).
5. Vehicle speed (34.8, 44.7, 55.3 mph [56, 72, 89 km/hr]).

No photometric measures are provided. A statistical analysis was conducted and none of the variables were associated with a significant difference in legibility distance (headlamp beams were not tested as a factor in the analysis). Legibility distances averaged 19% less for the highly reflective signs as compared with the moderated reflective-illuminated signs when low beams were in use. However, the authors argue that the use of the former configuration is justified since it still provided adequate reading time, and was being successfully used in field installations in the state of Louisiana.

Rumar and Öst (1975) have reported a number of field studies dealing with various aspects of highway signs. However, the major concern was with legibility. There were four principle studies:

1. The legibility of circular signs having a yellow center, a red border and a black symbol (a Landolt "C").
2. The legibility of direction arrows with a white legend and a border on a blue background.
3. The legibility of advanced direction signs employing a white legend and border on either a blue or a green background.
4. The effect of various symbol dimensions on legibility.

Sign luminance was varied by using different retroreflective sheetings, a painted surface or by illuminating the sign. Observers approached the sign in automobiles using either high or low beams. When using low beams, glare was provided by another set of low beams which were fixed on the rear of another car 328 feet (100 m) in front of and one lane to the left of the subject car. Thus, the position of the glare source was constant throughout the run. Signs were positioned on the side or above the road.

As noted, a Landolt "C" was used on some signs. In these cases the criterion was the distance at which the orientation of the gap in the ring could be detected. Other signs used a pair of three letter words and the criterion was the distance at which the subject could determine whether the two words were the same or different.

The results indicate that greater legibility distances were provided by illuminated signs than by highly reflective sheeting and European low beams. However, legibility distances with high beams were equal to or better than those provided by separate lighting.

The authors feel that, in view of the expense and difficulties associated with fixed illumination, highly reflective sheeting materials are preferred.

Studies were also conducted to measure the effect of dirt on signs. In general, dirt affected various retroreflective materials about equally. A sign having separate luminaires was relatively unaffected by dirt.

Studies were also conducted on the attention value of retroreflective signs. As expected, highly reflective signs were rated as more attention-getting than non-reflective or low-reflective signs.

A study was also conducted comparing the legibility distance of various symbol sizes at different levels of reflectivity. Three sizes of Landolt "C" were tested, 95, 190, and 285 mm in diameter. The relationship of legibility distance per unit symbol diameter was quite constant under both high and low beam conditions.

The authors also report a brief study of the effect of stroke width. The standard letter height to stroke width ratio in Sweden is 1:6.5. This was compared with two thinner and two thicker stroke widths. The results showed no strong differences comparing the various stroke widths. However, it was noted that this was a relatively brief study and real differences may not have been detected.

The Department of Transportation of the State of Ohio has reported a study (Richardson, 1976) which evaluated various reflective sheeting materials. Two methods were employed. The first, used on silk-screened signs, measured the smallest detail the subjects could resolve from sets of vertical markers varying in size and spacing. Negligible differences were found. The second method, used for signs with demountable legends, used 3 capital letters "I" oriented either vertically or horizontally and the experimenter measured the distance at which the subjects could determine the orientation. Variables were: sign position (ground mount or overhead), background material (opaque, moderately and highly reflective sheeting), legend material (buttons or highly reflective sheeting), and headlamp beam. Differences between the various combinations were not great except for the opaque background when viewed with high beams, which resulted in a substantial reduction in legibility distance. Button legends were found to be superior in every instance to sheeting legends, although these differences were generally minor. It is not clear whether they were statistically significant or not. Granting that the amount of data collected is small (five subjects, two observations of each condition) the author concludes that the use of highly reflective sheeting cannot be justified on a cost basis.

Conspicuity

A series of 14 studies by Forbes and his co-workers on sign conspicuity (Forbes, Pain, Fry, and Joyce, 1967; Forbes, Pain, Joyce, and Fry, 1968; Forbes, Fry, Joyce, and Pain, 1968) investigated a variety of factors, including luminance, and culminated in the development of a mathematical model which was then field validated. This work has been summarized by Forbes (1969).

A laboratory simulation was employed in all but the final stages of the program. In the simulation studies the subject monitored a small panel with 12 lights just below the point of presentation of the experimental scene, relighting these lamps by pressing a button with one hand as they were randomly extinguished. At intervals the subject was given a one second presentation of signs and required to indicate which sign was seen "first and best."

The first series of studies was largely designed to settle questions related to the simulation technique. The second series investigated sign size, brightness and legend to background contrast. It was determined that signs seen first and best were those with greatest luminance contrast against the surround, or the largest sign when luminance was constant. Size and contrast interacted to cancel one another when one increased while the other decreased. Legend luminance interacted with other factors, high luminance enhancing dark signs against a day-snow background. If both legend and background luminance were reduced the effect of this contrast on sign performance was reduced. In a test against simulated advertising signs, dark signs did best against bright surrounds and vice versa. In the final laboratory tests, green signs of varying luminance were tested against three different daytime surrounds and different colored signs were tested against different surrounds. Again, it was found that the higher luminance signs were seen best against dark backgrounds and vice versa. Some evidence for color contrast effects was found in that red and yellow backgrounds did better than would have been expected on a basis of luminance alone.

In the field test the subjects took a 40-mile drive, passing about 400 signs, of which 82 were selected for tests. These signs varied in size and surround. Observations were made day and night. Larger signs were noted at greater distances than smaller signs and when multiple overhead signs were seen on sudden exposure, the leftmost was seen best during the day and the one over the lane best at night.

Mathematical models were then tested against laboratory data for predictive capability. The best fit was obtained from a model which assumed that luminance ratios of legend to background and sign to surround affect conspicuity in an additive fashion.

A somewhat similar investigation has been reported by Eklund (1968). This study used slides presented tachistoscopically to investigate factors affecting the relative conspicuity of signs. Among the findings are that the greater the sign luminance and the more a sign differs from others, the more readily it will be seen.

Pain (1969) has reported an extension of the research of Forbes and his co-workers. Using neutral gray Munsell chips, Pain was able to control luminance and luminance ratio independently where previously these factors had been confounded. He found that both parameters have high attention-getting values. When varied together, luminance ratio has more value. High luminance enhances the attenion-getting characteristics of luminance ratios, especially for negative contrasts. On the basis of this work, the author suggests that the Forbes model previously described be modified to consider luminance ratios.

An attempt to relate sign conspicuity factors objectively has been described by Odescalchi (1960). Two studies were conducted. In the first, several groups of observers looked at different sized white signs under various background conditions at a variety of distances. They were instructed to look down the road, not directly at the sign, and rate the sign as "too large, just too large, adequate, just too small, or too small." The results are summarized as follows:

Conditions	Dist. From Observer to Sign (Yards)	Areas of White Panel Judged "Adequate" (In Square Ft.)
Open	150	16
	250	16
	350	29
	500	50
Shaded	250	31

In the second experiment, signs of various colors were compared with white signs in an effort to determine how much larger or smaller they had to be in order to be equally conspicuous. A pair-comparison technique was used, the subjects fixating a small gray panel on either side of which were placed the experimental panels. The results, in terms of the amount that colored sign area has to exceed white sign area to be equally conspicuous, are as follows:

Yellow	-10%
Red	+15%
Blue	+20%
Green	+40%
Black	+125%

Sign Surround

Conspicuity of a sign is largely a matter of contrast between the sign and its surround. These effects have been investigated in some detail by Forbes, Pain, Joyce and Fry (1968). This contrast effect may be achieved either in terms of color or luminance. Colors are fixed by specifications. For example, green is used as a background for guide signs, and a green sign may have limited conspicuity when seen against a green surround. Sign luminance can be manipulated independently of color to some extent, but surround luminance varies greatly with time of day and sometimes with time of year. Thus, maintaining conspicuity at a desired level is a difficult problem.

The nature of sign surrounds have been cataloged by Hansen and Woltman (1967). In this study, the investigators inventoried 4054 destination and distance signs along 1560 miles of representative freeway facilities in seven states. Terrain varied from almost perfectly flat to quite mountainous. Abutting land varied from rural to urban. The results indicate that signs are seen against a wide variety of surrounds, dependent on the location of the sign and the nature of the terrain. For example, a substantial percentage of overhead signs are seen against the sky, a surround which varies greatly in luminance, depending on time of day, sun position and whether the sky is cloudy or not.

In metropolitan areas especially, advertising signs provide considerable competition for highway signs, particularly since the former are frequently large, brightly lighted and sometimes feature motion effects or flashing lights designed to attract the driver's eye.. Advertising signs are frequently placed in commanding positions near freeways to assure their being seen by motorists who pass that way. It is natural that traffic engineers be concerned about the distracting effects of these signs, particularly when they are placed near busy interchange facilities.

Shoaf (1955), while reporting no research, does describe the traffic sign ordinance enacted in San Francisco. This article contains the specifications of the San Francisco ordinance for brightness, size and movement parameters associated with advertising signs near freeway facilities.

Ady (1967), investigated changes in accident patterns on a Chicago freeway at three sites near new and commanding advertising signs. The study was conducted using data one year before the signs were installed and one year after. Control factors were introduced by monitoring collision data in the areas near but outside the scope of influence of the advertising signs. No differences were found in the accident data associated with the signs in this study.

A comprehensive review of the literature relative to advertising signing and its interaction with traffic flow and safety problems has been offered by Simon (1967). While a considerable number of articles have been published, they suffer from a variety of problems in experimental design which make generalizations difficult.

Environmental Effects

The environment has important short- and long-term effects on the performance of signing materials. Modern day signing materials have been designed to minimize the immediate effect of rain, dew and frost to an appreciable extent. Such effects have been measured and reported by Woltman (1965), Brenning (1973) and Lowden and Stoker (1975). Of greater consequence for the purpose of this investigation are long-term environmental effects. Signing materials wear out in time due to action of sun and weather. Airborne particles settle on the sign and affect its luminance as well.

The near road environment, where many warning and regulatory signs are placed, has been an object of particular concern to investigators because, in this area, signing and delineating materials are subject to spray resulting from vehicles passing by in wet weather. One of the first important studies on this problem was reported by Davis and Fitzpatrick (1954). The authors' purpose was to determine the optimum positioning of roadsign signs to minimize dirt accumulation. A variety of experimental panels were installed at various heights and distances from the roadway and their reflective characteristics tested at various times over a period of more than a year.

The dirt accumulation was markedly nonlinear. For example, a position 6 feet (1.8 m) up and 10 feet (3 m) from the edge of the road had three times the luminance at the end of the test period as a sign in the standard position 5 feet (1.4 m) up and 8 feet (2.4 m) from the edge of the road. The improved reflectivity of the more distant sign as a consequence of reduced dirt accumulation more than compensated for the reduced efficiency of headlights at this distance.

A somewhat similar study has been reported by Anderson (1966). In this investigation, four test installations of white panels composed of retroreflective sheeting were set up. The units were about 4 feet (1.2 m) square and were set with their left edge 11 feet (3.4 m) from the pavement edge. These units were left in place and photometered regularly for 18 months. Additional small test panels were set well off into the roadside area to be certain they received no spray from passing cars. It was determined that the daytime reflectance of the test installations were little affected. The control panels stayed at about 98%, and all of the test panels but the extreme lower left ones retained 90% or better of original reflectance after one and a half years of exposure. However, the night reflectivity levels were significantly affected. The control panels were measured at about 80% of original luminance after the

18-month test period, while the test sign panels varied from 5% to 80%. The poorest performance was associated with panels which were lowest and closest to the road. The author recommends that signs be placed 14 feet (4.3 m) from the roadway edge and 6 feet (1.8 m) up, which he says would allow 50% or better retention of reflective efficiency over the test period concerned.

Roadway delineators have been an object of particular concern because they must be set on or very near the roadway to operate effectively. Reid and Tyler (1969) have reported an investigation of the changes in reflective efficiency of median mounted delineators positioned 33.5 inches (85 cm) up and 25.6 inches (65 cm) off the road during the winter in Great Britain. It was determined that within one week this particular set of delineators had fallen to 20% of their original reflective efficiency. Within three weeks they were down to about 5 to 6%.

Similarly, Kennedy (1974) investigated delineators made of retroreflective sheeting, position not indicated. He found the efficiency reduced to about 10% of original after three years. The dirt built up rather fast in this installation, reducing reflectivity to about 25% after one year. These installations were in Australia where snow and slush would not be a problem.

While it is valuable to know about the performance of retroreflective devices in particularly severe environments, such as close to the roadway, it would also be valuable to know something about their performance in normal guide signing positions well away from the immediate highway environment. No reports on this aspect of environmental effects have come to the attention of the present authors. It would be very useful were data available indicating the photometric performance of different materials as a function of factors such as: orientation, locations around the country, time and maintenance. Lacking such data the actual performance of these materials in the real world can only be approximated.

Discussion

The objective of this program is well defined in its title: "Determine the Luminous Requirements of Retroreflective Highway Signs." It is evident from the foregoing literature review that a substantial number of studies have been carried out in an attempt to provide an answer to this problem. The issue now is the extent to which available data are satisfactory.

In order to properly meet the objective of this study it is necessary to relate photometric measures to some meaningful criterion of sign performance. The dependent variable most commonly employed in studies of this type is "legibility distance." Some of the studies reviewed provided neither type of data, other studies provided one or the other but not both. However, a number of investigations do provide data in a potentially useful form, notably those of Allen, et al., Smyth, and Dahlstedt. Further, these studies, to the extent they can be compared, are in good agreement. For example, Table A-2 compares the recommendations of these three investigators.

TABLE A-2. Recommended Luminance Values (in Foot Lamberts) for Sign Legends or Backgrounds as a Function of Ambient Illumination. Data from three different authors.

Investigator	Ambient Level		
	Dark	Medium	Bright
Allen et al.	10	20	100
Dahlstedt	20	--	--
Smyth	8-10	15-30	--

These data are impressive. However, their relevance to the present case is not clear because these studies were all concerned with black and white signs only. Thus, effects of color contrast and the possible interaction of legend and background luminance were not addressed.

In the final analysis there are only two studies which provide adequate documentation of independent and dependent variables and deal with situations where: (1) both legend and background have significant luminance, and (2) the backgrounds have different colors. These are the investigations by Hills and Freeman and the recent work of Forbes and his co-worders. However, as has already been noted, the results of these two efforts do not agree well in some respects. Further, the present authors are concerned with some aspects of each study which make the utility of the data questionable.

The Hills and Freeman paper describes a thorough presentation of a broad range of background and legend luminances and three colors. There is no reported effort to validate the predicted legibility distances. The technique employed required the subject to view the display continuously while adjusting the legend luminance upward to the point of legibility. As a result, viewing time was at least partially confounded with background luminance and legend size. Especially at higher luminance levels, the sign was bright enough to significantly alter dark adaptation, which means that data for brighter signs and/or smaller legends were taken under different dark adaptation conditions than data on darker signs and/or larger legends. Further, as the authors have determined from working with their own version of this apparatus, fixating a display of this type at high luminance levels quickly produces an afterimage, which is seen as superimposed on the sign, giving it a non-uniform appearance and generally making the background appear less bright than it did originally. What this does to the data is uncertain. Thus, there may be some reason to question the validity of the Hills and Freeman findings, at least until they can be verified by procedures which overcome the problems noted above.

The study reported by Forbes and his co-workers apparently avoids the problems just noted. Although the descriptions contained in papers published to date are unclear concerning some details of the test procedure and levels of independent variables, the methodology seems basically sound. In spite of this however, there are two aspects of the results which are troublesome to the authors of this review.

The first is the substantial difference in measured legibility distance comparing the field and laboratory studies. It is true that Forbes, et al. attribute this to differences in viewing conditions ("glance" vs. "pure" legibility). However, in his 1939 paper reviewed earlier Forbes estimated this effect at 10-16%, substantially less than reported here.

The second is the simple linear relationship between luminance and legibility which is reported and the lack of an interaction between background luminance and required contrast. All of the studies reviewed, which have systematically varied luminance levels, report evidence of maxima, levels beyond which performance did not improve or may actually have declined. Further, basic vision research, such as that of Blackwell, leads to the expectation that the contrast required to achieve a given level of performance will decline as background luminance is increased. (This effect will be noted in the Hills and Freeman data, as an example.) Of course, these are merely questions which indicate, at worst, that further study is indicated before the recommendations can be taken at face value.

In sum, although there have been a number of studies which have sought some sort of answer to the problem posed in this investigation, there have been only two which have been carried out in such a way as to be potentially capable of providing definitive answers. Unfortunately, both of these studies have possible flaws and the results do not compare well. Further, the authors in neither case provide the traffic engineer with data which enable a ready appraisal of the merits of various retroreflective material options. Thus, it appears that further work on the problem is needed, not only to clarify some of the remaining problems, but to produce recommendations in a form which is useful to traffic engineers interested in cost-effectiveness decisions which consider visual performance as a variable.

APPENDIX B

LABORATORY STUDY

LABORATORY STUDY

This phase of the NCHRP 3-24 program consisted of a parametric laboratory study designed to provide basic data regarding human visual capability as a function of several pertinent variables.

VARIABLES: The following variables were investigated:

Color. Seven colors were used as backgrounds for the simulated signs:

1. Green
2. Blue
3. Red
4. Black
5. Yellow
6. Orange
7. White

White legends were used with the first four colors and black legends with the last three.

Background Luminance. The background luminance values used for the various colors are shown in Table B-1. Note that green, blue and red were used only at the four values indicated, legend luminance being varied to determine thresholds. Black was used at one level only (zero luminance). The other three colors used a black legend, the luminance of which remained constant (essentially zero ft-L) and thresholds were determined by varying background luminance through the range indicated. Details of the methodology will be explained later.

Legend Luminance. Legend luminance (white only) could be varied from a maximum of 215 ft-L (737 cd/m^2) to 0.008 ft/L (0.027 cd/m^2) in 21 steps. The filters and the luminance values associated with them are listed in Table B-2.

Surround Luminance. Sheets of white diffusely reflective material were hung behind the sign display (see Figure B-3). This

TABLE B-1. Luminance Levels Used for Various Colors in Laboratory Legibility Investigation.

		Luminance (Ft-L) *					
Filter No.	Filter Transmission (Percent)	Green	Blue	Red	Yellow	Orange	White
None	100.	11.0	11.0	9.6	46.1	17.6	61.5
1	48.8				22.5	8.6	30.0
2	23.0				10.6	4.0	14.1
3	9.9	1.1	1.1	0.9	4.6	1.7	6.1
4	7.0				3.2	1.2	4.3
5	5.0				2.3	0.9	3.1
6	2.5				1.15	0.44	1.54
7	1.0	0.1	0.1	0.09	0.46	0.17	0.61
8	0.76				0.35	0.13	0.47
9	0.46				0.21	0.08	0.29
10	0.25				0.12	0.04	0.15
11	0.10	0.01	0.01	0.01	0.05	0.02	0.06

* 1 ft-L = 3.43 cd/m^2

TABLE B-2. Luminance Levels for White Legends in Laboratory Legibility Investigation.

Filter Number	Filter Transmission (Percent)	Legend Luminance (Ft-L)*
None	100.	215.
1	45.9	98.7
2	26.9	57.8
3	19.4	41.7
4	12.0	25.8
5	9.2	19.8
6	5.4	11.6
7	3.3	7.1
8	2.4	5.2
9	1.6	3.4
10	0.84	1.81
11	0.54	1.16
12	0.25	0.54
13	0.10	0.22
14	0.062	0.13
15	0.044	0.09
16	0.035	0.075
17	0.024	0.052
18	0.013	0.028
19	0.0077	0.017
20	0.0037	0.008

* 1 ft-L = 3.43 cd/m^2

material could be illuminated by a series of overhead lights to a level of 1.5 ft-L (5.14 cd/m^2). Luminance of the surface with the lights off was 0.006 ft-L (0.021 cd/m^2).

Subject Visual Characteristics. The participants were screened and classified in the following groups:

a. Normal: 20/20 (6/6) far acuity and otherwise normal vision.

b. Poor acuity: 20/30 to 20/40 (6/9 to 6/12) far acuity and otherwise normal vision.

c. Old: 65 years of age or older with normal vision.

d. Poor low contrast acuity: At least 20/20 (6/6) high contrast far acuity with 20/35 to 20/40 (6/10.7 to 6/12) low contrast far acuity.

METHOD

Viewing Time. In previous investigations of sign legibility viewing time has generally not been controlled. There are two reasons why it is desirable to do so:

First, a restricted viewing time more nearly approximates real world conditions. In a 1939 paper, Forbes distinguished between "glance legibility" and "pure legibility," and pointed out that the former would yield more conservative legibility distances. Thus, more accurate estimates of legibility distances to be expected under operational conditions requires relatively brief exposures to the stimulus material.

Second, at high sign luminance levels, continuous fixation can significantly alter dark adaptation. As a result, sign luminance is confounded with dark adaptation in a way that is not representative of the real world.

For these reasons exposure time was restricted to one second in this study. One second is recommended by Forbes (1939) as a realistic approximation of the amount of time a driver can study a sign in any one glance while driving at highway speeds. Sufficient time was allowed between exposures, based on pilot data, to permit after images to fade and dark adaptation to be restored.

Visual Task. The visual tasks used by previous investigators have varied but have generally employed conventional letters. Sometimes the task involved the identification of single letters or groups of letters. In other studies unfamiliar or familiar place names were employed. A problem with the use of actual letters or place names is that the difficulty of the visual task varies from trial to trial.

For this test a visual task was sought which would minimize this problem. It was finally decided to employ a Landolt ring, a character which is commonly used in tests for visual acuity. The apparatus was designed to enable the gap in the ring to be oriented in any of four positions, corresponding to the twelve, three, six, and nine positions on the face of a clock. The subject was required to respond with his best guess of the gap position on all trials except those in which the ring was not visible.

Equipment. A way was sought to simply and accurately maintain independent control of background and legend luminance. An optical device first described by Hills and Freeman (1970) seemed to offer the best means to this end. With some modification, a similar unit was built for this investigation. A schematic of the equipment is shown in Figure B-1. The unit which provides the simulated sign display is diagrammed at the upper left. Inside the box at position A (dashed line) is a piece of plate glass which reflects about 8% of the light directed toward it and transmits about 90%. On the left of the box at position B is a slide mounting in which the sign background material was placed. Encapsulated lens retroreflective sheeting was used for the background. At C is a rotatable mounting in which clear plastic squares with the Landolt ring legends were placed. An ordinary mirror is placed at D. Two light sources are used, L_1 and L_2. L_1 provides background luminance. Light from L_1 is reflected at D, passes through A and is retroreflected by the material at B. About 8% of this luminance is reflected by A toward the subject

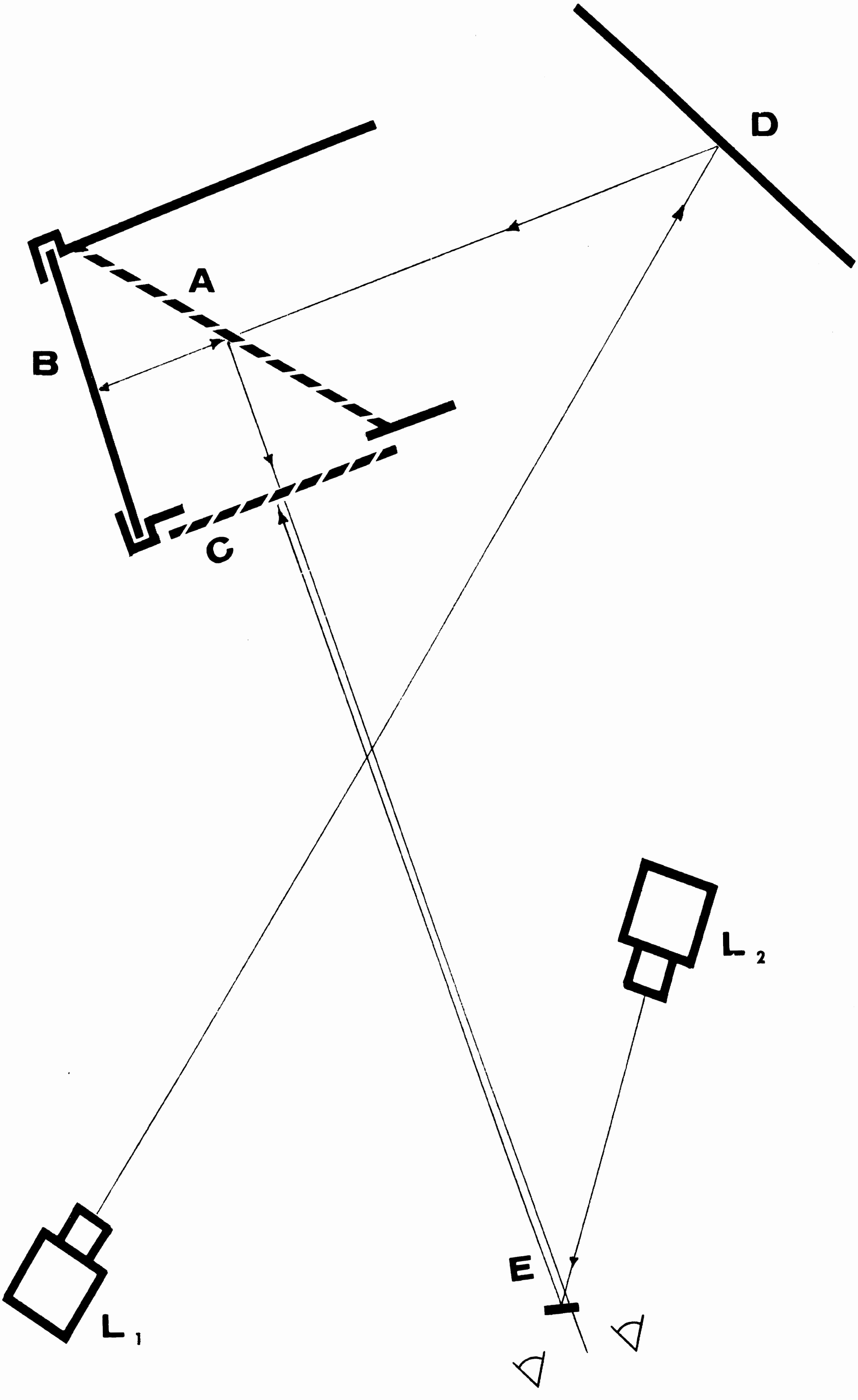


Figure B-1. Schematic of laboratory apparatus.

through C. L_2 provides legend luminance. The beam from this source, when reflected from a mirror in front of the subject's eyes at E, is centered upon the legend at C. The eyes of the subject are positioned above mirror E and centered so that the divergence angle is the same for both eyes. The divergence angle was about 0.3^o. The viewing box was set at a slight angle relative to the beam from mirror E to eliminate specular reflections.

The Landolt rings were cut from white encapsulated lens sheeting or flat black plastic sheeting as appropriate to make 2 complete sets of 11 legend targets for positive and negative contrast conditions. The rings were made with the stroke width equal to 1/5th overall height. Gap height was equal to stroke width. Specifications for the Landolt rings are given in Table B-3. It should be noted that only five of the rings were actually used in the study; those whose visibility distance specifications most nearly approached 30, 40, 50, 60 and 70 ft/inch letter height (3.6, 4.8, 6.0, 7.2 and 8.4 m/cm).

The light sources were standard 35mm slide projectors. Each was fitted with a pinhole aperture immediately behind the slide position in order to restrict the beam to a diameter no greater than required to illuminate the background of the sign display. Each projector was also equipped with a solenoid operated shutter, connected to a common control. Neutral density filters were made by taking pictures of a flat white background using black and white film and various levels of exposure. The resultant negatives were placed in cardboard 35mm mounts to be fitted in the projector trays.

Located immediately adjacent to the sign display unit was a television monitor. This provided the visual input to a simple tracking task. The monitor presented a scene which was white on one side and black on the other. A forcing function consisting of the sum of three sine waves drove the divider back and forth at a frequency of about 0.1 Hz.

An opaque screen was set in front of the TV. In it was a slot

TABLE B-3. Specifications of Landolt Ring Targets

Visibility Distance (ft/inch letter height)	Outside Diameter (inches)	Inside Diameter (inches)	Gap Size (inches)
71.4	0.7	0.42	0.14 *
62.5	0.8	0.48	0.16 *
55.6	0.9	0.54	0.18
50.0	1.0	0.60	0.20 *
45.4	1.1	0.66	0.22
41.7	1.2	0.72	0.24 *
35.7	1.4	0.84	0.28
29.4	1.7	1.02	0.34 *
25.0	2.0	1.20	0.40
20.0	2.5	1.50	0.50
16.7	3.0	1.80	0.60

*Used in study.

four inches (10 cm) high and the width of the TV screen (16 inches [40.6 cm]). The slot was covered with two polarized sheets, set for nearly maximum filtration. To the subject this tracking task presented the appearance of a dim purple bar which became longer and shorter. The subject was instructed to maintain the bar at a point about half way across the television set. He or she was provided with a small joy stick control for this purpose.

Performance on the tracking task was not scored. Primarily it was a way of insuring that the subject's eyes were fixated at a common point prior to each trial and accomodated to the proper distance.

Figure B-2 is a close-up of the sign display and television tracking task. Figure B-3 shows the same equipment as viewed from the subject's position.

The viewing box was equipped with a hinged shield which served the dual purpose of providing a constant 11" x 11" (28 x 28 cm) outline to the sign regardless of any slight errors that may have occurred in the actual positioning of the mechanism, and also screened the switches and other paraphernalia on the face of the box from the observer. This shield is shown opened in Figure B-4.

Figure B-5 is an overall view of the subject station. The subject was seated as shown with his head supported and restrained both vertically and horizontally by the yoke shown in detail in Figure B-6. The subject's arms were extended forward as shown in Figure B-5. The fingers of the left hand engaged the minature joy stick with which the subject controlled the tracking task. The palm of the right hand rested on a response box which enabled the subject to report the position of the gap in the Landolt ring by pressing an appropriate button.

Figure B-7 is a photograph of the experimenter's station. The projector near the top of the scene is L_1, which provided background luminance. The projector near the bottom of the scene is L_2, which provided legend luminance. The box closest to L_1 is a master control

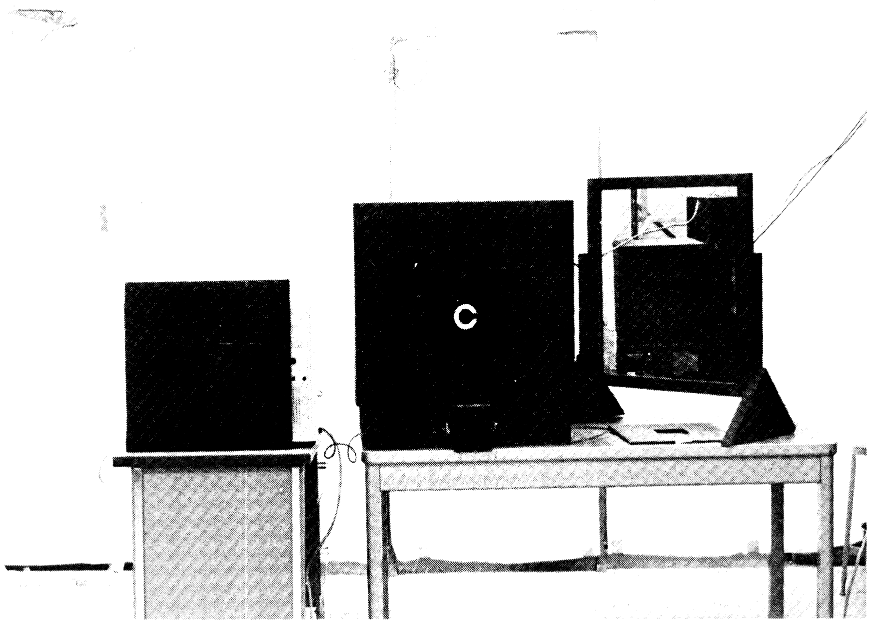


Figure B-2. Photograph of Sign Display Unit and Tracking Task Monitor.

Figure B-3. Photograph of Sign Display Unit and Tracking Task Monitor as seen from the Subject's Station.

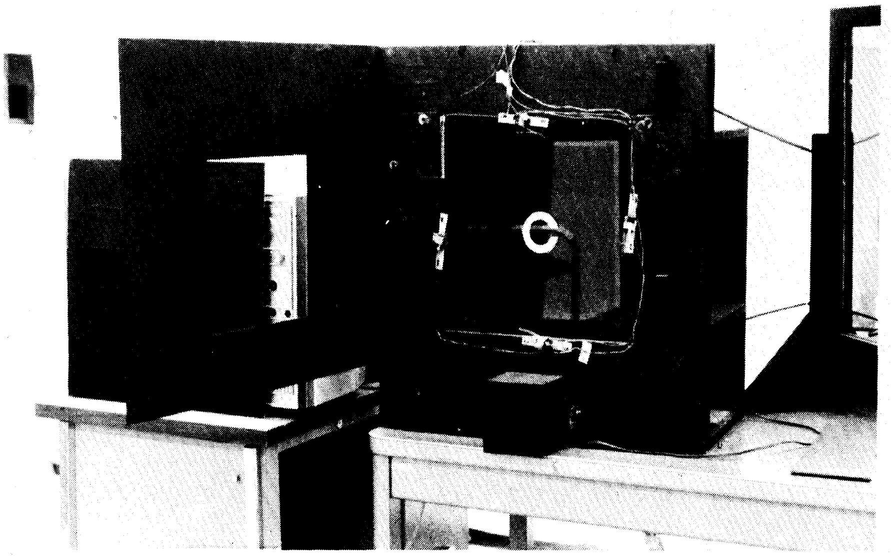


Figure B-4. Photograph of Sign Display Unit with Front Shield Open.

Figure B-5. Photograph of Subject Station.

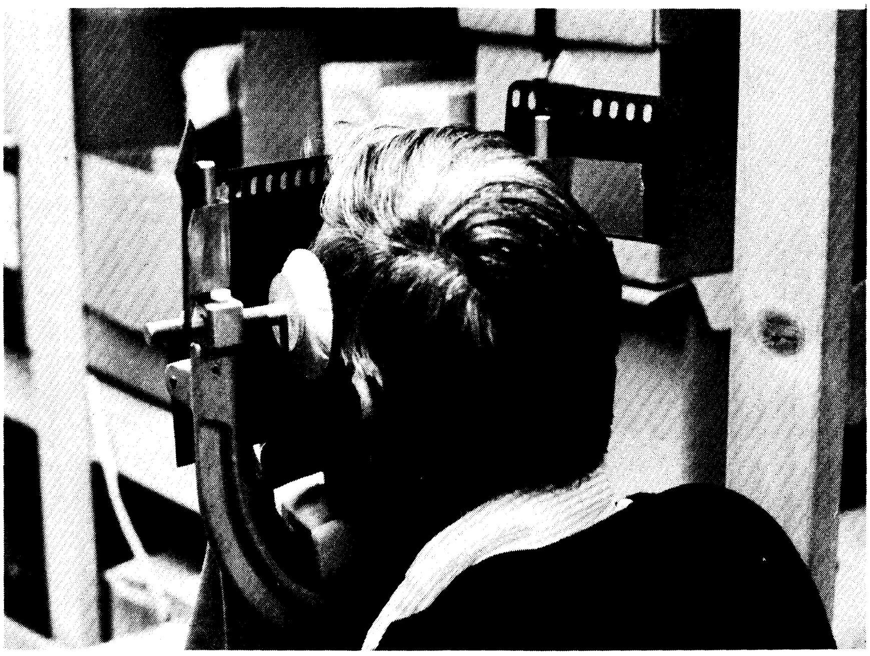


Figure B-6. Photograph of Head Support at Subject Station.

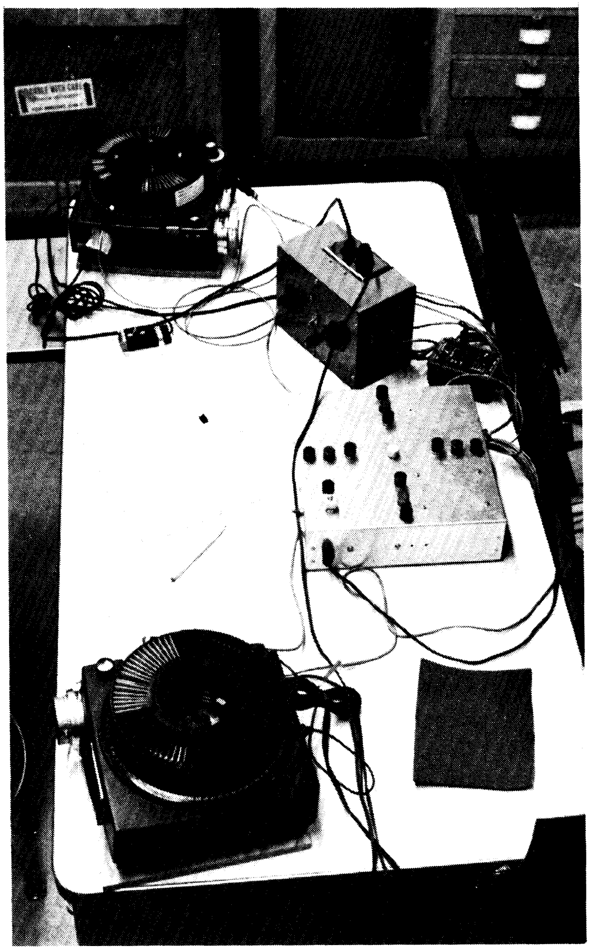


Figure B-7. Photograph of Experimenter's Station.

Figure B-8. Photograph of Experimenter's and Subject's Stations as seen from Sign Display Unit.

containing two variacs, which were used to set the color temperature of the projectors. These were also adjusted as required to maintain reference luminance values throughout the study. The larger box in front center of the desk is the legend rotator control. It also contained lights indicating the subject's response. Figure B-8 shows a view of the Experimenter's and Subject's Stations as seen from the position of the sign display unit.

Some room illumination was provided by a fluorescent desk lamp placed against the wall of the room to the experimenter's left. This source was adequate to permit the experimenter to record data and provided a base line adaptive level approximating a dark rural road for the subject. Stray light from this source was screened from the end of the room where the sign display unit was located.

It was desired that the subject be adapted to the mesopic level (a level where both rods and cones are functioning). It was concluded that approximately this level was achieved from the fact that a stable adaptation was reached about 5 minutes after the fluorescent fixtures with which the lab was illuminated were extinguished.

Photometry. The first step was to set the color temperature of each projector equal to 2860^0 K. This was done using a sheet of white cardboard placed at the position to be illuminated by each projector (background material holder for L_1, and face of legend holder for L_2). A Pritchard photometer was used to make the measurements. The variac in the projector master control was adjusted until the desired color temperature had been achieved for each projector.

The luminance of each background material was then measured, using L_1, with no neutral density filters in place. The same was done for the white legend material, using L_2. In addition, the transmissivity of the entire collection of neutral density filters was measured using L_2 and the white legend material. Using these data, neutral density filters were selected for both projectors to produce the desired luminance values. The filter values selected are listed in Tables B-1 and B-2 referred to earlier. Calculations were then performed to predict the background and legend luminance for each background color and combination of filters from the two projectors. (It should be noted that the legend projector contributed somewhat to the background luminance. This was accounted for in the calculations.) Photometric measures were then made using a substantial number of combinations of filters and background colors to verify that the calculations were correct.

During the data collection phase photometric checks were made twice a day as a minimum, once in the morning and once prior to the start of the afternoon session. Checks were made using maximum luminance for green background and white legend material. Drift rarely exceeded 10% and was often 5% or less. Occasionally checks were made at the end of a morning or afternoon session in order to be certain that excessive drift had not occurred during the session. These results were essentially the same as those from the regular morning and afternoon checks.

Subjects. Participants in this study were recruited by a newspaper advertisement. Potential subjects were asked to take a simple vision test, on the basis of which the experimental groups were composed. When each subject appeared for the vision test they were given the form shown in Exhibit B-1 to read and fill out. The form explained the purpose of the test, the types of experiments to be conducted, and solicited information relating to the subject's age, sex, driving experience, etc.

The visual screening was carried out using a Titmus Tester. Tests were conducted of far point acuity for both eyes, stereo depth acuity, color vision, vertical and lateral phoria, and low contrast far acuity. The last test, not normally available with the machine used, was created by purchasing another far point acuity test slide and inserting a 1% neutral density filter between the slide and the light source.

In all, forty-four subjects were screened for the test. These were then sorted into four groups as follows:

1. Normal. Normal subjects were classified as those having 20/20 (6/6) or better high contrast far acuity, normal results on all other tests, and having a low-contrast far acuity score as close as possible to the high contrast far acuity test score.

2. Poor acuity. Poor acuity subjects were those who were 20/40 (6/12) or as close to that as possible on the high contrast far acuity test, normal in other respects with a low contrast far acuity score as near as possible to the high contrast far acuity score.

3. Low contrast. Low contrast subjects were those who had 20/20 (6/6) or better high contrast far acuity, normal test results otherwise, and as large a discrepancy as possible in the low contrast acuity test scores.

4. Old. Those subjects classified as old were 65 or more years old with test results as near normal as possible.

Only two poor acuity subjects were run. It was apparent that the specific disorders which resulted in poor far acuity scores interacted with the experimental task in a way which produced exceedingly variable results. One poor acuity subject, as an example, found it more difficult to detect the gap position when it was oriented vertically than when it was oriented horizontally. As a consequence, his results were much worse than the other subject, even though they both had the same far acuity as measured by the vision tester. It was thought impractical to pursue this classification further. Instead, additional normal subjects were run to generate a more stable estimate of performance with green backgrounds.

Experimental Design. Because of the large number of variables considered in this investigation, it was not feasible to design a conventional, fully replicated experiment. A partially replicated design was substituted instead. It was carried out as follows:

Three "normal" subjects were selected to be administered a full

TABLE B-4. Listing of Subjects Used in the Laboratory Study

Classification	Sex	Age	Years Driving Exp.	High Contrast Acuity	Low Contrast Acuity	Replication	Wear Glasses?
Normal	M	24	8	20/15	20/15	Full	No
Normal	F	24	8	20/20	20/18	Full	No
Normal	F	20	4	20/18	20/20	Full	Yes
Normal	F	22	6	20/17	20/18	Partial	No
Normal	F	23	6	20/22	20/22	Partial	No
Normal	M	32	19	20/17	20/20	Partial	No
Normal	F	23	5	20/18	20/20	Partial	No
Low Contrast	F	35	19	20/20	20/40	Partial	Yes
Low Contrast	M	46	31	20/18	20/40	Partial	No
Low Contrast	M	23	6	20/15	20/40	Partial	Yes
Poor Acuity	F	24	7	20/40	20/30	Partial	No
Poor Acuity	M	27	11	20/40	20/40	Partial	No
Old	F	71	40	20/18	20/40	Partial	Yes
Old	F	67	45	20/20	20/35	Partial	Yes
Old	F	72	31	20/17	20/35	Partial	Yes
Old	M	67	47	20/17	20/40	Partial	No
Old	M	69	52	20/15	20/30	Partial	Yes

replication. They viewed all combinations of color, background luminance, and legend size at low surround luminance, and all levels of color, background luminance, and the 50 and 70 ft/inch (6 and 8.4 m/cm) letter height legends for the high surround luminance condition. This took four days for each subject. In addition, four other normal subjects viewed a full replication of the green background condition only. This took one full day per subject.

Subjects classified as "low contrast acuity," "poor acuity," and "old" received a partial replication consisting of two levels of background luminance, (maximum and third level) all colors and letter sizes. They were shown only the green background at high surround luminance levels. This took one full day per subject. Table B-4 provides a listing of the subjects and certain key data for each.

Procedure. When a subject appeared for a first session he was seated at the subject's station and read the instructions reproduced in Exhibit B-2. The head yoke was adjusted to permit a constant and proper viewing position. The seat height was adjusted as necessary. All controls and expected responses were explained. At this point the lights were turned off and the subject was given about ten minutes to dark adapt. During the dark adaptation interval, practice trials were administered and questions answered.

The order of presentation of the various treatment combinations (background color, legend size, background luminance, and surround luminance) was varied from subject to subject. The exact method of presenting treatments depended on the background color employed.

For signs in the red, blue, and green series both projectors were employed. First, a background luminance level was selected. The experimenter then selected a filter for the legend projector so that, on the first trial, the luminance of the background and the legend were as near identical as the available filters permitted. On the next trial the legend luminance was increased by one filter step. This process continued until the subject consistently reported the gap position correctly. The experimenter then began a series of descending trials, ending when the subject was missing the gap position consistently. This process was continued until a minimum of six replications had been achieved. The number of filter levels through which the experimenter had to search depended on the difficulty that the subject was experiencing in seeing the legend; varying from a minimum of two levels for the least difficult configurations (high luminance backgrounds and large letters) to eight or ten levels in some of the more difficult cases. Always the experimenter sought to go from a level where performance was no better than chance to a level where performance was essentially perfect.

Having completed the search at low legend luminance levels, the experimenter then switched to maximum legend luminance and began the search over again. Frequently the subject could detect the highest legend luminances without error, but in some cases (especially with smaller legends and low luminance backgrounds) they could not do so and a full search would be instituted, following the same procedures used at lower luminance levels. Again, this process was continued through a minimum of six replications. At this point the subject was given a short break while preparations were made for the next series of trials.

For positive contrast signs (orange, yellow, and white series) only the background projector was used. The experimenter began at the lowest luminance levels and conducted an ascending series of trials until the subject could reliably report the gap position. Then a series of descending trials was initiated. In this manner a minimum of six replications were secured. The same process was repeated at the highest luminance levels as well.

For the white on black series only the legend projector was used. A sheet of hardboard painted flat black was substituted in place of the retroreflective background material. The experimental procedure was the same as employed in the green, blue, and red series signs, except that background luminance remained constant.

Subject fatigue did not appear to be a problem. On the contrary, the subjects were very interested in the equipment, the test and the reasons for it. All questions were answered, they were allowed to see their data, and the procedures were fully explained. This undoubtedly helped to relieve the problem of boredom, which might otherwise have proven to be serious.

REDUCTION AND ANALYSIS OF THE LABORATORY DATA

Raw Data. The raw visual acuity data corresponded to a record of the subjects performance, (right [x], or wrong [O]), in determining the orientation of the gap in the Landolt C target. Separate score sheets were kept for each color, legend size, and background luminance treatment level. Each line on a score sheet referred to a given legend luminance treatment level.

Data Reduction. For each legend luminance condition (line on the score sheet) the subject's percent correct score was computed. The entire history of the subject's performance for each color, legend size, background filter (background luminance), surround luminance level and legend filter (legend luminance) treatment level was recorded on punched cards. On each card there were 21 fields of two corresponding to the subject's 21 performance scores at each legend filter. The following information was included as well: background color, legend size, background filter and subject identification.

Preliminary Data Analysis. Preliminary analysis indicated that the subjects' performance as a function of legend luminance had 3 distinct regions: 1) the low luminance region where the percent correct responses increased linearly as the log of legend luminance, 2) the mid-luminance plateau region where performance peaked, 3) the high luminance region where performance decreased with increasing legend luminance. In this preliminary analysis it was also determined that a convenient way to normalize the data was to use the logarithm of the luminance ratio (legend luminance/background luminance) as the independent co-ordinate rather than legend luminance.

Computer Analysis. Based upon the results of this preliminary analysis a computer program was written which read each punched card history of a subject's performance as a function of legend filter number, background color, legend size, background filter number and surround luminance and performed the following operations:

1. Averaged the percent correct response data of all subjects corresponding to a given treatment level.
2. Converted each legend background filter number for the given background color and legend background filter into a legend background luminance.
3. Converted the legend background filter number into a legend background luminance.
4. Computed the log luminance ratios corresponding to each legend filter.
5. Corrected the subjects performance score for his ability to obtain a score of 25% just by guessing.
6. Determined the 3 best least squares straight lines which fit the subject's true percent correct responses vs. log luminance ratio. The 3 best lines correspond to the low luminance, mid-luminance and high luminance performance regions discussed earlier. The 3 best lines are characterized by their slope and performance intercept. The points at which each of these lines intersects each other is also determined. An example of the program's ability to scale the visual acuity data is shown in Figure B-9 for the visual performance data of 3 normal subjects, for a white 60 ft/inch (7.2 m/cm) legend on a green background of .1 ft-L (0.34 cd/m^2).

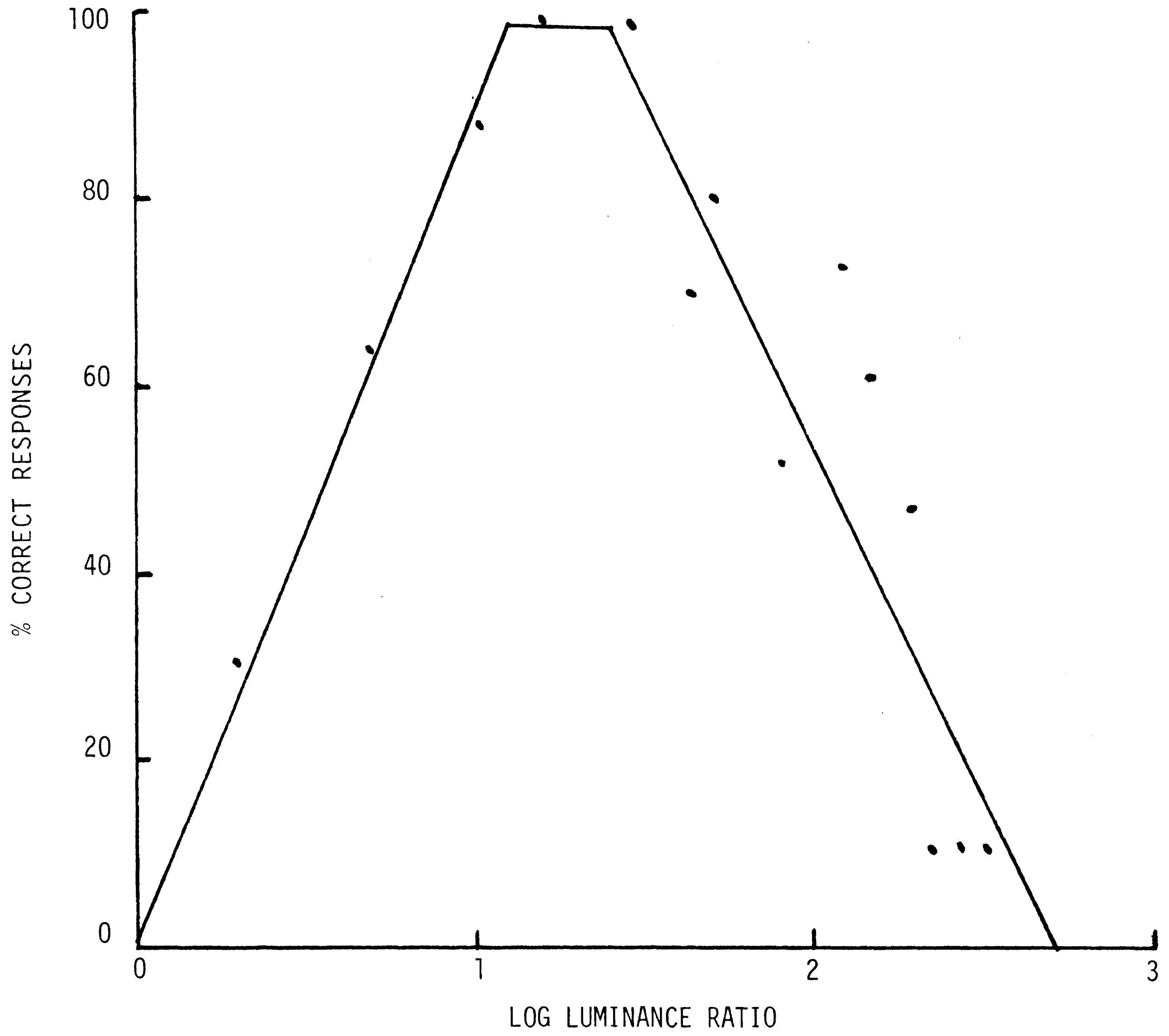


Figure B-9. An example of 3 best straight lines computer fit to visual acuity data, the dots represent the average data of 3 normal subjects for a 60 ft/in (7.2 m/cm) white legend on a green background of .1 ft-L (0.34 cd/m^2).

RESULTS

A brief summary of the results of this investigation has been given in Chapter 2. A number of significant variables were identified. These shall now be discussed in detail.

Sign Luminance. Both background and legend luminance are of importance as factors in sign legibility. It is clear from the results that maximum legibility distances are achieved by appropriate combinations of both background and legend luminance.

These data are illustrated by Figure B-10 which shows percent correct identification of the Landolt ring target as a function of the luminance of the sign background and the luminance contrast provided by the legend. This figure happens to be for a white on green combination and is based on the performance of the young normal subjects with the 60 ft/inch (7.2 m/cm) target. It is typical in form to all other combinations tested. (It will be noted that the 0.1 ft-L curve differs somewhat from that shown in Figure B-9. This is because B-9 is based on the first sample of 3 subjects and Figure B-10 includes data from all 7 subjects tested with the white on green configuration.) There is one curve for each of the four background luminance levels used. Several points should be noted:

1. For each background luminance level there is a region where performance improves with increasing legend luminance contrast. This is followed by a region where performance peaks and becomes more or less stable. Finally, there is a region where increasing legend luminance is associated with a decline in performance. An exception to the latter is the 10 ft-L (34.3 cd/m^2) curve. For this condition the maximum contrast obtainable with the equipment used was 22:1. In this range no performance decline was noted.

2. Peak performance for the two lowest background luminance levels is similar. Peak performance improves for higher background luminance levels.

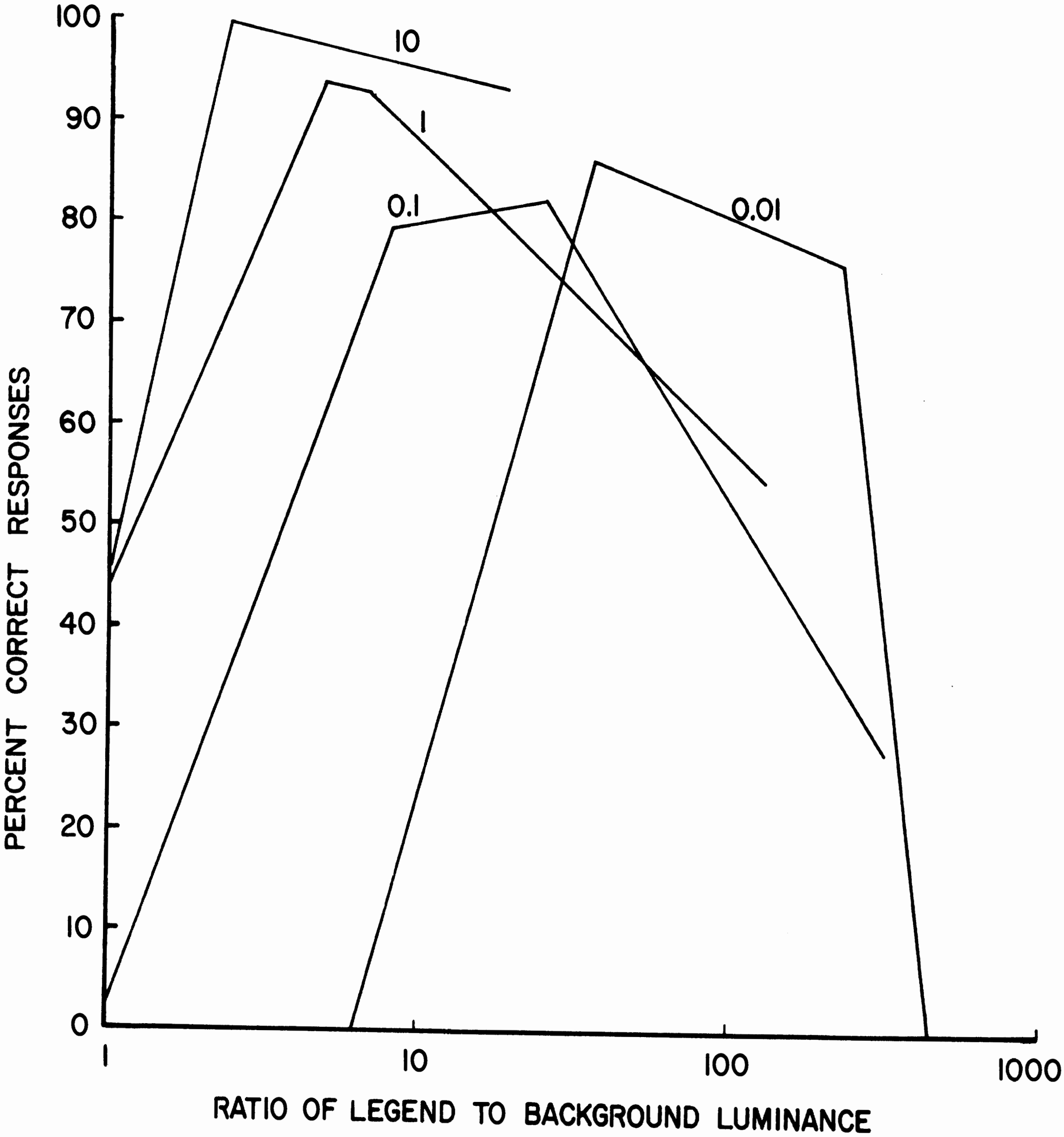


Figure B-10. Percent correct identification of acuity target as a function of background luminance (shown on curves, in foot-Lamberts) and the luminance ratio provided by the legend. Young, normal subjects, white on green sign, 60 ft/inch (7.2 m/cm) letter size. (1 ft-L = 3.43 cd/m^2)

3. The contrast ratio at which peak performance is achieved becomes lower as background luminance increases.

Another way of looking at these data is provided by Figure B-11. This shows the legend luminance ratio associated with 85% correct performance for different size Landolt ring targets and background luminances. (The lines are dashed above 60 ft/inch to indicate extrapolations. Data were taken using a 70 ft/inch character but the results were abnormally low, indicating that the character may have been defective.)

Figure B-11 illustrates again that equivalent legibility distances require more legend luminance contrast as background luminance decreases. What this figure also shows is that significant legibility distance is possible with no luminance contrast, if the background has sufficient luminance. In this case legibility distances of about 47 ft/inch letter height (5.64 m/cm) were measured at a contrast ratio of 1 for backgrounds of 1 and 10 ft-L (3.43 and 34.3 cd/m^2). This is the result of color contrast. It appears that color effects are not significant at levels below 0.1 ft-L (0.34 cd/m^2).

A further look at color contrast effects is provided by Figure B-12. This figure shows the percent correct responses measured using a contrast ratio of 1, different legend sizes, and different background luminances. At 0.01 ft-L (0.034 cd/m^2) no color effect could be measured. (Subjectively, at this level the background appeared gray, not green.) Increasing background luminance by a factor of 10 resulted in an appreciable color contrast effect. Further increases in background luminance brought about significant improvements in legibility, although there is some evidence of a leveling above 1.0 ft-L (3.43 cd/m^2).

Background Color. All effects discussed so far have been specific to the white on green combination, although representative of red and blue backgrounds as well. White on black as well as

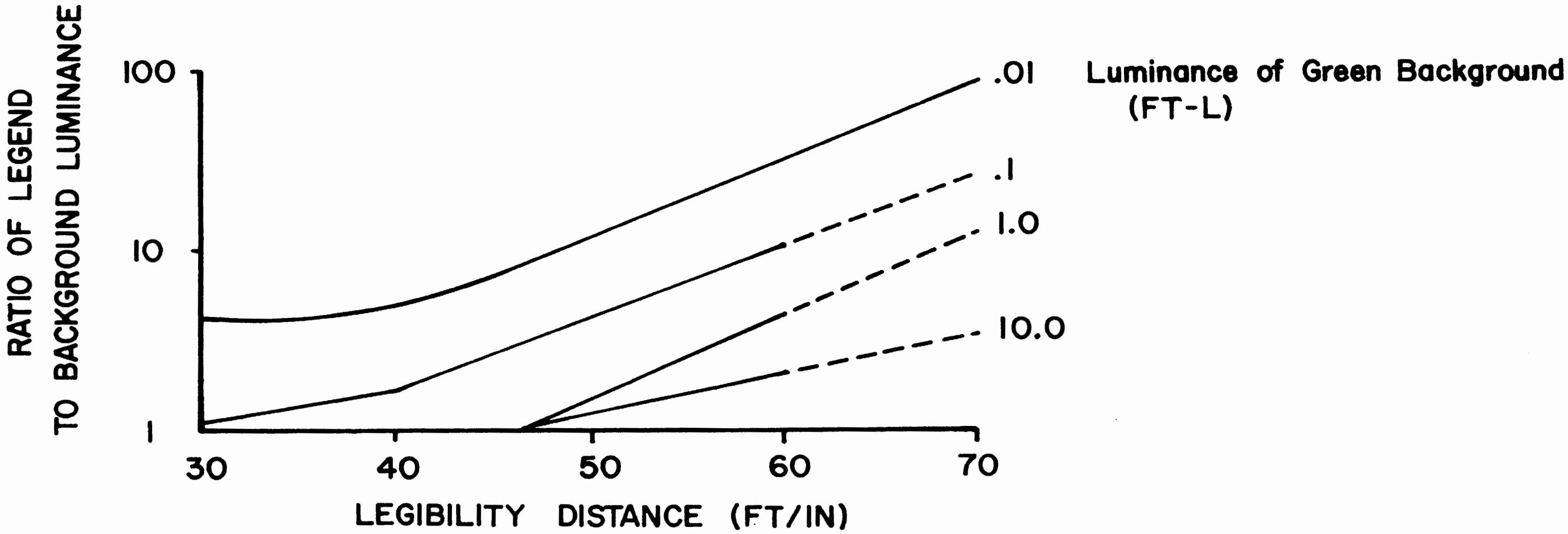


Figure B-11. Required legend luminance ratio for 85th% performance for a white legend on a green background; young normal subjects. (1 ft-L = 3.43 cd/m^2)

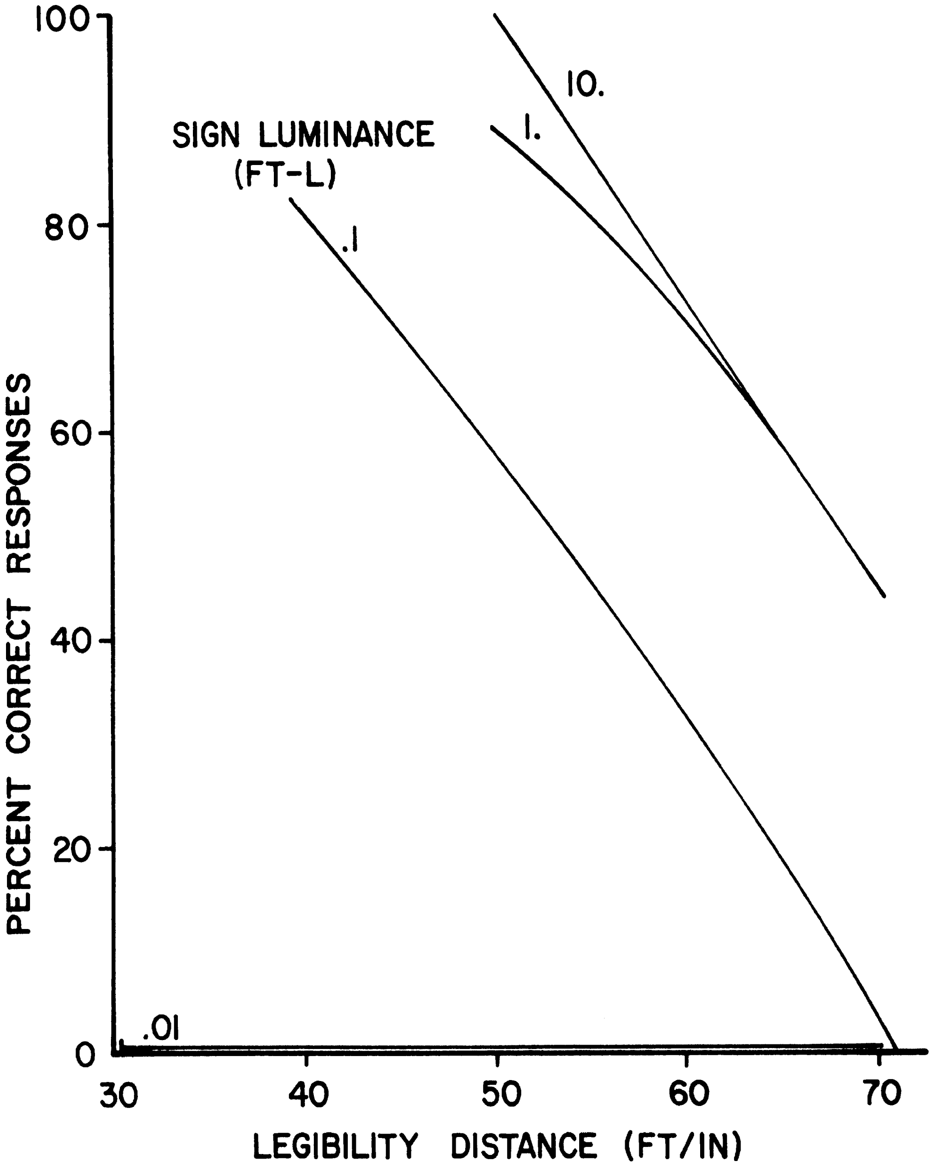


Fig. B-12, **The Effect of Color Contrast and Sign Luminance on Visual Acuity, White Legend on Green Background, No Luminance Contrast.** (1 ft-L = 3.43 cd/m^2)

black on white, orange and yellow are somewhat different cases which will be discussed shortly.

The results for blue backgrounds compared very closely with those for green. Such differences as were noted indicated that blue required somewhat lower levels of legend luminance to achieve the same legibility as green. (Forbes [1976] also found blue to be somewhat better in this respect than green.) However, these differences were slight, and of little practical consequence. Peak legibility distances were the same for blue as for green. For all practical purposes it is possible to use green background data to predict the legibility of blue background signs.

At the highest background luminance levels tested, the red and green data compare well. At levels of 1 ft-L (3.43 cd/m^2) and below legend luminance contrast had to be increased by a factor of 1.7 on a red background in order to achieve legibility performance equivalent to green. In practical terms, this means that using green data to predict the legibility of red signs would result in overestimations by perhaps as much as 5%.

The data for white on black are of particular interest here because, as noted in Chapter 1, this combination has been used in several studies. Figure B-13 shows percent correct identification as a function of legend luminance for two sizes of Landolt ring, 50 and 70 ft/inch (6 and 8.4 m/cm) letter height. For the larger character performance was best in a range from about 0.1 to 50 ft-L (.34 to 171.4 cd/m^2). The smaller character indicates an optimum luminance under these conditions of about 2 ft-L (6.9 cd/m^2). This figure is somewhat lower than indicated by the other studies described in Chapter 1 (i.e., 10-20 ft-L [3.43 and 68.6 cd/m^2]). However, the other studies used procedures which allowed the subjects to respond when they had sufficient confidence to do so. A forced-choice procedure, such as was used in this study, would be expected to yield lower thresholds because it measures visual capability alone, not confounded with subjective confidence levels. With that

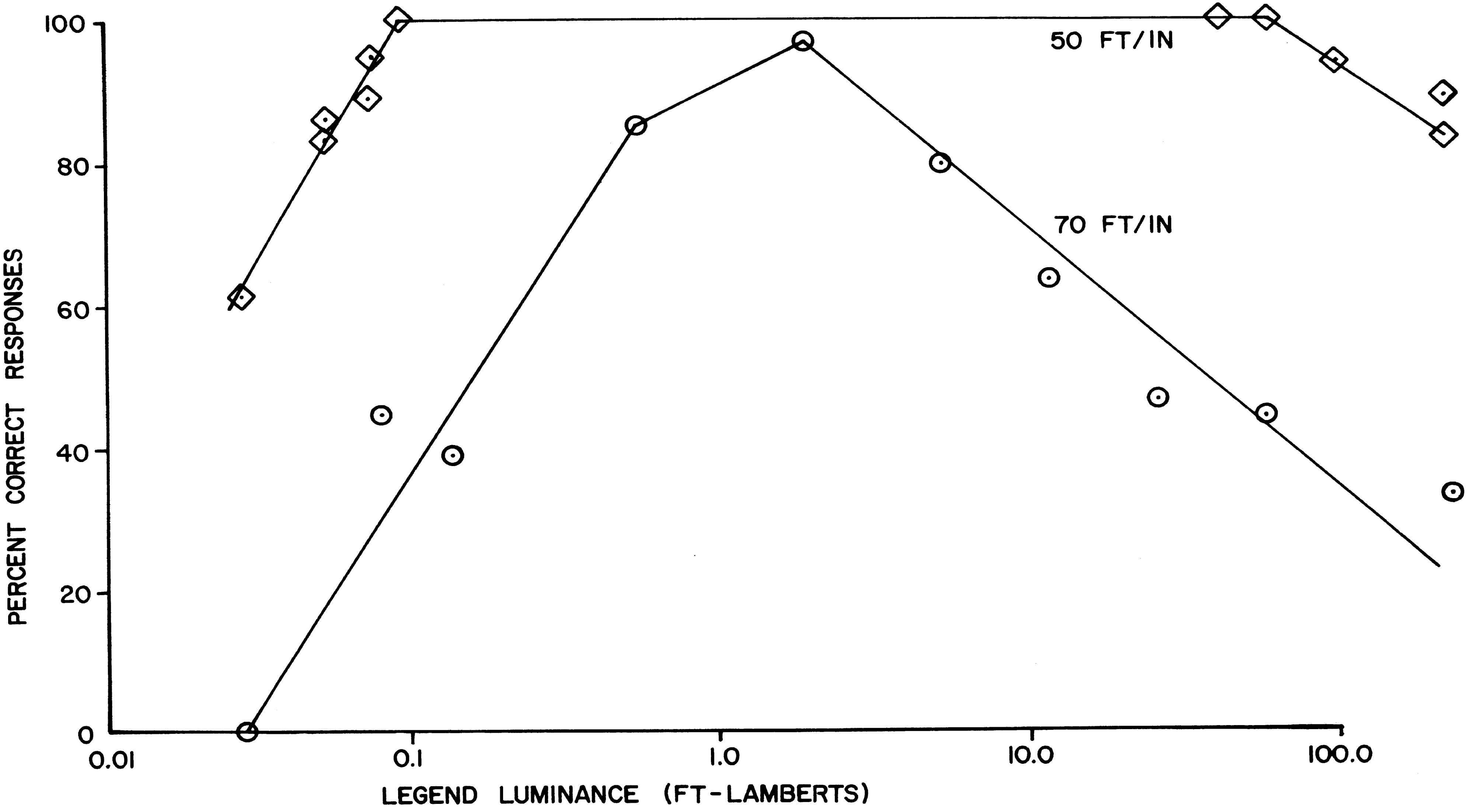


Figure B-13. Visual acuity performance of young subjects for a white Landolt C on a black background. (1 ft-L = 3.43 cd/m^2)

point in mind, the authors feel the comparison is quite favorable.

It should be noted that the data for black backgrounds are generally similar to those for colored backgrounds at the lowest luminance level tested. For example, note Figure B-11 where maximum legibility distance for the 0.01 ft-L (0.034 cd/m^2) background was achieved at about 1 ft-L (3.43 cd/m^2). This is consistent with the other findings referred to, which noted loss of color contrast effects at the lowest background luminance levels.

Positive contrast combinations tested included white, yellow and orange backgrounds. The results were similar and are illustrated in Figure B-14 for black on yellow. This figure shows the percent correct responses to two sizes of Landolt ring as a function of background luminance. As in the case of the negative contrast combinations, the results are characterized by a region of improving performance as luminance increases, followed by a plateau region of relatively stable performance. Within the range tested there was no evidence of a region of declining performance. This may result from irradiation effects "enlarging" the gap in the Landolt ring. Hence, it is probably safest to assume maximum legibility in the range from 1 to 10 ft-L (3.43 to 34.3 cd/m^2), as in the case of white on black. This is appropriate because it will be noted that performance begins to asymptote in this region for both types of configuration.

The data provide evidence for systematic differences in the luminance required for equivalent performance. This is illustrated in Figure B-15. The white background required the lowest luminance in order to achieve a given performance level, followed by orange and yellow. In no case are the differences very great. The only other investigator to report on similar color combinations is Forbes (1976). His data also suggest that white is the more efficient background (in terms of legibility distance per unit luminance), however he found yellow better than orange, the opposite of what is reported here. The authors can offer no explanation for this difference at this time.

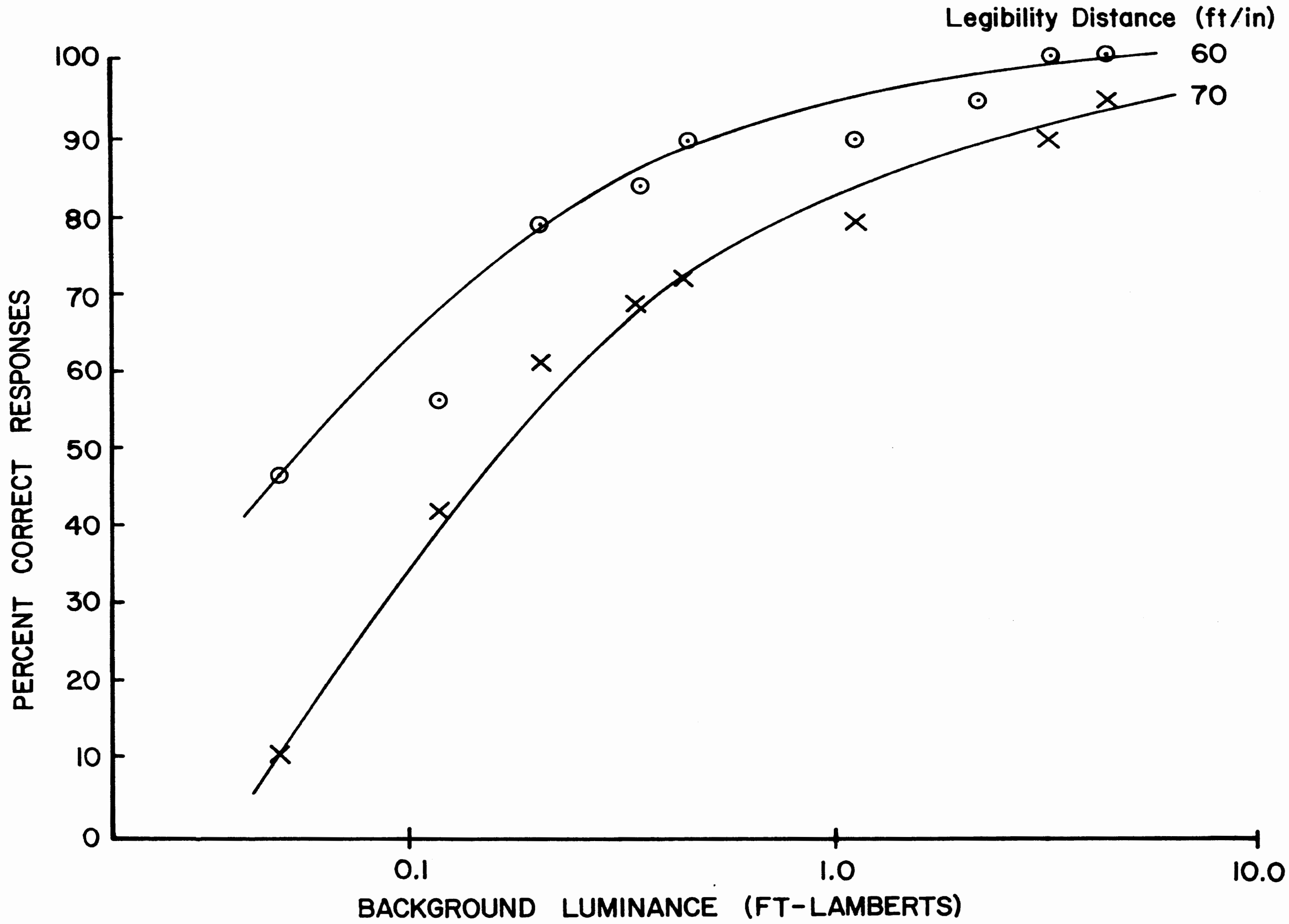


FIG. B-14, Visual Performance for a Black Legend on a Yellow Background; Young Subjects.

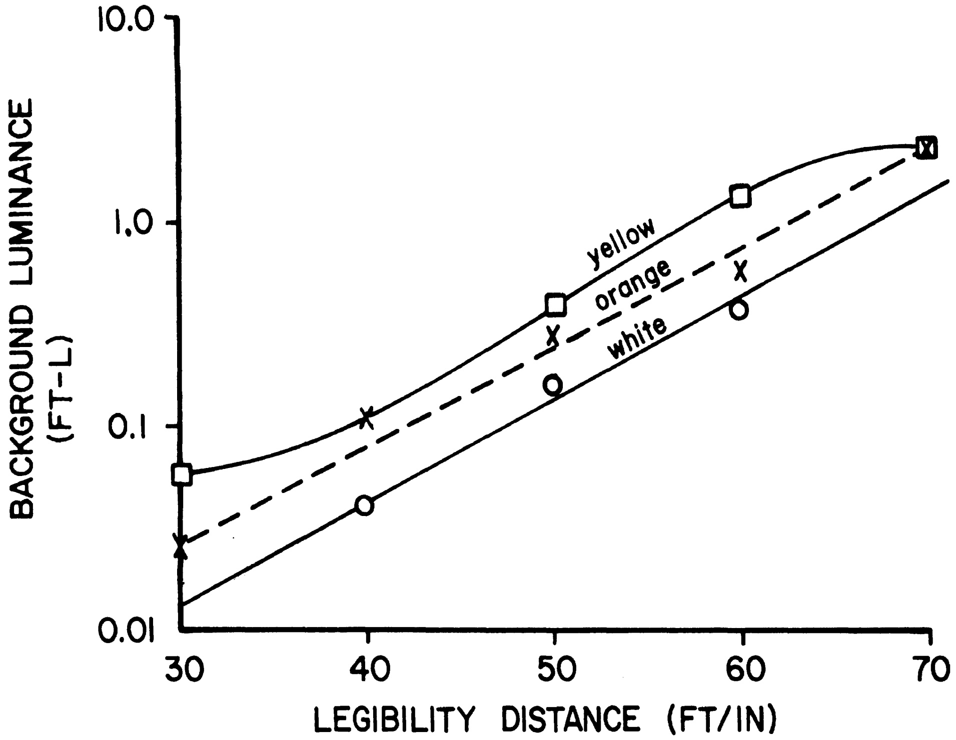


Figure B-15. Background luminance required for 85th percentile performance by young, normal subjects. Black legend on a yellow, orange and white background. (1 ft-L = 3.43 cd/m^2)

Subject Characteristics: Low Contrast Acuity. A comparison of the performance of normals and low contrast subjects is provided by Figure B-16. This figure has the same format as Figure B-10. It shows the percent correct identification of two sizes of Landolt ring (30 and 50 ft/inch [3.6 and 6.0 m/cm] letter height) at two background luminance levels (0.01 and 1.0 ft-L [0.03 and 3.43 cd/m^2]) for normal and low contrast (LC) subjects as a function of legend luminance contrast. Comparisons should be made between pairs of curves which differ only in subject characteristics. There are four such pairs. Two aspects of the data are particularly significant:

First, peak performance for both groups compares rather well. That is, both groups reached or exceeded an 85% correct level at some point.

Second, in all cases the luminance contrast required by the low contrast group, in order to match the performance of the normal group, is substantially greater. In three of the four cases illustrated, about ten times more luminance contrast was required by the low contrast group. This latter finding has significant implications for sign design, and will be more fully discussed later.

Subject Characteristics: Age. It will be recalled that younger and older subjects were matched as closely as possible on vision variables. The older group did tend to have poorer low contrast acuity scores though. This is important to remember while examining Figure B-17, which provides a basic comparison of the performance of the younger and older groups. This figure has the same format as Figures B-10 and B-16. It illustrates the relationship between legend size (40 and 60 ft/inch [4.8 and 7.2 m/cm] letter height), background luminance (0.01 and 1 ft-L [0.03 and 3.43 cd/m^2]) and luminance contrast for the two age groups. Four pairs of curves are shown and comparisons should be made between curves which differ only in age identification (Y vs. O).

The picture here is substantially different than for the low contrast subjects. There is some evidence of a need for greater

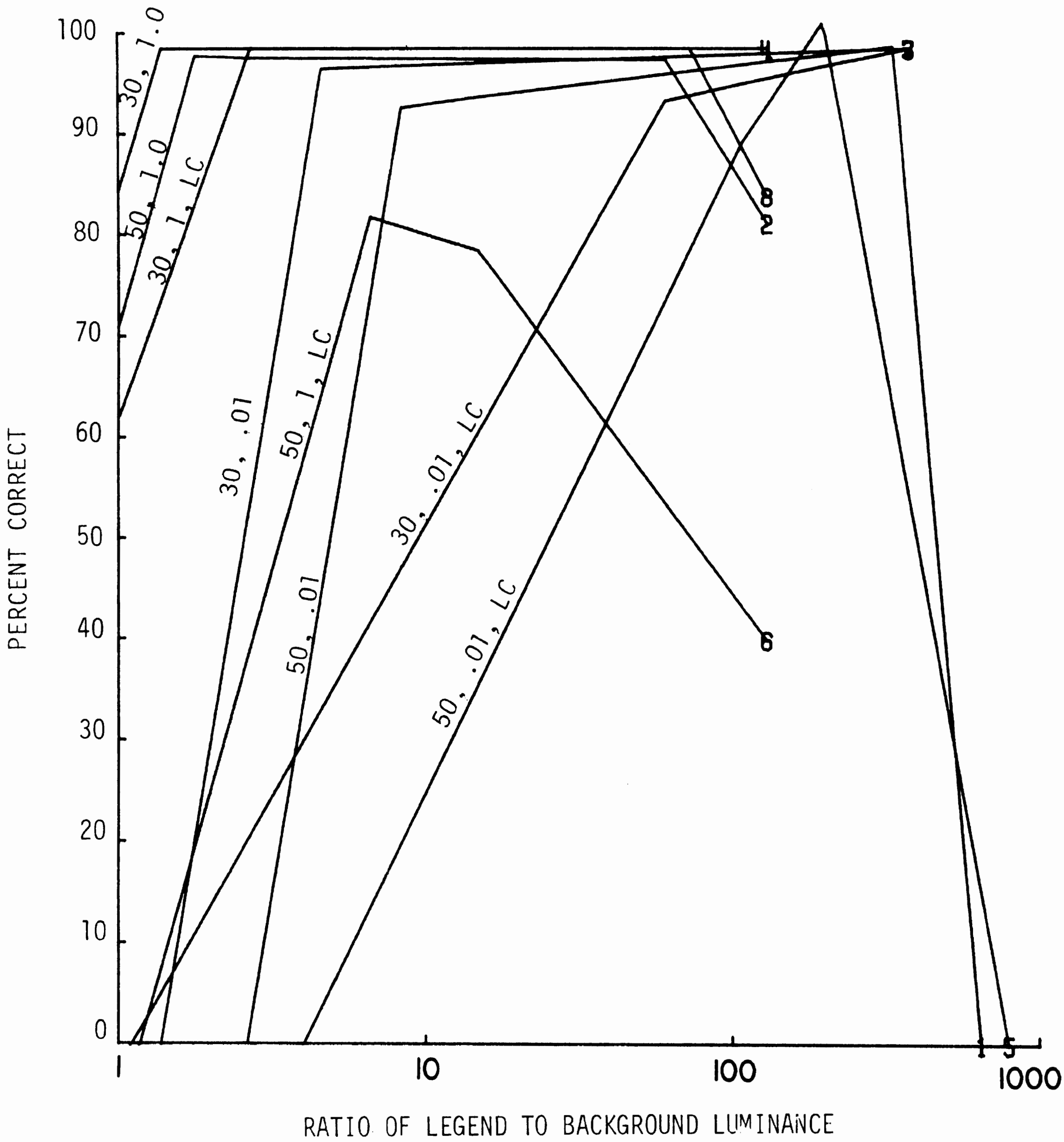


Figure B-16. A comparison between the visual performance of normal subjects and subjects who have poor low contrast (LC) acuity, white Landolt C on green background. (1 ft-L = 3.43 cd/m^2)

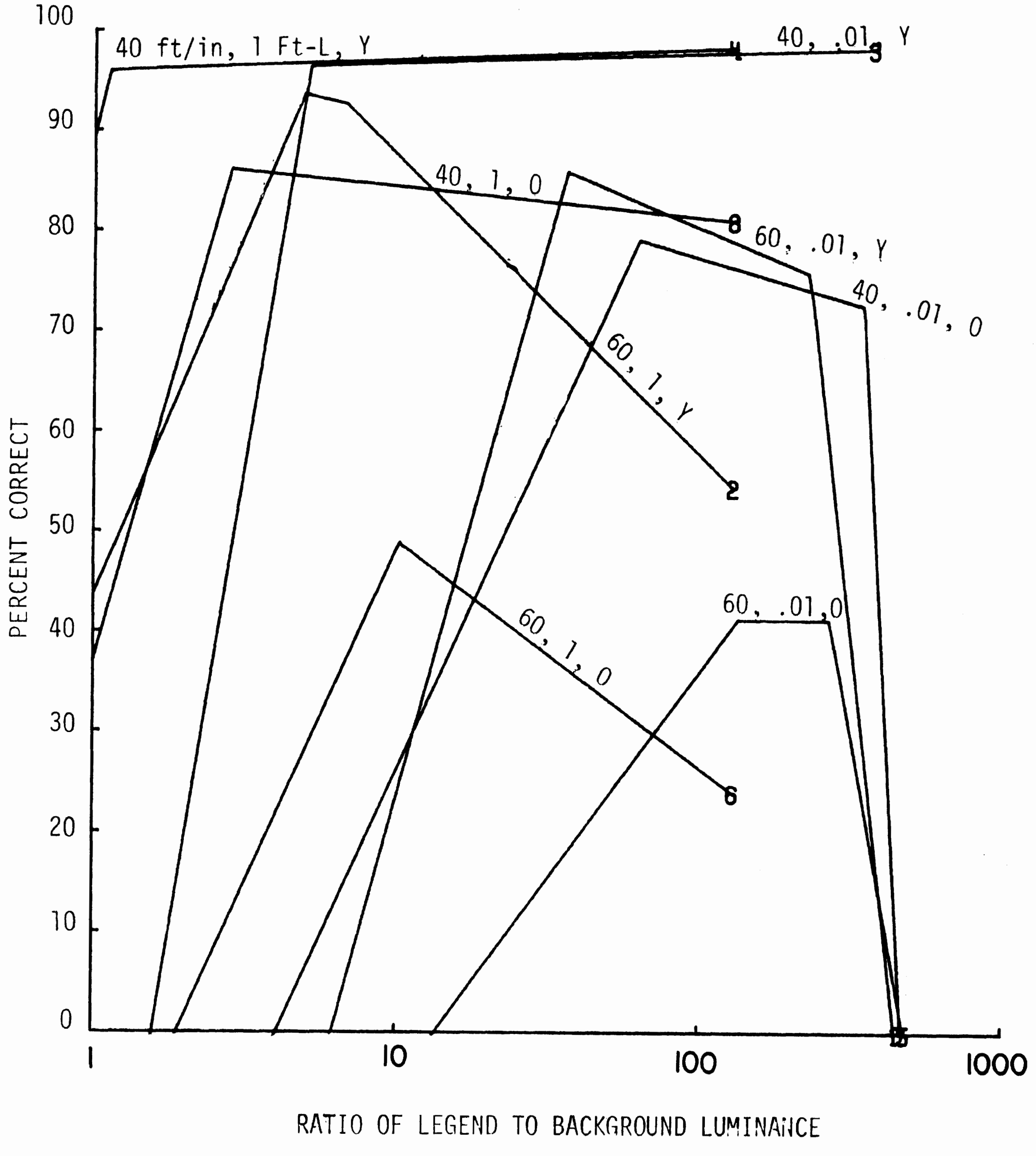


Figure B-17. A comparison between the visual acuity performance of younger and older subjects; white legend on a green background. (1 ft-L = 3.43 cd/m^2)

contrast on the part of the older subjects, especially for the larger legend. However, the differences are not generally as large as in the case of the low contrast subjects. The main difference is in the much poorer performance of the older subjects. While the younger subjects scored at least 85% correct on all combinations at some point, the older subjects managed to do that well on only one combination (40 ft/inch letters, 1 ft-L). The results are all the more remarkable when one considers that the original visual screening was carried out using Landolt ring targets, and the participants in each group matched on the basis of those scores.

Figures B-18 and B-19 illustrate the performance of the older subjects on the blue and red background configurations. Data for the younger subjects are not shown. It will be seen that the red and blue data are very close to those for green, with the exception of the higher luminance condition with blue (Figure B-18). The older subjects actually did somewhat worse under this condition than under the low background luminance condition, the only time such a reversal occurred in the entire experiment. No explanation can be offered for this anomaly at this time.

Although the older subjects did significantly worse than the younger subjects under the negative contrast conditions as noted in Figures B-17, 18 and 19, their relative performance was even poorer under positive contrast conditions. Percent correct identification peaked at no better than about 60% for the 40 ft/inch (4.8 m/cm) letter height condition and the subjects could extract no information at all using the 60 ft/inch (7.2 m/cm) character.

Surround Luminance. The effect of surround luminance was quite straightforward. Increasing surround luminance through the range tested increased legibility distance and reduced the effect of high legend luminance, especially for low background luminance conditions. For the specific levels used in this study the increase in legibility distance was in the 5 to 10% range.

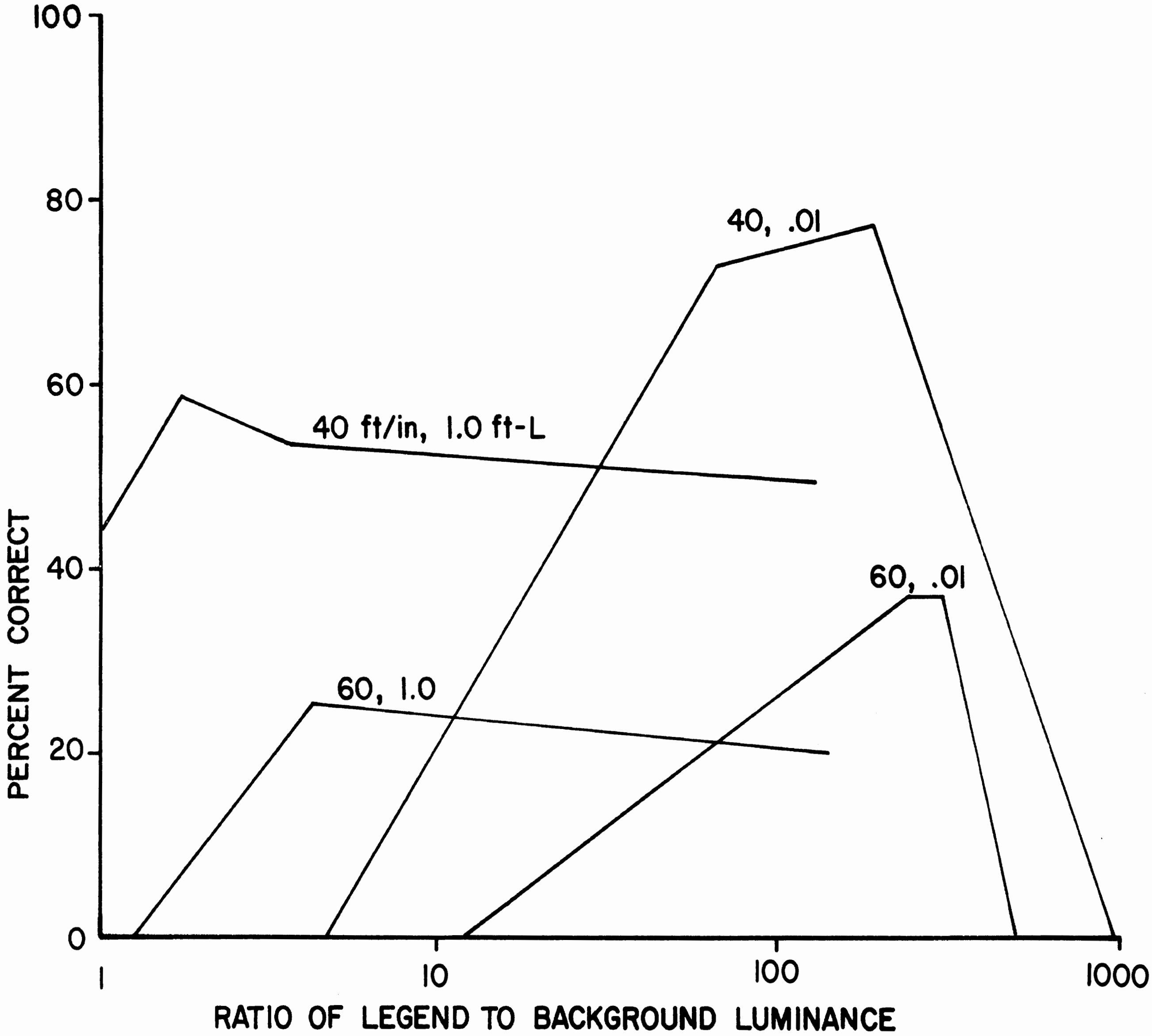


Figure B-18. Visual acuity performance of older subjects, for a white Landolt C on a blue background. (1 ft-L = 3.43 cd/m^2)

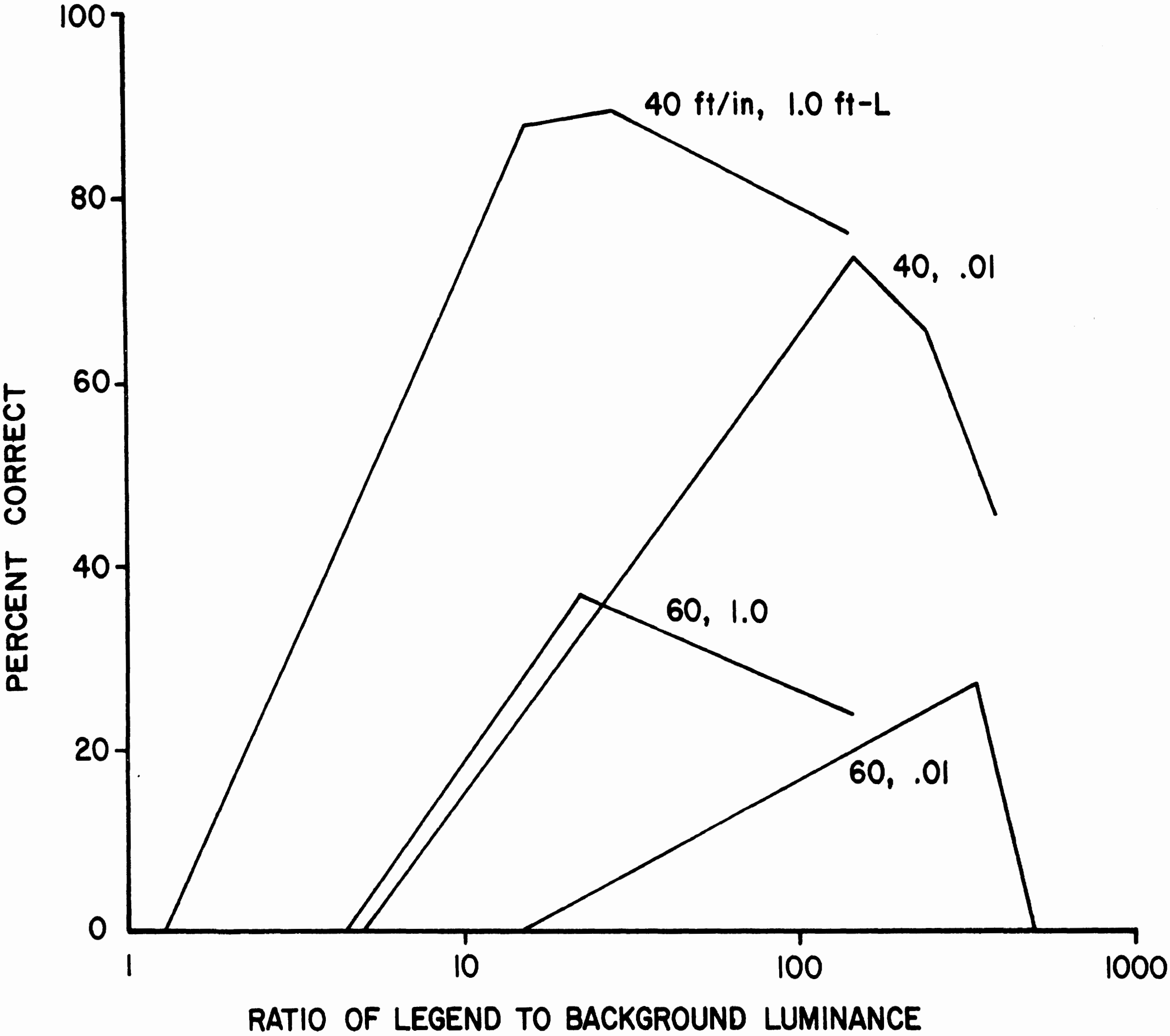


Figure B-19. Visual acuity performance of older subjects for a white Landolt C on a red background. (1 ft-L = 3.43 cd/m^2)

DISCUSSION

The results of this study have provided a great deal of valuable information applicable to the design of highway signs. Some of the more pertinent points are as follows:

1. Contrary to the results reported by some other investigators, low luminance sign backgrounds do not produce maximum legibility distances. This is an important point. It means that legibility conspicuity, and retention of color coding are compatible and are aided by the use of highly reflective materials or illumination.

It appears that the upper limit for sign background luminance will be determined by the point at which it becomes a disability glare source to the driver. The effect of a glare source depends on factors such as its intensity, angular relationships to other objects being viewed, dark adaptive state of the observer and, perhaps, its size. The maximum background luminance used in this test (negative contrast) was 10 ft-L (34.3 cd/m^2), and was designed to encompass the range of materials presently available or known to be under development. One would rarely, if ever, encounter a green, blue or red sign at this level today. A sign at one-tenth that level would be considered "bright" by most observers. As it happens, the two illuminated signs used in the field study reported in another section of this paper were illuminated to rather high levels (2 and 5 ft-L). They are situated at a major interchange in an otherwise dark rural area. Although this is an entirely subjective impression, these signs do not appear to pose a glare problem. It may be that 10 ft-L (34.3 cd/m^2) is not excessive for major signs set well above or off to the side of the road. It may be excessive for signs very close to the road. It seems clear that disability glare is not a problem with present retroreflective signing materials, nor should it be with materials which may be introduced in the near future. Research to define an upper limit for reflectivity may be beneficial as a guide to later development, however.

2. Optimum legibility requires that both legend and background luminance be considered. The results suggest that many types of signs could benefit from more contrast. However, especially in the case of signs having low background luminance, it is easy to have too much contrast, with consequent loss of legibility distance.

3. Color contrast is an important factor in sign legibility. It becomes operative at some point between 0.01 and 0.1 ft-L (0.03 and 0.34 cd/m^2) and increases at higher levels, perhaps leveling out at about 10 ft-L (34.3 cd/m^2).

4. The luminance of the sign surround is a significant factor. It appears that sign legibility improves with increasing surround luminance. It is important to remember that these data are based on uniform surround luminance conditions, which is not the way real world surrounds appear. Given extreme non-uniformity of surround, especially very bright sources close to a sign, the situation would be expected to change significantly for the worse. There are no data at present to provide guidelines for evaluating disability glare effects on sign legibility. It would be helpful if such information could be developed.

5. Differences in legibility associated with color are relatively minor. All configurations having one black element (either legend or background) yielded similar performance, except for the region of declining legibility associated with high luminance for a white on black configuration. Negative contrast conditions, where both elements have significant luminance, also yield similar performance and compare well with white on black at the lowest background luminance levels tested. Such performance differences as do exist between colors are of little consequence in the context of sign luminance guidelines.

6. Performance differences associated with subject classifications are very significant. The well-known 50 ft/inch (6 m/cm) letter height rule of thumb was developed using younger observers, the visual characteristics of whom were unknown but were probably

mostly near normal (20/20 [6/6]). These standards have often been criticized, usually on a basis that persons with far acuity as poor as 20/40 (6/12) can qualify for licenses in most states.

The data from this test suggest that the ordinary Snellen test for far acuity is a poor predictor of the ability to read highway signs. Clearly, more work is required to adequately define the visual correlates of driving ability, even for so basic a task as reading highway signs.

EXHIBIT B-1

SUBJECT INFORMATION FORM

EXHIBIT B-1

We will be conducting a study of the visibility of road signs. It is a laboratory test in which the subject has brief glimpses of simulated highway signs and tries to read the legend.

Today we would like you to fill in the form below and take a simple vision test. Depending on the results of that test, we may ask you to participate in the study.

We need a few people who are willing and able to participate for about seven days. These days would be scheduled at the convenience of the participants and spread over a month or so. The rest of the subjects will appear for one day only. We also need a few people who can participate in another phase of the test, at night, from about 7 pm to midnight (one night only). Indicate below which test you would prefer. (You may check one, two, or three options.) Please note that if you agree to the seven day test, you must complete the entire sequence before you will be paid.

If you have any questions about the test before you check a preference box, we will be happy to answer them.

7 day test	1 day test	night test
☐	☐	☐

NAME: ______________________________

SEX: M F AGE: ________

Years of driving experience: ________

Do you wear glasses (or contacts)? ☐ Yes ☐ No

If yes, can you drive without them? ☐ ☐

Telephone number: ______________

Best time to call: ______________

EXHIBIT B-2

SUBJECT INSTRUCTIONS

EXHIBIT B-2

SUBJECT INSTRUCTIONS - SIGN LABORATORY STUDY

This is a study of the legibility of highway signs. We are trying to find out how bright the background and legend of a sign have to be to be legible at the greatest possible distance.

The brightness of the sign you will see depends very much on your viewing position. To control for this it is necessary that you place your head in the yoke device in front of you. Try it now; adjust the chin rest up or down until it comfortably supports your head so that the lower shield blocks the projector to your left front. Your view of the TV and "black box" at the far end of the room should be about centered between the upper and lower shields.

Now, remove your head from the yoke for a moment. There are two things which you must do in this study. The first of these is a tracking task something like driving. The idea is to keep the dark bar on the TV set centered about halfway across the screen. You move the bar back and forth by moving this toggle right or left. Do this all the time the experiment is in progress.

Periodically we will give you a brief glimpse of a simulated sign. This will appear in the black box to the right of the TV. You will be warned that the sign is about to appear by a "beep" tone two seconds prior to its appearance. The sign legend consists of a single character, called a Landolt ring, which looks something like a letter "C." The gap in the ring can be oriented in any of four positions, top, bottom, right or left. When the sign is displayed you should try to determine the gap position. Then press one of the red buttons on this box to indicate the quadrant in which the gap appeared, top, bottom, right or left. In some cases the ring may be so faint you can't see it at all. If so, press the yellow button in the middle. However, if you can see the ring press one of the red buttons, even if you have to guess. This is very important. Use the yellow button only if you can't see the ring, don't use it to indicate that you are unsure of the gap position.

There is another use for the yellow button, by the way. Should you inadvertently press the wrong red button you can press the yellow button, which cancels the first response on my panel around the corner, and then press the correct red button.

That's about it. You will be seeing a variety of background colors and brightnesses on the sign and we will change the illumination on the wall behind the black box as well. We will tell you before we make any of those changes, however.

We realize that it is difficult to maintain a high level of interest in a study like this. You will be given frequent short breaks and longer breaks every hour or so. During these you may remove your head from the yoke and get up and move around if you like. Even so, if you become tired, as a series of trials is in progress, let me know and we will take a break. If you try to continue when very tired your performance will deteriorate and this messes up the data. Also, if you miss a trial for any reason let me know and we will repeat it.

Any questions?

APPENDIX C

FIELD VALIDATION STUDY

FIELD VALIDATION STUDY

PURPOSE

This study was conducted for two reasons: First, to verify that legibility distances predicted on a basis of the laboratory and analytical work approximated legibility distances obtained under real-world conditions.

Second, to determine what, if any, changes would be required to the laboratory data to correct for differences between laboratory and field procedures.

METHOD

In order to properly validate the model developed in this study it is not necessary to fully replicate all the conditions tested in the laboratory. An appropriate strategy is to test a substantial number of combinations of variables scattered throughout the matrix of possibilities. If the model can successfully predict the performance associated with these, there is no reason to believe it would not do equally well with the others.

Based on the laboratory data, the two variables of greatest significance are background luminance and legend luminance. Thus, these were the variables stressed in the field study.

Two field studies were conducted. The first of these was carried out using a private road at an airport near Ann Arbor. This shall be referred to as the "airport study." Small special signs were fabricated for the study and an acuity criterion was used, as in the laboratory investigation. The second study was carried out using existing signs along a section of freeway. The criterion here was the distance at which the subjects could read the legends well enough to understand what they said. This shall be referred to as the "freeway study."

Airport Study

Variables. The object of this study was to present as wide a range of background luminances and contrasts as possible, using currently available materials. For sign backgrounds there are basically three choices. These are listed below, together with the approximate photometric specifications (cd/ft-c/ft^2 for green materials, 0.2 and -4 degrees).

1. Non-reflective (0.1)
2. Moderately reflective sheeting (10.0)
3. Highly reflective sheeting (30.0)

For legend materials four levels were chosen. These are listed below with approximate photometric specifications (white):

1. Buttons (600)
2. Highly reflective sheeting (250)
3. Moderately reflective sheeting (70)
4. Moderately reflective sheeting - reflectivity 2 (50)

(Note that the specific luminance value for buttons is a "sheeting equivalent," derived from the button-sheeting study described in Appendix E.)

These data can be arranged in matrix form, as has been done below. The numbers in the cells are approximate luminance contrast ratios. The letters a through l are used to label the cells.

		BACKGROUND SPECIFIC LUMINANCE		
		0.1	10.0	30.0
Legend Specific Luminance	600	a 6000	b 60	c 20
	250	d 2500	e 25	f 8.3
	70	g 700	h 7	i 2.3
	50	j 500	k 5	l 1.7

For this study, buttons and the least reflective sheeting legend materials were viewed against all three backgrounds. All four legend materials were viewed against the highly reflective background, (cells a, b, c, f, i, j, k, and l). Three legend sizes were utilized (6, 10 and 15 inches [15.2, 25.4 and 38.1 cm]) and both high and low beams. This resulted in a total of 48 experimental conditions (8 contrast conditions x 3 legend sizes x 2 beams).

Test Signs. All the sign backgrounds were three feet square (0.91 m^2). The two reflectorized units were made by attaching sheeting material to plywood panels. The non-reflectorized unit had a porcelain enamel finish and was supplied by a manufacturer of such signs. A grooved plastic ledge was attached to each background to support the letter target.

The letters were all capital "E," supplied by various manufacturers. All had a stroke width to height ratio of 0.2 and an overall height to width ratio of 0.75. These were simply placed in the plastic ledge mentioned earlier and rested against the face of the sign as shown by the photograph in Figure C-1.

The entire sign was supported on a flat black panel, as shown in Figure C-2. With this arrangement the letter was about 4.5 feet (1.37 m) above the pavement. The sign was tilted backwards at an angle of about 20^o. This eliminated specular glare but also reduced the performance of the retroreflective materials somewhat. This angle was accounted for in the modeling effort.

Facility. The test was conducted on an unused private access road to the Willow Run Airport, near Ann Arbor. The road is asphalt, has two nine-foot lanes, is 2600 feet (792 m) long and is flat and straight. There are no sources of illumination on or near the facility. It is a good approximation of a dark country road.

A schematic of the facility is provided in Figure C-3. It will be noted that at one end there is a small parking lot. The other end intersects with a little used secondary road. East of the

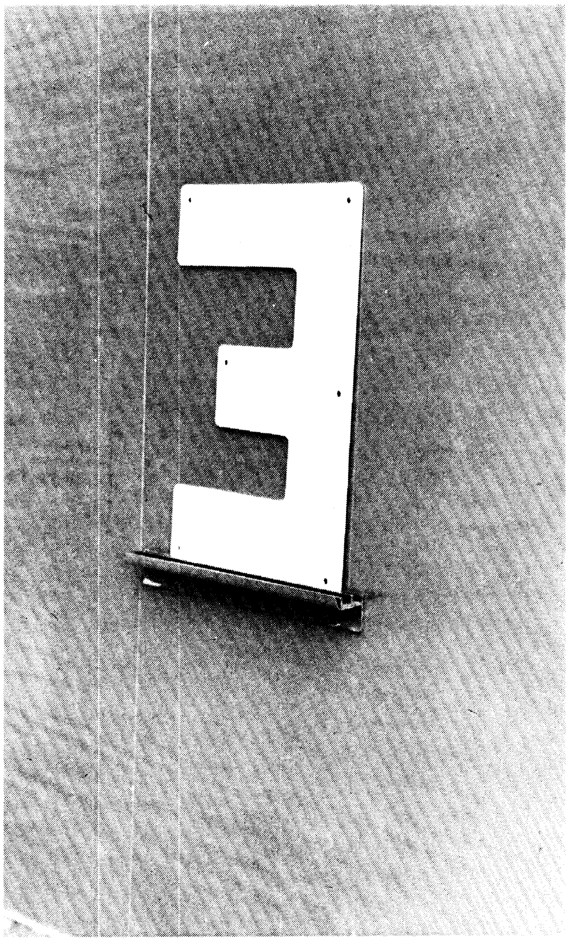


Figure C-1. Means of placing legend on test signs.

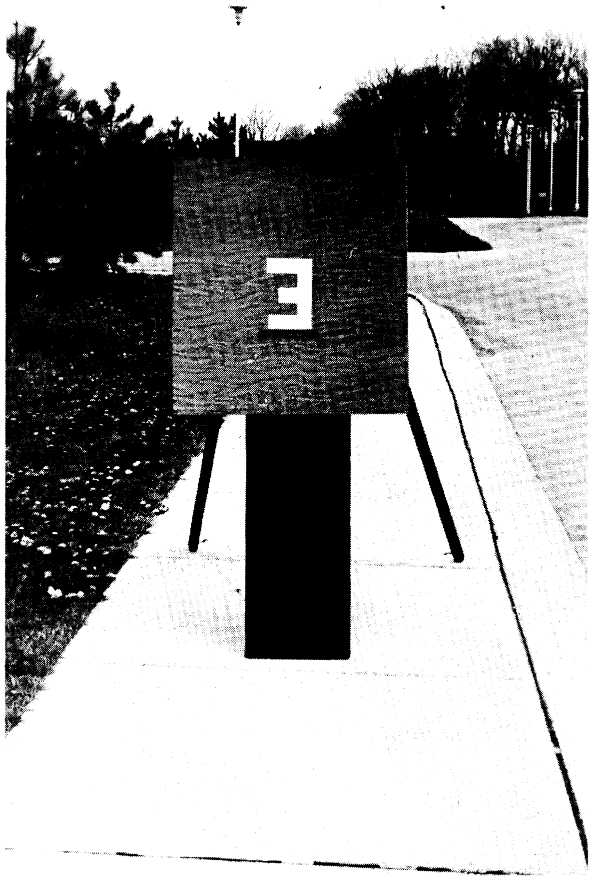


Figure C-2. Test sign placed on support panel.

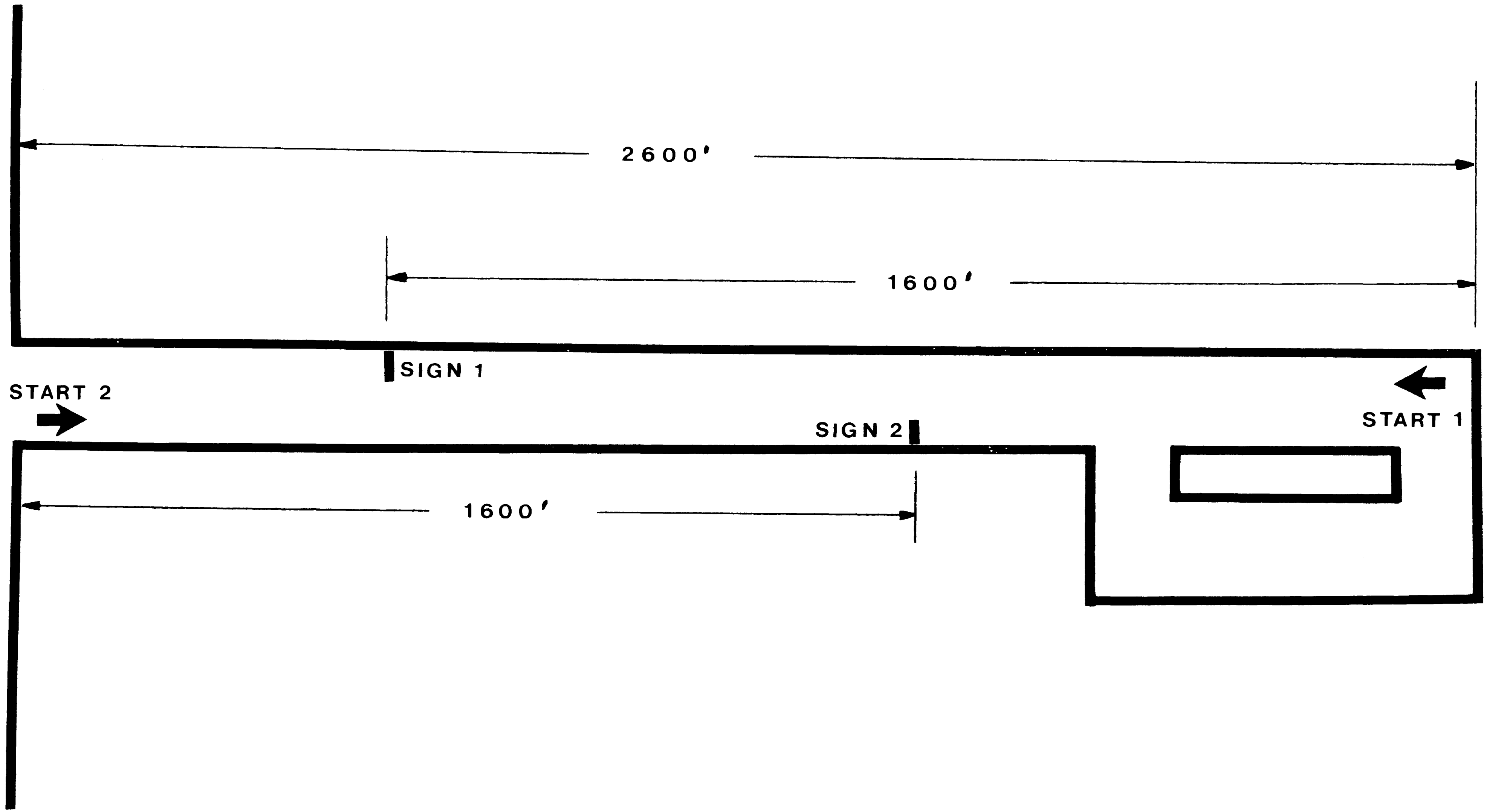


Figure C-3. Schematic of airport test road facility.

intersection the test road is a public highway. Although seldom used, an occasional car would appear beyond the signs while making eastbound runs. When this happened the run would be delayed until the headlamps had disappeared.

As shown in Figure C-3, two signs were set up, facing in opposite directions, 1600 feet (488 m) in from the ends of the road. The sign support was set on the paved surface, at the right edge. As a result the letter target was nearly in front of the right headlamp and about 2.5 feet (0.76 m) above it. Each run started with the subject vehicle at one of the indicated start positions. The driver proceeded in the right lane until it was necessary to move over to go around the sign. He or she then continued to the end of the road, turned around and started the next run.

Test Vehicle. The test vehicle was a standard full-size station wagon which has been modified for head lighting work. The vehicle has a distance measuring system with a digital readout in feet accurate to 0.1%. This readout can be videotaped.

Three subjects were run at one time, all seated in the front of the car. Each held a silent push button switch. When pressed, each switch turned on a small light bulb in the rear compartment of the vehicle. The experimenter, who sat in the second seat, also had a switch which turned on a fourth bulb. This array of bulbs was viewed by a video camera and also tape recorded. For each run then, a light came on at some arbitrary distance to indicate when each subject had identified the orientation of the letter and the last bulb came on to mark the position of the sign. By subtracting the first three measures from the last, legibility distance could be determined.

The car is equipped with a standard four unit headlamp system. These lamps were carefully aimed with calibrated mechanical aimers before the test started and at intervals during the test.

Subjects. Eighteen subjects participated in the study. All were volunteers who responded to a newspaper advertisement. They were paid for the time spent on the test.

The newspaper advertisement stressed "licensed drivers with good vision." However, each subject was checked for certain visual characteristics using a Titmus Tester before the test started. The tests were the same as used to screen the subjects for the laboratory study described earlier. The test results, together with the age and sex of the participants, are provided in Table C-1. The subjects were generally young with excellent vision. As would be expected, low contrast acuity scores were quite variable, with several individuals scoring as high as 20/35.

Procedure. The subjects reported to the Institute in groups of three. They were given the vision test and driven to the airport test road. One subject was selected to be the driver for the night and all were seated in the car. The instructions (Exhibit A-1) were read to them, all questions were answered and two practice runs given. Trials began immediately. The 48 trials took about 1½ hours to complete. A short break was allowed after the first hour. Any required make-up trials were taken at the end of the regular sequence.

The position of the backgrounds and the order in which the other variables were presented were varied systematically to compensate for order effects. The orientation of the letter "E" was changed based on a table of random numbers.

When trials had been completed at the airport test site, the subjects were driven back to the Institute to set up for the freeway study.

Freeway Study

The Freeway Study was run for two primary reasons:

First, to provide some additional data on real signs in a real driving environment.

Second, to gain an indication of the corrections which must be applied in extrapolating from the visual acuity tasks used in other

TABLE C-1. LISTING OF SUBJECTS FOR SIGN FIELD STUDY

Subject Number	Age	Sex	Normal Acuity	Lo Contrast Acuity	Stereo Depth*	Color	Vertical Phoria	Lateral Phoria
1	30	F	20/15	20/20	4	Normal	Normal	Normal
2	35	F	20/15	20/22	4	Normal	Normal	Normal
3	18	M	20/15	20/35	9	Normal	Normal	Some
4	21	M	20/13	20/17	9	Normal	Normal	Normal
5	29	F	20/13	20/15	4	Normal	Normal	Normal
6	23	F	20/13	20/17	2	Normal	Normal	Normal
7	24	F	20/17	20/20	5	Normal	Normal	Normal
8	22	M	20/17	20/20	9	Normal	Normal	Some
9	22	M	20/13	20/22	4	Normal	Some	Normal
10	21	F	20/22	20/22	6	Normal	Normal	Normal
11	22	F	20/13	20/22	5	Normal	Normal	Normal
12	21	M	20/15	20/17	4	Normal	Normal	Normal
13	26	M	20/18	20/35	3	Normal	Normal	Normal
14	18	M	20/18	20/30	6	Normal	Normal	Normal
15	23	F	20/20	20/35	2	Normal	Normal	Normal
16	23	M	20/13	20/20	4	Normal	Normal	Normal
17	18	F	20/20	20/35	7	Normal	Some	Normal
18	19	M	20/22	20/35	3	Normal	Normal	Normal

* On the Titmus tester used there are 9 graded stimuli for this test. The score shown represents the number correct.

phases of this research to actual message comprehension.

Variables: Because the study was confined to existing signs along a relatively short (15 mile) section of freeway, the range of luminances and contrasts was substantially more limited than was possible in the airport study.

Every guide sign along the road section selected was a candidate for inclusion in the study. Those which were selected had a flat, straight approach section of at least 1,000 feet and were accessible for photometry. (Some signs were so located that it was not possible to safely carry out the photometric measures which will shortly be described.) A total of 23 signs were selected. Photographs of these, together with photometric and dimensional specifications appear in Figure C-4.

Photometry. The photometry was carried out using a light source of known intensity and a Pritchard Photometer. By clamping the lamp to the roof of a station wagon and standing the photometer's tripod on the lowered tailgate it was possible to bring the light source and photometer into close proximity as required for measures on retroreflective materials. (See Figures C-5 and C-6 for photographs of the arrangement.)

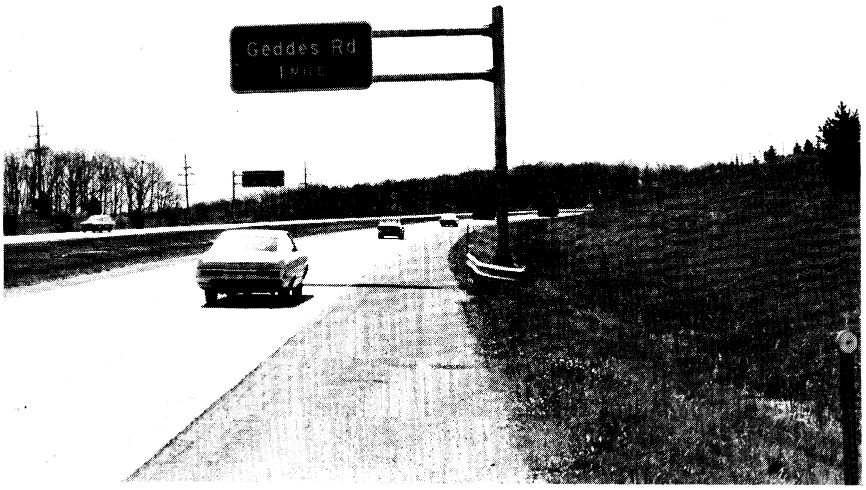
The light source was first calibrated using a sheet of white cardboard of known reflectance placed at a distance of 150 feet. From these measures it was possible to calculate the illumination falling on the signs to be photometered. The station wagon was then driven to each sign and the photometer positioned 150 feet away, using a reference mark which had been applied a few days earlier, when the photographs were made.

Because only approximate values were required, relatively few measures were made on each sign. These were generally concentrated in the region of the first letter of the place or road name on the sign (e.g., the "G" in Geddes on the first sign), unless preliminary scanning showed this area to be non-representative.

Figure C-4

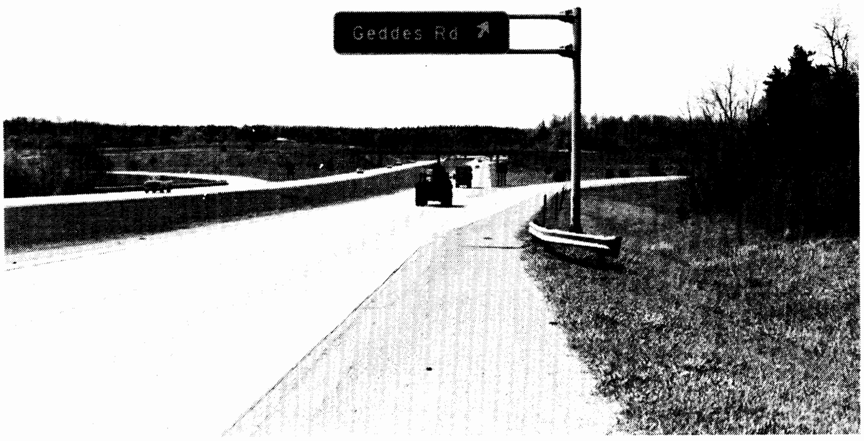
SIGNS USED IN FREEWAY FIELD VALIDATION STUDY

(Note: For each sign is shown the word[s] which the subjects were to have read, results of photometric readings, luminance contrast ratio, the letter sizes in the key word [in inches] height of the key word above the road surface [V, in feet], and, where appropriate, the distance of the first letter in the key word from the right edge of the pavement [H, in feet].)



Sign 1. "Geddes," Background - 12.6 cp/ft-c/ft^2, Legend - 47.9 cp/ft-c/ft^2, 3:5:1, 16" - 12", V =20.

Figure C-4 - Continued



Sign 2. "Geddes," Background - 14.7 cp/ft-c/ft^2, Legend - 185.4 cp/ft-c/ft^2, 12.6:1, 16" - 12", V = 19.

Sign 3. "Chicago," Illuminated sign, Background - 4.9 ft-L, Legend - 33 ft-L, 6.7:1, 16" - 12", V = 21.5.

Figure C-4 - Continued

Sign 4. "Saline," Background - 18.9 cp/ft-c/ft^2, Legend - 74.2 cp/ft-c/ft^2, 3.9:1, 16" - 12," V = 12.5, H = 20.

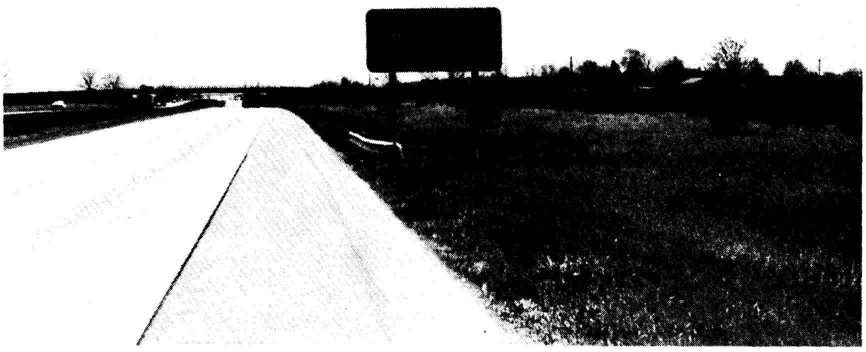
Sign 5. "Saline," Background - 10.5 cp/ft-c/ft^2, Legend - 64.9 cp/ft-c/ft^2, 6.2:1, 16" - 12," V = 13, H = 19.

Figure C-4 - Continued

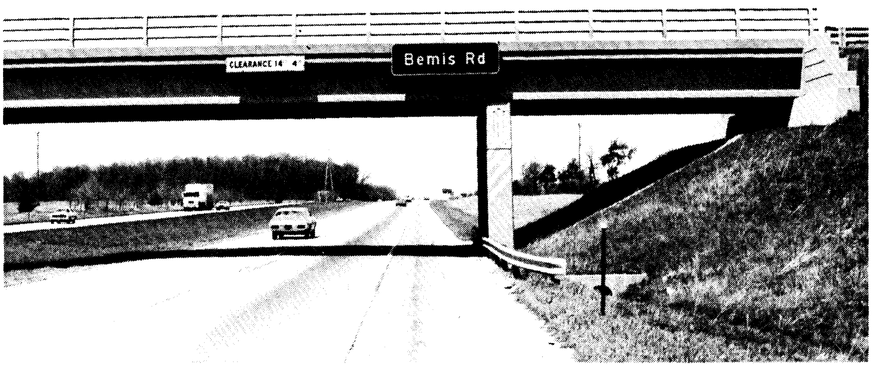
Sign 6. "Michigan Ave.," Background - 9.0 cp/ft-c/ft^2, Legend - 41.7 cp/ft-c/ft^2, 4.6:1, 13.3" - 10," V = 19.5, H = 6.

Sign 7. "Ypsilanti," Background - 20.1 cp/ft-c/ft^2, Legend - 77.3 cp/ft-c/ft^2, 3.8:1, 13.3" - 10," V = 12, H = 21.

Figure C-4 - Continued



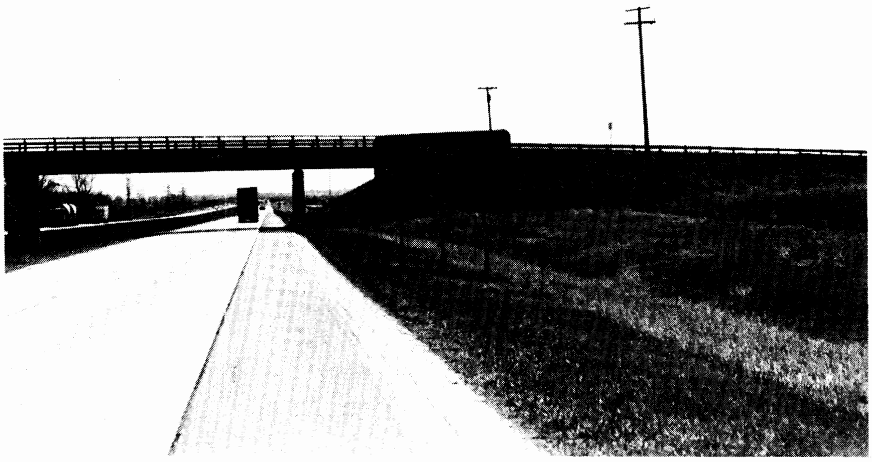
Sign 8. "Willis Rd.," Background - 26.3 cp/ft-c/ft^2, Legend - 112.8 cp/ft-c/ft^2, 4.3:1, 16" - 12," V = 11, H = 20.



Sign 9. "Bemis Rd.," Background - 10.8 cp/ft-c/ft^2, Legend - 68.0 cp/ft-c/ft^2, 6.3:1, 13.3" - 10," V = 18.5, H = 5.

Figure C-4 - Continued

Sign 10. "Willis Rd.," Background - 20.1 cp/ft-c/ft^2, Legend - 97.3 cp/ft-c/ft^2, 4.9:1, 16" - 12," V = 11.5, H = 20.



Sign 11. "Milan," Background - 9.6 cp/ft-c/ft^2, Legend - 27.0 cp/ft-c/ft^2, 2.8:1, 16" - 12," V = 11, H = 19.

Figure C-4 - Continued

Sign 12. "Federal Correctional Institution," Background - 24.7 cp/ft-c/ft^2, Legend - 58.7 cp/ft-c/ft^2, 2.4:1, 13.3" - 10", V = 13.5, H = 19.

Sign 13. "Milan," Background - 20.1 cp/ft-c/ft^2, Legend - 89.6 cp/ft-c/ft^2, 4.5:1, 16" - 12", V = 12, H = 19.

Figure C-4 - Continued

Sign 14. "Willow Rd." Background - 0.4 cp/ft-c/ft^2, Legend - 8.3 cp/ft-c/ft^2, 21.2:1, 13.3" - 10", V = 18.5, H = 5.

Sign 15. "Stony Creek Rd.," Background - 1.1 cp/ft-c/ft^2, Legend - 7.7 cp/ft-c/ft^2, 7:1, 13.3" - 10", V = 17.5, H =4.

Figure C-4 - Continued

Sign 16. "Willis Rd.," Background - 17 cp/ft-c/ft^2, Legend - 86.5 cp/ft-c/ft^2, 5.1:1, 16" - 12", V = 13, H = 20.

Sign 17. "Ypsilanti," Background - 6.2 cp/ft-c/ft^2, Legend - 92.7 cp/ft-c/ft^2, 15:1, 13.3" - 10", V = 11.5, H = 19.

Figure C-4 - Continued

Sign 18. "Willis Rd." Background - 17.6 cp/ft-c/ft^2, Legend - 92.7 cp/ft-c/ft^2, 14.7:1, 13.3" - 10", V = 17.5, H = 4.

Sign 19. "Bemis Rd." Background - 0.8 cp/ft-c/ft^2, Legend - 12.2 cp/ft-c/ft^2, 14.7:1, 13.3" - 10", V = 17.5, H = 4.

Figure C-4 - Continued

Sign 20. "Ypsilanti," Background - 10.8 cp/ft-c/ft^2, Legend - 30.9 cp/ft-c/ft^2, 2.9:1, 13.3" - 10", V = 14.5, H = 20.

Sign 21. "Coldwater," Background - 17.8 cp/ft-c/ft^2, Legend - 30.9 cp/ft-c/ft^2, 1.7:1, 16" - 12", V = 13, H = 20.

Figure C-4 - Continued

Sign 22. "Michigan Ave.," Background - 2.2 cp/ft-c/ft^2, Legend - 6.2 cp/ft-c/ft^2, 2.8:1, 13.3" - 10", V = 19, H = 4.

Sign 23. "West Chicago," Illuminated sign, Background - 2 ft-L, Legend 14 ft-L, 7:1, 16" - 12", V = 20.

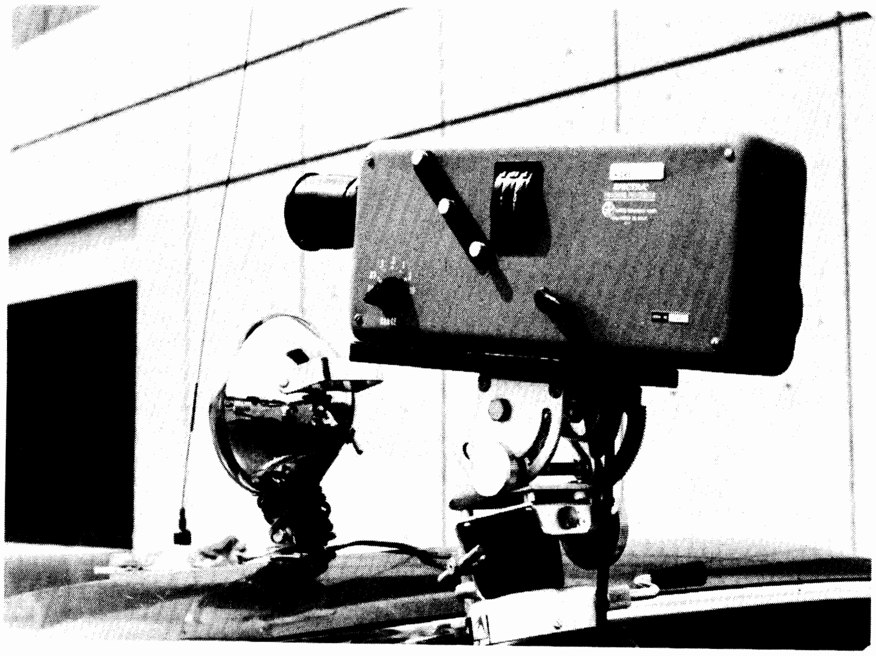


Figure C-5. Arrangement of light source and photometer used in measurements of sign luminance.

Figure C-6. Experimenter illustrating use of photometer as arranged for field measurements.

The photometric values shown in Figure C-4 thus represent approximate levels which the authors feel are typical for the signs in question. An examination of Figure C-4 makes it clear that, although there are no very bright signs (with exception of the illuminated ones), there is a substantial range of luminance and contrast values available. While the two illuminated signs differ in luminance by a factor of about two to one, both are illuminated to rather high levels, judged by values reported in the available literature.

Photometric measures were taken of the background materials for the airport study as well. It was found that the two retroreflective backgrounds departed significantly from specifications. (spec. 30 was actually 54 cp/ft-c/ft^2 and spec. 10 was actually 7.7 cp/ft-c/ft^2). It is recognized that there are substantial variations to be expected from sample to sample of retroreflective sheeting. Fortunately, unless luminance contrast is very low, random fluctuations like this have little effect on predictions of legibility distance. Therefore, legibility distance calculations were based on specifications in this study, in part to illustrate that precise photometry is not necessary.

Procedure. The same vehicle and instrumentation were used in this study as in the first. After a short break at the Institute the subjects returned to the car, where the experimenter read the instructions for this phase (Exhibit C-2). The car was then driven to the freeway entrance ramp, waited, if necessary, for a suitable gap in traffic, and then entered the freeway. The car was driven at about 55 mph. As each test sign drew near the experimenter alerted the subjects, described the type (ground mount or overhead) and finally pointed it out when it became visible.

Every effort was made to keep the test car as isolated from other vehicles as possible. This was considered achieved when lead vehicles passed a test sign at least a few seconds before the first subject responded and following vehicles were at least 400-500 feet behind. By occasionally making temporary speed adjustments or pulling off the road to allow traffic to pass, it was almost always possible to stay within the prescribed limits.

Data Reduction

Data were recorded on videotape. The image contained both a distance counter and the four light bulbs marking subject and experimenter responses. Data were first put into digital form by running the playback machine at slow speed and writing down the distances at which various responses occurred. Subtracting the subject's from the experimenter's response distance gave the legibility distance. When all data had been converted as described, means, standard deviations and standard errors of the means were calculated.

RESULTS

Airport Study. Table C-2 presents the comparative results of the validation study conducted at the airport. The table gives the sign parameters in terms of background and legend specific luminance, legend size and beam conditions. For each beam condition, the table shows the average measured legibility distance, the predicted legibility distance, and the percent error.

To illustrate the use of the table: the first row shows 6 inch (15 cm) button letters on a background with a specific luminance of 30. The average measured legibility distance with low beams was 423 feet (129 metres); the model predicted 398 feet (121 metres) for this combination, an error of 5.9%. Given the same conbination of materials with high beams, the average measured legibility distance was 429 feet (131 metres), the predicted distance 417 feet (127 metres), an error of 2.8%.

Of the 48 conditions investigated in the airport study, 26 were in error by 5% or less, 14 were in error by less than 10% but more than 5%, 6 were in error by less than 20% but more than 10%, and 2 were in error by more than 20% (25.6% being the maximum error). The mean absolute error was 6.4%.

Table C-2. RESULTS - AIRPORT STUDY

Specific Luminance ($cp/ft\text{-}c/ft^2$ at 0.2° and -4°)		Legend Size (inches)	LOW BEAM Legibility Distance (feet)			HIGH BEAM Legibility Distance (feet)		
Backgrnd.	Legend		Measured (avg.)	Predicted	Error %	Measured (avg.)	Predicted	Error %
30	600	6	423	398	5.9	429	417	2.8
30	600	10	616	636	3.2	644	674	4.6
30	600	15	904	922	2.0	885	922	4.2
30	250	6	398	368	7.5	408	417	2.2
30	250	10	661	587	11.2	651	655	0.6
30	250	15	874	853	2.4	846	922	9.0
30	70	6	354	309	12.7	366	329	10.0
30	70	10	525	496	5.5	577	534	7.5
30	70	15	697	703	0.9	771	769	0.2
30	45	6	336	250	25.6	373	289	22.5
30	45	10	522	428	18.0	515	447	13.2
30	45	15	651	619	4.9	685	656	4.2
10	600	6	408	368	9.8	404	378	6.4
10	600	10	580	597	2.9	556	597	7.3
10	600	15	838	830	1.0	821	870	6.0
10	45	6	380	348	8.4	391	378	3.3
10	45	10	565	549	2.8	650	587	9.7
10	45	15	731	769	5.2	835	853	2.2
0.04	600	6	314	319	1.6	268	270	0.7
0.04	600	10	489	544	11.2	379	457	20.0
0.04	600	15	861	830	3.6	664	694	4.5
0.04	45	6	368	348	5.4	328	339	3.3
0.04	45	10	561	558	0.5	576	578	0.3
0.04	45	15	766	788	2.9	899	856	4.8

NOTE: Specific Luminance data of 600 $cp/ft\text{-}c/ft^2$ is a "sheeting equivalent" value applied to button legends (see Appendix E).

Four of the largest errors (including the two largest) involve the 30 background, 45 legend conditions. Because the luminance contrast was so low this was a condition where variations from specification could have very significant impact on legibility distance. In view of the reasonable performance of the same background and legends in other combinations, the authors view this as the most probable explanation for the observed error.

Freeway Study. Table C-3 shows the results of the validation effort using real signs along the freeway. The table has basically the same format as Table C-2, except the photometry represents actual measurements instead of specifications. Thus, for example, sign 1 is shown to have certain photometric characteristics, contrast ratio, letter size and was read at an average distance of 686 feet (209 metres). For this particular sign the model predicted a legibility distance of 594 feet (181 metres), an error of 13.4%.

Clearly, the variables in this study could not be as closely controlled as in the first study. Significant sources of error were: (1) variability in ambient illumination, (2) glare from other vehicles, and (3) occasionally, headlamp contribution from other vehicles. However, only 3 of the 23 cases are in error by 20% or more, and the remaining 20 cases are in error by no more than 15%. More than half the predictions are within 10%.

DISCUSSION

Granting the multiple sources of error variance which can appear in any study, let alone one conducted under field conditions, the fact that the visibility distance model developed in this study seems capable of predicting field legibility distances generally within plus or minus 10% is very encouraging. In the opinion of the authors, the model has been demonstrated to have useful validity.

It will be noted that the laboratory data (which represent approximately 90th percentile performance), equate well with the average field performance of subjects having the same visual characteristics. This means that subjects in the laboratory setting did

Table C-3. Results - Freeway Study

Sign	Photometry (cp/ft-c/ft²) Background	Legend	Contrast Ratio	Letter Size (inches) Upper Case	Lower Case	Legibility Distance (feet) Measured (Avg.)	Predicted	Error %
1. Overhead	13.6	47.9	3.5:1	16	12	686	594	13.4
2. Overhead	14.7	185.4	12.6:1	16	12	801	717	10.5
3. Illuminated Overhead	*4.9	*33.0	6.7:1	16	12	1093	980	10.3
4. Ground Mount	18.9	74.2	3.9:1	16	12	749	669	10.7
5. Ground Mount	10.5	64.9	6.2:1	16	12	712	679	4.6
6. Overhead	9.0	41.7	4.6:1	13.3	10	508	520	2.3
7. Ground Mount	20.1	77.3	3.8:1	13.3	10	632	544	13.9
8. Ground Mount	26.3	112.8	4.3:1	16	12	689	726	5.4
9. Overhead	10.8	68.0	6.3:1	13.3	10	450	544	20.9
10. Ground Mount	20.1	97.3	4.9:1	16	12	724	717	1.0
11. Ground Mount	9.6	27.0	2.8:1	16	12	586	584	0.3
12. Ground Mount	24.7	58.7	2.4:1	13.3	10	563	501	11.0
13. Ground Mount	20.1	89.6	4.5:1	16	12	687	698	1.6
14. Overhead	0.4	8.3	21.2:1	13.3	10	344	425	23.5
15. Overhead	1.1	7.7	7.0:1	13.3	10	348	386	10.9
16. Ground Mount	17.0	86.5	5.1:1	16	12	703	688	2.1
17. Ground Mount	6.2	92.7	15.0:1	13.3	10	659	611	7.3
18. Ground Mount	17.6	92.7	5.3:1	16	12	723	688	4.8
19. Overhead	0.8	12.2	14.7:1	13.3	10	406	453	11.6
20. Ground Mount	10.8	30.9	2.9:1	13.3	10	466	482	3.4
21. Ground Mount	17.8	30.9	1.7:1	16	12	666	514	22.8
22. Overhead	2.2	6.2	2.8:1	13.3	10	394	386	2.0
23. Illuminated Overhead	*2.0	*14.0	7.0:1	16	12	1034	980	5.2

NOTE: Photometric Values shown represent actual field measurements.
*Foot Lamberts

significantly better at the task than did subjects in the field setting. Knowing the magnitude of this "field factor" makes it possible to correct the laboratory data and bring the predictions more nearly in line with reality. The ultimate objective, of course, is to predict a level where a large percent of the driving population (e.g., 85%) will be able to read the sign. This problem is more fully discussed in Chapter 3.

It is also worth pointing out that field performance was essentially the same regardless of the nature of the visual task. As the reader will recall, the airport study employed an acuity task (since it was the job of the subjects to detect the orientation of a capital letter "E"). However, in the study conducted on the freeway, the subjects were asked to respond when they could read a sign legend well enough to make out what it said, a task which is a closer approximation of the way in which people actually use highway signs. Despite this difference, the model performed about equally well for both tasks.

EXHIBIT C-1

SUBJECT INSTRUCTIONS
AIRPORT STUDY

EXHIBIT C-1

INSTRUCTIONS - AIRPORT STUDY

Part 1

This is a study of road sign legibility. It will be conducted in two parts. We'll talk about part 2 later. Here, at this site, we'll be driving slowly up and down this road viewing small special signs consisting of a green background and a single white letter E. All you have to do is determine whether the arms of the E are pointing right or left.

We'll start from this position in a few minutes when I ask you to. Drive at 20 MPH toward the other end of the road. Pretty soon you'll be able to see the test sign along the right edge of the road. When you can determine whether the E is facing right or left press the button you have in your hand. Hold it down for a moment and release. That's all there is to it. Continue on down past the sign and turn around where I tell you. Then we'll head back in the other direction and do the same thing. The letters will be different sizes, some of the backgrounds will appear brighter than others, and we will make runs under high and low beams, but your task is always the same. Namely to determine whether the E is facing right or left.

Any questions?

EXHIBIT C-2

SUBJECT INSTRUCTIONS
FREEWAY STUDY

EXHIBIT C-2

INSTRUCTIONS - FREEWAY STUDY

Part 2

In this part of the test you'll be reading actual highway signs along US 23 between here and Milan. We'll be concerned with only some of the signs you'll pass. I'll point each out to you as we approach. All will have green backgrounds with white letters. All will identify either a road, like "Washtenaw Ave." or a place, like "Chicago." They may have other information too, like "Exit 1 mile." I want you to be concerned only with the primary information, that is, the road or place name, on each sign. As we approach each sign there will come a time when you will be able to make out what the name is. This doesn't mean you can see every letter clearly but you can see it well enough to know it says "Ann Arbor" or whatever. Now, you may know this road well and you may know what the signs say. Obviously legibility is less of a problem if you know in advance what the sign says. Try to imagine that you do not know what the sign says and press the button when you think you can see the legend well enough to make it out.

All the driver has to do is go along in the right lane at 55 MPH. One problem is that we have to be pretty much by ourselves on the road. If there is a car close behind us or less than 5 or 600 feet in front of us, its headlamps will also light up the sign and make it easier for you to see it. In those cases you may have to slow down a bit or even pull off the road until the traffic clears. Keep a lookout to the rear and let me know if a car is getting close.

We'll be looking at two different types of signs, ground mounts and overheads. Ground mounts are off to the right side of the road, on the shoulder. Overheads are suspended over the roadway, either on a truss of some sort or on a bridge. I'll tell you what kind of a sign it is before we come to it.

Any questions?

APPENDIX D

LEGIBILITY DISTANCE MODEL

LEGIBILITY DISTANCE MODEL

A brief description of the legibility distance model has been provided in Chapter 1, along with an indication of how it was intended to fit into the NCHRP 3-24 program. This section shall be devoted to a more comprehensive description of the model to assist the reader in understanding the variables it is capable of dealing with as well as certain assumptions upon which it is based.

ELEMENTS OF THE MODEL

The major elements of the sign legibility computer model are shown in the program flow chart, Figure D-1. The following variables must be specified before computations may begin:

A. Vehicle factors:

1. Light distribution and intensity characteristics of the headlamps.
2. Position of the headlamps on the vehicle.
3. Headlamp aim.
4. Eye position of the driver.
5. Lateral and longitudinal position of the vehicle on the road.

B. Sign factors:

1. Specific luminance of the retroreflective sign components (background and legend).
2. Background color.
3. Sign position, vertically and horizontally, relative to the roadway.
4. Sign rotation, vertically and horizontally, relative to the roadway.
5. Legend size.

C. Road factors:

1. Alignment of the road (hills, curves) between the car and sign.
2. Surround luminance.

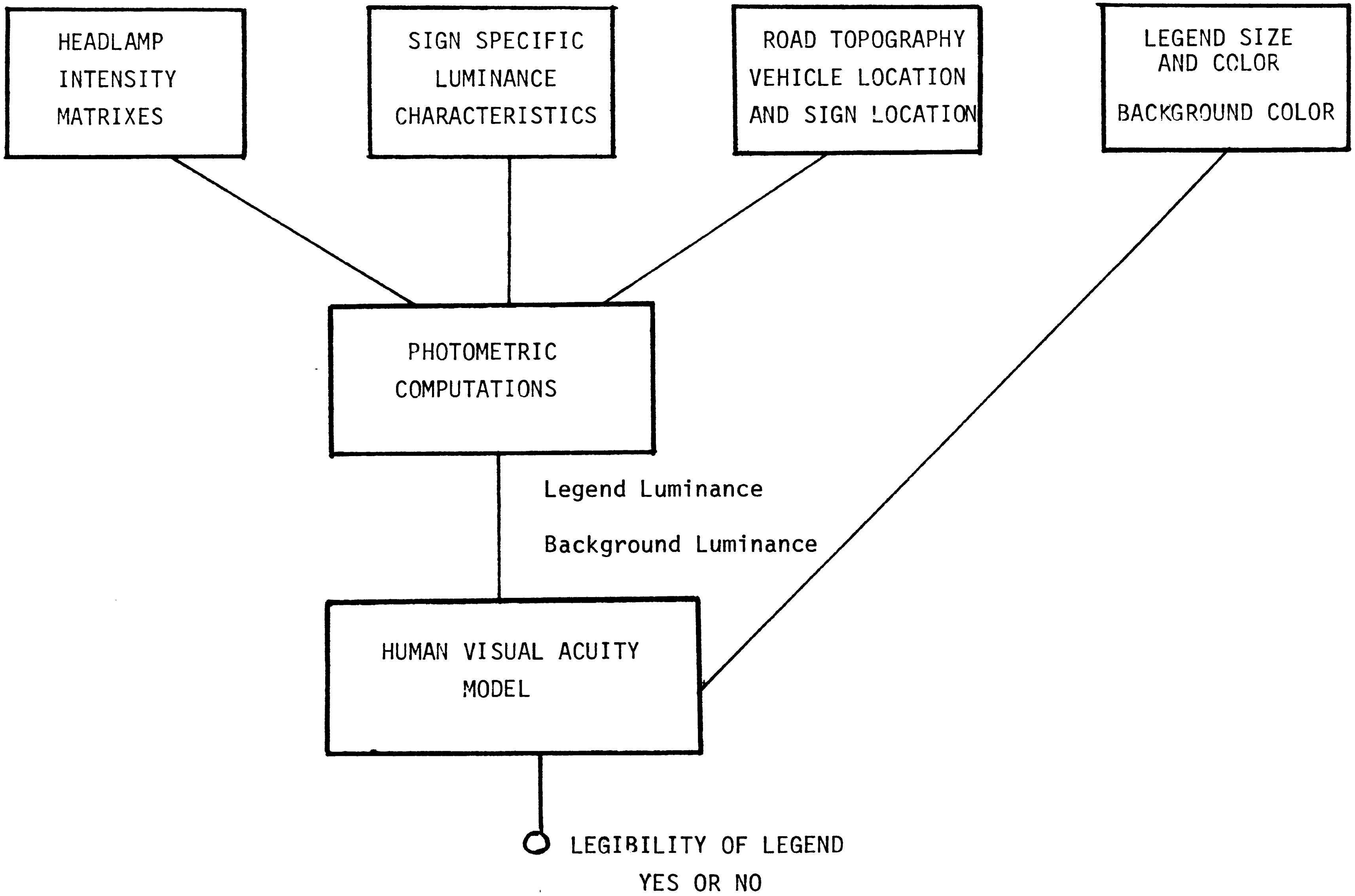


Figure D-1. Sign Legibility Program, Flow Chart

OPERATION OF THE MODEL

Basically, there are two phases in the operation of the model. These are as follows:

1. The initial separation between the sign and car is set large enough to be sure the sign is not legible. Then, considering the photometric characteristics of the vehicle's headlamps and the geometric relationship between the car and sign, calculations are carried out to determine the amount of light reaching the sign. Incidence and divergence angles are determined as well. Then, based on these data, and consideration of the specific luminance characteristics of the sign materials, calculations are performed to determine the luminance of the sign background and legend as it would be measured at the eyes of the driver of the oncoming car. A correction is applied to account for the attenuating characteristics of the vehicle's windshield.

2. Based on the results of step 1, and consideration of surround luminance and legend size, the laboratory data are referenced to determine whether the sign's message would be legible. If not, the vehicle is moved toward the sign a pre-selected distance (e.g., 20 feet) and the process repeated.

These points shall now be described in somewhat greater detail.

PHOTOMETRIC COMPUTATIONS

The objective of the photometric computations is to determine the luminance of the legend and background of the sign based on the variables listed in the section entitled "Elements of the Model" at the beginning of this section. The boundaries of the roadway, the location of the driver's eye, the vehicle headlamps, and the legend are all specified in three-dimensional Cartesian coordinates. From these Cartesian coordinates, four angles of central importance are computed for each headlamp. These are:

1. The horizontal angle from the headlamp to the sign legend (HA).
2. The vertical angle from the headlamp to the sign legend (VA).
3. The angle of incidence (IA).
4. The angle of divergence (DA).

These four angles are identified in Figure D-2. IA is the angle between the normal vector to the sign surface and the ray emanating from the headlamp to the sign legend. DA is the angle between the rays from the driver's eye to the legend (EL) and the ray from the headlamp to the legend (HL). The distance d from the headlamps to the legend is computed from the Cartesian coordinates for each headlamp separately.

The computation requires information regarding the reflective characteristics of the material employed. This is contained in specific luminance curves, such as shown in Figure D-3. Curves for the encapsulated lens material shown, as well as for others of interest, are converted to mathematical expressions for use in the model. As a preliminary step, computations of IA and DA are made to determine appropriate specific luminance (SL) characteristics for the sign background and legend. The SL must be updated with each iteration of the model (as the car is moved closer to the sign to find the legibility distance), since it can change rapidly with IA and DA.

All required information is now present to compute the luminance of either the legend or the background. As an example, the total legend luminance in ft-L is given by the equation:

$$LL = \frac{I_1}{d^2} \cdot SL_1 + \frac{I_2}{d^2} \cdot SL_2$$

where

I_1 and I_2 are the intensities in candela of that portion of the left and right headlamp beam directed toward the sign.

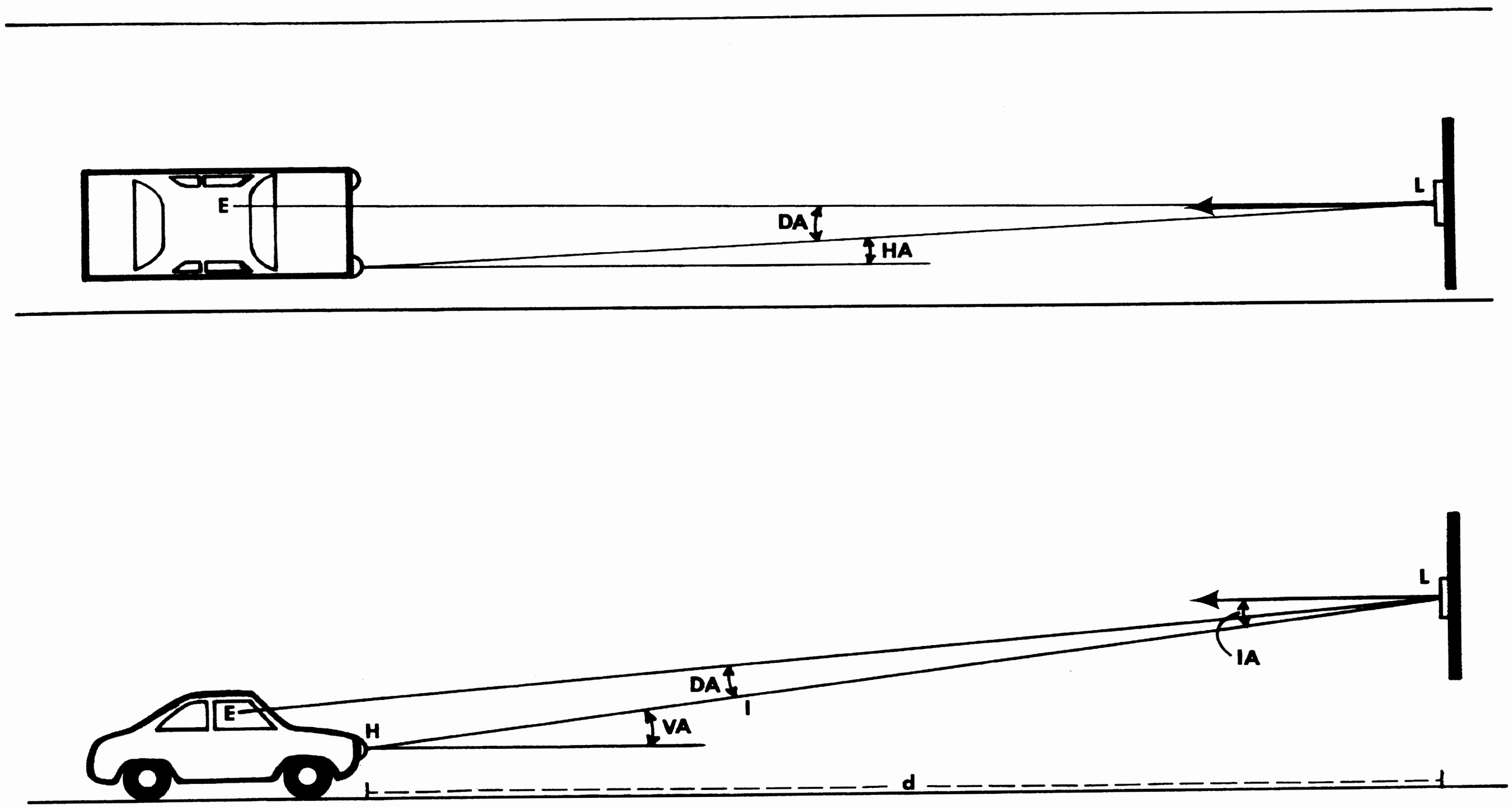


Figure D-2. Schematic representation of geometric parameters involved in calculation of sign luminance.

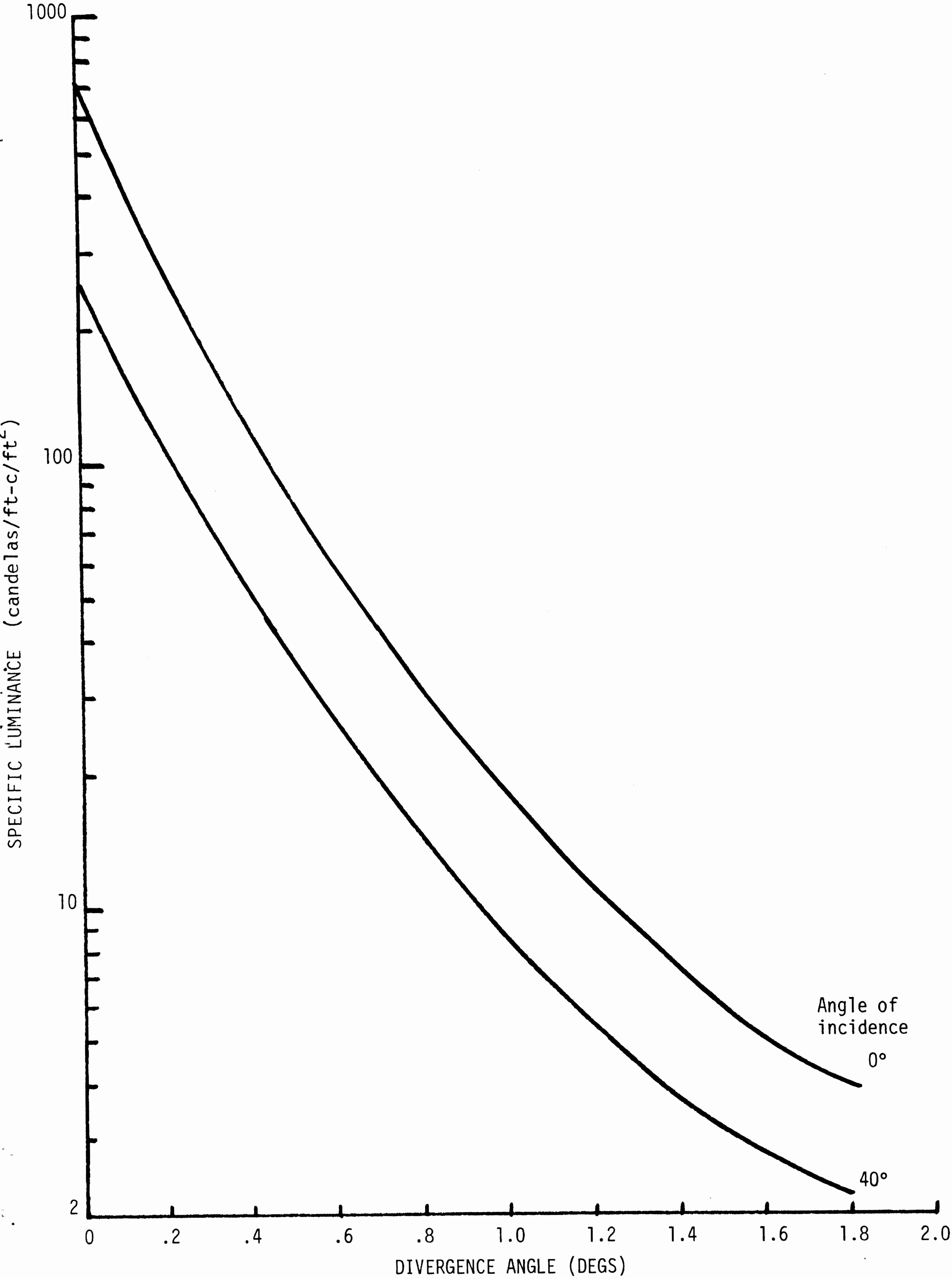


Figure D-3. Specific Luminance characteristic of white encapsulated lens sheeting.

SL_1 and SL_2 are the specific luminances values in $\frac{ft\text{-}L}{ft\text{-}C}$ of the legend material relative to the left and right headlamps respectively

d is the distance from the headlights to the legend

The same procedure is used to compute background luminance.

LEGIBILITY COMPUTATIONS

Given the luminance computations just described and specifications concerning legend size, background color and surround luminance, the model now draws on the data developed in the laboratory study described in Appendix B to determine whether the sign is legible. At present the equations in the model predict the 85th percentile legibility distance of young, normal subjects for a white legend on a green background. Provisions have been made for correcting these equations for other colored backgrounds.

There are two separate parts to the legibility computations. Part 1 predicts legibility distance at low and moderate levels of legend to background contrast where the subject's legibility distance increases with increasing luminance ratio. Part 2 predicts legibility distance decreases with increasing legend luminance. The details of these two parts will now be described.

Legibility Distance for Low and Moderate Levels of Contrast. The computer program used to fit the best least squares straight lines to the percent correct vs. log luminance ratio data, was used to compute the luminance ratio required for the 85th percentile performance for all combinations of legend size and background luminance used in the laboratory study. This information was developed in a form like that shown in Figure B-11. A second order polynomial was fitted to each of the four curves and an interpolation scheme was developed for determining the required contrast ratio for background luminance levels falling between the curves. If the computed luminance values are less than those required for the conditions specified, the sign is judged "not legible" and the program moves the car one step closer to the sign and iterates. If the computed luminance values are greater than those required for the conditions specified, the sign is judged "legible," unless the contrast is excessive. Whether the contrast is excessive is determined from Part 2 which will now be described.

Legibility Distance for High Levels of Contrast. Both the laboratory and field experiments indicate that legibility distance declines for excessive legend to background contrast levels. A model based upon the laboratory visual acuity data was developed to predict this decline. The assumptions used in the development of the model are outlined below.

1) The maximum 85th percentile visual acuity for young subjects is 70 ft/inch (8.4 m/cm) letter height.
2) For low luminance (< 0.1 ft-L [0.34 cd/m^2]) backgrounds, legibility distance is a function of legend luminance only and legibility distance declines in proportion to the increase in legend luminance above 1 ft-L (3.4 cd/m^2).
3) For moderate to high luminance backgrounds (.1 to 10 ft-L [0.34 to 34.3 cd/m^2]) the decline in legibility distance is proportional to increases in legend luminance ratio. There is no decline until the luminance ratio exceeds 20.

The constant of proportionality for the decline in legibility distance with luminance or luminance ratio was determined as follows:

a) The decline in performance with increasing legend luminance was determined from the laboratory data for a white legend on a black background.
b) The sensitivity of legibility distance to excessive contrast is the product of the (sensitivity of percent correct to increasing luminance ratio) and the (sensitivity of legibility distance to percent correct). In symbols:

$$\frac{\Delta \text{ leg. dist.}}{\Delta \text{ log unit}} = \frac{\Delta \text{ \% correct}}{\Delta \text{ log unit}} \cdot \frac{\Delta \text{ leg. dist.}}{\Delta \text{ \% correct}}$$

$$= -28 \times .4 = 11.4 \; \frac{\text{ft/in}}{\text{log excess contrast}}$$

Thus in the region where legibility distance is limited by excessive legend luminance:

$$\text{legibility distance} = 70 - 11.4 \log (B_L) \quad (B_B < .1 \text{ ft-L})$$

and in the region of excessive luminance contrast:

$$\text{legibility distance} = 7 - 11.4 \log \frac{B_L}{20\ B_B} \quad (B_B \geq .1 \text{ ft-L})$$

where B_B is background luminance and

B_L is legend luminance

Although all the assumptions used to develop these equations have not been rigorously proved, a thorough examination of the visual acuity data will show them to be plausible. The true strength of these equations lies in their ability to predict the field test results for the cases of excessive contrast.

APPENDIX E

DETERMINATION OF A "SHEETING EQUIVALENT" VALUE FOR BUTTON LEGEND MATERIALS

DETERMINATION OF A "SHEETING EQUIVALENT" VALUE FOR BUTTON LEGEND MATERIALS

INTRODUCTION

It was clear from the survey on practices in the use of signing materials (Appendix G) that button legends are among the most common in use today. Therefore, in order to be useful, the results of this investigation must apply to both button and sheeting legend materials. A difficulty arises in this regard because photometric data from the different materials are not comparable for purposes of legibility. Buttons are cube-corner retroreflectors and are very efficient. However, they typically occupy only about 20% of the area of a given letter. When viewed at an appropriate distance button legends appear continuous because of scattering of light in the eye (an effect known as irradiation). Thus, perceptually, a button legend is probably less bright than would be indicated by photometering its individual components. However, there are no data in the available literature which permit inferences about the correction which would be appropriate to make button legend materials comparable to sheeting materials. Since this study seeks to infer legibility distance from photometric data, such a correction is essential. Therefore, a limited investigation was undertaken to derive a "sheeting equivalent" index for button legend materials.

METHOD

The approach utilized in this study was to measure the amount of illumination required to enable identification of the orientation of a letter.

Four subjects participated in the study. All were young people (25 years old or less) with no visual abnormalities, 20/20 (6/6) or better high contrast far acuity and no worse than 20/25 (6/7.5) low contrast far acuity. They viewed the letters while seated in an automobile, two in the front seat, two in back.

The following independent variables were tested:

1. Letter type: capital letter buttons, upper case letter buttons, highly and moderately reflective sheeting (total of four different letters).
2. Letter size: 15, 10 and 6 inch (38.1, 25.4 and 15.2 cm).
3. Viewing distance: 750, 500, 467, 333, 300, 253, 200, 167, and 100 feet (229, 152, 142, 101, 91, 71, 61, 51 and 30 metres).

Only one letter size was used at each distance. The distances were selected to permit comparison of different size letters which subtended the same visual angle. (For example, a six inch [15.2 cm] letter subtends the same angle at 300 feet [91 metres] as does a 15 inch [38.1 cm] letter at 750 feet [229 metres]). Thus, effectively, there were three viewing distances, three letter sizes and four letter types, for a total of 36 configurations.

Projector L_2 from the main laboratory study was used to illuminate the letters. The projector was placed on the hood of the test vehicle, directly in front of the subjects, and operated at 110 V AC. Voltage was adjusted by a Variac and continuously monitored on a DVM during the study.

The procedure employed was fairly simple. When illuminated by the projector with maximum filtration, the letter should not have been legible. The experimenter would increase illumination step by step until the subjects could detect the orientation of the letter. The experimenter then continued to increase the illumination up to the maximum possible to determine whether the legend ever became so bright as to subjectively reduce its legibility.

The subjects were seated in the car and read the instructions in Exhibit E-1. After some practice trials the test began with the letters placed at the maximum distance. Distance was reduced with succeeding trials.

RESULTS

When pilot data were taken in setting up the test, the site selected appeared adequate to carry out the test as intended. However, on the night data taken, the ambient illumination was significantly higher (due, apparently, to reflections of ground lighting off a low cloud cover), so that it was possible for the subjects to see the letters even under lowest illumination from the projector at all but the greatest distances. This phenomenon was not apparent to the experimenters and the subjects failed to report it. As a result much of the data were lost and many of the desired comparisons could not be made. However, there were sufficient data to permit an estimate of the sheeting equivalent value, which was the primary purpose of the study.

The basic results are presented in Table E-1. This table lists the ratios of illuminance required to make each letter just legible. Thus, the small button letter rquired 1.2 times the illumination of the large button letter, the highly reflective sheeting letter required 3.1 times the illumination of the large button letter and so on.

Table E-2 converts the ratios of Table E-1 to estimates of specific luminance, based on photometric data run on the two sheeting letters. The average of the four numbers shown is 582. Thus a rough approximation of the "sheeting equivalent" specific luminance for button letters is 600 cd/ft-c/ft^2 at -4^o and 0.2^o.

This study was brief and the value derived for button materials is only an approximation. However, the 600 value was used in the predictive legibility distance model and was found to work adequately for situations where button legends were employed in the field validation study (see Appendix C). This is additional evidence that the value is reasonably correct.

TABLE E-1. Ratios of Illuminance Required to Make Each Letter Visible Compared to Each Other Letter Tested

	Small Button Letter (Upper Case E)	Highly Reflective Sheeting Letter	Moderately Reflective Sheeting Letter
Large Button Letter (capital E)	1.2	3.1	5.9
Small Button Letter (upper case E)		3.1	4.8
Highly Reflective Sheeting Letter			2.5

TABLE E-2. Inferred Specific Luminance of Button Letters Based on Ratios Presented in Table E-1.

	Large Button Letter (Capital E)	Small Button Letter (Upper Case E)
Highly Reflective Sheeting Letter (220 cd/ft-c/ft^2)	682	682
Moderately Reflective Sheeting Letter (90 cd/ft-c/ft^2)	531	432

EXHIBIT E-1

SUBJECT INSTRUCTIONS

BUTTON vs. SHEETING STUDY
INSTRUCTIONS

This is a study to compare the legibility of different types of highway sign legends. Basically, we are trying to find out how much illumination has to be directed toward each type of material before you can see it.

The legends you will be seeing are all capital letter E's, like the two I have placed on the dashboard. Some are uniform in appearance, like the one on the left, some are inset with buttons, like the one on the right. Your task is to determine whether the letter E's are oriented with the bars to the right, as in the case of the button letter on the dash, or to the left, as in the case of the uniform letter on the dash.

We will start each series of trials with the illumination so low that you will not be able to determine the orientation of the letter. You may not be able to see it at all as a matter of fact. We will then gradually increase the illumination and at some point you will be able to determine whether the letter is oriented right or left.

I'll turn off the dome light for a minute. If you look up the road you will see a letter E target straight ahead of us. The target will always appear in approximately the same position horizontally but may be closer or further away and appear larger or smaller. Note the small light above the letter E. This remains on at all times and serves to mark the target position so you can find it easily on trials where the target is very dim.

Now, look at your clipboards. Each board should have 3 sheets on it. The column numbers should go from 1 to 12 on the top sheet, from 13 to 24 on the second sheet, and from 25 to 36 on the bottom sheet. The rows are numbered from 20 to 0 on each sheet. We will start with column 1. I will call off the number "20." When you look at the target, you should not be able to determine its orientation, so you will write an N in column 1 opposite the number "20." I'll then call off "19" and you should again look at the target and try to determine its orientation.

Eventually the illumination will be high enough fo you to determine the orientation of the target E. On that trial write in an R or L, as appropriate. You should be fairly certain of the target orientation before you commit yourself. On the next trial, with more illumination, one of two things may happen. You may find that your first impression was wrong and the letter is oriented opposite to what you thought. Please, do not go back and erase the incorrect entry. Simply make the correct entry opposite the current level number.

On the other hand, if the orientation appears correct, I would like you to judge whether the letter is better or worse than on the preceding trial. In general we would expect that at first the letter would appear clearer or better with each increase in illumination. In that case enter a B for better. However, it may happen that the letter will become too bright sometimes and appear less clear or worse than on preceding trials. This is a judgment which will vary from person to person and depends on the type of material used and the distance at which it is viewed. But, if the letter begins to appear less clear than the preceding trial, enter a W for worse.

In order to see the letters properly it is essential that you group yourselves in the front and rear seats so that the targets are seen as close to the projector on the hood as possible. I suggest that the two people in the rear sit as close together as possible and those in the front sit as close as they can without blocking the view of those in back.

Maintain your viewing position as closely as possible. If you move your head very much it will cause the apparent brightness of the letters to change.

It's very important that you not talk or comment as you view the targets. We also ask that you not compare data until the study is completed. Let your data represent your own reactions only.

That's about it. Just to recap, each series of trials will start with intensity 20, which is minimum and go through 0, which is maximum. We would expect your first responses to be N, followed by an R or L at some point, followed by a series of B's with perhaps some W's near the bottom.

Are there any questions?

We will now give you a series of practice trials. I would like to point out, before we start, that the trials will come quickly, so you will not have a lot of time to make up your mind. You'll get the rhythm in the practice series.

APPENDIX F

PILOT INVESTIGATION OF THE EFFECT OF BACKGROUND AREA ON LEGIBILITY DISTANCE

PILOT INVESTIGATION OF THE EFFECT OF BACKGROUND AREA ON LEGIBILITY DISTANCE

INTRODUCTION

Among the questions raised in the course of the primary investigation was one concerning a potential interaction between legend size and the size of the simulated sign background. That is, it was felt possible that the legibility distances measured for various combinations of background and legend luminance may change if the size of the sign background were changed. If such an interaction does exist this would constitute an important effect which must be accounted for in the presentation of the final results.

It seemed most feasible to approach this question by means of a relatively brief pilot investigation, comparing the 11" x 11" background which was employed in the main study, with a much smaller format. A 4" x 4" size frame was selected for purposes of this test. If differences appeared in this study then a more comprehensive investigation would be warranted.

METHOD

One letter size was used in this investigation (50 ft/inch letter height [6m/cm]), one background color (green) and two levels of background luminance (10 ft-L and 0.1 ft-L [34.3 and 0.34 cd/m^2]). The two experimenters participated as subjects. Each subject began with the high luminance background, and finished with the low luminance background. The order of presentation of the frame sizes was changed systematically.

The general procedure was precisely that employed for subjects in the main investigation except that ten to twelve replications were made for each combination of conditions.

RESULTS

Table F-1 summarizes the results of the study. In reading this table comparisons should only be made within cells. That is, comparisons between two sign sizes should be made only for a given subject and background luminance. Thus, at 10 ft. L (34.3 cd/m^2) subject 1 did slightly better overall with the 4" x 4" frame while subject 2 did slightly better overall with the 11" x 11" frame. The opposite holds true at 0.1 ft-L (0.34 cd/m^2). However, the absolute magnitude of the differences is small in every case, with the possible exception of the 0.1 ft-L (0.34 cd/m^2) condition for subject 1, where the difference is on the order of 10%.

CONCLUSIONS

The results of this investigation suggest that the effect of background size on legibility distance is small or non existant. The investigators' experience in conducting the main laboratory study leads them to believe that the amount of data collected in this study would be sufficient to uncover an effect on the order of the primary effects discovered in the main investigation. A relatively minor effect could be missed.

TABLE F-1. Performance (Percent Correct) of Two Subjects on Legibility Task as a Function of the Simulated Sign Size.

Log Legend Luminance	0.1 Ft-L Background						10 Ft-L Background					
	4 x 4			11 x 11			4 x 4			11 x 11		
	S_1	S_2	Combined	S_1	S_2	Combined	S_1	S_2	Combined	S_1	S_2	Combined
2.33	100	100	100	.92	100	.96	.50	100	.75	.75	100	.87
1.99							.67	100	.82	.50	100	.75
1.76	.75	100	.87	.92	100	.96	.58	100	.79	.67	100	.82
1.62							.75	100	.87	.50	100	.75
1.41	.83	100	.91	.92	100	.96	.50	100	.75	.42	100	.71
1.30							.42	.88	.65	.33	100	.67
1.06	.83	100	.91	100	100	100	.08	.73	.41	.17	100	.58
0.85							0	0	0	0	0	0
0.72	.67	100	.82	100	100	100						
0.25	.75	100	.87	.75	100	.87						
-0.27	.50	100	.75	.58	100	.79						
-0.89	.09	.50	.29	0	.38	.19						
-1.12	0	0	0	0	0	0						

APPENDIX G

SURVEY ON CURRENT PRACTICES IN USE OF SIGNING MATERIALS

SURVEY ON CURRENT PRACTICES IN USE OF SIGNING MATERIALS

INTRODUCTION

As part of the Phase I effort in this investigation, a survey was carried out to catalog current practices in the use of various signing materials in the United States. While such information is of interest in general, it was hoped that insights could be gained, based on the substantial experience of the polled agencies, regarding the levels of luminance and contrast required for effective sign performance under various conditions.

METHOD

A questionnaire was prepared which sought information on the following points:

1. The type of materials currently employed in signing.
2. Practices relating to illumination.
3. Policies for use of different materials as a function of sign type and application.
4. Practices relating to inspection and maintenance.
5. Criteria and methods for refurbishing existing signs.
6. Criteria and methods for determining when signs have weathered to the point that they must be replaced.
7. Experience relating to the useful life of various signing materials.

The questionnaire was written with the assistance of the project consultants and the NCHRP technical monitor. A preliminary form was sent to three traffic engineering agencies to be filled out, criticized and returned. Two of the three agencies did so, and further modifications resulted from their inputs.

The final version of the survey was mailed to 49 traffic engineering agencies scattered throughout the United States. Included were 39 state highway departments and 10 turnpike authorities. In a two-month period 38 of the forms (78%) were returned. In almost every instance the forms which were returned contained the desired information. In a very few cases items were overlooked by the respondent or questions were misunderstood. A copy of the survey form, along with the cover letter which accompanied it, is reproduced as Exhibit G-1.

RESULTS

This portion of Appendix G will present an analysis of the basic data collected. Several of the questions elicited comments from the respondents. These are listed in detail in Exhibit G-2.

Materials Used. Table G-1 shows the distribution of responses to a question designed to determine the types of material used and their relative popularity. All nine material combinations listed in the questionnaire for signs employing demountable legends were mentioned at least once by the responding agencies. Most agencies employed more than one technique. One employed eight of the nine combinations. However, certain practices clearly dominate. The combinations most frequently mentioned were button copy on paint or porcelain enamel and button copy on engineer grade (enclosed lens) sheeting. Four other combinations were mentioned only about half as often as the first two. These were: button copy on high intensity (encapsulated lens) sheeting, high intensity copy on engineer grade sheeting, high intensity copy on high intensity sheeting, and engineer grade copy on engineer grade sheeting. The remaining three combinations were mentioned much less frequently.

A particular material combination was defined as "major" if it was used for 50% or more of the signs employed by a given agency, or was the combination most used for particular types of highways, if such a distinction was made by the agency. Not all agencies responded to the request for an indication of the percent to which a given material was used. However, of those agencies which did, only two combinations were mentioned more often than three times. These were:

TABLE G-1. Frequency With Which Various Signing Material Combinations Were Checked as Used by the Agency, Major Use or Experimental Only

Combinations	Used	Major Use	Experimental Use Only
1. Signs with demountable letters, symbols or legends:			
Button copy on:			
Paint or porcelain enamel (non-reflective)	22	6	
Engineer grade sheeting	24	9	
High intensity sheeting	11	1	2
High intensity sheeting copy on:			
Paint or porcelain enamel	6		1
Engineer grade sheeting	13	3	2
High intensity sheeting	13	3	2
Engineer grade sheeting copy on:			
Paint or porcelain enamel	4		
Engineer grade sheeting	14	1	1
High intensity sheeting	9		
2. Signs with direct applied letters, symbols or legends:			
Beads on paint	1		
Engineer grade sheeting	31	28	
High intensity sheeting	28	10	1

button copy on paint or porcelain enamel and button copy on engineering grade sheeting.

A number of respondents described certain material combinations as experimental. Generally these references were made to high intensity materials.

With reference to signs employing direct applied letters, symbols or legends, shown at the bottom of Table G-1, material usage was almost evenly divided between engineer grade and high intensity sheeting. Only one of the responding agencies mentioned the use of a beads-on-paint approach to this type of signing. Engineer grade sheeting was the major use for nearly three times the number of cases as high intensity sheeting.

Illumination. Eighty-two percent of the responding agencies do not illuminate roadside signs, while 92% illuminate overhead signs in at least some instances. A listing of the comments received to the request for an illumination policy is provided in Exhibit G-2.

There is appreciable variation in sign illumination policies. The most frequent response was that all overhead signs are illuminated. However, many agencies described selective policies based on the importance of the sign or the environment within which it is located.

Photometric Specifications. Ninety-five percent of the responding agencies indicated that they have photometric specifications for signing materials. All supplied copies of their current specifications.

Of the 33 agencies which supplied specifications for enclosed lens sheeting, 18 followed a pattern used by the 3M Company, 11 followed the pattern used in L-S-300-A and 4 used a pattern unlike either. For encapsulated lens sheeting, 26 agencies supplied specifications and 20 of these followed the 3M pattern.

The next four questions were to determine whether the agencies had established different photometric or material specifications for signs used in different applications. The responses are listed in Table G-2. Apparently relatively few agencies attempt to compensate for different visibility conditions by changing sign materials. However, more than half the responding agencies indicated they use different materials for different classes of signs. Many respondents indicated that they used high intensity sheeting for red and orange series signs (Exhibit G-2).

Eighty-nine percent of the responding agencies indicated they had not conducted any research to set photometric specifications for signing materials. Of the four agencies replying in the affirmative, one responded in a way indicating that they may not have understood the intent of the question and the others either said that the report had not been released or supplied no further information.

Quality Control. Sixty-three percent of the agencies indicated that they did not have photometric facilities available. Of those that did, 71% ran photometric checks on materials prior to use and 44% ran checks on materials which were either in use or had been retired from use.

About half the responding agencies indicated that they had sign shops remote to their central office and, of those, 95% said that these individual shops were responsible for their own quality control.

Inspection. Responses to the question concerning inspection were quite varied. Fifteen percent of the agencies said they conducted monthly inspections, 5% said every three months, 20% every six months, 33% every 12 months and 27% checked the "other" category. A number of comments were received to this question. These are reproduced in Exhibit G-2.

It would seem essential that nighttime inspections be conducted in order to properly assess the performance of retroreflective materials. In response to a question concerning the frequency of nighttime inspections, 9% of the agencies stated that they conducted

TABLE G-2. Percentage of Agencies Indicating Use of Different Signing Materials for Different Applications

Application	Yes	No
Overhead as compared with roadside sign installations?	24%	76%
Signs placed in brightly lit surroundings as compared with those placed in dark surroundings?	5%	95%
Signs placed on different classes of highway or where different traffic volumes are encountered?	19%	81%
Different classes of signs (guide, warning and regulatory)? Color differences aside, do you use different materials (e.g., high intensity sheeting) on some classes of sign and not others?	57%	43%

no nighttime inspections, 53% said that 25% of sign inspections were carried out at night, 12% said 50% of inspections were conducted at night and 26% said that 100% of their sign inspections were carried out at night.

In responding to the question concerning the utility of police reports or citizens' complaints, about 70% of the agencies indicated that they did not find either of these sources to be of any help in identifying worn-out signs.

There are available special devices to aid in the inspection of signs. The next question was designed to determine the extent to which such devices are employed. Of the responding agencies, however, only three (8%) indicated that they make use of any kind of objective reference in sign inspections.

Maintenance. Seventy-three percent of the responding agencies indicated that they have a sign cleaning program. Four percent of the agencies indicated that they clean signs as often as once every three months, 16% said once every six months, 32% indicated that they clean signs at least annually, while 48% of the agencies said they clean signs "as required." Responses concerning the basis for sign cleaning programs are listed in Exhibit G-2. In general, those agencies who checked the "as required" box indicated that cleaning was based on reports from inspections.

Refurbishing processes are available which are intended to prolong the life of signs. Fifty-eight percent of the responding agencies indicated that they used some kind of refurbishing process on at least some signs. This is generally based on visual inspection (68% of the response). The only other response checked at all was "manufacturers recommendations." A number of agencies checked both of these categories. Comments elicited from the respondents regarding this question are summarized in Exhibit G-2.

Replacement. One important benefit which may come from NCHRP 3-24 is to provide an objective basis for determining when signing materials have worn to the point where they must be replaced. The first question under this heading sought to determine how signs are judged ready for replacement at present. Many of the agencies checked more than one response to this question. Seventy-three percent indicated that visual inspection and best judgment was one way or the only way of determining when a sign was in need of replacement. The next most frequently mentioned category was age. Few responses mentioned the other categories.

The techniques employed in replacing signs are quite varied. Most of the responding agencies checked more than one option, usually depending on the size and location of the sign or the extent to which it was worn. Nearly half of the responses (42%) indicated that complete replacement was at least one of the techniques employed. The next two options (overlay with sheet aluminum and new sign film and strip sign film and reapply) were about equally often checked (29 and 24% respectively). The comments received to this question and summarized in Exhibit G-1.

The last question in the survey sought to determine the effective life of various signing materials based on the experience of the responding agencies. Responses to this question were quite varied with regard to some materials and quite uniform as regards to others. For example, useful life reported for engineering grade sheeting varied from 3 to 10 years, although the time most frequently mentioned was seven years. On the other hand, the combination of buttons on porcelain enamel was generally checked as lasting 15 or more years. Similarly, button copy was reported to last for 15 or more years by most of the agencies responding. Where high intensity sheeting was mentioned, it was usually stated that the agency had not had enough experience in order to evaluate its effective life.

CONCLUSIONS

The responses to this survey have indicated a wide diversity of materials, applications and philosophies. On the one hand, it is apparent that the agencies in question are sincerely concerned with the problem of legibility and how best to achieve it. On the other hand, it is apparent that there is no general agreement as to the best ways to bring about optimum legibility.

EXHIBIT G-1

SURVEY FORM and COVER LETTER

HIGHWAY SAFETY RESEARCH INSTITUTE
Institute of Science and Technology
Huron Parkway and Baxter Road
Ann Arbor, Michigan 48105

THE UNIVERSITY OF MICHIGAN

Dear Sir:

The AASHTO-sponsored National Cooperative Highway Research Program (NCHRP) is conducting Project 3-24 "Determine the Luminous Requirements of Retroreflective Signing Materials." The purpose of the project is to determine upper and lower luminance specifications for retroreflective signing materials so that traffic engineering agencies can make cost-effective choices for installation, maintenance and ultimate replacement of reflective signs. This project has been awarded to HSRI.

While information of the type sought under this procurement will undoubtedly be of value to agencies such as yours, the fact remains that basic questions such as what materials to use, how often or whether to clean or otherwise maintain them, and when to replace them have been dealt with by traffic engineering agencies for some time. Over the years much information must have been accumulated, based on experience, public reaction, research programs and the like to provide guidelines for these decisions. We feel that a compilation of this information would be of value not only in helping us plan the research to be carried out under NCHRP 3-24, but to other traffic engineering agencies as well. To that end we have prepared the attached questionnaire.

Basically this questionnaire seeks to determine: (1) the luminance levels your agency currently seeks in planning new signing for various applications, (2) maintenance criteria, methods and schedules, and (3) criteria for replacement. We would be very appreciative if you or someone with the necessary information would fill in the form and return it to us in the enclosed envelope. All responses will be treated as confidential and any information released by HSRI to the public will not identify agencies by name.

We realize that people like you receive many inquiries such as this one and that they take up a lot of your time. We sincerely regret this intrusion, but hope that you will share your experience with others who can use it. A copy of the results of this survey will be sent to you when the data have been compiled.

Thank you very much,

Paul L. Olson

Paul L. Olson
Human Factors, HSRI

PLO/md

USE OF RETROREFLECTIVE SIGNING MATERIALS

The Highway Safety Research Institute of the University of Michigan, as part of AASHTO-sponsored project NCHRP 3-24 has prepared this questionnaire in an effort to determine what retroreflective signing materials are used currently by your agency, something about your inspection and maintenance procedures and how you determine when a material has degraded to the point where it must be replaced. We are concerned with all types of signs (guide, warning, regulatory) employing reflective treatments.

Most of the questions can be answered by checking an appropriate box. In some cases additional information may be necessary. Some space has been provided where written comments are called for. If the space is not adequate or if you wish to make comments on other questions simply add sheets as required.

Please fill in your name, the name of your agency, and other information as requested below before starting to work on the questionnaire.

Thank you very much,

Paul L. Olson
Human Factors, HSRI
Huron Parkway at Baxter Rd.
Ann Arbor, Mich. 48105
(313) 764-4158

_______________________________ ( )
Your name Title Telephone

____
Department Agency

____
City State Zip

Note: This material will be treated as confidential. Information released by HSRI will not identify specific agencies.

I. NEW SIGNS

The purpose of this section is to determine what materials you are currently using for new retroreflective signs (including new material used to restore old signs).

A. Construction:

1. Signs with demountable letters, symbols or legends: (Please check the appropriate box or boxes below. If you use more than one type of construction, please indicate the approximate percent of each next to the appropriate boxes.)

   a. Button copy on:
      - Paint or porcelain enamel (non-reflective) ☐
      - Engineer Grade Sheeting ☐
      - High Intensity Sheeting ☐

   b. High Intensity sheeting copy on:
      - Paint or porcelain enamel ☐
      - Engineer grade sheeting ☐
      - High intensity sheeting ☐

   c. Engineer grade sheeting copy on:
      - Paint or porcelain enamel ☐
      - Engineer grade sheeting ☐
      - High intensity sheeting ☐

2. Signs with direct applied letters, symbols or legends: (The same instructions apply here as in question 1.)

   a. Beads on paint ☐
   b. Engineer grade sheeting ☐
   c. High intensity sheeting ☐

B. Illumination:

	Yes	No
Do you provide external illumination in any cases for:		
Roadside signs	☐	☐
Overhead signs	☐	☐

If your response was "yes" to either type of sign, please describe your sign illuminating policy.

____

____

____

C. Reflective Intensity:

1. Do you have photometric specifications for signing materials? (If yes, please describe, or provide a copy or dated reference). ☐ ☐

____

____

____

2. Do you have different photometric or material specifications for:

   a. Overhead as compared with roadside sign installations? ☐ ☐

   b. Signs placed in brightly lit surroundings as compared with those placed in dark surroundings? ☐ ☐

   c. Signs placed on different classes of highway or where different traffic volumes are encountered? ☐ ☐

   d. Different classes of signs (guide, warning and regulatory)? Color differences aside, do you use different materials (e.g. high intensity sheeting) or some classes of sign and not others? ☐ ☐

	Yes	No
If your answer to any of the above was yes, please describe the specifications, unless already described in your answer to question C.1.		

____

____

____

	Yes	No
3. Has your agency conducted research to set desirable photometric specifications for signing materials? (If yes, please provide a copy or dated reference.)	☐	☐

D. Quality Control:

	Yes	No
1. Does your agency operate or contract with a photometric laboratory for checking materials? (If no, skip to question 4.)	☐	☐
2. Do you run photometric checks on materials prior to use?	☐	☐
3. Do you run photometric checks on materials which are or have been in use?	☐	☐
4. Does your agency operate sign shops remote to your central office which make and/or refurbish signs?	☐	☐
5. If your answer to question 4 was yes, are these individual shops responsible for their own quality control?	☐	☐

II. INSPECTION

A. Frequency:

1. About how often are signs inspected by your agency?

   - Monthly ☐
   - Every 3 months ☐
   - Every 6 months ☐
   - Every 12 months ☐
   - Other (please explain) ☐

   ____

   ____

   ____

2. About what percent of these inspections are made at night?

   - 0% ☐
   - 25% ☐
   - 50% ☐
   - 75% ☐
   - 100% ☐

3. Has your agency found either of the following sources to be a significant aid in identifying worn out signs?

	Yes	No
Police reports	☐	☐
Citizen complaints	☐	☐

B. Equipment:

	Yes	No
1. Do you make use of any special equipment for inspection (e.g. photometers, reflectivity standards)?	☐	☐

2. If yes, please list the equipment you are using:

   ____

   ____

   ____

III. MAINTENANCE

	Yes	No
A. Cleaning:		
1. Does your agency carry out a sign cleaning program?	☐	☐

2. If yes, what is the approximate interval between cleanings?

   - 3 months ☐
   - 6 months ☐
   - 12 months ☐
   - 24 months ☐
   - As required (Please describe how this is determined)

   ____

   ____

   ____

	Yes	No
B. Refurbishing:		
1. Do you employ any refurbishing process (e.g. Clear Coating)?	☐	☐

2. If yes, how do you decide when to refurbish?

   - Manufacturer's recommendation ☐
   - Visual inspection ☐
   - Photometric data (please give minimum specifications). ☐

   ____

   ____

   ____

IV. REPLACEMENT

Signs may be replaced for many reasons. Basically we are here concerned with signs which "wear out," i.e. lose their effectiveness through degradation or failure of the retroreflective material. The term "replacement" means restoration of the message area with new material, it does not necessarily relate to the support structure.

1. How do you determine that a sign has worn to the extent that it must be replaced?

   Photometric performance (Please list minimum acceptable levels) ☐

   ____

   ____

   ____

   Visual inspection using reflectivity standards. ☐

   Visual inspection and best judgment ☐

   Age ☐

   Other (please describe) ☐

   ____

   ____

   ____

2. When a sign is determined to be in need of replacement, what approach is taken?

   Complete Replacement ☐

   Overlay with sheet aluminum and new sign film ☐

   Strip sign film and re-apply ☐

   Other (please describe) ☐

   ____

   ____

   ____

IV. REPLACEMENT (Continued)

3. About how many years of life have you been getting from your signs? (On the left, list the types of retroreflective treatments you use as described in Part I and then check the average years of useful life they have been providing.)

	3	4	5	6	7	8	9	10	11	12	13	14	15	More

This is the end of the questionnaire. Please check to be sure the top sheet has been filled in completely and that all relevant questions have been answered.

A self-addressed, stamped envelope has been supplied to return the questionnaire to us.

Thank you very much.

EXHIBIT G-2

LISTING OF WRITTEN RESPONSES TO VARIOUS QUESTIONS

ILLUMINATION POLICIES

1. All overhead normally illuminated.
2. Roadside - special cases only. Overhead - all new construction if power is feasible. Adding feature as funds allow.
3. All overhead.
4. Generally illumination provided on primary directional signs, either ground or overhead.
5. Illuminate only overhead guide signs on fully illuminated freeways.
6. No illumination.
7. Illuminate all overhead signs.
8. All overhead signs are illuminated.
9. All overhead signs are illuminated where there is no area lighting unless area lighting is sodium vapor, in which case the signs are lighted.
10. Overhead signs in toll plaza, approaches and exits.
11. All overhead signs.
12. Overhead signs lighted if road is lighted.
13. All overhead signs.
14. 90% of overhead illuminated.
15. Roadside signs mounted at overhead height.
16. Overhead illuminated at interchanges. High intensity will not be illuminated.
17. All overhead signs on freeways are illuminated.
18. Overhead illuminated only in highly urbanized areas.
19. Roadside - special cases only - Overhead - all illuminated.
20. Overhead illuminated when roadway is illuminated.
21. All overhead interstate signs illuminated.
22. All overhead are illuminated.
23. All overhead except "commercial design spans." All roadways with adverse geometric or operational conditions (overhead only).
24. All overhead and selected ground mounts for land service roads, primarily at traffic circles are lit.
25. All overhead signs are lighted when practical.

Illumination - continued

26. All overhead are illuminated.
27. All overhead are illuminated, few ground mounts.
28. None illuminated.
29. All overhead at exit gores on main line.
30. Many overhead in New York city are lighted. Only in special circumstances will signs in rest of state be lighted.
31. All overhead are lighted.
32. All overhead are illuminated (use opaque backgrounds).
33. All overhead illuminated. Roadside signs sometimes when they include flashing lights or when surround light levels are high.
34. All overhead are illuminated.

POLICIES RELATING TO USE OF DIFFERENT MATERIALS FOR DIFFERENT APPLICATIONS

1. High intensity limited to interstate signing contracts and special non-illuminated overhead signs.
2. High intensity background used on selective route marker and wrong way signs and all do not enter signs. Otherwise engineering grade.
3. Button copy on non-reflective used for externally illuminated overhead guide signs. Button copy and engineering grade used on all other freeway guide signs. High intensity used for all signs with a red background. Engineering grade for all else.
4. Button copy on major guide signs. Engineering copy and backgrounds on regulatory, warning and minor guide signs. Engineering background on some major guide signs.
5. Interstate highway signs do not have reflective backgrounds. Some orange warning signs use high intensity for higher night traffic volumes.
6. High intensity sheeting for orange construction and maintenance and some overhead signs.
7. High intensity used for (1) orange construction and maintenance signs. (2) All red background signs. (3) Railroad warning signs. (4) School signs and school children crossing signs. (5) All route markers for interstate use, including crossroad signing. (6) All route markers for freeway and expressway signing.

Use of Different Materials - Continued

8. Overhead signs - white porcelain backgrounds with black letters (lighted).
9. High intensity used for high hazard, construction or warning.
10. High intensity specified for all "red series" signs.
11. High intensity used on construction warning signs and regulatory signs which have red on them.
12. High intensity used on interstate signs. Otherwise used for specific signs and certain type locations but not for an entire class of signs.
13. Secondary road warning signs in low density areas are fabricated using open lens reflective paint.
14. All illuminated overheads have painted faces. Use high intensity for guide signs and red series regulatory signs.
15. Recent program to use high intensity on yield signs is in progress.
16. Guide signs - high intensity, regulatory and warning signs - engineering grade, service signs - both.
17. For future new construction high intensity materials will be specified for all signs except those with white background and guide sign backgrounds. Changes to latter under consideration.
18. Overhead signs are porcelain enamel. Freeway guide signs are required to have high intensity copy with engineering grade background.

POLICIES RELATING TO INSPECTION

1. Continuous inspection program during routine maintenance operations and repair work.
2. Additional daytime inspections are made on an informal basis.
3. Every 12 months is minimum. Maintenance personnel provide daily overall inspection capability.
4. Minimum every 12 months at night. Additional random inspection during day as time and opportunity permit.
5. Inspection made in conjunction with trips for other purposes and vary in interval.

Policies Relating to Inspection - Continued

6. Inspected by maintenance personnel. A lot on scheduled basis.
7. Generally done by head office personnel while traveling in the field.
8. Every six months and continuous inspection by sign crews supervisors and engineers.
9. Incorporated with their sign installations.
10. Inspections all informal. Maintenance foreman are responsible for constantly inspecting signs in their district.
11. Every six weeks or less.
12. Districts are on 7-8 year replacement program.
13. Continual with no reports within each of 4 regions.
14. Routine inspection program not yet operational. Random inspection made.
15. No formal inspection schedules are established.
16. Every 12 months and constantly checked during routine travel.
17. Monthly for urban. Six months for rural.

POLICES RELATING TO CLEANING

1. Hope to reduce from 12 to 6 month intervals.
2. Periodic program for all signs needing cleaning in the fall and spring of each year.
3. On basis of scheduled traffic control devices, inspections are performed at 6 or 12 month intervals.
4. Based on inspections.
5. Based on inspections.
6. (no program) Need is recognized. Manpower not available.
7. Based on inspections. However sign cleaning is a low priority.
8. By day and night visual inspection reports.
9. Varies with district. In major metropolitan area it is done twice a year by contract. Other areas once a year by contract or as necessary by department field forces.
10. No routine program - as necessary. Due to cutback little has been done in past year.

Policies Relating to Cleaning - Continued

11. Most are cleaned on 12 month basis but some are cleaned at 6 months as permitted by manpower requirements and weather.
12. Varies with each district.
13. As required - determined by visual inspection. Number of times signs are cleaned during fall, winter and spring is determined by how dirty the signs get due to snow and ice.
14. Every 3 months as determined by a visual inspection.
15. Varies depending on conditions. Visual determination or need.
16. Four year program.
17. Some cleaning is done but not on a complete systematic basis.
18. When time permits. Intent to clean every 12 months, however this is not always accomplished.
19. Based on field inspections (after inclement weather conditions, etc.).
20. Depends on manpower and budget - not always followed.

POLICIES RELATING TO REFURBISHING

1. Up to divisions as to when they have the money to do it. Based on need.
2. Painted signs - past policy to refurbish by painting backgrounds. Painted signs are being phased out. Clear coating has not been a successful field operation.
3. Signs are clear coated in shops or just after placement in the field. No written policy. Some districts do field clear coat in an effort to get additional life.
4. Set four year program.
5. Clear coating minimal, usually replace or overlay.
6. Limited use of clear coating.
7. Not practiced by all districts.
8. Clear coating has not worked out.

EXPERIENCE CONCERNING USEFUL LIFE OF
VARIOUS MATERIALS

1. Engineering grade - 4 years.

2. Engineering grade with clear coat at 3-4 years - 6 years.

3. Button copy on Engineering grade - 10 to 12 years.
High Intensity copy on Engineering grade - not enough experience.
Engineering grade copy on Engineering grade - 7 to 10 years.

4. Button copy on baked enamel - 15 years.
Button copy on Engineering grade - 8 years.
Button copy on High Intensity - too early to tell.
High Intensity copy on High Intensity - too early to tell (only 1 year).

5. Button copy on porcelain - more than 15 years.
Engineering grade copy on Engineering grade - 6 years.

6. Engineering grade - 6 years.
Porcelain enamel - oldest 15 years - not worn out yet.
High Intensity - 7 years on mid-60's material, other material available now.
Button copy - oldest 17 years - some bad, others good.

7. Insufficient data.

8. Buttons on porcelain - 10 years.
Engineering grade - 5 years.
All High Intensity applications - no data yet.

9. Average for all types - 10 years.

10. Engineering grade - as long as 10 years.

11. Engineering grade - 7 to 10 years.

12. Guide signs (painted) 5 years.
Warning and regulatory (engineering grade) 7 years.

13. Engineering grade - 10 years.
High Intensity - not enough time.

14. Road 10 years old - most signs still OK (porcelain and High Intensity).

15. Engineering grade - 8 years.
High Intensity in place since 1968, still OK.

16. Engineering grade - 6 to 10 years.
Buttons more than 15 years.
High Intensity copy 12 years. High Intensity Background - 10 years.

Useful Life - Continued

17. Button copy - more than 15 years.
    Engineering grade - 5 to 9 years.
    High Intensity - not yet known.
    Porcelain - more than 15 years.

18. Button copy on porcelain - 15 years.
    Button copy on Engineering grade - 5 to 6 years.
    Button copy on High Intensity - 5 years.
    Engineering grade on engineering grade - 5 to 7 years.
    Direct applied on engineering grade - 6 to 7 years.

19. Engineer grade sheeting - 5 to 7 years.

20. Engineer grade - 8 years.
    High Intensity - not enough experience.

21. Engineer grade - 7 to 10 years.

22. Button on Engineering grade - 10 years.
    High Intensity on Engineering grade - started 1972 - expect 12 to 15 years.
    Engineering grade on engineering grade - 7 years.
    Engineering grade on paint - 7 years.
    Button on paint - 10 years.

23. Button copy - more than 15 years.
    Engineering grade copy - 7 years.
    High Intensity - 8 years (experimental signs).

24. Button on paint - 5 years.
    Button on Engineering grade - 8 years.
    Engineering grade - 6 years.
    High Intensity - has not been in place long enough.

25. Reflective paint - 5 years.
    Engineering grade - 7 years.
    High Intensity - not enough experience.

26. Button copy - 12 years.
    Engineering grade - 7 years.

27. Copy - 10 years, painted enamel face - 8 to 9 years.
    "Cameo" - 12 years anticipated minimum.
    Engineering grade - 7 years.
    High Intensity - 10 years anticipated.

28. Engineering grade - 5 to 7 years.
    Buttons and porcelain - 15 years.

29. Paint - 15 years.
    Engineer grade - 7 years.

Useful Life - Continued

30. Engineer grade - 7 years.
    High Intensity - not enough experience.

31. Clear coat - 12 years.

32. Some signs in service 10 years or so but because of button copy are still pretty effective.

33. Not enough data.

34. Buttons on porcelain - OK after 8 years.
    High Intensity - OK after 3 years.
    Engineer grade - 6 years.

35. Button on porcelain - 15 years.
    High Intensity - under experimentation.
    Engineer grade - 5 to 6 years.

36. Button on Engineer grade - 7 years.
    Button on HINAC - 12 years (most replaced for other reasons and HINAC still good).
    High Intensity on Engineer grade - 7 years.
    High Intensity on HINAC - 10 years (still in use).
    High Intensity - 10 years (still in use).
    Engineer grade - 7 years.

37. Engineer grade - 3 to 9 years.
    High Intensity - not enough experience.
    Porcelain enamel - more than 15 years.