

---

# Selected Abstracts and Reviews of the Legibility Literature

Kristine Zeltner  
Pacharintra Ratanaproeksa  
Steve Goldstein  
Susan Adams  
Paul Green

JUNE 1988

**UMTRI** The University of Michigan  
Transportation Research Institute



Technical Report Documentation Page

1. Report No. UMTRI-88-22		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle SELECTED ABSTRACTS AND REVIEWS OF THE LEGIBILITY LITERATURE				5. Report Date June, 1988	
				6. Performing Organization Code 389214	
7. Author(s) Kristine Zeltner, Pach Ratanaproeksa, Steve Goldstein, Susan Adams, and Paul Green				8. Performing Organization Report No. UMTRI-88-22	
9. Performing Organization Name and Address The University of Michigan Transportation Research Institute 2901 Baxter Road Ann Arbor, MI 48109-2150 U.S.A.				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No. DRDA-86-1901-P1	
12. Sponsoring Agency Name and Address Chrysler Motors Corporation R&D Programs Administration 12000 Chrysler Drive Highland Park, MI 48288-1118				13. Type of Report and Period Covered Interim 1/1/88 - 5/31/88	
				14. Sponsoring Agency Code	
15. Supplementary Notes  Supported by the Chrysler Challenge Fund					
16. Abstract <p>This report is a refinement of the report <u>Legibility Abstracts from the UMTRI Library</u> (Adams, Goldstein, Zeltner, Ratanaproeksa, and Green, 1988) which contained 121 abstracts pertaining to legibility. Twenty-eight of these abstracts were particularly relevant to the legibility of automobile displays, and have been extensively edited for this report. Also included are full citations, critiques by the authors, a section summarizing key findings from the literature review, and indices by title, author, keyword and UMTRI Library number.</p> <p>The abstracts included herein differ from traditional abstracts in that they include figures and tables from the original articles, emphasize quantitative and engineering applications to the problems of legibility, and provide additional analysis of the results of certain articles by the authors of this review.</p> <p>Some key articles identified by the review include:</p> <ul style="list-style-type: none"><li>- Hind, Tritt, and Hoffmann (1976), for its analysis of the factors affecting legibility.</li><li>- Van Nes and Bouma (1980), for its numeral design recommendations.</li><li>- Howett (1983), for its letter height estimation procedures.</li><li>- Foster (1980), for its review of legibility research.</li></ul> <p>This document will serve as background material for those designing experiments on the legibility of instrument panel displays.</p>					
17. Key Words Human factors, human engineering, ergonomics, legibility, displays, instrument panels, signs				18. Distribution Statement	
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages	22. Price

Reproduction of completed page authorized



# TABLE OF CONTENTS

ABSTRACT	i
TABLE OF CONTENTS	iii
INTRODUCTION	1
KEY POINTS	3
BIBLIOGRAPHY	5
AUTHOR INDEX	55
TITLE INDEX	57
UMTRI LIBRARY NUMBER INDEX	59
KEYWORD INDEX	61



# INTRODUCTION

This report is the second in a series of three reports dedicated to reviewing the literature on legibility as part of the Chrysler Challenge Fund Project on Recognition and Comprehension of Electronic Display Graphics. This report is a refinement of the report Legibility Abstracts from the UMTRI Library (Adams, Goldstein, Zeltner, Ratanaproeksa, and Green, 1988), which contained all documents relating to legibility in the University of Michigan Transportation Research Institute (UMTRI) Library. The present report includes 28 of the 121 documents cited in the previous report.

Papers reviewed in this document were selected on the basis of the quality of the work and the relevance to instrument panel display legibility. Further, some papers which described strong methodology or contained useful general information not necessarily specific to instrument panel displays were also included. The documents reviewed include original research papers, research literature reviews, and papers relating more traditional engineering analysis.

The documents in this report are listed chronologically, and are alphabetized by author within years. Also included in this report is a section summarizing key findings from the literature review as well as indices by author, title, keyword, and UMTRI Library catalog number. The individual reviews are split into three parts: a citation for the document, an abstract, and an UMTRI review of the document. The abstracts in this report were either a modified version of the author's abstract presented in the original paper, an abstract created using various sections of the original paper (also modified), or an UMTRI-generated abstract. All abstracts were either modified or replaced by the authors of this report to assure that all relevant information was included, thus providing a uniform level of quality. The UMTRI review contains comments concerning the quality of the work and the presentation of the data, and the applicability of the paper to development of test procedures to be used in an ongoing study of automobile instrument panel displays. The section on key findings briefly enumerates several ideas critical to the development of legibility experiments. The section is split into two sub-sections, one concerning methodological and modelling issues, and the other concerning the factors affecting legibility.

One important difference between this document and traditional abstract summaries is the inclusion of figures and tables in the report, and the heavy emphasis on quantitative and engineering applications to the problems of legibility. A second major difference is the further

analysis done by the authors of this report on some of the documents reviewed. This further analysis helped to clarify and enhance some of the material reviewed in this document.

The emphasis of the literature reviewed in this document is on the legibility of highway and other types of signs. This emphasis is in part due to the focus of the UMTRI Library and the topics investigated by UMTRI researchers, and in part because of the inherent nature of the legibility literature. Studies on the legibility of license plates have been performed since the 1930's (Lauer, 1932, Aldrich, 1937). However, automobile instrument panel legibility issues are a fairly new topic, investigated only since the early 1960's. Therefore, relatively few of the included papers address instrument panels specifically.

Some of the key papers contained within this literature review include:

Hind, Tritt, and Hoffmann (1976), for its exhaustive data collection and analysis of factors affecting legibility

Van Nes and Bouma (1980), for its evaluation and recommendations for numeral design

Howett (1983), for its procedure for estimating letter size as a function of viewing distance and visual acuity

Foster (1980), for its concise and extensive review of legibility research

The literature reviewed on legibility is strong in many areas. First, there is much well-established methodology for determining various sign parameters, such as calculation procedures for legibility distances based on vehicle speed and sign placement (Mitchell and Forbes, 1942, Woods and Rowan, 1970). Such specific methodologies are not in general applicable to instrument panels. However, the task analysis concept presented in many reports is useful in helping to break down a driver's activities into steps. One representative paper (Woods and Rowan, 1970) is included in this report as an example. Second, there is an abundance of good data on the effects of illumination, contrast, luminance, and height to stroke width ratios on legibility (Kuntz and Sleight, 1950; Hind, Tritt, and Hoffman, 1976).

It should be noted that all author abstracts were modified in order to provide the reader with as much useful information as possible.

## KEY POINTS

Several important findings can be enumerated based on the review that follows.

Methodological and modelling issues are as follows.

Readability data differed significantly only between old (60-65 years old) and young subjects (20-25 years old). Middle aged subject's (40-45 years old) readability data was similar to young subjects (Welsh, Rasmussen, and Vaughan, 1977).

For divided attention tasks, the most predictive measure of traffic sign identification under normal conditions was reaction time measurement (Dewar and Ells, 1974). However, no advantage was found to using a loading task with reaction time measurement of traffic sign perception (Testin and Dewar, 1981).

For digital segmented numerals, similar to those used on automobile instrument panels, the probability of two numerals being confused is approximately equal to the inverse of the number of segments by which the two numerals differ (Van Nes and Bouma, 1980).

A rough rule of thumb is that changing background luminance by a factor of ten requires a change in contrast ratio by a factor of two in order to maintain a given level of legibility (Olson, Sivak, and Egan, 1983).

A straightforward procedure is presented to calculate the minimum required letter height for legibility of achromatic words on signs for varied distances and visual acuities (NBS Method, Howett, 1983).

Factors affecting legibility are as follows.

The relationship between ideal letter brightness and the logarithm of the background brightness was found to be approximately linear (Smyth, 1947). Further, in an experiment of questionable reliability, legibility distance in terms of feet/inch of character height was found to be proportional to the logarithm of the luminance level of the brighter of a letter-background pair (Forbes, Saari, Greenwood, Goldblatt, and Hill, 1976).

Two studies concluded that contrast direction had no effect on legibility in terms of ideal letter brightness (Smyth, 1947), or in terms of optimal letter and background brightness, stroke width, and height (Kuntz and Sleight, 1950). However, another investigation found that white-on-black characters may enhance color contrast effects on legibility, and white-on-black contrast conditions produced faster reading speeds than for black-on-white contrast directions (McLean, 1965). It was also found that the optimal height to stroke width ratio for black characters was between two and three times greater than for white characters. Further, averaging over many legibility factors, it was found that legibility was best for white-on-black characters, except under conditions of high luminance (Hind, Tritt, and Hoffmann, 1976).

A statistically significant but marginal difference between overall reading time for color contrast versus brightness contrast was found. Further, the addition of color contrast to a given achromatic brightness contrast may improve legibility for light-on-dark characters (McLean, 1965).

For traffic signs, glance legibility (reading displays when they are flashed for 50 msec or so) is not related to legibility distance (Dewar and Ells, 1974). It is believed by the authors of this document that glance legibility will not be an appropriate measure for instrument panel legibility as well.

Increases in legibility obtained by changing from a reasonably good font to a hypothesized better font are small relative to changes in other factors affecting legibility, such as changes in contrast, luminance, and illuminance (Hind, Tritt, and Hoffmann, 1976).

Based on the review of previous research, several specific recommendations concerning the legibility of highway signs are proposed, including recommendations on luminance and contrast levels for various background colors (Sivak and Olson, 1985).

# BIBLIOGRAPHY

(listed chronologically, alphabetized by authors within years)

UMTRI 30440

Uhlener, J.E. (1941). The Effect of Thickness of Stroke on the Legibility of Letters. Proceedings of the Iowa Academy of Science, 48, 319-324.

Keywords: stroke width, legibility distance

## UMTRI ABSTRACT

The study described in this paper examines the stroke width of three-inch block letters (height equals width) as a factor in legibility of highway signs. Dull black letters on a white background were tested outdoors under daylight conditions (250-550 fc).

In the first experiment 16 subjects made a total of 1344 observations. Visual acuity was tested but not reported. Four representative letters (E, N, C, P) were tested using stroke widths which varied between 8% and 32% of letter height. Three observations were made of each letter-stroke width combination, two while approaching, one while withdrawing. The results of the first study indicated that the optimal stroke width is 18% of letter height. Legibility distance was a parabolic function of stroke width:

$$\text{Legibility Distance} = 116 + 1236(\text{SW}/\text{H}) - 3370(\text{SW}/\text{H})^2$$

where SW = stroke width in inches, and H = letter height in inches.

A second experiment was conducted to verify the results of the first. Fifteen subjects made 1080 observations. Two groups of letters were examined (E, N, C, P and F, Z, B, O) using stroke widths of 16%, 18%, and 20%. Again 18% was found to be the optimal stroke width.

## UMTRI REVIEW

The experiment described in this paper seems well done and is clearly explained. The only important piece of information lacking is the visual acuity of the subjects tested. The equation given is quite specific to block capital letters, which are not often used on instrument panels. However, the relationship between legibility and stroke width is likely to be quadratic for other stroke width to height ratios.

- Bibliography -

UMTRI 30940

Smyth, J.S. (1947). The Brightness and Legibility at Night of Road Traffic Signs. Illuminating Engineering Society Transactions, 12(4), 71-94.

Keywords: sign, luminance

UMTRI ABSTRACT

This paper concerns the ideal brightness of lettered signs seen against different background brightness levels. A projected view of a street scene was used as the primary material in the experiment. A photograph of a "NO THROUGH ROAD" sign was mounted in the screen, backed by a panel with variable brightness. Six subjects were tested, all with normal vision. The subjects adjusted the sign letter brightness to correspond to three different criteria: minimum brightness at which the sign could be read; maximum brightness acceptable without discomfort or loss of background detail due to glare; and "ideal" brightness.

Results presented in Figure 3 below showed that for the brightest scene (1.4 fc), maximum and ideal letter brightness levels were separated by a ratio of 10:1, whereas for the darkest scene (0.0014 fc) the ratio is only 4:1. The values for minimum brightness are 1/10 of the ideal letter brightness. The mean ideal letter brightness rises from seven fc for the darkest scene to 25 fc for the brightest scene. There appears to be a fairly linear relationship between "ideal" letter brightness and the logarithm of the background brightness.

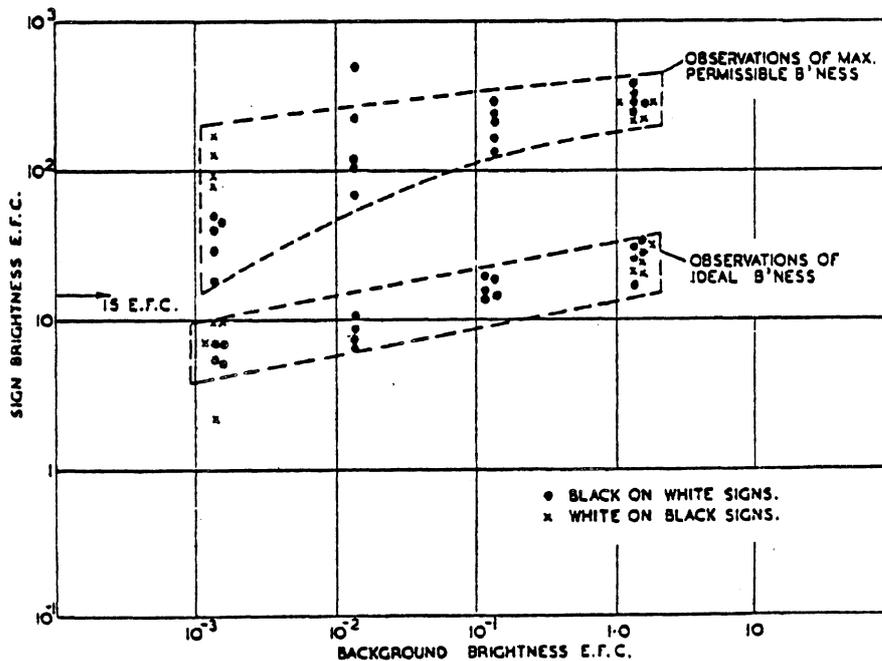


Fig. 3. Relation between sign brightness and background brightness.

- Bibliography -

The ideal brightness for legibility was found to be unaffected by the color of the sign, and was the same for black-on-white or white-on-black signs.

UMTRI REVIEW

The task performed in the experiment was rather subjective. However, the data were consistent across the people tested. This lends credibility to the results and conclusions found. With regard to instrument panels, if an automatic system is provided to adjust panel luminance based on ambient illumination levels, it should follow the linear-log relationship expressed in Smyth's report.

UMTRI 19156

Forbes, T.W., and Moscovitz, K. (1950). A Comparison of Lower Case and Capital Letters for Highway Signs. Proceedings of the Highway Research Board, 355-373.

Keywords: legibility distance, size, height, font, sign, case

UMTRI ABSTRACT

Signs showing scrambled letters, unfamiliar place names, and familiar place names were mounted on a bridge 17 feet above the ground. White-on-black, series E lower and upper case letters were used. Letter heights varied from 5 to 18 inches. A total of 75 people of varying visual acuity said when they could "recognize" and "read" signs (3,939 observations) as they walked towards them. Most participants had better than normal vision. Both day and night data were collected.

Where the sign width was fixed, lower case letters were easier to read. For fixed sign area, it would be expected that the space between lines can be less than for capital letters due to the open area between the stems of lower case letters.

Shown in Figure 8 below are the medians and distributions of the legibility distances for familiar words (without prior knowledge) and scrambled letters using lower or upper case characters. In those figures, the 85th percentile value represents what people with 20/20 vision could see. "Loop height", defined as the height of a lower case letter without any extending risers or descenders, is a constant physical dimension of lower case letters. This measure allowed for comparison to block capital letters, which have a constant height.

- Bibliography -

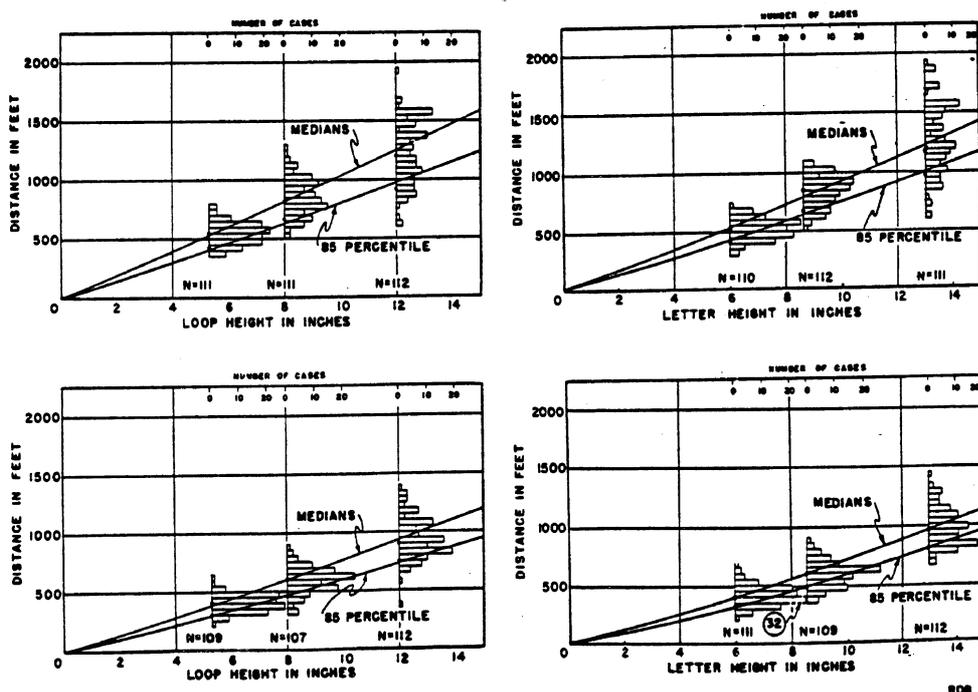


Figure 8

According to these data, the required size of letters depends only on the visual angle of the letters (arctangent of viewing distance divided by height). The legibility ratio is 55 ft of viewing distance per inch of letter height for scrambled capital letters and 75 ft/in for recognizing familiar names "without knowledge." Values for lower case letters are quite similar (63 ft/in for scrambled letters, 80 ft/in for familiar names without knowledge).

Standard deviations (in feet) for the legibility distance data are presented in Table 1 below:

Table 1. Standard Deviation of the Legibility Distance by Letter Type by Condition.

	<u>Letter Size</u>	<u>Capital Letters</u>		<u>Lower Case Letters</u>	
		Day	Night	Day	Night
Scrambled Letters	6"	82	87	72	72
	8"	106	96	91	91
	12"	178	139	149	135
Place Names w/o Knowledge	6"	82	101	125	82
	8"	135	120	183	125
	12"	231	183	308	202
Place Names w/Knowledge	6"	115	106	120	72
	8"	144	125	173	111
	12"	231	154	322	197

- Bibliography -

One trend shown by the above table is the increase in standard deviation for increasing letter size. The standard deviation is critical because one wants to assure a high percentile (e.g. 99%) of drivers can read a sign, not just the 50th percentile represented by the mean.

UMTRI REVIEW

This study is well done and widely cited in the highway signing literature. However, the report itself is poorly written and difficult to follow. The standard rule of thumb of allowing 50 ft/in of letter height comes, in part, from this research. One difficulty of applying this research to instrument panel problems is that the constant visual angle rule used by Forbes breaks down at distances less than one meter. Also, Forbes notes that many statistically significant differences were found between the medians of certain familiar names, but not between those of scrambled letters.

UMTRI 30441

Kuntz, J.E., and Sleight, R.B. (1950). Legibility of Numerals: The Optimal Ratio of Height to Width of Stroke. American Journal of Psychology, 63, 567-575.

Keywords: stroke width, height, illuminance

UMTRI ABSTRACT

Numerals of varying height and stroke width were read at various distances in order to determine the ratio yielding the highest legibility. Effects of numeral and background brightness on legibility were also studied.

Fourteen university students (20-35 years of age) with 20/20 vision looked down an eight-foot tunnel at numerals drawn with a LeRoy lettering set. Three levels of brightness and seven height to stroke width ratios were tested. Numerals were presented first at 200 mm, then 180 mm, and so on, until all numbers were read correctly. The following was concluded:

(1) The optimal height to stroke width ratio (H/SW) was 5:1. (See Figure 3.)

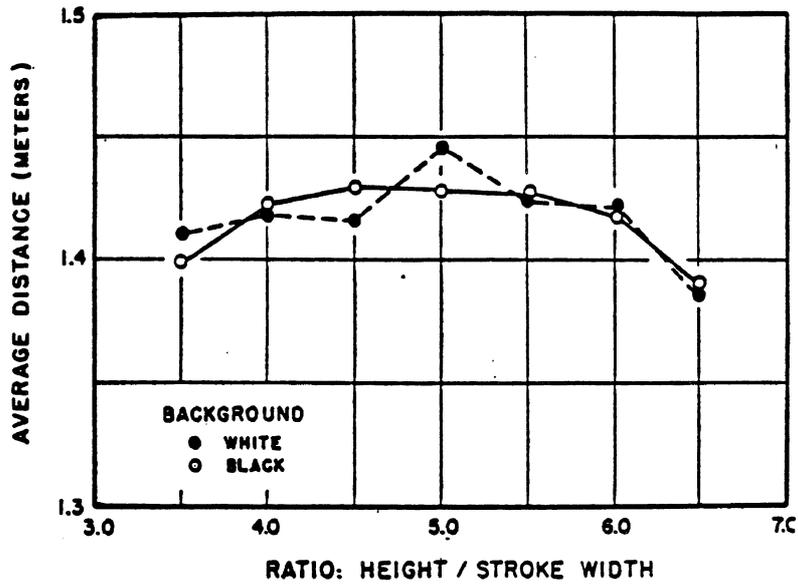


FIG. 3. AVERAGE LEGIBILITY DISTANCE FOR NUMERALS AS A FUNCTION OF HEIGHT/STROKE-WIDTH RATIO AND BACKGROUND

(2) The optimal H/SW ratio was approximately the same for all three numeral brightnesses tested (See Figure 4.)

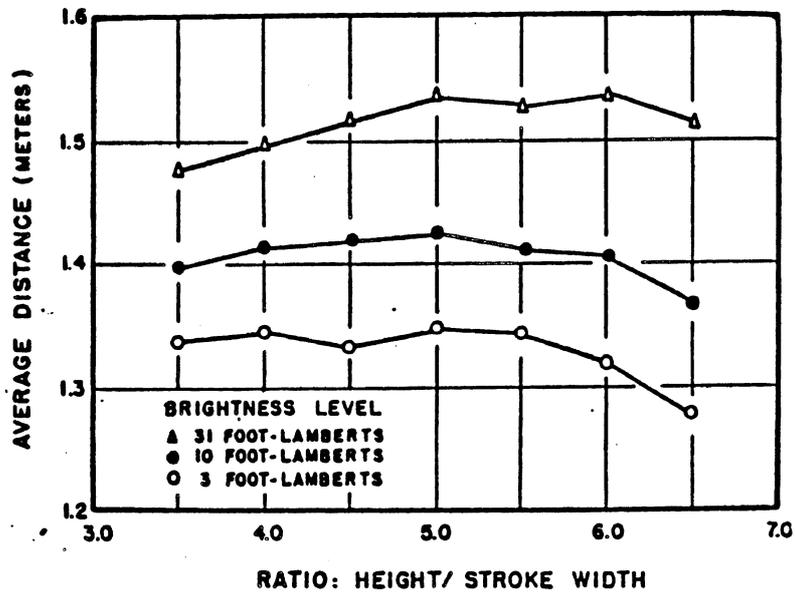


FIG. 4. AVERAGE LEGIBILITY DISTANCE FOR NUMERALS AS A FUNCTION OF HEIGHT/STROKE-WIDTH RATIO AND BRIGHTNESS

(3) Legibility of the numerals from most to least legible were: 1, 7, 0, 4, 3, 2, 9, 6, 5, and 8. This could indicate a need to modify numerals of low rank in order to improve their legibility.

(4) Contrast direction (black-on-white vs. white-on-black) had no effect on legibility.

- Bibliography -

UMTRI REVIEW

This report is fairly well-written and thorough. The authors initially claim that all subjects had "normal acuteness of vision" but later attribute one result to "subjects with defective vision," an inconsistency. One explanation is that acuity was only tested at one brightness level, while the experiment tested three levels. Acuity is known to vary with brightness, and should have been tested at each level.

Also, the largest interactions between variables involve the subjects, suggesting that it makes considerable difference which subject read the numerals. This can be explained in part by the fairly small number of subjects tested. Also, subjects with defective vision are aided by increasing target brightness considerably more than those with normal vision.

Based on these results, instrument panel labels having a font similar to LeRoy should have a height to stroke width ratio of 5:1 regardless of letter luminance and contrast direction.

UMTRI 20656

MacNeill, R.F. (1965). Colors and Legibility: Caution and Warning Data-Plates (Technical Note 3-65). Aberdeen Proving Ground, MD: U.S. Army Human Engineering Laboratory.

Keywords: color, illuminance

UMTRI ABSTRACT

This study compared the legibility of black printing on a yellow background with the legibility of five color combinations often used for caution and warning plates (white on orange, white-on-red, red-on-black, black-on-red and white-on-black). The specific colors chosen from Federal Standard 595 were:

Black	#37038
Red	#31136
Yellow	#23655
Orange	#32246

The plates were tested under three light levels: low red, low white, and high white. Ten male military personnel, ranging in age from 22 to 42 were tested. All had normal (20/20) vision.

To assess legibility, ten 5-letter words were arranged randomly on slides in two columns of five words. The slides were shown for 1.75 seconds each,

- Bibliography -

and participants read aloud as many words as they could.

The results of this study are unclear. The authors present "mean scores," but do not provide a definition of "score."

UMTRI REVIEW

Except for the lack of description of the scoring procedure, this report is well-written, and fairly complete in its coverage of the methods. A serious problem with the task chosen is that it confounds perception of colors with short-term memory constraints. It takes longer than 1.75 seconds to read 10 words aloud. Thus, subjects may have seen all of the words on a slide, but could have forgotten some when asked to repeat them. This does not necessarily mean they could not read them.

This study is presented as an example in which the methods seemed to be sound at first, but upon further examination were found to be faulty. For this reason, the results of this study will not be very helpful in designing the instrument panel experiment.

UMTRI 30448

McLean, M.V. (1965). Brightness Contrast, Color Contrast, and Legibility. Human Factors, December, 7(6), 521-526.

Keywords: illumination, color contrast, color

AUTHOR'S ABSTRACT, MODIFIED

This experiment investigated the effects of color and brightness contrast, direction of contrast, and six contrast values upon the legibility of a circular dial. The dial was 18 feet away from the subjects, had Futura demi-bold characters with a height to stroke width ratio of 5, and a constant illumination of 32 fc. The brightness of four chromatic hues (yellow, blue, red, and green) was matched with four achromatic (gray) hues. Reflectance values for the four hues (chromatic and achromatic) were approximately 66%, 56%, 44%, and 33%. Hues were paired in all possible combinations excluding chromatic with achromatic, resulting in luminance contrast values of approximately 15%, 21%, 25%, 32.5%, 41%, and 49.3% (% contrast =  $100(B_{\text{lighter}} - B_{\text{darker}}) / B_{\text{lighter}}$ ). For both contrast directions, the contrast values were equal.

Half of the 24 men tested had pilot training, all had 20/20 vision, and all passed the Ishihara Color Test. A tachistoscope was used to show each person 72 dials, with each of the 24 variations occurring three

- Bibliography -

times. Subjects reported the value displayed as accurately and as rapidly as possible. Further, the participants themselves operated the exposure duration control device used to illuminate the dial face.

Reading time results indicated that the addition of color contrast to a dial of a given achromatic brightness contrast value (for white-on-black conditions only) may improve the legibility of that dial. Legibility was also found to increase as contrast value increased. There was a significant difference between overall reading time for color contrast versus brightness contrast (0.69 second versus 0.71 second). As can be seen in Figure 4, it was found that for color contrast values above 15%, reading times were not significantly different. However, for the 15% and 41% brightness contrast conditions, there were significantly longer reading times. Further, Figure 4 shows data which appear noisy (no neat drop off in the reaction time curves), suggesting that more data should have been collected. It was found that for color contrast conditions, reading speed for light letters on a dark background was significantly faster than for dark letters on a light background. For brightness contrast conditions, contrast direction had no significant effect on reading time.

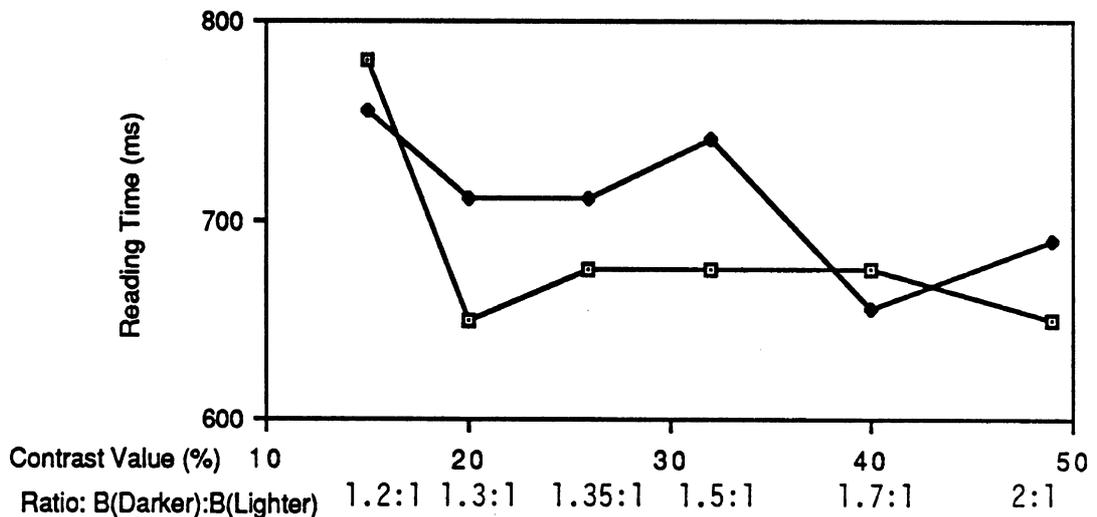


Figure 4

■ Color Contrast  
◆ Bright. Cont.

UMTRI REVIEW

The research presented in this article was well done, and reasonably comprehensive in scope. Limitations to the experiment include the use of a contrast value range which was somewhat low, and the lack of color specifications for the hues used in the experiment. Further, the results were somewhat

- Bibliography -

difficult to follow due to extensive use of abbreviations.

The article will have direct relevance to the ongoing research concerning the effects of color contrast on instrument panel design, as well as contrast direction, color contrast values, and luminance contrast values.

UMTRI 00586

Allen, T.M., Smith, G.M., Janson, M.H., and Dyer, F.N. (1966). Sign Brightness in Relation to Legibility, Lansing, Michigan: Michigan State Highway Commission, Office of Testing and Research.

Keywords: illumination, illuminance, sign, glance legibility, luminance

UMTRI ABSTRACT

This study examined the relationship between sign luminance and legibility over a wide range of ambient lighting conditions. Contrast level and direction were varied, and the sign legend and background luminance were monitored photometrically. Sixty people divided into three age groups were driven toward internally illuminated signs. Subjects were instructed to read the sign as soon as they could. Signs showed various combinations of black and white letters (three scrambled letters) and backgrounds. Series E letters under daytime conditions were used for pilot tests.

Data showed legibility increased 12% when contrast increased from 75% to 100%. The superiority of light letters on a dark background over dark letters on a light background was well supported by this study's findings. The interaction is shown in Figure 13 (next page).

UMTRI REVIEW

This report was well written and thorough. Methodology was realistic with the exception that three-letter words were used instead of those expected on highway signs. The findings in terms of varying luminance and contrast should provide firm guidelines in development of the Chrysler legibility experiments.

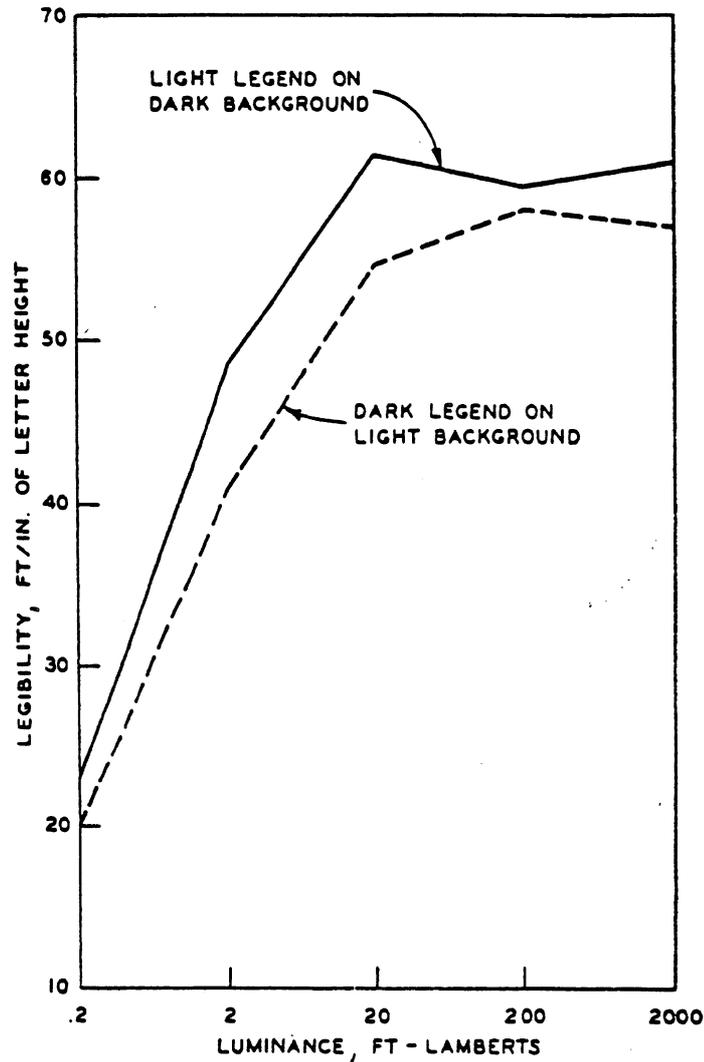


Figure 13. Effect of sign luminance on legibility, for the two contrast directions.

UMTRI 30371

Forbes, T.W. (1969). Factors in Highway Sign Visibility. Traffic Engineering, September, 39(12), 20-27.

Keywords: glance legibility, size, contrast, location

**AUTHOR'S CONCLUSIONS, MODIFIED**

Several experiments were performed to investigate the variables affecting highway sign visibility and attention value. By controlling these variables, it was possible to obtain an index of the factors most important in determining which signs were "seen first and best." The recorded subjective impression of the subjects proved to be a better index than search and response-time methods.

- Bibliography -

These indoor laboratory results were compared with a number of empirical mathematical models. One based on brightness ratios gave the best fit and another based on percent brightness contrast gave the next best fit to the experimental results, although no correlations between the estimated and actual values were calculated. The two formulas are as follows:

$$P = (S_{BRi} / \text{SUM } S_{BR}) \times 100$$

where:

P = percent seen first

$S_{BRi} = B_{RL} + B_{RB}$  for sign i

$BR_L$  = ratio of letter and sign brightness

$BR_B$  = ratio of sign and background brightness, the denominator being whichever is brighter

$\text{SUM } S_{BR}$  = the sum for all signs of  $S_{BR}$

$$P = (SC_i / \text{SUM } SC) \times AR_{LS} \times SF \times 100$$

where:

P = percent seen first

$SC_i = C_L + C_B$  for sign i

$C_L$  and  $C_B = (B_1 - B_2) / B_1$

$AR_{LS}$  = ratio of legend to sign area

SF = (area of largest sign) / (area of largest sign + area of next largest sign)

Night estimates based on these formulas were somewhat better than the day estimates, probably as a result of the greater variability in day viewing conditions.

The experiments indicated that signs located over the highway were more likely to be seen first than those to either side. The factors affecting legibility most were brightness contrast of letters-to-sign and sign-to-background. Chromatic or hue contrast was indicated as an added factor in some cases.

#### UMTRI REVIEW

The author presents a series of experiments which were conducted to discover, measure, and quantify characteristics other than legibility which cause a highway sign to be seen instead of missed. The experiments performed seem well designed and comprehensive. However, the discussion of the experimental procedure and evaluation of results were quite vague, lacking in key definitions and relevant statistics, such as correlation values for the data

- Bibliography -

collected (i.e., how well the empirical data correlated with actual data).

The concepts regarding the factors that make it easier to see a sign may provide helpful guidelines and ideas for the instrument panel study in terms of determining appropriate contrast levels and developing modified equations to predict recognition percentages.

UMTRI 15268 A03

Forbes, T.W. (1969). Factors in Visibility and Legibility of Highway Signs and Markings. Visual Factors in Transportation Systems, 12-29.

Keywords: color, height, stroke width, spacing, contrast, glance legibility

UMTRI ABSTRACT

This article provides basic definitions of terms associated with legibility and visibility (e.g., pure legibility, glance legibility, target value, and priority value) and through review of previous research identifies the factors which affect them. Studies with applicability to the instrument panel experiment are mentioned below.

Lauer (1932) recommended a letter width-to-height ratio greater than 33%, a stroke width 20% of average letter width, and a spacing 50% of average letter width.

Several studies addressed the effect of irradiation on legibility. This situation occurs with bright letters on a dark background. To the eye, these letters seem to have a wider stroke width than in reality, thus giving them a fuzzy, ill-defined appearance. Berger (1944-52), Harrington (1960), and Hodge (1962), agreed that a narrower stroke width gave better legibility. No concrete guidelines were given.

Forbes and Holmes (1939) indicated a linear relationship between legibility distance and height of letters of about 50 ft/in in daylight for black-on-white Series D letters. The narrower Series B letters gave about 33 ft/in.

Hurd (1946) and Forbes (1939) agree that when time to view signs is limited to a short glance of about one second, legibility distances are reduced by 10-15%, and about 3-4 short, familiar words can be recognized.

UMTRI REVIEW

This article is comprehensive and well-written. Its basic definitions and brief summaries of prior

- Bibliography -

research can serve as a general reference for designers. The information provided concerning visibility is not particularly applicable to the instrument panel study. However, the legibility results are of considerable value. Forbes includes comments which give the reader additional insight into the results presented. This document, while reporting data for highway signs, offers numerous specific recommendations which are appropriate for instrument panels as discussed above.

UMTRI 53348 A05

Woods, Donald L., and Rowan, Neilon J. (1970). Street Name Signs for Arterial Streets. Highway Research Record, 325, 51-61.

Keywords: legibility distance, color, letter size, location

UMTRI ABSTRACT

This paper presents the results of an engineering analysis of the factors involved in designing street name signs. The authors define a properly designed street sign as one which provides a driver with adequate time to maneuver safely.

Based on established human factors concepts and common sense, green was recommended as the optimal sign background color because of the sensitivity of the eye to blue-green at night and yellow-green during the day. Red, yellow, and orange were ruled out because of their possible association with other control devices. A sign with a black background would get "lost" too easily in the surrounding environment. A simple calculation of letter-background luminance contrast reveals that white letters on a green or blue background is the preferred combination of the particular colors tested.

An analysis of letter size is presented in terms of the distance required for the driver to read the street name sign and safely maneuver to make a left-turn maneuver onto an intersecting roadway. This distance is described by the following equation:

$$D = W + d_T + d_{P-R}$$

where  $W$ ,  $d_T$ , and  $d_{P-R}$  are defined in Figure 2.

- Bibliography -

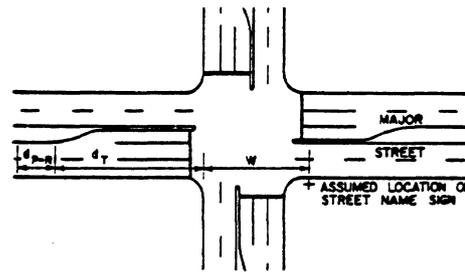


Figure 2. Major street with separate left-turn lane.

The necessary letter height can then be calculated by dividing the resulting distance ( $D$ ) by the known legibility distance of the letter; here the authors assume that a series D letter has legibility distance of 50 ft/in of letter height for persons with 20/20 static visual acuity (this distance decreases to 40 ft/in of letter height at night).

From the equations, six figures are derived which present minimum letter size as a function of street width. A family of curves, based on legibility distance, is presented in each figure. Speeds between 25 mph and 45 mph are examined as well as two levels of visual acuity (20/20 and 20/40). A static visual acuity of 20/40 probably should be assumed since it is the minimum acuity required for a driver's license. Also, the computations were made for minimum and desired perception-reaction times of 1.0 and 2.5 seconds respectively. The authors suggest that 1.0 second is too short for design on urban arterial streets; a value of 2.5 seconds is more realistic. The authors conclude that a minimum letter size of six inches should be used on all street name signs.

#### UMTRI REVIEW

The engineering analysis presented in this paper is well done and thoroughly explained. Since letter size is determined according to sign placement and the distances required to properly execute various maneuvers, it is difficult to apply these letter size formulas to the instrument panel study. Also, the decision process involved in this task is considerably different than in reading an instrument panel. Although the authors suggest that a sign with a black background would get "lost" too easily in the environment, this would not necessarily be true in the case of instrument panels. The authors' confidence in the Forbes and Holmes (1939) figure of 50 ft/in of letter height (for series D letters) suggests that this is a reliable guideline. Although the calculation parameters differ from those relating to automotive displays, the method used could be applied to the instrument panel study.

- Bibliography -

UMTRI 50568

Adler, B., and Straub, A.L. (1971). Legibility and Brightness in Sign Design. Highway Research Record, 366, 37-47.

Keywords: acuity, height, sign, sign material

AUTHOR'S ABSTRACT, MODIFIED

An important but neglected aspect of sign design is the choice of letter heights to satisfy nighttime legibility requirements. In choosing letter heights, the fundamental relationship of brightness and legibility must be taken into account. Sign brightness is a function of many factors, including sign material and position, road alignment, and vehicle and headlight characteristics.

A computer program was developed that determines necessary sign brightness as seen by approaching drivers as a function of sign material and position, road geometry, and vehicle parameters. Results are given in terms of minimum required letter heights.

First, the sign luminance must be found using Figure 2. For a given sign position (roadside or overhead), beam setting (high or low) and road distance, the sign luminance can be determined.

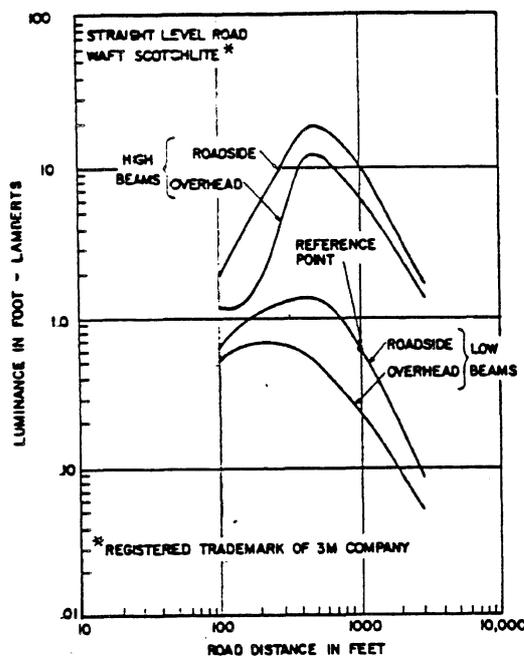


Figure 2. Sign brightness.

Next, using the luminance found in the previous step, the corresponding legibility factor can be found in Figure 1.

- Bibliography -

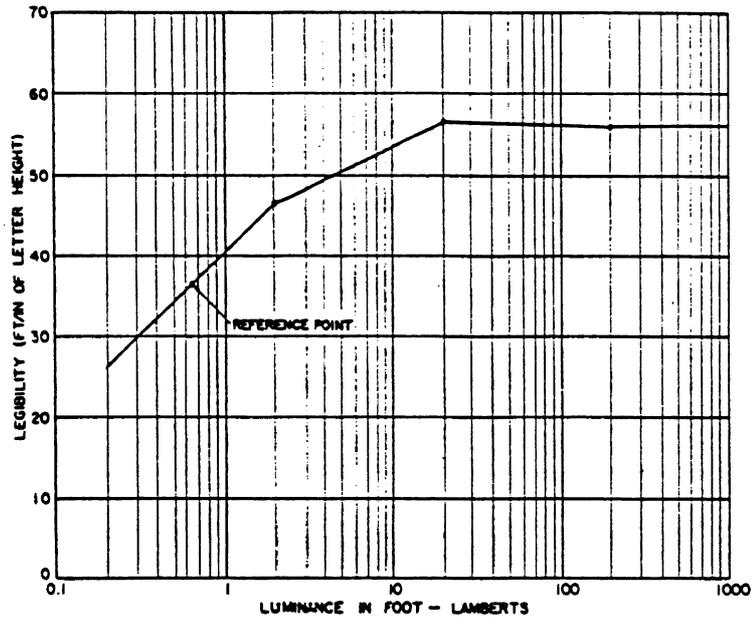


Figure 1. Legibility as a function of luminance.

Last, the road distance used in the first step is divided by the legibility factor found in the second step to determine the required letter height. A family of curves is shown in Figure 3 which give minimum letter height as a function of legibility distance, sign position, and headlighting.

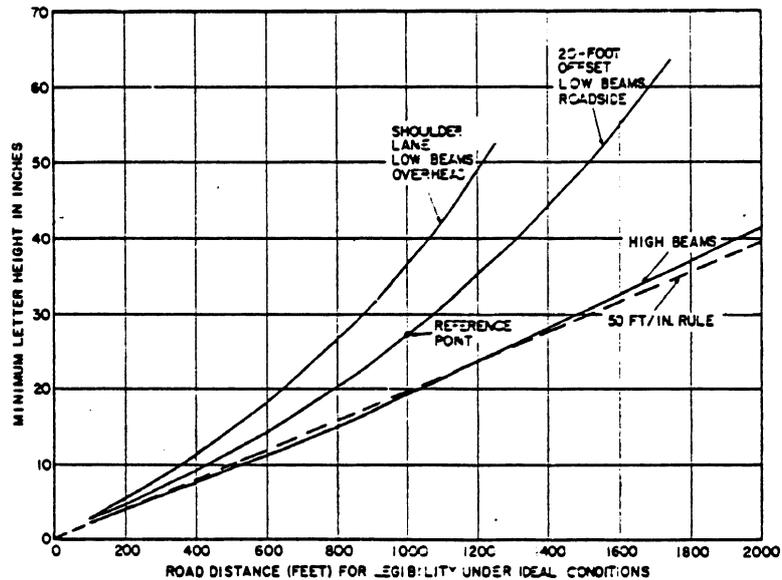


Figure 3. Minimum required letter height as a function of required legibility distances for a straight, level road.

Figure 3 reveals that for nighttime legibility, the required letter heights are much larger than the 50 ft/in rule indicates. Because of the widely varying

- Bibliography -

each sign should be treated as a separate design problem.

UMTRI REVIEW

This report offers useful quantitative recommendations for night legibility of highway signs. The author cites 14 studies and uses their findings to design the experimental parameters. Results may not be applicable to the instrument panel study since the calculation parameters differ from those of importance in the instrument panel study.

UMTRI 50569

King, G.F. (1971). Determination of Sign Letter Size Requirements for Night Legibility by Computer Simulation. Highway Research Record, (366), 48-63.

Keywords: letter size, legibility, sign

AUTHOR'S ABSTRACT, MODIFIED

A previously developed computer simulation program was used to examine the adequacy of letter sizes on existing signing along a 20 mile stretch of interstate highway. The procedure used for computing legibility distances was one developed by Mitchell and Forbes (1942). A total of 63 signs were analyzed in detail for minimum required legibility under three sets of conditions: daylight, high-beam illumination, and low-beam illumination. Although the standards of signing were found to be above average (according to accepted traffic engineering criteria and adherence to pertinent signing manuals), computer analysis revealed considerable deficiencies. The deficiencies were most pronounced for low-beam illumination and were especially severe for overhead signs. The analysis revealed letter size deficiencies for 27% of all signs for daylight, 35% for high-beam illumination, and 49% for low-beam illumination. For guide signs, the corresponding figures were 39%, 44%, and 63%. Only one of 13 overhead signs was found to be adequate for low-beam illumination. Considerable variation in required letter height was found even between identical signs.

UMTRI REVIEW

Although the results of this study are not directly applicable to instrument panels, the idea of computing digit size based on the factors which affect the legibility should be considered in the design of the instrument panel legibility experiments.

- Bibliography -

UMTRI 51215 A04

Woltman, H.L. (1973). Review of Visibility Factors in Roadway Signing. Highway Research Board Special Report, July, 134, 28-40.

Keywords: sign, height, stroke width, spacing, color

UMTRI ABSTRACT

The author reviews over 30 research reports from 1932 to 1971 on visibility factors in roadway signing. Specific citations concern legibility, letter brightness, need for contrast, lower case letters and familiarity effects, glance legibility, target value, the information system, luminance characteristics and angular position. In addition to the review, Forbes and Olsen offer discussions and critiques of Woltman's paper. The report recommends black letters on a yellow background as a first choice, and black-on-white or white-on-black as second choice. Two reviewed studies recommend a stroke width of 15-25% of the letter height. The author reports a contrast of 40-50% is needed for daytime legibility while 50-60% is needed for nighttime legibility.

UMTRI REVIEW

The author provides a clearly written and comprehensive report. It lacks, however, an integrative review of previous research. Findings could have been better represented in figures or tables. Specific and useful findings could be better obtained by reading the individual studies cited in Woltman's review.

UMTRI 33938

Dewar, R.E., and Ells, J.G. (1974). Methods for the Evaluation of Traffic Signs. Alberta, Canada: Calgary University.

Keywords: legibility, sign, glance legibility, reaction time

AUTHOR'S CONCLUSIONS AND RECOMMENDATIONS, MODIFIED

This report describes a series of 20 experiments carried out to develop and compare several methods for evaluating traffic signs. Some methods examined include on-road tests, time-lapse photography, questionnaires, reaction time, population stereotypes and others. Interested readers are encouraged to read the full report.

One significant finding concerns glance legibility, which refers to legibility when reading time is limited. Although this measure has been used in traffic sign research by a number of experimenters

- Bibliography -

in the past, the present research indicates that this measure is unrelated to legibility distance. Therefore, its validity as a tool for evaluating traffic sign perception must be questioned.

UMTRI REVIEW

The experiments were all very well done and clearly explained. The authors provide measures of correlation between the different methods and provide recommendations for appropriate use of each method. This is an excellent reference for determining what methods are appropriate for testing specific variables. Of particular interest to the instrument panel study are the author's findings that the reaction time measure of a divided attention task was the most predictive of sign identification under normal conditions. Based on these findings, the authors recommend that experimental conditions involve the type of attention demands found in the actual task. Also worth noting is the finding that glance legibility is unrelated to legibility distance.

UMTRI 52905 A04

Forbes, T.W., Saari, B.B., Greenwood, W.H., Goldblatt, J.G., and Hill, T.E. (1976). Luminance and Contrast Requirements for Legibility and Visibility of Highway Signs. Transportation Research Record, January, (562), 59-72.

Keywords: luminance, contrast, legibility, sign

UMTRI ABSTRACT

This paper describes two experiments. In the first set, colored slides were projected in a darkroom. Two series of blank signs in seven unspecified colors and two series of target signs carrying a capital letter C or O with different orientations were presented. The height to width ratio of the letters was 1.25:1 and the height to stroke width ratio was 5:1. Neutral overlays were used to vary the slide luminance between five levels simulating rural, suburban, and lighted city conditions (0.37 to 4.45 fL). An unreported number of subjects were asked to identify the letter or color shown. The exact nature of their response is unclear, as are the specifics concerning the test conditions.

Legibility distance (ft/in of character height) was found to be proportional to the logarithm of the luminance level of the brighter of each letter-background pair. The results for five color combinations are shown in Figure 3 (next page).

- Bibliography -

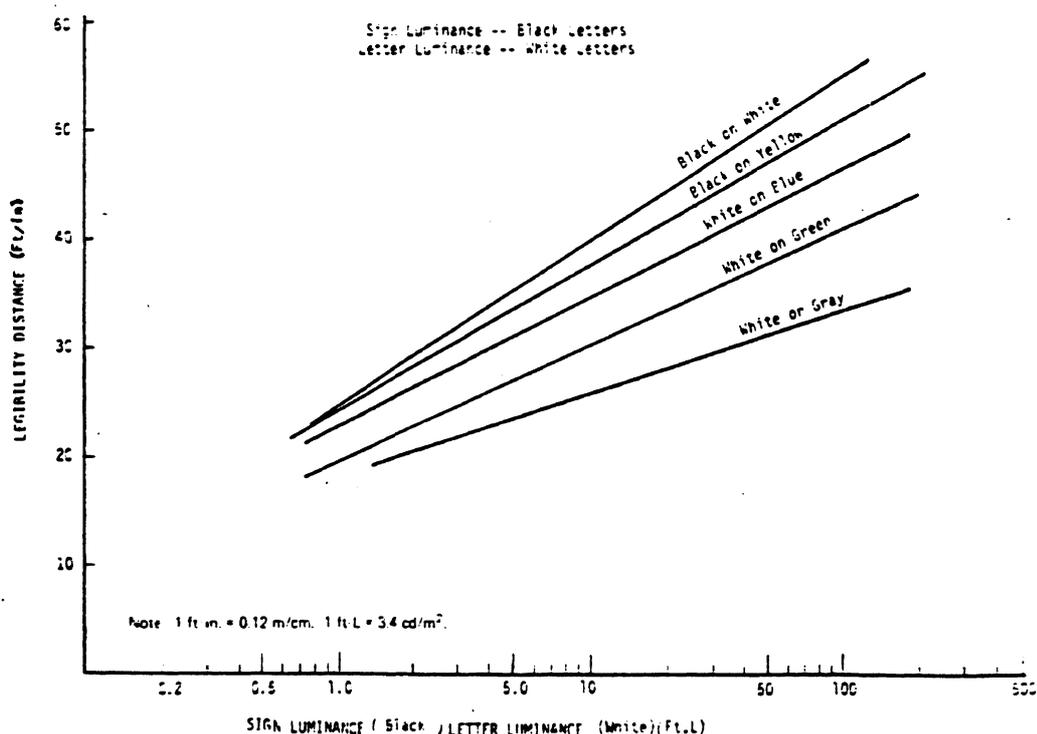


Figure 3. Average legibility and luminance for all 5 studies and 5 color combinations.

The second series of experiments was conducted outdoors at night. Signs with 12 inch letters were viewed by 50 subjects. Letters were square E's with a height to stroke width ratio of 5:1 or 7:1. Two color combinations (white on green, black on yellow) and two reflective materials were examined. Groups of six subjects approached the signs from a distance of 1200 feet in a vehicle whose headlights were either in the low or high-beam position. The subject's task was to say when they could read the letter. Three ambient luminance levels (2.75 fL, 0.34 fL, and 0.01 fL) were used.

As in the laboratory experiment, the authors found a linear relationship between the logarithm of the sign luminance and legibility distance (see Figure 4 below), though the outdoor data seem to be noisier. Also having a major effect was the luminance ratio, with legibility distance increasing about 20% as luminance ratio increased from 2:1 to 10:1. The ambient illumination level had no effect on legibility distance.

- Bibliography -

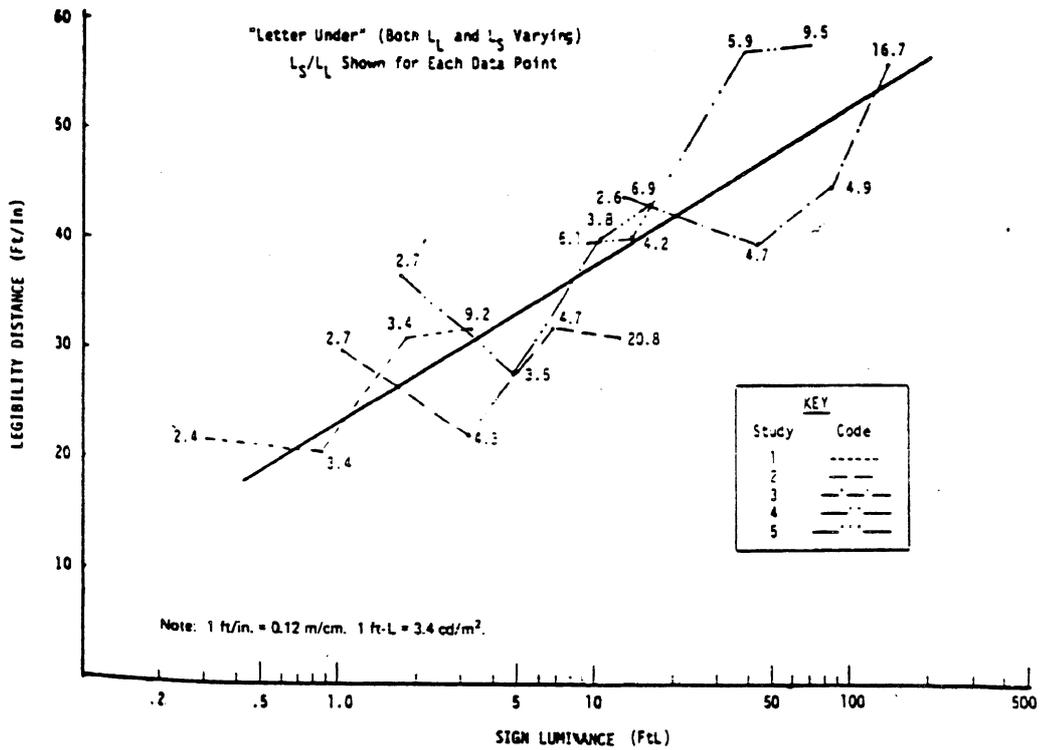


Figure 4. Legibility and sign luminance for black letters on a yellow background for all 5 studies and contrasts.

UMTRI REVIEW

This paper is poorly organized and incomplete in its description of the test methodology and conditions examined. For example, critical information concerning subjects (i.e. age, visual acuity) and the CIE coordinates for the colors are not provided. Further, some of the methods described are of questionable reliability. For instance, in the outdoor study, subjects themselves determined when they could correctly identify the target letter. Their answers were not verified by the experimenters.

The graphs and figures presented in the paper are poorly labeled and difficult to interpret. Nonetheless, the relationship discovered between legibility distance and luminance seems to be sufficiently supported, and can be applied to the issue of character height in the instrument panel study.

- Bibliography -

UMTRI 41434 A12

Hind, P.R., Tritt, B.H., and Hoffmann, E.R. (1976). Effects of Level of Illumination, Strokewidth, Visual Angle and Contrast on the Legibility of Numerals of Various Fonts. Proceedings of the Australian Road Research Board, Eighth Conference, 46-55. Parkville, Victoria, Australia: Australian Road Research Board.

Keywords: stroke width, contrast, luminance, legibility distance, numeral design

AUTHOR'S ABSTRACT, MODIFIED

This study attempted to find how the known factors of legibility interact. The experiments were conducted in a dark tunnel of the Victorian Country Roads Board. The factors investigated were: font design, height to width ratio, height to stroke width ratio, numeral/background contrast, luminance, grouping of numerals, and the distance between the display and observer. The various conditions investigated, based on previous research, were: six different numeral sets (the NAMEL, Berger, Motorways, Mackworth, Standards Association of Australia, and Tritt sets); height to stroke width ratios of 15.8:1, 12:1, 10:1, 8:1, 6:1; contrast direction; viewing distances ranging from 5.5 to 11 m; and luminance levels of 1.0 cd/m<sup>2</sup>, 5.7 cd/m<sup>2</sup>, 34 cd/m<sup>2</sup>, 206 cd/m<sup>2</sup>, and 1233 cd/m<sup>2</sup>.

Seven figures shown below illustrate the overall effects of the experimental variables and some of the major interactions. Figures 1 and 2 show the interaction between distance, luminance, height to stroke width and contrast for both contrast directions. For the black-on-white contrast direction, increases in height to stroke width ratio increased the percent recognized for all luminances tested. The opposite effect was found for the white-on-black contrast direction.

Figure 3 shows that differences in luminance had a large effect on optimum height to stroke width ratio for white characters, and virtually no effect on black characters. Further, it was found that for the range of luminances tested, the optimal height to stroke width ratio for black characters ranged between two and three times greater than the optimal height to stroke width ratio for white characters.

Figures 4 and 5 show the interaction between font and height to stroke width ratio. As can be seen from Figure 5, changes in fonts give absolute improvement in terms of percent recognition for white characters. This is not the case for black letters, as can be seen in Figure 4. Further, a decrease in height to stroke

- Bibliography -

width ratio decreases the percent recognition for white characters (Figure 4), but increases the percent recognition for black characters (Figure 5).

Figures 6 and 7 show the interaction between luminance and distance. For black characters (Figure 6), increases in luminance led to increases in percent recognition. Further, the optimal legibility for black characters was obtained for height to stroke width ratios greater than 6:1. For white characters (Figure 7), increases in luminance increased percent recognition up to an optimal luminance of 34.3 cd/m<sup>2</sup>. Further, the optimal legibility for white characters was obtained for height to stroke width ratios greater than 12:1.

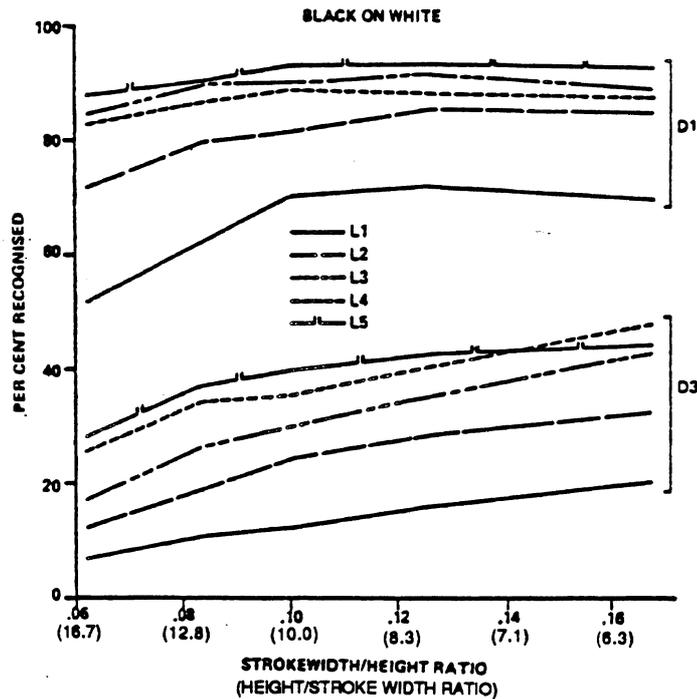


Fig. 1—Illustration of the effects of distance, luminance and strokewidth/height ratio on recognition of black numerals

- Bibliography -

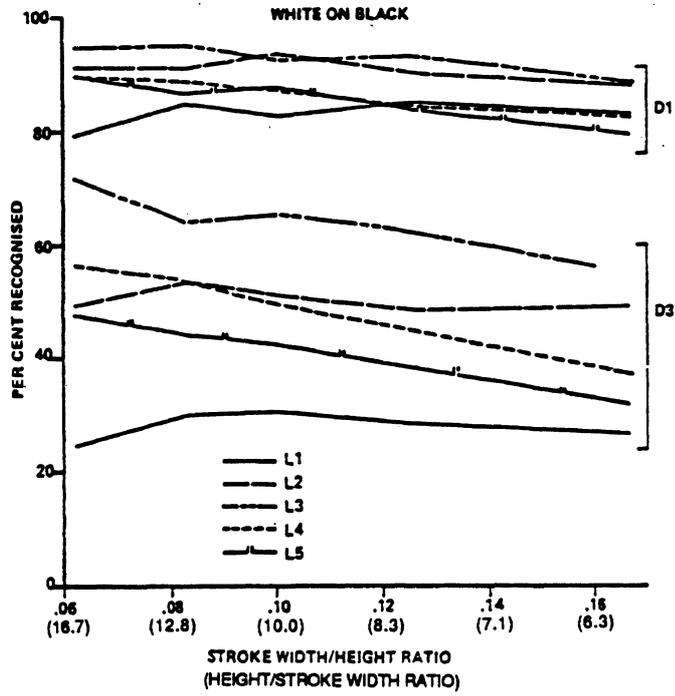


Fig. 2— Illustration of the effects of distance, luminance and strokewidth/height ratio on recognition of white numerals

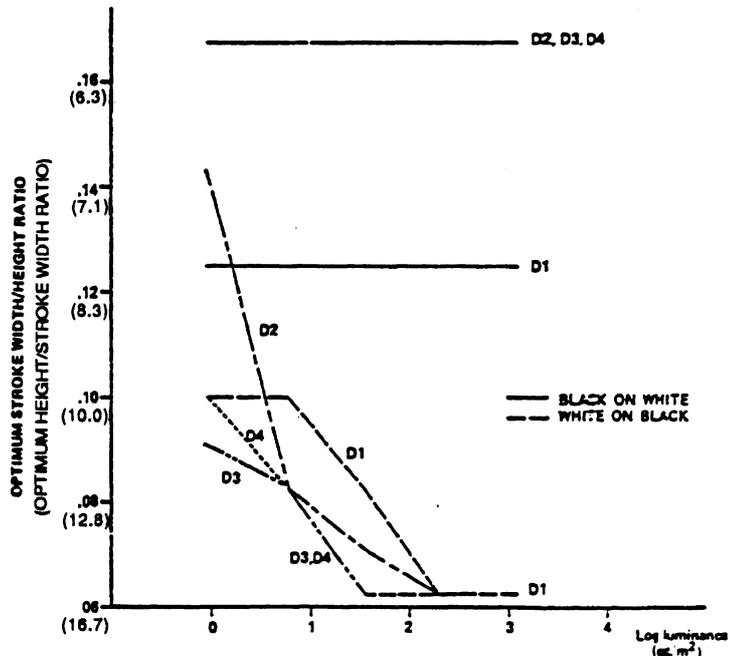


Fig. 3— Optimum numeral strokewidth/height ratios for different levels of luminance and distance and for black and white numerals

- Bibliography -

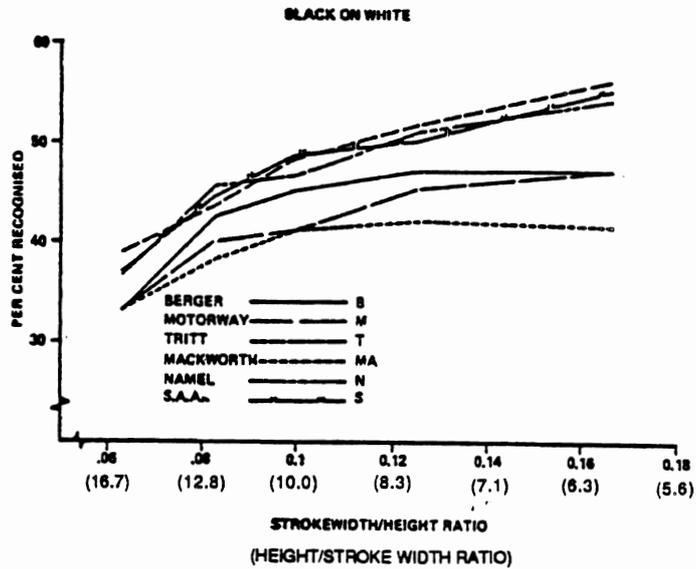


Fig. 4—The effect of font and strokewidth/height ratio on the percentage of black numerals recognised

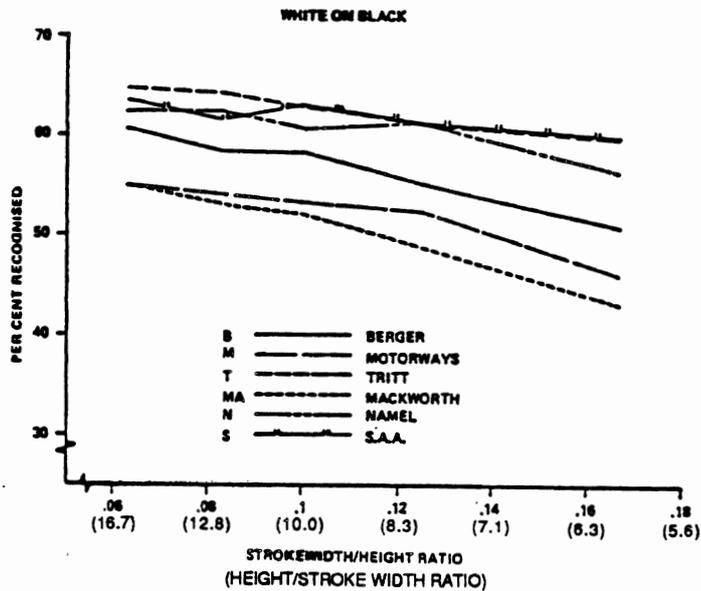


Fig. 5—The effect of font and strokewidth/height ratio on the percentage of white numerals recognised

- Bibliography -

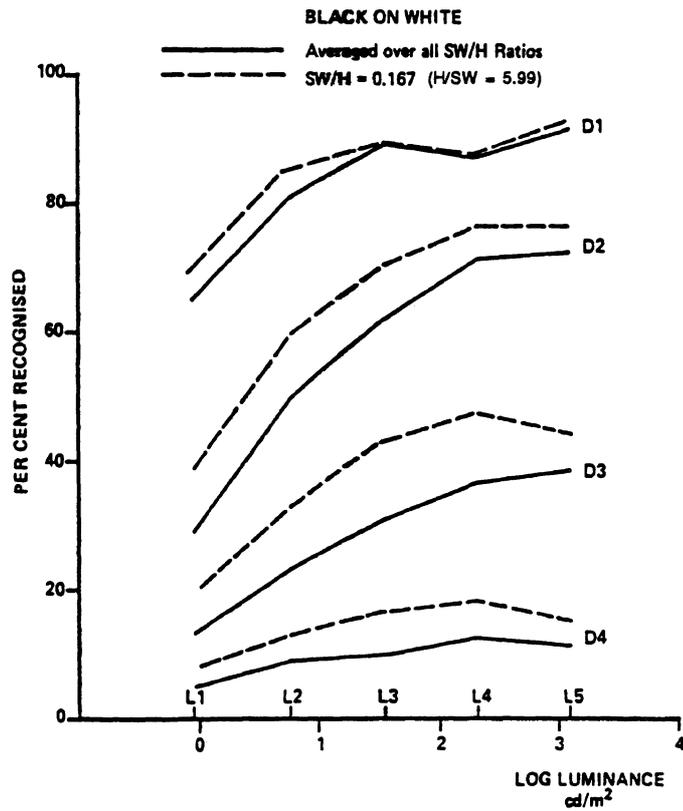


Fig. 6 — Effect of luminance and distance on the recognition of black numerals on white background

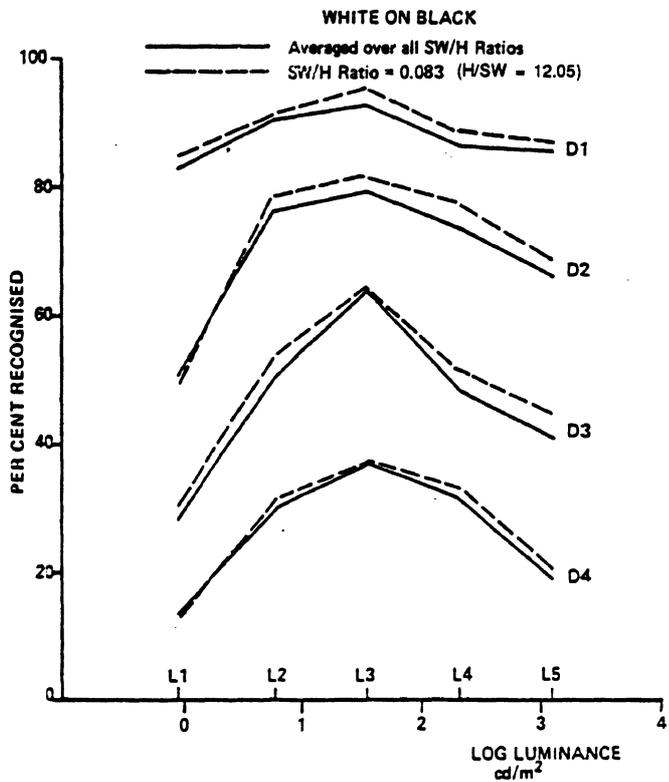


Fig. 7 — Effects of luminance and distance on the recognition of white numerals on black background

- Bibliography -

Other overall results include the following. White numerals on black backgrounds were more legible than black numerals on white backgrounds, except for high luminances. However, when averaged over all luminances, distances, numerals, and stroke width to height ratios, white letters on black backgrounds were more often recognized than black numerals on white backgrounds. In terms of ability to recognize, straight line numerals performed much better than curved numerals. Further, legibility varies more with changes in visual angle than with changes in luminance.

Based on the results of this experiment, superior sets of black-on-white and white-on-black numerals were developed, as shown below.

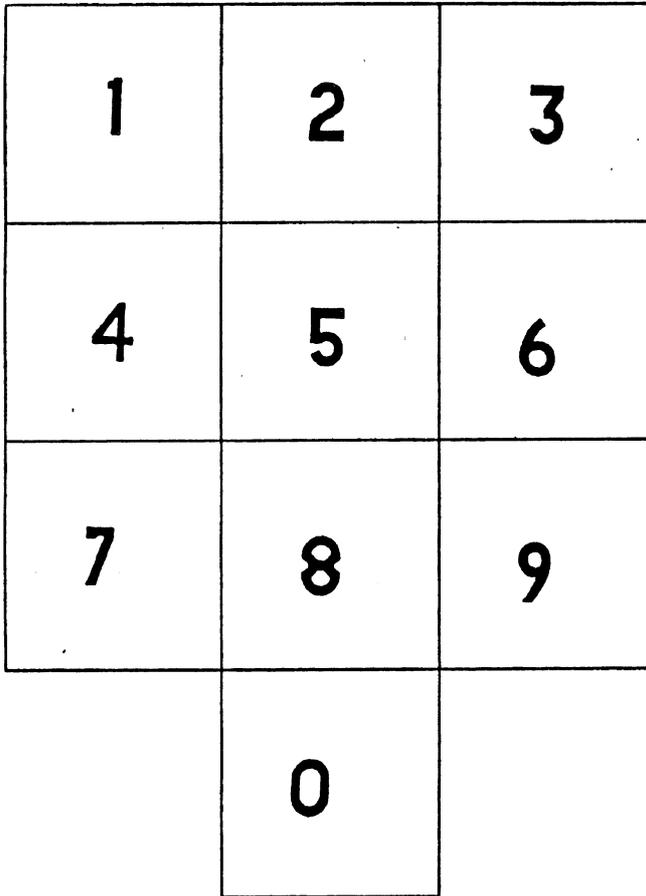


Fig. 13—An improved numeral set, black on white numerals

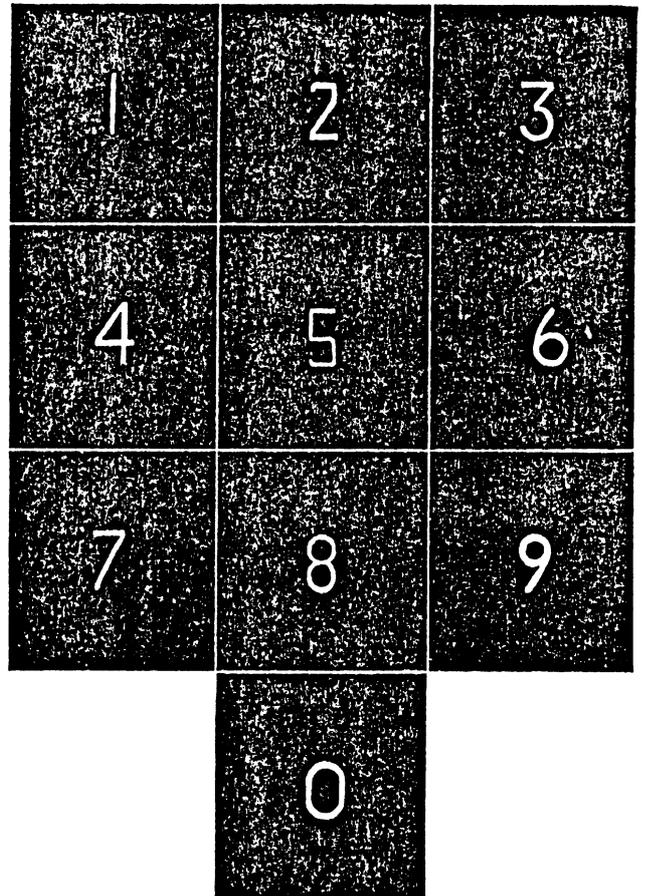


Fig. 14—An improved numeral set, white on black numerals

UMTRI REVIEW

This study was thorough, exhaustive (275,000 observations), and well done. The methods used in this experiment encompassed a wide range of nighttime conditions, and the results can contribute significantly to the development of test conditions for the instrument panel study in terms of stroke width to height ratios for the instrument panel numerals, background color, and luminance levels of the numerals.

- Bibliography -

UMTRI 40338

Welsh, K.W., Rasmussen, P.G., and Vaughan, J.A. (1977). Readability of Alphanumeric Characters Having Various Contrast Levels as a Function of Age and Illumination Mode (Technical Report Number FAA-AM-77-13). Oklahoma City, Oklahoma: Federal Aviation Administration Civil Aeromedical Institute.

Keywords: contrast, age

AUTHOR'S ABSTRACT, MODIFIED

Readability data were obtained from 36 subjects: 12 subjects in each of three age groups (20-25, 40-45, and 60-65 years old). Subjects viewed black alphanumeric characters (eight point Futura Demi-bold) against five levels of grey background. The five figure-to-background contrast ratios examined were 3.2:1, 6.6:1, 9.3:1, 12.8:1, and 16.2:1. Minimum illuminance required to identify all contrast combinations was determined at a viewing distance of 40 cm (15.7 in) under dim white and red illumination. Subjects identified all characters while viewing them through an artificial pupil (2.0 mm).

The data indicate that a significant increase in illumination was required for successive decreases in contrast ratio for all age groups and under both illumination modes (see Figures 3 and 4 below). Under red illumination, threshold luminance values showed a significant trend with age for all five contrast levels. Under white illumination, significant trends were indicated for three of the five contrast levels.

With reference to the younger group, individuals in the middle-aged and older groups required an average luminance increase of 18 and 63 percent respectively for equivalent readability scores under white illumination. Under red lighting, corresponding values were 18 and 58 percent.

- Bibliography -

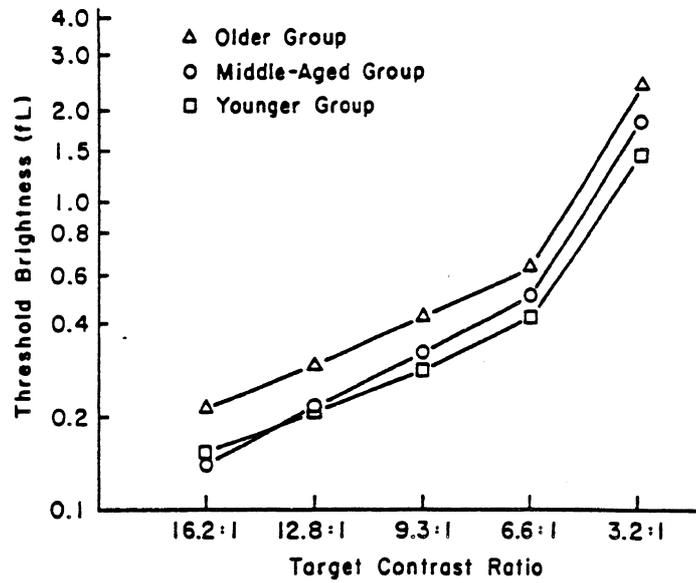


Figure 3. Luminance values measured from a reflectance plaque for threshold readability under white illumination for all contrast ratios and age groups.

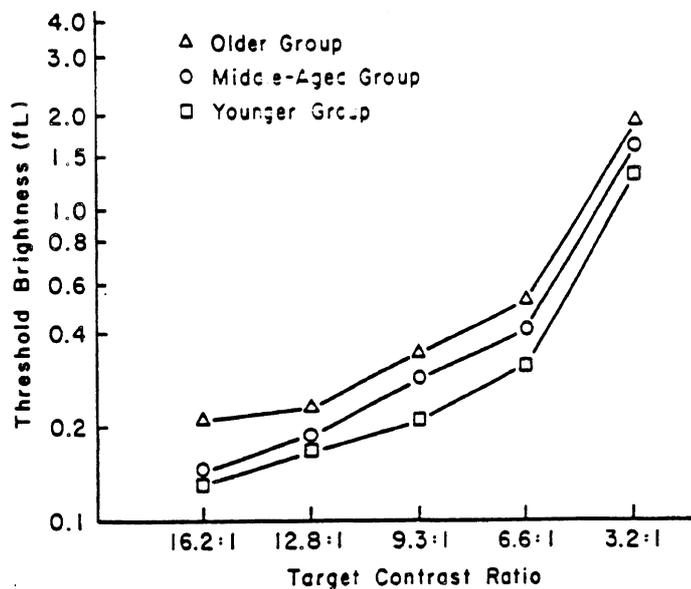


Figure 4. Luminance values measured from a reflectance plaque for threshold readability under red illumination for all contrast ratios and age groups.

- Bibliography -

UMTRI REVIEW

The authors provide a very thorough and clear explanation of their procedures and findings. Their findings concerning the relationship between illumination and contrast ratio are applicable to some of the issues to be addressed in the instrument panel study. One key point is that the major age group differences were found between young and old subjects. The middle-aged group was very similar to the young group. Thus, the data suggest the need to look primarily at the extremes, and not at middle-aged persons.

UMTRI 42824

Dudek, C.L., Huchingson, R.D., Stockton, W.R., Koppa, R.J., Richards, S.H., and Mast, T.M. (1978). Human Factors Requirements for Real-Time Motorist Information Displays (Technical Report Number FHWA-RD-78-5). Washington, D.C.: Federal Highway Administration.

Keywords: sign, sign material, luminance, contrast, color, legibility

UMTRI ABSTRACT

This paper provides practical guidelines for the development, design, and operation of driver visual displays for freeway traffic management. The guidelines for visual messages are based upon research and operational experience. Some of its relevant recommendations include: 1) For light reflecting signs, use a contrast ratio of 40% (daytime) and 50% (nighttime) 2) These contrast ratios only indicate whether the proposed color combination will have adequate brightness contrast to be legible 3) When color is to be visible at night, colors near the central portion of the spectrum should be used. It does not indicate whether the appearance of the sign will be acceptable.

The report also includes discussions on sign size, letter height, stroke width, and letter spacing specific to freeway signs. Recommendations for legibility distances of standard letter series are given in Table XIV-3 below.

- Bibliography -

TABLE XIV-3  
LEGIBILITY DISTANCES OF STANDARD LETTER SERIES

Letter Series	A	B	C	D	E	F
Ratio of Height to Stroke	11/1	8/1	7/1	6.5/1	6/1	5/1
Legibility Distance	----	33'/in	43'/in	50'/in	57'/in	60'/in
Design Legibility Distance	----	15'/in	20'/in	23'/in	26'/in	27'/in

Legibility distance is based on 20/20 static visual acuity and daytime conditions. Design legibility recommendations are based on 20/20 visual acuity and nighttime conditions.

Recommendations for dot matrix displays include a maximum allowable percent bulb failure of 10% and the use of upper-case letters. No research is known that supports improved legibility for slanted letters.

- Bibliography -

UMTRI REVIEW

The report is useful and well organized. The authors provide guidelines supported by cited sources rather than experimental findings. The document is well documented as well as extensive (384 pages). The discussions of ratio of height to stroke width, legibility distance, and design legibility distance of standard letter series are especially useful.

UMTRI 54156

Olson, P.L., and Bernstein, A. (1979). The Nighttime Legibility of Highway Signs as a Function of Their Luminance Characteristics. Human Factors, April, 21(2), 145-160.

Keywords: luminance, contrast, color, acuity, legibility distance, sign

AUTHOR'S ABSTRACT, MODIFIED

A laboratory study measuring reaction time was carried out to define the effects of luminance, contrast, color, and driver visual characteristics on sign legibility distance. The study consisted of subjects identifying the orientation of five sized Landolt rings at five distances (3.6, 4.8, 6.0, 7.2, and 8.4 m/cm letter height) for signs consisting of seven background colors (green, blue, red, black, yellow, orange, and white) for background luminances ranging from 0.07 to 211 cd/m<sup>2</sup>. For white legend signs, background luminance was fixed and the legend luminance was varied to find the zone from zero information transmission to the point where error free performance was achieved for both first high and low initial legend luminance. For black legends, background luminance was varied using the above procedure. Data were collected under low and high surround luminance conditions. Concurrently, 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 two-step field study was then conducted at night using 18 subjects in which legibility distance predicted by the model was compared with legibility distance measured on a number of real and simulated signs. One step consisted of subjects identifying the orientation of the letter E on custom made signs consisting of three different background reflectivities, four different legend reflectivities, and three different letter sizes. The second task had subjects identify various freeway signs while traveling down the freeway at approximately 90 km/h. Since real highway signs were used, this study did not use a variety of colored backgrounds. In general, predicted

- Bibliography -

legibility distances were within 10% of measured legibility distances found during the field study.

Results concerning effect of background color on legibility are as follows. At background luminance levels greater than  $3.77 \text{ cd/m}^2$ , red and green legibility data compare well. In terms of legibility, blue and green backgrounds also performed almost equally as well. In addition, white, yellow, and orange backgrounds produced similar legibility results, and had maximum legibility for luminances in the range of  $3.4$  to  $34 \text{ cd/m}^2$ .

It appears that color contrast effects become inoperative at levels between  $0.3$  and  $0.33 \text{ cd/m}^2$  for the ambient conditions used in this experiment. Further, data for black backgrounds were generally similar to those for colored backgrounds at the lowest luminance level tested.

#### UMTRI REVIEW

The research presented in this report was thoroughly done and quite comprehensive in scope in relation to highway signing principles. However, due to the nature of the data collected, the data presented in the report were often difficult to understand and interpret. It is assumed that the experimenters used the standard highway sign colors in their study, as no specifications were given.

Although retroreflectivity is not relevant to the instrument panel study, the strong methodology throughout and use of background color in the first experiment will prove useful in the design of the instrument panel legibility experiment. Specifically, this report should help to decide which colors should be used in the experiment, which colors need not be used due to similar legibility performance, and what luminance conditions should be studied.

UMTRI 46927

Forbes, T.W. (1980). Acuity, Luminance and Contrast for Highway Sign Legibility - Samples of Research Methods and Results; a Review of Fifteen Selected Studies by Various Investigators. East Lansing, Michigan: Michigan State University.

Keywords: acuity, luminance, contrast

#### UMTRI ABSTRACT

This review of 15 selected studies of acuity and legibility by various authors seeks to explain differences in the results obtained by different methods and approaches. Included in the review are 27

- Bibliography -

figures referring to the various studies cited. Studies with applicability to the instrument panel study are mentioned below.

The acuity studies conducted by Burg (1966) demonstrate the advantage of placing signs for viewing straight ahead as much as possible to facilitate reading. This conclusion is based on findings that static visual acuity is generally higher and decreases less rapidly with age than does dynamic visual acuity.

Richards (1977) conducted a study using dark letters on a white background and found that at age 40, twice as much background luminance is needed to see low contrast letters as for 20 year olds. At age 60, 2.8 times as much background luminance is needed to see low contrast letters.

Two outdoor full-scale legibility studies are discussed. One conducted by Forbes, Moskowitz, and Morgan (1950) gave daylight legibility distances and confirmed the relationships of letter height, width and stroke width to daylight legibility distance. Also, night legibility distances of white-on-black signs were found to be 20-30% shorter than daylight values.

Allen, Dyer, et.al. (1967) found that legibility increased as ambient illumination increased. Legibility distance of 20-30 ft/in of letter height resulted at 0.2 fL and this increased linearly to about 50 ft/in at 2 fL. From 2 to 20 fL, a further increase of legibility distance from 50 to 60 ft/in occurred with decreased slope which varied with the interacting variables.

Three laboratory legibility studies were reviewed. The first, conducted by Allen and Straub (1955) found that legibility increased as letter width and letter size were increased up to a square letter.

Studies of contrast sensitivity by Blackwell et al. (1968, 1971, 1973, 1977) examined more complex tasks and are therefore more valuable. Their comparison of threshold contrast sensitivity for age groups showed the contrast required for the 60 and above age group to be 2.5 times the contrast required for the 20-30 year group.

The four studies addressing legibility and surround luminance all concluded that an inverse relationship exists between surround luminance level and legibility distance. That is, as surround luminance level increases, so must legend and

- Bibliography -

background luminance levels in order to maintain legibility.

The authors conclude from the studies reviewed that differences in results between the different acuity and sign legibility studies may be due in great part to measurement methodology. Highly simplified laboratory studies aimed at measuring only one factor at a time are of great importance for certain basic determinations. However, for valid application to practical highway and everyday seeing problems, acuity and legibility measurements must be those using more realistic task complexity.

UMTRI REVIEW

The author's conclusion that highly simplified test methods may not have applicability to complex situations is worth noting. This suggests that in designing the instrument panel study, care should be taken to incorporate some complexity in the experimental task.

UMTRI 70009

Foster, J.J. (1980). Legibility Research 1972-1978: A Summary. Manchester, England: Manchester Polytechnic.

Keywords: literature review

AUTHOR'S INTRODUCTION, MODIFIED

The aim of this paper is to provide graphic designers and interested research workers with a summary of research published between 1972 and 1978.

A number of surveys of this general area have appeared recently (Macdonald-Ross and Smith 1977, Hartley and Burnhill 1977, Wright 1977, Hartley 1978). The present one is intended to complement those, by providing a more comprehensive summary of the work that appeared in 1972-1978. Within each section or subsection, material is usually dealt with in chronological order of its publication. Only a brief overview of this work will be given here.

Section 1 covers the problems of measurement and the criticisms that have been made of the conventional approach to legibility research. Sections 2, 3, and 4 deal with processes underlying the comprehension of graphic displays. In particular, section 3 covers experiments on letter and digit identification. A study by Bouma and Van Nes (1977) examined the discriminability of segmented digits and found that digits varied in identifiability (8 being the least discriminable), becoming less identifiable as the number of component line segments increased. Ellis and

- Bibliography -

Hill (1978) found that more errors were made reading segmented characters than conventional numerals. However, subjects could be trained to read segmented numerals as proficiently as conventional numerals, but proficiency was lost when retested a month later.

Section 5 is concerned with studies which have examined the effect of typography upon the effectiveness of printed verbal material. Section 6 covers signs, symbols and signing systems. Subsection 6.10 deals with color coding in search tasks. A survey by Christ (1975) found that when displayed items vary on one (nonredundant) dimension only, a target which is color coded can be found more accurately than one coded by size, brightness, or shape, although alphanumeric coding is superior to color coding. In experiments that measured search time, color coding was superior to any achromatic attribute, such as size, brightness, shape, or even alphanumeric character. Several other studies of color coding are mentioned, and generally all found color coding to be beneficial to a certain extent.

Section 7 is mainly concerned with research into the effect of illustrations on comprehension and learning. Section 8 encompasses engineering drawings, and Section 9 includes work on maps.

Section 10 covers the presentation of quantitative data. Van Nes (1972) found that subjects could make calculations more quickly and accurately when digits were presented in a digital format than when displayed in an analog format. Nason and Bennett (1973) found that digital counters could be read more quickly than analog dials.

Algorithms and the use of tables for presenting instructions are dealt with in Section 11, while Section 12 is concerned specifically with forms which have to be filled in. Finally, Section 13 summarizes studies of the reading of projected or televised material.

#### UMTRI REVIEW

The material presented in this 76-page literature review covers a wide range of topics on legibility and includes approximately 500 references cited by the author. With few exceptions, however, the topics covered in this report have little relevance to the instrument panel study. Although the reviews given are somewhat brief, the structure of the review allows the reader to easily find material of interest.

- Bibliography -

UMTRI 54550

Van Nes, F.L., and Bouma, H (1980). On the Legibility of Segmented Numerals. Human Factors, August, 22(4), 463-474.

Keywords: size, stroke width, font

AUTHOR'S ABSTRACT, MODIFIED

This paper reports experiments on segmented numeral discriminability. Ten subjects participated in three experiments. In Experiment 1, subjects viewed segmented numerals (height 19 millimeters, width 11.5 millimeters) projected on a screen 16 meters away. Letters were slanted eight degrees to the right of the vertical. Subjects were given as much time as they needed to verbally identify the numeral.

In Experiment 2, an indicator tube was positioned in front of the screen at an eccentricity of 30 degrees in the right visual field of the subject. The segmented numeral was flashed on the screen for 100 milliseconds. In Experiment 3, three indicator tubes were placed at eccentricities of 5, 7.5, and 10 degrees. Subjects were to identify the numerals verbally.

According to the data, perceptual confusions between members of pairs of seven-segment numerals decreased as these pairs differed in more line segments.

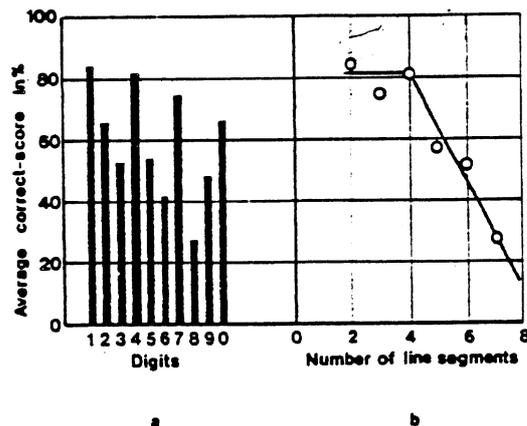


Figure 3. Figure 3a: Percentages of correctly recognized stimuli for each numeral, averaged over all experiments and subjects. Figure 3b: Relation between correct score and number of line segments of the numerals concerned.

Comparing the data from Figure 3a with the way the numerals are made up from line segments lead one to surmise that a relationship exists between the correct score for a particular numeral and the number of segments it counts.



Figure 11. Proposal for improved seven-segment numeral configurations.

When the percentages for confusion between each numeral pair were calculated and plotted against the different number of segments, the results were as shown in Figure 5.

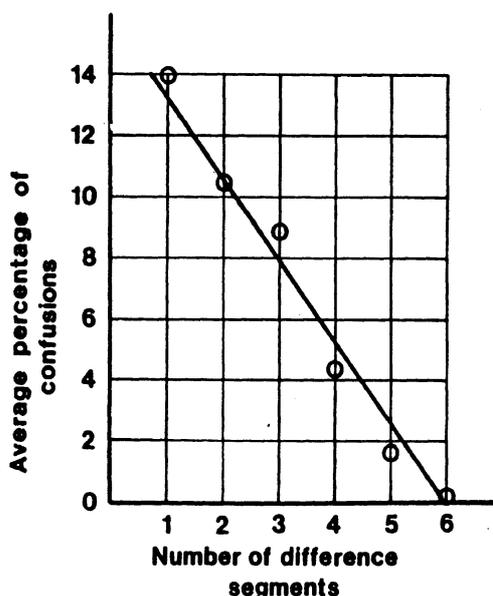


Figure 5. The percentage of responses representing confusions between numerals, expressed as a function of the number of difference segments between the numeral pairs concerned.

The probability of two numerals being confused is (by approximation) inversely related to the number of segments in which they differ. As a result, these recommendations are provided:

- 1) The smaller the number of segments in a digit, the better it is recognized.
- 2) The larger the total number of segments in which two digits differ, the less they will be confused.
- 3) A digit incorrectly recognized is more often perceived as one with a configuration simpler than the presented digit rather than more complex.

#### UMTRI REVIEW

The authors provided a concise and interesting report on segmented numerals. The experimental methods were sound. Its results are applicable to the

- Bibliography -

instrument panel study and provide valuable recommendations for changes in segmented numeral design. These recommendations would decrease the error in numeral perception.

UMTRI 47490

Perchonok, K., and Pollack, L. (1981). Luminous Requirements for Traffic Signs - a Comparison of Sign Performance and Requirements (Technical Report Number FHWA-RD-81-158). Washington, D.C.: Federal Highway Administration.

Keywords: sign, luminance, color

AUTHOR'S ABSTRACT, MODIFIED

Eleven traffic control signs were studied to determine several visibility thresholds under nighttime conditions. Eight men between the ages of 20 and the mid-40's served as subjects. Signs were driven from a distance of 3000 feet away toward subjects seated in a stationary vehicle with low-beam headlights. Subjects reported when they first detected the sign, when it first "looked like a sign", its color, shape, when they first detected the presence of a legend, when they first knew what the sign meant, and when they could first read the sign.

Actual detection and recognition distances were compared to analytically determined detection and recognition requirements. Thus, the signs were subjected to an engineering test to determine their adequacy. All signs met the detection requirements. Some signs fell short of meeting the recognition requirements, however. Specific details are omitted here due to lack of relevance to instrument panel displays. Interested readers are encouraged to read the entire 32-page report.

Appendix A contains information pertaining to drivers' sign requirements (i.e. necessary detection distance). Of particular relevance is the material about minimum necessary reading time. The following table summarizes recommendations for legends with up to 8 words. The three studies cited show approximate agreement up to about 3 words. However in cases where 4 or more words are used, the Dudek (1978) study indicates that much more reading time is required than do the other 2 studies.

- Bibliography -

Table 1. Required Reading Time (secs).

# of Words	Mitchell & Forbes '42	Res on Road Traffic '65	Dudek '78
1	1.3	2.2	1.0
2	1.7	2.6	2.0
3	2.0	2.9	3.0
4	2.3	3.2	4.0
5	2.7	3.5	5.0
6	3.0	3.8	6.0
7	3.3	4.1	7.0
8	3.7	4.4	8.0

UMTRI REVIEW

This report is well-written and thorough. The methods seem sound, with the possible exception of the subjectivity inherent in the task. The results are sign-specific, and therefore not generally applicable to instrument panels. However, the material in the appendix concerning reading time is of interest. It will be useful in predicting the effect of different display messages on driver reading speed.

UMTRI 54689

Testin, F.J., and Dewar, R.E. (1981). Divided Attention in a Reaction Time Index of Traffic Sign Perception. Ergonomics, February, 24(2), 111-124.

Keywords: sign, attention value, reaction time

AUTHOR'S ABSTRACT, MODIFIED

This experiment examined the need for including divided attention demands of driving when studying traffic sign perception. Forty-eight undergraduate students (24 male, 24 female) participated as subjects. Subjects were presented slides of traffic signs and were instructed to indicate whether the slide's meaning was the same as, or different from, that of the immediately preceding typed message. Subjects were also presented with a loading task which involved the presentation of a number matrix stimulus, to which the subject responded by pressing 'yes' or 'no' buttons. Three different loading tasks were used. In the detection task the subject was to indicate whether there were any numbers presented. In the identification task the subject was to indicate whether there was a 7 in the number matrix. The memory task required the subject to indicate whether the present matrix contained the number which appeared in the upper left-hand corner of the preceding matrix. A combined task was also used to divide the subject's attention between two visual inputs. A control group received no loading task.

- Bibliography -

The reaction times to 16 signs were correlated with the legibility distances of the same signs measured in a previous roadway experiment. Contrary to the conclusion of Dewar et al. (1976) that a loading task may increase the validity of the reaction time index, the present study found no advantage to using a loading task in association with the reaction time measure of traffic sign perception.

UMTRI REVIEW

This report was well written. Likewise, the experiment was controlled and its results valid. The authors conclude that increasing the complexity of the task is not necessary in order to sufficiently replicate field results. Thus, the more time-consuming and expensive field research can be replaced by the laboratory reaction time method to evaluate traffic signs for legibility. These results should be considered when designing the task for the instrument panel study.

UMTRI 70010

Howett, G.L. (1983). Size of Letters Required for Visibility as a Function of Viewing Distance and Observer Visual Acuity; (Technical Note NBS 1180). Washington, D.C.: National Bureau of Standards.

Keywords: acuity, legibility distance, size, stroke width, height, contrast, luminance

AUTHOR'S ABSTRACT, MODIFIED

A procedure is derived to determine the minimum letter height for legibility of words on a sign at any given distance by an observer with any given visual acuity. The derivation is strictly mathematical and is based on the assumption that beyond a distance of a few meters, a person's visual acuity is specifiable by a fixed visual angle, independent of the distance. The formulas given for correcting the stroke width for nonstandard contrast or background luminance are based on data on visual acuity as a function of contrast and background luminance. This was published recently by Japanese researchers Nakane and Ito (1978), and Kaneko (1982). The formula required to determine letter size follows:

$$SW = 1.45 \times 10^{-5} \times S \times d$$

where:

- SW = required stroke width (same units as d)
- S = denominator of Snellen index (20/S) for the most visually impaired people
- d = maximum distance at which sign will be read.

- Bibliography -

To determine the letter height, multiply SW by the height to stroke width ratio of the typeface to be used.

For the above formula to be accurate, use very black letters on a very white background and light the sign to a luminance level of at least 85 cd/m<sup>2</sup> (25 fL) on the white background. If both of these conditions are infeasible, the luminance of the letters and background must be measured and used in the following formula.

$$S' = S \times (85/Lb)^{0.2131} \times (90/C)^{0.5316}$$

where:

S' = adjusted value of S  
C = percent contrast  
Lb = luminance of the background.

Go back to the first formula and use S' instead of S. Multiplying the result by H:SW as before gives the solution.

If it is expected that the luminance of the sign's background may be lower than 85 cd/m<sup>2</sup>, but contrast is not a problem, the following formula is used:

$$S' = S \times (85/Lb)^{0.21310}$$

Go back to the first formula and use S' instead of S. Multiplying the result by H:SW as before gives the solution.

#### UMTRI REVIEW

This report is extremely well done in every aspect. Although very detailed and technical, the author is clear, making it relatively easy to follow. The results are presented in a logical step-by-step manner, thus ensuring their usability. When applying these results to the instrument panel study, one area of concern arises. The driver views the instrument panel at a distance much less than a few meters. Therefore, one assumption underlying the derived formula is not met. However, the formula still provides a good approximation of required character size.

- Bibliography -

UMTRI 48608

Olson, P.L., Sivak, M., and Egan, J.C. (1983). Variables Influencing the Nighttime Legibility of Highway Signs (Technical Report Number UMTRI-83-36). Ann Arbor, Michigan: The University of Michigan Transportation Research Institute, July.

Keywords: sign, sign material, contrast, age, acuity

UMTRI ABSTRACT

This report describes four studies concerned with the nighttime legibility of retroreflective signs. The first study was a laboratory investigation of the effect of sign background luminance, legend luminance contrast, surround luminance, background color, glare illuminance and angle, and subject age on sign legibility. An unreported number of young and old subjects indicated the direction of a Landolt ring gap; different size rings simulated different viewing distances. Sign background color variations included green, blue, red, and black, all of which used white legends. White, yellow, and orange backgrounds were tested with a black legend. Sign legend luminance of the white legend varied from 0.038 to 733.0 cd/m<sup>2</sup>. Surround luminance varied between three levels: 0.03, 3.43, and 17.0 cd/m<sup>2</sup>.

The results indicated that legend luminance contrast is the most important variable in sign legibility at night, and that there is a relatively narrow range of optimum contrast. Maximum legibility is achieved at contrast of 30 to 60:1. See Figure E-1 on next page.

- Bibliography -

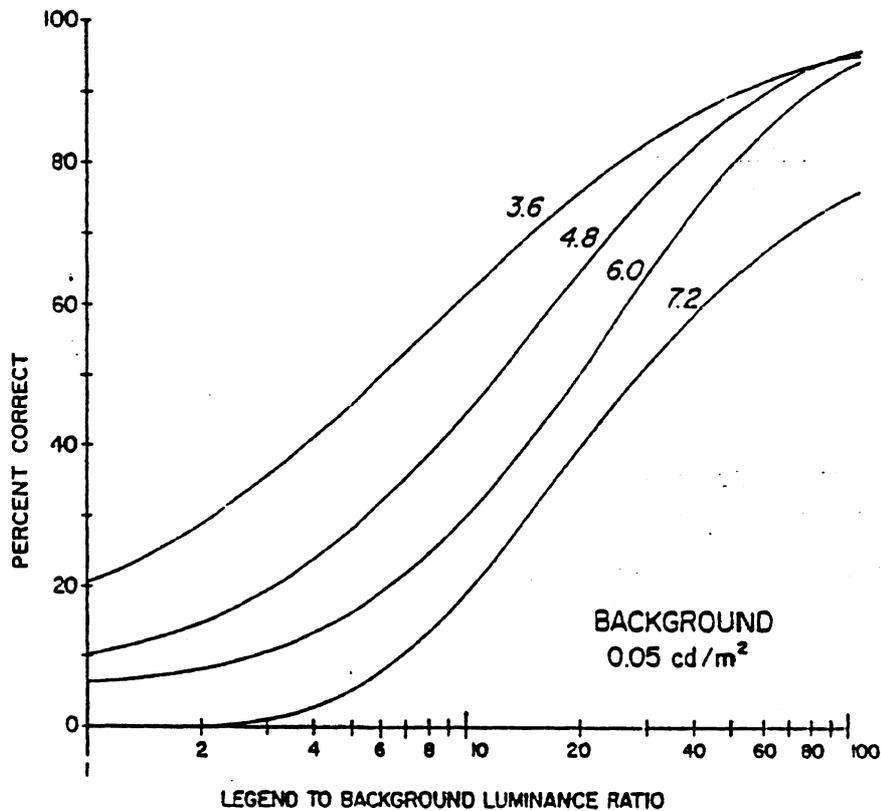
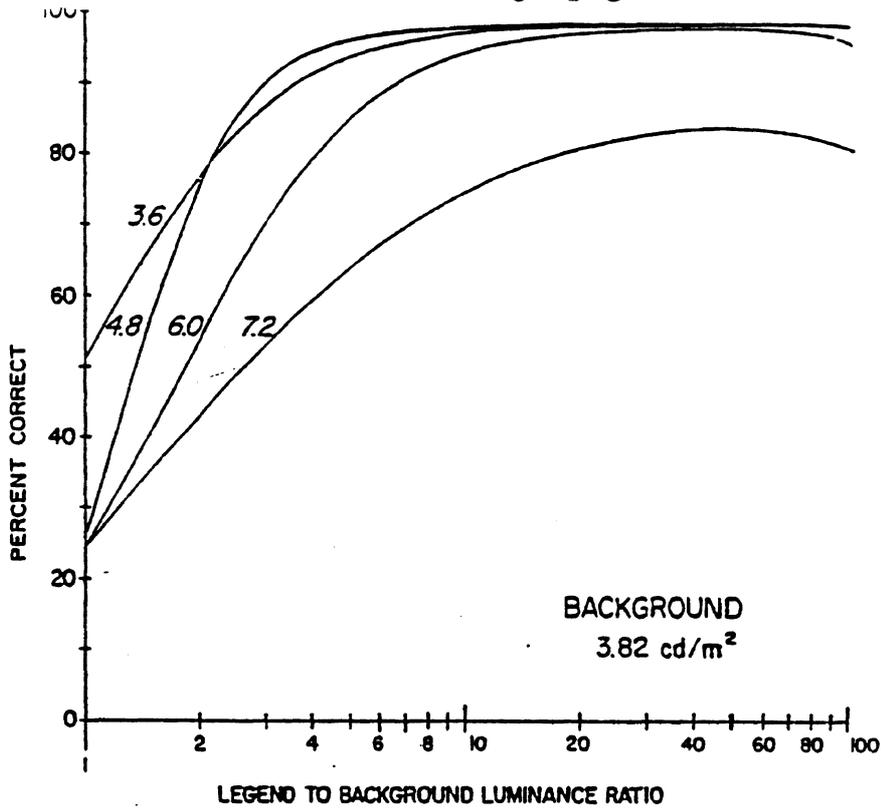


Figure E-1. Percent correct responses to four legend sizes (in m/cm) as a function of legend luminance contrast and two levels of background luminance (3.82 and 0.05 cd/m<sup>2</sup>). Dark surround (0.034 cd/m<sup>2</sup>). Young subjects.

- Bibliography -

As a rough rule-of-thumb, the data suggest that changing background luminance by a factor of ten requires the contrast ratio be changed by a factor of two to maintain a given legibility level. Sign background color and surround luminance both have relatively minor effects on legibility. In general, the older subjects did much poorer than the younger subjects. However, the difference was minimized by high-luminance backgrounds.

The next two studies were carried out under field conditions. Small signs were used, and 12 subjects rode toward them, pressing a button to indicate the distance at which they became legible. The results indicate that the expected age effect on legibility of signs is eliminated if the age groups are matched in terms of their low-luminance/high-contrast visual acuity. The fourth study concerned glare effects associated with retroreflective signs, a topic not related to the Chrysler instrument panel study.

UMTRI REVIEW

The authors present a well-organized paper as well as provide a complete description of experimental procedures. The report contains over 70 figures and tables. It will be useful in the instrument panel study because it describes drivers' needs as well as useful relationships between contrast and background luminance.

UMTRI 74672

Society of Automotive Engineers (1984). Physical Characteristics of Visual Displays. Ergonomic Aspects of Electronic Instrumentation: A Guide for Designers, (SP-576), 11-20.

Keywords: instrument panel, luminance, color, size, height, spacing

UMTRI ABSTRACT

This guide was originally produced at Ford Motor Company of England and later referred to as an SAE report. It describes general ergonomic principles that apply to instrumentation. Part 6 of this handbook discusses the important characteristics of visual displays. Other topics include character generation, installation, and auditory displays. Relevant recommendations are included below.

Brightness of electronic automobile displays should be adjustable by the user within a range of 500-60,000 lux. To counter the effects of ambient illumination, various filters (discussed in detail in the report) should be used. Light characters on a dark

- Bibliography -

background are most appropriate in vehicles, and the contrast between display luminance and ambient luminance should be greater than 3:1 - 5:1. To reduce glare, surfaces having low reflectivity should be used. Also, displays and driver should be shielded from reflective effects.

The optimal character size for electronic displays is defined by a subtended angle of 15 minutes. Character height to width ratio should be 1.3:1 to 1.4:1, and the height to stroke width should be 6.7:1 to 10:1 for electronic displays. The maximum horizontal spacing of characters is 75% of character width, while the recommended vertical spacing is 30-50% of symbol height. A simple font, with no serifs or italics, should be used.

UMTRI REVIEW

This report is clearly written but gives a very superficial treatment of the design of displays. For the most part, only single point values (recommended values, minima) are provided, not figures, tables, or equations showing tradeoffs. In general, the recommendations seem reasonable. However, no citations or references are given to support them.

UMTRI 71552

Galer, M., and Simmonds, G.R.W. (1985). The Lighting of Car Instrument Panels - Drivers' Responses to Five Colours (SAE Paper Number 850328). Warrendale, Pennsylvania: Society of Automotive Engineers.

Keywords: age, color, instrument panel

AUTHOR'S ABSTRACT, MODIFIED

Drivers' subjective responses and reading errors for five colors of instrument panel lighting were measured under simulated nighttime driving conditions. A 1981 European Ford Granada instrument panel was backlit either blue/green, red, green, orange, or yellow. Eighty drivers tested each of the five display colors. A group of drivers with color defective vision was also tested.

At a tone from the computer controlling the driving simulator, the subject was asked to: (a) state the speed shown on the speedometer, and (b) to state whether the speed was within the speed limit shown on the screen in front of them. They also ranked the colors for ease of reading, ease of checking the speed against limits, distraction, attractiveness, general preference and choice for their own car.

- Bibliography -

Blue/green ranked highest in all seven categories, followed by yellow and green (similarly ranked), orange, and finally red, which was least preferred in all areas.

Color preference varied with age and sex. For example, although blue/green ranked highest, men over 50 considered it difficult to read. Also, while people under 50 found the green display easy to read, people over 50 found it difficult. Drivers who wore bifocal lenses preferred the yellow display. Drivers with color defective vision found red unsatisfactory, but otherwise showed no preference.

Panel lighting color had no significant effects on the driver performance measures.

UMTRI REVIEW

This report was interesting, well-written, and complete in its coverage of the experiment. However, no specifications for the colors (i.e. CIE coordinates) are given, so the experiment would be difficult to replicate. Therefore, it is impossible to apply the results to real instrument panel design problems.

One issue the authors mention is that the pointers on the dials of the instrument panel were orange. These contrast well with blue/green, and could explain the high preference for this color. Other colors (i.e., orange) may have been at a considerable disadvantage due to lower contrast.

UMTRI 56288 A03

Sivak, M., and Olson, P.L. (1985). Optimal and Minimal Luminance Characteristics for Retroreflective Highway Signs. Transportation Research Record, (1027), 53-57.

Keywords: illuminance, sign, sign material

UMTRI ABSTRACT

The authors present optimal and minimal sign luminance recommendations based on a review of available applied research. To account for various conditions, the geometric mean was computed from various studies' optimal values. See Figure 1, next page.

- Bibliography -

Black Legend on Light Background

The following studies have relevant luminance recommendations or findings for the situation where only the background luminance is appreciably greater than 0.

<u>Luminance Value</u> <u>(cd/m<sup>2</sup>)</u>	<u>Study Characteristics</u>
343.0	Allen and Straub laboratory study (5)--an asymptote was apparently not reached even with the highest level tested
34.3	Allen et al. field study (7)--dark rural (used both 100% and 75% legend/background luminance contrast)
60.0	Dahlstedt field study (8)
206.0	Hind et al. laboratory study (6)--the data appear to asymptote at 206 cd/m <sup>2</sup>
55.0	Olson et al. laboratory study (4)--(recommended luminance: 10-100 cd/m <sup>2</sup> )
24.0	Smyth laboratory study (9)

Figure 1.

Optimal recommendations are based largely on peak luminance-legibility relationships. Specifically, 75 cd/m<sup>2</sup> is recommended as the optimal luminance for signs with light (white, orange, or yellow) backgrounds and black legends. The authors suggest 12:1 as the optimal legend to background contrast. In the absence of other criteria, minimal recommendations are based on performance levels of 6 m/cm letter height (0.72 ft/in) (20/23 visual acuity) for younger persons and 4.8 m/cm (0.576 ft/in) (20/29 visual acuity) for older persons. The recommended minimal luminance of the lighter components is 2.4 cd/m<sup>2</sup>. This recommendation applies to light backgrounds (white, yellow, or orange) with black legends, and to white legends with dark (green, blue, red, or brown) backgrounds having a background luminance of up to 0.4 cd/m<sup>2</sup>.

UMTRI REVIEW

This report was well-written and informative. It provides a valuable summary of previous research and a discussion of contributing variables and correction factors such as surround illuminance, driver age, alcohol intoxication, and dirty signs. The optimal luminance recommendations are quite useful to the instrument panel study.

- Bibliography -

# AUTHOR INDEX

<u>AUTHOR</u>	<u>PAGE</u>
Adler, B. ....	20
Allen, T.M. ....	14
Bernstein, A. ....	37
Bouma, H. ....	42
Dewar, R.E. ....	23, 45
Dudek, C.L. ....	35
Dyer, F.N. ....	14
Egan, J.C. ....	48
Ells, J.G. ....	23
Forbes, T.W. ....	7, 15, 17, 24, 38
Foster, J.J. ....	40
Galer, M. ....	51
Goldblatt, J.G. ....	24
Greenwood, W.H. ....	24
Hill, T.E. ....	24
Hind, P.R. ....	27
Hoffmann, E.R. ....	27
Howett, G.L. ....	46
Huchingson, R.D. ....	35
Janson, M.H. ....	14
King, G.F. ....	22
Koppa, R.J. ....	35
Kuntz, J.E. ....	9
MacNeill, R.F. ....	11
Mast, T.M. ....	35
McLean, M.V. ....	12
Moscowitz, K. ....	7
Olson, P.L. ....	37, 48, 52
Pollack, L. ....	44
Rasmussen, P.G. ....	33
Richards, S.H. ....	35
Rowan, Neilon J. ....	18
Saari, B.B. ....	24
Simmonds, G.R.W. ....	51
Sivak, M. ....	48, 52
Sleight, R.B. ....	9
Smith, G.M. ....	14
Smyth, J.S. ....	6
Stockton, W.R. ....	35
Straub, A.L. ....	20
Testin, F.J. ....	45
Uhlaner, J.E. ....	5
Van Nes, F.L. ....	42
Vaughan, J.A. ....	33
Welsh, K.W. ....	33
Woltman, H.L. ....	23
Woods, Donald L. ....	18



# TITLE INDEX

<u>TITLE</u>	<u>PAGE</u>
The Effect of Thickness of Stroke on the Legibility of Letters .....	5
The Brightness and Legibility at Night of Road Traffic Signs .....	6
A Comparison of Lower Case and Capital Letters for Highway Signs .....	7
Legibility of Numerals: The Optimal Ratio of Height to Width of Stroke .....	9
Colors and Legibility: Caution and Warning Data-Plates .....	11
Brightness Contrast, Color Contrast, and Legibility .....	12
Sign Brightness in Relation to Legibility .....	14
Factors in Highway Sign Visibility .....	15
Factors in Visibility and Legibility of Highway Signs and Markings .....	17
Legibility and Brightness in Sign Design .....	20
Determination of Sign Letter Size Requirements for Night Legibility by Computer Simulation .....	22
Review of Visibility Factors in Roadway Signing .....	23
Methods for the Evaluation of Traffic Signs .....	23
Luminance and Contrast Requirements for Legibility and Visibility of Highway Signs .....	24
Effects of Level of Illumination, Strokewidth, Visual Angle and Contrast on the Legibility of Numerals of Various Fonts .....	27
Readability of Alphanumeric Characters Having Various Contrast Levels as a Function of Age and Illumination Mode .....	33
Human Factors Requirements for Real-Time Motorist Information Displays .....	35
The Nighttime Legibility of Highway Signs as a Function of Their Luminance Characteristics .....	37
Acuity, Luminance and Contrast for Highway Sign Legibility - Samples of Research Methods and Results .....	38
Legibility Research 1972-1978: A Summary .....	40
On the Legibility of Segmented Numerals .....	42
Luminous Requirements for Traffic Signs - a Comparison of Sign Performance and Requirements .....	44
Divided Attention in a Reaction Time Index of Traffic Sign Perception .....	45
Size of Letters Required for Visibility as a Function of Viewing Distance and Observer Visual Acuity .....	46
Variables Influencing the Nighttime Legibility of Highway Signs .....	48
The Lighting of Car Instrument Panels - Drivers' Responses to Five Colours .....	51
Optimal and Minimal Luminance Characteristics for Retroreflective Highway Signs .....	52



# UMTRI LIBRARY NUMBER INDEX

<u>UMTRI LIBRARY NUMBER</u>	<u>PAGE</u>
00586 .....	14
15268 A03 .....	17
19156 .....	7
20656 .....	11
30371 .....	15
30440 .....	5
30441 .....	9
30448 .....	12
30940 .....	6
33938 .....	23
40338 .....	33
41434 A12 .....	27
42824 .....	35
46927 .....	38
47490 .....	44
48608 .....	48
50568 .....	20
50569 .....	22
51215 A04 .....	23
52905 A04 .....	24
53348 A05 .....	18
54156 .....	37
54550 .....	42
54689 .....	45
56288 A03 .....	52
70009 .....	40
70010 .....	46
71552 .....	51



# KEYWORD INDEX

<u>KEYWORD</u>	<u>PAGE</u>
acuity .....	20, 37, 38, 46, 48
age .....	33, 48, 51
attention value .....	45
case .....	7
color contrast .....	12
color .....	11, 12, 17, 18, 23, 35, 37, 44, 50, 51
contrast .....	15, 17, 24, 27, 33, 35, 37, 38, 46, 48
font .....	7, 42
glance legibility .....	15, 17, 23
height .....	7, 9, 17, 20, 23, 46, 50
illuminance .....	9, 11, 12, 52
instrument panel .....	50, 51
legibility distance .....	5, 7, 18, 27, 37, 46
legibility .....	22, 23, 24, 35
letter size .....	18, 22
literature review .....	40
location .....	15, 18
luminance .....	6, 14, 24, 27, 35, 37, 38, 44, 46, 50
numeral design .....	27
reaction time .....	23, 45
sign material .....	20, 35, 48, 52
sign .....	6, 7, 14, 20, 22, 23, 24, 35, 37, 44, 45, 48, 52
size .....	7, 15, 42, 46, 50
spacing .....	17, 23, 50
stroke width .....	5, 9, 17, 23, 27, 42, 46

