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Sue Adams
Steve Goldstein
Kristine Zeltner
Pach Ratanaproeksa
Paul Green

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16. Abstract

This report cites all documents relating to legibility in the University of Michigan Transportation Research Institute (UMTRI) Library. For each of these documents, the authors, title, UMTRI Library catalog number, and an abstract are provided. In addition, indexes are provided by author, title, and UMTRI catalog number.

This report identifies 121 documents which have the UMTRI Library code PMKL (Legibility). Among these documents are 41 technical reports, 16 conference proceedings, 59 journal articles, and 5 books. The documents cited within this report are primarily concerned with highway sign or license plate design, but touch upon a variety of issues, including letter size, legend and background luminance, luminance contrast, legend and background color, and viewer acuity. This report will be used to develop a literature review on the legibility of text on automobile instrument panels.

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INTRODUCTION

This bibliography is a precursor to a larger annotated bibliography and literature review to be prepared for the Chrysler Corporation, and supported by the Chrysler Challenge Fund. The literature review will examine the legibility of both continuous stroke and dot matrix displays. Display parameters receiving particular attention will be character size, color, illumination levels, luminance contrast, task, and viewer's visual acuity. This bibliography cites the literature found in the University of Michigan Transportation Research Institute (UMTRI) Library which pertains to the subject of display legibility. Much of this research has concerned the legibility of highway signs, license plates, and aircraft cockpit instrument panels. Although the UMTRI collection is extensive, it has yet to be automated. Consequently a great deal of time was required to compile this document. The final literature review will also examine other sources, including Paul Green's personal files, and materials from the University of Michigan library system.

This document contains a citation and an abstract of each of the articles found in the UMTRI library. The articles are cited chronologically then, within each year, alphabetically by first author. Abstracts provide brief descriptions of the content of the referenced document. In those cases where the author of the document has provided an abstract, the author's abstract is used (denoted AUTHOR'S ABSTRACT). Although some of these abstracts are a bit unclear or incomplete, they have been included based on the assumption that they reflect the quality of the author's work. In those cases where no abstract is provided, either the authors of this bibliography prepared an abstract (denoted UMTRI ABSTRACT), or the introduction, conclusions, or some descriptive section of the document is used instead (denoted AUTHOR'S SUMMARY, for example). Since this document is a composite of the works of many authors, the quality, length, and detail of the abstracts varies. A sample bibliographic entry is shown in Figure 1.

There are three indices located at the end of the bibliography. The Author Index lists, alphabetically, all authors cited in the bibliography, and on what pages their work can be found. The Title Index lists, alphabetically, the titles of all articles cited. Finally, the UMTRI Catalog Number Index gives, in numerical order, the UMTRI Catalog number of each article cited and the page number on which the corresponding article is discussed.

In reviewing the articles selected for this document it was found that a number of the articles were not particularly relevant to the instrument panel study to be

conducted, and others would require significant effort to apply in the context of the instrument panel study. Many of the articles, however, will be very useful in designing the experiment and determining conditions to be tested.

[1]UMTRI 30448
[2]McLean, M.V. [3](1965). [4]Brightness Contrast, Color Contrast, and Legibility. [5]Human Factors, December, [6]7(6), [7]521-526.

[8](AUTHOR'S ABSTRACT)
[9]An experimental study was conducted investigating the effects of color and brightness contrast, direction of contrast, and six contrast values upon the legibility of a circular dial. The brightness of four chromatic hues was matched with four achromatic hues. Hues were combined in all possible combinations excluding chromatic with achromatic, resulting in six contrast values. For both dark on light and light on dark contrast directions, the contrast values were equal. Half of the twenty-four subjects had pilot training and half did not. A dodge type tachistoscope was used to present the stimulus conditions. Reading time results indicated that the addition of color contrast to a dial of a given achromatic brightness contrast value, with a light on dark contrast direction, will not degrade and may improve the legibility of that dial. Legibility was also found to increase as contrast value increased. The study indicates that the use of color should be reconsidered in its application as a coding technique in complex system displays.

1. UMTRI Library catalog number
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3. Year of publication
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Figure 1. Sample bibliographic entry

BIBLIOGRAPHY

(listed chronologically, alphabetized by author within year)

UMTRI 30370
Forbes, T.W. (1939). A Method for Analysis of the Effectiveness of Highway Signs. Journal of Applied Psychology, 23, 669-684.

(AUTHOR'S SUMMARY)

(1) A method for the analysis of the effectiveness of highway signs was tried out. Applications to practical shop and field problems were indicated. The analysis was based on the experience of those in the highway sign field, and also previous work by others on the effectiveness of signs and advertisements, with modifications for the present problem.

(2) Sign effectiveness was analyzed into Legibility (pure legibility and glance legibility) and Attention Values (priority value and target value).

(3) Test equipment for the measurement of the two types of legibility was devised. It consisted of a universal signboard with interchangeable letters, and a shutter to allow short presentations of the test signs.

(4) A technique was tried out also for checking the target and priority value of signs in their actual highway location.

(5) Legibility distances were obtained for a small group of observers for standard Series B and E letters for different sizes and spacing. The results showed an interesting relationship to the rule of thumb in use by practical sign experts, but a more extensive study is necessary.

(6) Short time or "glance legibility" distance appeared to be slightly less than the corresponding pure legibility distance for a given letter and spacing.

(7) The increase of glance value from familiarity was demonstrated with 3 and 4 letter combinations. Symbols derive their advantage from simplicity of layout and familiarity value.

(8) It was demonstrated that not more than 3 or, at most, 4 words are seen at a single glance. On high speed highways where rapid or glance legibility is most desirable, therefore, sign text should be limited to this number of words or symbols.

(9) The following factors would be expected to affect target value; color contrast, relative size, simplicity and contrast of layout (as in the symbol sign), placement and, at night, reflectorization. Certain of these factors were demonstrated.

(10) Factors expected to be fundamental for priority value were reading habits, prior position on the highway, and proximity to another attention

compelling sign or object. Observations were suggestive.

(11) The observations were very few in number, but they illustrate the practicability of the approach, i.e., the analysis of the effectiveness of highway signs into fundamental factors which may be measured.

(12) The technique described may be used in the sign yard and on the highway respectively to check in an objective manner the effectiveness of signs and sign installations. A more extensive investigation of the factor of pure legibility has been conducted on a joint basis since this preliminary work and will be reported later. Similar extensive studies of the other factors are to be hoped for.

UMTRI 30440

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

(AUTHOR'S PROBLEM STATEMENT)

This is part of a study dealing with the optional characteristics for greatest efficiency of highway signs. Because there is still considerable room for improvement in the legibility of signs and only a limited amount of experimental data available, this investigation was undertaken. This present project is based on work done before by Lauer, (1932) Aldrich, (1937) Forbes, (1939) and deals on the whole with the separate variables of letter legibility such as stroke, height-width ratio and spacing, each variable being isolated for experimentation. In this paper, however, the discussion will deal only with the isolation of the stroke as a factor in legibility.

(AUTHOR'S CONCLUSIONS)

1. The results of these experiments would seem to indicate that the optimal stroke of three-inch block letters is, on the average, closest to 18 per cent of the width or height of the letter.

2. The general acceptance of constancy of angle should make this applicable to any size block letter.

3. The legibility distances obtained for letters having a stroke of 16 and 20 per cent are fairly close due to the parabola at this section of the curve.

4. A 16 per cent stroke, on the average, gives a higher legibility distance than a 24 per cent stroke.

5. These data are presented with a full knowledge of the limits of application to letters of other characteristics. Further experiments are in progress at this time which suggest the need for reduction in the width of stroke with the reduction of the height-width ratio to assure maximum legibility.

UMTRI 30613
Mitchell, A., and Forbes, T.W. (1942). Design of Sign Letter Sizes. American Society of Civil Engineers, January, 68, 95-104.

(AUTHOR'S SUMMARY)

A method has been described for determining the necessary letter size for effective highway sign design in terms of warning time, warning distance, and a 90 percentile design speed. The increased warning distance necessary at higher speeds has been provided through the use of driver warning time as the basic consideration. Appropriate braking distances have been introduced where necessary.

Table 1 (or Eqs. 9 and 11) furnishes values for convenient computation of the letter height needed, and a simplified outline of procedure is given in the paper.

By use of such a method, it is possible to fit the sign to the highway and the driver and to obtain consistently effective signs for widely varying conditions of velocity and sign location with respect to the hazard or the maneuver point.

UMTRI 30445
Hurd, F. (1946). Glance Legibility. Traffic Engineering, 17, 161-162.

(UMTRI ABSTRACT)

A study of glance legibility was conducted by students of the Yale Bureau of Highway Traffic, New Haven, Connecticut. The rapid reading of sign copy was checked for round style letters versus standard block letters, scrambled letters versus familiar words, and the number of words read. The letters used were 4-inch series B, black on white background. The letters were arranged on a rack and exposed to subjects for specific periods of time by opening and closing a shutter mechanism. Eighteen subjects, positioned within the legibility threshold of the 4-inch letters, were instructed to identify various letter arrangements. It was found that recognition of rounded letter words was 8% better than for block letter words. Also, familiar rounded letter words were recognized correctly while nonsensical rounded letter words were not completely recognized. Finally, observers recognized words forming a familiar sentence more easily than groups of unrelated words. Groups of nonsensical words were not easily recognized.

UMTRI 30940
Smyth, J.S. (1947). The Brightness and Legibility at Night of Road Traffic Signs. Illuminating Engineering Society Transactions, 12(4), 71-94.

(AUTHOR'S SYNOPSIS)
An investigation to determine the most satisfactory brightness of lettered signs seen against different background brightness levels is described. "Ideal" sign brightnesses are suggested, lying between the minimum for threshold legibility and the maximum acceptable without ill effects from glare. The ideal brightness for legibility was found to be unaffected by the colour of the sign and was the same for black on white or white on black signs. The effect of disturbing factors such as glare from automobile headlights, and dirt collection on the sign are considered; such handicaps do not affect legibility distance very greatly, but may seriously reduce the conspicuity of the sign.
The second part of the paper gives an account of a study of reflex reflecting lensed symbols used on traffic signs: methods of fitting lenses, and small modifications to some symbols are suggested to make recognition easier.
The work described was carried out by a technical committee, called by the Illuminating Engineering Society at the request of the Ministry of Transport. The results have led to some recommendations made in the Departmental Report on Traffic Signs, 1944.

UMTRI 19156
Forbes, T.W., and Moscowitz, K. (1950). A Comparison of Lower Case and Capital Letters for Highway Signs. Proceedings of the Highway Research Board Proceedings, 355-373.

(AUTHOR'S SYNOPSIS)
During the last two years the California Division of Highways has experimented with the development and use of lower case letters for overhead destination signs on freeways. Recognition of word patterns is known to be fundamental in close reading of ordinary printed material and it was thought that habit and pattern factors might also make this form of letter desirable for highway signs. Opinion as to their effectiveness has been varied, however. The problem therefore was to measure the distance at which lower case signs could be read as compared to rounded capital letters.
Experiments were undertaken jointly by the California Division of Highways and the University of California Institute of Transportation and Traffic Engineering, to determine the distances at which signs

of each kind of alphabet could be read. Letters from 5 in. to 18 in. in height were mounted on a bridge 17 ft. above the ground and a total of 75 observers made 3939 individual observations under daylight and artificial illumination.

White on black, series E capital letters and lower case letters of approximately the same average width-height ratio were used. These letters represented the development of this form of letter for freeway signs by the California Division of Highways. The stroke of the series E capital was widened slightly, also to correspond to the letters used by the California Division of Highways. By means of a prearranged series of positions, each size and form of letter was presented an equal number of times on right and left and at top and bottom of the sign background to balance out errors due to position on the sign bridge.

In order to approximate the effects of word pattern (as opposed to letter legibility) and word familiarity, three sets of measurements were made: (1) using scrambled letters; (2) using California place names, being viewed for the first time; and (3) using California place names, being viewed for the second time.

The "scrambled" groups gave control of guessing and equalized familiarity between observers. The familiar place names, unknown to the observers ahead of time, should involve pattern recognition similar to that by drivers somewhat familiar to the territory. The familiar names known ahead of time to the observers might correspond to the reading of signs by drivers who drive the same highway every day - for example, commuters on freeways.

As was expected, for both kinds of alphabet the distances increased with the size of letters and with the degree of familiarity. The increase due to increasing familiarity was greater for lower case letters than for capitals.

The comparison of lower case and capital letters can be stated in several ways. If recognition distance (and legibility distance) is expressed in terms of letter height using the total height of the "risers" of the lower case letters, these letters appeared at some disadvantage, presumably because they were narrower.

On the basis of width, the lower case words could be seen farther than the capital words, presumably because they were higher. Thus where length of sign is the controlling factor, which is often the case, these lower case letters would have the advantage.

On the basis of sign area, the advantage of one type of alphabet over the other depends on the vertical spacing or margins. Due to the open area between the stems of lower case letters in a word, it would be expected that the margins or space between lines can be

less than for capital letters without loss of legibility. Further observations are needed to determine these factors for the two forms of letter.

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.

(AUTHOR'S SUMMARY AND CONCLUSIONS)

A study was made with numerals of varying height and stroke width read at various distances, in order to determine the ratio yielding highest legibility. Effects of brightness and background on legibility were likewise studied. The following conclusions seem to be warranted:

(1) Using a midstroke-height measurement for the numerals made with a modified LeRoy Lettering Set, the optimal height vs. stroke width ratio (H/s.w.) is between 6.0:1 and 4.0:1, or, more precisely stated, at 5.0:1.

(2) The optimal ratio is approximately the same for numeral brightnesses of 3.0, 10.0, and 31.0 footlamberts.

(3) The several numerals used show clear differences in legibility. They rank from most to least legible in the order 1, 7, 0, 4, 3, 2, 9, 6, 5, 8 indicating a need for modification in the form of certain numerals in order to improve the legibility of those of low rank.

(4) Legibility of black numerals on white background and that of white numerals on black background is the same under the conditions of this experiment.

UMTRI 30442

Christie, A.W., and Rutley, K.S. (1961). Relative Effectiveness of Some Letter Types Designed for Use on Road Traffic Signs. Roads and Road Construction, August, 39, 239-244.

(AUTHOR'S DISCUSSION, first 3 paragraphs)

The largest observed effect on reading distance was produced by a change in spacing. Increasing the marginal spaces from approximately two-stroke widths (ignoring descenders in the bottom line) to approximately five-stroke widths caused a reduction of about 12 per cent in the reading distance for the lower-case script. This finding supports the conclusion from an earlier experiment (Appendix I) that to obtain the maximum legibility distance from a given sign area the marginal spaces should be of the order of twice the stroke width of the lettering (where light-coloured lettering on a dark ground is used).

If the other conclusion from the earlier experiment is also true (see Appendix I), namely that the inter-linear spaces should also be about two-stroke widths for maximum legibility, then the reading distances obtained for the three closely spaced scripts must all be near the maximum values for these scripts (in the case of the sign legends and observers used), although doubtless slight improvements could be made by small adjustments to the spacings.

The most remarkable feature of the results for the three closely-spaced scripts is that the reading distances are so nearly equal. Although the statistical tests show that the observed difference between the reading distance for the serifed upper-case script and those for the other two scripts is probably a real one, the difference is so small that caution is necessary in interpreting its meaning. As mentioned previously, it is not certain that precisely the optimum conditions were used in the designs tested; for example, some improvement seems possible in the reading distance for the lower-case script by a reduction in the interlinear spaces. The spacing conventions were more nearly the same for the comparison of the two upper-case scripts and here the observed difference is more likely to be due to differences in legibility of the scripts, although it may not be due to the serifs since the scripts differed in other respects (for example, the width to height ratio of the letters). Therefore, although the results do not show whether upper-case scripts or lower-case scripts are the better, or whether script or sans-serif scripts are the better, they do suggest that there are unlikely to be large differences between the maximum reading distances obtainable with good upper and lower-case scripts whether serifed or sans-serif. Certainly none of the three scripts tested has an appreciable advantage over the others in this respect.

UMTRI 02492
Gregsten, M.J. (1961). Advance Direction Signs and Specular Reflections. Traffic Engineering and Control, October, 3(6), 347-349.

(AUTHOR'S RECOMMENDATIONS)

(1) All advance direction signs, whether illuminated or not, should be aligned in a vertical plane and turned away from oncoming traffic.

(2) The angle of turn-out should be $3^{\circ} \pm 1^{\circ}$ for motorway signs and $5^{\circ} \pm 1^{\circ}$ for signs on all-purpose roads.

(3) On straight roads and right-hand bends the angle of turn-out should be measured from the normal to the carriageway.

(4) On left-hand bends the angle of turn-out should be measured from the normal to a chord of length equal to the legibility distance, reckoned at the rate of 50 ft. per in. of letter height, drawn back from the sign.

UMTRI 33405
California Highway Patrol (1963). Report on Comparison Tests of Standard and Reflectorized License Plates. Sacramento, California: California Highway Patrol.

(AUTHOR'S INTRODUCTION)

The purpose of this study was to compare durability and legibility of reflectorized license plates with the same qualities in standard plates.

All laboratory testing of the reflectorized plates was done by the Structural Materials Section of the Materials and Research Department of the Division of Highways. In these tests, comparison of the wearing qualities of the plates was of primary concern and comparison of the visibility aspects was secondary.

Field tests reported in this study were conducted on the Emergency Vehicle Operations Course at the Highway Patrol Academy. This was done to permit uninterrupted tests to be made and to insure that no motorists would be exposed to the hazards involved in this type of testing. In addition, no artificial light sources were present in this area.

Field tests were grouped into two categories. Static tests covered all situations in which the plate-bearing vehicle was parked. Dynamic tests included the situations in which both vehicles were in motion at the time the observations were made.

The license plates used were of the 1963 fee-exempt, State-owned vehicle series. The reflectorized plate was numbered E250064 and the nonreflectorized was E28857. A mechanical device which measures distance in feet and in inches was used for all field measurements. This device is accurate to within one inch. Two 1957 black Chevrolet staff cars were used for these tests.

Four volunteer California Highway Patrol cadets and two Research Technicians were used for the field tests. The only requirement was that each individual have normal vision.

(AUTHOR'S SUMMARY)

The reflectorized plates lost some reflectance under various types of abrasion. These plates more readily picked up and retained road oil and dust and were more difficult to clean due to the roughness of the reflectorized surface. Even with reduced reflectance, however, the reflectorized plates are at least as legible as the standard baked enamel plates under both daylight and reflected light conditions.

Analysis of the tests performed on the standard baked enamel license plates and the baked enamel plates with reflectorized characters indicates that there is little difference in wearing qualities and both can be expected to last for similar lengths of time.

The two types of license plates are equally legible and visible in daylight but the reflectorized plate is considerably more visible and legible under reflected light at night. This was found to be true regardless of the intensity of headlight beams and presence of indirect lighting. The reflectorized numbers were also found to be legible from greater distances and at higher speeds where one vehicle was approaching another from the opposite direction.

One test was made in foggy weather. The results of this test were inconclusive for the reason that test conditions did not lend themselves to accurate measurements. That is, fog density tends to vary from minute to minute and from one area to an adjacent area. Subsequent foggy weather tests were not attempted and rainy weather comparison was also foregone for the same reason.

No comparison was made of the two types of plates relative to the lateral distance each would be visible from a roadway. Ideal test conditions were found to be difficult to achieve and preliminary tests indicated that too many variables, such as peripheral vision limitations, scattering of rays from the light source, speed and angle of approach, and external distractions, would affect this relationship.

UMTRI 16480
Ashwood, J.E. (1964). Relative Legibility Distances of Route Numbers and Place Names of Directional Signs. Traffic Engineering and Control, March, 654-655.

(AUTHOR'S CONCLUSIONS)

The conclusions were:

(i) No significant difference was found between the reading distances for white and yellow route numbers.

(ii) The reading distance for single-digit numbers was about 20 per cent greater than that for three-digit numbers.

(iii) When the height of the route numbers was made the same as that of the initial capitals, i.e. of the place names 40 per cent greater than the x-height of the lower case letters, no significant difference was found between the average reading distances for a representative group of place names (varying in length, etc.) and for a group of route numbers containing equal proportions of one-digit and three-digit numbers.

UMTRI 02440
Christie, A.W., and Hirst, G. (1965). Legibility of Signs with Green Backgrounds. Traffic Engineering and Control, March, 6(11), 672-673.

(AUTHOR'S INTRODUCTION)

If the legend on a sign is to be read easily there has to be a contrast in luminance (brightness) as well as in colour, that is, the legend must be dark if the background is light, or light if the background is dark. However, the choice of colours is not confined to black and white. If the legend is black it is possible to use an off-white background with very little loss in legibility, and if a yellow background with a reflection factor of only about 55 per cent is used there may even be a gain in daylight legibility. Similarly if the legend is white it is possible to use dark blues or greens in place of black with little loss in legibility. According to Lauer, legibility falls off when the difference between the reflectances of the legend and background is less than about 45 per cent. Although it is probably not desirable to degrade the contrast quite as much as this there certainly exists a variety of combinations of colour shades which will give adequate legibility.

The experiment described in this article was carried out to check that, from the point of view of daylight legibility, certain shades of green were satisfactory for use as the background colour on traffic signs with white lettering. Given a variety of colours satisfactory from the legibility point of view, a final choice of which to use could be made on aesthetic grounds, or on target value, or on other grounds.

A possible method of evaluating the various colour combinations would be to carry out full-scale comparative measurements of legibility distance on each. However, such tests are time-consuming and a visual acuity type of test was used instead. This enables the necessary observations to be made with a fixed distance between the signs and observers. Estimates of the effect of different colour combinations on legibility distances can be derived from estimates of the size of the smallest detail that can be read.

UMTRI 30443
Desrosiers, R.D. (1965). Moving Picture Technique for Highway Signing Studies - an Investigation of Its Applicability. Public Roads, April, 33(7), 143-147.

(AUTHOR'S ABSTRACT)

Establishment of the feasibility of motion picture laboratory tests as a substitute for field research on

highway signing was explored in the study reported in this article. Heretofore research related to highway signing generally has been in the form of field tests - a procedure doubly costly in collection of data and research time. Field research is hampered by changing weather conditions, variation in light, interference from traffic, and difficulties associated with obtaining a suitable test site. Development of a suitable laboratory test, it was believed, would eliminate these problems and also permit additional control of variables that might affect the results.

The study reported here was undertaken to validate the substitution of the laboratory tests, in which a moving picture technique was used, for the more commonly used field research. Comparisons of results of field and laboratory tests are reported for the mean legibility distances of signs having two, four, and six legends. The number of errors made by the test participants, the possible effect of their guessing, and the effect of the length of the test word were investigated.

Results of the study established that a laboratory test can be substituted for field tests if the researcher is interested in determining functional relationships between variables. If absolute values are desired, a correction factor must be applied to the laboratory data if they are to reasonably represent field conditions.

UMTRI 33345 A01

Grey, M. (1965). The Road User and the Improvement of Vehicle Registration Plates. Chroniques Internationales de Police, January/February, (70), 8-20.

(UMTRI ABSTRACT)

The author discusses several studies conducted to determine methods of improving the legibility of vehicle registration plates. More than one study concluded that reflectorized plates improve legibility. Other studies examined the number of characters on the plate, the order of the characters, the specific characters used, character size and stroke width, and the colors of the plate and characters. This information is presented in summary form, very little technical detail is given.

UMTRI 20656
MacNeill, R.F. (1965). Colors and Legibility: Caution and Warning Data-Plates (Technical Note 3-65). Aberdeen, MD: Human Engineering Laboratory.

(AUTHOR'S 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. The plates were tested under three light levels: low red, low white, and high white. Results showed that black on yellow and white on black were significantly more legible than the other four color combinations in at least one of the light levels, as well as when data were pooled for all three light levels.

UMTRI 30448
McLean, M.V. (1965). Brightness Contrast, Color Contrast, and Legibility. Human Factors, December, 7(6), 521-526.

(AUTHOR'S ABSTRACT)
An experimental study was conducted investigating the effects of color and brightness contrast, direction of contrast, and six contrast values upon the legibility of a circular dial. The brightness of four chromatic hues was matched with four achromatic hues. Hues were combined in all possible combinations excluding chromatic with achromatic, resulting in six contrast values. For both dark on light and light on dark contrast directions, the contrast values were equal. Half of the twenty-four subjects had pilot training and half did not. A Dodge type tachistoscope was used to present the stimulus conditions. Reading time results indicated that the addition of color contrast to a dial of a given achromatic brightness contrast value, with a light on dark contrast direction, will not degrade and may improve the legibility of that dial. Legibility was also found to increase as contrast value increased. The study indicates that the use of color should be reconsidered in its application as a coding technique in complex system displays.

UMTRI 33345 A02
Rumar, K. (1965). Comparison of the Visibility and Readability between Conventional License Plates and License Plates with a Reflective Background. Chroniques Internationales de Police, January/February, (70), 21-44.

(AUTHOR'S SUMMARY)

A comparison of visibility and readability between reflectorized and conventional license plates has been made under different conditions of darkness as well as in daylight.

Two shapes of plates were investigated: rectangular (10 X 45 cm.) and near-square (20 X 25 cm.). The conventional plates were white and the reflective, silver, yellow and red. The symbols were in all cases black and of Swedish standard size.

The measured distances were obtained by observers in a moving car reporting when they detected, or could read, the test plates. The results can be summarized as follows:

1. There was no difference under any conditions between rectangular and square plates.
2. In daylight, the same reading-distance was obtained (approx. 40 m.) for both types of plates.
3. At night, the reflectorized plates gave longer both reading and detection distances when the observation car used its headlights.
   a) When the "test-plate" car showed no lights, reflective plates were readable from twice the distance (approx. 35 m.) of conventional plates.
   b) When the test plate was located between two lit headlights, the reading distance for reflectorized plates was three times longer (approx. 35 m.), than for conventional plates.
   c) The detection distance for reflective plates was approximately six times (115 m.) that of conventional plates when the test-plate car used only a single headlight.
4. When the test-plate car showed no lights, the reflective plates gave five times the detection distance (approx. 250 m.) of conventional plates.

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.

(AUTHOR'S ABSTRACT)

Various combinations of black and white letters and backgrounds were night-tested in the field, using an internally illuminated sign, to collect data regarding the relationship between sign luminance and

legibility over a wide range of ambient lighting conditions. Observers in three age groups were pretested for visual acuity and daylight sign legibility, before the night tests. Contrast level and direction were controlled, and the sign legend and background luminance were monitored photometrically. Minimum and optimum brightness values over a sign face are suggested for typical rural, suburban, and urban ambient illumination conditions. Recommendations are given for further needed research.

UMTRI 14539
Rumar, K. (1966). Comparative Legibility Tests between Reflectorized and Non-Reflectorized Registration Plates (the Dynamic Part) D-1 to D-4. Uppsala, Sweden: Uppsala University, June.

(AUTHOR'S DISCUSSION)
An inconsistency in the obtained results is that different types of plates (A, B, C, D) prove to be the best legible under different conditions. The explanation is probably that the optimum stroke-width varies both with type of plate (bright or dark) and with the illumination conditions. Earlier experiments (9, 10, 11, 31, 42) have shown that with optimum stroke-widths on both types, the bright and the dark plates should have about the same legibility.

It has been suggested that the requested legibility distance should be set at 45 m. Tests of visual acuity (15, 20, 37, 46) show that 45 m must be considered as a maximum legibility distance for symbols about 80 mm high, 46 mm broad, and with a stroke-width of about 12 mm. Consequently, the values received in D-1 were expected. The limiting factor is the resolution capacity of the human eye. Various investigations (8, 35, 37) have shown that the correlation between the conventional static visual acuity (VA) and an acuity measured on moving targets (DVA) is not specially high. That means that measurements made under static conditions are not always valid for dynamic situations.

As is seen from the symbol-combination-table in the Appendix the same symbols have not been used for the various plates. Experiments (6, 11, 19, 29, 43) have shown that the confusion-tendencies, the optimum stroke-widths, and the optimum forms vary with the specific symbols used. Thus the variation of symbols, that was necessary to prevent memorizing, is an extra source of variance in our experiments. The used number of symbols on each plate -eight - is more than many persons can memorize, even for a short time (6, 11, 14, 19, 36). To try whether the symbol-combinations for any special type of plate seemed to be more difficult to remember a check was made. The number of answers,

incorrect only in one or two symbols, was counted and added to the correct answers. However, the results turned out to be the same. This is an indication that the memory-problems have not influenced our results.

In the Appendix are given the results of the analyses of variance that have been applied on the results. From the tests of significance can be seen, that only three variables gave clearly separated results. Thus in test D-1, the legibility varied significantly with the illumination angles, also the interaction between angle and painted/reflectorized type of plate proved significant. Finally the reflectorized plates were significantly more legible in test D-4. The reason why no one of the other obtained differences (e.g. in D-3) turned out to be significant must be that the individual differences were too large.

These experiments deal only with the legibility of the plates. The great advantage with reflectorized plates is shown to be their superior visibility during night traffic (7, 12, 24, 28, 30, 32, 34, 38, 39, 41, 45). If this fact should rule the choice of plate-type the best plates must be those with bright background and dark symbols.

Several investigations (1, 2, 4, 7, 11, 12, 13, 18, 21, 23, 24, 25, 28, 32, 33, 40, 41) support on the whole the results obtained in our experiments.

One important question is whether the types of tests used can be considered representative of the situations in which the legibility of registration plates is necessary and most frequently occurring. Test D-1 is not exactly such a situation, but is chosen more from a theoretical point of view. The tests D-2 to D-4 are chosen in cooperation with policemen who have great experience in the subject and who ought to be the most appropriate ones to judge these things.

The final conclusion must be that the disadvantages with reflectorized license plates that have been found in these (and in other) investigations are smaller than the advantages found, at least from perceptual point of view.

UMTRI 30614
Hofstetter, H.W. (1967). Computed Distances of Legibility of Standard Traffic Control Signs. American Optometric Association Journal, May, 38(5), 381-385.

(UMTRI ABSTRACT)

Twenty three signs were selected for study from the U.S. Department of Commerce set of Standard Traffic Control Signs. The group of 23 included regulatory, warning, guide, and construction and maintenance signs. The legibility of the four categories was compared, and it was found that the regulatory signs had the shortest legibility distances and durations of legibility, while

the warning signs had the longest. The median distance for warning signs is just over 300 ft. (3.5 seconds at 60 Miles Per Hour (M.P.H.), and the median distance for regulatory signs is about 230 ft. (2.6 seconds at 60 M.P.H.). For all categories combined, the median is under 300 ft. (3.4 sec. at 60 M.P.H.), and two-thirds of the signs have maximum legibility at less than 350 ft. (less than 4.0 sec. at 60 M.P.H.).

UMTRI 08886

Rumar, K. (1968). Lesbarkeitstests mit Reflektierenden und Nicht Reflektierenden Kraftfahrzeug-Kennzeichen (Legibility Tests of Reflectorised [sic] and Non-Reflectorised Motor Vehicle Registration Plates). Zeitschrift fuer Verkehrssicherheit, 3rd Quarter, 14(3), 167-177.

(AUTHOR'S ABSTRACT)

In order to find out the difference in legibility between reflectorized and conventional registration plates four experiments corresponding to realistic traffic situations were carried out. The plates used were black with white symbols, white with black symbols and yellow with black symbols all in 2 mm relief. The white plates were also tried in a flat version.

The results were that the two types of plates are equally legible under daylight conditions. During nighttime conditions under large angles observer-plate-light source the legibility of the reflectorized plate is somewhat poorer than that of the conventional plate. But under all conditions when there is a light source in the vicinity of the observer, the reflectorized plates are far more legible.

Some other aspects of the license plates are also discussed in connection with a thorough study of literature on the subject area.

UMTRI 30371

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

(AUTHOR'S CONCLUSIONS)

A study using simulated signs presented under laboratory conditions controlled many of 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.

These indoor laboratory results were compared with a number of mathematical models. One based on brightness ratios gave the best fit and another based

on per cent brightness contrast the next best fit to the experimental results. The latter was more easily applied to estimate visibility of full scale test signs. Using the percent contrast equation reasonably good calculated estimates were obtained of the actual distances at which signs were seen by two groups of experimental subjects under day and under night conditions. The night estimates were somewhat better than the day estimates probably as a result of more variability of 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 most effective factors were brightness contrast of letters-to-sign and sign-to-background. Indicated as an added factor in some cases was chromatic or hue contrast.

To measure all of the factors which may have some interrelated influence on sign visibility a great deal more work is needed. In the meantime, however, the brightness ratio and percent contrast equations may be used for estimation of relative visibility of given types of sign installations. In addition, of course, adequate legibility distances must be provided. A method is suggested for making the necessary estimates.

Estimates based on brightness contrast factors should be applied with due consideration of the wide range of backgrounds against which highway signs are seen as shown in our study and also in a study by Hanson and Woltman. Differences in different seasons of the year as well as from changing viewpoint of the driver must be considered.

UMTRI 15268 A03

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

(AUTHOR'S SUMMARY)

Studies of sign legibility factors have indicated greater legibility for wide letters, stroke-width from 14 to 25% of letter height, wider letter spacing and brightness contrast in the range of 50% or better. Legibility distances for block letter signs under daylight conditions may be taken to be about 50 ft/in. of letter height. Under night conditions, legibility distances of 33 ft/in of letter height determined with scrambled letters and constant illumination represent a conservative value for estimation purposes.

Although *familiar* words gave 65 ft or more of legibility distance per inch of letter height in various studies, these longer distances should be discounted because of the effect of the familiar test words and better than normal vision of observers in most of the studies. Most state laws and regulations

require drivers to pass visual tests for 20/40 vision only.

Methods of calculating sign letter size for certain speed and warning distance have been published. Legibility distance increases with letter height, letter width, and with brightness level up to a certain optimum brightness. It is reduced by glare and high ambient illumination from the surroundings. Therefore, an urban area may require higher brightness levels for signs than dark rural conditions. For high illumination, floodlighted signs may be needed, but, for most rural highway signing, brightness levels from reflective materials will produce sufficient legibility distance.

Attention-gaining visibility characteristics of highway signs at supra-threshold levels are important when highway signs compete with other signs and visual stimuli. A four-year laboratory study indicated that brightness ratio of sign-to-background and legend-to-sign were additive and, together with relative size, largely determined this type of attention-getting visibility characteristics. Average percent contrast was used to estimate outdoor visibility distances obtained in both night and day observations with sufficient accuracy for estimation purposes.

Other factors such as chromatic contrast and illumination-level should be studied for more refined evaluation of sign effectiveness. However, the sum of percent contrast of sign-to-background and letter-to-sign applied to the maximum expected visibility distance gave usable estimates.

UMTRI 52013

Fisher, A.J., and Cowl, R.R. (1970). The Reduction of Specular Reflections from Traffic Signs Used on Lighted Roads. Australian Road Research, June, 4(4), 3-8.

(AUTHOR'S ABSTRACT)

Specular reflections of street lighting lanterns from overhead traffic signs on a lighted expressway have been observed. These reflections reduce the contrast between the sign legend and its background and decrease sign legibility.

One method of reducing these troublesome reflections is to use materials having reflecting properties of a matt surface. This paper describes testing techniques and results which can be used in the choice of suitable background materials for road signs used on lighted roads.

UMTRI 15881
King, L.E., and Tierney, W.J., III (1970). Glance Legibility - Symbol Versus Word Highway Signs. Morgantown, West Virginia: West Virginia University.

(AUTHOR'S ABSTRACT)
The major objective of this research was to investigate and compare the glance legibility of symbol and word message highway signs. Two hundred and eight subjects, including male and female drivers and nondrivers, were tested and reported. The test utilized motion picture film segments to present the subject with both symbol and word traffic signs, one at a time, for exposure durations of 1/3, 1/6, 1/9, and 1/18 second. After each exposure, the subject was asked to match the test sign to a similar sign, one of nine shown on a following film segment, and the accuracy of the match was recorded. The subjects were also asked to interpret the meaning of eighteen unfamiliar symbol highway signs. The results of this study show that symbol signs are more effective in transmitting a message than are word signs. The results also indicate that any change-over from a word system to a symbol system should be accompanied by an educational program to familiarize drivers with the meanings of the symbol signs.

UMTRI 50377
Migliorino, G., and Raimondi, T. (1970). Un'Apparecchiatura per lo Studio delle Condizioni Ottimali di Leggibilità sui "Visual Displays" (An Apparatus for the Study of the Best Conditions for Legibility in "Visual Displays"). Automobilismo e Automobilismo Industriale, January, (1-2), 60-70.

(AUTHOR'S ABSTRACT)
After a few notes on the recent technological progress in the field of human engineering and on the role played by visual displays, the authors describe an apparatus built by the Working Group on Man-Machine Systems, acting in the University of Palermo, for the study of optimal conditions of legibility on instrument panels.

UMTRI 53348 A05
Woods, Donald L., and Rowan, Neilon J. (1970). Street Name Signs for Arterial Streets. Highway Research Record, 325, 51-61.

(AUTHOR'S ABSTRACT)
This paper presents the results of an engineering analysis of the street name signing problem to meet driver informational needs on modern arterial streets. Evaluation of the relative contrast between the letter

and sign background for various combinations of letter color and background color are discussed, and an analytical analysis of the letter size required for the driver to properly execute a left-turn maneuver onto an intersecting roadway is presented. Alternative designs for providing street name information to the driver are discussed, and a design procedure that considers the driver's perception-reaction time and visual acuity and the physical characteristics of the intersection is presented.

1. The most desirable combination of colors for street name signs is white letters on a green background from both a target value and legibility standpoint (excluding any psychological response to color).
2. A perception-reaction time of 1.0 sec is too short for design on urban arterial streets; a value of 2.5 sec is more realistic.
3. A static visual acuity of 20/40 probably should be assumed in designing sign installations.
4. A minimum letter size of 6 in. should be used on all street name signs.
5. Advance street name signs should be placed a minimum of 200 ft in advance of the intersection, and a distance of 300 to 350 ft is desirable for 40 or 45-mph operation.
6. The advance street name sign should include the U.S. or state highway number when the street is also a designated highway.

UMTRI 50568
Adler, B., and Straub, A.L. (1971). Legibility and Brightness in Sign Design. Highway Research Record, 366, 37-47.

(AUTHOR'S ABSTRACT)

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 incorporates these factors and determines sign brightness as a function of road distance. The distance at which the sign must be first legible is used in conjunction with the computed brightness and published empirical data relating brightness to legibility to calculate required letter heights. Minimum letter height requirements for road distances up to 2,000 ft are presented. The cases reported include a straight road, high and low headlight beams, six sign positions, four horizontal alignments, and

four vertical alignments. For nighttime legibility, it was found that required letter heights are much larger then the 50-ft-per-in. rule indicates. Because of the widely varying sign brightness found in actual roadway conditions, each sign should be treated individually as a separate design problem.

UMTRI 50569
King, G.F. (1971). Determination of Sign Letter Size Requirements for Night Legibility by Computer Simulation. Highway Research Record, (366), 48-63.

(AUTHOR'S ABSTRACT)

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. 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, according to accepted traffic engineering criteria and according to adherence to pertinent signing manuals, were found to be above average, 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 percent of all signs for daylight, 35 percent for high-beam illumination, and 49 percent for low-beam illumination. For guide signs, the corresponding figures were 39, 44, and 63 percent. Only 1 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. Analysis of these variations and of the other deficiencies revealed a disproportionate influence of apparently minor changes in approach horizontal and vertical alignment.

UMTRI 16174
Lowden, P.R., and Stoker, J.R. (1971). The Relative Effect of Dew on Three Reflective Sign Materials. Sacramento, California: California Division of Highways.

(AUTHOR'S ABSTRACT)

A series of tests related to the effect of dew formation on reflective sign materials is presented.

Still and motion pictures recorded the effects of simulated dew (steam) in the laboratory as well as actual dew formation in field tests. Three sign materials were used for comparison throughout the tests. The effect of dew formation was recorded using time lapse photography. All materials darkened gradually as dew formed on the signs; none of the materials exhibited consistently better legibility.

Due to the limited number of tests and observations made, it was concluded that a much more extensive series of tests with a broad range of variables would be necessary to properly evaluate the sign materials under dew conditions. No recommendations are made at this time.

UMTRI 41797

Sanderson, J.E. (1971). A Comparison of N. Z. Worded and International Symbol Signs. Wellington, New Zealand: New Zealand Ministry of Transport.

(AUTHOR'S ABSTRACT)

In a study carried out for the N.R.B. by Market Research N.Z. Ltd in 1969 it was found that International symbol type signs were generally not very well understood by N.Z. Drivers. Thus if more use is to be made of these signs in N.Z. an extensive educational program would have to be launched. Before considering introducing International symbol signs an evaluation of the benefits they would have would be desirable. There is one obvious benefit - that of eliminating the language problem. This problem doesn't seem to be very great in N.Z. however.

This paper reports on an attempt to compare some N.Z. and International type signs under laboratory conditions using what has been termed rapid recognition, legibility distance, and acuity as the bases for comparison. The same bases were also used to compare International type signs having white reflectorised backgrounds and International type signs having black backgrounds.

UMTRI 28139

Stoke, C.B., and Simpson, C.H., Jr. (1971). A Comparison of the Legibility and Visibility of Enamel and Reflectorized 1971 Virginia License Plates. Charlottesville, Virginia: Virginia Highway Research Council.

(AUTHOR'S ABSTRACT)

The Safety Section of the Virginia Highway Research Council carried out observation tests of the legibility and visibility of reflectorized and enamel license plates.

The primary objectives were to determine the comparative legibility and visibility distances of these plates under low beam headlights and from several angles of approach.

Fifteen subjects were selected from the civilian driving population and law enforcement agencies. Each was required to have a valid motor vehicle operators license and to pass a visual screening examination.

License plates were mounted on the rear of a 1968 Chevrolet four door sedan. A 1970 Ford station wagon was used as the test vehicle. The same vehicles were used for each subject. Tests were carried out during favorable weather conditions, in a rural locale at night.

For legibility tests the test vehicle started 200 feet from the stationary vehicle and proceeded until the subject could read all the digits without error.

Visibility tests started 2,000 feet from the stationary vehicle and proceeded at a speed not in excess of 5 mph until either the license plate or car could be seen.

Tests were performed at various angles of approach and at various lighting arrays.

In each set of legibility tests, the reflectorized plate could be read at a greater distance than could a similar enamel plate. In each set of recognition visibility tests an individual was able to determine that a danger to his vehicle operation existed at a greater distance when the stationary vehicle he was approaching was equipped with a reflectorized license plate.

In each set of legibility tests, the reflectorized plate could be read at a greater distance than could a similar enamel plate. In each set of recognition visibility tests an individual was able to determine that a danger to his vehicle operation existed at a greater distance when the stationary vehicle he was approaching was equipped with a reflectorized license plate.

In each set of point source visibility tests, the distance at which a subject could detect light coming from a stationary vehicle was significantly greater for an automobile equipped with reflectorized license plates.

UMTRI 17350 A05

Forbes, T.W. (1972). Visibility and Legibility of Highway Signs. Pages 95-109 in Forbes, T.W. (ed.). Human Factors in Highway Traffic Safety Research. New York: Wiley.

(AUTHOR'S SUMMARY)

Efficiency of highway signs has been analyzed into legibility and attention value. The former is composed of pure legibility and glance legibility, the latter of target value and priority value.

Numerous studies have shown that legibility depends on letter height, height-to-width ratio, stroke width, spacing between letters, spacing between lines, contrast, and illumination. These studies are quoted and optimum values for these factors are quoted.

For ordinary black-on-white or white-on-green highway signs with wide letters, legibility distances were 50 feet to 65 feet to the inch of letter height. Some longer distances have been reported for signs with high luminance and high letter contrast. The distances given are for people with 20/20 or "normal" vision and must be reduced for 20/40 vision, the minimum allowed for driver's license in most states.

Lower-case letters and capital letters with similar stroke and width-to-height ratios gave about the same legibility distances per inch of loop height and letter height. Signs can be designed to be adequate for a given design speed and warning distance. Reports are quoted which describe two methods of calculating letter size needed. Ordinarily at least 40 to 50 percent letter to sign contrast is needed. Three to four familiar words could be read at a glance.

Attention value for signs that are easily within legibility distance depends on a number of factors. Early studies showed that contrast with the background and location on the road, sign position, reading habits, and "set" to find a certain route affect target value and priority value. A later study showed that, in general, visibility (which signs will be seen first) depends on brightness contrast of letter to sign and of sign to background. Color contrast (hue) might add to this effect but, in general, colors were effective in proportion to their brightness and brightness contrast.

Very bright signs will be seen to best advantage against a bright background but may interfere with dark adaptation in a dark rural setting.

A simplified mathematical model for estimating visibility distances was reported. Relative effectiveness of mounting signs over the highway as against on the side of the road, and relative percentages of backgrounds against which highway signs are seen were considered.

The proper design for signs, for both legibility and visibility is of primary importance for efficient and safe traffic on city streets and on high-speed highways and freeways.

UMTRI 51106

Hills, B.L. (1972). Measurements of the Night-Time Visibility of Signs and Delineators on an Australian Rural Road. Australian Road Research, December, 4(10), 38-57.

(AUTHOR'S ABSTRACT)

The visibilities of in-service signs and delineators have been measured under practical driving conditions on a four-lane divided highway. The night-time experiments were conducted using American-British dipped beams. It was found that the night-time

legibility distances of reflective signs were on average half those obtained during the daytime. Ageing and dirt accumulation were shown to reduce sign legibility distances by 30 per cent or more at night. These same factors were found to reduce the reflectivity of delineators on guide posts set back 10 ft from the pavement by as much as 18 times. The corresponding reduction in visibility was from 1,000 ft to less than 100 ft. The mean detection distance for the 3 ft guide posts was 590 ft for normal observers. On average, the guide posts were found to be slightly more visible than their red delineators. For a colour defective (protanomal) observer, the mean detection distance of the delineators was half that of the guide post. Heavy rain was found to have little effect on the performance of enclosed lens reflective sheeting, although other evidence suggests that drizzle can reduce its visibility considerably.

The dependence of current signing and delineation practices in Australia upon a high level of maintenance has therefore been shown. The study also indicates that there is a need for a careful examination of the present standards for delineators.

UMTRI 17970 A03

Woltman, H.L. (1972). A Review of Visibility Factors in Roadway Signing. Workshop on Highway Visibility, Highway Research Board.

(UMTRI ABSTRACT)

The author reviews the literature concerning the visibility factors of roadway signing. The legibility issues discussed are letter to background contrast, letter height, height-width ratio, stroke width, spacing between letters and spacing between lines vertically. Also examined are legend/background color combinations, legibility distances, lower case letters, familiarity effects, and glance legibility. Target value, as it is influenced by background, and angular position of a sign are also discussed. The article also provides recommended practices for the design of highway signs.

UMTRI 33943

Dewar, R.E. (1973). Psychological Factors in the Perception of Traffic Signs. Alberta, Canada: Calgary University.

(AUTHOR'S ABSTRACT)

This report is an extensive review of the literature pertaining to the psychological processes involved in the perception of highway traffic signs, and is one of three reports commissioned by the Road and Motor Vehicle Traffic Safety Branch of the Ministry of Transport and presented at a Sign Seminar sponsored

by the Council on Uniform Traffic Control Devices for Canada.

The results of this review are presented as a list of priority research questions. Firm data are not yet available in many areas, but this report makes its contribution by indicating and documenting the areas of weakness and suggesting definitive research action. It is hoped that the material contained in this report will facilitate the evolution of an improved sign system in Canada.

UMTRI 32261 A13

Forbes, T.W. (1973). Highway Sign Luminance, Contrast, Visibility and Legibility. Proceedings of the International Road Federation World Meeting. VII, Paper C3. Washington, D.C.: International Road Federation.

(UMTRI ABSTRACT)

The author reviews the literature to date concerning highway sign luminance, contrast, visibility and legibility. More specifically, the attention gaining characteristics of signs such as sign position, brightness, percent contrast and size are discussed. Studies have found that signs placed over the highway are seen "first and best" as compared to signs placed at the side of the road. Sign content and interpretability are briefly mentioned. The author suggests that complex messages take longer to interpret than simple messages or symbol signs. Sign legibility studies are discussed at length, particularly the optimal luminance required for legibility, the optimal spacing between letters, upper versus lower case letters, the effects of brightness contrast on visibility and legibility, and the optimum luminance and contrast for visibility and legibility. The author notes that contrast between sign and background should be examined as well as the contrast between sign and legend.

UMTRI 51215 A04

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

(AUTHOR'S ABSTRACT)

The transmission of information to drivers on the highway has been a challenge since the early days of the automobile. Visual transmission by means of signs was an obvious development. The many highway problems (among them visibility, legibility, message content, and national uniformity) that have developed since World War I have required systematic work and resolution.

It is generally acknowledged that sign performance is dependent on attention value and legibility. Forbes (8) has reported that these are functions of target value and priority value, pure legibility and glance legibility respectively. Each factor is related directly to contrast - the sign with surround, providing attention value; letters with background, providing legibility.

Literally, contrast is the difference in brightness and color between an object and its background. It is a subjective experience that is given to extreme variation, particularly at night. Excessive stimuli from glare sources (such as opposing headlights and luminaires, colored taillights, and electric advertising) contrast with the generally inadequate luminance for effective nighttime perception elsewhere in the highway scene. A study by Forbes (8) described pure legibility as the reading distance derived from an unlimited observation time for reading the sign and glance legibility as the distance under limited reading time.

Target value is generally employed to describe those characteristics that make a sign stand out against its natural background or surround, and priority value refers to other factors, such as location or mounting position, that affect the order in which signs might be read. It has been shown that contrast factors affect target value and that location, number of signs, reading habits, search procedure, and "mental set" affect priority value.

UMTRI 32345 A05

Attwood, D.A. (1974). Driver Performance Related to the Vehicle. Proceedings of the Scientific Conference on Traffic Safety, 28-37. Ottawa, Canada: Traffic Injury Research Foundation of Canada.

(AUTHOR'S ABSTRACT)

The effects of the vehicle on driving performance are discussed under the headings of anthropometry, visibility, controls design, workplace, layout, and environment. Solutions to the problem of improving driver performance are offered in terms of improved controls, displays and vehicle design.

UMTRI 33938

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

(AUTHOR'S CONCLUSIONS & RECOMMENDATIONS)

The series of experiments comprising the present research project was formulated to develop and compare several methods for evaluating the perception of

traffic signs. The major conclusions based on the results of this research are as follows.

Legibility distance of traffic signs can best be determined by having them viewed by the subject while driving under normal conditions. Only this technique should be used to obtain criterion measures against which to validate other methods of sign legibility. The speed at which the subject drives the vehicle is of relatively little importance in determining legibility distance.

A modified on-the-road technique, using miniature traffic signs viewed by the subject driving at a reduced speed has been found to predict legibility distance under normal driving conditions very well. It would be an adequate field method for traffic sign evaluation.

Time lapse photography of traffic flow is another valuable tool for recording drivers' responses to signs. Marked variations occur in traffic flow and behavior patterns from day to day, and from one location to another. Therefore, care must be taken to record an adequate sample of driving behavior.

Comprehension, or intrinsic meaning, of unfamiliar symbols can be adequately measured by the use of either a multiple choice questionnaire or an open-ended question format. In the case of the former method, care should be taken to construct all erroneous choices so that they are perceived as plausible answers, otherwise a 4-choice format may in effect be a 2 or 3-choice format. Under such circumstances the probabilities of making a correct guess increase.

The multiple-choice format, with choices related to action to be taken or meaning (whichever is appropriate to the individual sign) permits an adequate measurement of comprehension of ambiguous messages. The semantic differential technique provides an index of subjective meaning of traffic sign symbols. This measure (all four semantic differential factors) is highly correlated with intrinsic meaning and would be a valuable adjunct in the measurement of meaning of unfamiliar symbolic messages.

The population stereotypes technique is useful for determining existing expectations with regard to symbolic representation of messages. Such information would be helpful in guiding the design of symbolic traffic signs.

Unfamiliar symbolic messages with little intrinsic meaning are difficult to learn and remember. Some symbols, after being learned, are forgotten within a few weeks. This illustrates the need for an extensive education campaign whenever a new symbol is introduced into a signing system.

Subjective indices of preferences for symbolic messages and judgments of clarity of their meaning

provide little useful information in the evaluation of traffic sign symbols.

Glance legibility has been used in traffic sign research by a number of experimenters in the past. However, 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.

Verbal reaction time is a good method for determining the speed with which subjects can extract the meaning from a traffic sign. This laboratory method is a valid predictor of legibility distance of verbal signs, but in the case of symbolic messages a valid prediction can be obtained only under conditions which involve the type of attention demands and visual distractions found in the driving task.

UMTRI 30534 A05

Duncan, J., and Konz, S. (1974). Effect of Ambient Illumination on Legibility of Displays of Liquid-Crystals and Light-Emitting Diodes. Proceedings of the Human Factors Society 18th Annual Meeting, 102-108. Santa Monica, California: Human Factors Society.

(AUTHOR'S ABSTRACT)

Two liquid-crystal (LC) and three light-emitting diode (LED) electronic digital displays were evaluated at 1.5, 15, and 45 fc on the display using five criteria: 1) recognition time of single digits, 2) no-error viewing distance, 3) preferred viewing distance, 4) preferred illumination, and 5) subject vote.

Recognition time (at a constant viewing angle of 31 min. of arc for the display character height) of the two seven-segment LED displays did not change significantly in the selected range of illumination. For the hexidecimal LED display, recognition time increased significantly from 1.5 to 15 and 45 fc. Recognition time of the reflective LC display decreased significantly from 1.5 to 15 and 45 fc. For the transmissive LC display, recognition time increased significantly from 15 to 45 fc.

The no-error viewing distance of .77" LED display decreased significantly from 1.5 and 15 to 45 fc but increased significantly from 1.5 to 15 and 45 fc for the reflective LC display.

No-error and preferred viewing distances were predicted with multiple regression equations; using just display character height and stroke width/height gave a multiple R = .91 for non-error viewing distance. The character height viewing angle obtained for non-error viewing distance was 5 min. of arc, but was 17 for preferred viewing distance.

Mean preferred illumination was 62 fc for the reflective LC display, 27 for the transmissive LC

display, 21 for the .27", seven-segment LED display, 18 for the .77", seven-segment LED display, and 10 for the .27", hexidecimal LED; any difference greater than 9 fc was significant.

Preference for the liquid-crystal displays increased at the expense of the light-emitting diode displays as ambient illumination increased from 1.5 to 45 fc.

UMTRI 30376

Mortimer, R.G., and Olson, P.L. (1974). Development and Use of Driving Tests to Evaluate Headlamp Beams (Technical Report UM-HSRI-HF-74-14). Ann Arbor, Michigan: The University of Michigan Highway Safety Research Institute, March.

(AUTHOR'S ABSTRACT)

Results of analyses of accident data to evaluate the contributory role of headlighting were inconclusive. Reflectance values of various objects in the driver's field-of-view were measured. Pilot studies were made to evaluate test targets, and results were used to describe desirable characteristics of a test target for use in subsequent tests.

A series of headlighting field tests were carried out to develop a reliable field test method, evaluate variables affecting visibility provided by headlamps, and generate data for use in validating a mathematical model. Driving tests were also used to evaluate glare effects of various beams to oncoming and preceding drivers.

Three types of targets were developed for the work: a simulated overhead sign, a simulated roadside sign, and a general purpose target to simulate objects on or near the roadway. The latter target could be placed to the right or left of the test vehicle or in the center of its lane of travel. In addition, its reflectivity could be changed.

The following variables were investigated: (1) headlamp beam, (2) lateral separation between vehicles, (3) longitudinal separation between vehicles, (4) target type, (5) target reflectivity, (6) target position relative to car path, and (7) target height.

All of the above variables were found to be significantly related to the distance at which the orientation of the target could be identified.

Targets positioned to the right of the lane are more easily seen than those on the left under glare conditions, and with low beams. Other factors being equal, the closer a target is to the pavement, the more easily it is seen. Retro-reflective targets are seen at far greater distances than painted targets, but very high levels of reflective brilliance may actually

impede their legibility by making the target itself a glare source.

The test-retest coefficient of reliability of the field test procedure developed in this program is estimated to be 0.97, producing a variation of less than 5% in the visibility distances when the same subjects are retested on the same night. When a different group of subjects, a different test road, headlamps aimed independently on the two occasions, and a stationary glare car in one case and a fully dynamic test in the other case, were used the differences in the mean visibility distances did not exceed about 15%. Thus, test reliability is considered to be satisfactory.

Comparisons between U.S. low and high beams showed that on two-lane roads visibility is greatest if dimming occurs from high to low beams at about 1500 feet. The U.S. low beam headlamps used in these tests provided greater visibility of a target on the right side of the lane than the European H_4 headlamps that were used. A type of mid beam provided greater visibility on the right than the U.S. or European beams.

Road evaluations of glare from the headlamp beams showed that the European high beam produced relatively much more requests for dimming from oncoming drivers than the U.S. high beam. Drivers were also influenced by the number of headlamps on the oncoming vehicle, but not in the case of the following vehicle. Discomfort glare due to beams reflected in rearview mirrors was affected by mirror reflectivity and beam intensity, but not by the presence or absence of road lighting.

UMTRI 32071

Rizenbergs, R.L. (1974). High-Intensity Reflective Materials for Signs (Report Number 397). Lexington, Kentucky: Kentucky Bureau of Highways.

(AUTHOR'S ABSTRACT)

Field observations and laboratory tests and evaluations were conducted on High-Intensity and Engineering Grade materials (Scotchlite), manufactured by the Minnesota Mining and Manufacturing Company, and were compared in regard to reflectivity, durability, and cost.

The High-Intensity grade materials were found to have outstanding performance characteristics in comparison to Engineering Grade materials. The material significantly enhances sign legibility under low-beam illumination, and accelerated weathering tests showed superior durability.

UMTRI 31502
Rumar, K., and Öst, A. (1974). The Night Driving Legibility Effects of Dirt on Road Signs (Report Number 164), Uppsala, Sweden: Uppsala University.

(AUTHOR'S SUMMARY)
In order to obtain thorough information about dirt on road signs and its effect on legibility, three problems have been dealt with:
1. Dirt was measured each week on small road signs mounted at different distances from the road. It was found that, under unfavourable conditions reduction of reflected light and of contrast went up to 75% and 95%, respectively. Dirt accumulation can, however, be significantly decreased by moving the road sign further away from the road side.
2. Dirt was carefully collected from road signs and analyzed. The results showed that most of the dirt originated from the road surface.
3. Using a thoroughly tested field method, legibility distances were measured to shoulder mounted road signs in various stages of dirtying. The road signs were illuminated by car headlights or separate road sign illumination - both external and internal.
In night driving without separate sign illumination the results clearly showed a marked decrement in legibility caused by dirt. In daylight or with separate illumination, however, the effects of dirt were very limited.

UMTRI 33372
Cook, K.G. (1975). Reflectorized License Plates: A Review and Analysis of Research, Technical Data and Documentation Related to Their Use (Report Number ABC-123). Arlington, Virginia: Century Research Corporation.

(AUTHOR'S ABSTRACT)
This review and integration of the literature and knowledge on the reflectorized license plate starts with the related subject of the visual and the informational requirements of driving. What visual processes and tasks are called into play in driving? How do these vary in the population of drivers? In what ways do marginal environmental conditions and complex visual scenes affect them? In this and other sections, the contribution of reflectorized license plates in providing assistance in these visual requirements will be examined.
A major premise for designing vehicle signal systems is that they should aid the observer in sorting out and clarifying the status of traffic in his visual scene; a second major premise is that signals provided by the observed vehicles should clarify traffic

expectations and reduce surprises. The role of the reflectorized license plate in assisting a driver in achieving these goals is discussed.

UMTRI 52637
Jacobs, R.J., Johnston, A.W., and Cole, B.L. (1975). The Visibility of Alphabetic and Symbolic Traffic Signs. Australian Road Research, May, 5(7), 68-86.

(AUTHOR'S ABSTRACT)

The techniques used in this study permit the determination of sign visibility under controlled conditions for observers with both normal and reduced visual acuity. Sixteen familiar road sign messages (regulatory and warning) were examined in both alphabetic and symbolic form for observers with visual acuities from normal to as low as 6/21. Threshold legibility distances were calculated using probit analysis for individual signs and groups of signs. The experiments show that

(a) the average 50 per cent threshold legibility distance for symbolic signs is about twice that for alphabetic signs for all levels of visual acuity,

(b) the shape coding included on the signs does not enhance their legibility among a set of signs,

(c) the sign size required for 0.95 probability of correct identification is approximately 1.7 times larger than the size giving 0.50 probability of correct identification, and

(d) reduced visual acuity has a predictable effect on legibility distance, e.g. a change in visual acuity from 6/6 to 6/12 halves the 50 per cent threshold legibility distance.

Practical sign design for the actual driver population is discussed and it is concluded that the use of symbolic sign messages and larger alphabetic sign messages is required.

UMTRI 52408
King, L.E. (1975). Recognition of Symbol and Word Traffic Signs. Journal of Safety Research, June, 7(2), 80-84.

(AUTHOR'S ABSTRACT)

A 35 mm slide tachistoscope projector was used to present 26 subjects with both symbol and word traffic signs, 1 at a time for an exposure duration of either 1/3- or 1/18 second. Each presentation was followed by either a 5-second delay period, a 10-second delay period, or a 10-second interference period, after which the subject was asked to match the test sign to an identical sign, which was 1 of 10 shown on a following slide. The accuracy of the match was recorded. During the 10-second interference period, the subject was required to perform a simple reading task. Ten

subjects were tested at the 1/3-second viewing time and 16 at the 1/18-second viewing time. All subjects, both drivers and nondrivers, were familiar with the word signing system, but only 1 had been previously exposed to the symbol system. The results of this study show that, under these laboratory test conditions, symbol signs are more accurately recognized at the 1/18-second viewing time than are word signs.

UMTRI 52976
Dewar, R.E. (1976). The Slash Obscures the Symbol on Prohibitive Traffic Signs. Human Factors, June, 18(3), 235-258.

(AUTHOR'S ABSTRACT)
The problem of whether drivers should be told what they can do (permissive message) or what they cannot do (prohibitive message) is discussed as it relates to traffic sign symbols. A widely used version of the prohibitive message (symbol surrounded by a red ring with a slash through the symbol) was found to have limited legibility because the slash obscures the symbol. Two experiments examined the glance legibility of 15 symbols under each of four conditions - slash over symbol, slash under symbol, partial slash, and no slash. The results indicated that the glance legibility of traffic sign symbols is better when no slash or a partial slash is used to convey the prohibitive message.

UMTRI 53048
Dewar, R.E., Ells, J.G., and Mundy, G. (1976). Reaction Time as an Index of Traffic Sign Perception. Human Factors, August, 18(4), 381-391.

(AUTHOR'S ABSTRACT)
Verbal reaction times to identify and to classify 20 traffic sign messages were measured under three conditions-sign alone, sign plus visual loading task, and sign plus visual loading task plus visual distraction. Similar trends were found in the three experiments: reaction times were smaller for the classification task than for the identification task, smaller for warning than for regulatory signs, and smaller for verbal than for symbolic messages. Comparison of these reaction time data with on-the-road measures of legibility distance revealed significant correlations. The correlational data add credibility to laboratory measures of reaction times as valid indices of traffic sign perception.

UMTRI 33194 A16
Doughty, J.R. (1976). Traffic Signs and Markings. Transportation and Traffic Engineering Handbook, 731-781.

(AUTHOR'S ABSTRACT)
This chapter includes general information on the need for and use of traffic signs and markings. It does not serve as a standard or replace the *Manual on Uniform Traffic Control Devices for Streets and Highways* (hereafter, simply called the *Uniform Manual*), but it does provide information and guidelines for: (1) kinds of design and elementary layouts; (2) warrants and requisite studies; (3) materials, maintenance, inventory, and schedules; and (4) equipment and shop requirements.
The standards recommended and frequently referenced herein are those prescribed in the *Uniform Manual*. In the interest of uniformity throughout the United States, all signs should follow these accepted standards. A considerable number of states have issued their own sign manuals, patterned closely after the *Uniform Manual*, or have adopted the *Uniform Manual* by reference. Local authorities, in the design and application of signs, should follow the standards of their state. Practicing traffic engineers in other countries should follow their appropriate manual (Pan American, Canadian, Australian, European, etc.).

UMTRI 53933 A02
Forbes, T.W. (1976). Luminance and Contrast for Sign Legibility and Color Recognition. Transportation Research Record, (611), 17-24.

(AUTHOR'S ABSTRACT)
A laboratory study of sign legibility has shown that a contrast of between 30 and 50 percent is required to maintain 75th percentile legibility. Legibility distance increased gradually with greater contrast to about 80 percent; above a luminance ratio of 5 to 1, legibility did not increase greatly. As ambient levels increased, legibility distance increased linearly with the logarithm of either the letter or the sign luminance, whichever was greater. Five color combinations were measured. This report gives additional results on color recognition and applies the effects of luminance and contrast to legibility distance for 11 color combinations, after corrections were made for letter and stroke width. A method for estimating legibility was developed for black and white letter and sign combinations. The effects of luminance and contrast on color recognition at five ambient levels showed the need to increase luminance and contrast as ambient levels increase. Laboratory

luminance data, confirmed by two sets of outdoor measurements, furnished a basis for determining the luminance ratios used in the legibility estimates. A basis for estimating glance legibility distance in relation to ordinary legibility (long viewing time) is suggested.

UMTRI 33552

Forbes, T.W. (1976). Luminance and Contrast for Sign Legibility - Additional Results and Applications. Proceedings of the Transportation Research Board 55th Annual Meeting. Washington, D.C.: Transportation Research Board.

(AUTHOR'S ABSTRACT)

A laboratory study of legibility, a partial report of which was made previously, showed 75 percentile legibility lost below 30 percent to 50 percent contrast, but increasing to and leveling off above about 85 percent contrast for a given ambient luminance level. For legibility, a legend to sign contrast of at least 80 percent (5 to 1) was recommended. With increasing ambient level, legibility distance increased linearly with the logarithm of letter or sign luminance, whichever was greater. Five color combinations were measured.

The present report gives additional results on color recognition and applies luminance and contrast effects to legibility distance (Dl) for eleven color combinations, after correction for letter width and stroke width. A measure of estimating legibility was developed for black and for white letter sign combinations. The method involves luminance ratios and maximum Dl values based on a stroke width one-sixth of letter height.

Luminance and contrast effects on color recognition at five different ambient levels showed the need for increasingly high luminance and contrast with higher ambient levels. Laboratory luminance data, confirmed by two outdoor measurements, furnished a basis for luminance ratios used in legibility estimates.

A rough basis for estimating glance legibility distance in relation to that for long viewing time is suggested.

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.

(AUTHOR'S ABSTRACT)
The study reported on in this paper took place in two parts: laboratory tests and outdoor observations. In the laboratory tests, which were conducted in a darkroom, 51 series of test signs were projected from color slides against five backgrounds simulating rural, suburban, and lighted city conditions. Luminances ranged from 0.37 to 4.45 ft-L (1.3 to 15.1 cd/m^2). Legibilities ranged from 20 to 60 ft/in. (2.4 to 7.2 m/cm) and increased approximately linearly with log luminance. Legibility was impaired when contrast was below 50 to 60 percent and was maximum when contrast was between the ratios of 6 and 13 to 1. Optimum stroke width appeared to be narrower for white than for black letter combinations. Color recognition fell below 75 percent correct at lower luminances except for red. The reverse was true for small targets. Outdoor observations of 12-in (30.5 cm) reflective letters (two color combinations) under headlights confirmed the lower contrast limits for legibility and effects of stroke width. High-beam outdoor legibility curves and laboratory-corrected trends were similar. Apparently, glance legibility, which was measured by the laboratory procedure, requires higher luminance. In a previous visibility study, luminance contrasts of sign to background and legend to sign were critical. These results suggest minimum requirements for both legibility and visibility.

UMTRI 52833
Hicks, J.A., III (1976). An Evaluation of the Effect of Sign Brightness on the Sign-Reading Behavior of Alcohol-Impaired Drivers. Human Factors, February, 18(1), 45-52.

(AUTHOR'S ABSTRACT)
The purpose of this investigation was to evaluate the relationship between highway sign brightness and alcohol impairment under night driving conditions. Sign brightness was controlled by varying sign reflectivity and headlight brightness. Data were collected under controlled conditions with the subjects actually driving the vehicle. The dependent measure was the correct reading distance. Three blood alcohol concentrations (BAC's) were investigated: Sober, 0.08%, and 0.15%. Fourteen subjects participated under a different BAC on each of three separate nights.

Results confirmed the experimental hypotheses that high reflectance signs significantly increase sign-reading distance under night driving conditions and that alcohol-impaired drivers require significantly brighter signs. Increases in both sign reflectance and headlight brightness yielded significant improvements in sign-reading performance under all three BAC conditions. A significant interaction between the reflectance and headlight main effects indicated that the higher reflectance signs yielded a greater relative improvement in sign-reading performance under low-headlight conditions than under high-headlight conditions.

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.

(AUTHOR'S ABSTRACT)

Examination of the effects of level of illumination, stroke-width, visual angle and contrast on legibility of numerals show that some fonts tested are significantly better than others. There is an optimum luminance level (of about 34.3 cd/m^2) for the legibility of white letters on a black background. Optimum legibility is obtained when stroke-width ratios are less than 0.167 for black numerals and about 0.083 for white numerals. A set of numerals was selected from all those tested which is significantly better than any of the standard sets, particularly for black numerals on a white background.

UMTRI 34935 A14

Mortimer, R.G., and Olson, P.L. (1976). Evolution of a U.S.-ECE Improved Headlamp Beam. Proceedings of the International Ergonomics Association, 6th Congress, 294-298, Santa Monica, California: Human Factors Society.

(AUTHOR'S ABSTRACT)

Conventional U.S. and European headlights were used as a basis for comparison with three experimental mid beams in field tests to evaluate visibility and glare of alternative "meeting" beams. Mean visibility distances of targets to the left of the drivers, at the center line of the two lane road used, were about half of those targets at the right side of the lane. Visibility distance of targets at the left of the lane were slightly greater with the ECE low and the mid beam using the ECE low beam than the other beams, but only

close to the meeting point. Mean visibility of targets on the right of the lane was up to 24% greater with mid beams with either U.S. or ECE low beams. Discomfort glare was rated the same for all beams for targets on the right; but less for ECE low beam and the mid beam using the ECE low beam than the mid beams using the U.S. low beam when observing targets on the left. It was concluded that improving meeting beams should use headlamps similar to the ECE low beam for urban driving, augmented by a third lamp such as the U.S. "type III" lamps used in these tests to form the "ECE-US mid beam" for use as a meeting beam on two lane and divided highways.

UMTRI 39799
Richardson, W.C. (1976). Comparison of Legibility Potential of Reflective Sign Components. Columbus, Ohio: Ohio Department of Transportation.

(AUTHOR'S ABSTRACT)

Legibility of new reflective signs made from representative combinations of background and legend components was estimated in a quasi-natural environment by measuring subjects' ability to resolve elements of a test pattern applied uniformly to each sign. Silkscreened signs and freeway guide signs with demountable copy were treated in separate full-scale, controlled experiments. Sign performance in both cases was usually better than one arc minute resolution, with an experimental precision of 0.1 arc minute. Variation among brands in the silkscreened group was almost negligible despite the range of sign luminance obtained. the freeway type signs showed generally better performance than the others. Unit reflector legend was superior to cutout legend against any background. Reflective backgrounds performed slightly better at high levels of illumination than at low levels. Non-reflective backgrounds performed better at low levels of illumination than at high levels.

Cost projections based on current materials prices and an assumed longer life for high intensity sheet revealed that even a conservatively-estimated ten percent rate of sign destruction by vandalism and crashes would eradicate and even reverse expected savings arising out of conversion from engineer grade to high intensity sheet.

UMTRI 53933 A03
Robertson, R.N. (1976). Evaluation of High-Intensity Sheeting for Overhead Highway Signs. Transportation Research Record, (611), 28-34.

(AUTHOR'S ABSTRACT)
The purpose of this research was to determine the feasibility of using high-intensity sheeting on overhead highway signs without external illumination. The brightness of five high-intensity overhead signs without illumination was compared with that of five conventional signs with illumination. All experimentation was conducted in the field under the physical and environmental conditions experienced by the highway user. Luminance measurements were recorded from the travel lanes of illuminated and nonilluminated roadways. It was concluded that external lighting can be eliminated through the use of high-intensity sheeting on many overhead signs without adversely affecting the service to motorists.

UMTRI 36906
Welsh, K.W., Vaughan, J.A., and Rasmussen, P.G. (1976). Survey of Cockpit Visual Problems of Senior Pilots (Report Number FAA-AM-77-2). Oklahoma City, Oklahoma: Federal Aviation Administration Civil Aeromedical Institute.

(AUTHOR'S ABSTRACT)
Fifty general aviation pilots (average age 49; range 40-73) completed a questionnaire concerning cockpit visual problems. The results of the questionnaire indicated that proper interpretation of the airspeed indicator and the altimeter required the best visual acuity (48 and 39 percent of the respondents respectively). However, 33 percent reported the attitude indicator, an instrument with relatively few numerals or markings, required optimum visual acuity. Thirty-seven percent of the pilots reported that the engine instruments, usually smaller scale, are difficult to read. Light reflected from instrument cover plates caused visual problems for 32 percent of the pilots, with most difficulty occurring during daylight hours. Forty-eight percent of the pilots reported a delay in focusing from outside the cockpit to the charts and instruments, while 6 percent reported a delay of focusing from inside to outside the cockpit. More instrument readability problems were evident while flying at night than during dusk or daylight. The effects of decreasing focusing power, altered dark adaptation, and need for more lighting are discussed with respect to the older pilot. Recommendations are made to investigate the effects of instrument lighting, vision standards, and instrument

design and location with respect to the limitations of the aging visual system.

UMTRI 33421
Woltman, H.L., and Youngblood, W.P. (1976). An Assessment of Indirect Factors Affecting Reflective Sign Brightness. Proceedings of the 55th Annual Meeting of the Transportation Research Board. Washington, D.C.: Transportation Research Board.

(AUTHOR'S ABSTRACT)

This study was undertaken to determine the effect of stream traffic and road surface conditions on the brightness of retroreflective signing materials commonly used for guide, warning and regulatory signs. Field luminance measurements were made of a variety of retroreflective materials with vehicle configurations simulating various stream traffic densities. Additionally, field measurements were made using a single car for both wet and dry conditions.

Earlier studies by the authors have investigated the performance of various materials of current use on Interstate guide signs with the single car two beam headlamp system and effect of a proposed three beam system on retroreflective materials. The present experiment was undertaken to determine the relative change in sign luminance from some indirect factors which the authors observed in their earlier studies and which might be expected under typical operational conditions.

Several stream traffic spacing patterns were developed, to represent various traffic volumes. Observations were also made under natural and simulated rainfall conditions. Results of both investigations reveal useful additional sign luminance attributable to an additive effect from other vehicle headlamps and from headlamp reflection from a wet road surface which is specularly reflective.

UMTRI 53933 A04
Woods, D.L., and Rowan, N.J. (1976). Overhead signs without External Illumination. Transportation Research Record, (611), 38-44.

(AUTHOR'S ABSTRACT)

The basic objective of this research was the evaluation of high intensity reflective sheeting for use on overhead sign installations without external illumination. The effects of height above the roadway and angle of sign tilt with respect to the vertical, headlight configuration, and vehicle approach speed to sign legibility distance were measured for both an externally illuminated sign and a high-intensity reflective sheeting sign. It was concluded that the

nighttime legibility distance of overhead signs was not appreciably affected by increases in mounting height in the range of 5.5 to 7.0m (18 to 23 ft), by changes in angle of the sign with respect to the vertical in the range of -5 to +5 deg, or by vehicle approach speed. Headlight configuration, as expected, was the dominant factor in the legibility distance of the unilluminated high-intensity sign. Further, the high-intensity sheeting can be used without external illumination for overhead sign installations in spite of the observed difference in legibility distances. The average legibility distance is 19 percent less with low beams and 5 percent more with high beams on the high intensity sheeting without external illumination than on the standard installation without illumination.

UMTRI 33457

Woods, D.L., and Rowan, N.J. (1976). Overhead signs without External Illumination. Proceedings of the 55th Annual Transportation Research Board Meeting. Washington, D.C.: Transportation Research Board.

(AUTHOR'S ABSTRACT)

This research had as a basic objective the evaluation of high intensity reflective sheeting manufactured by the Minnesota Mining and Manufacturing Company for use on overhead sign installations without external illumination. The effects of height above the roadway, angle of sign tilt with respect to the vertical, headlight configuration, and vehicle approach speed on sign legibility distance for both an externally illuminated sign and a high intensity reflective sheeting sign were measured.

It is concluded that the nighttime legibility distance of overhead signs is not appreciably affected by increases in mounting height in the range from 5.5m (18') to 7.0m (23'), by changes in angle of the sign with respect to the vertical in the range from -5° to +5°, or by vehicle approach speed. Headlight configuration, as expected, is the dominant factor in the legibility distance of the unilluminated high intensity sign.

Further, the high intensity sheeting can be utilized without external illumination for overhead sign installations in spite of the observed difference in legibility distances. The average legibility distance for the high intensity sheeting was five percent greater than for the illuminated sign for the high beam configuration and 19 percent less for the low beam configuration.

UMTRI 37436
Dahlstedt, S.G.R. (1977). Vägmärkens Läsbarhet vid Mörkerkörning. En Problemanalys och Några Resultat Rörande Effeketn av Frostbeläggning (The Legibility of Road Signs During Night Driving - an Analysis and Some Results Concerning the Effect of Frost) (Report Number 120). Linköping, Sweden: Statnes Väg - och Trafikinstitut.

(AUTHOR'S SUMMARY)

The objective of the present study was to compare the legibility of road signs with different kinds of retro-reflective sheeting under dry frosty conditions at two levels of vehicle head-lighting.

The results do not permit any general conclusions about the superiority of a certain kind of sign, but the interactions rather indicate that the best legibility is obtained by different signs under different conditions. The variation in legibility between various conditions is interpreted as effects of deviations from an optimal luminance level.

With the study as a starting point an overview is then given in which various factors influencing the night-time legibility of road signs are presented. Beginning with this overview a model for an alternative method for legibility studies is discussed.

Finally some of the results are discussed from traffic safety point-of-view, and the great differences between arithmetic means and 5th percentiles are observed.

UMTRI 53439
Dahlstedt, S., and Svenson, O. (1977). Detection and Reading Distances of Retroreflective Road Signs During Night Driving. Applied Ergonomics, March, 8(1), 7-14.

(AUTHOR'S ABSTRACT)

The detectability and legibility of road signs of different reflective intensities were studied in night driving conditions. The results indicated that for obtaining optimal detectability and legibility distances, the reflective intensity of a new road sign should be in the range of 4 to 10 mcd/lux-cm^2. For signs in this range it was shown that doubling the area of a sign increased a detection distance of about 600 m by about 150-200 m. Opposing headlights on an oncoming car decreased detection distances of 500-900 m by about 100 m. Finally, it was found that standard signs, with a text 170 mm high, permitted reading from a distance of about 115 m.

UMTRI 53532
Gordon, D.A., and Boyle, J.A. (1977). The Legibility of Symbolic Parking Signs. Public Roads, September, 41(2), 68-73.

(AUTHOR'S SUMMARY AND FINDINGS)
This study is concerned with the legibility of symbolic signs proposed for use in Dallas, Tex. Thirty-four experimental subjects viewed the signs and an acuity chart, binocularly with corrected vision. Findings of the study were as follows:
- Legibility distances of different elements of the signs differed markedly. On the average, symbols were identified at over 5 times the distance of word messages. Messages with large lettering were identified at about twice the distance of messages with small lettering on the same sign. These disparities in legibility may be reduced by shortening messages, employing capital letters, and using larger, more uniform size print, as prescribed in the Manual on Uniform Traffic Control Devices. (1)
- Symbol threshold visual angle averaged 10.5 minutes, compared to 4.19 minutes for letter lines, and 3.3 minutes for the Snellen E Chart. At maximum seeing distance, symbols would have to be more than twice the size to be identified. These results suggest that symbol legibility can be considerably increased by improving the symbol design.
- The conventional "parking prohibited" symbol is difficult to read. An experimental symbol with a large slash which extended beyond the circle gave double the legibility distance of the conventional symbol.
- The legibilities of the four symbols intercorrelated highly, but showed low correlation with visual acuity and word message legibilities. The findings suggest that abilities other than visual acuity are involved in identifying parking symbols.
- Predicted legibility distances are given in table 3 for signs ranging from 1 to 4 ft (0.3 to 1.2 m) in size. These projections are given for the average driver and for the 94th percentile (poorly sighted) driver.

UMTRI 40941
Gurney, G.F., McNaught, E.D., and Bryden, J.E. (1977). Evaluation of Adirondack Park Highway Signs (Technical Report Number FHWA-NY-77-RR 56). Albany, New York: New York State Department of Transportation.

(AUTHOR'S ABSTRACT)
Highway information signs distinctive in color have been proposed for New York's Adirondack Park. Consisting of yellow legends on brown backgrounds, a combination now widely used in the park for non-highway

signs, these colors would replace the standard white legends on green or blue backgrounds now used for minor destination (MUTCD Series D 15), parking and rest areas (D 30), and miscellaneous information signs (D 61). The first two series are constructed of engineering-grade reflective sheeting backgrounds and legends, while the third uses routed letters on a wooden panel. The visibility, legibility, and aesthetics of yellow-on-brown signs were compared to the standard colors. Comments solicited from drivers during an opinion survey in the park were highly favorable toward the yellow-on-brown signs. A photographic survey indicated that this color combination is aesthetically pleasing in the park's environment. These photos also point out that visibility of any sign color combination is highly dependent on the background against which it is viewed. Measurements on 18 test signs for 145 test subjects indicated slightly greater visibility and legibility distances for white-on-green and white-on-blue, on the average than for yellow-on-brown. These differences were too small to have any practical significance, however, and all sign colors exceeded the normal legibility criterion of 50 ft/in. of letter height.

UMTRI 40586
Hahn, K.C., McNaught, E.D., and Bryden, J.E. (1977). Nighttime Legibility of Guide Signs (Technical Report Number NYSDOT-ERD-77-RR 50). Albany, New York: New York State Department of Transportation, August.

(AUTHOR'S ABSTRACT)

Nighttime legend, panel, and surrounding brightnesses were measured on 120 large guide signs throughout New York State to evaluate their legibility under headlight illumination. Panel and legend condition, background brightness, and sign legibility were rated subjectively, and sign age, material type, and sign position were recorded. Brightness was highly variable, and generally below that required for optimum legibility. Examination of measured brightness data in terms of established legibility-brightness relationships indicates that many signs do not provide adequate nighttime legibility, particularly in areas of high ambient illumination. This was confirmed by subjective ratings of nighttime legibility. While differences in brightness were apparent between enclosed-lens-sheeting and corner-cube-button leg-ends, and between overhead- and shoulder-mounted signs, these differences had little effect on legibility. Although the number of signs in those categories were small, older signs and those with deteriorated legends may be markedly lower in legibility. The measured contrast between legend and panel brightness was low for many signs, and appears to have an adverse effect on

legibility. The target value of many large guide signs is limited by high surrounding brightness, and by blockage by other highway features.

UMTRI 40082
McCarthy, J.V., and Hoffmann, E.R. (1977). The Difficulty that Traffic Signs Present to Poor Readers. Parkville, Australia: Melbourne University, Department of Mechanical Engineering.

(AUTHOR'S ABSTRACT)
Although some Australian adults have significant difficulties with reading, verbal messages are used widely in the traffic sign system. A review was made of literature relating to poor reading and to traffic sign evaluation, and laboratory experiments were carried out to provide data on the performance of poor readers in tasks involving the legibility, interpretability and short-term retention of traffic signs. While it was shown that only a small proportion (less than 1.1 per cent) of adults are likely to be so disabled in reading as to be completely unable to read verbal traffic sign messages, evidence was obtained to support the replacement of some verbal signs by symbolic signs at least in some crucial locations. Evidence was also found to support the usage, where applicable, of signs containing either permissive information, or a combination of permissive and prohibitive information, rather than just prohibitive information alone.

UMTRI 53829 A07
Mounce, J.M., Messer, C.J., Huchingson, R.D., and Dudek, C.L. (1977). Bulb-Loss Effects on Message Readability of Motorist-Information Matrix Signs. Transportation Research Record, (643), 40-45.

(AUTHOR'S ABSTRACT)
This study addresses the question of the amount of bulb loss that can be tolerated in an electronic motorist-information sign before the message becomes illegible, misunderstood, or misinterpreted. A representative group of traffic descriptor and advisory words and route numerals were displayed on a real-time matrix sign. Selected percentages (10 to 50) of bulbs were failed in a random pattern, and slides were taken of the resulting displays. These slides were shown to subjects who were instructed to respond by writing the word if it was legible. From these data, specifications for 85th and 95th percentile correct comprehension were determined for both familiar and unfamiliar motorists.

UMTRI 38139
Olson, P.L., and Bernstein, A. (1977). Determine the Luminous Requirements of Retroreflective Highway Signing (Technical Report UM-HSRI-77-6). Ann Arbor, Michigan: The University of Michigan Highway Safety Research Institute, May.

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

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

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

UMTRI 44559
Staley, R.A. (1977). The Visual Impact of Trucks in Traffic. Washington, D.C.: American Trucking Associations.

(AUTHOR'S INTRODUCTION, ABBREVIATED)
The purpose of this research was to determine how many persons actually see trucks in traffic in the course of a year, a mile, or an hour. Also to be determined was the portion of a truck actually viewed, plus the length of time that other vehicles typically follow a truck under varying traffic conditions. Average road speeds were determined for ten highway classes. Finally, a separate analysis was made of the

sizes and shapes of signs most appropriate to traffic conditions - in terms of legibility and visibility distance.

To add validity to the data base which this project creates, field research was carried out in four areas of the country; utilizing only highways and streets known to be major truck routes. To further refine the data base, analyses were conducted on ten different types of rural, suburban and urban roads and streets. Separate measurements were made of the length of time that a vehicle will follow a truck under differing traffic conditions and on various types of roads and streets. In the course of the test operations, average operating speeds were obtained for all road sections analyzed. These were separately tabulated and averaged by type and classification of highway - and the data were compared with published Federal vehicle speed information.

The final section of the project report consists of a literature search and commentary on the subject of sign sizes and designs. In the report appendix, a full explanation is presented of the methodologies employed in carrying out the visual impact survey. Copies of instructional material and worksheets are included as well as a log of all highways examined.

(AUTHOR'S SUMMARY, ABBREVIATED)

The visual impact analysis shows that the average combination vehicle creates almost 5 million visual impressions annually (4,984,101), based on the typical "mix" of travel by road system, and U.S. yearly average travel of 49,125 miles. Of this total, 81 percent of the viewers see the front and one or both sides, 11 percent see only the sides, and 7 percent (372,284) see the rear.

Utilizing a technique described in the text and appendix, the time spent by an individual vehicle in following a truck before overtaking and passing it was observed and tabulated. The implications of the findings here concern a measure of the time during which a motorist will be "impeded" by the presence of the truck ahead. While no valid overall average times could be determined due to the large number of variables, the range by highway type was found to be: a minimum average of 20 seconds for rural toll roads, up to a maximum average of 81 seconds on the urban Interstate system routes. Another typical example, urban - or city - streets - was found to yield an average following time of 62 seconds per vehicle.

Average speeds in miles per hour were computed for all test section operations, and these were cumulated and weighted by highway type. The resultant data were found to closely approximate existing Federal tabulation based on speeds on straight, level, road

sections with free-flowing traffic. The highest average truck speeds (55.0 mph) were measured on rural sections of the Interstate highway system, and the similar access-controlled rural primary multilane facilities were calculated at 53.3 mph. At the other extreme, city street speeds in downtown and in industrial areas were found to produce an average truck speed of only 18.4 mph - measured during non-rush hours.

Finally, a literature search and analysis was undertaken on the size and design of signs designed to be visible from vehicles in motion. While little in the way of definitive conclusions can be drawn from this work, it may be stated that visual perception of message signs from a moving vehicle is subject to several variables - including design, contrast, height, size and illumination.

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.

(AUTHOR'S ABSTRACT)

Readability data of alphanumeric characters that vary in figure-to-ground contrast ratio were obtained from 36 subjects; 12 subjects were placed in each of three age groups (20-25 yr, 40-45 yr, and 60-65 yr). 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 through an artificial pupil (2.0 mm) and, when required, while wearing a spectacle lens correction.

Data indicate a significant difference in luminance values for successive changes in contrast ratio under both illumination modes. 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.

UMTRI 53691 A08
Woltman, H.L., and Youngblood, W.P. (1977). Evaluating Nighttime Sign Surrounds. Transportation Research Record, (628), 44-48.

(AUTHOR'S ABSTRACT)
The accuracy of a variety of instruments that might be suitable for field measurement of nighttime sign surrounds was evaluated by comparing measurements made with them with measurements made with a laboratory-quality telephotometer. A technique for the evaluation of surrounds that identifies them by luminance measurements was developed. The measurement of numerous surrounds leads to the conclusions that conventional descriptions are often inappropriate, that opposite sides of the same roadway may vary in luminaire intensity, and that roadway geometrics may cause variations in surrounds. Photographs and luminance values that represent four generalized luminance levels and a description of each are given.

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.

(AUTHOR'S ABSTRACT)
This document provides practical guidelines for the development, design, and operation of driver displays, both visual and auditory, for freeway traffic management.
The emphasis is on the recommended content of messages to be displayed in various traffic situations; the manner in which messages are to be displayed--format, coding, style, length, load, redundancy, and number of repetitions; and where messages should be placed with respect to the situations they are explaining.
The guidelines for visual and audio messages to be displayed in incident management/route diversion situations are based upon research and operational experience.
The subject matter in the Design Guide is basically restricted to human factors design considerations with respect to motorist information displays for traffic management in freeway corridors. Once a decision has been made by the engineer to implement a motorist information system, the publication should provide guidance in message selection and the manner of message presentation for specific situations.

Although the Design Guide is primarily intended for traffic engineers working in city, county, state, or private organizations, it should also be useful to traffic engineering students or trainees and to FHWA engineers at the district and regional levels who are responsible for project review and approval.

This report is the first in a series of seventeen.

UMTRI 54235
Anonymous (1979). Liquid Crystal Displays: Next Generation Instrument Panels?. Automotive Engineering, May, 87(5), 78-81.

(UMTRI ABSTRACT)

This document examines the adaptation of LCD technology for automotive instrumentation. LCD construction, liquid crystal material, polarization, multiplexing of alphanumeric displays, analog displays, and large area LCD's are discussed. Designs for highly functioning and reliable TND (twisted nematic displays) consider temperature, moisture, and color.

UMTRI 54295
Gordon, D.A., and Schwab, R.N. (1979). The Application of Visibility Research to Roads and Highways. Public Roads, June, 43(1), 15-22.

(AUTHOR'S ABSTRACT)

This article defines visibility and the related measures of legibility and conspicuity and explains how recent research has served to improve visibility on United States roads. Topics reviewed in this article include: roadway lighting studies, including the relationship between the driver's demand for visibility and visibility supplied by fixed illumination, the relation between the probability of dry weather, nighttime accidents to visibility and illumination measures, and the significance of fixed illumination at isolated rural intersections; pavement marking systems, including the effect of increasing the luminance of yellow traffic markings by the addition of white paint, the effect of loss of visibility due to age on road markings, and the effect of reflector type pavement markers or use in fog-prone areas; sign visibility requirements, including the effect of sign conspicuity of the driver's ability to follow a test route, the legibility of various combinations of background and letter luminances, and the legibility of symbolic parking signs; and the question of how visual conditions influence the driving process.

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.

(AUTHOR'S ABSTRACT)

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

The results indicate that more highly reflective backgrounds permit somewhat greater legibility distances. Perhaps more important, reflectorized backgrounds reduce the effect of changes in viewing conditions, which can be quite substantial in the case of non-reflective backgrounds. The contrast provided by the legend is very important. Luminance contrast requirements are lowest for highly reflective backgrounds and increase as background reflectivity decreases.

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.

(AUTHOR'S CONCLUSIONS)

Clearly there are several types of vision thresholds ranging from contrast detection of a single, simplified target to recognition thresholds for more complex targets and tasks including legibility under various conditions such as those on the highway.

It may be concluded 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 70009
Foster, J.J. (1980). Legibility Research 1972-1978: A Summary. Manchester, England: Manchester Polytechnic.

(AUTHOR'S INTRODUCTION)

The aims of this review are to provide graphic designers and interested research workers with a summary of the psychological research, relevant to the work of the designer, which was published between 1972 and 1978 . I have attempted to scan all the major psychological journals, and selected those papers which seemed to me to be of interest to the person who has to make decisions about the layout and appearance of material for visual display.

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.

The organization of the material is modeled on the categorization used by Macdonald-Ross and Smith (1977), although it has been necessary to make some modifications.

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. Section 2 briefly summarizes some recent studies of eye movements. Section 3 deals with letter and digit identification, and Section 4 is concerned with the study of reading, subdivided into word identification and text reading. Sections 2 and 4 provide a highly selected coverage of the literature on these topics, and are merely intended to indicate the nature of the research and theorizing which has been produced.

Section 5 is concerned with studies which have examined the effect of typography upon the effectiveness of printed verbal material. It is divided into sub-sections on prose and non-prose settings, both containing further subdivisions for the particular typographic variables studied and for special contexts such as the teaching of reading.

Section 6 covers signs, symbols and signing systems. Section 7 is mainly concerned with research into the effect of illustrations on comprehension and learning; the first subsection indicates the more theoretical issues underlying some of the research on picture recognition. Section 8 encompasses engineering drawing, and Section 9 includes work on maps. Section 10 covers the presentation of quantitative data, including graphs and tables used for presenting data. 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.

Within each section or subsection, material is usually dealt with in chronological order of its publication. Exceptions to this rule will be found where it seemed most helpful to summarize together a number of studies by one author, or a series of experiments on a common theme.

Apart from this Introduction, all references are grouped together at the end of the monograph.

UMTRI 54659
Lozano, R.D. (1980). The Visibility, Colour and Measuring Requirements of Road Signs. Lighting Research and Technology, 12(4), 206-212.

(AUTHOR'S ABSTRACT)

This paper reviews the requirements for colour and SCIL values in the specification of retroreflective materials employed in road signs. Visibility, legibility, colour, luminance are some of the factors analysed. Based on this analysis several conclusions are given. They support the thesis that the main point is 'the minimum necessary' and not 'the best possible' for a specification in a standard.

UMTRI 54550
Van Nes, F.L., and Bouma, H (1980). On the Legibility of Segmented Numerals. Human Factors, August, 22(4), 463-474.

(AUTHOR'S ABSTRACT)

Research on the legibility of many new symbol configurations has not kept pace with their increasing use. Such novel configurations appear, for instance, in segmented numerals. This paper reports experiments on their discriminability. Perceptual confusions between members of pairs of seven-segment numerals decreased as these pairs differed in more line segments. Not all segments are equally important for perception. Their perceptive weight can be deduced from their respective contribution to the differences in shape and corresponds to the actually occurring confusions between numeral pairs. These results led to suggestions for improved numerals: a simplified configuration for 6 and 9, another choice of vertical segments for 1, and an accentuation of important segments by broadening or lengthening them somewhat. First, the improvements aim at increasing the discriminability of the numerals, second, at increasing

their acceptability; i.e., resemblance to the traditional numeral shapes plays a role.

UMTRI 54946
Cole, B.L., and Jacobs, R.J. (1981). A Comparison of Alternative Symbolic Warning Signs for Railway Level Crossings. Australian Road Research, December, 11(4), 37-45.

(AUTHOR'S ABSTRACT)
Most level crossings have light traffic and good accident records and the only protection that can be justified in cost benefit terms is a system of warning signs. The Australian standard specifies a warning sign using the 'cross bucks' symbol which might not be correctly interpreted and might also be confused with the crossroads warning sign. Wigglesworth, in a review of level crossing protection for the Ministry of Transport, Victoria, recommended the adoption of a train symbol. The UN protocol symbol is a steam train but steam trains are no longer used on scheduled railway services. However, a diesel train symbol does not have distinctive features easily adaptable to symbolic representation and such a symbol might not have an adequate legibility distance. This paper compares the two Australian Standard railway warning signs, a steam train symbol and two diesel train symbols. The criteria for evaluation are interpretability and legibility distance. Consideration is also given to what are the community stereotypes for a railway warning sign. It is concluded that the steam train symbol remains a community stereotype despite the rarity of steam trains, is likely to be correctly interpreted and has a long legibility distance.

UMTRI 47029
Gordon, D.A. (1981). The Legibility of Highway Guide Signs with Special Reference to Cardinal Direction Indications (Technical Report Number FHWA-RD-80-170). Washington, D.C.: Federal Highway Administration.

(AUTHOR'S ABSTRACT)
This report is concerned with the legibility of the message elements displayed on the highway guide signs. The work was carried out on a vision testing alley, using scaled down replicas of highway signs.
Cardinal Direction indications (North, South, East, West) demonstrated satisfactory legibility. They could be identified at further distance than any of the sign elements except the message "Next Right."
Capital/lower case cardinal direction indications were seen 10 percent further than conventional block letters. The use of capital/lower case lettering can

increase element legibility without requiring appreciably more sign space.

The findings indicate that route numbers had poorest legibility of the eight types of information displayed on the guide signs tested. They were seen at 10 percent shorter distance than place names.

The feasibility of performing sign legibility research on small scale replicas is supported. The minimum letter height of .0085 m (one-third of an inch) is recommended to achieve adequate subject testing distance.

UMTRI 45926
Lesage, Pierre B. (1981). Design and Comprehension of Bilingual Traffic Signs (document number TP 3037 CR: 8101). Road and Motor Vehicle Traffic Safety Branch, Transport Canada, Ottawa, Ontario, Canada, March.

(AUTHOR'S SUMMARY)

In order to develop a better understanding of how bilingual traffic signs are perceived and processed by road users, a study was undertaken by the firm of Pierre B. Lesage conseils et Recherche en Gestion et Communications Ltee on behalf of the Road and Motor Vehicle Traffic Safety Branch, Transport Canada. The study was designed to objectively evaluate the current range of bilingual sign designs and make recommendations on appropriate message placement principles.

The study consisted of three phases: review of current signing practices; literature review; and, development, conduct and analysis of laboratory testing of various bilingual signs. Based on available information, it was decided to use glance legibility as the objective measurement of sign performance. 256 subjects, equally divided into 4 language sub-groupings, were exposed to various combinations of 13 bilingual sign messages (65 signs in total).

The major findings of this study were as follows:

1. Bilingual signs require more reading time than unilingual signs.
2. The dominant language should be located either at the "TOP" of a "TOP-BOTTOM" sign message configuration, or at the "LEFT" of a "LEFT-RIGHT" configuration.
3. Neither the "TOP-BOTTOM" nor the "LEFT-RIGHT" sign message configuration was found to be significantly better than the other.
4. Clear demarcation of the two languages (for example, by a line) significantly improved sign performance, particularly for unilingual subjects.
5. Use of "pivot" words (a word common to both languages) resulted in poorer sign performance than corresponding fully-translated signs.

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.

(AUTHOR'S ABSTRACT)
Eleven traffic control signs were studied to determine several visibility thresholds in uncluttered, nighttime conditions with alerted subjects. Initial detection and sign comprehension thresholds were compared, respectively, to analytically determined driver detection and recognition requirements. All signs met the detection requirements. Regarding recognition, inadequacy of certain signs was indicated; they were the WRONG WAY and STOP signs for higher speed traffic and the School Crossing sign even at urban speeds.

Certain other sign weaknesses were identified. Among these, the legend of YIELD signs was inadequate at most travel speeds. Signs with red backgrounds were conducive to the legend being mistaken for the sign itself. In general, of color, shape, and message comprehension; errors of color were the most frequent type.

A limited amount of data were available to study sign brightness. For two equal sized DO NOT PASS signs, there was no clear improvement for the brighter sign regarding legibility or message comprehension. For a larger, type I STOP sign versus a smaller, type II (brighter) one, results suggested sign size effects dominated brightness effects.

UMTRI 45456 A02
Terada, I., and Akeyoshi, K. (1981). Improvement of LCD Legibility for Automobiles (SAE Paper Number 810171). Electronic Displays and Information Systems, February, 37-42, Warrendale, PA: Society of Automotive Engineers.

(AUTHOR'S ABSTRACT)
Recently liquid crystal display (LCD) is quite expected for automotive instrument panels because it has many possibilities in design. But it is not sufficient in using LCD for automobile yet and the legibility of the LCD instrument panel has not been discussed.

This paper describes methods of improving LCD legibility and a sample of LCD instrument panel is shown.

(AUTHOR'S CONCLUSION)

Dependency upon legibility of the LCD has been described, and the recent LCD technology has been shown.

The difficulties involved in improving the LCD legibility for automobile use have, on the whole, been overcome by:

1) Using the transflective mode in the display except for the transmissive warning indicators.

2) Making index of refraction smaller and cell gap thinner.

3) Using thin rear-glass cell construction.

4) Giving a suitable scattering angle to the reflector.

5) Coloring the display with color polarizers and color filters.

Besides, it is very important to prevent the surface of LCD from the perfect reflection. To make the surface of LCD rough or multi-layer thin film is an effective way.

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.

(AUTHOR'S ABSTRACT)

Laboratory studies of traffic sign perception have often neglected to duplicate the divided attention demands of the driving task, even though it has been suggested that the inclusion of a loading task would increase the validity of such research. The present experiment examined the need for this division of attention by requiring subjects to identify traffic sign messages while performing a second, loading task involving the cognitive components of detection, identification or memory. A control group received no loading task. 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 54662

Sivak, M., Olson, P.L., and Pastalan, L.A. (1981). Effect of Driver's Age on Nighttime Legibility of Highway Signs. Human Factors, February, 23(1), 59-64.

(AUTHOR'S ABSTRACT)

A field investigation of the effect of driver's age on nighttime legibility of highway signs was

performed. Subjects of two age groups (under 25 and over 61 years of age) participated. The results indicate that legibility distances for the older subjects were 65 to 77% of those for the younger subjects with equal high-luminance visual acuity. This finding implies that older drivers are likely to have less distance (and thus less time) in which to act on the information transmitted by highway signs. Consequently, it is argued that (1) legibility standards for highway signs should not be based exclusively on data obtained from young observers and (2) standard (high-luminance) acuity tests have questionable relevance to nighttime visual performance.

UMTRI 55065
Anderton, P.J., and Cole, B.L. (1982). Contour Separation and Sign Legibility. Australian Road Research, June, 12(2), 103-109.

(AUTHOR'S ABSTRACT)
Closely adjacent contours can reduce the legibility of a character or word, a physiological phenomenon known as contour interaction. The legibility of an alphanumeric legend can be reduced as a consequence of this phenomenon if the spacing between letters is narrowed, although it has been shown that the loss of legibility is usually too small to be of practical significance. In this paper it is shown that a bold surrounding contour can cause a more significant loss of legibility. However, variation in the luminance (brightness) of the display within the range of 30 to 100 cd/m^2 does not affect legibility or the extent of contour interaction.

UMTRI 46839 A01
Baeger, H. (1982). Liquid Crystal Displays with Integrated Electronics for Dashboard Instrumentation (SAE Paper Number 820005). Electronic Displays and Information Systems and On-Board Electronics, February, 1-5. Warrendale, PA: Society of Automotive Engineers.

(AUTHOR'S ABSTRACT)
Today, millions of liquid crystal displays are used in wrist watches, clocks, pocket calculators, and measuring instruments. For automotive application, many problems had to be solved. The present paper gives a survey of the most important results of VDO development work aiming at a display system which will be fully suited for automotive application.

(AUTHOR'S FOCAL POINTS OF DEVELOPMENT)
To make LCD fully useful for automotive instrumentation, the following problems had to be solved:

1. Production of large-area cells
2. Improvement of the readability of the displays, i.e. extension of the viewing angle
3. Improvement of the climatic stability of the displays
4. Extension of the operating temperature range of the liquid crystal mixtures
5. Improvement of electrical connection reliability

UMTRI 48798 A08
Bryant, J.F.M. (1982). The Design of Symbolic Signs to Ensure Legibility. Proceedings of the 11th Australian Road Research Board Conference, 161-171. Vermont South, Australia: Australian Road Research Board.

(AUTHOR'S ABSTRACT)
Design procedures to ensure the legibility of symbolic signs have not been developed to the extent that similar procedures have for verbal signs. The three parameters of luminance, contrast and size are considered in the light of recent research into the visibility of symbolic signs and a procedure is developed which will ensure that significant detail, necessary for the comprehension of the symbolic image incorporated in the sign, is sufficiently legible for defined populations under the intended conditions of use. The procedure has been incorporated into standards for the design and use of graphic symbols and public information symbol signs by the Standards Association of Australia and similar methods are under consideration by the International Standards Organization.

UMTRI 47513 A14
Doughty, J.R. (1982). Traffic Signs and Markings. Pages 707-735 in Homburger, W.S., Keefer, L.E., and McGrath, W.R. (eds.). Transportation and Traffic Engineering Handbook (2nd ed.). Englewood Cliffs, NJ: Prentice-Hall.

(AUTHOR'S ABSTRACT)
This chapter includes general information on the need for and use of traffic signs and markings. It does not serve as a standard or replace the *Manual on Uniform Traffic Control Devices for Streets and Highways* (hereafter, simply called the *Uniform Manual*)[1] but provides information and guidelines for (1) types of design and elementary layouts; (2) warrants and requisite studies; (3) materials, maintenance, inventory, and schedules; and (4) equipment and shop requirements.
The standards recommended and frequently referred to in this chapter are those prescribed in the *Uniform Manual*. In the interest of uniformity throughout the

United States, all signs should follow these accepted standards. A considerable number of states have issued their own sign manuals, patterned closely after the *Uniform Manual* or have adopted it by reference. Local authorities, in the design and application of signs, should follow the standards of their state. Practicing traffic engineers in other countries should follow their appropriate manual (Pan American, Canadian, Australian, European, etc.)

UMTRI 70787
Dudek, C.L., and Huchingson, R.D. (1982). Human Factors Design of Dynamic Visual and Auditory Displays for Metropolitan Traffic Management (Technical Report Number FHWA/RD-81/039). Washington, D.C.: Federal Highway Administration.

(AUTHOR'S ABSTRACT)
This report summarizes the findings and design implications of a series of research studies with respect to parameters of dynamic visual displays (Changeable Message Signs) and auditory displays (Highway Advisory Radio). Laboratory, proving ground and field studies were conducted.

Dynamic visual display factors investigated have been classified into five areas: 1) message factors, 2) character factors, 3) accentuation factors, 4) dynamic factors, and 5) visibility factors.

In-situ controlled field studies were conducted to validate findings from previous HAR laboratory studies. Specific areas investigated were: 1) language style, 2) information load, 3) redundancy, 4) description of alternate routes, and 5) advance road sign for radio tuning.

This volume is the first in a series. The others in the series are:

Volume No.	FHWA No.	Short Title
2	FHWA/RD-81/040	Dynamic Visual Displays
3	FHWA/RD-81/041	Highway Advisory Radio

UMTRI 55177 A01
Gordon, D.A. (1982). Legibility of Highway Guide Signs. Transportation Research Record (855), 1-6.

(AUTHOR'S ABSTRACT)
A study concerned with the legibility of guide signs is reported. The work was carried out on a vision testing alley, and scaled-down replicas of highway signs were used. These findings indicate that route numbers had the poorest legibility of the eight types of information displayed on the guide signs tested. They were seen at 10 percent shorter distance than place names. Cardinal-direction indications

(North, South, East, West) demonstrated satisfactory legibility. They could be identified farther away than any of the sign elements except the message "NEXT RIGHT". Capital/lower-case cardinal-direction indications were seen 10 percent farther away than conventional block letters. the use of capital/lower-case lettering can increase element legibility without requiring appreciably more sign space. The feasibility of performing sign legibility research on small-scale replicas is supported. A minimum letter height of 0.85 cm (0.33 in) is recommended to achieve adequate subject testing distance.

UMTRI 48798 A06

Hoffmann, E.R., Smith, G., Kalnins, C., and Sanders, B. (1982). Legibility of Symbolic Turn-Restriction Signs of Various Formats. Proceedings of the 11th Australian Road Research Board Conference, 127-134. Vermont South, Australia: Australian Road Research Board.

(AUTHOR'S ABSTRACT)

Experiments were carried out to measure two aspects of traffic sign legibility - distance legibility and glance legibility. Turn restriction signs of the following formats were compared: (a) Prohibitory (P), based on AS1742, with the diagonal either over (O) or under (U) the arrow and slanted down to the left (L) or to the right (R) or without the diagonal (N), (b) mandatory (M) with a white arrow on a blue ground (B) as commonly used in Europe and a red annulus form (R). The distance legibility results showed that the mandatory blue (MB) format was generally recognized at a smaller visual angle (greater distance) than the MR format and was also superior to the prohibitory formats. The rank order of the prohibitory format signs, increasing from the smallest threshold visual angle (decreasing from the greatest legibility distance) was: PN, PUL, POL, PUR, POR. the glance legibility tests gave a similar rank order of formats to that obtained in distance legibility tests.

UMTRI 55252 A05

McNees, R.W., and Messer, C.J. (1982). Reading Time and Accuracy of Response to Simulated Urban Freeway Guide Signs. Transportation Research Record (844), 41-50.

(AUTHOR'S ABSTRACT)

The results and methodology used in a laboratory study to determine motorists' time required to read urban freeway guide signs and the accuracy with which they read the signs are presented. The study was performed by using licensed drivers as subjects. The subjects, ranging in age from 18 to 79 years, were taken along a hypothetical urban freeway route where

2-, 3-, 4-, and 5-panel signs were used. A sign bridge typically has between one and four sign panels that have a green background and a white border around each panel. Each panel contains one or two route designations, one or more destination cities, and additional action messages. Each panel contained either 2, 4, 6, 8, or 10 units of information. The results of this study indicate that the optimum accuracy level was about 6 units of information/panel. When the information level was less than 16 units, 100 percent of the subjects could read the signs acceptably; when the level was between 16-30 units, 51 percent could read the sign acceptably; and when the level was between 31-50 units, only 33 percent could read the sign acceptably. It is apparent that route-selection accuracy decreases as the number of route choices increases. On a large sign (3 or more panels), the information content should not exceed 16 units of information/sign bridge. The time required to read a sign also increases with the number of route choices and total information on the sign.

UMTRI 46839 A04

Ogawa, F., Sato, N., and Mimitsuka, T. (1982). Liquid Crystal Displays with FIP Illuminator (SAE Paper Number 820008). Electronic Displays and Information Systems and On-Board Electronics, February, 21-26. Warrendale, PA: Society of Automotive Engineers.

(AUTHOR'S ABSTRACT)

The legibility and usefulness of liquid crystal displays (LCD's) in automotive applications depends entirely on the type and control of the illumination technique chosen.

The use of a fluorescent indicator panel (FIP) as an illumination source from the backside of an LCD is proposed.

The LCD surface brightness levels and legibility over a wide ambient lighting range are discussed. Three operational modes (transmissive, reflective, and transflective) of the FIP-LCD system are considered.

UMTRI 54949

Sivak, M., and Olson, P.L. (1982). Nighttime Legibility of Traffic Signs: Conditions Eliminating the Effects of Driver Age and Disability Glare. Accident Analysis and Prevention, April, 14(2), 87-93.

(AUTHOR'S ABSTRACT)

The effects of observer age and environmental glare on nighttime legibility of traffic signs were investigated in two field experiments with the subjects driving or riding in a car towards a sign. Experiment 1 showed that equating older and younger subjects in

terms of their low luminance/high contrast visual acuity resulted in elimination of any age effects on legibility. Furthermore, the presence of a glare source with an illuminance of 0.17 or 0.017 lux offset 2° from the sign legend improved legibility distance significantly. The results of Experiment 2 indicated that a glare source with an illuminance of 0.0098 lux had no effect on legibility when presented at an offset angle of 1.5° or 0.6°, but it had a significant detrimental effect at an offset angle of 0.2°. The present findings suggest that (1) the usually observed age-related performance decrement on nighttime legibility tasks is the result of visual-acuity deficits, and not shortcomings in information-processing ability; (2) legibility is relatively unaffected by glare, unless the glare angle is very small or glare level very high; and (3) glare sources positioned outside of the fovea might improve nighttime legibility performance under certain conditions.

UMTRI 46839 A06

Terada, I., Akeyoshi, K., and Kadoo, F. (1982). Further Study on LCD Legibility Improvement for Automobiles (SAE Paper Number 820011). Electronic Displays and Information Systems and On-Board Electronics, February, 41-46. Warrendale, PA: Society of Automotive Engineers.

(AUTHOR'S ABSTRACT)

Electronic instrument panels have now begun to find their way into some cars. And, recently, liquid crystal display (LCD) is about to be adopted in automobiles as a speedometer, a tachometer and other gauges.

This paper describes considerations of LCD on the viewing angle, the response time, the contrast and so on. This is a further study of the previous report (1).

(AUTHOR'S CONCLUSION)

Main restriction and limitation of using LCD for automobiles have been described, and the characteristics of recent LCD has been shown. The difficulties involved in improving the LCD legibility for automobile use have, on the whole, been overcome by using:

I) The transflective and negative type in the display.
II) Heavy pattern in design.
III) Suitable switching time and driving condition.
IV) Thin rear-glass cell and thin cell gap.
V) Suitable roughness of the surface finish.

UMTRI 46839 A08
Yamaguchi, T., Kishino, T., and Dorris, J.M. (1982). The Visual Recognition of Vacuum Fluorescent Displays Under Sunlight Conditions (SAE Paper Number 820013). Electronic Displays and Information Systems and On-Board Electronics, February, 51-60. Warrendale, PA: Society of Automotive Engineers.

(AUTHOR'S ABSTRACT)
The visual recognition of self-luminous displays in the automobile instrument panel under direct sunlight conditions is a major design criteria. The user-display interface requires the designer to consider factors of visibility, legibility, reading fatigue and styling. All factors are important, but under direct sunlight conditions, visibility has to take the highest priority and is the most important design factor.
The object of this paper is to delineate visibility parameters by analyzing the results of experiments designed to determine the minimum brightness levels and type of filtering required to obtain visual recognition of vacuum fluorescent displays under the sunlight conditions.

UMTRI 48550
Dewar, R.E. (1983). Criteria for the Evaluation of Traffic Sign Symbols (Technical Report Number AIR 394-4). Vermont South, Australia: Australian Road Research Board.

(AUTHOR'S ABSTRACT)
Two groups of practicing traffic engineers, one from Victoria and one from New South Wales and two groups of traffic sign experts, one from Australia and one from New Zealand, participated in a survey to determine opinions on the importance of six criteria for traffic sign symbols. The practicing traffic engineers had views similar to those of the experts. No differences were found between the Australia and the New Zealand samples. Understandability and conspicuity were considered to be more important than the other criteria. Reaction time, legibility distance and glance legibility were of equal importance for traffic sign symbols. Learnability was rated less important than were the other five criteria.

UMTRI 55217
Gebhardt, K., and Scheufler, H. (1983). Eine Neue Generation von Bordcomputern in Kraftfahrzeugen (A New Generation of On-Board Computers in Cars). Automobiltechnische Zeitschrift, February, 85(2), 81-84.

(AUTHOR'S ABSTRACT)
In a cooperative project a new generation of on-board computers has been developed. This type of computer is characterized by separation of the display from the operation unit to facilitate operator interaction.
The functions of the computer have been designed so as to avoid any numerical input by the driver.
Four buttons within the operation unit provide full access to the computer. In order to measure ambient temperature, a temperature sensor is installed behind the front bumper. This unit is the first in production with a Liquid Cristal [sic] Display. The main advantages of such a display are optimal visibility under day and night conditions with the added bonus of extremely low dissipated power.

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.

(AUTHOR'S ABSTRACT)
A formula is derived giving the letter stroke width needed for legibility of words on a sign at any given distance by an observer with any given visual acuity. The stroke width, in turn, determines the letter size, depending upon the characteristics of the type face used. 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 information implicit in the formula is also presented graphically, in four plots that apply to four different combinations of length units for measuring stroke width and viewing distance. Also presented are formulas and graphs for correcting the critical stroke width for nonstandard contrast or background luminance. These correction formulas are based on a body of data on visual acuity as a function of contrast and background luminance, and a formula fitting the mid-ranges of the data, both published recently by other researchers.

UMTRI 47881 A02
Kadoo, F., Akeyoshi, K., and Terada, I. (1983). A New LCD Instrument Panel for Automobiles (SAE Paper Number 830040). An Update on Automotive Electronic Displays and Information Systems, February, 27-34, Warrendale, PA: Society of Automotive Engineers.

(AUTHOR'S ABSTRACT)
Under existing circumstances, the practical constructions of liquid crystal display (LCD) devices for automotive application are very few and very complicated.

At the moment there are few research papers that undertake this topic.

This paper presents a new practical construction of LCD, that is not only easy to assemble but also has good legibility.

A sample LCD instrument panel, which has the new construction, is shown in this report.

UMTRI 48515
Olson, P.L., and Sivak, M. (1983). Nighttime Legibility of License Plates (Technical Report Number UMTRI-83-35). Ann Arbor, Michigan: The University of Michigan Transportation Research Institute, July.

(AUTHOR'S ABSTRACT)
This study evaluated the legibility of license plates under field viewing conditions. The independent variables were: plate background luminance, legend luminance, glare, and subject age. The plates were mounted on the front and rear of a vehicle and the subjects were driven slowly past, pressing buttons to indicate legibility distance.

The results indicate a general superiority for fully reflectorized plates, especially under conditions of glare. The older subjects, in particular, seemed to benefit from the highly reflective plates.

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.

(AUTHOR'S ABSTRACT)
Four studies were carried out to evaluate the nighttime legibility of signs made with retro-reflective materials.

The first study investigated the effect of sign background luminance, legend luminance contrast, surround luminance, background color, glare illuminance and angle, and subject age on sign legibility.

The results indicate 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.

Background luminance is a significant factor as well. In general, as background luminance increases, legibility increases and legend contrast requirements decrease.

Environmental glare has a relatively small effect on sign legibility, noticeable only at very small angles and high intensities. Increases in legend luminance contrast, background and surround luminance all reduce glare effects.

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 subjects rode towards them, pressing a button to indicate the distance at which they became legible. The results indicate that the usually obtained age effect on legibility of signs is eliminated if the age groups are matched in terms of their low-luminance/high-contrast visual acuity. Furthermore, an apparent improvement in legibility with the presence of glare was obtained at a glare angle of 2°; substantial disability glare effect was present for a glare angle of 0.2°.

the fourth study was carried out to evaluate possible glare effects associated with bright highway signs. The results indicate that most retroreflective signs do not pose glare problems. Possible exceptions are signs (e.g., construction warning signs) placed very close to targets of interest, advertising signs, and internally illuminated signs.

UMTRI 70700

Sivak, M., and Olson, P.L. (1983). Optimal and Replacement Luminances of Traffic Signs: A Review of Applied Legibility Research (Technical Report UMTRI-83-43). Ann Arbor, Michigan: The University of Michigan Transportation Research Institute, December.

(AUTHOR'S ABSTRACT)

This study reviewed applied research on sign legibility to obtain information regarding optimal and replacement luminance values of retroreflective traffic signs. The report presents tabular summaries of 18 experimental studies, followed by a synthesis of findings in terms of luminance recommendations and corresponding retroreflectance values.

The reviewed data suggest that for signs having light (white, yellow or orange) backgrounds with black

legends placed in low luminance surrounds, the optimal luminance of the background is 75 cd/m^2. For fully reflectorized signs the optimal luminance of one component (legend or background) depends on the given luminance of the other component. The data suggest that for these signs the optimal legend-to-background contrast is 12:1.

Assuming legibility criteria of 6 m/cm of letter height for younger drivers and 4.8 m/cm for older drivers, the data suggest that the replacement luminance is 2.4 cd/m^2. This applies to light legends with dark backgrounds (green, blue, red, or brown) having luminance of up to 0.4 cd/m^2, and to light backgrounds (white, yellow, or orange) with black legends.

Using these optimal and replacement luminance values, optimal and replacement retroreflectance values were derived for signs placed in four locations, illuminated by U.S. or European low-beam headlighting systems. The values for generally ideal conditions are presented in Tables 1 and 2. Additionally, Table 3 lists possible correction factors for some less than ideal conditions.

UMTRI 71619 A19

Forbes, A.R. (1984). The Performance of Give Way Signs: Some Empirical Findings. Proceedings of the Road Traffic Safety Seminar, 332-346. Wellington, New Zealand: Road Traffic Safety Research Council.

(AUTHOR'S SYNOPSIS)

National variations in the design of roadway signs and markings supposedly conforming to a single international standard are commonplace. Further, no internationally agreed procedure for comprehensive appraisal of sign performance exists. This paper describes a facility and procedure for measuring some aspects of sign performance, and a procedure for measuring certain others. Evidence obtained by means of these off-road procedures and bearing on the recognisability, comprehension and learnability of Give Way signs of various formats is presented and conclusions drawn about their relative merits.

(AUTHOR'S SUMMARY)

As would be expected, the great majority of subjects apparently knew that "Give Way" means give way. From poor initial comprehension both the other signs, following only one presentation of the meaning, appeared to be understood almost as well. This finding is the more noteworthy because all the other signs in the series were unfamiliar also, and subjects had no reason to believe that the Give Way sign embedded in the series was the focus of special attention.

Further, its position in the series militated its having a high probability of correct recall (23).

The imperfect understanding of even the current New Zealand Give Way sign should be viewed with concern. Subjects were given full credit if they wrote down its meaning as "You are required to give way to other traffic", obviously a lax criterion. Those who elaborated on this correctly were given full credit with greater assurance. Most commonly, those getting credit had written down nothing or "Don't know". Even after the correct meaning had been told them, however, several subjects gave meanings of the form "You have to be prepared to give way to traffic coming from your right". How many more, had they elaborated beyond "to other traffic" would have restricted that to traffic on one's right is a matter for anxious conjecture. (A laboratory investigation of understanding of rules of precedence at intersections is being undertaken later this year.)

UMTRI 72250
Fowkes, M. (1984). Presenting Information to the Driver. Displays, October, 215-223.

(AUTHOR'S ABSTRACT)

The presentation of information to the driver is assessed from a historical perspective, highlighting those factors that have influenced current practice, and therefore expectation of instrument panel displays. The driver's use of these displays is then analyzed from a systems viewpoint, identifying important factors which influence the visibility and legibility of displays. The development at the Motor Industry Research Association of a vehicle simulator is reported, and the manner of its use to human factors research suggest that future implementation of on-board vehicle electronic displays could assist drivers by simplifying the driving tasks, i.e. reducing current levels of visual inspection tasks and information processing.

UMTRI 71179
Galer, M., Spicer, J., and Holtum, C. (1984). The Readability of Dot-Matrix Warning Symbols in Cars. Proceedings of the Ergonomics Society Annual Conference, 257-260. Loughborough, England: Ergonomics Society.

(AUTHOR'S ABSTRACT)

The Institute for Consumer Ergonomics embarked on a programme with Jaguar Cars to evaluate the information display and to equip Jaguar Cars with experimental data to reinforce any requests for

legislative change that may be necessary when contemplating use of the new technology.

The ergonomics evaluation addressed itself to the recognition of the warning symbols in dot-matrix format as compared with standard ISO symbol format. 200 drivers tested the readability of 14 warning symbols. The symbols were presented in slide form using a projection tachistoscope.

No difference was found in ease of reading between the two methods of presenting the warning symbols.

UMTRI 70981

Macdonald, W.A., and Hoffmann, E.R. (1984). Drivers' Awareness of Traffic Sign Information (Technical Report Number AIR 382-1). Melbourne, Australia: Melbourne University, Department of Mechanical Engineering.

(AUTHOR'S ABSTRACT)

Field and laboratory experiments were carried out to validate a method of measuring drivers' level of awareness of traffic sign information under normal driving conditions. The reliability and sensitivity of the experimental measure (RSI - the level of reported sign information) were sufficient to show significant effects of factors such as type of sign, sign 'action potential', sign background complexity and sign conspicuity; the dominant factor was sign action potential. Inexperienced drivers exhibited a significantly higher level of RSI (mean of .39) than experienced drivers (mean of .26). Sign legibility was poorer in the laboratory and this significantly decreased the level of RSI for verbal signs, relative to field levels of RSI. Also, the effects of sign conspicuity were greater in the laboratory. Nevertheless, there was a high level of agreement between laboratory and field results, both in absolute levels of RSI and in the patterns of influence of the various independent variables. Future use of the laboratory method is recommended.

UMTRI 70665

Sivak, M., and Olson, P.L. (1984). Nighttime Visual Problems of Elderly Drivers. Ann Arbor, Michigan: The University of Michigan Transportation Research Institute, June. Valencia, Spain: International Congress of Traffic Psychology and Highway Safety.

(AUTHOR'S CONCLUSIONS)

This article reviewed recent studies performed at the University of Michigan Transportation Research Institute dealing with nighttime visual problems of elderly drivers. These studies have shown that older drivers have significant disadvantages in term of their (1) ability to read traffic signs, (2) ability to see

low-contrast objects, and (3) susceptibility to glare. The primary countermeasures would include low-luminance visual screening and increased sign luminance for improved sign legibility, use of brighter or retroreflective clothing by pedestrians for improved pedestrian visibility, and change of reflectivity levels of dual-reflectivity mirrors for reduced glare from rear-view mirrors.

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.

(UMTRI ABSTRACT)

This handbook was produced for the designers and design engineers of Ford Motor Company Ltd. General ergonomic principles which apply to instrumentation are provided. In particular, Part 6 of this handbook discusses the important visual characteristics of visual displays.

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, should be used. Light characters on a dark background are most appropriate in vehicles, and the contrast between ambient luminance and display luminance should be greater than .2-.3. To reduce the effects of glare, surfaces having low reflectivity should be used. Also, displays and driver should be shielded from reflective effects.

As the resolution of a character is increased, the required character size decreases. The active area of a character can be increased by either increasing the size of the emitter or decreasing the spacing between emitters.

The optimal character size for electronic displays is defined by a subtended angle of 15 min. Character width should be 70-80% of character height, and the stroke width to height ratio should be 10-15% 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.

A number of important color issues are discussed. First, color should be used to group information displays and to highlight particular displays. Also, the brightness sensitivity of the eye is greatest at blue-green-yellow wavelengths, but varies depending on whether the eye is dark or light adapted. The effects of chromatic aberration should be considered since the

ability of the eye to focus all wavelengths equivalently at any instance of time is affected. No more than 5 colors should be used on a single display. Other issues are also discussed.

UMTRI 73010 A39
Ells, J.G., Dewar, R.E., and Belsher, G. (1985). Communicating Information about Dangerous Cargo. Proceedings of the Canadian Multidisciplinary Road Safety Conference IV, 533-547. Montreal, Canada: Canadian Multidisciplinary Road Safety.

(AUTHOR'S ABSTRACT)
Legibility distances were determined for six signs portraying information about hazardous cargo. Each sign was characterized by a combination of three attributes - colour, a symbol, and a number. Large and small signs were tested under conditions of daylight and darkness. Both reflectorized and non-reflectorized signs were examined in the darkness condition. Firemen viewed the signs from each of several distances with the naked eye or with binoculars. The results indicated that legibility distances could be significantly increased over those for currently used signs by increasing the dimensions of the signs and by reflectorizing them. Simplicity of design and high figure-ground contrast led to greater legibility distances for symbols

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.

(AUTHOR'S ABSTRACT)
Drivers' subjective responses to five different colours of instrument panel lighting, and their ability to read the instruments accurately were measured under simulated driving conditions. The instrument panels tested were of a current production 1981 European Ford Granada design fitted into a fully trimmed Ford Granada buck. The instrument panels had five colours of filters over the back lighting lamps, BLUE/GREEN, RED, GREEN, ORANGE and YELLOW. Eighty drivers tested each of the five display colours under night-time lighting conditions. They were asked to rank the colours for ease of reading, ease of checking the speed against limits, distraction, attractiveness, general preference and choice for own car. The BLUE/GREEN, GREEN and YELLOW were all liked, with the balance clearly in favour of the BLUE/GREEN. RED was not liked by many drivers and disliked by most. The colours appealed differently to different age and sex groups. There was

no difference between the colours in terms of accuracy of reading the speed or deciding whether the speed was within a speed limit.

UMTRI 72864
Jenkins, S.E., and Charlesworth, K.D. (1985). A Comparative Determination of the Daytime and Night-Time Legibility of Alternative Designs of 'Stop' and 'Slow' Bats (Technical Report Number ARR 136). Vermont, South, Australia: Australian Road Research Board.

(AUTHOR'S ABSTRACT)
ARRB was requested by the Department of Main Roads, New South Wales to carry out daytime and night-time legibility experiments to evaluate several designs of "STOP" and "SLOW" bats. The designs differed in having either black or white legend and border, and different background materials. The daytime legibility trials showed clearly that the black legend and border was considerably better than the white legend and border. For the black legend the type of background material had very little influence on the legibility distance, there being no significant difference between the fluorescent yellow-orange, fluorescent red-orange, red retroreflective Class 2 or the yellow retroreflective Class 2 backgrounds. For the night-time trials all backgrounds were retroreflective and the bats with the longest legibility distances appeared to have black legends and borders. There is a compelling case for a single design of "STOP" bat for day and night use having a black legend and border. The background material which performed as well as any other under day and night conditions was a fluorescent retroreflective red-orange.

UMTRI 73173
Mace, D.J., King, R.B., and Dauber, G.W. (1985). Sign Luminance Requirements for Various Background Complexities (Technical Report Number FHWA/RD-85/056). Washington, D.C.: Federal Highway Administration.

(AUTHOR'S ABSTRACT)
The Federal standards (FP-79) for luminance of retroreflective materials for traffic signs are acceptance standards; they provide no differentiation based on driver need. Driver needs for sign luminance are of 3 types -- luminance for sign comprehension, luminance levels that define sign legibility, and luminance levels for sign conspicuity. This study was directed toward establishing, for different levels of scene complexity, luminance levels for conspicuity of yellow diamond warning signs at night. A procedure based upon rating sign locations on 4 scales was useful for identifying low complexity and high complexity

scenes. A field study demonstrated that at low complexity sites, Type II signs degraded to 36 percent of Federal standard provided adequate luminance (.14 candelas/sq ft) (1.51 candelas/sq m) for sign recognition beyond 500 ft (150 m). At high complexity sites, new Type II signs in excess of the federal standard of provided luminance (.40 candelas/sq ft) (4.3 candelas/sq m) that was inadequate for sign recognition at 500 ft (150 m). At speeds below 35 mi/h, the required recognition distance is less and signs degraded to 72 percent providing a luminance of .25 candelas/sq ft (2.69 candelas/sq m) were adequate. The results clearly support earlier research in demonstrating that the visual complexity of a scene is a very important factor in determining nighttime sign luminance requirements.

UMTRI 56176
Sivak, M. (1985). Multiple Ergonomic Interventions and Transportation Safety. Ergonomics, August, 28(8), 1143-1153.

(AUTHOR'S ABSTRACT)
This article discusses arguments and research evidence concerning multiple ergonomic approaches to problems of transportation safety. Transportation accidents (and their consequences) are the result of multifactor processes. Therefore, the probability of an accident (and of an injury, given an accident) can be influenced by interventions directed at any of the factors. Furthermore, the most effective accident countermeasures are not necessarily those directed at the 'cause' of accidents. As examples, multiple ergonomic countermeasures are noted for road accidents involving alcohol-intoxicated drivers and elderly drivers, as well as for minimizing injuries resulting from road accidents.

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.

(AUTHOR'S ABSTRACT)
Presented in this paper are optimal and minimal sign luminance recommendations based on a review of available applied research. Optimal recommendations are based largely on peak luminance-legibility relationships. In the absence of other criteria, minimal recommendations are based on performance levels of 6 m/cm (20/23) for younger persons and 4.8 m/cm (20/29) for older persons. By using a computer sign legibility model, calculations were then made to

determine the photometric characteristics of signing material required to obtain the values indicated.

UMTRI 73515 A01
Galer, M., Spicer, J., and Holtum, C. (1986). The Recognition and Readability of Dot Matrix Warning Symbols in Cars (SAE Paper Number 860180). Electronic Displays and Information Systems, February, 55-59, Warrendale, PA: Society of Automotive Engineers.

(AUTHOR'S ABSTRACT)
In recent years the number of warning functions in cars has grown rapidly. Traditionally these have been single areas dedicated to specific warning functions. Manufacturers have found it difficult, time consuming and costly to respond to legislative changes or market variations.

An information display was developed that is microprocessor driven and provides a single area displaying warning symbols supplemented by an alphanumeric read out. This comprised a 32 x 32 dot matrix and warning frame, backed up by a 14 segment, 10 x 2 character message centre.

The Automotive Ergonomics Unit embarked on a joint programme with the company to evaluate the information display.

The ergonomics evaluation addressed itself to the recognition of the warning symbols in dot matrix and conventional ISO style format. An experiment was conducted in which 200 drivers tested the readability of 14 warning symbols when presented in dot matrix and conventional ISO style format. The symbols were presented as slides using a projection tachistoscope.

No difference was found in ease and accuracy of recognition between the two formats of warning symbols.

McNeese, M.D., and Katz, L. (1987). Legibility Evaluation of a Large-Screen Display System Under Medium Ambient Illumination. Proceedings of the Society for Information Display, 28(1), 59-65.

(AUTHOR'S ABSTRACT)
A human performance evaluation of a large-screen light-valve display system was performed to determine character legibility requirements for four viewing distances (6-15 ft.) and a viewing angle of 45 degrees off-axis, under medium ambient illumination. Other independent variables included dot-matrix size and contrast polarity. Results from Experiment 1 indicated that both dot-matrix size and viewing distance, and their interaction, significantly influenced legibility measures. The only character configurations that fulfilled legibility criteria over the entire range of viewing distances were the 10 X 14 dot-matrix formats

for both positive and negative contrasts. Negative contrast was significantly better than positive contrast. Visual angle was somewhat correlated with performance, but the relationship was non-linear. The extent to which a stimulus of a given visual angle exceeded legibility criterion depended on the combination of its dot-matrix format, contrast polarity, and viewing distance. Experiment 2 results for off-axis viewing indicated that only the 10 X 14 dot-matrix format (with the double stroke and negative contrast) was legible through 45 degrees. Thus, the results of this study indicate that several legibility requirements (e.g., visual angle) specified for other display media are inappropriate for light-valve projection display technology.

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