Dynamic Lane Assignment Using Fiber-Optic Signs

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The legibility distance for various fiber-optic changeable lane-use displays was evaluated. Legibility distance for the arrow shafts of the various displays was approximately 800 ft. Legibility for the word messages was near 200 ft. The word messages were identified as being a possible source of confusion to the driver, which would effectively reduce the overall efficiency of the sign in providing information. An inverse relationship between legibility and target value was identified for the sign. Decreasing the light output of a display improved the legibility but reduced the target value at practical light output settings. The selection of operational settings for a given installation must optimize this relationship to obtain acceptable levels of legibility and target value. A small legibility distance was associated with the word messages in this study. This was partly because of the width of the individual letters, the letter spacing, and the light output within the area of the word message. Design procedures should be developed that will promote uniform application of fiber-optic technology to the field of traffic signing.

Maintaining uncongested traffic conditions at intersections that exhibit wide variations in turning movements is a challenging problem for transportation agencies in many metropolitan areas. Limitations in the amount of available right-of-way (ROW) causes expansion of these facilities to become both physically and economically unfeasible. New technologies must be identified and developed that will allow the existing geometry at these locations to be utilized more efficiently.

Lane-use information at intersections is presently conveyed to drivers via pavement markings and overhead reflective signs. Problems occur at intersections that use these traffic control devices for lane-use assignments when wide variations in turning movements exist. The static nature of these devices does not allow lane usage to be optimized based on the traffic demand. The use of changeable message signs would provide a more efficient means of responding to cyclical variations in turning movements.

A sign's effectiveness is dependent on the legibility and target value of the sign. Legibility and target value of signs vary with the contrast between the sign legend and background as well as the contrast between the sign and its surroundings. Factors that contribute to a sign's effectiveness are external illumination, whether the sign reflects or emits light, and the size of the sign and its legend (*1*). Although design procedures for reflective signs have been documented throughout transportation and human factors engineering journals, the design and operation of internally lighted displays depend on basic rules of thumb and experience. Design procedures for changeable message signs are not yet well established, due largely to the rapid development of changeable message signs (*2*). Design procedures must be developed that take into account the limitations of driver visibility in both daytime and nighttime driving conditions. Liability issues further mandate that changeable message signing conform as closely as possible to requirements of the *Manual on Uniform Traffic Control Devices* (MUTCD) for signing (*2*).

Fiber-optic technology provides a viable alternative to many other types of changeable message signs. Fiber-optic displays are typically associated with the provision of higher levels of resolution, very uniform light output between individual pixels, and lower costs than are associated with other types of internally illuminated signs (*3*). A large amount of work has been done by European companies to quantify the light output of this type of sign and to develop design procedures that limit the number of pixels used to form a display based on the average pixel output (*3*). Procedures that provide engineers with the ability to design displays that can be discerned at specific distances must be developed. The development of national standards for the design of fiber-optic displays is essential to ensure that future transportation systems continue to provide information to drivers in a safe, effective, and uniform manner.

Table 1 shows the range of pixel sizes that are typically used in fiber-optic displays as well as the function for which these displays are used. The largest pixels shown in Table 1 are typically smaller than the lighting elements used in other types of internally lighted signs. Smaller pixel sizes allow symbols and words to be formed with greater resolution so that a more continuous appearance is obtained. The application of a single light source to the common end of a bundle of fiber-optic strands produces highly uniform light output for individual pixels. The high light output and intensity associ-

TABLE 1 Typical Fiber-Optic Pixel Sizes

PIXEL DIAMETER[1]	TYPICAL USE/APPLICATION
0.055"	Pedestrian Signals
0.068"	Lane Assignment/Regulatory Signing
0.090"	
0.125"	Lane Control Signing
0.177"	Word Message Signing
0.238"	Used for turn angles that need wide angle of dispersion.

[1]Obtained from the National Sign and Signal Company

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ated with these pixels eliminates the "phantom effect" exhibited by other types of internally illuminated signs.

Several trade-offs must be identified and addressed when considering the use of internally lighted fiber-optic signs rather than conventional reflective signs. The ability of fiber-optic signing to produce light can be both an advantage and a disadvantage. Although fiber-optic signs provide more target value than do reflective signs, the amount of light produced by fiber-optic signs must be adjusted to ensure that the sign is legible sufficiently in advance of the point where the information is needed. A variety of information can be presented using fiber-optic displays, whereas conventional reflective signs provide only one message.

Several disadvantages associated with internally illuminated signs also exist. These disadvantages make the decision to use this type of sign highly dependent on the benefits that can be gained at the facility. These benefits include higher capital, maintenance, and operating costs. Backup systems that provide redundancy must be designed so that, in the event of a mechanical breakdown, bulb failure, or power outage, the sign will still be capable of providing a message. Internally lighted signs are also heavier than conventional reflective signs and require the development of special, more substantial supports and mast arms to accommodate the increased weight.

STUDY DESIGN AND METHODOLOGY

Research focused on the evaluation of a fiber-optic lane-use sign developed by the Texas Transportation Institute (TTI) and the National Sign and Signal Company. The sign was tested at the Texas A&M University Riverside Campus. The scope of this research was limited to a quantitative analysis of the nighttime legibility distance associated with the sign under controlled viewing conditions. A model was also developed to relate the luminous output of the displays to the voltage applied to the sign.

Laboratory Design

The laboratory was designed to provide realistic viewing conditions for a three-lane approach to an intersection. The laboratory layout shown in Figure 1 was developed through various subjective analyses by various TTI and Texas Department of Transportation (TxDOT) traffic and transportation officials of preliminary laboratory arrangements. A sign tower was used to support two three-lens traffic signal heads with 12-in. lenses, two overhead high-intensity grade retroreflective signs, and the overhead fiber-optic changeable message sign. The distance between the right edge of the signals and the sign to the left of the signals was 3 ft. External illumination was provided by placing Type II, 250-watt, high-pressure sodium luminaries 120 ft in front of and behind the sign tower.

Design Characteristics of the Fiber-Optic Sign

The sign used in this research was purchased for the purpose of evaluating (a) the light output characteristics of fiber optics, (b) the legibility distance associated with the sign displays, and (c) the target value associated with each display.

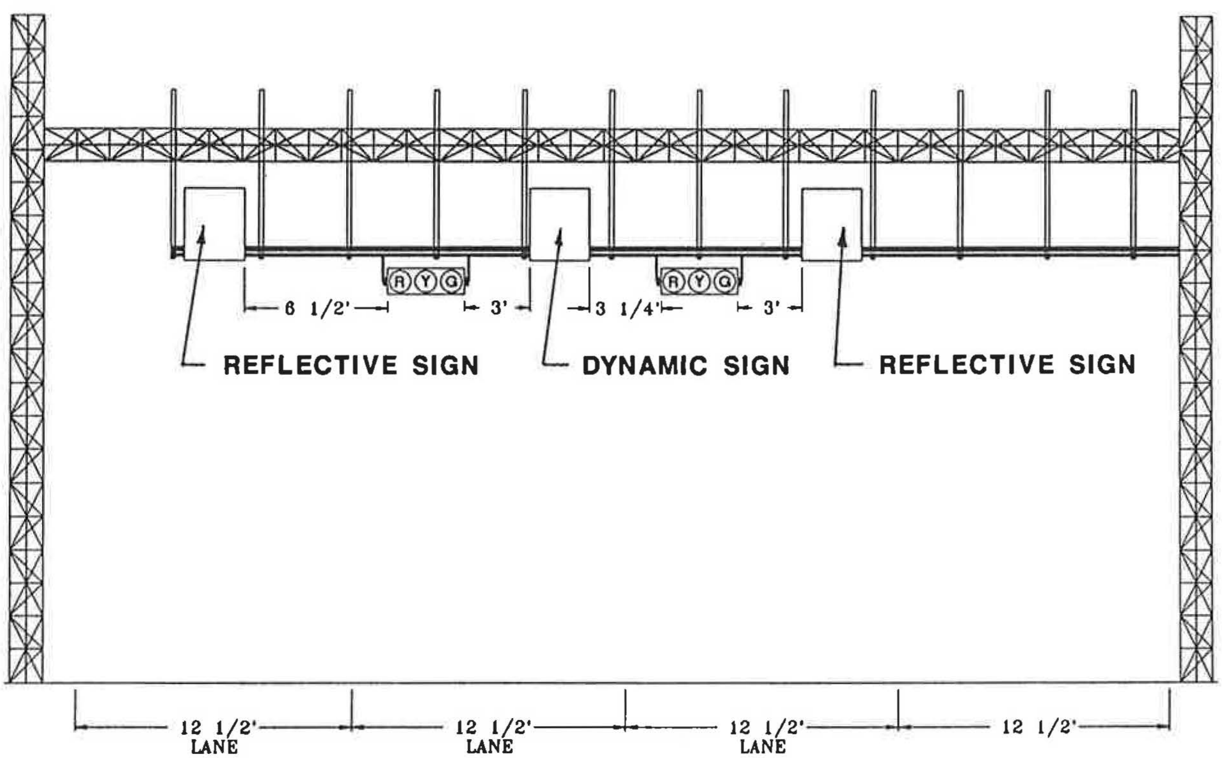

FIGURE 1 Laboratory layout used for legibility studies.

The sign was used to produce the eight different displays shown in Figure 2. Figure 3 shows a detailed layout of the face of the fiber-optic sign. Each pixel is part of a line or group of fiber-optic pixels that make up a single element of a sign display. A total of 14 lamps and transformers powered the individual lines used to form various displays. Lines were grouped as necessary to form specific displays. Two overlapping lines were used to form an arrow shaft. Pixels were arranged such that pixels from each line that formed a shaft alternated on ½-in. centers. This allowed both ½- and 1-in. pixel spacings to be evaluated.

The pixel layout allowed both a single-row and a bold or outline arrow shaft to be produced. The height and stroke width associated with bold arrow displays were designed to parallel those of arrow shaft designs used in reflective signing. The radius of the left-turn arrow was slightly larger than that of a standard R3-6L retroreflective sign. This radius was increased so that the light output would be spread over a wider expanse of the sign. This reduced the concentration of light across the sign face and provided a more legible display with higher target value than would have otherwise been obtained.

Two different stroke widths for word messages were also evaluated. The letters were 5 in. tall and conformed to letter design and spacing for standard Series-E lettering (*4*). The major concern with the design of the lettering was that the word messages not interfere with the arrow shafts because they were intended to supplement the information conveyed by the arrow shafts.

Development of Relationships Between Luminous Output and Voltage

Analytic measurements of the luminous output at specific voltages across the sign were taken. These measurements were used to develop a relationship between the voltage applied to the sign and the luminous output of each display.

Study Methodology

Three types of studies were used in this research. A pilot study was first conducted to relate the limitations of the human eye to light output levels of the light-emitting components at the laboratory. This was accomplished by evaluating the threshold intensity of the traffic signals and the point of irradiation for the fiber-optic displays. This threshold intensity corresponds to the light output of the signals that caused disability glare with respect to a person's ability to view the fiber-optic display. The point of irradiation corresponded to the voltage level that caused irradiation to occur for a given fiber-optic display.

The results of the pilot study were analyzed to determine a range of voltages for both the traffic signals and the fiber-optic displays that provided acceptable viewing conditions for the study participants. Voltage levels selected for the evaluation of the traffic signal viewing condition corresponded to the mean voltage associated with the pilot study viewings and a voltage setting used in previous subjective observations. Subjective evaluations of the fiber-optic displays were made for 35-, 50-, and 65-volt settings.

Additional subjective observations were conducted to limit the number of display factors that varied during the evaluation of legibility distance. Several variables identified prior to this survey were evaluated concerning their effect on legibility and target value. These variables included the following:

- The effects of pixel spacing,
- Differences in the formation of arrow shafts,
- The effectiveness of the sign at different levels of light output, and
- The effectiveness of the word messages.

General comments and observations concerning the overall effectiveness of the sign were also solicited.

Quantitative Evaluation of Glance Legibility

The purpose of this portion of the study was to evaluate the legibility associated with different elements of the fiber-optic

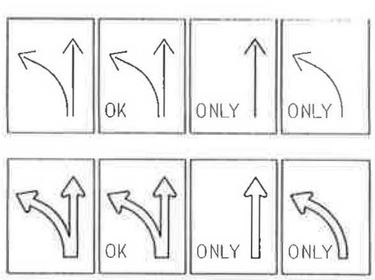

FIGURE 2 Fiber-optic test displays.

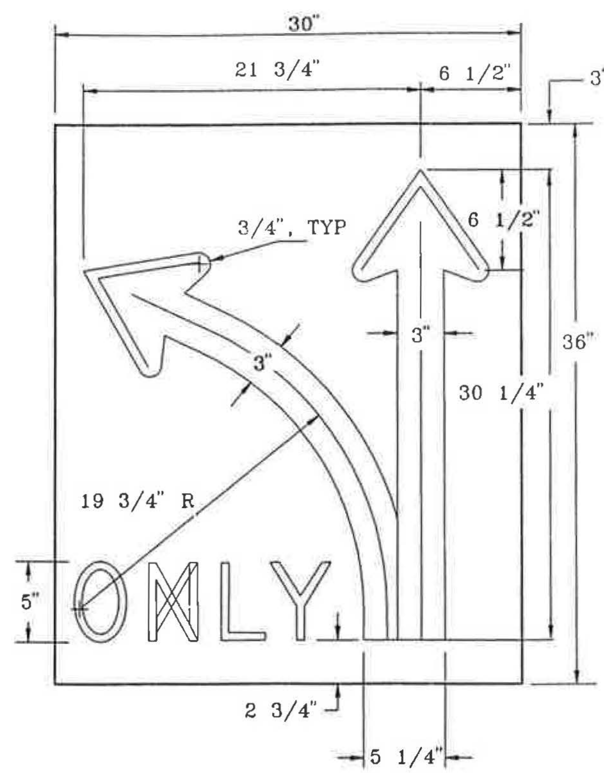

FIGURE 3 Detailed layout of the fiber-optic sign face.

sign. Glance legibility was evaluated in an attempt to provide results that would more closely represent actual driving conditions (*5*). The displays shown in Figure 2 were presented to study participants at distances from the sign of 800, 600, 400, and 200 ft. Specific settings used for the laboratory components during the legibility studies were selected based on results from the subjective observations and the pilot study. These settings included the following:

- ½-in. pixel spacings,
- No adverse weather conditions,
- 50 volts across the traffic signals,
- A constant level of external illumination, and
- Voltage settings corresponding to specific light outputs for the fiber-optic displays, as determined by subjective observations.

The study participants were instructed to travel to a distance of 800 ft from the face of the sign and park the test vehicle in the lane that lined up with the fiber-optic sign. Each participant was then informed that eight different displays would be presented on the sign and remain visible for a total of 3 sec. Each participant was instructed to view the sign long enough to identify the visual image, then look away and begin drawing the display exactly as it appeared to them. The remaining displays were presented to the subject in the same manner. The participant was then instructed to proceed to 600 ft where this procedure was repeated. Displays were presented in a random order to ensure that each display was given proper consideration by the study participants. Analysis of the data involved "grading" the drawings from each study participant to determine the glance legibility distance associated with specific elements that make up the different displays.

RESULTS

Subjective Analysis

Several factors associated with the design of the fiber-optic sign were subjectively evaluated during this part of the study. These factors were evaluated using a survey provided to the study participants. The factors that were evaluated included the following:

- The effect of luminous output on legibility and target value,
- The type of arrow design, and
- The design of word messages.

Evaluation of the legibility and target value of the sign at different voltage levels illustrated the relationship of these variables to light output. Legibility of the displays was found to decrease as the light output increased. Target value, however, was found to increase with increasing light output. The relationships between legibility, target value, and voltage indicate the existence of an inverse relationship between target value and legibility.

Subjective evaluations were made by professional observers from a distance of 300 ft. The consensus of these observers indicated a preference for the single-row arrow design rather than the bold arrow design. The difference in target value for the two types of arrow shaft designs was not believed to provide a significant advantage for the bold arrow indications over the more legible single-row alternative.

Two different word messages were viewed during this part of the study. Each word message was displayed using two different stroke widths. Different stroke widths were formed using one row (single-stroke) and two rows (double-stroke) of pixels. Double-stroke word messages could not be discerned. Some letters of the single-stroke word messages were partially legible at the 300-ft viewing distance. The observers did not, however, think that the words could be discerned if the effects of dynamic visual acuity were taken into account. The consensus of the group was that the word messages should be enlarged and possibly repositioned so that the legibility of these messages would be improved. The group preferred the single-stroke words to the double-stroke words. The double-stroke words were subsequently eliminated from further observations.

Analysis of Analytic Measurements of Luminous Output

Preliminary analysis of the analytic measurements of the luminous output for each display indicated consistent overestimation of the luminous output at low voltage levels and underestimation of the luminous output at high voltage levels. The reoccurrence of these discrepancies indicated the possible presence of power losses within the system. Consequently, regression analysis was performed using the model shown in the equation below.

$$I = m * V^2 + n * V \qquad (1)$$

where

- I = intensity at the sign face (candelas),
- m = constant for each display that includes (a) conversion between power and intensity and (b) the resistance associated with the display,
- V = voltage measured across the fiber-optic display (volts), and
- n = a constant that corresponds to energy that is either not converted to light or is otherwise lost.

The coefficients of regression were equal to 1 at three significant figures. Visual analysis of the data indicates that this model slightly overestimates the luminous output at lower voltage levels. The magnitude of these discrepancies, however, did not have any practical significance (i.e., this difference in luminous output could not be detected). The discrepancy between the actual and calculated values were attributed to fluctuations in voltage for the electric generator and to the relative magnitude of these losses at low levels of light output. Consequently, the model was believed to provide an acceptable means of estimating the luminous output of each display across the range of voltage settings used in the remainder of the study.

Results of Glance Legibility Studies

Studies required participants to view eight displays at 800, 600, 400, and 200 ft. After viewing these displays, participants were required to draw the display exactly as it had appeared to them. These drawings were evaluated to determine when the participants were able to distinguish the following:

- The general format of the sign,
- The appearance of the word messages, and
- The difference between single-row and bold arrow shafts.

This information was meant to provide an estimate of the overall effectiveness of the sign with respect to glance legibility. Analysis of individual elements also allowed statements to be made concerning the effectiveness of the design of these elements.

Specific settings were utilized for the laboratory components for the purposes of evaluating glance legibility associated with each fiber-optic display. The voltage setting placed across the traffic signals was 50 volts. Glare associated with this setting provided a more comfortable viewing condition without significantly reducing the target value as compared to the 65-volt setting. Light output levels associated with 35- and 50-volt settings were selected for the evaluation of glance legibility for the fiber-optic displays. Two settings were selected so that the significance of the difference in light output at these voltages could be evaluated.

Figure 4 illustrates at what point study participants were able to discern the general format of the sign. This point was determined when word messages and arrows were identified as separate elements. Identification of this point is important since, prior to this point, word messages were typically perceived as a second or third arrow by the majority of the study participants at both voltage levels tested. At the point that participants realized the word message was a separate element, they were also able to recognize that it was not an arrow. Prior to this point the message was typically represented as a blur until it was correctly identified.

Approximately 85 percent of the participants who viewed the displays were able to discern the separation between the word message and the arrow shaft(s) at a distance of 400 ft from the face of the sign for both voltage levels. The use of smaller distance intervals would have provided a more uniform distribution for the observations. Little difference in the ability of the participants to discern this separation, therefore, is believed to have existed at the two different voltage settings that were tested.

Glance legibility distance was also evaluated for the OK and Only word messages. The size and spacing of the word messages corresponds to standard Series E lettering used for reflective signing. The arrows that make up the displays are the primary information to be conveyed to the driver. The purpose of the word messages was to supplement the information provided by the arrows. Figure 5 indicates that approximately 10 percent of the participants were able to discern the message OK farther than 200 ft away. A slightly higher number of the participants was able to read the message Only prior to this distance (see Figure 6). No difference in legibility is believed to have existed at the two different voltages for the OK message. The 35-volt setting appeared to provide slightly more legibility for the Only word message than did the 50-volt setting.

The reason for the difference in legibility between the OK and Only messages is believed to lie in the length of the word and the legibility of the "o" and the "y" letters in Only. The legibility of the "o" in both word messages and the "y" in Only was much better than that of the "k," "n," and "l."

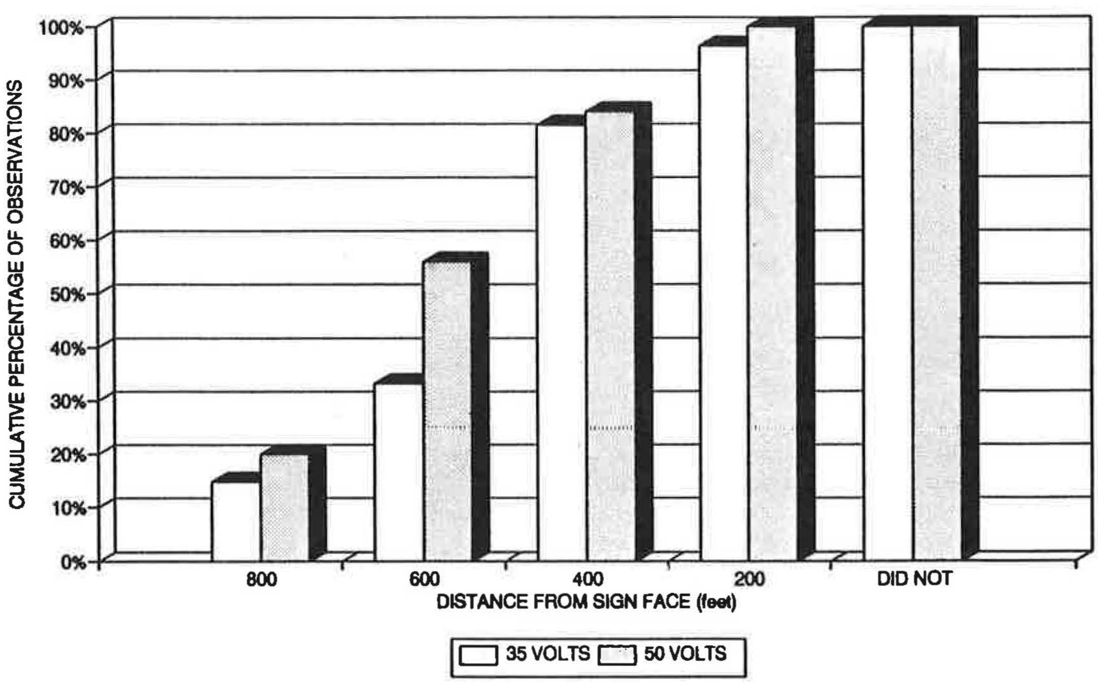

FIGURE 4 Glance legibility for general format of sign.

These letters had better legibility because of their width, outside position in the message, and because of their simple shapes, especially at the 35-volt setting. Once participants were able to distinguish the "o" and "y" in the Only indication, it is believed that they inferred the remaining letters within this message based on their previous experience. Because the OK word message was only two letters long and because of the complexity of the design of the letter "k," participants were believed to have had more difficulty in making these inferences. Several participants identified the word messages as saying "On" and "Off" prior to the distance at which they were actually able to discern this meaning. These

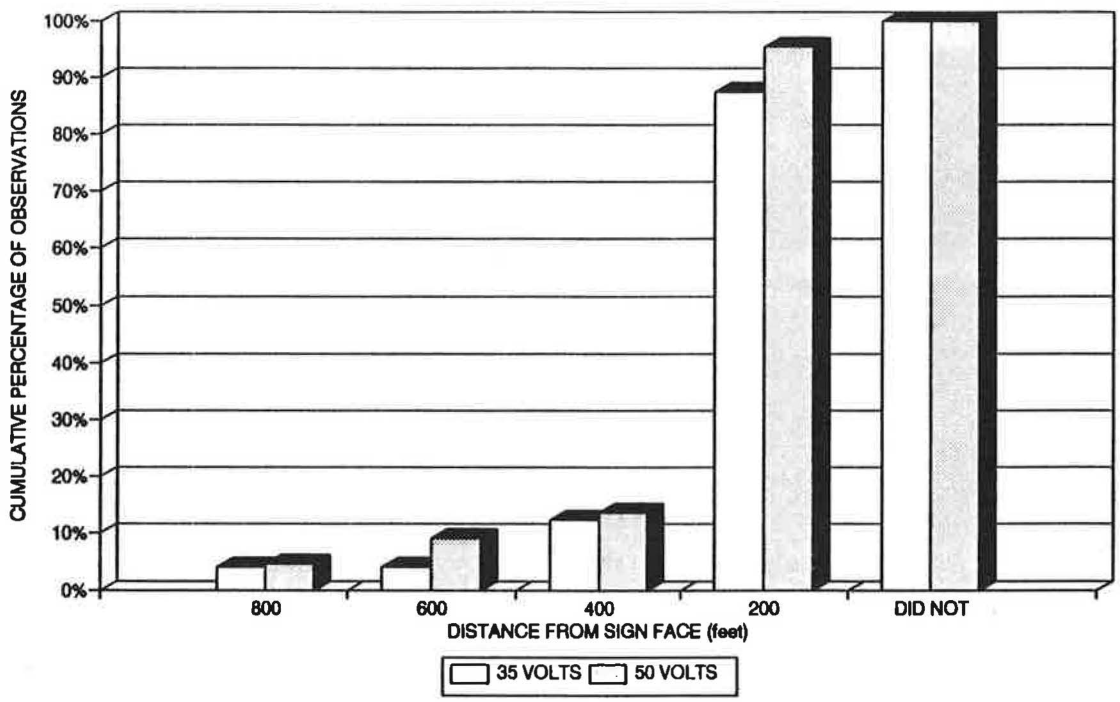

FIGURE 5 Glance legibility distance for OK word message.

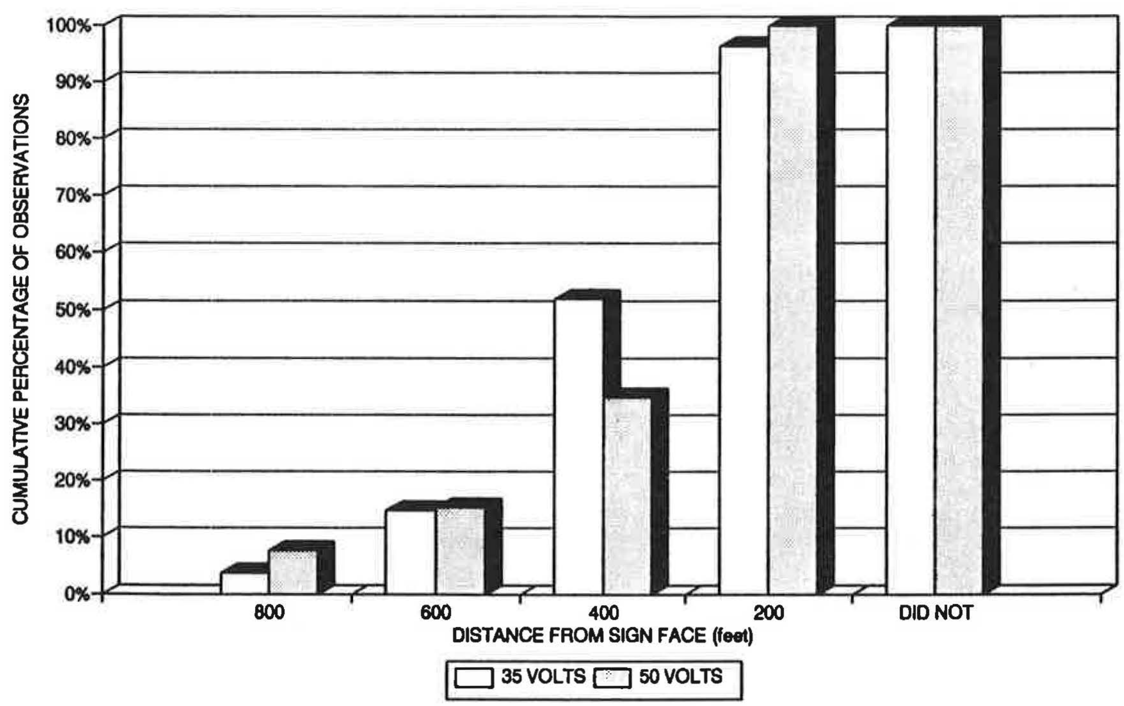

FIGURE 6 Glance legibility distance for Only word message.

findings indicate that the spacing of word messages needed to account for the concentration of light within the message, which is different from that typically used in the design of reflective displays.

The distance at which people were able to detect the difference between single-row and bold arrow shaft design was also analyzed. The ability to discern this difference was originally intended to be used in evaluating the minimum visual acuity of the participants. The ability of the participants to discern this level of detail was not consistent for either voltage. Although no single distance could be identified as the point at which this level of detail became evident, virtually all participants identified a difference in shaft design at or before 200 ft. These results indicate, therefore, that the ability to identify fine details in symbol designs is highly dependent on the capabilities of an individual's eye to deal with the light emitted by the sign.

FINDINGS AND RECOMMENDATIONS

This research has shown that fiber-optic signs are equally or more effective in conveying the messages of lane assignment at intersections when compared on the basis of target value and legibility. Further, the changeable aspects of the fiber-optic sign provide the added dimension of achieving dynamic lane assignment (i.e., altering the lane assignment display to fit the desired operational pattern at a given time).

This research indicated that a relationship exists among light output, target value, and legibility of the fiber-optic sign. Target value was found to increase with light output while legibility decreased. The selection of voltage settings for operating the fiber-optic signs should involve optimizing the relationship between these variables with respect to surrounding or ambient illumination conditions.

For the relatively dark environment of the experimental test facility, it was found that the best viewing conditions for night operation were achieved when the fiber-optic sign was operated between 35 and 65 volts based on a nominal 120-volt supply. Thirty-five volts provided the best legibility, but 65 volts provided the best target value. The principal importance of this finding is that all fiber-optic sign circuits should contain a variable voltage supply so that the voltage level can be adjusted to fit the ambient light conditions.

The placement of the traffic signals relative to the fiber-optic sign was found to be critical to the proper operation of both components. The interaction of the signals and fiber-optic sign was dependent on the operational settings for and the visual separation between each piece of equipment. These devices provide equally important but very different types of information. Operational settings and the amount of visual separation should, therefore, provide adequate target value for both the traffic signals and the fiber-optic signing without hindering the legibility of the fiber-optic sign.

The findings of the glance legibility studies indicate a strong dichotomy in the legibility of the symbols versus the words. In general, the subjects could discern the shape of the arrows at 800 ft, but the word messages remained a blur until they were in the range 200 ft from the sign. For the word messages to have a desirable effect, their legibility needs to be increased. Letter size and spacing are key factors and need to be explored further in conjunction with light output in lieu of stroke width.

These findings raise the question of whether the word messages contribute to or detract from the effectiveness of the sign in transmitting information to the driver sufficiently in advance of the intersection. Past studies have shown that signs that use symbols exclusively are more efficient in providing information to the driver than are signs that mix words and symbols or signs that use words exclusively (*6,7*). This statement is supported by the increased use of symbols in traffic signs over the last 30 years. Consequently, it is believed that the lane-use information presented by the displays would be conveyed in a more safe and effective manner through the use of arrows exclusively.

Research is needed to develop design procedures for fiber-optic displays that relate light output and visual acuity to legibility distance. The difference in legibility between the letters of the word messages examined in this research was attributed to their proximity to other letters in the word and to the complexity of their shape. This indicates that minimum visual acuity of an object is related to the total light output per unit area within the object. The procedures used in this research to identify the point of irradiation for the fiber-optic displays could be used to relate minimum visual acuity, light output per unit area, and the overall dimensions of letters and symbols. This information could be used to develop a standard letter series for use with fiber-optic signs.

The number of rows, either one or two, used to form the arrows does not have any appreciable effect on legibility. Neither does pixel spacing; however, the closer pixel spacing provides an aesthetic quality in smoothness of the symbol. From the standpoint of continuity of service, pixel spacing should be maintained closer than needed and every other pixel should connect to an alternate light source. In this manner, two lamps will be used to form an arrow or line of a symbol. When one of the lamps expires, then, the symbol is maintained even with half the pixels operational.

It is recommended that the fiber-optic lane assignment displays be evaluated under actual traffic operating conditions. A location for such a study has been selected and the signs have been designed and procured. The results of this research were used in developing the design of the new signs. Single-row pixels for the symbols, 0.70-in. spacing of pixels, and 6-in. letters with single-row pixels were specified.

The research to be performed in the field study includes integrating and coordinating the dynamic lane assignment display with the signal timing and phasing plan. Transition patterns from one lane assignment configuration to another constitutes a major concern. These various aspects of the project will be studied at the TTI sign laboratory at the Texas A&M Riverside Campus prior to installation at the study location.

Ultimately, the dynamic lane assignment concept will be integrated with the overall plan for transportation system management.

ACKNOWLEDGMENT

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