Evaluation of Variable Message Signs: Target Value, Legibility, and Viewing Comfort

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Three different technologies for variable message signs were evaluated in terms of target value, legibility distance, and viewing comfort. The technologies evaluated were flip disk, light-emitting diode (LED), and fiber optic. For comparison purposes, conventional overhead guide signs were also evaluated. Twelve signs were evaluated in the field in a human factors study; hired observers measured target value and legibility distance from a moving vehicle on the freeway and subjectively evaluated viewing comfort. Observations were made under four lighting conditions: midday, night, washout, and backlight. For target value, legibility distance, and viewing comfort, fiber-optic signs performed better than LED signs in most conditions. However, both types have acceptable performance overall. The effects of observer age were identified and documented. Both fiber-optic and LED signs are recommended as acceptable for the freeway management system in the Phoenix, Arizona, urban area.

Variable message signs are one way an intelligent vehicle-highway system can communicate real-time traffic and incident information to the driver. Variable message signs are seeing more widespread use, and their technology is changing rapidly. This paper presents results of a study evaluating three different sign technologies. The results will be useful to those who are planning and designing freeway management systems and other applications that use variable message sign technology.

Several technologies have been developed for variable message signs, including shuttered fiber optic, light-emitting diode (LED), electromagnetic flip disk, fiber-optic-enhanced flip disk, lamp matrix, and liquid cell. The first three technologies—shuttered fiber optic (referred to simply as "fiber optic"), LED, and flip disk—were evaluated in this study.

Four fiber-optic signs and two LED signs were installed on the Phoenix urban area freeway system in February 1991 for evaluation. Four flip-disk signs, which were already in use on the freeway system, were also evaluated. Two conventional overhead guide signs were included in the experiment for comparison purposes. Thus, 12 signs were evaluated in the study.

STUDY OBJECTIVE

To be effective, a variable message sign must

- Attract the motorist's attention;
- Be legible and provide sufficient legibility distance for the driver to read the sign at freeway speeds;
- Cause minimal visual discomfort to the driver; and
- Be effective under a variety of lighting conditions (e.g., bright daylight, night, and low sun angles).

The study evaluated each of the three variable message sign technologies for target value, legibility distance, and viewing comfort. This analysis revealed the relative performance of each technology and determined whether each technology performed at an acceptable level in each category.

DESCRIPTION OF SIGNS

Each of the fiber-optic and LED signs had three rows of legend with 18 characters in each row. Each character is formed by an array of 35 pixels 7 high and 5 wide. The flip-disk signs also had three rows of letters. Fiber-optic characters are 16.1 in. high, LED characters are 17.8 in. high, and flip-disk characters are approximately 18 in. high. The LED sign face has a nonglare polycarbonate sheet.

The conventional signs (white letters on a green background) used in the evaluation were interchange sequence signs, with 13.3-in. capital letters and 10.0-in. lowercase letters. Both conventional signs used high-pressure sodium overhead lighting fixtures to illuminate them at night. All signs were mounted overhead. Table 1 gives the numerical designation, type of technology, location, type of structural support, and directional orientation of each sign used in the analysis.

TARGET VALUE

Target value describes how noticeable a sign is or how well it attracts the motorist's attention. The effectiveness of a sign and the length of time the motorist has to read a sign may depend on target value.
TABLE 1  Sign Type, Location, and Description

<table>
<thead>
<tr>
<th>SIGN</th>
<th>TYPE(1)</th>
<th>LOCATION</th>
<th>STRUCTURE</th>
<th>DIRECTION(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMS1</td>
<td>F.O.</td>
<td>I-10 WB at RAY ROAD</td>
<td>OVERPASS</td>
<td>NB</td>
</tr>
<tr>
<td>VMS2</td>
<td>F.O.</td>
<td>I-10 WB at GUADALUPE RD</td>
<td>OVERHEAD</td>
<td>NB</td>
</tr>
<tr>
<td>VMS3</td>
<td>LED</td>
<td>SR360 WB at McClintock</td>
<td>OVERHEAD</td>
<td>WB</td>
</tr>
<tr>
<td>VMS4</td>
<td>F.O.</td>
<td>I-17 SB at CENTRAL AVE</td>
<td>OVERHEAD</td>
<td>EB</td>
</tr>
<tr>
<td>VMS5</td>
<td>FLIP</td>
<td>I-10 WB at 13th STREET</td>
<td>OVERHEAD</td>
<td>WB</td>
</tr>
<tr>
<td>VMS6</td>
<td>FLIP</td>
<td>I-10 WB at DECK TUNNEL</td>
<td>TUNNEL</td>
<td>WB</td>
</tr>
<tr>
<td>VMS7</td>
<td>FLIP</td>
<td>I-10 EB at 21st AVE</td>
<td>OVERHEAD</td>
<td>EB</td>
</tr>
<tr>
<td>VMS8</td>
<td>FLIP</td>
<td>I-10 EB at DECK TUNNEL</td>
<td>TUNNEL</td>
<td>EB</td>
</tr>
<tr>
<td>VMS9</td>
<td>LED</td>
<td>I-10 EB at 10th STREET</td>
<td>OVERHEAD</td>
<td>EB</td>
</tr>
<tr>
<td>VMS10</td>
<td>F.O.</td>
<td>I-10 EB at 19th STREET</td>
<td>OVERHEAD</td>
<td>EB</td>
</tr>
<tr>
<td>CS1(3)</td>
<td>CONV</td>
<td>I-17 SB near 16th ST.</td>
<td>CANTILEVER</td>
<td>EB</td>
</tr>
<tr>
<td>CS2(4)</td>
<td>CONV</td>
<td>I-10 WB near 35th AVE.</td>
<td>OVERPASS</td>
<td>WB</td>
</tr>
</tbody>
</table>

1  Key to Sign Type Definition
   F.O. = Fiberoptic
   LED = Light Emitting Diode
   FLIP = Flip-Disk
   CONV = Conventional

2  The directional orientation of the approach roadway at the sign location.

3  Conventional Sign 1 is an interchange sequence sign reading,
   16th St                        1/4
   Sky Harbor Airport            1 1/4

4  Conventional Sign 2 is an interchange sequence sign reading,
   35th Ave                      1/4
   43rd Ave                      1 1/4
   51st Ave                      2 1/4

Previous studies of target value have been done in highly controlled laboratory settings. In this study a very simple measure of target value was used. As observers approached a sign, they were asked to look for it. The distance to the sign from the first point it was noticed is the target value.

LEGIBILITY DISTANCE

Legibility distance is the distance from which a driver is able to read a sign. Sign legends must be large enough that the driver has enough time to read the message and respond safely. For overhead guide signs on freeways, standard alphabets, stroke widths, and letter sizes have been adopted to assure adequate legibility. For nighttime legibility, standard levels of illumination have also been adopted.

No standards have been set for variable message signs to guarantee adequate legibility. The formation of letters by a matrix of lamps, disks, or light sources is very different from a standard alphabet on a conventional sign. Therefore, it is expected that the legibility distance is quite different from the 50 ft of legibility distance for each inch of letter height provided by standard alphabets.

VIEWING COMFORT

Viewing comfort describes any discomfort caused by glare or harshness of light. In a dark driving environment, a brightly lit sign is sometimes so bright that it causes discomfort for a driver because the eye is slow to adapt to a bright light source in dark surroundings. Similarly, after a driver passes the sign, the eye may adapt slowly to the dark surroundings, causing discomfort due to the inability to see well. These effects are more pronounced in locations where ambient light levels are very low (rural and semirural areas) and less pronounced where ambient light levels are medium to high (such as urban freeways). Older drivers are more sensitive to, and take longer to recover from, glare. The large illuminated area on a variable message sign may cause glare or discomfort problems. Some variable message signs have a light output adjustment feature that can reduce this potential problem.

OBSERVER GROUP

Target value, legibility distance, and viewing comfort were evaluated by 62 hired observers. Each observer was seated as a passenger in a moving automobile, so that signs could be viewed under dynamic conditions.

Of the 62 observers, 31 were between the ages of 18 and 31 (18 men, 13 women; average age of 21), and 31 were between 60 and 79 (16 men, 15 women; average age of 66). Past research has confirmed the substantial effects of age on visual performance. In technical terms, these effects include a decrease in amplitude of accommodation, reduction in pupil size, decrease in rate and amount of dark and light adaptation, loss of transmission of light due to increased opacity of the
eye media, reduction in sensitivity (especially at low luminance levels), and degenerative changes in the various parts of the visual system, including the retina. Within the highway and traffic engineering community there is increasing concern about whether our roads and traffic control devices are designed to meet the needs of older drivers. For this reason, much of the study was dedicated to the evaluation of signs by older drivers.

Apart from targeting these specific age groups, no effort was made to recruit drivers with any special characteristics. However, all observers were required to be licensed drivers and to pass a visual acuity test for 20/40 vision.

STUDY DESIGN

Studies were conducted four times a day between February 25 and March 30, 1991. Signs were evaluated under four lighting conditions to determine the effects of the position of the sun with respect to the signs. Observations were taken immediately after sunrise, during midday, just before sunset, and at night. Nighttime observations began about an hour after sunset, and midday observations began at about 10:30 a.m. The early morning and late afternoon studies allowed for the analysis of the backlight and washout conditions on the eight variable message and two conventional signs on east-west roadways.

Backlight describes conditions in which the sun is directly behind the sign (in front of the driver). This condition causes a strong silhouette that makes the sign more difficult to read. Washout describes conditions in which the sun is directly behind the driver, just above the horizon, and shines directly on the face of the sign, causing a glare or reflection on the sign face.

Washout and backlight represent the most severe tests of legibility and viewing comfort. Washout and backlight effects depend on the position of the sun with respect to the sign and the observer. The observation dates used in this study (from February 25 to March 30) were just before and after the vernal equinox (March 21). At the equinox the sun rises directly in the east and sets directly in the west. For signs on east-west roadways, the observation dates happened to provide a more rigorous evaluation of washout and backlight than would have been possible at other times of the year (when the sun is rising and setting farther to either the north or the south).

One group of 31 observers observed signs in the early morning and late afternoon (washout and backlight conditions), and a second group of 31 observers observed signs during the daytime and nighttime. Thus, each of the 62 individuals observed each sign under two lighting conditions.

The study team recognized that repeated use of the same observer had some disadvantages. Target value measurement is less reliable for a repeat observer because the observer becomes familiar with the sign locations.

Test messages were placed on the signs to evaluate the legibility distance. The first line of the test message read "SYSTEM TEST," a message designed to maintain credibility with the public during the month-long test. The second line contained a randomly generated string of six letters, similar to an eye chart, with a space between each letter. Random letters were used to provide a more rigorous test of legibility.

Letter combinations were changed after the midday evaluations so that observers did not see any combination more than once during the day. Twenty test messages were rotated among the 10 variable message signs twice each day, to eliminate any bias caused by the possibility that some combinations may have been easier to read than others.

This study was conducted under field conditions, not in a controlled laboratory environment. It was possible to control many variables and confounding factors, but not all of them. Those that could not be controlled included weather conditions, such as rain, and the contrast ratios on the signs. Uncontrolled contrast ratios may have influenced the measurements of target value and legibility distance.

NEEDED LEGIBILITY DISTANCE AND TARGET VALUE

An important part of the study determined the amount of legibility and target value that is necessary to provide adequate viewing of the signs.

**Legibility Distance**

A variable message sign must be legible from some distance so that the driver, at a typical travel speed, has enough time to read the message. On the basis of a review of previous research, a minimum exposure time of 6.0 sec on a three-line sign is recommended for unfamiliar drivers (1). This recommendation is based on an 85th-percentile reading time. Assuming some vehicles travel 60 mph (88 ft/sec), 6.0 sec is equal to 528 ft.

As a driver approaches an overhead sign, sign readability becomes restricted by the vertical cutoff angle of the windshield. This means that the sign will become hidden from the motorist's view as the vehicle nears the sign.

Messer and McNees discuss this aspect and cite other publications that recommend a vertical cutoff angle of 7.5 degrees (2). For the existing variable message signs, the average height to the center of the sign is 23.0 ft. Average driver eye height can be assumed to be 3.5 ft. The vertical displacement of 19.5 ft combined with the 7.5-degree cutoff angle means that the sign becomes obscured by the vehicle roof at a distance of 150 ft.

Combining a minimum of 528 ft for reading distance with 150 ft because of vehicle cutoff results in a distance of 678 ft. To be acceptable, a sign with a three-line message should be legible from a distance of no less than 678 ft.

**Target Value**

Although there is no commonly accepted rule of thumb for how much target value is needed, it is generally agreed that more is better. For this project a conservative value of two times the legibility distance was selected. This means that once a driver notices a sign, he or she can devote time to other driving tasks before devoting time to reading the sign. Thus, 1,356 ft is the desirable (acceptable) target value for variable message signs.
The researchers selected a discomfort rating less than or equal to 1.0 as acceptable (equivalent to little discomfort).

**STUDY PROCEDURE**

A 20-min orientation preceded the field test. The purpose and importance of the study were emphasized. The observers were taught the meanings of target value, legibility distance, and viewing comfort and were asked to explain each of these factors to the experimenter to demonstrate that they had a satisfactory understanding of the meanings. They were shown photographs of various types of freeway signs, including variable message signs, so that they would know what to look for on the freeway.

A visual acuity test was given to each observer, in which they were to read three lines of an eye chart from a distance of 20 ft to test for 20/30, 20/20, and 20/15 vision. If these tests were failed, they were tested for 20/40 vision, which is the minimum allowable visual acuity level to qualify for a driver's license. Observers were instructed to wear contact lenses or glasses if so required by their driver's licenses.

Of the 31 observers in the younger group, 16 wore glasses and 5 wore contact lenses. Of the 31 observers in the older group, 28 wore glasses and none wore contact lenses. The average corrected vision of the younger observers was 20/17 (21 observers with 20/15 vision, 9 observers with 20/20, and 1 observer with 20/30). The average corrected vision of the older observers was 20/22 (14 observers with 20/15 vision, 8 observers with 20/20, 4 observers with 20/30, and 5 observers with 20/40).

Once the observers demonstrated an understanding of the parameters involved in the project, the field test began. The test involved a 67-mi drive on the Phoenix freeway system. Observers were seated in the front passenger seat of an automobile. One experimenter drove the vehicle, and a second was seated in the back seat to record data. If safety permitted, the vehicle was driven at a constant speed of 55 mph.

Two practice signs (conventional overhead guide signs) were analyzed by each observer before testing to ensure that they understood the parameters that they were to evaluate and the equipment used to measure distances.

Target value and legibility distances were measured with a distance measuring instrument (DMI) made by Nu-metrics Instrumentation, Inc. The DMI was wired to a transmission sensor. After installation, the DMI was calibrated on a 1,000-ft test section of road.

The DMI was actuated when the observer first noticed a sign, when the observer could read the legend on the sign, and when the vehicle passed under the sign. Values for target value and legibility distance were calculated from the measured distances.

**Target Value**

At distances of 1 to 2 mi before reaching each sign, observers were asked to start looking for a particular sign. The experimenters' instructions were similar to the following examples: “Begin looking for the next variable message sign”; “Evaluate the first green overhead sign beyond the next overpass.” Observers actuated the DMI when they first saw the sign.

**Legibility Distance**

Observers were asked to actuate the DMI when they were sure they could distinguish all six letters in the test message and to read the message aloud to the experimenter immediately to verify that they could read the message.

**Viewing Comfort**

Observers were then asked to concentrate on the viewing comfort of each sign. During the orientation observers were informed that discomfort might be caused by any of the following factors:

1. Reflection of sunlight off of the sign (glare),
2. Reflection of headlights off of the sign (glare),
3. A sign that is too bright in comparison with its surroundings, and
4. The position of the sun behind the sign.

After passing the sign, they were asked to rate the discomfort of the sign as no discomfort, little discomfort, moderate discomfort, or high discomfort. Observers were asked to determine for themselves what each level of discomfort meant but to use a consistent scale in rating the 12 signs.

**FINDINGS AND ANALYSIS**

Table 2 presents a detailed tabulation of target value, legibility distance, and viewing comfort; findings related to this table are described in the following paragraphs. Table 2 uses bold type to indicate technologies with acceptable target value, legibility distance, and viewing comfort. Use of the word “significant” in the following paragraphs means statistically significant with 95 percent confidence.

**Target Value**

The analysis of the target value of each technology was difficult because potential target values for some signs were constrained by roadway geometry. In some cases, the location at which an observer noticed the sign was influenced by horizontal or vertical curvature or overpasses obstructing the line of sight as much as it was influenced by the sign's attracting the observer's attention. The maximum possible target value (longest possible line of sight) for each sign was measured by the experimenters; it ranged from 1,567 to 9,221 ft.

To compare adequately the target values of the different technologies, four signs (one of each type) were selected for
TABLE 2  Comparison of Target Value, Legibility Distance, and Viewing Comfort for Each Technology

<table>
<thead>
<tr>
<th>TARGET VALUE (feet)</th>
<th>FIBEROPTIC</th>
<th>LED</th>
<th>FLIP-DISK</th>
<th>CONVENTIONAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Possible</td>
<td>3286</td>
<td>2886</td>
<td>2811</td>
<td>3200</td>
</tr>
</tbody>
</table>

Observed Values

<table>
<thead>
<tr>
<th></th>
<th>FIBEROPTIC</th>
<th>LED</th>
<th>FLIP-DISK</th>
<th>CONVENTIONAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid-day Y(1)</td>
<td>3087</td>
<td>2634</td>
<td>2544</td>
<td>2229</td>
</tr>
<tr>
<td>O(2)</td>
<td>2841</td>
<td>2499</td>
<td>2591</td>
<td>1713</td>
</tr>
<tr>
<td>A(3)</td>
<td>2960</td>
<td>2562</td>
<td>2568</td>
<td>1962</td>
</tr>
<tr>
<td>Night Y</td>
<td>2958</td>
<td>2514</td>
<td>884</td>
<td>2078</td>
</tr>
<tr>
<td>O</td>
<td>2701</td>
<td>2004</td>
<td>898</td>
<td>1600</td>
</tr>
<tr>
<td>A</td>
<td>2830</td>
<td>2249</td>
<td>891</td>
<td>1839</td>
</tr>
<tr>
<td>Backlight Y</td>
<td>2467 *</td>
<td>1659*</td>
<td>1657</td>
<td>1285 *</td>
</tr>
<tr>
<td>O</td>
<td>1080 *</td>
<td>1170**</td>
<td>1270</td>
<td>928 *</td>
</tr>
<tr>
<td>A</td>
<td>1873</td>
<td>1433</td>
<td>1442</td>
<td>1097</td>
</tr>
<tr>
<td>Washout Y</td>
<td>2994 *</td>
<td>2331*</td>
<td>2317</td>
<td>2003 *</td>
</tr>
<tr>
<td>O</td>
<td>2350 *</td>
<td>1950*</td>
<td>1067</td>
<td>1436 *</td>
</tr>
<tr>
<td>A</td>
<td>2708</td>
<td>2162</td>
<td>1692</td>
<td>1736</td>
</tr>
</tbody>
</table>

LEGIBILITY DISTANCE (feet)

<table>
<thead>
<tr>
<th></th>
<th>FIBEROPTIC</th>
<th>LED</th>
<th>FLIP-DISK</th>
<th>CONVENTIONAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid-day Y</td>
<td>1006</td>
<td>812</td>
<td>731</td>
<td>739</td>
</tr>
<tr>
<td>O</td>
<td>959</td>
<td>681</td>
<td>667</td>
<td>667</td>
</tr>
<tr>
<td>A</td>
<td>983</td>
<td>743</td>
<td>698</td>
<td>695</td>
</tr>
<tr>
<td>Night Y</td>
<td>687</td>
<td>794</td>
<td>363</td>
<td>363</td>
</tr>
<tr>
<td>O</td>
<td>667</td>
<td>602</td>
<td>348</td>
<td>348</td>
</tr>
<tr>
<td>A</td>
<td>678</td>
<td>694</td>
<td>355</td>
<td>355</td>
</tr>
<tr>
<td>Backlight Y</td>
<td>782 *</td>
<td>616*</td>
<td>263</td>
<td>263</td>
</tr>
<tr>
<td>O</td>
<td>535 *</td>
<td>337**</td>
<td>177</td>
<td>177</td>
</tr>
<tr>
<td>A</td>
<td>659</td>
<td>502</td>
<td>219</td>
<td>219</td>
</tr>
<tr>
<td>Washout Y</td>
<td>882 *</td>
<td>554*</td>
<td>472</td>
<td>472</td>
</tr>
<tr>
<td>O</td>
<td>817 *</td>
<td>400*</td>
<td>363</td>
<td>363</td>
</tr>
<tr>
<td>A</td>
<td>853</td>
<td>487</td>
<td>420</td>
<td>420</td>
</tr>
</tbody>
</table>

VIEWING COMFORT (discomfort rating, 3 = high discomfort)

<table>
<thead>
<tr>
<th></th>
<th>FIBEROPTIC</th>
<th>LED</th>
<th>FLIP-DISK</th>
<th>CONVENTIONAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid-day Y</td>
<td>0.5</td>
<td>0.6</td>
<td>0.9</td>
<td>0.1</td>
</tr>
<tr>
<td>O</td>
<td>0.5</td>
<td>1.3</td>
<td>1.8</td>
<td>0.7</td>
</tr>
<tr>
<td>A</td>
<td>0.5</td>
<td>1.0</td>
<td>1.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Night Y</td>
<td>0.6</td>
<td>0.4</td>
<td>2.2</td>
<td>0.1</td>
</tr>
<tr>
<td>O</td>
<td>0.5</td>
<td>0.8</td>
<td>2.6</td>
<td>0.4</td>
</tr>
<tr>
<td>A</td>
<td>0.5</td>
<td>0.6</td>
<td>2.4</td>
<td>0.3</td>
</tr>
<tr>
<td>Backlight Y</td>
<td>1.7 *</td>
<td>1.8*</td>
<td>2.5</td>
<td>1.7 *</td>
</tr>
<tr>
<td>O</td>
<td>2.0 *</td>
<td>1.6**</td>
<td>2.6</td>
<td>1.7 *</td>
</tr>
<tr>
<td>A</td>
<td>1.9</td>
<td>1.7</td>
<td>2.5</td>
<td>1.7</td>
</tr>
<tr>
<td>Washout Y</td>
<td>0.5 *</td>
<td>1.8 *</td>
<td>2.0</td>
<td>0.3 *</td>
</tr>
<tr>
<td>O</td>
<td>0.5 *</td>
<td>1.7 *</td>
<td>1.9</td>
<td>0.6 *</td>
</tr>
<tr>
<td>A</td>
<td>0.5</td>
<td>1.8</td>
<td>1.9</td>
<td>0.5</td>
</tr>
</tbody>
</table>

(1) Y = Younger observers
(2) O = Older observers
(3) A = All observers
* Sample size < 26
** Sample size < 13

The values shown are the mean in each category.

Acceptable values are shown in bold type. Unacceptable values are shown in light type.
comparison. The four signs had similar maximum possible target values, as follows:

<table>
<thead>
<tr>
<th>Sign</th>
<th>Type</th>
<th>Maximum Possible Target Value (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMS5</td>
<td>Flip disk</td>
<td>2,811</td>
</tr>
<tr>
<td>VMS9</td>
<td>LED</td>
<td>2,886</td>
</tr>
<tr>
<td>CS2</td>
<td>Conventional</td>
<td>3,200</td>
</tr>
<tr>
<td>VMS10</td>
<td>Fiber optic</td>
<td>3,286</td>
</tr>
</tbody>
</table>

Observations from these four signs were used to compare the target values of the four technologies. The mean target values for each of these four signs (as noted by observers) are compared to each other and to the desirable target value of 1,356 ft. Target values are compared for the four lighting conditions and for both age groups. All data are shown in Table 2. Care must be used in interpreting the data in Table 2 and in the following paragraphs. It is emphasized that there is some difference in the maximum possible target value of the four signs.

**Midday Target Values**

All midday observations, except for those taken while it was raining, were considered in this analysis. For the fiber-optic, LED, and flip-disk signs, there are small differences in the mean target values as a function of either age or technology. The mean target value for the conventional sign is substantially lower.

All four types of sign had target values that exceeded the desirable target value of 1,356 ft. Target values for fiber-optic and LED signs ranged from 2,499 ft (LED, older observers) to 3,087 ft (fiber optic, younger observers).

**Nighttime Target Values**

The analysis of nighttime target values includes all nighttime observations except for those taken while it was raining. The fiber-optic sign had the highest mean nighttime target value: 2,830 ft. The LED sign had a mean nighttime target value of 2,249 ft; it showed a larger difference between older and younger observers. The mean target value for the conventional sign was 1,839 ft.

The most striking difference, however, was with the flip-disk sign, which had a mean nighttime target value of only 891 ft.

The fiber-optic, LED, and conventional signs all had target values that exceeded the desirable target value of 1,356 ft. Flip-disk signs fell short; 898 ft for older observers and 884 ft for younger observers. The target values for fiber-optic and LED signs exceeded 2,000 ft.

**Backlight Target Values**

This analysis includes all observations taken while the sun was shining behind the sign. Some of the backlight analysis is based on morning observations and some is based on afternoon observations, depending on the orientation of the signs.

The fiber-optic sign had the highest average target value: 1,873 ft. The LED and the flip-disk signs had similar target values of 1,433 and 1,442 ft, respectively. The mean target value for the conventional sign was 1,097 ft.

For the backlight condition, there is a greater difference in target values for older and younger observers than was noted during the daytime and nighttime observations. This difference is most notable with the fiber-optic signs, for which the mean target values were 2,467 ft for the younger observers and 1,080 ft for the older observers (who often commented about discomfort from sun in their eyes).

None of the four types of signs met the desirable target value of 1,356 ft for older observers. The conventional sign also fell short for younger observers. The other three types of sign exceeded 1,356 ft for younger observers.

**Washout Target Values**

The washout analysis includes all observations taken while the sun was shining in front of the sign.

The fiber-optic sign had the highest target value for this condition, with an average of 2,708 ft. LED signs averaged 2,162 ft and flip-disk signs 1,692 ft.

There is a substantial difference in target values between the older and younger observers. The difference is most notable for the flip-disk signs, for which the mean target values were 2,317 ft for the younger observers and only 1,067 ft for the older observers. The older observers often commented that there was too much glare off of the flip-disk signs, making them difficult to recognize.

Except for the flip-disk sign when observed by the older group, all signs exceeded the desirable target value of 1,356 ft. The target values for fiber-optic and LED signs exceeded 1,950 ft.

**Legibility Distance**

**All Observations**

Average legibility distances for all variable message signs were as follows:

- Younger observers—687 ft
- Older observers—579 ft
- All observers—634 ft

The legibility distance of the variable message and conventional signs was not compared.

Mean legibility distance for each sign is illustrated in Figure 1. Figure 2 shows mean legibility distance for each technology on the basis of all observations of the signs (the numbers above the bars are sample sizes).

The fiber-optic signs had the greatest overall legibility distance throughout the study, followed by the LED and flip-disk signs. The overall legibility distance for the flip-disk signs was significantly lower than it was for the other three technologies; it was inadequate according to the 678-ft acceptable minimum.

The younger observers consistently had higher legibility distances than the older observers. Whereas the difference between age groups was relatively small for the fiber-optic
FIGURE 1  Mean legibility distance by sign, all observations.

FIGURE 2  Mean legibility distance by technology, all observations.
signs, Figure 2 shows that for the LED and flip-disk signs, legibility distance was approximately 100 to 175 ft better for the younger observers.

Figure 2 shows the sample mean for each technology. To demonstrate significant differences in legibility distances, a 95 percent confidence interval (lower and upper limits) can be used. This means that there is a 95 percent probability that the population mean (all drivers with the same characteristics as the observers) falls within the given interval above or below the sample mean.

The lower 95 percent confidence interval for the mean legibility distance of the fiber-optic signs was 798 ft, and the upper 95 percent confidence interval for the mean legibility distance of the LED signs was 750 ft. Thus, legibility distance for the fiber-optic signs was significantly higher than for LED signs. The flip-disk signs had by far the poorest legibility distance.

Midday Legibility Distance

Figure 3 illustrates the average midday legibility distances for the three variable message sign technologies and for both age groups (the numbers above the bars are sample sizes). In the daytime, older observers had slightly lower legibility distances than the younger observers. This difference was largest with the LED signs.

Figure 3 shows the mean daytime legibility distances for each technology. On the basis of confidence intervals, the fiber-optic technology had a significantly higher legibility distance than the LED or flip-disk signs. All sign types met the acceptable legibility distance of 678 ft except for flip-disk signs for older observers.

Nighttime Legibility Distance

The nighttime analysis includes all observations taken at night, except for those taken while it was raining. The LED signs had the highest overall nighttime legibility distance of the variable message signs. The average distance was just slightly higher than it was for the fiber-optic signs. The older observers had greater legibility distances for the fiber-optic signs than for the LED signs; the younger observers had greater legibility distances for the LED signs than for the fiber-optic signs.

Both observer groups had a low legibility distance for the flip-disk signs. There was little difference in legibility distances among age groups for the fiber-optic and the flip-disk signs, but there was a substantial difference among age groups for the LED signs—probably because the older observers more often experienced glare problems with the LED signs at night but never mentioned glare problems with the fiber-optic signs.

The fiber-optic and conventional signs were not significantly different at night, but the flip-disk had much poorer legibility at night.

The flip-disk signs fell far short of the 678-ft acceptable legibility distance. LED signs and fiber-optic signs for older drivers also fell short.

![Figure 3 Mean legibility distance by technology, daytime observations.](image-url)
Backlight Legibility Distance

The flip-disk signs had significantly lower legibility distances in backlight conditions than the other two sign types. There was no statistically significant difference between the fiber-optic and LED technologies.

All three sign types failed to provide an acceptable legibility distance of 678 ft, although the fiber-optic signs exceeded this level for the younger observers.

Washout Legibility Distance

Fiber-optic signs had the highest legibility distance under washout, followed by LED and flip-disk signs.

Legibility distances for the older observers were lower than they were for the younger observers. Older observers appeared to have a greater problem with the reflection of the sun off of the sign than the younger observers did. The legibility distance of the fiber-optic signs was probably superior to the LED and flip-disk signs under this condition because very little glare reflected off of the fiber-optic signs; observers often mentioned glare problems associated with the LED and flip-disk signs.

Of the three technologies, the fiber-optic signs performed significantly better than the LED and flip-disk signs. Fiber-optic signs (853 ft) exceeded the acceptable legibility distance. LED (487 ft) and flip-disk signs (420 ft) did not.

Legibility Distance in Rain

Rain occurred during only 11 out of 124 observation studies (8 daytime studies and 3 nighttime studies). In most cases, legibility distance was less under rainy conditions.

Viewing Comfort

For analysis, discomfort ratings were converted to a numerical scale (no discomfort = 0; little discomfort = 1; moderate discomfort = 2; high discomfort = 3).

Midday Discomfort Rating

Table 2 shows that the conventional signs had the lowest discomfort rating. The fiber-optic signs had the lowest discomfort rating of all of the variable message signs, followed by the LED and flip-disk signs. An analysis of observers' comments indicates that the flip-disk signs were uncomfortable because the letters were not bright enough. Observers often mentioned that the letters were too dim and did not stand out against the sign background. The only repetitive comment about the discomfort of the LED signs was that observers thought that the letters were not bright enough on sunny days.

There was little or no difference in discomfort rating for the older and younger observers for the fiber-optic signs, but there was a large difference between the two age groups for the LED and flip-disk signs.

Nighttime Discomfort Rating

Table 2 reveals very low discomfort ratings for the fiber-optic, LED, and conventional signs and very high discomfort ratings for the flip-disk signs. The only major difference between age groups was that the discomfort rating for LED signs was about twice as high for the older observers as it was for the younger observers. The older observers often stated that there was too much glare off of the LED signs.

Nearly all of the nighttime observers had difficulty with the flip-disk signs and associated a great deal of discomfort with them.

Backlight Discomfort Rating

Table 2 reveals that the discomfort ratings for the fiber-optic, LED, and conventional signs were quite similar in backlight conditions with very little difference for the two age groups. The discomfort rating for the flip-disk signs was much higher than for the other signs.

With the sun shining directly in their eyes, observers often experienced great difficulty in reading the signs. Thus, discomfort ratings for the backlight condition are much higher than for the other lighting conditions.

Washout Discomfort Rating

The fiber-optic and conventional signs had low discomfort ratings under washout conditions, whereas the LED and flip-disk signs had high discomfort ratings. There was little difference in the discomfort ratings of the two age groups.

The most common contributor to the discomfort during washout was the reflection of the sun off of the sign and into a driver's eyes. This was most prevalent with the LED and flip-disk signs because the sun tended to reflect off of the transparent cover on the front of the sign. The fiber-optic sign produced little or no glare: observers never mentioned glare as a problem in viewing the fiber-optic signs.

CONCLUSIONS

From the findings and analysis, the following conclusions are made.

Target Value

1. During the daytime, there are small differences in target values between the three types of variable message signs. All three technologies have acceptable performance.
2. During the daytime, all three types of variable message signs have higher target values than conventional freeway guide signs.
3. At night, fiber-optic and LED signs have higher target values than either flip-disk or conventional signs.
4. For all four lighting conditions, fiber-optic and LED signs have higher target values than conventional freeway guide signs.
5. The flip-disk signs have very poor nighttime target values.
6. In comparison to daytime conditions, target values decrease for nighttime, backlight, and washout conditions.
7. Younger drivers generally have higher target values than older drivers. In some cases there is a very large difference between younger and older drivers.
8. Bright sunlight and glare have larger negative effects on older drivers than on younger drivers.

Legibility Distance

1. Fiber-optic signs have significantly higher average legibility distances than the LED or flip-disk signs during midday and washout conditions. During backlight conditions, the fiber-optic and LED signs have significantly higher average legibility distances than flip-disk signs.
2. At night, fiber-optic and LED signs have similar legibility distances. However, flip-disk signs have significantly lower legibility distances at night.
3. A comparison of legibility distances for variable message sign technologies versus an acceptable legibility distance of 678 ft shows the following:
   - Flip-disk signs provide acceptable legibility distance only in the daytime. Therefore, they are unacceptable.
   - All three sign types are deficient for the backlight condition.
   - Fiber-optic signs provide acceptable legibility distance overall.
   - Fiber-optic signs perform slightly better than LED signs overall.
4. Older observers generally have lower legibility distances than younger drivers.

Viewing Comfort

1. Flip-disk signs have the highest discomfort rating of all four sign types analyzed; this was consistently true for all four lighting conditions. Flip-disk signs have an unacceptable discomfort rating.
2. Glare and strong sunlight are major contributors to viewing discomfort.
3. Fiber-optic signs have the lowest discomfort rating of all three types of variable message sign during the midday and washout conditions.
4. For nighttime and backlight conditions, fiber-optic signs are about equal to LED signs; both are better than flip-disk signs.

5. Fiber-optic and LED signs have an overall acceptable discomfort rating.

Because this study was conducted under field conditions and not in a controlled laboratory environment, uncontrolled contrast ratios may have influenced the measurements of target value and legibility distance reported in this section.

The observer studies were successful in analyzing the various human factors associated with the use of the signs. Both fiber-optic and LED signs compare reasonably well with conventional signs. Flip-disk signs do not perform as well; they have unacceptable performance in most categories.

In terms of absolute performance, the fiber-optic technology performed better than the LED technology for target value, legibility distance, and viewing comfort. Both technologies had acceptable performance overall and in most categories. On this basis it is recommended that both fiber-optic and LED signs are acceptable for the freeway management system in the Phoenix, Arizona, urban area.

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REFERENCES


The contents of this paper reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of Kimley-Horn and Associates, the Arizona Department of Transportation, or FHWA. This paper does not constitute a standard, specification, or regulation.

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