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**GUIDELINES ON THE USE AND OPERATION
OF CHANGEABLE MESSAGE SIGNS**

by

Conrad L. Dudek

Research Report 1232-9
Research Study 2-18-90/4-1232

Sponsored by

Texas Department of Transportation
In cooperation with
U.S. Department of Transportation, Federal Highway Administration

TEXAS TRANSPORTATION INSTITUTE
Texas A&M University System
College Station, TX 77843

June 1992

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|--------|---------------|-------------|---------|--------|
|--------|---------------|-------------|---------|--------|

LENGTH

| | | | | |
|----|--------|-------|-------------|----|
| in | inches | 25.4 | millimetres | mm |
| ft | feet | 0.305 | metres | m |
| yd | yards | 0.914 | metres | m |
| mi | miles | 1.61 | kilometres | km |

AREA

| | | | | |
|-----------------|---------------|-------|---------------------|-----------------|
| in ² | square inches | 645.2 | millimetres squared | mm ² |
| ft ² | square feet | 0.093 | metres squared | m ² |
| yd ² | square yards | 0.836 | metres squared | m ² |
| ac | acres | 0.405 | hectares | ha |
| mi ² | square miles | 2.59 | kilometres squared | km ² |

VOLUME

| | | | | |
|-----------------|--------------|-------|--------------|----------------|
| fl oz | fluid ounces | 29.57 | millilitres | mL |
| gal | gallons | 3.785 | litres | L |
| ft ³ | cubic feet | 0.028 | metres cubed | m ³ |
| yd ³ | cubic yards | 0.765 | metres cubed | m ³ |

NOTE: Volumes greater than 1000 L shall be shown in m³.

MASS

| | | | | |
|----|----------------------|-------|-----------|----|
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams | Mg |

TEMPERATURE (exact)

| | | | | |
|----|------------------------|-------------|---------------------|----|
| °F | Fahrenheit temperature | $5(F-32)/9$ | Celcius temperature | °C |
|----|------------------------|-------------|---------------------|----|

APPROXIMATE CONVERSIONS FROM SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|--------|---------------|-------------|---------|--------|
|--------|---------------|-------------|---------|--------|

LENGTH

| | | | | |
|----|-------------|-------|--------|----|
| mm | millimetres | 0.039 | inches | in |
| m | metres | 3.28 | feet | ft |
| m | metres | 1.09 | yards | yd |
| km | kilometres | 0.621 | miles | mi |

AREA

| | | | | |
|-----------------|---------------------|--------|---------------|-----------------|
| mm ² | millimetres squared | 0.0016 | square inches | in ² |
| m ² | metres squared | 10.764 | square feet | ft ² |
| ha | hectares | 2.47 | acres | ac |
| km ² | kilometres squared | 0.386 | square miles | mi ² |

VOLUME

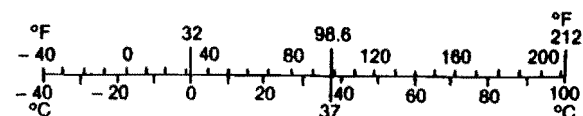
| | | | | |
|----------------|--------------|--------|--------------|-----------------|
| mL | millilitres | 0.034 | fluid ounces | fl oz |
| L | litres | 0.264 | gallons | gal |
| m ³ | metres cubed | 35.315 | cubic feet | ft ³ |
| m ³ | metres cubed | 1.308 | cubic yards | yd ³ |

MASS

| | | | | |
|----|-----------|-------|----------------------|----|
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.205 | pounds | lb |
| Mg | megagrams | 1.102 | short tons (2000 lb) | T |

TEMPERATURE (exact)

| | | | | |
|----|---------------------|-------------|------------------------|----|
| °C | Celcius temperature | $1.8C + 32$ | Fahrenheit temperature | °F |
|----|---------------------|-------------|------------------------|----|



* SI is the symbol for the International System of Measurement

(Revised April 1989)

SUMMARY

This report is intended to be a primer on the characteristics that affect the design, use and operations of changeable message signs (CMSs), and to provide guidance on the selection of the appropriate type of CMS display. Guidelines on the selection and design of CMS messages are presented in a companion Report No. FHWA/TX-92/1232-10 entitled, "Guidelines on the Selection and Design of Messages for Changeable Message Signs".

This report is an update and consolidation of the following reports:

1. C.L. Dudek and R.D. Huchingson. Manual on Real-Time Motorist Information Displays. Report FHWA-IP-86-16. August 1986.
2. C.L. Dudek. Guidelines on the Use of Changeable Message Signs. Report FHWA-TS-90-043. May 1991.
3. C.L. Dudek. Portable Changeable Message Signs at Work Zones. Report FHWA/TX-85/07+292-4. July 1984.

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1. INTRODUCTION

Objectives and Scope

This report is intended to be a primer on the characteristics that affect the design, use and operations of CMSs, and to provide guidance on the selection of the appropriate type of CMS display. Guidelines on the selection and design of CMS messages are presented in a companion Report No. FHWA/TX-92/1232-10 entitled, "Guidelines on the Selection and Design of Messages for Changeable Message Signs" (1).

This report is an update and consolidation of the following reports:

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2. C.L. Dudek. Guidelines on the Use of Changeable Message Signs. Report FHWA-TS-90-043. May 1991.
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The reader may desire to reference these three reports for supplemental information relevant to the material contained herein. Also, the National Academy of Sciences has hired a consultant to prepare a Synthesis of Practice Report on Changeable Messages Signs. The Synthesis Report, scheduled for publication in late 1993, should provide useful insight as to the state-of-practice in the United States. A national survey will be conducted to solicit specific information relative to standards for both permanently mounted and transportable CMSs, procurement practices, operational practices, performance measures, placement practices, maintenance experiences, communications and control approaches, and lessons learned. A comprehensive survey of practices in Texas will be conducted as part of Study 1232.

The reader should be cautioned that there are still many voids in technology relative to the visual aspects of CMSs. Also, CMS hardware continues to change and improve. Research and activities that are necessary to gain better understanding and use of CMSs include the following (2-4):

- Data to provide guidelines on visibility, target value, and legibility for the several types of CMSs under various environmental conditions (e.g., daylight, nighttime, fog, rain, etc.).
- Studies to determine optimum matrix sign features, particularly for light-emitting CMSs, such as character spacing and font, size and spacing of pixels, and light intensity. Mutual programs among users and manufacturers leading toward standardization based on optimum features.

- Data to provide guidelines on site specific considerations (e.g., background, interior lighting, highway lighting, etc.) and CMS adjustment options and requirements (e.g., tilting , rotating, etc.).
- Studies to provide guidelines on the use and effectiveness of incorporating flashing beacons with CMSs.
- Field studies to better assess maximum and optimum message lengths in operational settings.
- Additional field studies to evaluate message effectiveness in terms of driver response.
- More detailed documentation of hardware problems and actions taken by operating agencies to circumvent these problems.
- More detailed documentation of maintenance costs and problems for various types of CMSs.
- Research in terms of human behavior and standardization of practice concerning whether messages should be displayed during nonincident conditions and whether nontraffic-related messages should be displayed on CMSs.
- Data to provide guidelines on night and weekend operations of CMSs from traffic management centers. What are the legal concerns when the traffic management centers are closed?

Applications of CMSs

Potential applications of CMSs and other types of real-time motorist information displays are listed in Table 1-1. CMSs are applicable to the following five categories of operational problems related to high-speed highways (2-4):

1. Recurring Problems - Mainly peak-period traffic congestion where demand exceeds capacity for relatively short time periods.
2. Nonrecurrent Problems - Caused by random or unpredictable incidents such as traffic accidents, temporary freeway blockages, maintenance operations, etc.
3. Environmental Problems - Caused by acts of nature such as rain, ice, snow, fog, etc.
4. Special Event Traffic Problems - Problems associated with special events (e.g., ballgames, parades, etc.)

5. Special Operational Problems - Operational features such as reversible, exclusive, or contraflow lanes and certain design features such as drawbridges, tunnels, toll booths, and weigh stations.

CMSs can be either permanently installed or transportable to serve the specific needs of a highway agency. A variety of CMS controls and operations are employed (2,3). The methods used by highway agencies are dictated by the objective(s) of the CMS system and are influenced by cost and personnel considerations.

**Table 1-1
APPLICATIONS OF CHANGEABLE MESSAGE AND
OTHER TYPES OF REAL-TIME DISPLAYS (Ref 2)**

I. Traffic Management and Diversion

- Freeway Traffic Advisory and Incident Management
- Freeway-to-Freeway Diversion
- Special Events
- Adverse Road and Weather Conditions
- Speed Control

II. Warning of Adverse Conditions

- Adverse Weather and Environmental Conditions (fog, smog, snow, rain, dust, wind, etc.)
- Adverse Road Conditions (ice, snow, slippery pavement, high water, etc.)
- High Truck Loads

III. Control at Crossings

- Bridge Control
- Tunnel Control
- Mountain Pass Control
- Weigh Station Control
- Toll Station Control

IV. Control During Construction and Maintenance

- Warnings
- Speed Control
- Path Control

V. Special-Use Lane and Roadway Control

- Reversible Lanes
- Exclusive Lanes
- Contraflow Lanes
- Restricted Roadways

2. TYPES AND CHARACTERISTICS OF CHANGEABLE MESSAGE SIGNS (4)

This chapter provides a summary of the types and characteristics of commonly-used CMSs. Emphasis is placed on the characteristics that relate to the human factors aspects of the various CMSs. Special considerations, such as hybrid displays and transportable signs, are also discussed. CMS technologies that are currently receiving most attention by highway agencies in North America and Europe are highlighted.

Types of Changeable Message Signs

CMSs CAN BE CONVENIENTLY CLASSIFIED INTO THREE CATEGORIES, NAMELY:

1. **LIGHT-REFLECTING,**
2. **LIGHT-EMITTING, AND**
3. **HYBRID.**

Light-reflecting signs reflect light from some external light source such as the sun or headlights (e.g., reflective disk). Light-emitting signs generate their own light on or behind the viewing surface (e.g., fiber optic). Some manufacturers have combined two CMS technologies (e.g., reflective disk and fiber optic) to produce hybrid displays that exhibit the qualities of both. (Some agencies have combined CMSs with static displays to form what can also be considered to be hybrid displays.)

Displays that are commonly used for highway applications (2-4) can be grouped into the following five basic categories:

1. Static with beacons
 - Static message signs with flashing beacons
2. Background light source
 - Blank-out
3. Electromechanical
 - Rotating drum (prism)
 - Reflective Disk matrix
4. Light source
 - Bulb matrix (incandescent)
 - Fiber optics matrix (fixed grid)
 - Light-emitting diode (clustered)

5. Light source/electromechanical
 - Fiber optics matrix with shutters
 - Disk matrix with fiber optics

Characteristics of Various Types of CMSs

Pertinent features of various types of CMSs are summarized on the following pages. The emphasis is on human factors considerations. More detailed information on display types can be obtained by contacting sign manufacturers, TxDOT Districts, and other transportation agencies which have installed real-time information systems.

Static Sign

Appearance

- Static signs are used in support of real-time information displays. From an appearance standpoint, static signs have the same characteristics as conventional highway signs.

Message Display

- One and only one fixed message is continuously displayed.

Uses

- Static signs are typically used as advance or guidance signs. A special guidance usage of static signs is the "trailblazer" sign.
- Flashing beacons can be used in conjunction with static signs to produce dual status displays. The dual status capability is applicable to real-time advisory and advance signing under some conditions.

Blank-Out Sign

Appearance

- The viewing faces of the various blank-out sign designs are somewhat different in appearance. Various design configurations include:
 1. Formed neon-type clear gas tubing on a painted background.
 2. Fluorescent lamps behind a "cut-out" legend.
 3. A single fluorescent lamp behind an alzak reflector.
 4. Fiber optics on a fixed grid.
- Any color combination may be employed on the viewing face.
- Exact shapes of symbols may be displayed on most designs.

Message Display

- A message is displayed only when the sign (or a portion of the sign) is illuminated (on-off operation). Otherwise, the viewing face is blank.
- Message changing is instantaneous. All or part of the sign message can be illuminated at one time, depending on sign design.

Rotating Drum (Prism) Sign

Appearance

- Typically, the viewing face is similar in appearance to that of a conventional highway sign. Most designs use either raised sheet metal letters on a painted aluminum background or spray masked lettering on a painted wood, aluminum, or translucent plastic background to form messages.
- Messages may be back illuminated if desired.
- Any color may be incorporated into the message or background.
- Exact shapes of symbols and standard lettering types can be displayed.

Message Display

- Messages are displayed by rotating the drum(s) to the appropriate viewing position. An individual message line or "blank" can be displayed on each drum side.
- Drums can be rotated singularly or in unison.
- Drum rotating speeds range from 1 to 10 rpm. Therefore, approximately 2.0 seconds would be required to rotate a triangular drum to a new message position at the fastest rotating speed (10 rpm).
- In the process of drum rotation, undesired messages may become visible for a short period of time.
- The number of possible messages is theoretically equal to the product of the numbers of sides per drum. For example, a four-drum sign with triangular drums could display 81 ($3 \times 3 \times 3 \times 3$) unique messages. Typically, rotating drum signs have no more than four drums and display up to 12 unique messages. Triangular and square drums are most common, although some agencies are using signs with six-sided drums.
- If desired, drum-face panels can be manually removed and replaced with newly fabricated panels.

Notes

- The rotating drum sign is the most common type of CMS used in western Europe for diverting intercity traffic in rural areas from one highway to another.
- Newer forms of rotating drum CMSs include both rotating horizontal and vertical panels that allow the highway agency to change the appearance of the number of overhead signs by changing the positioning of the sign borders.

Reflective Disk Matrix Sign

There are at least three types of reflective disk CMSs:

1. circular disks,
2. rectangular disks, and
3. dimensional square disks.

A distinct characteristic of a reflective disk CMS is that it uses power only when the disks are rotated or flipped. Light-emitting CMSs require power at all times when a message is displayed.

Reflective Disk Matrix Sign - Circular

Appearance

- The viewing face is formed by an array of permanently magnetized, pivoted, circular-shaped indicators inset on a dark background surface. Messages are displayed by electromagnetically rotating appropriate disks to reveal a reflectorized yellow side.
- Modular array designs are most common.
- Use of color is normally limited to a two-color combination. Typically, disks are brightly colored on one side (reflective yellow) and matte black on the other.
- As is the case with many matrix CMSs used on highways, the common 5 x 7 and 4 x 7 matrix arrays restrict the presentation of the exact shapes of symbols and lower case lettering.

Message Display

- Messages can be displayed statically or flashed on and off simulating a flashing mode.
- Message change is effected by sequential writing across the sign face. One of two methods is employed:
 1. Module-by-module/line-by-line writing.
 2. Column-by-column writing.
- With either method, portions of both the old and new messages are visible during the change phase unless the sign is blanked before writing the new message.
- Character heights from 12 to 18 inches (305 to 457 mm) are common on designs applicable for highway use.

Notes

- Each disk is attached by two pivoting points to its base along a central axis. The disks are rotated to show either the reflective yellow or matte black depending upon the signal from the controller. The rotation mechanisms vary slightly among manufacturers. As a result, different speeds of rotation, durability and weight of disks can be expected among signs. (5)
- Legibility of reflective disk signs can be quite good during daytime conditions when the sun is in front of the sign, although some highway agencies indicate that some reflective disk signs do not have adequate target value. (5)
- Oftentimes when the sun is behind the sign, the poor legend contrast results in poor legibility. External or internal illumination, therefore, must be used to compensate for the lower target value. (5)
- It is necessary to illuminate reflective disk signs for nighttime and low ambient lighting conditions. Both mercury vapor and high-pressure sodium bottom-mounted external lighting have been successfully used. (5)
- Since the disks are recessed from the sign face, the sun and external lamps can cast shadows which cover portions of the legend. The portion of the message that receives the direct sun light or the direct light from the external lamps can be extremely bright compared to the rest of the legend; thus, messages can become illegible. (5,6)
- The front screen on many existing reflective disk signs is composed of clear Lexan. The mirror effect from the sun or external lighting at times degrades legibility by causing reflections. Anti-glare Lexan has also been used in attempts to rectify the reflectance problem. The results have not been successful. Its use by the Ontario Ministry of Transportation, for example, resulted in considerable nighttime reflection problems. The full bottom line of the display is obliterated by the reflected and scattered light from the external lighting. (5)
- Internal fluorescent lighting has also been used. This requires the need for long, narrow access doors on some signs. Internal illumination also can blur the legend when anti-glare Lexan is used on the front face. (5)
- Some reflective disk sign faces do not have a continuous matrix but are designed with a series of individual character modules spatially separated. At times, the black paint on the panel sections separating the matrix modules deteriorates and lightens in color. It then becomes difficult during daylight hours to read the messages because spaces between the characters are almost the same color as the disks. (6)
- One highway agency has indicated that disk matrix signs appear to be less noticeable when they are in close proximity to standard green overhead direction signs. This problem appears to occur because the overhead direction signs reflect more light than the disk signs due to their larger reflective surfaces. (6)

Reflective Disk Matrix Sign - Rectangular

The rectangular reflective disk CMS is very similar in operation to the circular disk sign.

Appearance

- The viewing face is formed by an array of permanently magnetized, pivoted, rectangular disks measuring 1-5/8 inches (43.7 mm) wide by 2-1/2 inches (63.5 mm) high. This size rectangular disk provides a minimum of 16 percent more color in a given space than a circular disk.
- Each disk is made up of two parts: a non-moving indicator painted fluorescent yellow and flat black, and a movable "flipper" painted fluorescent yellow on one side and flat black on the other side.
- The rectangular matrix display of the size commonly used on highways restricts the presentation of exact shapes of symbols and lower case characters.
- The sign consists of a series of individual 5 x 7 disk character modules that are spaced uniformly on the sign. Therefore, proportional spacing is not possible.

Message Display

- Messages can be displayed statically or flashed on and off using a simulated flashing mode. Each line can be "flashed" individually.
- The flipper portion of each disk has two permanent magnets fixed to one side. An electromagnet is located directly behind the disk and by changing the polarity reacts with the permanent magnets on the flipper causing it to flip.
- All message lines can be change simultaneously. A message on a three-line sign can change in 0.1 second.
- Trailer-mounted signs are most common.
- Typical character heights are 18 inches (457 mm), although 24-inch (609.6-mm) character signs are available.
- Flash and sequence rates can be varied from 1 to 6 seconds.

Notes

- The target value and legibility characteristics and problems are similar to the circular reflective disk sign. (5)

Reflective Disk Matrix Sign - Dimensional Square

Appearance

- The viewing face is formed by a full matrix array of 2-1/4-inch by 2-1/4-inch (57.2 mm by 57.2 mm) elements that rotate to display a fluorescent yellow or flat black side. The elements have sloping sides and are "3-dimensional" thus providing some depth to the message element.
- Each element is enclosed in a square case; thus the element and case form a cube.
- The square shape of the displayed yellow element provides about 30 percent more message area than the circular disk.
- The 3-dimensional (sloping side) design of the elements is intended to provide legibility as a viewer moves off center to the sign.
- The display element is not coated but is molded from polycarbonate with a fluorescent material molded into the plastic surface.

Message Display

- Character heights from 7.5 to 75 inches (190.5 to 1,905 mm) are available. Character height depends upon matrix size, font used and center to center spacing of the cubes.
- A mini electric motor flips the element on command. A momentary flow of current magnetizes the armature and instantly turns the reflective surface of the element in or out depending upon the direction of current flow.
- The design allows the elements to be changed five times a second.

Bulb Matrix (Incandescent) Sign

Appearance

- The viewing face is formed by an array of incandescent light bulbs affixed to a dark background surface. The light bulb array can either be a continuous field of bulbs or a fixed number of matrix modules (small banks of bulbs with "bulbless" areas between banks).
- The lamps are individually surrounded by reflectors or shades to form a grid to direct the light and to prevent lamps which are "on" from reflecting from the glass lamps that are "off."
- When used, reflectors are generally silver coated which tends to reduce the contrast ratio when the sun shines on the sign face.
- Exact shape presentation of symbols or lower case letters is restricted on the sizes of signs generally used for highway applications.
- Since the lamp output can be varied by relatively simple dimming circuitry, the display can adapt to most ambient lighting conditions.

Message Display

- Messages can be displayed statically, flashed on and off, sequenced, or run-on. In its simplest form, the bulb-type matrix sign can be operated as an on-off "blank-out" sign.
- Changing of messages is almost instantaneous. All or part of a message can be changed at one time.
- Typical displays currently used on highways have up to 4 lines of copy; the number of alphanumeric characters per line ranges between 12 and 20. Character heights from 12 to 18 inches (305-457 mm) have been used, although larger character sizes are available.

Notes

- Although bulbs have high power requirements and a relatively short life, bulb matrix CMSs are the most widely used CMS for commercial outdoor advertising. This is probably a result of the excellent visibility under all lighting conditions and the low capital cost. The Ontario Ministry of Transportation indicates that the only other technology that comes close to the brightness of incandescent bulbs of a similar size is the super bright LED cluster. (5)

Fiber Optics Matrix Sign (Fixed Grid)

Appearance

- Light radiated from an internal point source (halogen lamp) is directed to the sign's viewing face through a bundle of optically polished glass fibers. On the sign face, the points of light (pixels) can be arranged in a matrix array. (Figure 2-1)
- Each point of light that appears on the matrix screen comes from the end of an individual light guide. The light guide is terminated by a light conducting cone which enlarges the light spot and gives a controlled low angle of emission. (Figure 2-2)
- Some manufacturers use modules with beam splitters and two halogen lamps. By using the beam splitter, 50 percent of the light from lamp 1 reaches each of the two input ends of the multi-branched cable light guides which form the sign. If lamp 1 fails, then lamp 2 is automatically switched on and illuminates both light guides the same way. The use of the splitter arrangement makes it possible to illuminate up to a maximum of 240 fiber light dots with one lamp. Both lamps can be illuminated to increase the contrast ratio of the sign message. (Figure 2-3)
- The matrix array can be either a macrogrid with fiber dots approximately 15/16 inch (24 mm) in diameter, microgrid with fiber dots approximately 5/32 to 1/4 inch (4 to 6 mm) (Figure 2-4), or mixedgrid which has a combination of macro and microgrids (Figure 2-5). The microgrid provides a means for more detailed and better presentation of symbols (7).
- Through the use of individual color filters, any color combination can be utilized. Heat-absorbing filters are necessary for most colors except red and yellow.
- In contrast with bulb matrix and light-reflecting signs (e.g., reflective disk), the legibility angle of fiber optic signs is very narrow. Figure 2-6 illustrates an example of emission characteristics of a sign with 1/4-inch (6-mm) light dots under laboratory conditions (i.e., using rectangular signs with small surface and a standardized lighting unit).

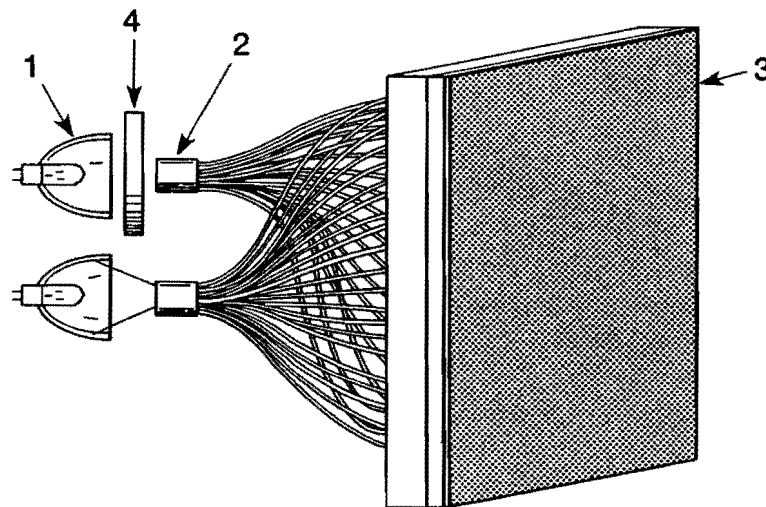
Message Display

- A message is displayed only when the internal light source is activated.
- The sign can display symbols (within certain limits) as well as word messages.
- Messages can be displayed statically or flashed on and off. Normally, fiber optic displays are operated as on-off "blank-out" signs.
- Message changing is almost instantaneous.

- The ends of the light guides are fixed into the matrix holes using special clips. These clips allow the light guides to be easily re-positioned for minor or major modifications to the message.
- All stored messages are "hardwired" with each message requiring an individual light source and fiber bundle. Generally, the maximum storage capacity is around 15 separate "hardwired" messages.

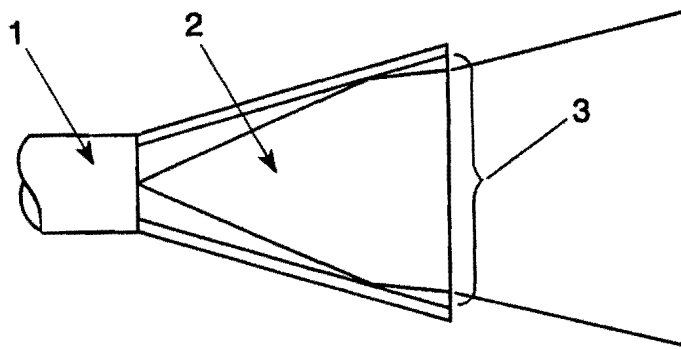
Notes

- The fiber bundles can either be sheathed or without a casing. European standards require that the fiber bundles be sheathed. A PVC casing is generally used. No standards are available in the United States where manufacturers generally do not directly cover the fibers, but use a less expensive procedure of installing the bundles in a special enclosure to protect them from the weather. No data are available to provide guidance as to the cost-effectiveness of each procedure.
- In most cases, glass fibers are used. Some manufacturers now use plastic fibers. The long-term effect of plastic fibers on luminance, and consequently legibility, is not known. There is indication that the plastic may degrade and yellow in high temperature environments.



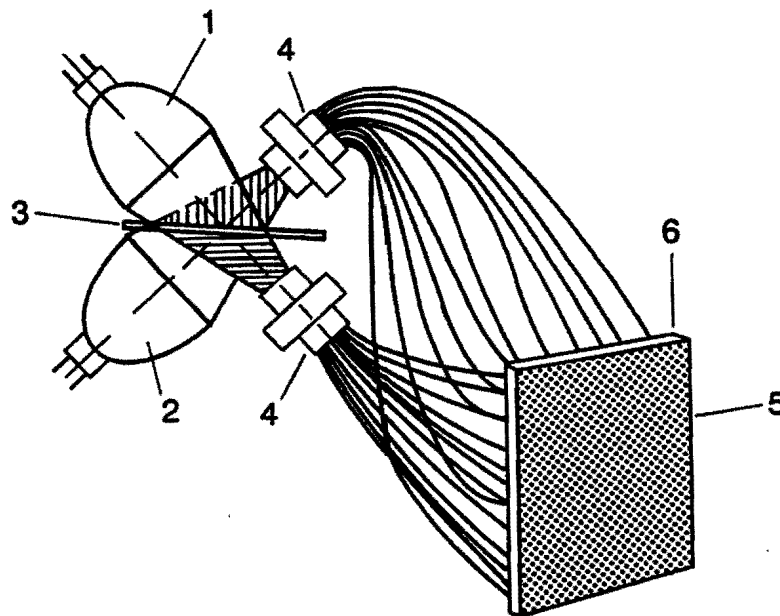
1. Halogen lamp
2. Multi-branched, flexible light guides
3. Screens
4. Filter

Figure 2-1. Fixed Grid Fiber Optic Module (Ref 5)



- 1. End of the light guide
- 2. Light conducting cone
- 3. Diameter of the light spot on the matrix (4mm)

Figure 2-2. Fiber Optic Light Guide and Cone (Ref 4)



- 1. Halogen lamp 1
- 2. Halogen lamp 2
- 3. Beam splitter
- 4. Multi-branched, flexible light guides
- 5. Matrix screen
- 6. Light spots

Figure 2-3. Fiber Optic Light Beam Splitter (Ref 4)

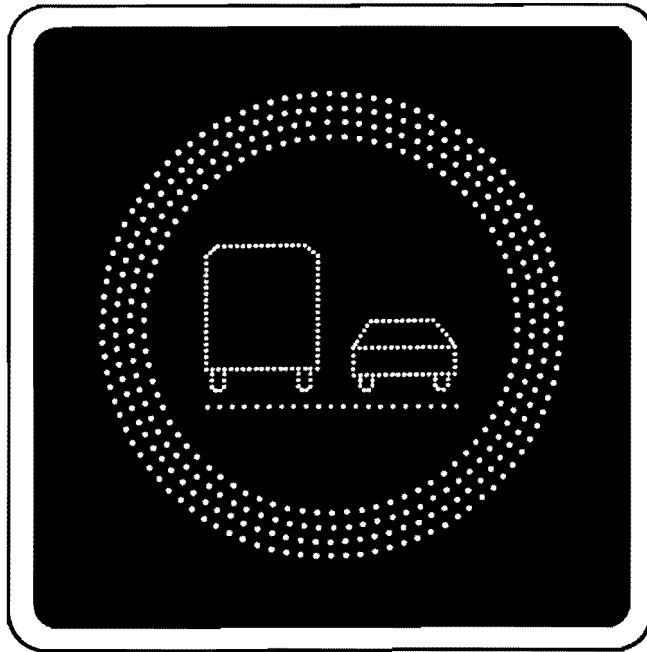


Figure 2-4. Matrix Sign of the Microgrid Type (Ref 7)

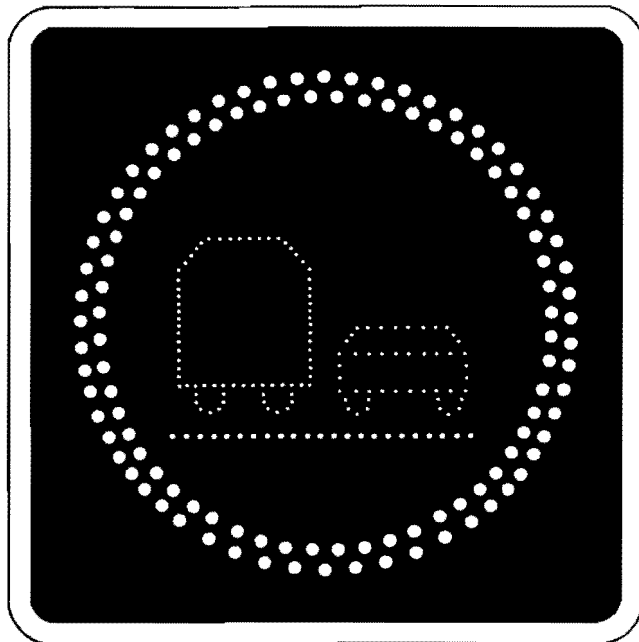


Figure 2-5. Matrix Sign of the Mixedgrid Type (Ref 7)

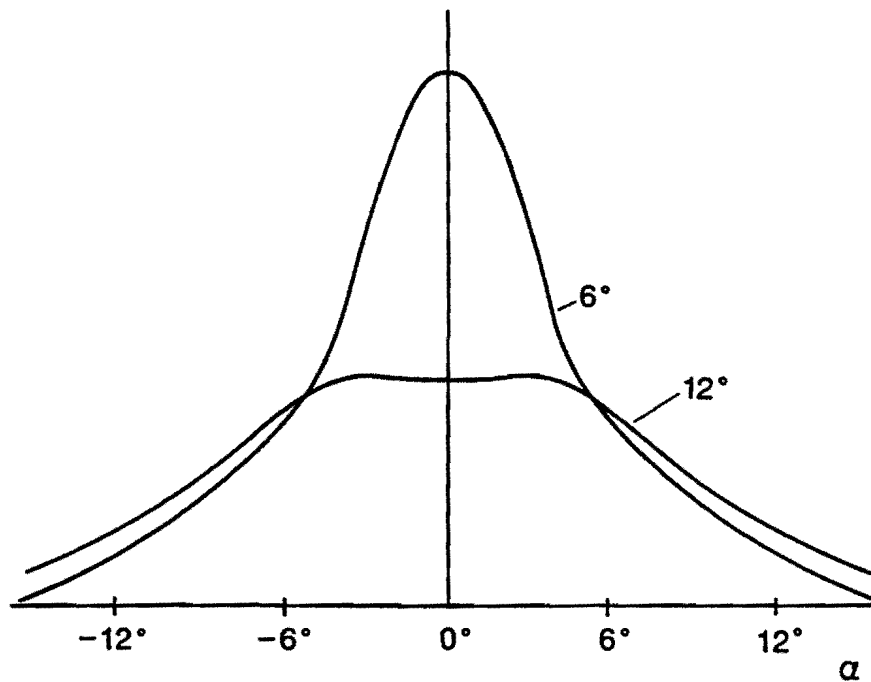


Figure 2-6. Fiber Optic CMS Light Emission Characteristics from Laboratory (Ref 4)

Light-Emitting Diode Matrix (Clustered) Sign

General LED Features

- Light-emitting diodes (LEDs) are solid state devices that glow when a voltage is applied. Changing the amount and composition of impurities added to the semiconductor results in LEDs of different colors. Available colors are: red, green, yellow and orange.
- Because LEDs are solid state devices, the writing speed is much faster than that of electro-mechanical technology. (5)
- Reliability of LEDs is high. Most of the LEDs are rated for 100,000 hours of continuous operation (12 years of CMS operations) at the rated current and voltage. (5)
- Power consumption per single LED is usually in the order of milliwatts but because of the small sizes and limited brightness, a large number must be used to produce an effective sign.
- LED lamps are available in standard and super bright. Super bright LEDs produce a light output in the range of 240 to 3,000 millicandela (mcd). The red LED lamps are the brightest of the colors. The intensity of an LED, however, reduces with time due to material deterioration. (5)

- One measure that LED manufacturers take to increase the life and reduce power consumption of an LED matrix is pulse width modulation (PWM), or switching an LED on and off many times a second and controlling duty cycles which determine apparent brightness of an LED. Tests conducted by the Ontario Ministry of Transportation showed that the eye can register a 0.16 millisecond light pulse repeated every 16 milliseconds without experiencing recognizable flicker. (5)
- Since LEDs are low voltage devices, high currents are required to power up a display.
- The intensity of LEDs reduces as temperatures increase. Ventilation is necessary for high temperatures.

Appearance

- The viewing face of an LED clustered CMS is formed similarly to the bulb matrix sign, with the exception that each lighted element is a cluster of LED lamps rather than an incandescent bulb. Each character module will normally be an 5x7 array of LED lamp clusters.
- Tests conducted in Europe indicate that the standard LED lamps do not provide adequate luminance contrast for daytime use (8,9). Super bright LEDs must be used.
- The Ontario Ministry of Transportation is using CMSs having clusters consisting of 9 red super bright LED lamps of 1,000 mcd output each and 55 green super bright LED lamps of 300 mcd output each (total of approximately 24 cd) for the 18-inch (457-mm) high characters. The combination of the red and green lamps yields an amber color. The signs also have the capability of displaying messages in red or green. (5)
- Part of the brightness of LED clusters can be attributed to light concentration in the axis direction. An LED cluster made up of twenty-nine super bright LEDs consuming 1.9 Watts of electric power produces a quantity of light equivalent of a 25 Watts incandescent lamp in the axis direction of 6 degrees. (5)
- Viewing angles of overhead signs in the highway environment are small. The Ontario Ministry of Transportation found the 6 degree beam width was sufficient for overhead installations on freeways. Figure 2-7 gives an indication of the direction of the LED cluster. (5)

Message Display

- Messages can be displayed statically, flashed on and off, or sequenced. In its simplest form, the LED matrix sign can be operated as an on-off "blank-out" sign.
- Changing the messages is almost instantaneous. All or parts of the message can be changed at one time.

- At the time of this report, the first and only LED cluster CMS in North America for freeway corridor operations will be installed by the Ontario Ministry of Transportation on Highway 401 in Toronto. Therefore, there are no "typical" display sizes that can be reported at this time. The display face design for the Toronto CMS is shown in Figure 2-8.

Notes

- The LED cluster consists of a number of super bright LEDs with a socket mounting. It is imperative that the bases of the LEDs be hermetically sealed with epoxy. A glass bulb enclosure, as shown in Figure 2-9, can be used to further seal the units. The number of LEDs contained in the enclosure will depend on the space available and brightness requirements.
- Sun reflection from the encapsulated glass or glass bulb adversely affects the contrast ratio and consequently, reduces message legibility. Also, direct ultraviolet light from the sun deteriorates the LEDs. Therefore, it is necessary to screen the LEDs from the sun. Figure 2-10 shows the LED cluster mix of 9 red and 55 green LEDs and a light guide cylinder, acting as a sunvisor, which were selected by the Ontario Ministry of Transportation. (5)
- Sun reflectance from Lexan sun shield placed on the front of the CMS can also adversely affect legibility. (5)

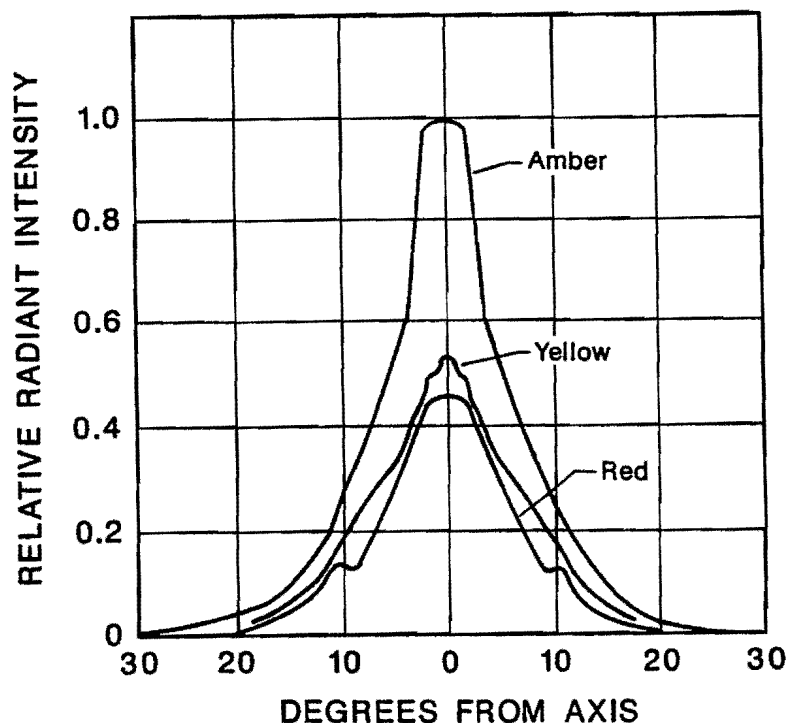


Figure 2-7. LED Cluster Beam Distribution (Ref 5)

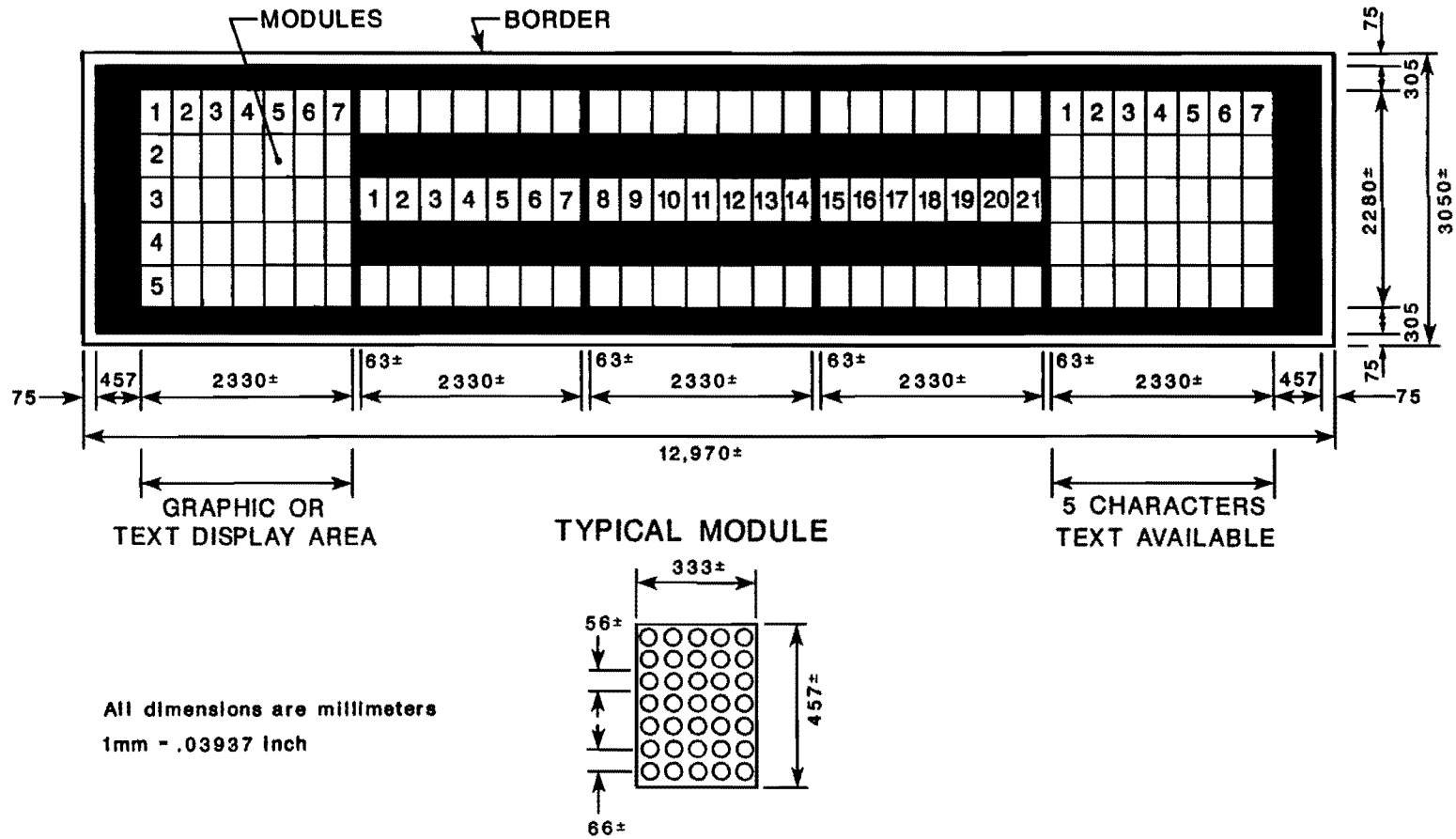
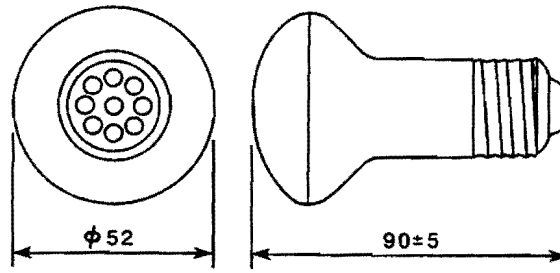


Figure 2-8. Ontario Ministry of Transportation Selected Sign Face (Ref 5)

•R52 type



•T40 type

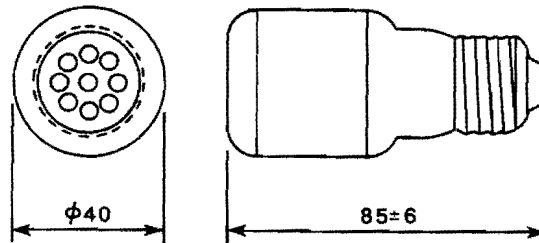


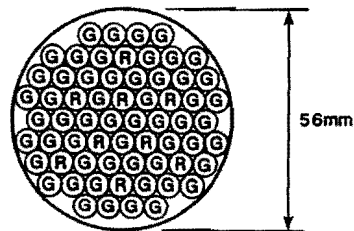
Figure 2-9. LED Cluster in Glass Bulb - Stanley (Ref 5)

(55) LED's, RATED 300 MCD OUTPUT

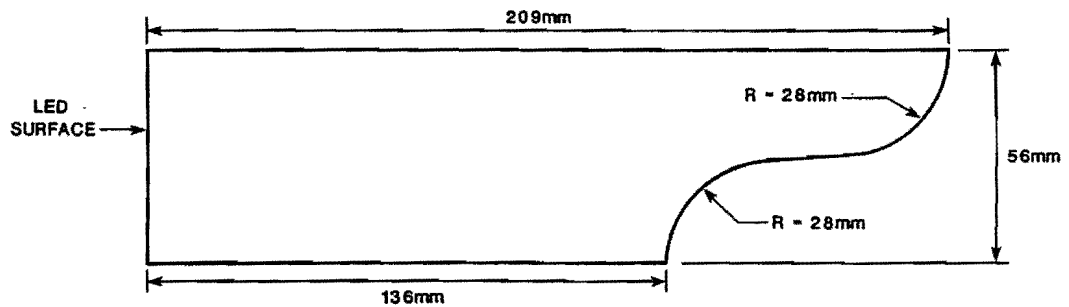
(9) LED's RATED 1000 MCD OUTPUT

NOTE:

RED LED'S ARE CONTROLLED
INDEPENDENTLY FROM GREEN LED'S



LED CLUSTER



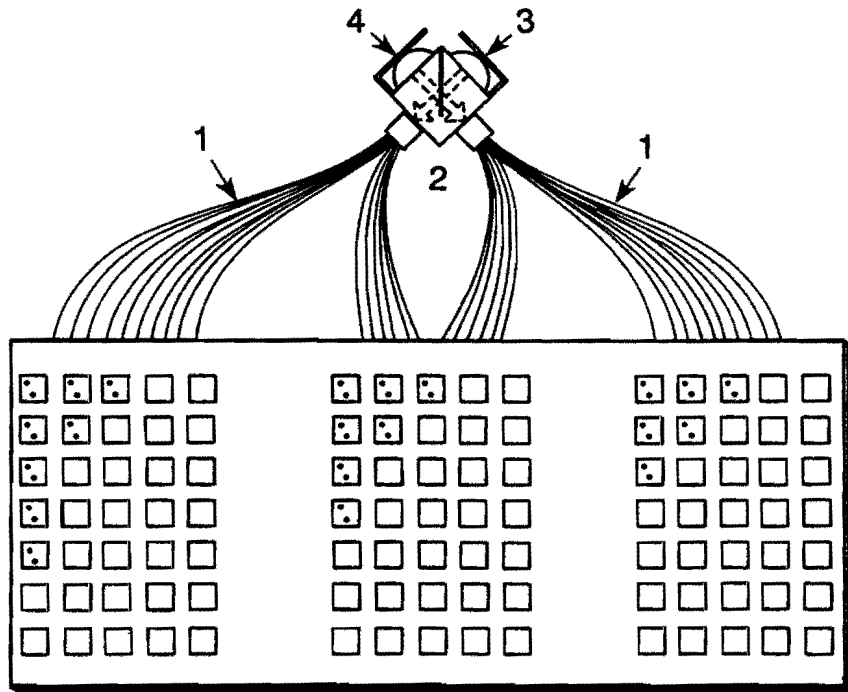
LED CLUSTER SUN VISOR

Figure 2-10. LED Cluster with Sun Visor (Ref 5)

Fiber Optics Matrix with Shutters Sign

Appearance and Operation

- The viewing face is formed similarly to the bulb matrix sign with the exception that each lighted element is one or more fiber optic light dots rather than an incandescent bulb.
- Each character module will normally be a 5x7 array of 1-inch pixels (25-mm) square pixels with fiber optic lighted dots. A fiber optic cable leads the light from a halogen lamp to a corresponding light dot approximately 3/16 inch (5 mm) diameter. The signs have the capability for three fiber optic dots per pixel; however, in practice the signs come equipped with two fiber optic cable leads per pixel. Two 50 Watt halogen lamps are used for each set of three characters (105 pixels). One lamp is used during normal daytime operations to illuminate the two fiber dots in each pixel. Both lamps are illuminated during the day to achieve an "overbright" condition when the sun is in front of the CMS and reflecting light directly on the sign face. The second lamp is also used as a standby in case of the failure of the primary lamp. At night, the primary halogen lamp is dimmed. The halogen lamps are rated for averages between 6,000 and 8,000 hours (10). Figure 2-11 illustrates the halogen light module and fiber optic bundles connected to a typical three-character module.
- The primary halogen lamp is continuously illuminated. Each pixel with the two fiber optic dots has a corresponding shutter that rotates to either permit light from the halogen lamps to pass through the fibers or to block the light. Shutters are controlled by a short current pulse. An inherent magnetic memory in each shutter retains the shutter position indefinitely without control power.
- The brightness of a shuttered fiber optic CMS can also be changed by physically changing the number of fibers per pixel. The manufacturer has determined that two fibers per pixel produces the optimum brightness for rural freeway CMSs with 12.6-inch (320-mm) character heights. (10)
- The front face of the sign is covered with a matte black material such that only the 1-inch (25-mm) pixels are visible. The matte black material is intended to reduce the glare created when the sun or other illumination sources shine directly on the sign face.
- The cone of vision produced by the focused fibers is very small, and consequently, the off-axis viewing is somewhat restricted.
- The 5x7 matrix array of fibers restricts the presentation of exact symbols and lower case letters.



1. Fiber optic harness (105 bundles)
2. Lighting module mounted on vibration absorbing platform
3. Primary lamps 10V 50W (6000 hours)
4. Back-up lamps 10V 50W (6000 hours)

Figure 2-11. Light Module and Fiber Optic Bundles Connected to Typical Three-Character Module (Ref 4)

Message Display

- Until recently, only 12.6-inch (320-mm) character heights were available. The majority of the installations have been in Europe where the highway agencies felt that the 12.6-inch (320-mm) character height was adequate for the specific applications on four-lane intercity freeways. Demands for 18-inch (457-mm) character heights in North America has encouraged the manufacturer to build signs with 16.5-inch (420-mm) characters. As of this writing shuttered fiber optic CMS with an 16.5-inch (420-mm) character have been installed by at least two agencies in North America. One sign has been installed in Toronto in late 1989 by the Toronto Metropolitan Transportation Department. The Maryland State Highway Commission installed three signs on a rural freeway in early 1990.
- The manufacturer constructed the 16.5-inch (420-mm) CMS by making no other major changes except to increase the spacings between the pixels to increase the letter size from 12.6 to 16.5 inches (320 to 420 mm) (10). Therefore, the legend will not be as bright. The effect that this change has on legibility is not known at this time. However, it is speculated that the contrast ratio will not be as high as for the 12.6-inch sign.
- CMS boards used in France consist of three rows of 15 alphanumerical letters 12.6 inches (320 mm) high. Each letter is a 5x7 matrix of pixels; each pixel has two optical fibers. The bundles of these correspond to groups of three characters (210 fibers). A group of three photoelectric cells enable regulation of the light intensity in relation to the outside light.
- Each line of message must be increased in units of three characters (e.g., signs can be purchased with 12, 15, 18, etc. characters per line).

Notes

- Users in Europe report good operational reliability (11). The Ontario Ministry of Transportation indicated that a test model of the shuttered fiber optic CMS was built very well and was of showroom quality (5).
- Currently, the controller is composed of European components.
- Both front and rear opening models are available.

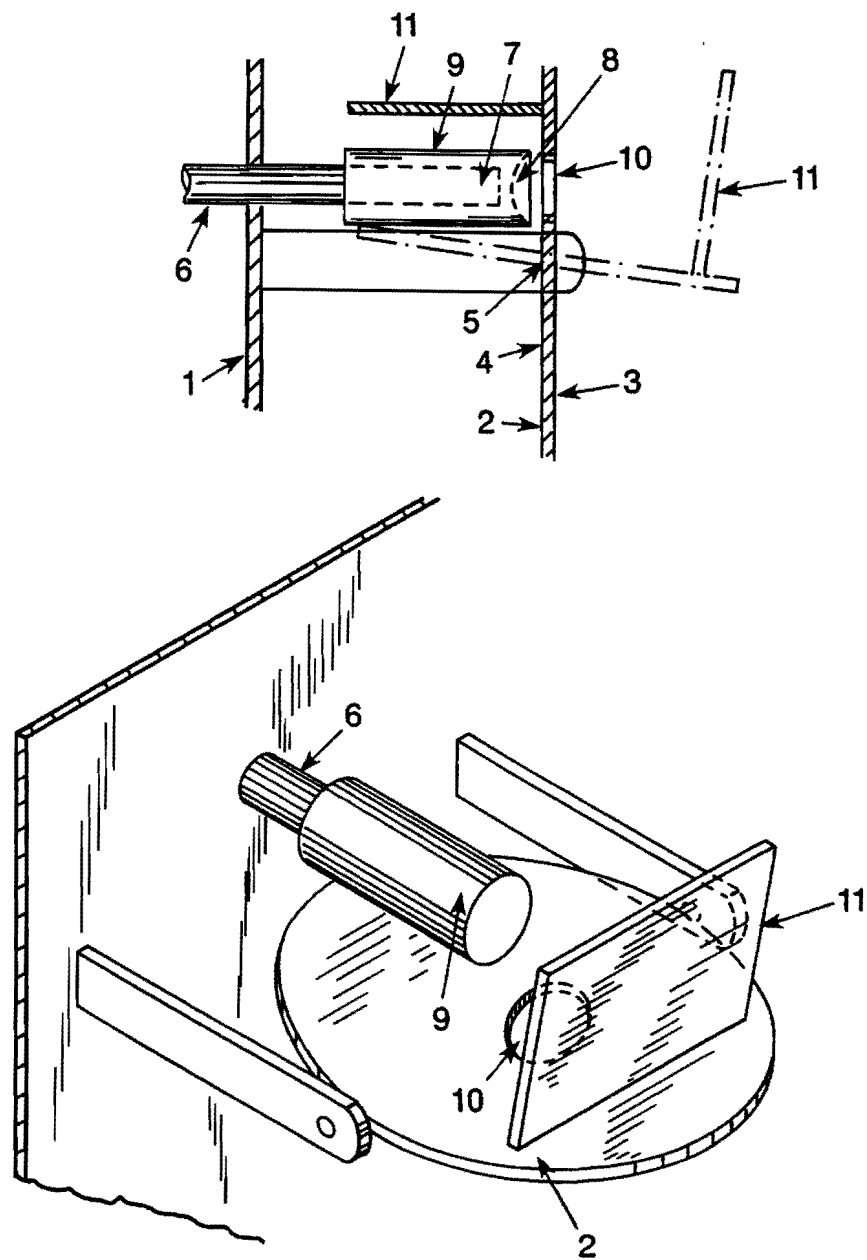
Disk Matrix with Fiber Optics Sign

Appearance

- The basic operations depend on the established principles of the reflective disk (flip-disk) sign technology which is supplemented by fiber optics. A fiber optic pixel, approximately 3/16 inch (5 mm) diameter, is located behind each reflective disk and radiates through small holes in the disk. The fiber optic pixel is illuminated at all times and shows when the disk is in the "on" position (yellow) and is covered from view when the disk revolves to exhibit the black "off" side as indicated in Figure 2-12. The pixels in use, therefore, show both the reflective disk and the illuminated fiber optic light.
- The fibers are terminated in an enclosure which surrounds a lamp. Each such lamp can feed about 1,000 pixels. Early versions of the sign contained 400 Watt high-pressure sodium lamps. The lamp has a rated life of 24,000 hours (about 3 years of continuous operation). A lamp dimming circuit was provided to vary the pixel light output. The manufacturer is currently changing to halogen lamps.
- In the case of power failure, the CMS can rely on the flip disks to revert to either the message under use or to a default message.
- The fiber optic pixels exhibit a directionality similar to the fiber optic CMSs. The effective visual cone is estimated at 20 degrees (5).
- The matrix array of disks/fiber optics restricts the presentation of exact shapes of symbols and lower case characters.

Message Display

- The sign utilizes the features of both the fiber optic and reflective disk technology.



- | | |
|---|-----------------------------|
| 1. Back plate | 7. Fiber optic bundle |
| 2. Reflective disk, black side (off position) | 8. Fiber optic lens |
| 3. Reflective disk, reflective side (on position) | 9. Supporting socket |
| 4. Disk | 10. Aperture (through disk) |
| 5. Disk pivot point | 11. Shroud |
| 6. Fiber optic cable | |

Figure 2-12. Mechanics of FO/RD Pixel (Ref 4)

Transportable Signs

General

In some situations, it may be desirable to utilize transportable signs to display real-time information. Types of transportable signs include the following:

- Truck- or trailer-mounted signs
- Pickup signs (leg-supported signs which can be placed in a truck or trailer, hauled to a site, and set out on the roadside)
- Ground-mounted signs with removable, transportable message panels.

Advances in telecommunications technology have enabled trailer-mounted sign manufacturers to offer optional features for remote control of the CMSs. At least one sign manufacturer is offering the following remote control options:

1. Computer base station operation,
2. Voice synthesizer operation,
3. Telephone land line operation, and
4. Cellular Telephone operation.

Computer base station operation allows the sign operator to have complete remote control of the on-board CMS computer. The operator can monitor and remotely control one or more trailer-mounted CMSs. The voice synthesizer operation allows the sign operator, with the use of any standard touch tone telephone, the ability to 1) monitor sign operation (messages displayed and time interval), and 2) change standard messages and times. The telephone land line operation allows the sign operator to monitor the message board status via a remotely located IBM compatible P.C. or voice synthesizer. This operation requires that a telephone line be run to the sign trailer. The cellular telephone operation eliminates the need for a telephone line.

Applications in Work Zones (12)

There are a variety of applications for CMSs at urban freeway construction and maintenance work zones. However, because of their flexibility and capability, they are sometimes incorrectly used, thus reducing their effectiveness. The primary purpose of CMSs in work zones is to advise the driver of unexpected traffic and routing situations. Repeat drivers (i.e., familiar drivers) become accustomed to the situation after a period of time and will begin to ignore the sign. When the message is later changed for a new situation, the repeat drivers may not read the message. Prolonged use of a CMS at one location and for one purpose may, therefore reduce the effectiveness of the sign. Thus CMSs should generally be used for short periods of time (e.g. one to two weeks) and for special applications. Examples of special applications where CMSs can be effective in urban freeway work zones include:

1. New detours
2. Change in detours
3. Introduction of a lane drop where a continuous lane once existed
4. Special speed control measures
5. Periodic use of flaggers, and
6. Location where sight distance is restricted and congestion occurs due to a lane closure.

When CMSs are used at a work site, a driver views the signs as furnishing reliable, accurate, and up-to-date information. All precautions must be taken to insure that these expectations are met. This means that considerable effort will be required in operating the signs.

The characters on a bulb CMS used at freeway work zones should be about 18 inches high. Such a sign will allow approximately 85% of the drivers to begin reading the message approximately 650 feet from the sign provided there are no obstructions (e.g. trucks) in the drivers' line of sight.

As a general rule, CMSs should be placed only on one side of the freeway -- either left or right depending upon the need. CMSs should never be placed and operated simultaneously on both sides of the freeway. Two signs operating simultaneously on both sides tend to be distracting and confusing. Drivers are never sure which sign to look at, and chances are, they will fail to read the message. When two signs are needed, they should be placed on the same side of the roadway and should be separated by at least 1,000 feet.

3. SOME GENERAL CONSIDERATIONS (4)

CMS Criteria

THE PHOTOMETRIC AND PHYSICAL DESIGN REQUIREMENTS FOR CMSs ARE BASED ON THE FOLLOWING FOUR FUNCTIONAL REQUIREMENTS THAT THE SIGNS HAVE TO FULFILL (7):

1. CONSPICUITY,
2. LEGIBILITY,
3. COMPREHENSIBILITY, AND
4. CREDIBILITY.

Conspicuity (target value) is the quality of an object or a light source to appear prominent in the surroundings. It is the capability of one entity in the visual field to be more easily noticed than any surrounding information.

The legibility of a sign is a measure of how readily an observer may recognize the words or symbols. It is usually measured in terms of the threshold distance on which the sign becomes legible.

The comprehensibility of a sign is a measure of how readily an observer can understand the message intended to be conveyed by the sign.

Credibility refers to the extent to which motorists believe that a traffic control device has a message that is 1) reliable, 2) accurate, and 3) up-to-date, and that the message refers to them.

Maintain Credibility

THE SYSTEM WILL WORK ONLY IF THE DRIVERS BELIEVE IN THE SYSTEM.

An important consideration in a successful driver information system (where success is measured by achieving desirable driver response) is to develop and maintain credibility - drivers' faith in the system. The quickest way to fail is to lose driver confidence. The most elaborate and costly system with presumably well-planned messages deteriorates into an operational headache if the confidence of the motoring public is lost.

DRIVER EXPECTATIONS MUST BE CONSIDERED WHEN OPERATING REAL-TIME DISPLAYS.

Drivers view these systems as furnishing them with reliable, accurate, and up-to-date information. All precautions must be taken to insure that these driver expectations are met. This requires additional effort and operational procedures on the part of the operating agency. In contrast to fixed messages on static regulatory, warning, and guide signs that always apply regardless of traffic conditions, changeable message displays elicit different driver expectations.

THE AGENCY MUST BE WILLING TO DEVOTE THE ADDED TIME AND RESOURCES NECESSARY TO OPERATE THE SYSTEM PROPERLY FOR IT TO BE AN ASSET. OTHERWISE, THE MESSAGES WILL LOSE CREDIBILITY AND BE IGNORED.

Operating real-time displays will require extra care and time to insure the right messages are displayed at the proper time. It cannot be assumed that this is being accomplished without monitoring the operation while messages are displayed. Drivers will have negative attitudes about a system that displays information contrary to existing conditions, displays information that is not understood or cannot be read in ample time to make the appropriate maneuvers, recommends a course of action that is not significantly better than their intended action, or often tells them something they already know. Once the drivers lose faith in the system, do not expect them to respond appropriately in the future. Thus, money may be spent operating a system that no longer is doing a job.

IT WOULD BE BETTER TO DISPLAY LESS INFORMATION OR NO INFORMATION AT ALL IF THE SIGN OPERATOR IS UNSURE OF THE TRAFFIC CONDITIONS.

It is important that the information displayed is reliable. A relevant question to ask is: "Can the drivers disprove the information given?" If they can, don't expect the drivers to respond to information they know is incorrect. Repeated display of erroneous information is one way of losing driver confidence. Therefore, extreme care must be exercised to assure that the proper message is displayed.

MAKE SURE THE RECOMMENDED ALTERNATE ROUTE RESULTS IN A SIGNIFICANT IMPROVEMENT IN TRAVEL.

Credibility may be lost when drivers respond to real-time information, but feel as though they have been placed in a worse situation than that experienced on the freeway or along their intended course. This is particularly true when drivers are encouraged to reroute. The alternate route must provide a very significant improvement in travel (13). Drivers are more receptive to diverting before they get on the freeway (14). Once on, drivers are not concerned with saving only a few minutes. The savings must be very significant and must be perceived by the drivers as such. If not, don't expect the same drivers to respond the next time.

DON'T ENCOURAGE MOTORISTS TO DIVERT IN ORDER TO BALANCE DEMANDS WITH AVAILABLE CAPACITY DURING RECURRENT CONGESTION.

There were attempts in the late 1960s to balance on-ramp demands for recurrent congestion during the peak periods by suggesting that drivers use other on-ramps. This approach was found to be ineffective (15) and is a good way to lose credibility.

One of the goals of a more recent CMS system, the INFORM system, is operational balance between the Long Island Expressway (IH-495) and the parallel Northern State Parkway/Grand Central Parkway. Researchers on the INFORM project found this to be a delicate task (16). Messages that were too strongly worded were found to be counterproductive; there was concern that this could lead to significant credibility problems. The INFORM signing strategy was altered to provide as much information as possible on the location of delays so that drivers can make reasonably intelligent decisions on route choice given their current positions and ultimate destinations.

When to Display Messages

Once a system is installed in a freeway corridor, a question always arises concerning when messages should be displayed. There are two schools of thought on this issue:

1. Always display a message on a sign regardless of whether or not there is an incident on the freeway. Or, as a minimum, always display a message during the peak period and when incidents occur during off-peak.
2. Display a message only when unusual conditions exist.

The authors of the "Manual on Real-Time Motorist Information Displays" (3) subscribe to the latter of the two approaches. This stems in part from the human factors principles of:

- 1. DON'T TELL DRIVERS SOMETHING THEY ALREADY KNOW (TRIVIAL INFORMATION).**
- 2. FOR MORE EFFECTIVE SYSTEMS, USE THE DISPLAYS ONLY WHEN SOME RESPONSE BY DRIVERS IS REQUIRED, (i.e., CHANGE OF SPEED, PATH, OR ROUTE).**

The display of trivial information will result in many drivers failing to read the CMS even when important information is given. To circumvent any possible adverse public reaction to seeing blank signs, the public could be educated through the media that the signs will be activated only when unusual freeway conditions exist. When so advised, drivers should be alert whenever any message is displayed because they know that it will likely affect them.

Another concern is the difficulty in describing to motorists on CMSs the many levels of congested traffic conditions that exist on the freeway under various peak, non-incident situations. It then becomes incumbent upon the operator to second guess motorists in terms of their interpretations of "normal" or "congested" conditions which are based in large part on previous experiences. Also, the dynamic nature of traffic will generally require frequent CMS message changes.

To circumvent the possible problem with blank signs, some agencies occasionally display relevant information concerning conditions on other freeways, when messages are not required for the primary freeway. For example, current or future roadwork information on other freeways is sometimes displayed.

There may be circumstances that dictate the need for continuously displaying messages. For example, on the INFORM system in Long Island, New York, the CMSs were installed about two years before the system became operational (16). Adverse public reaction by motorists viewing blank signs for about two years, prompted the local transportation agencies to adopt a philosophy of displaying messages at all times. CMSs standing dormant for long periods of time results in longer periods for gaining public acceptance. INFORM decided to display "NORMAL TRAFFIC CONDITION AHEAD" during non-incident conditions.

Set Objectives

DIFFERENT OBJECTIVES WILL REQUIRE DIFFERENT MESSAGES.

It is extremely important for the operating agency to specify what is to be achieved with the information display. This may sound like an absurd statement, because an obvious reply is: "Of course we know what we want to do; we want to alleviate congestion!" This is certainly a credible goal, but it is necessary to be more specific in defining:

- What the problem is that is to be addressed with the CMS,

and then to specify:

- Who is to be communicated with (target audience);
- What type of driver response is desired;
- Where the change should take place;
- What degree of driver response is required; and
- How the system will be operated.

In other words, the problem needs to be defined and objectives must be established. Establishing objectives is important because the objectives directly influence message content, format, length, redundancy, placement, etc.

At the same time objectives are being set, boundary conditions must also be established. The area of influence (location and freeway length) of the information system must be established. Specific questions to be resolved include the following:

- Which drivers will be affected?
- Are drivers to be affected on the freeway, at the ramp, on an arterial approaching the freeway, or perhaps at home or work?
- To what length of freeway will the messages apply?

Exactly what is displayed on the information system will be influenced by the information available to the agency about traffic conditions in the freeway corridor. The displayed message must be accurate, timely and reliable so that credibility is maintained. In turn, the information available about traffic conditions (as well as its accuracy, timeliness and reliability) are directly related to the type of surveillance used to monitor the freeway and arterial street routes involved.

Although the purpose of the CMS system may be to provide motorists with information to make appropriate route choice decisions, the information is also of value to motorists who do not divert. It provides motorists with trip time assurances. Thus, while the information may not always help motorists to arrive at their destinations more quickly, it may allow them to understand reasons for the delay and to better predict when they may arrive (16).

SOME CONGESTION PROBLEMS CAN BE ALLEVIATED USING LOW COST SIGNING SYSTEMS.

Setting objectives and evaluating the operational constraints may at times lead to the decision to employ low cost signing techniques as an interim measure to alleviate congestion due to incidents. One such technique would involve displaying a single message only when a traffic state of a pre-specified level of severity exists.

Determine the Audience Before Selecting a Message

Drivers who may view or hear an incident-type message on a freeway obviously are different in many ways. They differ with respect to their destinations, their familiarity with the area, their trip purposes, and their willingness to be diverted in incident situations. There are some differences between the familiar and unfamiliar driver in terms of their informational needs, but, by and large, their reasons for selecting one route rather than another are quite similar (17).

However, the fact that diverse groups may in general desire a common type of information does not mean that they will be able to understand equally well any language system. It is not likely that any signing system will be in a form suitable for all the drivers reading it. This problem is not as serious as it might at first appear. First, many problems can be solved if only a portion of the traffic demand is diverted from the congested freeway section. Secondly, the message designer may know (from the location of the facility within the metropolitan area and from the time of day or week) the approximate composition of the drivers who will be viewing the sign (i.e., whether they are predominantly local commuters or visitors passing through the city).

Some Reasons Why Drivers Will Not Divert

One primary function of a CMS system is to manage traffic by rerouting along alternate facilities. Success of the diversion strategy will be dependent upon convincing drivers that they are better off by taking the recommended alternate route, in addition to having established credibility in the signing operations. Although it is possible to convince a large percentage of drivers, it may be difficult to convince all drivers. For example, when CMSs were used for special event traffic in Dallas, averages between 71 percent and 85 percent of the freeway traffic destined to the special event used the recommended route (18). The small percentage (15% to 29%) of drivers who did not divert cited the following reasons:

1. Anticipated unsatisfactory conditions (principally traffic problems) on the alternate route.
2. Did not see or understand the message.

3. Were unfamiliar with the alternate route recommended and were uncertain of adequate guidance along it.
4. Lacked confidence in the information.

The implication of this study is that a small percentage of drivers will not divert even to an effectively designed sign due to skepticism based upon previous driving experiences. However, an agency can build confidence in most drivers by establishing message credibility through accurate, timely, and reliable messages and operations.

4. SIGNING ELEMENTS AND CHARACTERISTICS (3)

This chapter describes the real-time signing system elements and their characteristics. Several message design issues are defined and explained. These include message content, load, unit, length, format, and redundancy.

Signing System Elements

Experience and research have shown that real-time signing systems, will consist of one or more of the following three elements:

- Advisory Signs
- Guide Signs
- Advance Signs

Advisory Signs

These signs display real-time information about the freeway status and advisories concerning the best course of action. Advisory signs can be located on the freeway, at the entrance ramps, or on arterial streets approaching the freeway.

Guide Signs

Occasionally, drivers are advised to take a specific alternate route to their destinations or to divert to another route to travel around an incident and associated congestion. If the affected drivers are not familiar with the route or area, guide signs along the alternate route are essential. Although the guide signs may in some cases be changeable displays, most often they are specially designated visual static trailblazer signs or standard route trailblazers.

Guide signs or trailblazers can be located along the alternate route for both incident management functions and freeway-to-arterial point diversion functions. In the special case of freeway-to-freeway point diversion, guidance along the alternate or bypass route can be provided by existing route markers or destination names trailblazed on existing freeway signs, or by innovative trailblazed symbols or codes.

Advance Signs

Sometimes it is necessary to inform the drivers that displays located farther downstream will provide them with up-to-date information concerning traffic conditions and advisories. These advance signs will always be visual displays.

Message Content

Message content refers to the specific words, numbers, symbols, and codes used on a display.

Advisory Sign Message Elements

Advisory sign messages consist of the following elements:

- A problem statement (accident, maintenance, construction, etc.)
- An effect statement (delay, heavy congestion, etc.)
- An attention statement (addressing a certain group or audience)
- An action statement (what to do)

The minimum information is the problem and action statements. The driver needs to know what to do and one reason for doing it. The location of the problem is also sometimes useful in a diversion decision. An example is as follows:

| | |
|-------------------------------|-----------------------|
| ACCIDENT AT MILFORD STREET | ← Problem Statement |
| HEAVY CONGESTION | ← Effect Statement |
| UTOPIA TRAFFIC | ← Attention Statement |
| USE WILLIAMS STREET | ← Action Statement |

THE ESSENTIAL CHARACTERISTIC OF ADVISORY SIGN MESSAGES IS TO PROVIDE DRIVERS WITH ENOUGH INFORMATION TO MAKE DECISIONS.

The length of message and number of words displayed will be affected by the amount of available reading time and the information processing limits of drivers.

Guide Sign Message Elements

Guide signs provide the mechanism for drivers to follow a route other than the intended primary route to a specific destination, or to follow a diversion route to bypass an incident and associated congestion. As such, the signs must give drivers the assurance that they are traveling on the correct route and provide them with advance notice when turning movements are required. The essential message elements to accomplish this are:

- Destination affirmation
- Route affirmation and direction

Destination affirmation assures the drivers they will reach their destination. Route affirmation and direction information provide assurance that they are still on the correct route heading in the proper direction to their destination or to bypass the incident. Symbols, codes, and logos can be effectively used within the limits set forth in the Manual (3).

Advance Sign Message Elements

The message elements for an advance sign used in conjunction with an advisory visual display consist of the following four basic elements (not necessarily in the order shown):

- Information alert
- Nature of information (best route, traffic conditions, etc.)
- Destination for which information applies
- Location of the information ("ahead" or specific distance)

For single point diversion signing situations where two known alternative major routes are available (such as a radial freeway and loop freeway for drivers traveling through the city), the following additional informational element is desirable:

- Route markers of the two major alternative routes

Message Load (Unit) and Length

The message load, as used herein, will refer to the informational "load" in the message expressed in terms of **units** of information. Message **length** refers to the number of words or characters in the message.

The **informational unit** refers to each separate data item given in a message which a motorist could recall and which could be a basis for making a decision. The following example of the message shown on page 38 serves to illustrate the concept of units of information:

| <u>Question</u> | <u>Info. Unit Required</u> |
|--------------------------------------|----------------------------|
| 1. What happened? | Accident |
| 2. Where? | At Milford Street |
| 3. What effect on traffic? | Heavy Congestion |
| 4. Who is the advisory intended for? | Utopia Traffic |
| 5. What is advised? | Use Williams Street |

Hence, the above message contains five (5) **units** of information.

Message Format

Message **format** is the arrangement of the units of information on a sign to form the total message. Compatibility must be maintained between words within a line and between message units on a sign. Another usage of the term **format** is the manner in which word messages are arrayed on the CMS.

Discrete (Static) Formats

When the entire message is presented at one time, this is referred to as **discrete** or **static display**. Figure 4-1 presents four discrete formats: vertical, compact, chunk extended and message extended.

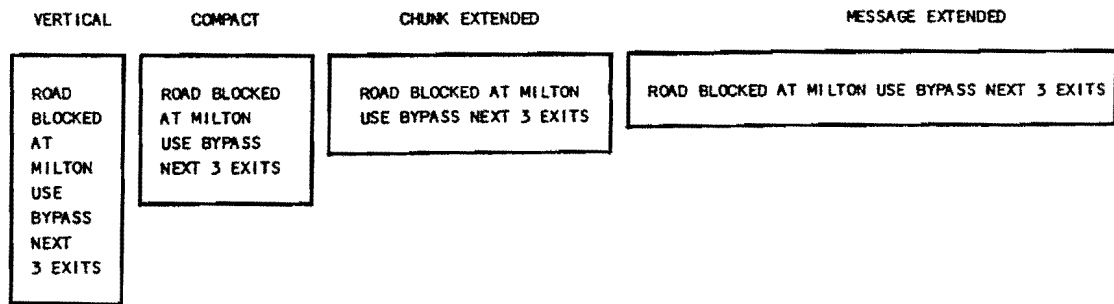


Figure 4-1. Types of Discrete (Static) Formats

THE COMPACT AND THE CHUNK EXTENDED ARE THE RECOMMENDED FORMATS FOR DISCRETE DISPLAYS.

For most freeway installations the compact and the chunk extended formats are the most effective discrete formats (19).

Modes of Movement

Certain types of matrix sign systems have automatic sequential or run-on capabilities. **Sequencing** refers to presenting in discrete manner two or more different message elements within the same signing space. **Running** messages do the same thing, but in a continuous manner so that the reading speed is paced by the speed of the running message.

Sequential formatting (sometimes referred to as message extended) is accomplished by dividing the message into parts. Each part is displayed or exposed in sequence for a set period of time. For example, the message **LEFT LANE CLOSED AHEAD, SPEED LIMIT 30 MPH** could be presented in a two-part sequence as **LEFT LANE CLOSED AHEAD** followed by the display of **SPEED LIMIT 30 MPH**. An illustration of a sequential message in compact format of this message is presented in Figure 4-2. The message format illustrated is an 8-word presentation using a sequence of two exposures to display the entire message. The message can be repeated several times by continuously cycling (in this case, alternating) through the parts of the message.

Run-on format sign displays present messages as a train of words moving continuously across a display from right to left. Run-on sign displays are also called moving message or continuous message displays. A common example of run-on messages is the special message bulletins frequently shown on television. An example of a run-on message is shown in Figure 4-2.

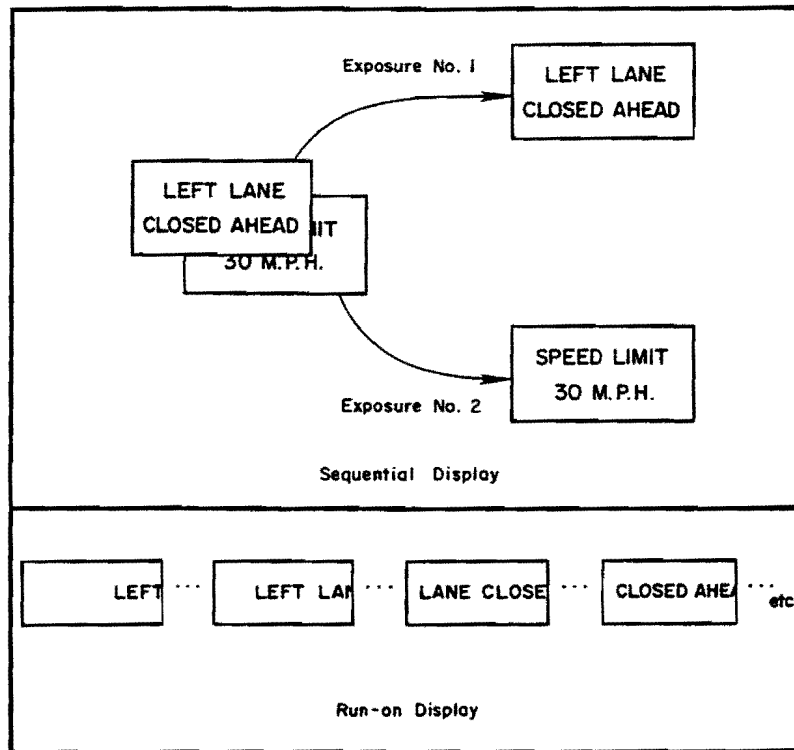


Figure 4-2. Illustration of Sequential and Run-On Display Format

RESEARCH HAS INDICATED THAT RUN-ON MESSAGES ARE NOT SUITABLE FOR DISPLAYING MESSAGES TO DRIVERS TRAVELING AT HIGH FREEWAY SPEEDS, AND ARE THEREFORE NOT RECOMMENDED FOR INCIDENT MANAGEMENT AND ROUTE DIVERSION SIGNING (20).

Typically, a sequencing or run-on message is repeated several times on a sign. The number of seconds allocated to display the complete message one time on a sign is called the **message cycle**. A message cycle includes the blank time used to delineate the end of the message.

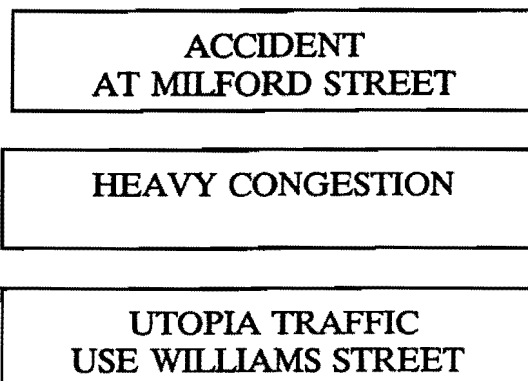
Splitting Messages (Chunking)

Quite frequently incident management or point diversion situations dictate the need for longer messages than can be processed by drivers viewing a CMS or placed on the CMS due to size limitations. Long messages displayed at one time on a CMS tend to overwhelm drivers to the extent that they are not able to read and process the information in the short time they are within the viewing distance of the message (20). This phenomenon has not been completely researched in the highway environment. However, there is evidence to indicate that drivers cannot efficiently scan long messages, and considerable time is lost in the scanning process. Laboratory studies, for example, have indicated that drivers can read

and recall an 8-word message better when it is broken up into "chunks" of 2 to 4 words rather than if the 8 words were displayed all at one time (20). Message formats that display one word at a time should be avoided.

A message can be displayed by sequencing message chunks on a sign or, if necessary, displaying separate chunks of information on two signs.

Chunking must be accomplished by splitting the message into compatible units of information. For example, the advisory message shown on page 38 can be chunked into the following compatible phrases:



Note that **HEAVY CONGESTION/UTOPIA TRAFFIC** are not compatible phrases and therefore would not be chunked together. **UTOPIA TRAFFIC/USE WILLIAMS STREET** are compatible in the sense that the action statement refers to the destination group. Collectively, the message elements form a message that will stand alone like a sentence.

Sequential Message Formats

There are three ways in which a sequenced message can be displayed. It can be displayed at one word per sequence (word sequencing), two words per sequence (line sequencing), or four words per sequence (chunk sequencing) (19).

EITHER WORD, LINE OR CHUNK SEQUENCING CAN BE USED FOR MESSAGES UP TO 4 WORDS. FOR 8-WORD MESSAGES, BEST RESULTS ARE OBTAINED WITH EITHER CHUNK OR LINE SEQUENCING IN EITHER THE COMPACT OR CHUNK EXTENDED FORMATS.

Word sequencing of 8-word messages should be avoided. The message extended format should also be avoided.

Message Redundancy

Repetition

Redundancy is a concept which has been employed in several different ways. Sometimes it refers to repetition of the complete message or key words in the message. In this sense it provides assurance that all or nearly all drivers see the message at least once. If the information must be learned, such as a street name or trailblazer code, repetition gives drivers an additional learning trial. They will then be able to recognize these names or symbols when they appear later on other signs.

As discussed under "Message Format" on page 40, sometimes the length of the total message required for a visual display is too long to either be displayed on a single sign at one time or be read by drivers in the available reading time. It then becomes necessary to divide the message into parts and to use a sequential format, display separate parts of the message on two signs, or use a combination of the two. When sign space permits, it is recommended that key words be repeated which appear in the first part of a message sequence or on the first sign.

An example of a sequential format incorporating repetition of a key word is as follows:

ACCIDENT
AT KINGMAN

ACCIDENT
TAKE TEMP. BYPASS

The key word **ACCIDENT** is repeated in the second message, thus insuring that all drivers see the reason for taking the temporary bypass and, perhaps, stressing the urgency of doing so.

Redundancy in Coded Information

In addition to its usage as repetition, the word **redundancy** has been employed in the context of coded information. For example, the interstate shield is redundant in its shape, color, and route number. A driver viewing the route marker at a distance, or when it appears with state route markers on a sign, may be able to distinguish the interstate marker either from the cue of its shape or from the red, white, and blue color pattern or from the number. These cues reduce the amount of visual search required and provide for quicker recognition

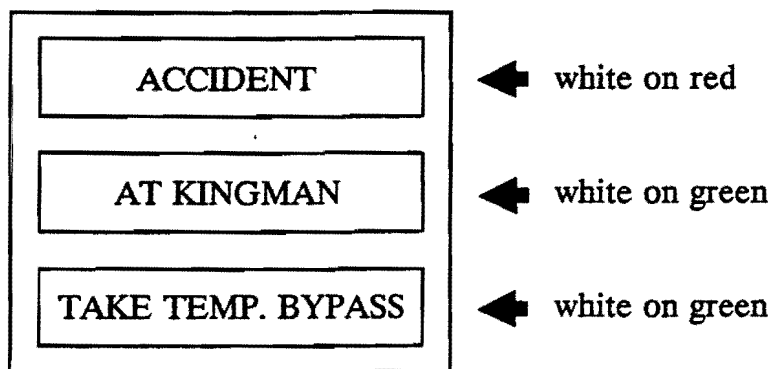
The following trailblazer shown below is another example of redundancy in the visual cues:



The trailblazer logo has redundancy in several respects: the distinctive shape and color of the "FP" logo; the background color of the sign; the shape of the sign; and in this instance, the word name explaining the code. Once the association between the logo and the generator name is made, the word name is unnecessary.

The distinctive coding of a critical message element has been used to enhance its probability of being read and also to stress its urgency.

An example on a rotating drum sign is as follows:



The red background of the word message **ACCIDENT** plus the fact that its background differs from that of the other two messages increased the probability that this message will be read first, and also may stress the urgency of the message. Thus, the red background is a redundant cue to the word message.

Redundancy in Word Messages

Redundancy has also a third meaning. It has been employed in a negative sense to imply unnecessary information or information which may be understood from the context and, hence, adds little new information for most drivers. For example, the fact that a familiar street name is an "avenue," "boulevard," or "lane," may be well understood and redundant in this sense. The message **ACCIDENT AHEAD**, when it appears on a freeway sign, has a redundant word, since most certainly the accident is somewhere downstream of the drivers viewing the sign. Eliminating unnecessary words helps conserve space on limited capacity signs.

5. GUIDELINES FOR MESSAGE LENGTH, EXPOSURE TIME AND DISPLAY FORMAT (3)

Introduction

Reading time is simply the time it actually takes a driver to read a sign message. **Exposure time** or available viewing time is the length of time a driver is within the legibility distance of the message. That is, it is the maximum time available to the driver to read a message. Thus, exposure time must always be equal to or greater than the critical reading time selected for design purposes.

Exposure time is directly related to message legibility distance and driving speed.

THE DESIGNER HAS SOME CONTROL OVER THE MINIMUM EXPOSURE TIME OF A MESSAGE.

For a given operating speed, exposure time will increase with increasing legibility distance (assuming the message is continuously displayed). For example, an overhead sign message legible at 650 ft (197.6 m) will be exposed to drivers traveling at 55 mph (88.6 km/hr) for approximately 8 seconds. With a legibility distance of 1,000 ft (304 m), the message will be exposed for about 12 seconds. Once exposure time requirements have been determined based on the operating speed and the longest message, sign design and placement criteria can be established to fulfill message legibility requirements.

IN AN EXISTING SYSTEM, REQUIRED EXPOSURE TIMES DICTATE THE MAXIMUM LENGTH OF MESSAGE THAT CAN BE DISPLAYED.

For a given legibility distance, exposure time will reduce with increased speeds (assuming the message is continuously displayed). For example, an overhead sign message legible at 650 ft (197.6 m) will be exposed to drivers traveling at 40 mph (64.4 km/hr) for approximately 11 seconds. At 55 mph (88.6 km/hr), the same message will be exposed for about 8 seconds. Once a sign is installed, the maximum exposure time is firmly established. This will control the maximum message length that can be displayed.

Factors Affecting Reading Time

At a given driving speed, several factors affect driver reading time of signs having similar legibility distances. These include:

- Driver work load
- Message load
- Message length
- Message familiarity
- Display format

Real-time displays can, at most, register up to only two ideas:

- What is the condition
- What should be done

Brevity is the heart of effective signing. People will be moving when they see the message. They must therefore also devote time to the traffic and roadway situations, as well as distractions while driving. Thus, they can only absorb a few words. These words must communicate the basic information.

Driver Work Load

One important consideration in establishing adequate message exposure times is the need of drivers to time-share their attention to the roadway and traffic with sign reading. Because of this time-sharing, it will take longer to read a sign than if the drivers could devote all their attention to the sign.

THE MESSAGE MUST BE LEGIBLE AT A DISTANCE THAT ALLOWS SUFFICIENT EXPOSURE TIME FOR DRIVERS TO ATTEND TO THE COMPLEX DRIVING SITUATION AND GLANCE AT THE SIGN A SUFFICIENT NUMBER OF TIMES TO READ AND COMPREHEND THE MESSAGE.

Message Load

Message load refers to the informational "load" in the message.

THERE IS EVIDENCE THAT NO MORE THAN THREE UNITS OF INFORMATION SHOULD BE DISPLAYED ON ONE SEQUENCE WHEN ALL THREE UNITS MUST BE RECALLED BY DRIVERS (19, 23). FOUR UNITS OF INFORMATION MAY BE DISPLAYED WHEN ONE OF THE UNITS IS MINOR AND DOES NOT HAVE TO BE REMEMBERED BY DRIVERS IN ORDER TO TAKE APPROPRIATE ACTION TO THE ADVISORY MESSAGE.

A UNIT OF INFORMATION MAY BE DISPLAYED ON MORE THAN ONE LINE ON THE SIGN. HOWEVER, A SIGN LINE SHOULD NOT CONTAIN MORE THAN TWO UNITS OF INFORMATION.

Message Length

Message length refers to the number of words in a message. Although message length is somewhat interrelated with message load,

THERE IS EVIDENCE THAT AN 8-WORD MESSAGE (ABOUT FOUR TO EIGHT CHARACTERS PER WORD) EXCLUDING PREPOSITIONS SUCH AS "TO", "FOR", "AT", ETC., IS APPROACHING THE PROCESSING LIMITS OF DRIVERS TRAVELING AT HIGH SPEEDS (20, 23).

Message Familiarity

Another factor that influences sign reading time is driver expectancy and familiarity with what will be displayed. Commuters, having seen several messages displayed on the CMS, develop expectations of message classes and types. Based on previous experience, they tend to gloss over familiar elements of the message and concentrate on those elements that change from one situation to another. (This assumes that standard message formats are used consistently.) For example, once commuters establish expectancies that a portion of the message will read **ACCIDENT AT (location)**, they quickly identify the form of the word **ACCIDENT** and concentrate on the "location" information. Thus, their reading times reduce with repeated exposure to standardized messages.

Unfamiliar drivers, on the other hand, seeing the message and perhaps the sign for the first time, must read the entire message. Their reading times will thus be longer than that required for familiar drivers (with respect to the sign and messages).

Reading and Message Exposure Times for Familiar Drivers

Figure 5-1 shows the recommended minimum CMS message exposure time based on the number of words in the message. Also shown are the minimum exposure times for static guide signs which were recommended by Mitchell and Forbes (21) and the British Transportation Road Research Laboratory (TRRL). Note that the minimum message exposure time requirements are much higher for CMSs. This is true because drivers must read the entire message on a CMS in contrast to searching for specific relevant information on a static guide sign.

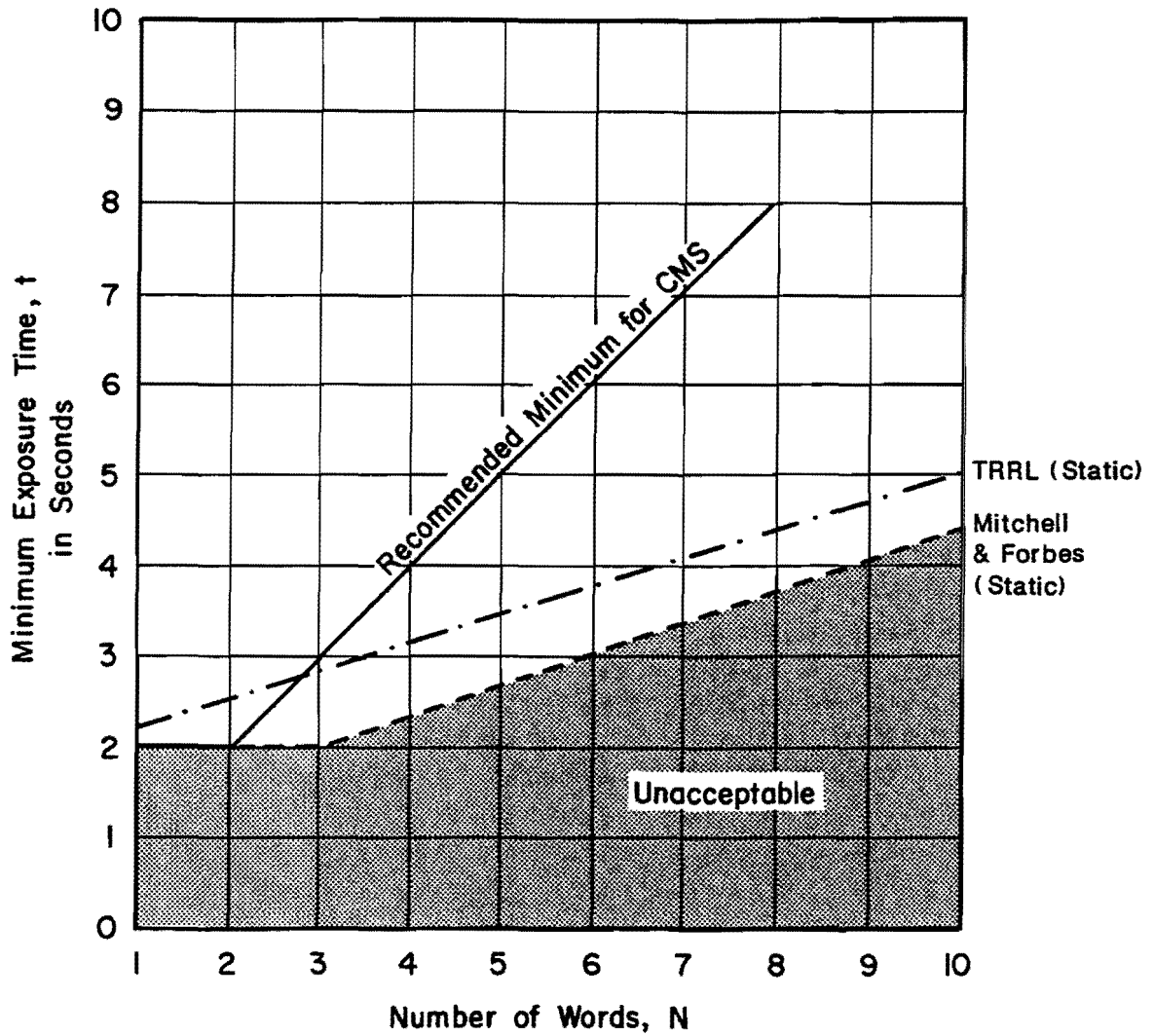


Figure 5-1. Minimum Reading and Message Exposure Times for Short Word Messages (Ref 3)

Reading and Message Exposure Times for Unfamiliar Drivers

RESEARCH (19, 20, 18, 22) HAS INDICATED THAT A MINIMUM EXPOSURE TIME OF ONE SECOND PER SHORT WORD* (FOUR TO EIGHT CHARACTERS) OR TWO SECONDS PER UNIT OF INFORMATION, WHICHEVER IS LARGEST, SHOULD BE USED FOR UNFAMILIAR DRIVERS. ON A SIGN HAVING 12 TO 16 CHARACTERS PER LINE, THIS MINIMUM EXPOSURE TIME WILL BE TWO SECONDS PER LINE.

***Excluding prepositions**

Four-line CMSs designed to display 13 to 20 characters per line are capable of accommodating about eight short words (not counting prepositions of the type normally associated with incident management/route diversion situations). When it is necessary to display long words, such as destination or street names, these words should be counted as two short words.

Field experience (18, 22) has suggested that when an 8-word message is broken into two phrases and the two phrases are sequenced (alternated) at a 2-line display, the guideline of two seconds per message line works satisfactorily. Allowing two seconds per line results in a display time of four seconds per phrase, or a total of eight seconds for the entire message. At 55 mph (88.6 km/hr), it takes about eight seconds for drivers to travel 635 ft. (193 m) (the legibility distance of an 18-inch [46-cm] character lamp matrix sign); eight seconds of exposure time is, therefore, available at this speed. On highways where the prevailing speeds are greater than 55 mph (88.6 km/hr), less than eight seconds are available to the highway agency to communicate messages to drivers.

Display Formats

Equally important to the length and exposure time of a message is the display format. Display format is distinguished from message format in that display format refers to the manner in which a message is displayed, while message format is the arrangement of the message elements. There are three basic display formats to be considered: discrete, sequential, and run-on.

- A discrete display is one in which the entire message is displayed at once.
- A sequential display is one in which the message is broken into parts and displayed one part at a time.
- A run-on, or moving display, presents a message by moving the message continuously across the sign from right to left. Run-on messages are not recommended because they take longer for drivers to read.

Discrete Display Formats

Most of the types of real-time displays available use the discrete format where the entire message is displayed at one time. (In some cases, certain lines on the sign may be flashed on and off.) These displays are typically one to four lines in length. Following is a description of various displays and the recommended minimum exposure time necessary for proper reading of each. Under loaded conditions, the exposure time should be higher than that shown.

- A one-line display would appear as follows:

ACCIDENT AHEAD

Minimum 2.0 seconds exposure

- A two-line display would appear as follows:

ACCIDENT AHEAD
USE SERVICE ROAD

Minimum 4.0 seconds exposure

- A three-line sign, as follows:

ACCIDENT AHEAD
USE SERVICE ROAD
TO ROWLAND

Minimum 6.0 seconds exposure

- A four-line sign, as follows:

ACCIDENT
AT GRIGGS AVE
USE SERVICE ROAD
TO ROWLAND

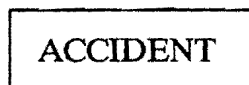
Minimum 8.0 seconds exposure

Sequential Display Formats

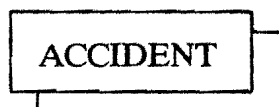
Sequential displays are those in which parts of the message are displayed in sequence. The message sequence is normally repeated (cycled) several times. There are several ways to display messages sequentially. The one best suited to a particular installation will depend on the length of message, the number of lines on the sign, and the length of the words in the message.

There are several possible format configurations for a one-line sign. The corresponding recommended minimum message exposure, sequence element exposure, blank and cycle times, are shown on the next two pages. The recommendations for the exposure times are based on data collected in laboratory studies (20). Adjustments to the exposure times may need to be made in the field to fit specific installation requirements.

The first type of one-line sign format configuration is a one-word (up to eight characters) per line format.



Minimum 2.0 seconds exposure



**Minimum 3.0 seconds exposure (1.5 seconds/sequence element, no star time required)
Cycle = 3.0 seconds**

If a driver first sees the second part of a two-element sequential message, the message should normally be intelligible without delineating the end of each message sequence.

However, when the number of sequence phrases or elements is three or more, the message would not be as intelligible without delineating the end of a message sequence.

WHEN A MESSAGE IS CHUNKED INTO THREE OR MORE PHRASES OR ELEMENTS THAT ARE SEQUENCED OR CYCLE ON A SIGN, 3 OR MORE "STARS" OR ASTERISKS SHOULD BE DISPLAYED ON A FRAME AT THE END OF THE CYCLE TO POSITIVELY SEPARATE SUCCESSIVE REPETITIONS OF THE MESSAGE. IT IS RECOMMENDED THAT THE ASTERISKS BE DISPLAYED FOR 0.5 SECOND WITH A 0.25 SECOND BLANK TIME BEFORE AND AFTER THE ASTERISKS (19).

An alternative to the stars is to have a blank time of 1 second delineate the end of message before the sequence is repeated and no more than 0.25 second between sequences (20). Research (19) indicated that the stars are more effective than using a blank time.

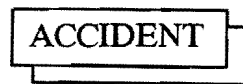
A question often arises as to whether the message should be displayed at a slow rate so that it is displayed once while the driver is in the legibility zone, or whether the message should be displayed at a faster rate and exposed twice to the driver. Proving ground studies (19) indicate that on 2-sequence messages, up to 4 words or 2 units of information per sequence can be displayed at rates as fast as 0.5 second/word without loss of recall. The driver can see the message cycle twice. Messages longer than 4 words or 2 units should be cycled at a speed of at least 1 second/word. As previously discussed, 1 sec/word with repetition is recommended.

Another feature which must be considered for a sequential message with three or more elements is that many drivers will enter the sign legibility zone and begin reading the sign in the middle of a message sequence. In some cases, the information may not be intelligible unless the drivers read the message from beginning to end. Increasing the "normal" minimum exposure time requirements insures that the sign letter size selected will be large enough to enable most drivers to read the message in a logical order, thus enhancing driver understanding. Until more field experience dictates otherwise, the authors are recommending that at least 3 seconds of added time be used.

Optional

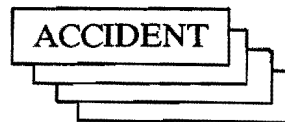
Recommended

**Minimum 9.5 seconds exposure (0.75 seconds/sequence element, plus 1.0 second star time (twice), plus 3.0 seconds added time)
Cycle = 3.25 seconds**



**Minimum 8.5 seconds exposure (1.5 seconds/sequence element, plus 1.0 second star time, plus 3.0 seconds added time)
Cycle = 5.5 seconds**




**Minimum 11.0 seconds exposure (0.75 second/sequence element, plus 1.0 second star time (twice), plus 3.0 seconds added time)
Cycle = 4.0 seconds**





**Minimum 10.0 seconds exposure (1.5 seconds/sequence element, plus 1.0 second star time, plus 3.0 seconds added time)
Cycle = 7.0 seconds**

Research (19, 20) has shown that 4-word messages can be displayed satisfactorily in the above format (one word at a time). However, it has been shown that 8-word messages are too long for this type of format. In the absence of evidence to suggest otherwise, the authors recommend that the sequencing of single words be limited to four sequences, and thus four words.

For one-line signs having 20 characters per line, the following guidelines are recommended:

| <u>Optional</u> | | <u>Recommended</u> |
|---|---|---|
| |  | Minimum 2.0 seconds exposure |
| Minimum 4.0 seconds exposure (1.0 seconds/sequence element (twice), no star time required) Cycle = 2.0 seconds |  | Minimum 4.0 seconds exposure (2.0 seconds/sequence element, no star time required) Cycle = 4.0 seconds |
| |  | Minimum 10.0 seconds exposure (2.0 seconds/sequence element, plus 1.0 second star time, plus 3.0 seconds added time) Cycle = 7.0 seconds |

Recommended minimum exposure times for 2-line signs having up to 8 and 16 characters per line are as follows:

| | | |
|---|---|---|
| Minimum 4.0 seconds exposure (1.0 seconds/sequence element (twice), no star time required) Cycle = 2.0 seconds |  | Minimum 4.0 seconds exposure (2.0 seconds/sequence element, no star time required) Cycle = 4.0 seconds |
| |  | Minimum 8.0 seconds exposure (4.0 seconds/sequence element, no star time required) Cycle = 8.0 seconds |

6. PRINCIPLES AND CONCEPTS OF VISIBILITY OF SIGNS (4)

Visibility (24)

The visibility of signs and other traffic control devices depends on the visual capabilities of motorists and the photometric qualities of the devices. At night, sign lighting, roadway lighting and vehicle lights help to maintain visibility of signs.

The concept of visibility is a general one. In the case of signs, there are two aspects to visibility: the ease with which a sign can be detected in the environment (**conspicuity**) and the ease with which the message can be read (**legibility**). Generally what makes a sign easy to detect also makes it easier to read (but this ceases to be true, for example, if a sign is too luminous--easily detected but impossible to read because of glare).

Illuminance (25,26)

Illumination is used in a qualitative sense to refer to the act of illuminating or state of illuminating. **Illumination is the measure of the light falling on a surface.** The light may come from the sun, lamps or any other bright source.

The intensity of the light source was traditionally expressed in terms of **candlepower** (cp). The standard reference was actually a wax candle of a certain specification. Today, however, instead of candles, the more precise unit of illumination is the **candela** (cd).

The illuminance on any surface may be computed from the number of candelas emitted by a source and the distance to the surface.

$$\text{Illuminance (lux)} = \frac{\text{intensity of source (candela)}}{\text{distance (meters)}^2}$$

Thus, a 1 cd source would produce 1/4 lx at a distance of 2 meters; 1/9 lx at a distance of 3 meters, and so on.

Luminance (Brightness)

Luminance is a measure of the amount of light reflected by a surface. It is independent of the distance to the object reflecting the light. **Brightness is the human sensation associated with luminance.** However, apparent brightness may be influenced by other factors such as the amount of dark or light adaptation of the eyes. It is not always a function of the physical energy alone.

Since luminance is a function of light that is emitted or reflected from the surfaces of signs and other objects, it is greatly affected by the reflectance power of the respective surface. The luminance of lamps on the other hand is an exact measure of the light they emit.

In the metric system, luminance is measured in units of candelas per square meter (cd/m^2).

In the English speaking world the terms millilambert (mL) and footlambert (ft L) are still used to measure luminance. However, today the cd/m^2 has gradually become the most frequently used unit to define the luminance of surfaces.

One mL is the amount of light emitted from a surface at the rate of $0.001 \text{ lumen}/\text{cm}^2$. A ft L is the amount of brightness of an ideally reflecting surface illuminated by one footcandle.

The following equations apply:

$$1 \text{ cd}/\text{m}^2 = 0.292 \text{ footlambert (ft L)}$$

$$1 \text{ footlambert (ft L)} = \text{ca } 3.5 \text{ cd}/\text{m}^2$$

$$1 \text{ millilambert (mL)} = 3.183 \text{ cd}/\text{m}^2$$

The human eye is sensitive to a large range of luminance. Figure 6-1 illustrates the luminance levels of some common environments [Van Cott and Kinkade, 33]. Rod vision permits detecting objects as low as 0.000001 fL ($0.0000035 \text{ cd}/\text{m}^2$). Cone vision allows up to over $20,000 \text{ fL}$ ($70,000 \text{ cd}/\text{m}^2$). Fresh snow on a sunny day would be almost $10,000 \text{ fL}$ ($35,000 \text{ cd}/\text{m}^2$). Typical daytime (outdoors) luminance are in the range of 100 to $1,000 \text{ fL}$ (350 to $3,500 \text{ cd}/\text{m}^2$).

Reflectance

Most of the light by which we see is reflected from one or more surfaces. Two surfaces may have the same illuminance on them, but their luminance may be quite different because their reflectances are different (e.g., white paper and dark fabric).

If the luminance of various surfaces are compared they can also be expressed in terms of reflectance. **Reflectance is usually expressed as the percentage of reflected light to incident light.** Reflectance percentage is defined by the formula:

$$\text{Reflectance (\%)} = 100 \times \frac{\text{luminance}}{\text{illuminance}}$$

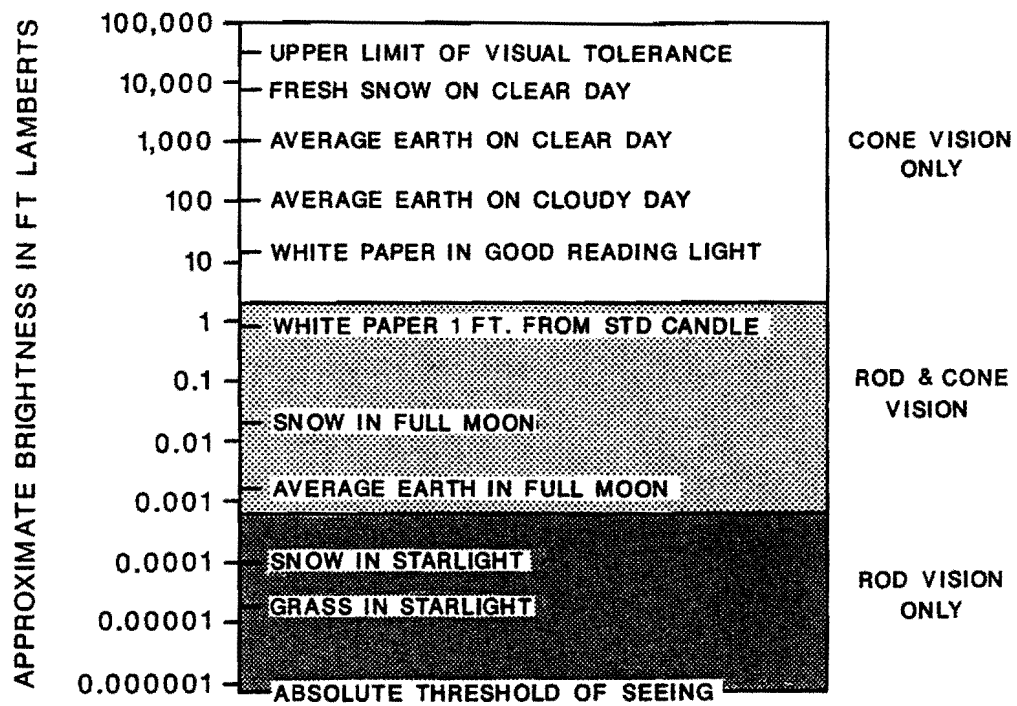


Figure 6-1. Examples of various levels of luminance (Ref 25)

Detection of a Sign

In general, the detection of a sign against a uniform background poses no problem for motorists. A sign is much more difficult to detect against complex backgrounds such as overpasses, buildings, trees, advertising signs, vehicles, etc. commonly found in urban areas. At night, the background objects that adversely affect sign detection and legibility are mainly light sources such as advertising, vehicle lights, shop windows, etc. Collectively, these interferences are referred to as "visual noise."

The phenomenon of visual noise is difficult to quantify. Therefore, the concept of conspicuity is used to qualify the visibility of signs. **Conspicuity**, as previously defined, is the ability of an object or light source to stand out clearly in a complex environment.

Reading Signs: General (24)

The reading of a sign under dynamic observation conditions (e.g., driving on a highway) depends primarily on three factors:

1. Time required to read a message,
2. Visual acuity of motorists, and
3. Luminous conditions under which the sign is observed.

Reading Signs by Day

Luminance (Brightness) Contrast

Conspicuity (target value) and legibility are two important CMS characteristics. Contrast between the sign and the roadside environment influences the conspicuity (target value) of the sign. The issue is: can drivers detect the sign and distinguish it from various backgrounds such as the sky, trees, buildings, other structures, etc.? Luminance contrast, in this case, is computed as follows:

$$\text{Contrast (\%)} = 100 \times \frac{L_T - L_B}{L_B}$$

where L_B = luminance of background
 L_T = luminance of target (sign)

Legibility--the ability of drivers to see the message on the sign--is influenced by the contrast between the sign message and sign panel. With respect to legibility, luminance contrast is computed as follows:

$$\text{Contrast (\%)} = 100 \times \frac{L_L - L_{LB}}{L_{LB}}$$

where L_{LB} = luminance of legend background (sign panel)
 L_L = luminance of legend

When dealing with dark lettering on a light panel, the value of contrast (%) is always between zero and 100 percent (brighter sign panel minus darker sign legend divided by a brighter sign panel). However, in the case of light-emitting CMSs where the target (sign legend) is the brighter of the two, the contrast value may be very large (darker sign panel minus brighter message lights divided by darker sign panel). Current practice is to describe this phenomenon in terms of contrast ratio which results in a number. For example, a contrast ratio of 8 indicates that the light-emitting legend is 8 times more luminous than the background.

Contrast Luminance Ratio

Contrast ratio is used to describe the legibility characteristics of signs. **Contrast ratio, simply stated, is the ratio of the luminance of an object to the luminance of the background.** In the case of signs, contrast ratio is the ratio of the sign legend to the sign background. Since the background luminance is now the luminance of the legend background (sign panel) and not the ambient luminance behind the sign, the value used for contrast ratio is as follows:

$$C' = \frac{L_L}{L_{LB}}$$

where C' = contrast ratio
 L_{LB} = luminance of legend background (sign panel)
 L_L = luminance of legend

Light-Emitting Signs

Colomb and Hubert (8) specify that in daylight, the true luminance of a light-emitting matrix CMS is the sum of the internal luminance (L_I) of the illuminated sign (the light-emitting pixels) and the external luminance (L_E) resulting from ambient illumination. The external luminance (L_E) is the same as the luminance of the legend background (sign panel) (L_{LB}) in the ambient condition in which the sign is being used. Therefore, the contrast ratio (C') becomes:

$$C' = \frac{L_I}{L_{LB}} = \frac{L_I + L_{LB}}{L_{LB}}$$

To illustrate how contrast ratio can be determined, consider the CMS module of 5 x 7 pixels shown in Figure 6-2. Each pixel can be composed of a single bulb or several light points (e.g., 2, 3, 4, 5, etc. fiber optic light points or LEDs).

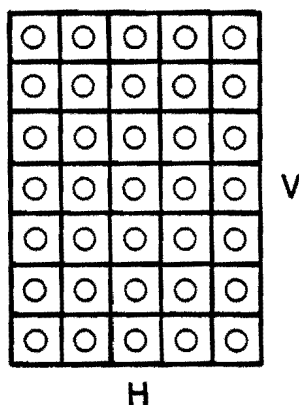


Figure 6-2. A Matrix of 5 x 7 Pixels

Colomb and Hubert recommend that the internal illuminance (L_I) should be determined by measuring the illuminance of the 35 pixels (I_{35}) rather than measuring the illuminance of each pixel (I_i). There were two primary reasons why this procedure was chosen. First of all, in practice there is a scattering between the intensity of each pixel because of the geometric orientation of each light source which is not always exactly the same. Therefore, the approach of measuring the light intensity of the entire array results in a more precise mean value. Secondly, the procedure is easier than measuring the intensity of each pixel.

Therefore for a 5 x 7 matrix array,

$$L_I = \frac{I_{35}}{A_{35}} = \frac{I_p \times 35}{A_{35}}$$

where I_{35} = luminous intensity of the 5 x 7 pixel array of the matrix
 I_p = average luminous intensity per pixel of the matrix
 A_{35} = area of the block of matrix containing the 35 points.

Kerr et al. (27) calculated contrast ratios of light-emitting CMSs by using the formula (sign on - sign off)/(sign off). The luminance of the sign when it is "off" is essentially the luminance of the sign background. Therefore, the formula used by Kerr et al. is as follows:

$$C = \frac{L_Y - L_N}{L_N} = \frac{L_L - L_{LB}}{L_{LB}}$$

where L_Y = luminance of sign with message on (true luminance of sign)
 L_N = luminance of sign with message off (luminance of legend background)
 It can be shown from the equations used by Colomb and Hurbert and Kerr that

$$C = C' - 1$$

$$C' = C + 1$$

Therefore, contrast values calculated by Colomb and Hurbert are only one unit above that computed by Kerr. For example, a contrast ratio of 8 computed using the Colomb and Hubert would be calculated to be 7 using the Kerr approach. Which is essentially the same for all practical purposes.

The use of $C' = L_L/L_{LB}$ is currently the criterion used by France and has been proposed to the other European countries as a European standard relationship (28).

Reading Signs at Night

At night, the luminance of the backgrounds on CMSs and on static signs with dark backgrounds tends towards zero. Therefore, the luminance of the sign legend is the primary criterion used for determining the legibility of the sign at night. (8)

Irradiation and Glare

Most light-emitting displays have good target value and legibility at night. However, during nighttime operations, the legend may appear too bright and may blur due to irradiation. **Irradiation** is a phenomenon resulting from extremely high luminance contrast where the lighter surface tends to "bleed" onto the darker surface.

Discomfort glare from oncoming headlights is another common problem. If CMSs employing untested brightness levels are allowed, the effects could reach the point of being annoying and distracting as well as unreadable.

Clearly no single luminance contrast will be suitable for both daytime and nighttime operations. During a bright, sunny day, the intensity of the lighting system must be much brighter for contrast. The problem is more acute when the sun rays directly strike the sign face. Under cloudy conditions, the sun brightness must be reduced somewhat and, in darkness, the intensity of the CMS must be automatically reduced to a minimum level.

Thus, the problem of developing CMSs suitable for changing ambient lighting is a challenging one--how to provide adequate intensity and luminance contrast for target value and legibility both in bright light and darkness. The new and emerging light-emitting CMS technologies must have provisions for lowering the intensities to cope with the wide range of environmental lighting conditions.

Reduced Sign Visibility Due to Sun Interference

Potential Problems

In addition to the visibility concerns discussed above, two other problems must be addressed: 1) low level sunlight in front of the CMS panel, and 2) low level sunlight behind the CMS panel.

Sun Behind the CMS (Backlight)

One critical scenario occurs when the sun appears to be directly behind and nearly over the sign. The reflections from the pavement and from other vehicles between the driver and the sign cause a blinding glare or dazzle through which only a silhouette of the sign is visible. Thus, the sign positions to be avoided are signs whose rear surfaces are west-southwest and east-northeast oriented. Although both orientations are critical, rear surface orientation to the west-southwest has more affect on CMS legibility than east-northeast orientation. This is true because the rising sun is less intense than a setting sun due to more frequent haze in the mornings (5).

Sun Facing the CMS (Washout)

Another condition that arises that requires attention is when the sun is facing the CMS. For light-reflecting CMSs, such as the reflective disk and the hinged flap, direct sun light on the signs will ordinarily enhance legibility. However, all light reflecting CMSs are equipped with a clear sign face (usually Lexan) in order to protect the moving parts (e.g., disks, flaps, etc.) by sealing them from the unfriendly environment. The clear protective sign face causes visibility problems because it reflects and scatters incident light thus obscuring the message. All reflecting technologies have these problems and therefore do not compare favorably with the light-emitting technologies.

Legibility of light emitting CMSs (e.g., bulb matrix, fiber optics, LED, etc.) are adversely affected when the sun light falls directly on the sign face. Sun light reflecting directly off the lamps, glass fiber pixels, glass enclosures for the LEDs, etc., reduce the contrast between the sign message and background.

7. VISIBILITY AND LEGIBILITY CRITERIA - LIGHT-EMITTING SIGNS (4)

Light-Emitting CMSs

Before a sign can communicate its intended meaning, it must be perceived and read under a wide variety of conditions. This chapter focuses on factors affecting the target value and legibility of light-emitting CMSs.

Listed below are the most common types of light-emitting CMSs. With the exception of the blank-out sign, all the listed CMSs are matrix signs.

| Category | Type |
|--------------------------------|--|
| Background light source | Blank-out |
| Light source | Bulb matrix (incandescent) Fiber optics matrix (fixed grid) Light-emitting diode (clustered) |
| Light source/electromechanical | Fiber optics matrix with shutters Disk matrix with fiber optics |

Light-emitting matrix CMSs consist of a large number of separate light pixels. A pixel, as used in this report, is one or a group light-emitting (or light-reflecting) components which form one cell of a character. For example, a shuttered fiber optic CMS may have two fiber optic light dots forming a pixel; a pixel on a clustered LED CMS may have 64 LEDs.

Sign Design Factors Affecting Legibility of Light-Emitting Signs

Sign design factors that affect the legibility of light-emitting CMSs include the character height; font style; spacing and size of pixels (character width); spacing characters, words and lines; size of sign borders; and contrast (luminance) ratio.

In order to be able to perceive the separate light pixels as a continuum (i.e., a letter or number), the spacing of the pixels must be smaller than a specific value. On the other hand, in order to be able to discern separate parts of the character the spacing between the pixels (or between groups of pixels forming parts of the character) must be larger than another specific value. In other words, if the spacing is too large, the separate pixels do not merge into one image; if the spacing is too small, distinct parts of the character cannot be seen separately. These two values (the lower and the upper boundary values) depend upon the conditions of observation, the characteristics of the observer, the other factors. But most of all, they depend upon the contrast ratio--the ratio between the luminous intensity of the individual light pixels and the sign background. (7)

The legibility of light-emitting CMSs, then, is primarily affected by the character height, character width and the contrast ratio (7, 27). Character height and width are dictated by the spacing between the pixels. Contrast ratio is affected by the size and intensity (luminance) of the pixels (emitters) forming the characters. It follows, then, that the legibility of a light-emitting CMS is affected by the spacing between the pixels and characters and the size and intensity of the pixels. Changing one of these elements without changing one of the other elements can adversely affect the legibility of a CMS. For example, consider a CMS with proper threshold levels of pixel spacing, spacing between characters, size of pixels and intensity of pixels that result in a given legibility distance. If the spacing between the pixels was increased to obtain a larger character while holding the other parameters constant, it is expected that the result would be characters that appear to have a thinner stroke width. The resultant effect may be a shorter legibility distance. Therefore, to maintain the same legibility distance, it may be necessary to increase the number or diameter of the emitters in the pixels in order to reduce the effective spacing between pixels, or to increase the intensity of the light source in order to produce the same effective stroke width. Since interrelationships exist among these elements, they are important elements to address in the design of CMSs.

Unfortunately, very little objective data are available relative to these design factors to provide definitive guidelines for the various types of light-emitting CMSs. Some information useful in evaluating these CMS design factors are summarized in this chapter. Until objective data become available, it is recommended that before CMSs are purchased, the highway agencies install and test prototype models to evaluate legibility characteristics under various environmental conditions.

Character Height and Legibility

FOR MOST FREEWAY APPLICATIONS, CMS SHOULD HAVE CHARACTERS AT LEAST 18 INCHES (457 MM) IN HEIGHT.

Studies have shown that CMSs used on freeways in the United States should have character heights of at least 18 inches (457 mm). Message requirements for most applications and visual noise in urban and suburban environments require 18-inch (457-mm) character heights.

As a general rule, follow these guidelines to determine matrix sign letter heights:

- For freeway applications, use letter heights of 18 inches (457 mm) or greater.
- For other than freeway applications, use letter heights between 10 and 18 inches based on 36 ft/in legibility distance.
- Never use letter heights of less than 10 inches (254 mm) for bulb matrix CMSs, as lamp brightness is not sufficient.

Unfortunately, only a few experimentally-controlled studies have been conducted in the United States to provide data concerning the legibility of light-emitting or light-reflecting matrix CMSs. The results of field studies conducted by Dudek and Huchingson et. al., in the early 1980s (19,29) to measure the legibility distances of bulb and reflective disk matrix CMSs with 18-inch (457 mm) characters using subject drivers are shown in Tables 7-1 and 8-1. These data indicate that legibility distances for bulb matrix CMSs are about 15 percent longer than reflective disk CMSs (for single-line, single stroke words).

Subjective studies by Caltrans (6) indicated that the bulb matrix is superior to the disk matrix CMS in visibility at nighttime, in low light situations (overcast skies and at dusk) and when the sun is to the rear of the sign. Their subjective evaluations of a disk matrix CMS with 18-inch (457-mm) letters indicated that messages were readable at a distance of 700 ft (213 m). The 700-ft (213-m) legibility distance is comparable to the average legibility distance of 725 ft (221 m), but much higher than the 85th percentile legibility distance of 500 ft (152 m) shown in Table 7-1.

Shown in Tables 7-2 and 8-2 are the results of a field study conducted by Upchurch et. al. (30) in 1990. This study measured the legibility distances of clustered LED (17.8 inch [452 mm] characters), fiberoptic (16.1 inch [409 mm] characters), and reflective disk matrix (18 inch [457 mm] characters) CMSs under four different lighting conditions: day-light, night, washout (sun facing sign), and backlight (sun behind sign). Although the authors did not control the contrast ratios of the signs to produce identical conditions, the study provide additional in-sights on legibility distances. (31) A comparison of CMS technologies versus an acceptable legibility distance of 678 feet (3) showed that the fiberoptic signs provided acceptable legibility distances and performed slightly better than the LED signs tested. Overall, the fiber optic signs had a significantly higher average legibility distance than the LED or reflective disk signs during mid-day and washout conditions. During backlight conditions the fiberoptic and LED signs each had significantly higher average legibility distances than the reflective disk signs. At night, fiberoptic and LED signs had similar legibility distances which were significantly higher than the reflective disk signs.

The Department of Transport (32), United Kingdom, is currently developing standards for light-emitting CMSs. The minimum CMS character heights specified by the Department of Transport for upper and lower case letters based on the sign group and highway speed are shown in Table 7-3. As noted in Table 7-3, the United Kingdom requires a minimum character height of 16.5 inches (420 mm) for highway speeds up to 70 mph (112 km/hr). However, they are moving toward a 17.7 inch (450 mm) character height.

Western Europe had adopted a legibility criterion of 656 ft (200 m) for light-emitting CMSs that display symbols for speed control and lane control on interurban motorways (7). The trend is toward CMSs having character heights of between 15.7 and 18.7 inches (400 to 457 mm) for the speed and lane regulation messages. France (33) specifies character heights between 15.7 and 18.7 inches (400 and 457 mm) for speed control CMSs, and 15.7 inches (400 mm) for information and direction CMSs installed on interurban motorways. West Germany (34) specifies character heights between 16.9 and 18.3 inches (430 and 465 mm) for speed control CMSs. The Netherlands (7) requires 17.7-inch (450-mm) character heights. At least one highway agency in France found that although a fiber optic CMS with

**Table 7-1
DAYLIGHT LEGIBILITY DISTANCES FOR
18-INCH BULB MATRIX CMS (Ref 3)**

| Character Style | Legibility Distance (ft) | |
|--|--------------------------|-----------------|
| | 50th Percentile | 85th Percentile |
| WORD, single-line, single-stroke | 850 | 700 |
| NUMBER, single-line single-stroke | 750 | 575 |
| NUMBER, single-line double stroke (thick/thin) | 850 | 700 |

**Table 7-2
AVERAGE LEGIBILITY DISTANCES FOR LED
AND FIBEROPTIC SIGNS UNDER DIFFERENT
LIGHTING CONDITIONS (Ref 30)**

| Condition | Legibility Distance (ft) | | |
|-----------|--------------------------|-----|------------|
| | Reflective Disk | LED | Fiberoptic |
| Mid-Day | 698 | 743 | 983 |
| Night | 355 | 694 | 678 |
| Washout | 420 | 487 | 853 |
| Backlight | 219 | 502 | 659 |

**Table 7-3
CHARACTER HEIGHTS
DRAFT STANDARDS: DEPARTMENT OF TRANSPORT,
UNITED KINGDOM (Ref 32)**

| Sign Group | Speed Range mph (km/hr) | Minimum Character Heights inch (mm) | |
|------------|----------------------------|---|----------------------------------|
| | | Upper Case Only 5 x 7 | Upper and Lower Case 7 x 9 |
| A | up to 70 (112) | 16.5 (420) | 33.9 (860) |
| B | up to 60 (96) | 11.8 (300) | 15.7 (400) |
| C | up to 50 (80) | 7.9 (200) | 10.6 (270) |
| D | up to 40 (64) | 3.5 (90) | 4.7 (120) |

Group A CMSs

Warning Signs

Regulatory Signs

Lane Control Matrix Signs

Signs Conveying an enforceable speed limitation of prohibition

Signs warning of impending hazard

Group B CMSs

Motorway advisory signals

Group C CMSs

Directional information signs

Other informatory signs

Information complementing Group A or Group B signs

Signs for car parks

12.6-inch (320-mm) characters seems acceptable for the intercity motorways, 18-inch (457-mm) characters would be more comfortable for motorists to read (11).

Font Style

Most matrix signs are limited in alphabet to upper-case letters. The arrangement of the matrix makes it difficult to form some of the parts of lower case letters. This is true especially for letters with loops, such as "g," "q," or "y." In general, the practice of using upper case letter should be followed.

The 5 x 7 and 4 x 7 matrix fonts are usually sufficient for messages displayed with all upper case letters. Messages with lower case letters generally require a 7 x 9 font. For general public reading, the 5 x 7 standard (rounded character) font style provides slightly superior legibility on a CMS to a 4 x 7 character or a square character font style. The reader is referred to Reference 4 for examples of fonts adopted by the Ontario Ministry of Transportation, France, and the International Commission on Illumination.

Some bulb matrix signs use a slanted font for word messages. No research is known that supports improved legibility for slanted letters. However, the slanted font does require more horizontal space (up to several bulb columns) than a display of the same message in vertical font.

Spacing and Size of Pixels (Character Width)

In the mid-1980s, the International Commission on Illumination, Technical Committee on Roadsigns (4) suggested that, for fixedgrid fiber optic CMSs, the center-to-center spacing between normal 1/5- to 11/32-inch (5 to 9-mm) diameter light units should be smaller than 2.4 inches (60 mm) in order to make them appear as a continuous line; the spacing between lines that must be seen separately should be at least 5.9 inches (150 mm).

The United Kingdom draft CMS standards specifies the minimum and maximum size of light units based on character height. The United Kingdom requirements are shown in Table 7-4.

Table 7-4
SIZE OF MATRIX ELEMENTS
DRAFT STANDARDS: DEPARTMENT OF
TRANSPORT, UNITED KINGDOM (Ref 32)

| Character Height 5 x 7 Matrix inches (mm) | Element Size | |
|---|------------------------|------------------------|
| | Minimum inches (mm) | Maximum inches (mm) |
| 8.7 (220) | 15/32 (12) | 45/64 (18) |
| 10.4 (225) | 33/64 (13) | 25/32 (20) |
| 11.4 (290) | 19/32 (15) | 28/32 (22) |
| 13.0 (330) | 43/64 (17) | 63/64 (25) |
| 14.4 (365) | 25/32 (20) | 1-3/16 (30) |
| 15.7 (400) | 25/32 (20) | 1-3/16 (30) |
| 17.3 (440) | 25/32 (20) | 1-3/16 (30) |

Spacing of Characters, Words and Lines

The United Kingdom draft CMS standards, specifies that the minimum spacing between characters should be equivalent to a single column of inactive matrix elements. The desirable minimum should be two columns of inactive matrix elements. Minimum word spacing should be equivalent to two columns of inactive elements; and the minimum spacing between lines of text should be the equivalent of three rows of inactive elements. (32)

For information and direction CMSs, France requires that the spacing between characters be equal to or greater than 2/7 times the character height, and the spacing between lines of characters be equal to or greater than 4/7 times the character height

Size of Sign Borders

As a minimum, the CMS should have a background buffer surrounding the sign characters similar to the border placed on static guide signs. It has been suggested by Bomier (35) that the background buffer surrounding the message should be at least one alphanumeric sign line height. Lotens (36) found that a sufficiently high legibility is maintained on fiber optic CMSs by using a border of 1.1 x the letter height. Lotens' experiments were carried out with relatively young observers; it is not known whether this conclusion applies to older observers who have less sensitivity to contrast. The United Kingdom also specifies in their draft CMS standards that the sign borders should be a

minimum of 1.1 times the height of the upper case letters (32). France specifies that the border must be equal to or greater than the character height (33).

Contrast (Luminance) Ratio

LIMITED RESEARCH SUGGESTS THAT OPTIMUM LEGIBILITY IS OBTAINED WHEN THE CONTRAST RATIO (C') IS BETWEEN 8 AND 12. LEGIBILITY MAY BE REGARDED AS ACCEPTABLE FOR CONTRAST RATIOS BETWEEN 3 AND 25 (28). HOWEVER, THE RESEARCH SUGGESTS THAT LESS THAN 50 PERCENT OF MOTORISTS WILL BE ABLE TO READ THE MESSAGE WELL WHEN THE CONTRAST RATIO IS 3 OR LESS (8).

It is difficult to determine precise contrast ratio limits for light-emitting signs because it depends on the luminance of the ambient environment. Limited objective data are available which provide guidance regarding the optimum contrast ratios for various daytime lighting conditions. The criteria proposed by the United Kingdom are shown in Table 7-5 (32). As noted in the table, for daylight conditions (external illuminance between 4,000 and 40,000 lux), the required contrast ratio ranges between 7 and 50. For reduced lighting conditions (external illuminance between 4 and 400 lux), the required contrast ratio lies between 3 and 25.

French researchers, Bry and Colomb (24), determined that optimum legibility is achieved with contrast ratios between 8 and 12, and acceptable legibility is achieved with contrast ratios between 3 and 25. Contrast ratios below this range make reading difficult. Contrast ratios above this range result in excessive differences in luminance between the legend and the sign background which adversely affects reading. France, therefore specifies that the contrast ratio should be between 3 and 25 for daytime operations (33).

Figure 7-1 shows the results of studies reported by Colomb and Hubert (8) concerning the daytime legibility of light-emitting CMS modules with character height of 12.6 inches (320 mm) observed at 656 ft (200 m) from the modules. The researchers computer the average luminance of the sign modules during the experiment to be 200 cd/m². The luminance of the CMS module characters ranged between 280 and 4,090 cd/m².

As shown in Figure 7-1, the percentage of subjects who correctly read the legend rapidly increased from 10 percent to 50 percent as the contrast ratio (C') rose form 1.5 to 3. The percentage of correct answers continued to increase as the contrast ratio increased, but leveled off at about 85 percent for contrasts between 8 and 20. (The researchers did not study contrast ratios above 20.)

Table 7-5
LIMITS OF CONTRAST RATIO 10° AND 20°
ILLUMINATION DRAFT STANDARDS:
DEPARTMENT OF TRANSPORT,
UNITED KINGDOM (Ref 32)

| External Illuminance | Sign Group A | Sign Group B | Sign Group C |
|----------------------|--------------|----------------------|----------------------|
| 40,000 lux | 7 to 50 | 7 to 50 | 5 to 50 3 to 25* |
| 4,000 lux | 7 to 50 | 7 to 50 | 7 to 50 3 to 25* |
| 400 lux | 3 to 25 | 3 to 25 | 3 to 25 |
| 40 lux | 3 to 25 | 3 to 25 | 3 to 25 0.5 to 3* |
| 4 lux | 3 to 25 | 3 to 25 0.5 to 3* | 3 to 25 0.5 to 3* |
| | | | |
| Fog Setting | 3 to 25 | 3 to 25 | 3 to 25 0.5 to 3* |

*Optional

Group A CMSs

- Warning signs
- Regulatory signs
- Lane Control Matrix Signs
- Signs Conveying an enforceable speed limitation or prohibition
- Signs warning of impending hazard

Group B CMSs

- Motorway advisory signals

Group C CMSs

- Directional information signs
- Other informatory signs
- Information complementing Group A or Group B signs
- Signs for car parks

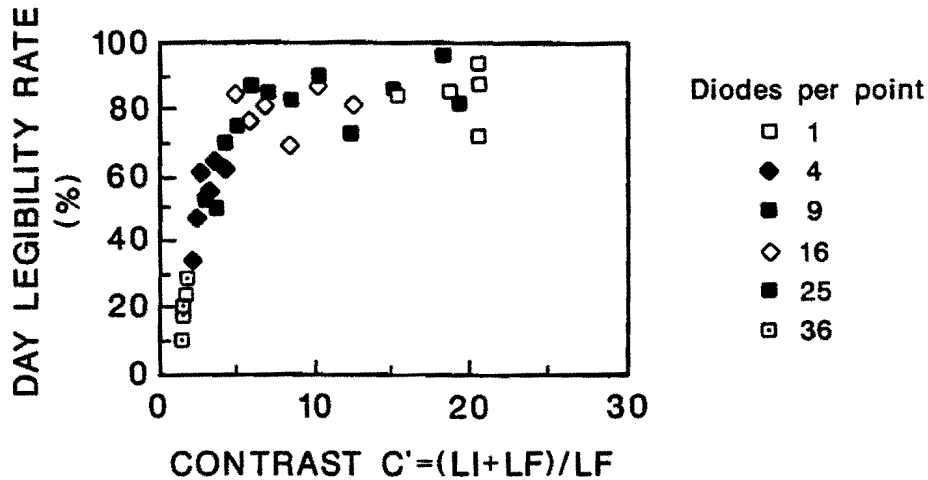


Figure 7-1. Percentage of Letters Correctly Read in Daylight Versus contrast (Ref 8).

Padmos et al. (37) conducted field studies of fixed grid fiber optic signs commonly used in The Netherlands. Five subjects were asked to increase the intensity of the test fiber optic CMS character module until successive criteria were reached. The criteria were as follows:

| Criterion | Description |
|------------|---|
| Visible | Just beyond doubt a light character is visible |
| Legible | Just beyond doubt recognizable |
| Separated | Separation of individual pixels is just visible; the separated lines in pairs are just visible; the character becomes disturbingly frayed |
| Optimum | Optimum luminance; conspicuous but not glaring |
| Merging | Used only after prior separation; separate pixels merge again through irradiation at higher luminance |
| Glaring | Superfluously bright; too ponderous |
| Irradiated | Legibility just starts to decrease through irradiation. |

The subjects viewed the CMS module from a distance of 328 ft (100 m). Based on this study, Padmos et al. were able to plot the relationships between horizontal luminance and message luminance for all the criteria. (See Figure 7-2.)

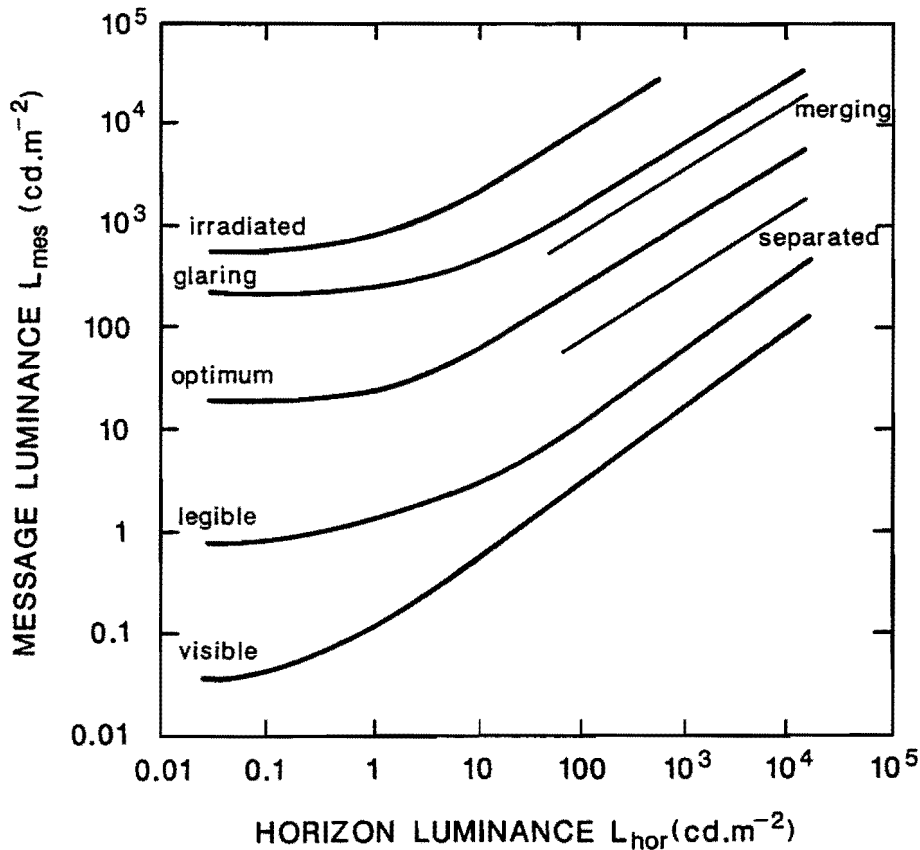


Figure 7-2. Mean Relationships for CMS Legibility Criteria (Ref 41)

Ensuring Sufficient Luminance on CMSs for Daytime Use

Before selecting a CMS, it is important to establish the minimum contrast ratio threshold level for the sign. In addition it is important to determine the 1) amount and degree of the most unfavorable conditions of illumination to which it may be exposed and 2) luminous intensity in conjunction with the optical properties of the front of the sign.

Reading CMSs at Night - Luminance Requirements

In the daytime, both the legend and sign panel luminance are measured in order to determine contrast ratio. At night, only the character luminance intervenes in the determination of luminance requirements since the luminance of the CMS background tends toward zero. Therefore, the luminance of the sign legend is the primary criterion used for determining the legibility of the CMS at night (8).

LIMITED RESEARCH SUGGESTS THAT ABOUT 40 PERCENT OF MOTORISTS HAVE DIFFICULTY IN READING LIGHT-EMITTING CMSs AT NIGHT (8).

Very limited data are available that help to determine the acceptable sign luminance for nighttime applications. Figure 7-3 shows the results of nighttime studies conducted by Colomb and Hubert (8). The percentage of subjects correctly identifying the displayed characters on prototype CMSs are plotted against the luminance of the characters tested which ranged between 9 and 730 cd/m^2 .

The results shown in Figure 7-3 indicate that an average of only 60 percent of the motorist were able to read the prototype CMSs in controlled field tests. The lower performance in comparison to daytime results, according to the authors, is probably explained by the observers' loss of visual acuity at night.

The results also show that the percentage of correct responses was rather consistent throughout the range of message luminance studies. According to Colomb and Hubert, most of the observers judged the highest luminance levels as being uncomfortable. This perceived discomfort, however, did not adversely affect performance because each character was presented long enough for the individual's vision to adapt to the slightly more difficult reading conditions.

Colomb and Hubert felt that the night results did not allow them to deduce precise values of luminance required for reading light-emitting CMSs at night. They, however, referred to their previous study (38) in which simulation was used and which indicated a narrower range of luminance between 30 and 230 cd/m^2 . Accordingly, France specifies a nighttime luminous intensity per pixel of 1 to 5 cd in well lit areas and 0.1 to 1 cd in poorly lit areas for CMSs having 15.7-inch (400-mm) characters (33). The Netherlands specify that on interurban freeways the luminous intensity of the message at night should be between 60 and 100 cd/m^2 for white symbols and between 40 and 60 cd/m^2 for red symbols (7).

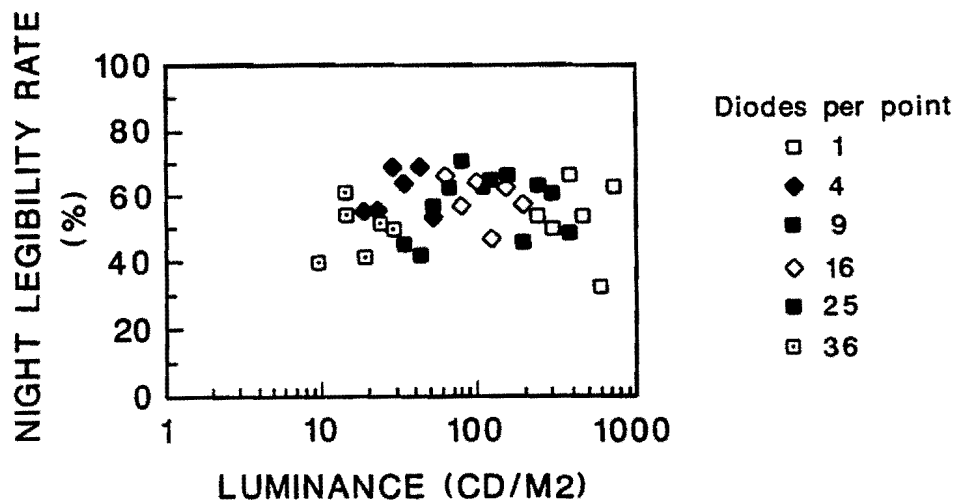


Figure 7-3. Percentage of Letters Correctly Read at Night Versus Contrast (Ref 8)

LIMITED RESEARCH SUGGESTS THAT AT NIGHT THE BEST LEGIBILITY RESULTS ARE OBTAINED WHEN THE LUMINANCE OF THE LEGEND IS BETWEEN 30 AND 230 CD/M² (8).

Irradiation

Character Spacing

Experience has indicated that applying character spacing guidelines currently used for static signs oftentimes results in irradiation problems on light-emitting CMSs--blurring of letters--even while using light-dimming devices.

THE EVIDENCE SUGGESTS THAT IT MAY BE NECESSARY TO SPACE THE CHARACTERS AT DISTANCES GREATER THAN THAT RECOMMENDED FOR STATIC SIGNS. RESEARCH WILL BE REQUIRED TO ESTABLISH MORE DEFINITIVE GUIDELINES.

Light Intensity

To reduce irradiation a variable or step-down photocell control of the power supply is usually necessary to decrease the light intensity of the legend. It may not always be economically feasible to have photocell control which is capable of varying the light intensity of the legend in a continuous fashion with the continuously changing ambient lighting conditions. A discrete step-down system is, therefore, oftentimes used.

Lamp and Emitter Replacement for Message Readability

The failure of lamps or other emitters on a light-emitting matrix sign directly affects the readability of the display. A character module for a light-emitting matrix CMS is generally made up of a 5 x 7 set of lighted pixels.

Lamp failure will generally degrade the appearance of the display to an unacceptable level before readability is seriously impaired. A national sign manufacturer recommends that all lamps be replaced at or before 10 percent failure levels (normally 9 to 12 months). Adherence to this practice will suffice in maintaining adequate readability.

Reduced Sign Visibility Due to Sun Interference

Sun Behind the Sign

At least four things (not all practical) can be done to help alleviate the problem when the sun is behind the CMS:

1. Increase the size of the sign panel,
2. Increase the luminance of the sign characters,
3. Reduce the length of the sign message, and
4. Avoid west-southwest and east-northeast CMS positioning.

Sunlight can be a significant problem to CMS legibility if, from the driver's perspective, it appears behind the CMS. One way to reduce the problem when drivers must simultaneously look at a CMS and bright sunlight is to increase the surface size of the CMS. (Although the driver's sun visor can help in some situations, the sun visor is of no use when the sun is below or equal to the signboard altitude.) Unfortunately, it is neither practical nor feasible to construct a CMS board large enough to completely compensate for the sun position. (One author estimated that for a proposed site having an overhead CMS with a legibility distance of 900 ft, a 328-ft CMS panel would be required to completely compensate for the sun positions behind the sign (35).)

As a minimum, the CMS should have a background buffer surrounding the sign characters according to the criteria suggested earlier in this chapter.

Another measure that can be taken to compensate for the dazzle created by sun, is to increase the luminance of the sign characters in order to increase the contrast ratio between the sign characters and the ambient background without causing irradiation.

It is important to remember that the legibility distance is greatly reduced when the sun is behind the CMS. Consequently, the messages displayed must be necessarily shorter than under normal conditions.

Obviously, no practical solution exists for compensating for the sun background. The best solution is to, if possible, avoid west-southwest and east-northeast positioning of CMSs.

Sun Facing the Sign

Legibility of light-emitting CMSs is adversely affected when sunlight falls directly on the sign face. Sunlight reflecting directly off the lamps, glass fiber pixels, LED pixels, etc., reduces the contrast between the sign message and background. In addition, screens used to protect the face of CMSs, regardless of material type, will reflect sunlight, thus producing glare which could further reduce the legibility of messages.

At least three things can be done to reduce the effects of the sun shining directly on the face of the CMS:

1. Use a sun screen or shield,
2. Use a black matte finish on the face, and/or
3. Tilt the sign.

Accentuation

In reading multilined CMS messages, drivers will typically read top-to-bottom even when there is limited time to scan the CMS. Experimentally, attempts have been made to alter the order of reading the lines by accentuating the second or third line via use of red lights, flashing lights, and double-stroke characters on one line only. In general, experimental accentuation attempts have been unsuccessful although red colored lights were more successful in directing attention than the other techniques (19).

8. VISIBILITY AND LEGIBILITY CRITERIA - LIGHT REFLECTING SIGNS (4)

This chapter focuses on factors affecting the target value and legibility of light-reflective CMSs.

Light-Reflecting CMSs

The most common types of light-reflecting CMSs are shown below. The first two categories include light-reflecting CMSs that resemble static signs in appearance. Brightness contrast, color contrast, character size and spacing, and coding criteria that have been developed for static signs would be applicable to this group of light-emitting CMSs.

| Category | Type |
|----------------------------|--|
| Static w/ beacons | Static message signs with flashing beacons |
| Electromechanical | Rotating drum (prism) |
| Electromechanical (Matrix) | Reflective Disk Matrix |

The third category, electromechanical (matrix), are those which use matrix configurations to form the legends on the signs. Some criteria developed for static signs still apply. However, font style is an additional issue that must be addressed.

Character Height and Legibility - Matrix Signs

FOR MOST FREEWAY APPLICATIONS, CMS SHOULD HAVE CHARACTERS AT LEAST 18 INCHES (457 mm) IN HEIGHT.

Studies have shown that CMSs used on freeways should have character heights of at least 18 inches. Most light-reflecting matrix CMSs used on highways are capable of displaying three lines of message with 18-inch (457-mm) high characters. Some light-reflecting CMSs, such as the reflective disk matrix sign, can also be programmed to display oversized triple-line, blocked letters.

Available data on the legibility of matrix signs are very limited. The results of a legibility study conducted on I-279 near Pittsburgh with 20 subjects viewing overhead reflective disk signs while driving in traffic are presented in Table 8-1. The results of a study done in the Phoenix area under different lighting conditions are shown in Table 8-2.

**Table 8-1
DAYLIGHT LEGIBILITY DISTANCES FOR 18-INCH
REFLECTIVE DISK MATRIX SIGN (Ref 3)**

| Character Style | Legibility Distance (ft) | |
|--------------------------------------|--------------------------|-----------------|
| | 50th Percentile | 85th Percentile |
| WORD, single-line single-stroke | 725 | 500 |
| NUMBER, single-line single-stroke | 600 | 475 |
| WORD, triple-line, blocked | 1,850 | 1,350 |
| NUMBER, triple-line, blocked | 800 | 475 |

**Table 8-2
AVERAGE LEGIBILITY DISTANCES
FOR DISK MATRIX SIGNS
UNDER DIFFERENT
LIGHTING CONDITIONS (Ref 30)**

| Condition | Legibility Distance (ft) |
|-----------|--------------------------|
| Daylight | 698 |
| Night | 355 |
| Washout | 420 |
| Backlight | 219 |

Font Style - Matrix Signs

See Section on "Font Style" in Chapter 7.

Spacing of Pixels - Matrix Signs

A schematic of a typical 5 x 7 module for a circular disk matrix CMS was shown earlier in Chapter 6, Figure 6-2. McDonald et al. found that with the equal dot spacing presently offered in manufactured circular disk matrix CMSs, the width-to-height ratios are approximately 0.7. Laboratory and proving ground studies conducted by McDonald et al. of ten matrix configurations with width-to-height ratios between 0.5 and 1.0 where the vertical and horizontal separations did not exceed one dot diameter, indicated that the spacing of the dots should be arranged to achieve a width-to-height ratio approaching 1.0. For circular disks with a 5 x 7 matrix, this is best achieved with no vertical separation and a half dot separation on the horizontal. Width-to-height ratios above 1.0 were not tested. (39)

Spacing of Characters - Matrix Signs

The laboratory and proving ground studies conducted by McDonald et al. indicated that on circular disk CMSs, a 2 dot separation between letters provides better overall performance than a 1 dot separation. (39)

Also see Section on "Spacing of Characters, Words and Lines" in Chapter 7.

Size of Sign Borders - Matrix Signs

See Section on "Size of Sign Borders" in Chapter 7.

Color Contrast - Matrix Signs

Of four colors (white, yellow/orange, saturn yellow and red/orange) tested by McDonald et al., saturn yellow was clearly the color giving the longest legibility distance over a range of daytime and nighttime lighting conditions (39).

Reduced Sign Visibility Due to Sun Interference

Sun Behind the Sign

See Section on "Sun Behind the Sign" in Chapter 7.

Sun Facing the Sign

A condition that arises that requires attention is when the sun is facing the CMS. For light-reflecting CMSs, such as the reflective disk and the hinged flap, direct sun light on the signs will ordinarily enhance legibility. However, all light-reflecting CMSs are equipped with a clear sign face (usually Lexan) in order to protect the moving parts (e.g., disks, flaps, etc.) by sealing them from the unfriendly environment. The clear protective sign face causes incompatibilities between daytime and nighttime needs. An anti-glare Lexan sign face is the best for daytime viewing as it significantly decreases extraneous reflections but it is no good at all in nighttime conditions (with additional illumination) as it scatters the incident light in hazy patches thus obscuring the message. A clear Lexan sign face is the best for nighttime illumination (whether interior or exterior) but reflects random images in the daytime which degrade legibility of the display. All light-reflecting CMS technologies have these problems. (5)

Also see Section on "Sun Facing the Sign" in Chapter 7.

Reduced Legibility Due to Lighting Interferences

External and internal lighting used with light-reflecting CMSs oftentimes casts shadows on the legend that make the message illegible. Also, external lights reflect off the Lexan face covering which results in the same type of legibility problems described in the previous section on sun interferences.

Accentuation

See Section on "Accentuation" in Chapter 5.

9. GUIDELINES FOR ADVISORY SIGN LOCATION IN URBAN AREAS (3)

General Location Guidelines

- **LOCATE ADVISORY CMSs UPSTREAM OF BOTTLENECK AND HIGH ACCIDENT LOCATIONS.**
- **MAKE SURE ADVISORY CMSs ARE UPSTREAM OF MAJOR "DECISION POINTS" (RAMPS AND INTERCHANGES THAT WILL BE USED FOR DIVERSION).**
- **FREEWAY-TO-FREEWAY INTERCHANGES ARE MAJOR DECISION POINTS. CONSIDER LOCATING CMSs IN ADVANCE OF THESE MAJOR INTERCHANGES.**
- **CMSs SHOULD NOT BE LOCATED WITHIN A MAJOR INTERCHANGE.**
- **AVOID USING CMSs LOCATED UPSTREAM OF A FREEWAY-TO-FREEWAY INTERCHANGE TO DIVERT TRAFFIC TO RAMPS DOWNSTREAM OF THE INTERCHANGE.**

General Spacing Guidelines

Two factors affect the initial spacing requirements of CMSs used for incident management and diversion to major generators. Unfortunately, the factors result in conflicting requirements for sign spacing. First of all, cost considerations dictate the need to space the signs as far apart as possible. Secondly, long messages must be "chunked" and displayed on two signs. Ideally, the two signs should be close to each other so that the drivers can relate the message on the second sign to that on the first sign. Also, driver recall of the message may be affected if the signs are too far apart.

Although not conclusive, the information reported thus far seems to indicate that, from an operational standpoint, a spacing of at least 3/4 mile (1.2 km) seems to work well when addressing a bottleneck area.

Location with Respect to Exit Ramps and Advance Guide Signs

THE ADVISORY CMS MUST BE LOCATED UPSTREAM OF THE EXIT DIRECTION SIGN OF THE RAMP USED FOR DIVERSION.

When the CMS tells drivers to use a specific ramp, it must be located upstream of the Exit Direction Sign for that ramp. Otherwise, drivers will not have enough time to change lanes and prepare to exit. Also, erratic and hazardous driving maneuvers are likely to be made by familiar drivers. Unfamiliar drivers will most likely miss the exit.

WHEN THE EXIT RAMP HAS BOTH 1-MILE (1.6 KM) AND 2-MILE (3.2 KM) ADVANCE GUIDE SIGNS, THE RECOMMENDED LOCATION FOR THE ADVISORY CMS IS BETWEEN THE TWO ADVANCE GUIDE SIGNS. (SEE FIGURE 9-1).

This will better prepare the drivers for the exit maneuver to that ramp. (Note: the preceding recommendation applies to the location with respect to the nearest exit ramp that will be used for diversion. The CMS can also be used to divert traffic to ramps farther downstream.)

IN URBAN AREAS WHERE THE ADVANCE GUIDE SIGNS ARE PLACED CLOSER TO THE EXIT BECAUSE OF CLOSELY SPACED INTERCHANGES, THE ADVISORY CMS CAN BE LOCATED BETWEEN THE TWO ADVANCE GUIDE SIGNS, PROVIDED THE ADVANCE GUIDE SIGN CLOSEST TO THE RAMP IS AT LEAST 1/2 MILE (0.8 KM) FROM THE RAMP. WHEN QUEUING IS ANTICIPATED UPSTREAM OF THE RAMP, THE ADVISORY CMS SHOULD BE LOCATED UPSTREAM OF THE TWO ADVANCE GUIDE SIGNS. (SEE FIGURE 9-2).

It is important to remember that drivers are not anticipating changing routes until they read the message on the CMS. Thus, the group of drivers to whom the message applies may be distributed somewhat uniformly across all lanes. The drivers in the inside lane must have ample opportunity to read the message and change lanes for exiting.

WHEN INTERCHANGE SEQUENCE SIGNS ARE USED FOR CLOSELY SPACED INTERCHANGES IN URBAN AREAS, THE ADVISORY CMS SHOULD BE LOCATED UPSTREAM OF AT LEAST TWO ADVANCE INTERCHANGE SEQUENCE SIGNS FOR THE RAMP USED FOR DIVERSION. (SEE FIGURE 9-3).

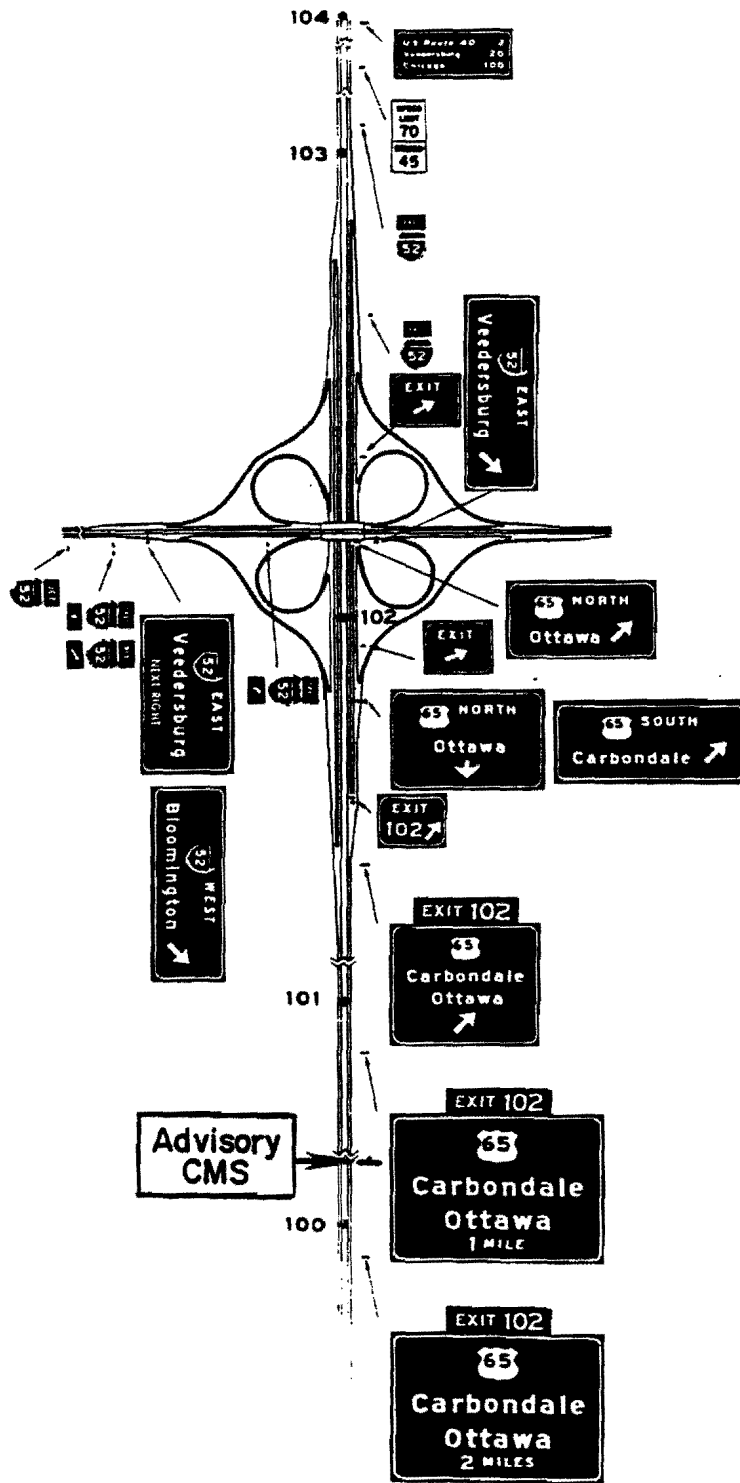


Figure 9-1. Recommended Advisory CMS Location When 1-Mile and 2-Mile Advance Exit Signs Are Available (Ref 3)

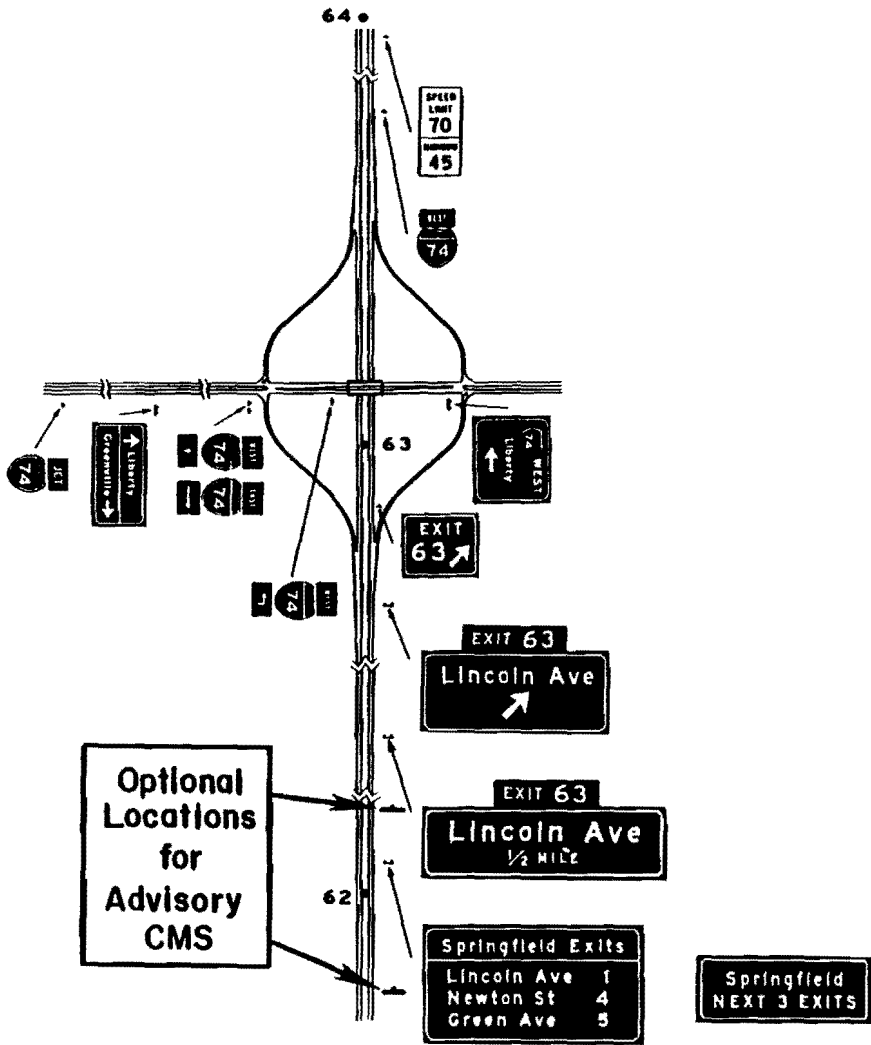


Figure 9-2. Recommended Advisory CMS Locations When Advance Exit Signs Are Close to Ramp (Ref 3)

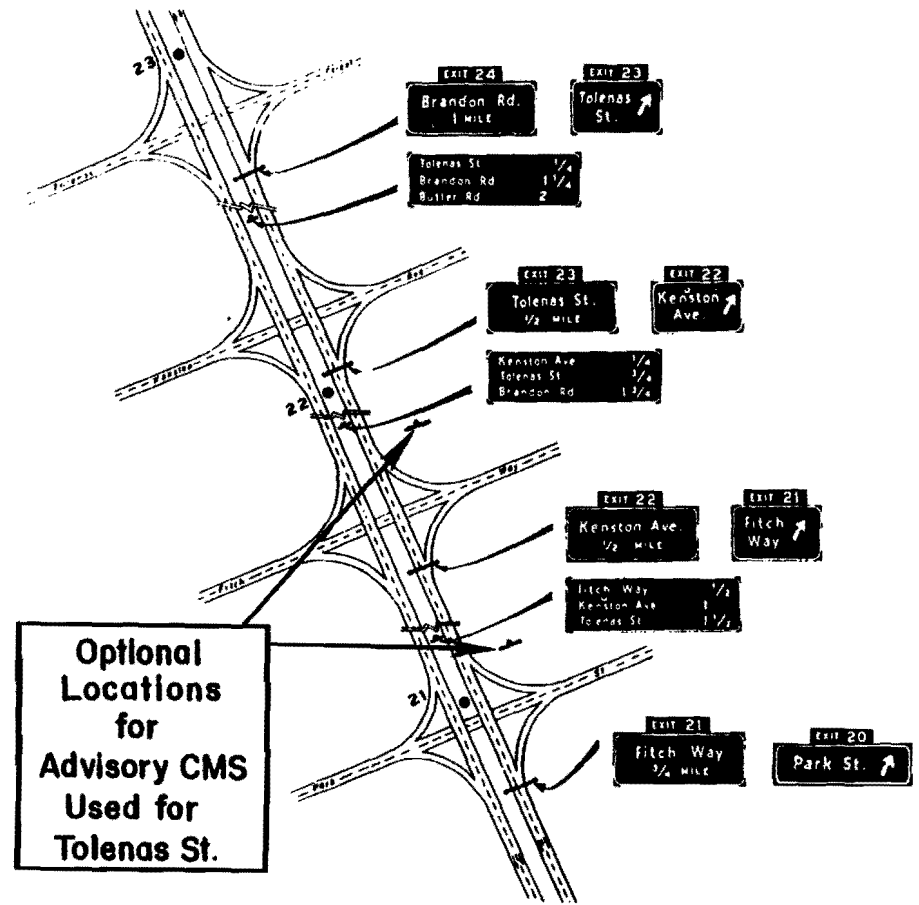


Figure 9-3. Recommended Advisory CMS Location When Interchange Sequence Signs Are Used (Ref 3)

Spacing Between the Advisory CMS and Advance Guide Signs

THE RECOMMENDED MINIMUM SPACING BETWEEN THE ADVISORY CMS AND A DOWNSTREAM ADVANCE GUIDE SIGN IS 1,000 FEET (300 M).

The MUTCD recommends an 800-ft. (240 m) minimum spacing between guide signs. Due to longer decision-reaction times associated with diversion messages, greater distances are required for drivers to make decisions. The authors believe that at least 1,000 feet (300 m) is needed for drivers to make this unexpected decision and then to read the upcoming Advance Guide Sign.

RECOMMENDED MINIMUM SPACING BETWEEN THE ADVISORY CMS AND AN UPSTREAM ADVANCE GUIDE SIGN WILL DEPEND UPON SEVERAL FACTORS, INCLUDING MESSAGE LENGTH, MESSAGE FORMAT, AND OPERATING SPEED. RECOMMENDED MINIMUMS ARE PROVIDED IN TABLE 9-1 FOR A 55 MPH (88.5 KM/HR) OPERATING SPEED AND A 20-FOOT (6.1 M) SIGN PLACED 20 FEET (6.1 M) FROM THE EDGE OF THE SHOULDER LANE.

The minimum distance between the CMS and an upstream Advance Guide Sign is composed of three elements.

- Minimum message exposure distance
- Distance from the point where the CMS is out of clear vision to the location of the CMS
- 350 ft. (106.4 m) additional visibility distance

The sum of the minimum exposure distance (determined from minimum message exposure time) and the "dead space" is the minimum required message legibility distance.

The third component is 350 ft. (106.4 m) of additional visibility distance. The additional visibility distance is added to allow the drivers time to recognize that the sign is displaying a message and, in the case of unfamiliar drivers, to recognize the existence of the CMS.

**Table 9-1
RECOMMENDED MINIMUM SPACING BETWEEN
SIDE-MOUNTED ADVISORY CMSs AND UPSTREAM
ADVANCE GUIDE SIGNS FOR AN OPERATING
SPEED OF 55 MPH (88.5 KM/HR)**

| Number of Freeway Lanes (One Direction) | Minimum Spacing (ft.) | | |
|---|--|-----------|-----------|
| | Required Minimum Message Exposure Time | | |
| | 4 seconds | 6 seconds | 8 seconds |
| 2 | 950 | 1100 | 1250 |
| 3 | 1050 | 1200 | 1350 |
| 4 | 1100 | 1250 | 1400 |

1 ft. = .304 meters

Notes:

Distances are for side-mounted signs 20 ft. (6.1 m) wide placed 20 ft. (6.1 m) from the shoulder lane.

Values in Table 9-1 are the sums of the following distances:

- Minimum message exposure distance
- Distance at which the CMS is out of cone of clear vision
- 350 ft. (106.4 m) additional visibility distance

The sum of the minimum message exposure distance and the distance at which the CMS is out of cone of clear vision is equal to the required minimum legibility distance.

10. ASSESSMENT OF CMS TECHNOLOGY RELIABILITY AND MAINTENANCE REQUIREMENTS AND COSTS

Reliability Comparison of Selected CMS Technologies

This section of the chapter is largely adapted from the Ontario Ministry of Transportation Report entitled, "Technology Evaluation for Changeable Message Signs - Summary Report" (5). The Ontario report contained the most comprehensive written information on the reliability comparison of several CMS technologies at the time the present report was prepared. Therefore, the reliability discussion that follows basically reflects one agency's subjective view of the reliability comparison of CMS technologies. This is supplemented with information the author received via telephone conversations with other selected highway agencies. As reported in Chapter 1, a comprehensive nation-wide survey will be conducted by NCHRP of the reliability and maintenance requirements of the various CMS technologies. The reader is advised to review the results of the NCHRP survey and to consult with other highway agencies that are using CMSs to obtain more specific information on experiences. Also, the reader is advised to consult with CMS manufacturers and suppliers, who are continually improving the hardware, to obtain information on the latest products.

Electromechanical Signs

The reliability of electromechanical technologies used in the sign display industry is rated on the number of successful movements (changes) of certain display parts. Although, as a rule, individual components do not tend to wear, the most prevalent failures can be traced to the environment (i.e., dust, salt, ice, temperature, etc.). Exposure to the rugged highway environment can tend to "lock" some of the moving parts. (5)

Reflective Disk Signs

The Ontario Ministry of Transportation reported a 4 percent yearly failure rate of individual display parts with the reflective disk sign on the Queens Expressway in Toronto. The most prevalent cause of failures were that disk pivots tend to "lock" due to accumulated dust, salt, and ice. The majority of the failures occurred in the winter months and were attributed to higher concentrations of airborne particles in the environment and lower temperatures. (5)

Regular maintenance of the reflective disk signs in Toronto is undertaken twice each year to keep the number of locked disks to less than 2 percent, and consists of cleaning the disks with compressed air. Although the material cost is very small, each scheduled maintenance procedure requires three man-days to complete. (5)

Maintenance of external or internal lighting used to illuminate the sign face is an additional problem that must be addressed. (5)

Light-Emitting Changeable Message Signs

Incandescent Bulb Signs

There are no moving parts in incandescent bulb signs. One of the greatest concerns relative to reliability and maintenance is life of the bulbs themselves. The life of the bulb depends mainly on duration of on-time. The bulb life is adversely affected by vibration, inrush current, cycling and rain. Conversely, decreasing the input voltage increases bulb life significantly. Careful consideration of these factors in the design of the mounting and electrical hardware can prolong the bulb life. (5)

Fixed-Grid Fiber Optic Signs

Fiber optic CMSs that have a fixed set of preprogrammed messages are very popular in western European countries such as Belgium, France, Germany and The Netherlands. No moving parts are required to display messages on fixed-grid fiber optic signs. Messages are changed merely by activating a switch. Reports from western Europe indicate that the signs have very high reliability and very little maintenance is required. The most frequent maintenance activity is a periodic replacement of one of the halogen lamps. (40)

Shuttered Fiber Optic Signs

Shuttered fiber optic signs are a combination of electromechanical shutters and halogen lamps. Lamp reliability depends greatly on input voltage which controls the brightness of the signs. The mechanical shutter is susceptible to environmental conditions similar to the electromechanical technologies. Earlier versions of the shuttered fiber optic CMSs indicated considerable problems with the electromechanical shutters. (5) Recent experiences in France, however, indicate that the shutter problems have been considerably reduced as a result of improvements to the shutter mechanism by the sign manufacturer (11).

Light-Emitting Diode Signs

Clustered LED CMSs are beginning to be used in North America for highway applications. The major advantages of LEDs are low power consumption, high efficiency and excellent reliability. Since there are no moving parts in LED CMSs, their reliability should be less dependent on the environmental conditions (e.g., dirt, salt, ice, etc.) that adversely affect electromechanical signs. However, temperature control within the sign is necessary in order to reduce the effects of extreme ambient temperatures. Hermetic enclosures are made of durable plastic or glass that is resistant to ultraviolet radiation. (5)

The super bright LEDs are rated for 100,000 hours of continuous operation at the rated voltage. The life is further extended by the LEDs' off periods and by underrating the input voltage. Brightness reduction using pulse width modulation (PWM) for night viewing also increases the life of LEDs (e.g., 7 minutes of continuous operation at full brightness "fatigues" an LED as much as 12 hours of night operation). LEDs are subject to degraded operation under high temperatures. Therefore, adequate ventilation and cooling must be provided. (5)

Light Source/Electromechanical Signs

Fiber Optic/Reflective Disk Signs

Insufficient information is available concerning the reliability and maintenance requirements for the FO/RD technology because of its recent introduction for highway applications. The FO/RD sign has features similar to both the reflective disk and fiber optic technologies.

Maintenance Considerations

NCHRP Synthesis 61 (2) and Synthesis 12 (41) list the following questions with respect to maintenance which a highway agency should consider:

1. What do you know about the supplier you are dealing with? Can he help you tomorrow? Ten years from now? How long has he been in the business?
2. Have you considered what would happen if the supplier's business fails?
3. Does he have the resources to help you with a tough problem that requires technological know how?
4. Will you get professional counseling as part of your purchase? If not, how much will it cost?
5. Who will train your people to use the equipment? Will they come back to train new people when needed? Is there a cost for this service?
6. How much space will the system require?
7. How often in the past year have you had to add or change equipment? Will you have this same requirement next year? Will you be able to arrange such changes easily?

8. How much does it cost to add equipment? Disconnect it? Move it?
9. Does the supplier make it a practice to design systems with adequate room for expansion?
10. Does the supplier keep up with rapid changes in technology? Will you be able to add new features or other new service developments? Will the system be obsolete before it is fully depreciated?
11. What does the warranty cover? For how long? What is the cost of parts not covered by the warranty?
12. What happens if your equipment doesn't perform as promised? Has your attorney checked your contract to see if the terms of performance are spelled out?
13. What happens if there is a commercial power failure? Will the program in computer memory be destroyed? What is the cost of temporary standby power?
14. How much will it cost to insure your own equipment? If you buy, is your present insurance contract adequate?
15. Is maintenance included in the total purchase or lease/purchase price? If maintenance isn't included, exactly how much will parts and labor cost? What are the costs of maintenance contracts after the first few years?
16. How many maintenance men are employed by the supplier? Where are they located?
17. What are the hours of the maintenance representatives? How fast will they respond to your calls for service? Can you get 24-hour emergency trouble service if needed? Can you get weekend service if necessary? Do you pay overtime charges?
18. Are all parts and supplies you will need readily available? Will spare parts be available in 5 years? 10 years? 15 years?

Ontario Ministry of Transportation CMS Maintenance Cost Analysis

The Ontario Ministry of Transportation performed cost analyses to compare the long term estimated costs of different technologies using the proposed Highway 401 CMS matrix design shown previously in Chapter 2, Figure 2-8. Some cost analyses results of interest for several CMS technologies are shown in Table 10-1. The assumed number of service calls per year and the breakdown of labor and materials costs are given in Table 10-2 (5).

**Table 10-1
CHANGEABLE MESSAGE SIGN COST SUMMARY
PERFORMED BY THE ONTARIO MINISTRY OF TRANSPORTATION (Ref 5)**

| | Annual Energy Maint. | Annual Routine Maint. | Annual Emergency Total | Total Annual Cost | 10 Year Opertns |
|---------------------------------|----------------------|-----------------------|------------------------|-------------------|-----------------|
| LED Cluster | \$ 760 | \$ 8,620 | \$4,200 | \$13,580 | \$135,800 |
| Fiber Optic/ Reflective Disk | \$ 280 | \$ 6,780 | \$4,400 | \$11,260 | \$112,600 |
| Fiber Optic- Shuttered | \$ 820 | \$10,450 | \$5,020 | \$15,470 | \$154,700 |
| Reflective Disk | \$ 640 | \$12,820 | \$4,200 | \$17,660 | \$176,600 |
| Incandescent Bulb | \$5,000 | \$19,630 | \$3,000 | \$28,830 | \$288,300 |
| LCD Backlit | \$3,000 | \$14,340 | \$5,000 | \$22,340 | \$223,400 |

**Table 10-2
ESTIMATED YEARLY MAINTENANCE CALLS AND COST
(\$1989 PER SIGN) -
ONTARIO MINISTRY OF TRANSPORTATION (Ref 5)**

| | Calls/Year | Labor Costs | Material Costs |
|---------------------------------|------------|-------------|----------------|
| LED Cluster | 3 | \$ 3,260 | \$ 5,360 |
| Fiber Optic/ Reflective Disk | 5 | \$ 5,140 | \$ 1,640 |
| Fiber Optic- Shuttered | 5 | \$ 7,090 | \$3,360 |
| Reflective Disk | 5 | \$ 6,930 | \$ 5,890 |
| Incandescent Bulb | 15 | \$33,400 | \$19,370 |
| LCD Backlit | 5 | \$ 6,940 | \$ 7,400 |

Power Requirements of CMSs

The choice of CMSs will be dictated by several factors including message requirements and flexibility, target value, legibility, operational considerations, and cost. In addition to the initial cost, the highway agency should also consider the operating costs of the CMSs throughout the life expectancy of the signs. Power consumption is an important cost element. Table 10-3 presents power consumption estimates made in 1974 for various types of CMSs (2,42).

The Ontario Ministry of Transportation in 1989 estimated that for the clustered LED CMS under consideration by the Ministry (Chapter 2, Figure 2-8) the internal illumination with fluorescent lamps would bring the power consumption to approximately 2,800 Watts. It was further estimated that bulb matrix signs at full brightness would consume approximately 30 kW if 30-Watt reflector lamps are used. Shuttered fiber optic signs would consume approximately 5 kW of electric power. The FO/RD technology uses four 400-Watt High Pressure Sodium lamps with a power consumption of approximately 1920 Watts at full brightness. LED cluster signs have a low power consumption of 2000 Watts at full brightness. (5)

Estimated power consumptions include 150 Watts for the controller, 800 Watts for cabinet heating and a "housekeeping" allowance of 800 Watts for a signcase. Manufacturers should be consulted for more precise estimates when the sign size and feature requirements are known by the highway agency.

**Table 10-3
APPROXIMATE POWER REQUIREMENTS
FOR VARIOUS SIGN TYPES (1977) (Ref 48)**

| Sign Type | Power Req. (kW) | Description |
|-------------------------|-----------------------------------|--|
| Fixed, no flashers | 0 | |
| Flashers (2) | 0.1 -0.2 | |
| Neon | 0.2 | 8 letter, 10 in. high |
| Hinged panel | 0.4 0 | during face change other times |
| Scroll | 0.2 0.15-0.35 0.4 - 1.2 | during face change internal lighting heat if needed |
| Drum | 0.5 - 1.0 0.15-0.35 0.3-1.0 | during face change heating each drum, if needed external lighting |
| Vane Matrix | 0.05-0.1 0.1-0.4 | control unit lighting |
| Disk Matrix | 0.7 0.6 | control unit and heater or blower external lighting |
| Portable bulb matrix | 1.0-1.5 2.0 | typical message maximum |
| Bulb matrix | 0.011-0.015 2.0-5.0 | each bulb typical single line |

Note: Annual Cost = Power Requirement (kW) x
cost per kW-h x number of hours per year

Example: Maximum cost for a two-drum sign that:

- undergoes face changing 20 h/year
- is heated 2000 h/year
- is illuminated 4000 h/year
- assumed cost of electrical power is \$0.05/kW-h

$$(1.0 \text{ kW})(\$0.05/\text{kW-h})(20\text{h/year}) + (2 \text{ drums} \times 0.5 \text{ kW/drum})$$

$$(\$0.05/\text{kW-h})(2000 \text{ h/year}) + (1.0 \text{ kW})(\$0.05/\text{kW-h})$$

$$(4000 \text{ h/year}) = \$301/\text{year}$$

11. SELECTING THE APPROPRIATE CHANGEABLE MESSAGE SIGN (4)

Recommended Selection Process

As might be expected, the selection of the appropriate CMS is a complex task requiring trade-offs between display capability to fulfill a specific need and display cost (including operating and maintenance considerations). Further complicating the selection process is the large number of signing techniques available, each possessing quite different design and operating features.

The agency should take an objective approach to selecting the type of CMS for each application. Each type of CMS has unique advantages and features that can provide valuable service depending upon the specific needs of the agency. It is also important to remember that what may be considered as an implied disadvantage of a CMS for one application may be an advantage for another application.

The recommended procedure for determining the types of CMSs that will be acceptable for a given application is as follows:

1. Clearly establish the objectives of the CMS.
2. Prepare the messages necessary to accomplish the objectives.
3. Determine legibility distance required to allow motorists ample time to read and comprehend the messages.
4. Determine locations of the CMS which allows motorists ample distance to read, comprehend and react to the messages.
5. Identify type and extent of localized constraints that might affect the legibility of the CMS.
6. Identify the environmental conditions under which the CMS will operate.
7. Determine the target value and legibility of candidate CMSs.
8. Determine costs of candidate CMSs.
9. Select the CMS that will allow the selected messages to be read under all environmental conditions within the cost constraints of the agency.

Too often, agencies will purchase CMSs before signing objectives and messages are determined. The consequence is disappointment in the inability of the CMS system to display the appropriate messages, and in lower than expected target value and legibility for the environmental conditions present at the site.

The above procedure is an iterative process. Therefore, it is likely in practice that some of the steps will be repeated. The sections that follow summarize some of the issues involved in the procedure. It should be emphasized that the steps, although listed and discussed individually, are interrelated.

1. Clearly Establish the Objectives of the CMS

The importance of setting signing objectives cannot be overemphasized because the objectives directly influence message content, format, length, and redundancy, and consequently, the size and placement of the CMS.

2. Prepare the Messages Necessary to Accomplish the Objectives

Once the objectives are set, then the various CMS messages necessary to accomplish the objectives should be developed. The length of the messages will help define the character size, message line length, and number of message lines required on the CMS. At this stage, it may be necessary to modify some of the messages to reduce their lengths as a result of conditions determined in steps 3 through 9.

3. Determine Required Legibility Distance

Using the guidelines presented in this report, the legibility distance required to allow motorists ample time to read and comprehend the messages is determined.

4. Determine Location of CMS

Based on the required legibility distance, the potential locations for the CMS are determined which will allow ample time for motorists to read, comprehend and then react to the messages. The CMS must be placed such that the CMS and existing static signs form an integrated and compatible system of information.

5. Identify Type and Extent of Localized Constraints

Field inspections are advisable to ensure that there are no physical obstructions due to bridges, sign structures, geometries, etc. that would adversely affect CMS legibility. In addition, field inspections will also help determine whether or not it is possible to actually install a CMS at the site. Obstruction problems would require that the agency either relocate the CMS or reduce the length of the messages.

6. Identify Environmental Conditions

The environmental conditions in which the CMS must operate should be clearly identified. Weather conditions such as snow, rain, etc. and other conditions such as blowing dust, heat, cold, etc. will have an effect on the sign's operation and will, in most cases affect the legibility of the messages. These environmental conditions should be made known to the manufacturer so that the best CMS performance characteristics can be achieved.

7. Determine Target Value and Legibility of Candidate CMSs

An obviously important, but unfortunately elusive, step is to determine the target value and legibility of the candidate CMSs that are being considered by the agency. Little published objective data is available that will help to determine target value and legibility. There are many subjective claims made concerning the legibility distances of selected types of CMSs but they have not been substantiated via well-balanced objective field studies. One recommended approach that can be used by the agency in the absence of objective CMS legibility data is to have each potential manufacturer furnish one CMS, install the signs side-by-side, and conduct an evaluation of the candidate signs. An evaluation of the capabilities of the CMSs may dictate the need to reduce the message length or to require the manufacturer to modify the hardware and/or electronics to improve legibility.

8. Determine Costs of Candidate CMSs

Detailed cost analyses should be made of the candidate CMSs.

9. Select CMS Type

The CMS can be selected based on satisfying the system requirements.

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