Guidelines on the Use of Changeable Message Signs--Summary Report

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16. Abstract

This report is a summary of some of the information that was assembled and presented in final report FHWA-TS-90-043 entitled, ‘Guidelines on the Use of Changeable Message Signs”. The final report provides guidance on 1) selection of the appropriate type of CMS display, 2) the design and maintenance of CMSs to improve target value and motorist reception of messages, and 3) pitfalls to be avoided, and it updates information contained in the 1986 FHWA publication “Manual on Real-Time Motorist information Displays.” The guidelines and updated information are based on research results and on practices being employed by highway agencies in the United States, Canada and western Europe. CMS technology developments since 1984 are emphasized.

This summary report focuses on matrix-type CMSs, with particular attention to the newer light-emitting signs. Although there are many types of new and emerging CMSs technologies, CMSs that have actually been installed for highway applications are emphasized.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd □ 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2 = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2 = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (Lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp □ 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] ^{o}F □ y ^{o}C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliters (ml) □ 0.03 fluid ounce (fl oz)
1 liter (1) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] ^{o}C □ x ^{o}F

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10

CENTIMETERS: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 25.40

QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10286.

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1. INTRODUCTION

Background

Real-time motorist information displays, particularly changeable message signs (CMSs), are playing increasingly important roles in attempts to improve highway safety, operations, and use of existing facilities. Highway CMSs are traffic control devices used for traffic warning, regulation, routing and management, and are designed to affect the behavior of motorists (thus improve the flow of traffic) by providing real-time highway related information.

The 1986 FHWA publication "Manual on Real-Time Motorist Information Displays" (1) provides practical guidelines for the development, design, and operation of real-time displays, both visual and auditory. The emphasis in the Manual is on the recommended content of messages to be displayed in various traffic situations; the manner in which messages are to be displayed-format, coding, style, length, load, redundancy, and number of repetitions; and where the messages should be placed with respect to the situations they are explaining.

The use of matrix-type CMSs, particularly light-emitting technologies, has increased in recent years. In spite of the increased use of matrix CMSs, there have been no documented guidelines relative to desirable physical design features. Toward this end, the Office of Implementation of FHWA sponsored work to consolidate available information relative to the latest CMS technologies. The results are published in an FHWA report entitled, "Guidelines on the Use of Changeable Message Signs." (2) The report provides guidance on 1) selection of the appropriate type of CMS display, 2) the design and maintenance of CMSs to improve target value and motorist reception of messages, and 3) pitfalls to be avoided, and it updates information contained in the "Manual on Real-Time Motorist Information Displays." The guidelines and updated information are based on research results and on practices being employed by highway agencies in the United States, Canada and western Europe. CMS technology developments since 1984 are emphasized.

Purpose and Scope

This report is a summary of some of the information that has been assembled and presented in the FHWA report, "Guidelines on the Use of Changeable Message Signs". This summary report focuses on matrix-type CMSs, with particular attention to light-emitting signs. Although there are many types of new and emerging CMSs technologies, CMSs that have actually been installed for highway applications are emphasized. Other emerging CMS technologies that have not been installed and tested in highway applications (e.g., liquid crystal, fluid cell, cathode ray tube, and laser scan) are not addressed.

As a prelude to the discussion that follows, three important points are made regarding the report and the information gathered in Europe. First of all, this report was prepared prior to the unification of Germany. Thus, the Federal Republic of Germany (West Germany) is identified as a distinct country in this report. Secondly, information was gathered from Belgium, England, France, West Germany, and The Netherlands. The term "western Europe! when used in this report refers principally to these countries. Thirdly, information was gathered from publications, personal interviews and through visits to the above countries in western Europe by the author.

A Brief History of Changeable Message Sign Designs in North America

CMSs have been used in highway applications in the United States for over 30 years. The first type of CMS was very crude and consisted of inserts that could be slid into place to display appropriate messages. Fold-out, blank-out (including neon), rotating drum, and rotating tape (scroll) signs then came into being and provided transportation engineers with the capability of displaying information in "real-time." These signs, however, had the capability of displaying only a small number of messages. Although these signs were innovative at the time, transportation engineers recognized the need for more flexibility. . Other CMS technologies then evolved including vane, flap, bulb and disk matrix signs which provided greater message flexibility; however, only messages that were "fixed" into the sign system could be displayed.

In the early 1970s, computer equipment became relatively inexpensive and many matrix CMS manufacturers began incorporating this technology into their designs, providing unlimited message capability. The bulb matrix CMS became the most popular sign of highway agencies and was chosen for almost all of the freeway surveillance, control and. motorist information systems.

Immediately following the energy crisis in the 1970s, the popularity of bulb matrix signs in the United States decreased considerably . Although the initial cost was higher, the lower energy consumption coupled with a perceived indication of lower maintenance propelled the disk matrix CMS into a position of dominance in highway applications.

The need for higher target value and legibility in certain highway applications and improvements in technology have recently spurred a renewed interest in light-emitting CMS technologies. In addition to bulb matrix CMSs, fiber optic, light-emitting diode (LED) and liquid crystal display (LCD) CMS technologies have also been investigated for possible highway applications since the early 1970s. Fiber optic/reflective disk, cathode ray tube and laser scan technologies are- more recent entries. Holography is another potential technology that has been considered since the early 1970s.

Although fiber optic CMSs were installed in the United States in the early 1970s, they have not been used extensively in this country. However, improved fiber optic CMS technology resulting in improved legibility characteristics, and new sign designs with larger character heights and unlimited message capability have generated renewed interest in this technology by highway agencies in the United States.

The development of super bright LEDs that provide improved outdoor sign luminance in comparison to standard LEDs has also spurred renewed interest in LED technology for CMSs. In late 1989, the Ontario Ministry of Transportation awarded a contract to a local manufacturer to build 13 clustered LED CMSs. One major advantage of the LED CMS cited by the Ministry is that.it is totally solid state and has no mechanical parts. Thus, the Ministry expects maintenance to be extremely low compared to other existing CMSs. Also, life expectancy of each LED is 100,000 hours or the equivalent of about 12 years of CMS operation. (3)

Manufacturers of disk matrix signs have incorporated a fiber optic cable in the middle of the disk as a means of increasing target value and legibility. CMSs using the fiber optic/reflective disk (FO/RD) technology have been installed in locations in western Europe for test purposes but, as of this writing, have not been tested in the United States.

Liquid Crystal Display (LCD) technology is used for several display systems such as computer monitors, calculators, watches, clocks, etc., but has not yet been introduced into the highway operations field. Experiences with existing applications indicate that considerable improvements need to be made in legibility before LCD technology can become a serious candidate for highway use. Other emerging CMS technologies include fluid cell (liquid cell), cathode ray tube, laser scan and holography. Indications are that these technologies are not feasible for highway use at the present time.

Although the light-emitting technologies appear to provide better target value and longer legibility distances than light-reflecting technologies under certain environmental conditions, they are not without their problems. Much still needs to be learned about the design and visual aspects of light-emitting CMSs.

A Brief History of Changeable Message Sign Designs in Western Europe

To understand the difference in technology development in western Europe compared with the United States, it is important to compare the objectives of CMS installations. CMS systems in western Europe are used primarily on interurban motorways and primarily for 1) speed control and safety (accident avoidance when a queue exists) and 2) lane closures. CMSs for these applications are generally mounted over each lane. On high traffic volume motorways, the CMSs are spaced 1,640 to 3,280 ft (500 to 1,000 m) apart. International symbols are used to display the messages because of the language differences among the countries. Only a limited number of messages are required to sign for the different conditions. Some countries are now beginning to use supplemental CMSs to display the reasons for the speed reductions and lane closures. These CMSs are mounted on the sign truss either between the lane CMSs or on the side of the road. Again, internationally accepted symbols are used.

CMSs are also used in some countries on interurban motorways to divert traffic from the primary to an alternate highway. This is accomplished by changing the destination positioning on the sign to indicate which of the two movements (through or exit) motorists must make in order to reach a given destination.

The CMS application objectives in western Europe allude to the facts that 1) CMSs are primarily used on interurban motorways and 2) for most applications the need is for CMSs with 'a fixed number of messages (up to approximately 16). In contrast, many applications in the United States are on urban freeways. The complexity of the messages that must be displayed and the flexibility needed to display a wide variety of information to motorists for traffic control and management in urban freeway corridors require the use of CMSs with greater message capability and flexibility.

The first CMSs in western Europe were simple folding types which, if needed, could be manually unfolded and folded by highway patrols. Later, CMSs that could be remotely operated from control centers were developed. At first, electromechanical systems were predominately used; a great many types of designs emerged. Although many types of designs were available, practical experience revealed that it was possible to limit electromechanical CMSs to only a few designs.

Great improvements in CMS technology were made when concepts based on lighting techniques were developed. The United Kingdom developed fixed grid incandescent bulb matrix CMSs. "Fixed grid" implies that light-emitting units (such as bulbs) are positioned within an array only in positions necessary to display all the potential characters and symbols. Lighting technology advancements then led to the development of the fixed grid fiber optic CMS which has become very popular in western Europe. The fixed-grid fiber optic CMS has no moving parts.

The first fiber optic CMSs had what is referred to as a macrogrid. The macrogrid has fiber cable lighted dots approximately 15/16 inch (24 mm) in diameter. An improvement in fiber optic CMSs was the development--largely in West Germany--of the microgrid sign. The microgrid, which has smaller lighted dots that are approximately 5/32 to l/4 inch (4 to 6 mm) i. diameter, enabled a more detailed and better representation of words and symbols. Thus the quality and resolution of the characters were greatly improved.

The mixed grid system was also developed in West Germany. The mixed grid, as the term implies, is a combination of the macrogrid and microgrid. Larger sign symbols (circles, triangles, arrows) are displayed by means of medium size optics. Symbols, numerals and letters are displayed on the microgrid. This arrangement resulted in a high quality display of characters. Also, the number of glass fibers, lamps and electro-technical facilities were reduced.

In France, these fiber-optic systems are constructed by means of a metallic shield. in which circular perforations (diameter < 2/5 inch [< 10 mm]) contain the individual fiber-optic ends. An anti-reflecting layer is placed over the whole sign.

The fixed grid fiber optic CMS is the most widely used CMS in France, West Germany, The Netherlands and Belgium for speed control and safety and lane closure applications. Highway agencies in these countries feel that the fiber optic CMSs provide satisfactory target value and legibility distances for their applications (4). Also, the fact that the signs do not have moving parts is a considerable asset in the view of the agencies.

The United Kingdom has a written policy to use only light-emitting CMSs on interurban motorways. They currently use bulb matrix CMSs.

Some private companies operating interurban motorways in France are now using shuttered fiber-optic CMSs with unlimited message capability.

A few highway agencies in western Europe have subjectively evaluated LED CMSs and found them to be inferior to the fiber optic CMSs with respect to target value and legibility. However, their evaluations were made before the introduction of the super bright LEDs into highway CMSs.

One of the most diverse CMS systems in western Europe is the system operated by the City of Paris on the southern part of the 34-mile (55-km) peripheral highway around the City. Reflective disk, fiber optic, fiber optic/reflective disk, neon, LCD and LED signs are being evaluated. Results of the evaluation should be available in 1991.

Traffic diversions from primary interurban highways to alternate interurban routes are generally accomplished in western European countries with rotating drum (prism) CMSs.

2. TYPES AND CHARACTERISTICS OF MATRIX CHANGEABLE MESSAGE SIGNS

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 which exhibit the qualities of both. (Some agencies have combined CMSs with static displays to form what can also be considered to be hybrid displays.)

Characteristics of selected light-reflecting, light-emitting and hybrid matrix CMSs with emphasis on human factors considerations are summarized below. In particular, summaries are given relative to appearance and message display characteristics. Where information based on field experiences was available relative to legibility and maintenance issues, supplementary notes are added. The information is provided to highlight issues that should be considered in the design, placement and operations of CMSs. Additional characteristics and photographs of all of the various types of CMSs are presented in Reference 2. More detailed information concerning the displays can be obtained by contacting agencies which have installed real-time information systems and sign manufacturers.

Selected Light-Reflecting Matrix Changeable Message Signs

The most common type of light-reflecting matrix CMS is the disk matrix. 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 Signs - 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 electro-magnetically rotating appropriate disks to reveal a reflectorized yellow side. (Figures 1 and 2)

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 or 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 flipped 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. (Figure 3) The rotation mechanisms vary slightly among manu-facturers. As a result, different speeds of rotation, durability and weight of disks can be expected among signs. (3)

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. (3)

Oftentimes when the sun is behind the sign, the low legend contrast results in poor legibility. External or internal illumination, therefore, must be used to compensate for the lower target value. (3)

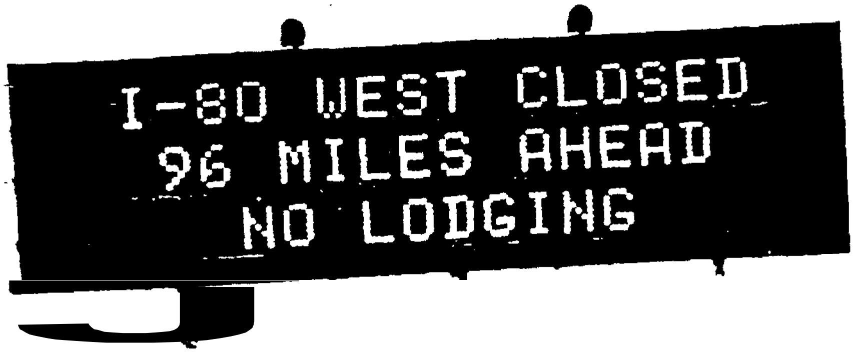


Figure 1. Modular Circular Disk Matrix Sign in Cheyenne, Wyoming

Figure 2. Modular Circular Disk Matrix Sign near Pittsburgh, Pennsylvania

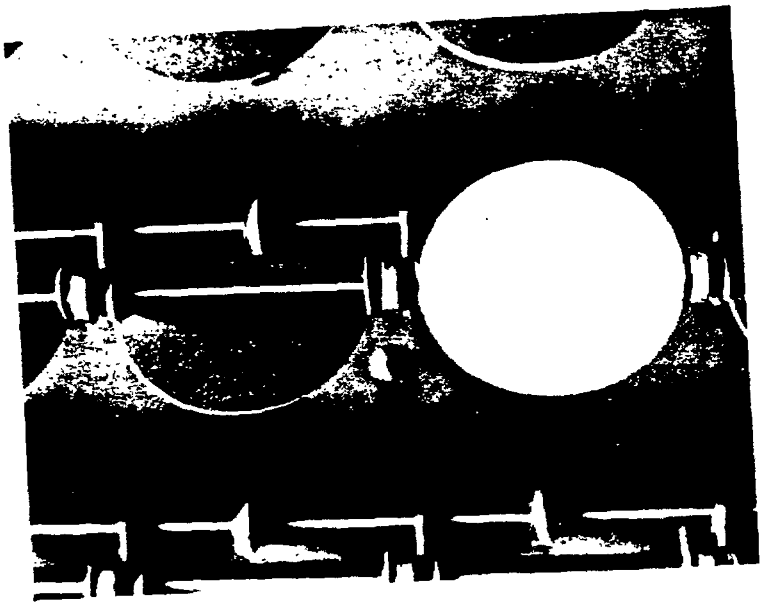


Figure 3. Close-Up View of Circular Disk Indicators

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. (3)

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 is sometimes much brighter compared to the shaded portion of the legend; thus, messages can become illegible. (3,5)

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 been used in attempts to rectify this problem. However, there are indications that 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 was obliterated by the reflected and scattered light from the external lighting. (3)

Internal fluorescent lighting has also been used. This requires long, narrow access doors on some signs. Internal illumination also can blur the legend when anti-glare Lexan is used on the front face. (3)

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. (5)

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 signs reflect more light than the disk signs, due to their larger reflective surfaces. (5)

Reflective Disk Matrix Signs - Rectangular

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

Appearance and Operation

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. (Figures 4 and 5)

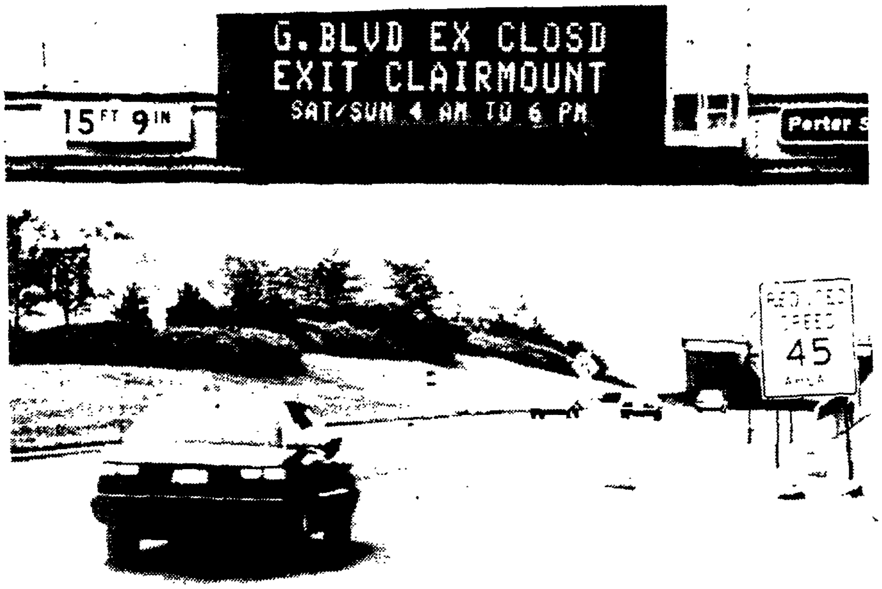


Figure 4. Rectangular Disk Matrix Sign

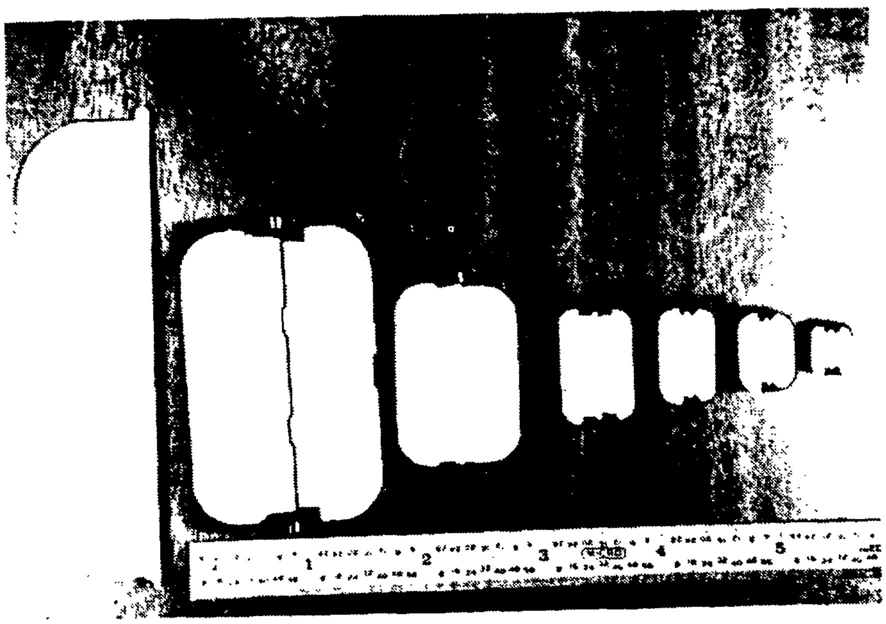


Figure 5. Close-Up View of Rectangular Disk Matrix Sign

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 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.

As is the case with many standard 5 x 7 matrix arrays, the rectangular matrix display of the size commonly used on highways restricts the presentation of exact shapes of symbols and lower case characters.

Message Display

Messages can be displayed statically or flipped on and off in 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 changed 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 28-inch (711-mm) character signs are available for permanent installations.

Flash and sequence rates can be varied from 1 to 6 seconds.

Notes

The target value and legibility characteristics are similar to the circular reflective disk sign. (3)

Reflective Disk Matrix Signs - Dimensional Square

Appearance

The viewing face is formed by a full matrix array of 2-l/4-inch by 2-l/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. (Figure 6)

Each element is enclosed in a square case; thus the element and case form a cube. (Figure 7).

Figure 6. Dimensional Square Disk Matrix Sign

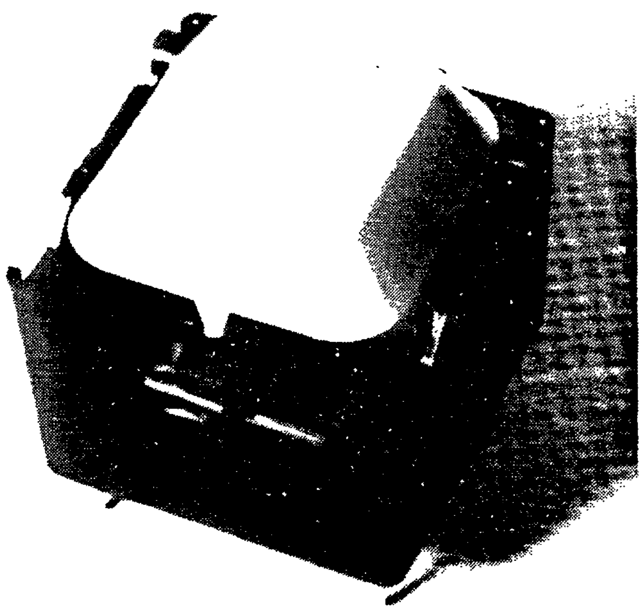


Figure 7. Close-Up View of Dimensional Square Disk Matrix Sign

The square shape of the displayed yellow element provides about 30 percent more color in a given space 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 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.

Each matrix element is controlled by a mini electric motor. A momentary flow of current magnetizes the armature and 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.

Notes

No information is available concerning the relative target value and legibility characteristics of the dimensional square reflective disk sign.

Selected Light-Emitting Matrix Changeable Message Signs

Some of the more-common and emerging types of light-emitting matrix CMSs are:

1. Bulb matrix (incandescent),
2. Fiber optics matrix (fixed grid),
3. Light-emitting diode matrix (clustered), and
4. Fiber optics matrix with shutters.

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." (Figure 8)

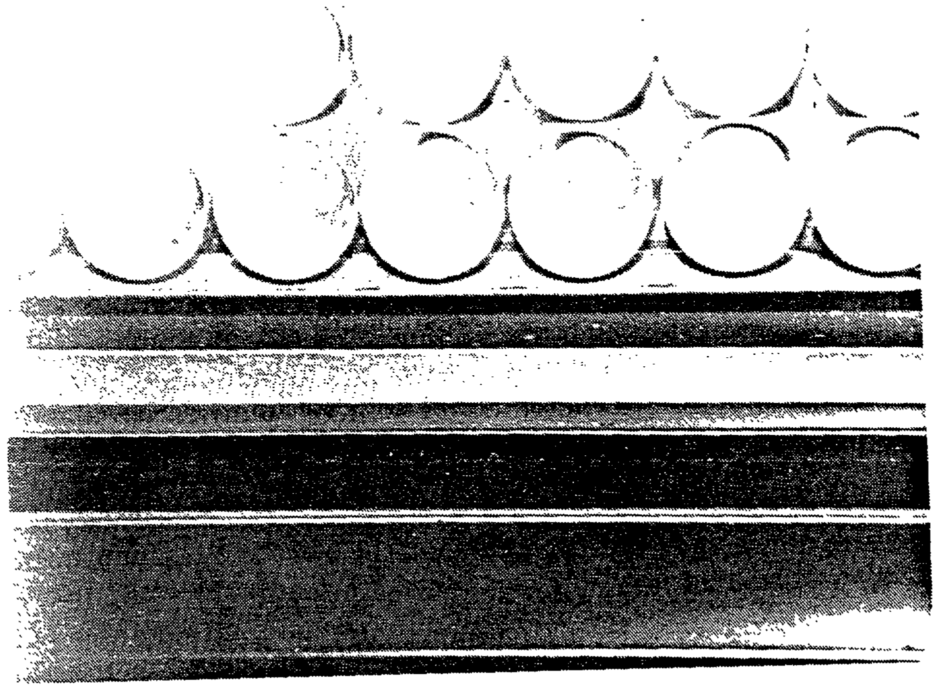


Figure 8. 30 Watt Incandescent Bulbs in Canisters (Ref. 3)

When used, reflectors are generally coated with a silver colored material which tends to reduce the contrast ratio when the sun shines on the sign face.

Exact shape presentation or the display of lower case lettering types is not possible on the sizes of signs generally used for highway applications (i.e., 5 x 7 or 4 x 7 fonts).

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 to 457 mm) have been used, although larger letters 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, at a similar pixel size, is the super bright LED cluster. (3)

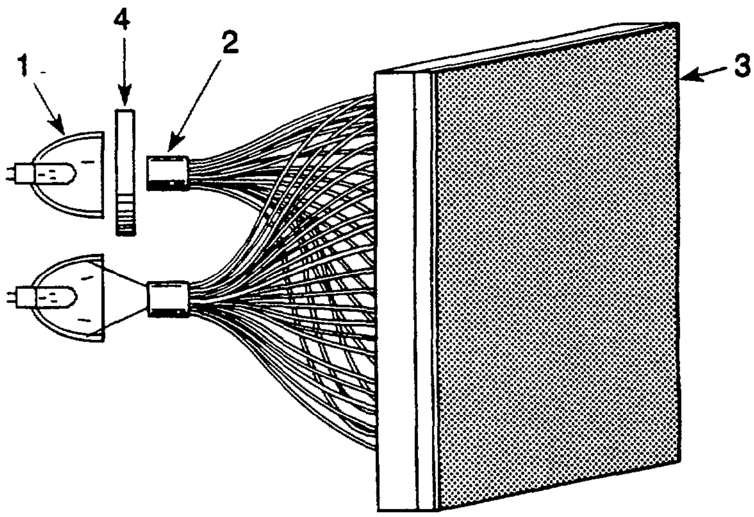
The lifetime of incandescent bulbs can be increased by decreasing the applied voltage, For example, lowering the voltage of 40 Watt bulbs to run at the output of normal 30 Watt bulbs will extend life to approximately 6,000 hours. Sound judgement has to be exercised to obtain the optimal voltage (life) to light output (efficacy) ratio. (3)

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 9)

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.



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

Figure 9. Fixed Grid Fiber Optic Module (Ref 3)

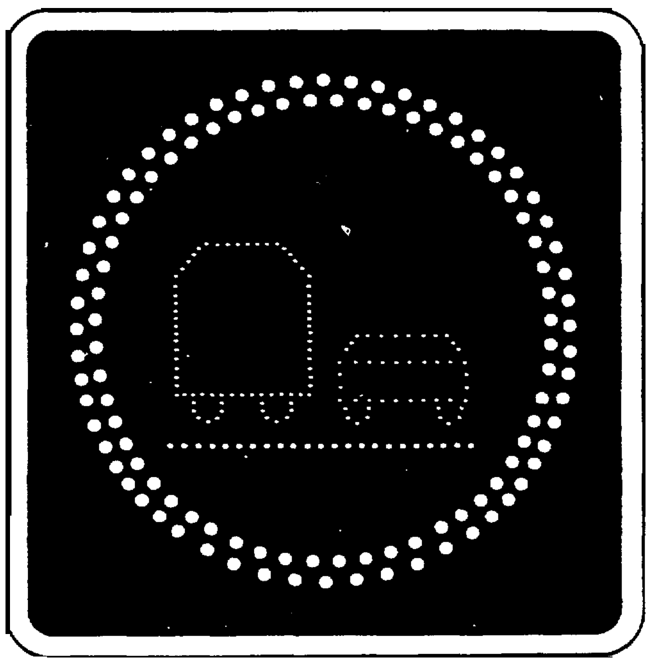


Figure 10. Matrix Sign of the Mixedgrid Type (Ref. 12)

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.

The matrix array can be either a macrogrid with fiber dots approximately 15/16 inch (24 mm) in diameter, microerid with fiber dots approximately 5/32 to l/4 inch (4 to 6 mm), or mixedgrid which has a combination of macro and micrograms (Figure 10).

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.

Message Display

A message is displayed only when the internal light source (halogen lamp) is activated.

The sign can display symbols (within certain limitations) 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 about 16 separate “hardwired” messages.

Notes

Standards from France and West Germany are given in Reference 2.

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.

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. (3)

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. (3)

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. (3)

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 Trsnsportation showed that the eye can register a 0.16 millisecond light pulse repeated every 16 milliseconds without experiencing recognizable flicker. (3)

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 in a manner similar 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 5 x 7 array of LED lamp clusters.

Tests conducted in Europe indicate that the standard LED lamps do not provide adequate luminance contrast for daytime use (6,7). 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 (Figure 11). 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. (3)

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. (3)

Viewing angles of overhead signs in the highway environment are small. However, the Ontario Ministry of Transportation found the 6 degree beam width was sufficient for overhead installations on freeways. (3)

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 CMSs for freeway corridor operations have been 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 CMSs is shown in Figure 12.

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 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 11 shows the LED cluster mix and a light guide cylinder, acting as a sunvisor, which were selected by the Ontario Ministry of Transportation. The cylinder design was calculated by the Ministry to give the best protection from the sun, while permitting the required viewing angle. (3)

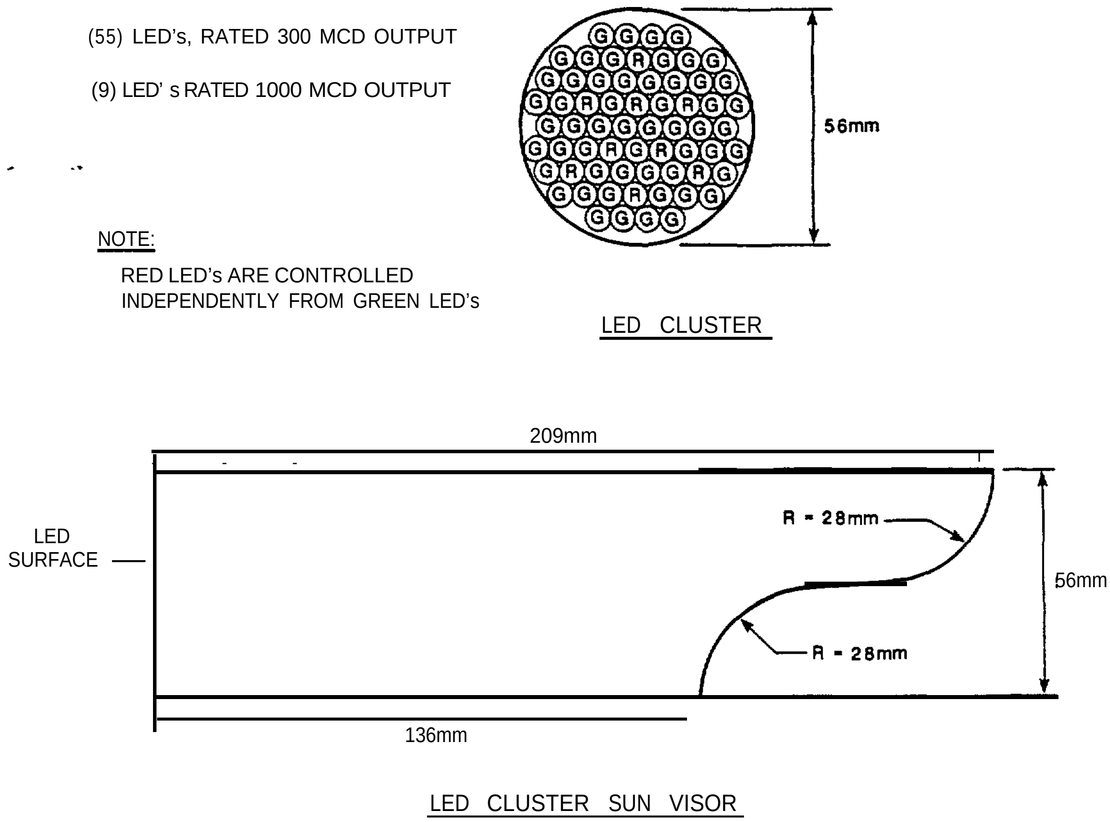


Figure 11. LED Cluster with Sun Visor (Ref.3)

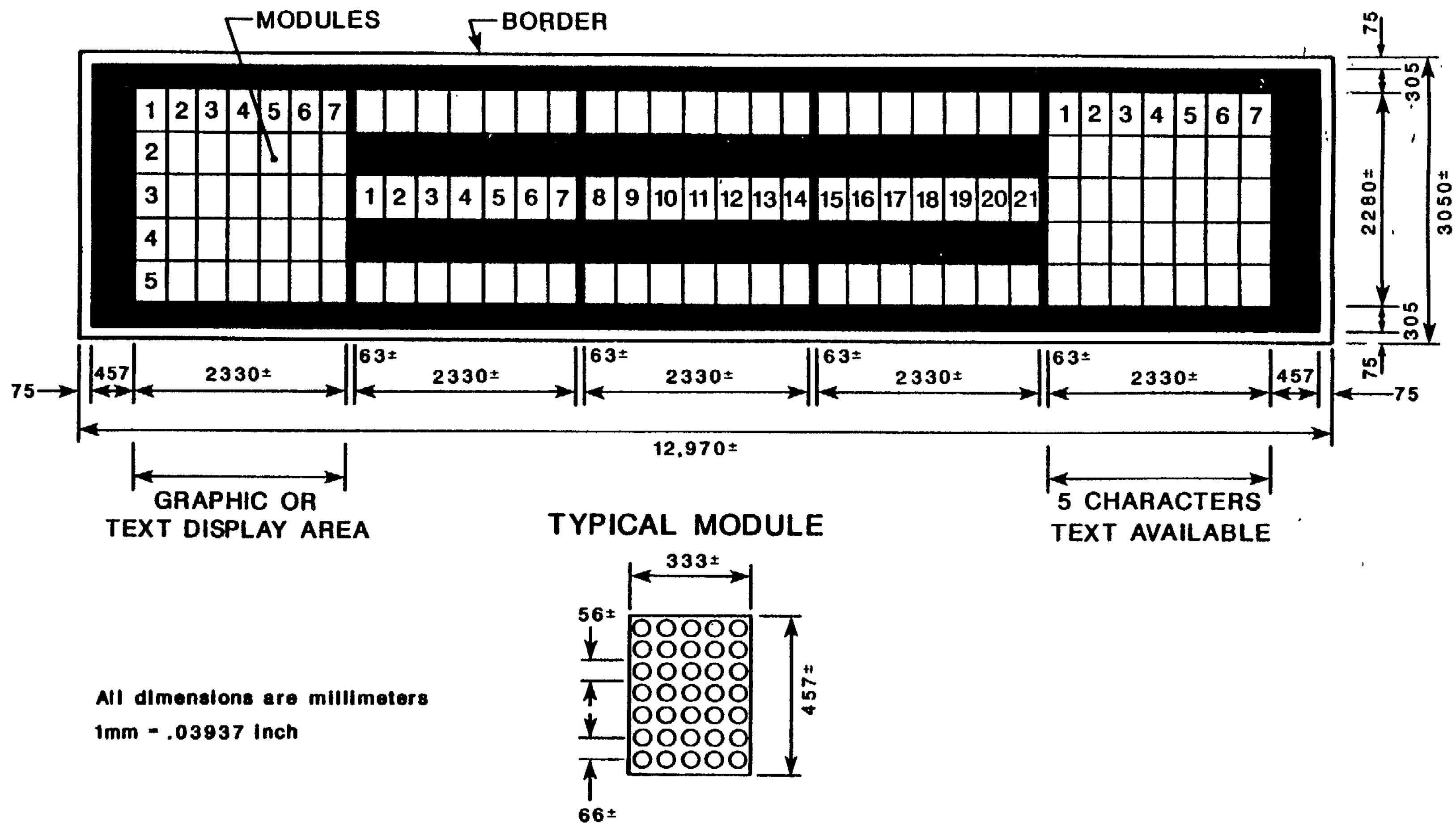


Figure 12. Ontario Ministry of Transportation Selected Sign Face (Ref 3)

A Lexan sun shield pladed on the front of the CMS can also adversely affect legibility because of sun reflectance. (3)

Commercial indoor-advertising CMSs are available that use high output LEDs in a set (circuitboard) full matrix configuration. These signs were found by the Ontario Ministry of Transportation to be unsuitable for outdoor application because the sun reflects off the LED-elements and adversely affects legibility. Installing anti-glare Lexan over the LED matrix which is color tinted the same color as the LEDs helps to alleviate the problem. Manufacturers recommend against the use of the indoor CMSs outdoors due to problems with deterioration from humidity and dirt. (3)

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 forming a pixel rather than an incandescent bulb. Each character module will normally be a 5 x 7 array of fiber optic pixels. (Figure 13)

A fiber optic cable leads the light from a halogen lamp to a corresponding light dot approximately 5/32 inch (4 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 dots). 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. (Figure 14)

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 subjectively determined that two fibers per pixel produces what it considers to be the optimum brightness for rural freeway CMSs having 12.6-inch (320-mm) high characters. (8)

The front face of the sign is covered with a matte black material such that only the l-inch (25 mm) square 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.

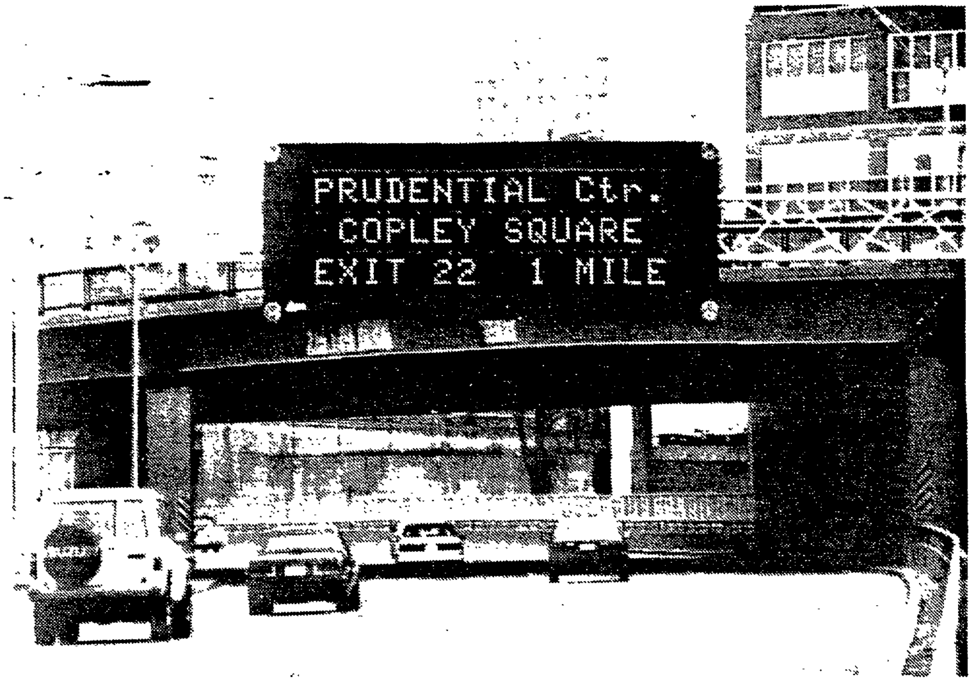
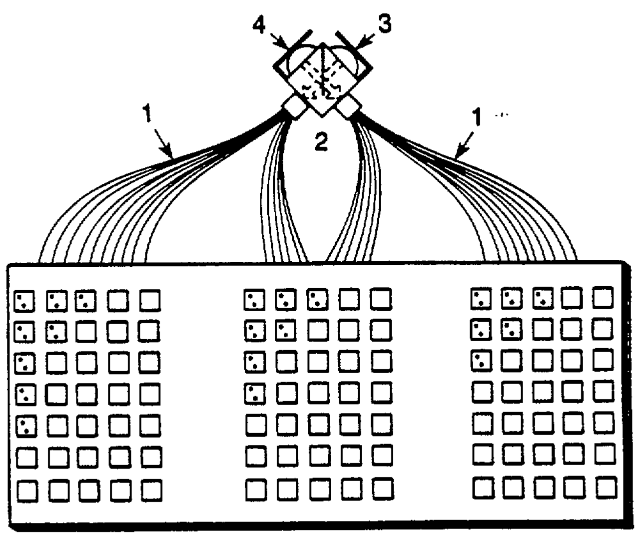


Figure 13. Shuttered Fiber Optic Sign



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 14. Light Module and Fiber Optic Bundles Connected to Typical Three-Character Module

Message Display

Until recently, only 12.6-inch (320-mm) character heights were available. The majority of the installations have been in France where the highway agencies initially felt that the 12.6-inch (320-mm) character height was adequate for the specific applications on four-lane intercity freeways. However, the agencies now believe that drivers would feel more comfortable with a larger character height. Demands for Winch (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 CMSs with 16.5inch (420-mm) characters have been installed by at least two agencies in North America. One sign was installed in late 1989 by the Toronto Metropolitan Transportation Department. The Maryland Highway Commission installed three signs on a rural freeway in late 1990.

The manufacturer constructed the 16.5-inch (420-mm) CMS by essentially making no other major visual aspect 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). The effect that this change has on legibility is not known at this time.

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. (9) 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. (3)

Currently, the controller is composed of European components (3).

Both front and rear opening models are available.

Selected Hybrid Matrix Changeable Message Signs

CMSs that incorporate features of both the reflective disk and fiber optic CMSs have recently been introduced.

Reflective Disk and Fiber Optics Matrix 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 single fiber optic light dot, approximately 3/16 inch (5 mm) diameter, is located behind each reflective disk and radiates through small holes in the disk. The fiber optic dot 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. The pixels in use, therefore, show both the reflective disk and the illuminated fiber optic light. (Figures 15 and 16)

The fibers are terminated in an enclosure which surrounds a 400 Watt high-pressure sodium lamp. Each such lamp can feed about 1,000 pixels. The lamp has a rated life of 24,000 hours (about 3 years of continuous operation). A lamp dimming circuit is provided to vary the pixel light output.

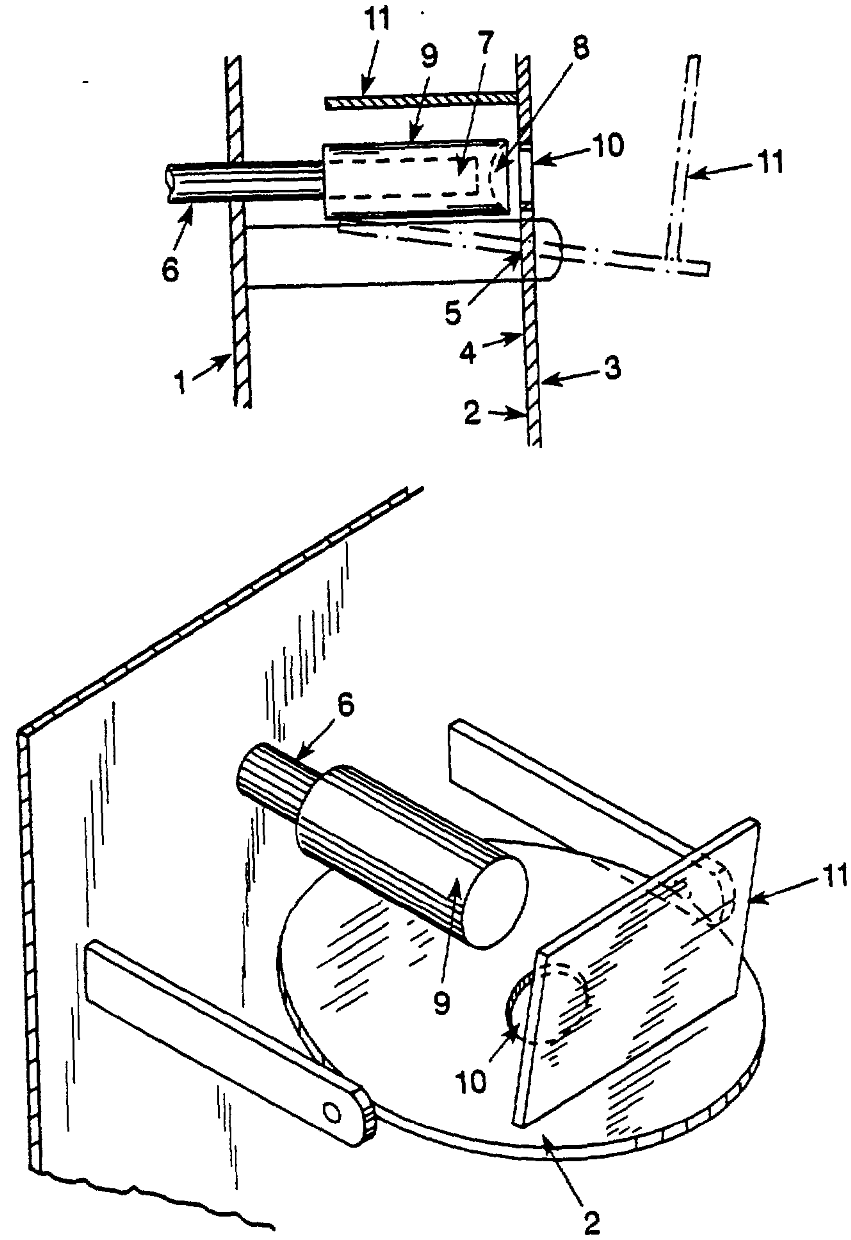
In the case of power failure, the CMS can rely on the flip disks to revert to either the message under use or to a default message.

The fiber optic pixels exhibit a directionality similar to the fiber optic CMSs. The effective visual cone is estimated at 20 degrees. (3)

Message Display

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

Figure 15. FO/RD Sign in Paris, France



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

Figure 16. Mechanics of FO/RD Pixel

3. VISIBILITY AND LEGIBILITY CRITERIA FOR LIGHT-EMI'ITING SIGNS

This section summarizes available design criteria for light-emitting CMSs which affect the legibility of-the signs. The design criteria discussed include character height, font style, spacing and size of pixels, character spacing, word spacing, line spacing, borders, and contrast ratio, The effects of sun position (behind and facing the sign), nighttime luminance and irradiation are also discussed. The reader should refer to the full report, "Guidelines on the Use of Changeable Message Signs," (2) for greater details.

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 of characters, words and lines; size of sign borders; and contrast (luminance) ratio.

In order 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. 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, and other factors.

The legibility of light-emitting CMSs is primarily affected by the character height, character width and the contrast ratio--the ratio between the luminous intensity of the individual light pixels and the sign background (12.15). 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. Changing one of these factors without changing one of the other 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 were 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 factors, they are important to address in the design of CMSs.

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

. Character -Height and Legibility

The "Manual on Real-Time Motorist Information Displays" (1) recommends that, because of message requirements and visual noise, CMSs used on urban and suburban freeways in the United States should have character heights of at least 18 inches (457 mm). This criterion is based on objective field studies with bulb and disk matrix CMSs. The Manual further recommends that in the absence of more definitive data, 36 ft/inch should be used as a guide for determining required letter height. The Manual offers the following guidelines in determining matrix sign letter height requirements:

- For freeway applications, use letter heights of at least 18 inches (457 nun) or greater.
- For other than freeway applications, use letter heights between 10 and 18 inches based on 36 ft/inch 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. (10.11) to measure the legibility distances of bulb and reflective disk matrix CMSs with l8-inch (457-mm) characters using subject drivers are shown in Tables 1 and 2. These data indicate that legibility distances for bulb matrix CMSs are about 15 percent higher than reflective disk CMSs (for single-line, single stroke words). Subjective studies by Caltrans (5) 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 2. No published objective data are available concerning the legibility of other kinds of CMSs (e.g., clustered LED, fiber optic, etc.).

Western Europe has 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 (l2). The trend is toward CMSs having character heights of between 15.7 and 18.7 inches (400 and 475 mm) for speed and lane regulation messages. France (13) specifies character heights between 15.7 and 18.7 inches (400 and 475 mm) for speed control CMSs, and 15.7 inches (400 mm) for information and direction CMSs installed on interurban motorways. West Germany (14) specifies character heights between 16.9 and 18.3 inches (430 and 465 mm) for speed control CMSs. The Netherlands (12) requires 17.7-inch (457-mm) character heights.

Table 1
DAYLIGHT LEGIBILITY DISTANCES FOR l8-INCH
BULB MATRIX CMS (Ref. 1)

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 2
DAYLIGHT LEGIBILITY DISTANCES FOR 18-INCH
REFLECTIVE DISK MATRIX SIGN (Ref. 1)

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

The Department of Transport (16) United Kingdom, is currently developing standards for light-emitting CMSs. The Department of Transport currently specifies a minimum character height of 16.5 inches (420 mm) for warning, regulatory, lane control, speed enforcement, and impending hazard warning CMSs. They are, however, moving toward a 17.7-inch (450-mm) character height.

Font Style

The 5 x 7 or 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 of upper case letters, the 5 x 7 standard (rounded character) font style provides slightly superior legibility on a CMS sign to a 4 x 7 character, a square character font, or the Lincoln/Mitre character style. However, Dudek and Huchingson et al. (10) found that a combination of 5 x 7 and 4 x 7 character fonts resulted in superior reading in contrast to the individual fonts. Various fonts are shown in Reference 2.

Spacing and Size of Pixels (Character Width)

In the mid-1980s, the International Commission on Illumination, Technical Committee on Roadsigns (12) suggested that, for fiiedgrid fiber optic CMSs, the center-to-center spacing between normal l/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 draft requirements are shown in Table 3.

Table 3
SIZE OF MATRIX ELEMENTS
DRAFT STANDARDS: DEPARTMENT OF TRANSPORT,
UNITED KINGDOM (Ref. 16)

Character Height 5 x 7 Matrix inches mm	Element Size Minimum inches (mm)	Element Size Maximum inches (mm)
8.7 (220)	l5/32 (12)	45/64 (18)
10.4 (2.55)	33/64 (13)	25/32 (20)
11.4 (290)	19/32 (15)	28/32 (22)
l3.0 (330)	43/64 (17)	63/64 (25)
14.4 (365)	25/32 (20)	l-3/16 (30)
15.7 (400)	25/32 (20)	l-3/16 (30)
17.3 (44)	25/32 (20)	l-3/16 (30)

Spacing of Characters, Words and Lines

The United Kingdom draft 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. (16)

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 (13).

Borders

Sunlight can be a significant problem to CMS legibility if, from the driver's perspective, it appears behind the CMS. One way to reduce this problem when drivers must simultaneously look at a CMS and bright sunlight is to increase the surface size of the CMS effectively screening the driver from the sun. Unfortunately, it is neither practical nor feasible to construct a CMS board large enough to completely compensate for the sun position.

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 (17) that the background buffer surrounding the message should be at least one alphanumeric sign line height. Lotens (18) found that a sufficiently high legibility is maintained on fiber optic CMSs by using a border of 1.1 times 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 (16). France specifies that the border must be equal to or greater than the character height (13).

Contrast (Luminance) Ratio

Luminance contrast is critical to drivers being able to detect a sign at a great distance and to read the word message at a closer distance. Contrast between the sign and the roadside environment influences both its conspicuity (target value) and its legibility. Legibility is also influenced by the contrast between the legend on the display and the sign background.

Contrast ratio is oftentimes 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 luminance to the sign background luminance. Luminance is a measure of light coming from a surface. The luminance of a light source (e.g., lamp) is an exact measure of the light it emits. Illumination, on the other hand, is a measure of light falling on a surface; the light can come from-the sun, lamps or other bright sources. (19.20)

Limited objective data are available which provide guidance regarding the optimum contrast ratios for various daytime lighting conditions. France specifies that the contrast ratio should be between 3 and 25 for daytime operations (13). French researchers, Bry and Colomb (2l), 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 3 make reading very difficult. Contrast ratios above 25 result in excessive differences in luminance between the legend and the sign background which adversely affects reading. Further studies reported by Colomb and Hubert (6) in France indicated that only 50 percent of subjects were able to correctly read the legend on a CMS when the contrast ratio was 3. The percentage of correct answers increased 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.) Colomb and Hubert stated that their results were compatible with the results of Padmos et al. (22). The criteria proposed by' the United Kingdom are shown in Table 4 (16). 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.

Experiments conducted by Kerr et al. (15) revealed that older motorists exhibit lower patterns of recognition when reading CMSs compared to young motorists, and this variation in performance must be considered when developing CMSs. Based on the results, Kerr et al. suggested that a contrast ratio of about 7 might be chosen to provide CMS displays which are best suited to the population as a whole. Van Meeteren et al. (23) have shown that a contrast ratio in the order of 10 gives optimum visual acuity. This contrast ratio of 10 is also supported by Bomier (17).

Padmos et al. (22) conducted field studies of 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.

Table 4
LIMITS OF CONTRAST RATIO 10° AND 20° ILLUMINATION
DRAFT STANDARDS: DEPARTMENT OF TRANSPORT,
UNITED KINGDOM (Ref. 16)

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*
41ux	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 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

The subjects viewed the CMS module from a distance of 328 ft (100 m). Based on this study, Fadmos et al. were able to plot the relationships between horizontal luminance and message luminance for all the criteria. (See Figure 17)

Sun Behind-the Sign

At least four things 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. As a minimum, the CMS should have a background buffer surrounding the sign characters according to the criteria suggested earlier in of 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.

Sun Facing the CMS

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 four options are possible for reducing the effects of the sun shinning directly on the face of the CMS:

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

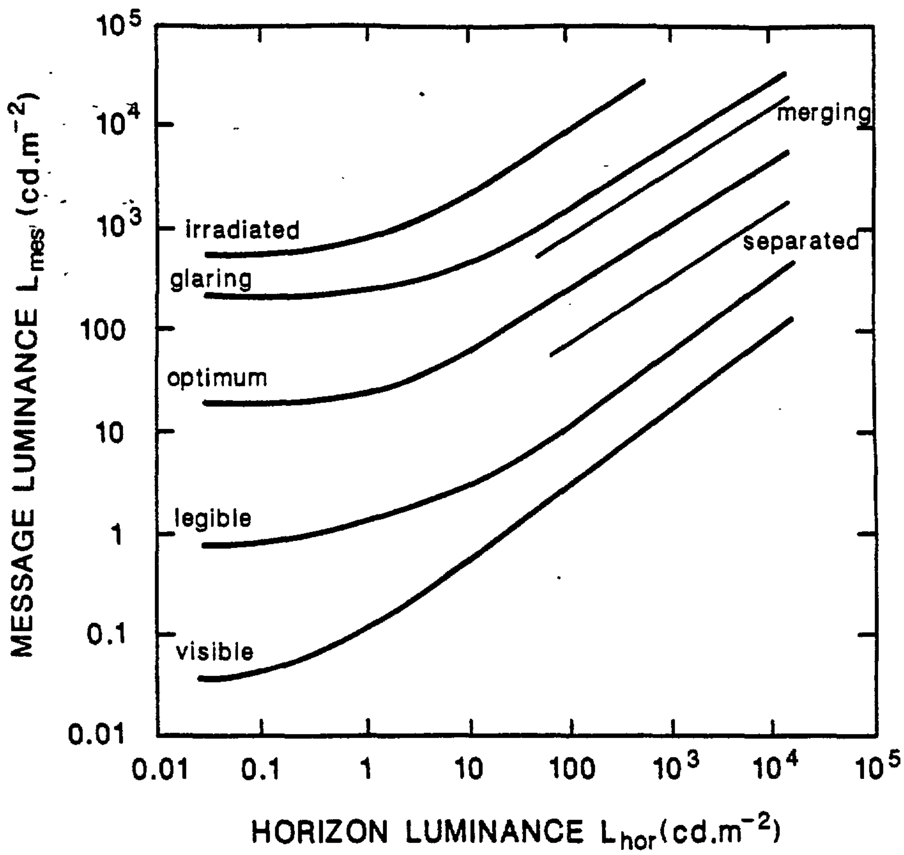


Figure 17. Mean Relationships for CMS Legibility Criteria (Ref 22)

Nighttime Sign Luminance for Light-Emitting Signs

In the daytime, both the legend and CMS panel luminance are measured in order to determine contrast ratio. At night, only the luminance of the sign legend 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 sign at night. (6)

Very limited data are available that help to determine the acceptable sign luminance for nighttime applications. A study by Colomb and Hubert in France (24) using simulation indicated acceptable luminance within a range between 30 and 230 cd/m^2 for nighttime applications. Colomb and Hubert (6) also found that an average of only 60 percent of the motorists tested were able to read a prototype CMSs in controlled field tests at night with this luminance. The lower performance in comparison to daytime results, according to the authors, is probably explained by the observers' loss of visual acuity at night.

France specifies a nighttime iuminous intensity per pixel of 1 to 5 cd in well lit areas and 0.1 to 1 cd in poorly lit areas for motorway information and direction CMSs having 15.7-inch (400 mm) characters (13). The Netherlands specify that 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 (12).

Irradiation

Most light-emitting CMSs have good target value 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.

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. The problem is more acute when the sun rays directly strike the sign face. Under cloudy conditions, the sign luminance 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. To alleviate the problem, reduce the intensity of the light source, decrease the stroke width, or increase the recommended spacings between characters. Consequently, light-emitting CMSs must have provisions for changing the sign luminance to cope with the wide range of environmental lighting conditions. 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.

4. ASSESSMENT OF CMS TECHNOLOGY RELIABILITY, 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." (3) 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. The reader is advised to consult with a larger number of 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.

Reflective Disk Siens

The reliability of electromechanical technologies used in the CMS 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 to the moving parts. (3)

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 which may be attributed to higher concentrations of airborne particles in the environment and lower temperatures. (3)

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. (3)

Maintenance of external or internal lighting used to illuminate the sign face is an additional problem that must be addressed. (3)

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. (3)

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. (4)

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 had considerable problems with the electromechanical shutters. (3) 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. (9)

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, (3)

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 (i.e. 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. (3)

Hvbrid Changeable Message 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 (25) and Synthesis 12 (26) 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?

Changeable Message Sign 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 Figure 12. Some cost analyses results of interest for several CMS technologies are shown in Table 5. The assumed number of service calls per year and the breakdown of labor and materials costs are given in Table 6.

Table 5
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 6
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

5. SELECTING THE APPROPRIATE CHANGEABLE MESSAGE SIGN

&commended 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. In setting objectives, the agency must first be 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 CMS system will be operated.

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 guidelines presented in the "Manual on Real-Time Motorist Information Displays" (1) or "Guidelines on the Use of Changeable Message Signs" (2), 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. Guidelines for placement can be found in the "Manual on Real-Time Motorist Information Displays (I).

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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