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Guidelines on the Use of Changeable Message Signs

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16. Abstract

The 1986 FHWA publication "Manual on Real-Time Motorist Information Displays" 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.

This report is intended to provide guidance on 1) selection of the appropriate type of Changeable Message Sign (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. 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. Since the use of matrix-type CMSs, particularly light-emitting technologies, has increased in recent years, matrix CMSs have received additional attention in this report.

The report concentrates on design issues relative to CMSs with special emphasis on visual aspects, but does not establish specific criteria to determine whether to implement displays. The intent is to address display design issues for diverse systems ranging from highly versatile signing systems integrated with elaborate freeway corridor surveillance and control operations to low cost, less sophisticated surveillance and signing systems intended to alleviate a single specific problem.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

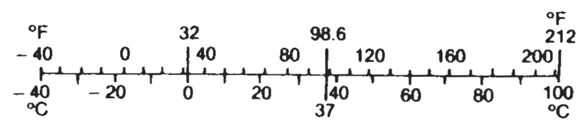
Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	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 m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
	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)

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1. INTRODUCTION

A. 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 real-time information not only benefits individual motorists and the responsible highway organization but also the general public. Motorists are interested in reaching their destinations as safely as possible without undue delays. The responsible highway organization is interested in utilizing optimally the available highway capacity of the corridor or network. The general public desires satisfaction of its demands for safe transportation with the least possible adverse environmental impacts due to noise and exhaust gases and the highest energy efficiency.

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 of the investigation are published herein.

B. Purpose and Scope

This report is intended to provide 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. 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. Since the use of matrix-type CMSs, particularly light-emitting technologies, has increased in recent years, matrix CMSs have received additional attention in this report.

Although the report is primarily intended for traffic engineers working in city, county, state or private organizations, it should also be useful to traffic engineering students or trainees and to FHWA engineers at the district and regional levels who are responsible for project review and approval. It is intended for a wide audience of users ranging from individuals who are developing their first system and are not familiar with real-time display technology to those responsible for the operation of existing systems. Thus, the experienced designer or operator of real-time displays may find some sections of the report somewhat elementary.

The report concentrates on design issues relative to CMSs with special emphasis on visual aspects, but does not establish specific criteria to determine whether to implement displays. The intent is to address display design issues for diverse systems ranging from highly versatile signing systems integrated with elaborate freeway corridor surveillance and control operations to low cost, less sophisticated surveillance and signing systems intended to alleviate a single specific problem.

The report is in no way a step-by-step procedures handbook. It is designed to provide useful guidelines in making engineering decisions, particularly concerning the visual aspects of CMSs. It represents the latest information made available to the author. However, the reader should be cautioned that the report is not the final word. The knowledge base relative to CMSs is far from complete. There are 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 were presented by Dudek in NCHRP Synthesis Report 61, Changeable Message Signs in 1979 (2) and are still valid today. They include the following:

- 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, 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?

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 and through personal visits to these countries by the author.

C. 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):

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.

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

CMS systems can perform a critical role in alleviating many of the above operational problems by furnishing motorists with real-time information about the problem and the best course of action.

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. Table 1-2 summarizes the types and techniques and possible traffic operation applications (2). 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 1-2
SIGN CONTROL AND OPERATION TECHNIQUES (Ref 2)

CMS Sign Installation	Type of CMS Operation	Description	Possible Applications
Permanent	Remote Automatic Control	Sign messages are displayed and changed automatically by a remote control system when varying adverse environmental roadway or traffic conditions are sensed by detectors. Manual override capability is normally provided.	(A)
	On-site Automatic Control	Sign messages are displayed and changed automatically by an on-site control system when varying adverse environmental roadway or traffic conditions are sensed by detectors.	(B)
	Remote Manual Control	Sign messages, based on varying environmental roadway or traffic conditions, are displayed and changed by sign operators from remote central office location.	(C)
	On-site Manual Control	Sign messages, based on varying environmental roadway or traffic conditions, are displayed and changed by an operator using a control panel located at the sign site. In the case of a manually operated fold-out sign, the sign is opened to display a message. In both cases, personnel must travel to the sign site after the need for a message has been determined.	(D)
	Fixed-time Automatic Control	Sign messages are displayed and changed automatically at preselected times of the day.	(E)
	Fixed-time Remote Manual Control	Sign messages are displayed and changed at preselected times by operators from a remote location.	(F)
	Fixed Time On-site Manual Control	Sign messages are displayed and changed at preselected times by operators at the sign site.	(F)
Transportable	Variable Message On-site Control for Unpredictable Event	Sign is moved into place when an unpredictable event occurs (e.g., major accident). Sign messages are displayed and changed on-site, based on varying traffic conditions.	(G)
	Variable Message On-site Control for Predictable Event	Sign is moved into place for a predictable event (e.g., special event, parade, holiday traffic congestion at a tunnel, bridge, etc.). Sign messages are displayed and changed on-site based on varying traffic conditions.	(H)
	Fixed Message for Unpredictable Event	Sign is moved into place when an unpredictable event occurs. Only one message is displayed.	(I)
	Fixed Message for Predictable Event	Sign is moved into place for a predictable event. Only one message is displayed.	(J)

(A) Traffic management and diversion (traffic advisory and incident management, freeway-to-freeway diversion, special events, adverse road and weather conditions, speed control); warning of adverse conditions (weather, environmental, road); control at crossings (bridge, tunnel, mountain pass); special roadway control (restricted roadways).

(B) Traffic advisory (warning of slow traffic, speed control); warning of adverse conditions (weather, environmental, road, high truck loads); control at crossings (bridge, tunnel, mountain pass); control during construction and maintenance; special roadway control (restricted roadways).

(C) Same as for Remote Automatic Control. Also, control at weigh stations and toll stations; control during construction and maintenance.

(D) Same as for Remote Manual Control. Note: Due to the delays in traveling to the CMS site(s), messages generally are not as timely in comparison with remote control operation.

(E) Special-use lane and roadway control (reversible, exclusive, and contraflow lanes and restricted roadways).

(F) Same as for Fixed-time Automatic Control.

(G) Traffic management and diversion (traffic advisory and incident management, freeway-to-freeway diversion, adverse road or weather conditions).

(H) Traffic management and diversion (special events); control at crossings (bridge, tunnel, mountain pass); control during construction and maintenance.

(I) Same as for Variable Message On-site Control for Unpredictable Event. Note: Displays and messages are not changed to respond to varying traffic conditions.

(J) Same as for Variable Message On-site Control for Predictable Event. Note: Displays and messages are not changed to respond to varying traffic conditions.

2. TYPES AND CHARACTERISTICS OF CHANGEABLE MESSAGE SIGNS

This chapter provides a summary of the types and characteristics of available 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. CMSs technologies that are currently receiving most attention by highway agencies in North America and Europe are highlighted.

A. 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 have been or are being used for highway applications (1-4) can be grouped into the following six basic categories:

1. Static with beacons
   - Static message signs with flashing beacons

2. Background light source
   - Blank-out

3. Electromechanical
   - Fold-out (type I)
   - Scroll (belt)
   - Rotating drum (prism)
   - Disk matrix
   - Flap matrix
   - Rotating Cylinder/Triangle
   - Vane matrix

4. Light source
   - Bulb matrix (incandescent)
   - Fiber optics matrix (fixed grid)

- Light-emitting diode (board)
- Light-emitting diode (clustered)

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

6. Manual
   - Cloth
   - Fold-out (type II)
   - Removable panels

B. 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 the bulb matrix signs in the United States reduced considerably. Although the initial cost was higher, the lower energy consumption coupled with a perceived indication of lower maintenance propelled the circular reflective disk matrix CMS into a position of dominance in highway applications for several years. As field experience was gained, however, highway operations personnel began to indicate lower target value and legibility relative to the bulb matrix CMS during certain environmental conditions. Also, the greater use of the signs provided opportunities to better identify specific design and placement considerations (discussed later in this chapter) that should be addressed by an agency to enhance legibility.

Rotating triangles (tri-color) were also installed and tested, and were found to have lower target value and legibility in comparison to bulb matrix CMSs.

Rectangular reflective disk matrix CMSs mounted on trailers became popular for applications in highway work zones. Larger versions of the rectangular disk matrix CMS are currently being evaluated for traffic management applications in freeway corridors, and results will soon be available. Indications are that the target value and legibility characteristics of the rectangular disk matrix CMS are similar to the circular disk matrix signs.

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 are used extensively on high-speed motorways in western Europe, there are at least three reasons why previously they have not been used extensively on freeways in the United States. First of all, early fiber optic signs in the United States were considered too dim for daytime use on freeways. Secondly, until just a few years ago, only fixed grid (e.g., lane control, speed control and pedestrian crossing) fiber optic signs were available; shuttered fiber optic signs designed to display an unlimited number of messages were not available. Thirdly, the new shuttered fiber optic CMSs with unlimited message capability were manufactured with maximum character heights of only 12.6 inches (320 mm). (The Manual on Real-Time Motorist Information Displays (1) recommends 18-inch (457-mm) characters for CMSs installed on urban freeways.) 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.

In 1989, two highway agencies in North America, namely, the Metropolitan Toronto Transportation Department and the California Department of Transportation, District 7, Los Angeles installed the 12.6-inch (320-mm) character shuttered fiber optic CMS on urban freeways in their jurisdictions for test purposes. The sign in Los Angeles is still being evaluated. The Metropolitan Toronto Transportation Department determined that the 12.6-inch (320-mm) character was too small for urban freeway use. Toronto had the sign removed and asked the manufacturer to furnish a fiber optic sign with larger characters. A new shuttered fiber optic sign with 16.5-inch (420-mm) characters was installed in January 1990 and is currently undergoing evaluation. In early 1990, the Maryland State Highway Commission installed three shuttered fiber optic signs with 16.5-inch (420-mm) characters on a rural freeway. The signs are currently being evaluated.

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. The clustered LED is a relatively new CMS technology that has received considerable attention by officials in non-highway modes of transportation. For example, there has been increased use of the signs in subways and airport terminals. The recent breakthrough for highway applications (outdoors) has been the development of super-high output (super bright) LEDs. The new super bright LEDs provide good luminance for outdoors. 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. Each LED cluster performs the same function as one bulb in an incandescent bulb matrix CMS. The Ontario CMSs will have clusters of 64 super bright LEDs--9 red and 55 green. This combination will produce the yellow hue for the characters desired by the Ministry. (5)

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, and laser scan. 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.

C. 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 are 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 as shown in Figure 2-1. Although many types of designs were available, practical experience revealed that it was possible to limit electromechanical CMSs to only a few designs.

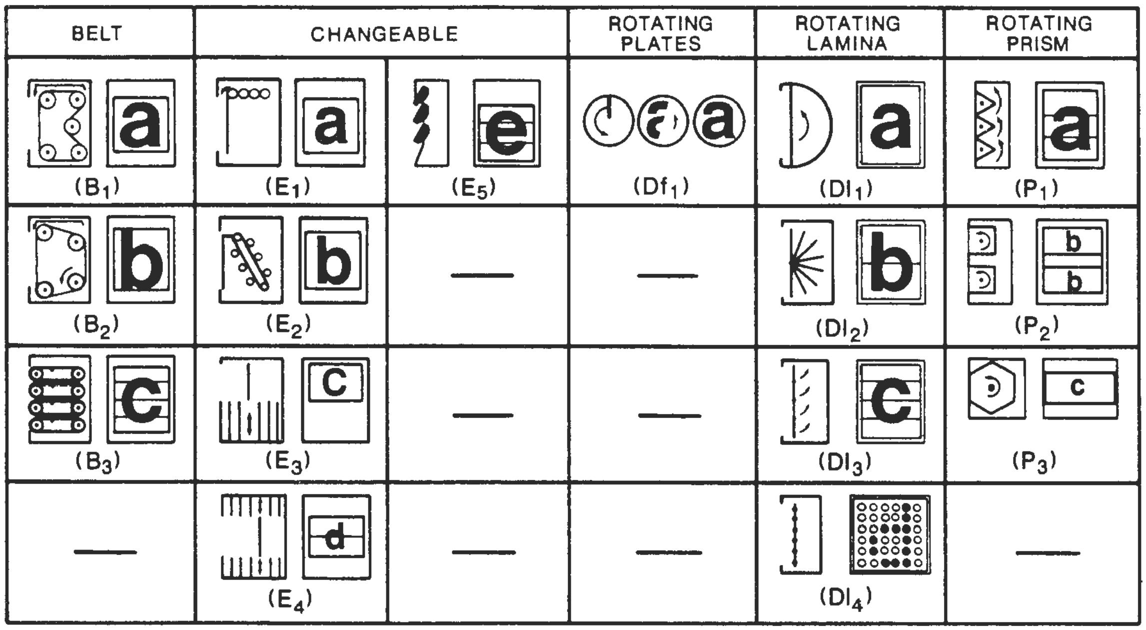
Great improvements in CMS technology were made when concepts based on lighting techniques were developed. The United Kingdom developed fixed grid incandescent bulb matrix CMSs. "Fixed grid" implies that light-emitting units (such as bulbs) are positioned within an array only in positions necessary to 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 1/4 inch (4 to 6 mm) in 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 (6). Also, the fact that the signs do not have moving parts is a considerable asset in the view of the agencies.



B_1 Continuous belt	Df_1 Rotating shutter
B_2 Roller	Dl_1 Single flip-over plank
B_3 Multiple continuous belts	Dl_2 Multiple flip-over plank
E_1 Single roller	Dl_3 Rotating planks
E_2 Continuous belt roller	Dl_4 Matrix sign
E_3 Simple plate	P_1 Three-sided rotating prism
E_4 Split plate	P_2 Four-sided rotating prism
E_5 Lamina plates	P_3 Multi-sided rotating prism

Figure 2-1. Different Types of Electromechanical Changeable Message Signs Used in Western Europe (Ref. 4)

The United Kingdom has a written policy to use only light-emitting CMSs on interurban freeways. 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.

D. Characteristics of Various Types of CMSs

This section summarizes pertinent features of various types of CMSs with emphasis on human factors considerations. More detailed information on display types can be obtained by contacting sign manufacturers and transportation agencies which have installed real-time information systems. A list of several highway agencies and their signing experiences relative to the use of CMSs for urban freeway corridor traffic operations as of 1989 is presented in Table 2-2.

It should be noted that technology in the field of real-time signing hardware is increasing rapidly. One should be alert to improvements in existing hardware and development of new signing techniques subsequent to the publication of this report.

Table 2-2
SUMMARY OF
FREEWAY SURVEILLANCE AND CONTROL PROJECTS
USING CMSs (MARCH 1989)

Site	Project	Implementation Date	CMS (Type- #)
Los Angeles, California	Los Angeles Metropolitan Area Management System	1971 & on	Bulb-21; Disk-18 Fiber Optics-1
San Francisco, California	San Francisco-Oakland Bay Bridge	1971 & on	Bulb-15
Tampa, Florida	Howard Franklin Bridge Surv. & Control System	1984 & on	Disk-4; Drum-12
Tampa, Florida	Sunshine Skyway Bridge Motorist Warning System	1984 & on	Disk-2
Chicago, Illinois	Chicago Metropolitan Area Traffic Systems Center	1961 & on	Disk-8
Detroit, Michigan	SCANDI	1981 & on	Tri-Color-5; Disk-1
Minneapolis, Minnesota	Twin City Traffic Management System	1980 & on	Bulb-2; Drum-4
New Jersey Turnpike	N.J. Turnpike Automatic Traffic Surv. & Control System	1976 & on	Neon-41; Drum-67
Long Island, New York	Information for Motorists Project (INFORM) (formerly IMIS)	1984 & on	Disk-74
New York-New Jersey	Tunnel Traffic Control System	1972 & on	Disk-12
Cincinnati, Ohio	I-75 Traffic Diversion System	1974	Bulb-19
Pittsburgh, Pennsylvania	Penn-Lincoln Parkway Surv. & Control System	1976 & on	Disk-2; Drum-1
Virginia	Hampton Roads Bridge Tunnel	1977	Bulb-23, Scroll-6 Blankout-21
Virginia	I-66/I-395 Traffic Management System	1984 & on	Disk-70
Seattle, Washington	The Flow System	1981 & on	Neon-1; Disk-6 Blankout-21
Toronto, Canada	Burlington Skyway Freeway Traffic Management System	1975 & on	Disk-7 Fiber Optics-1
Toronto, Canada	QEW Mississauga Freeway Traffic Management System	1975 & on	Disk-2
Toronto, Canada*	401 Incident Management Project	1990	Clustered LED-13

* Planned

D.1 <u>Static Sign</u>

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.

Figure 2-2. Flashing Beacon Sign Used in Houston, Texas.

Figure 2-3. Special Event Trailblazer Sign in Dallas, Texas.

D.2 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.

Figure 2-4. Neon-Type Blank-Out Hazard Warning and Bulb Matrix Speed Signs on the New Jersey Turnpike

D.3 Fold-out (Flap) Sign

Appearance

- A fold-out sign is a conventional highway sign with a hinged viewing face. When the hinged face is opened, drivers view the front of the sign face. When closed, only the back side of the hinged section is visible.
- Any color can be incorporated into the message(s) or background.
- Exact shapes of symbols and standard lettering types can be displayed.

Message Display

- Individual messages are statically displayed.
- Message changing can be affected manually or by a motor-driven assembly.
- Time required to change messages varies from one to several seconds. However, under normal applications, message change time may not be critical.

Figure 2-5. Electromechanically Operated Fold-Out Sign at High Water Crossing

D.4 Rotating Scroll (Tape) Sign

Appearance

- The viewing face is formed by flexible cloth or plastic material stretched between rollers on which messages are printed using a silk screen or spray masking process.
- In many instances, the material is translucent, permitting back illumination.
- Any color may be incorporated into the message or background.
- Exact shapes of symbols and standard lettering types may be displayed.

Message Display

- Messages printed on the tape are displayed by rotating the tape to the appropriate viewing position. If desired, a blank space may be left on the tape so that no message is visible when the tape is rotated to that position.
- Tapes can be vertically or horizontally rotated, depending on sign design.
- At least 1.0 second is required to rotate the tape (change messages) to an adjacent message or blank space.
- In the process of tape rotation, undesired messages may become visible to drivers. To correct this problem, some designs employ a curtain device during message changing.
- Depending on the sign design, from 2 to 30 printed messages can appear on a tape. Typically, no more than 12 messages are printed on a tape. With a larger number of messages, the time to change to a message located at a distant point on the tape becomes unreasonable for some applications.

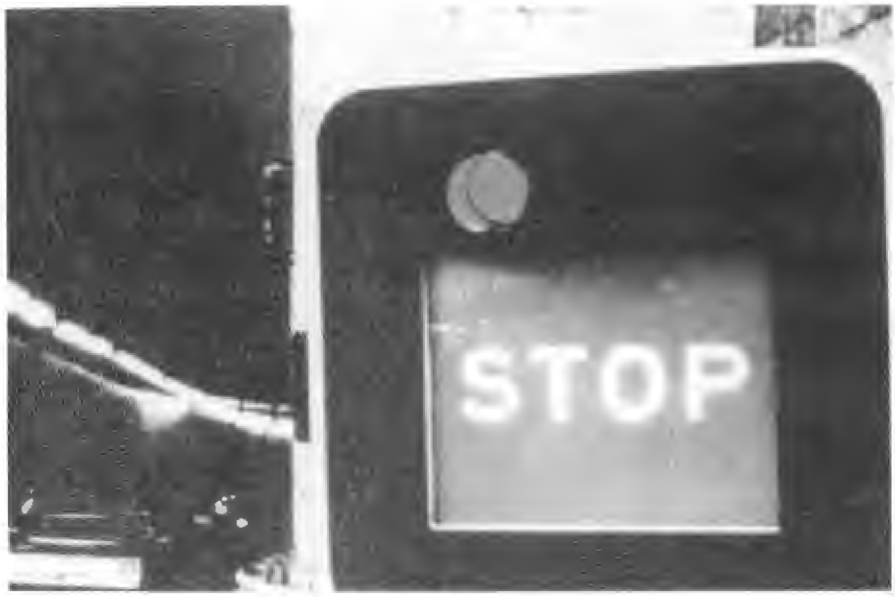


Figure 2-6. Scroll Sign Mounted Used at the Portal of the Lincoln Tunnel in New York

Figure 2-7. Rotating Tape Signs Used on I-70 near Dillion, Colorado

D.5 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 x 3 x 3 x 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 (e.g., Minnesota Department of Transportation) 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. (See Figure 2-12.)

Figure 2-8. Rotating Drum Sign Used in Dallas, Texas

Figure 2-9. Rotating Drum Signs on the New Jersey Turnpike

Figure 2-10. Horizontal Drum (Prism) Sign at Heathrow Airport in London

Figure 2-11. Vertical Drum (Prism) Sign on Motorway A1 in the United Kingdom

Figure 2-12. Horizontal and Vertical Rotating Drum Sign in Frankfurt, West Germany

D.6 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 restricts 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 (Figure 2-16), 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 low legend contrast results in poor legibility (Figure 2-17). 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 (Figure 2-18). 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 shadded portion of the legend; thus, messages can become illegible. (5,7)

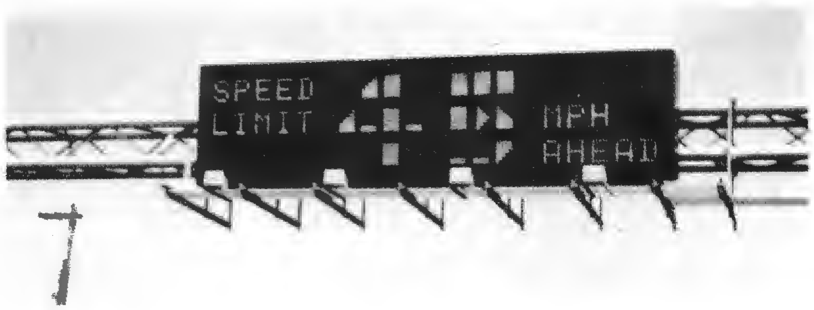
- The front screen on many existing reflective disk signs is composed of clear Lexan. The mirror effect from the sun or external lighting at times degrades legibility by causing reflections as shown in Figures 2-19 and 2-20. Anti-glare Lexan has also been used in attempts to rectify the reflectance problem. The results have not been successful. Its use by the Ontario Ministry of Transportation, for example, resulted in considerable nighttime reflection problems as shown in Figures 2-21 and 2-22. 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. (7)

- 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. (7)

Figure 2-13. Modular Circular Disk Matrix Sign in Cheyenne, Wyoming



'igure 2-14. Modular Circular Disk Matrix Sign near Pittsburgh, Pennsylvania

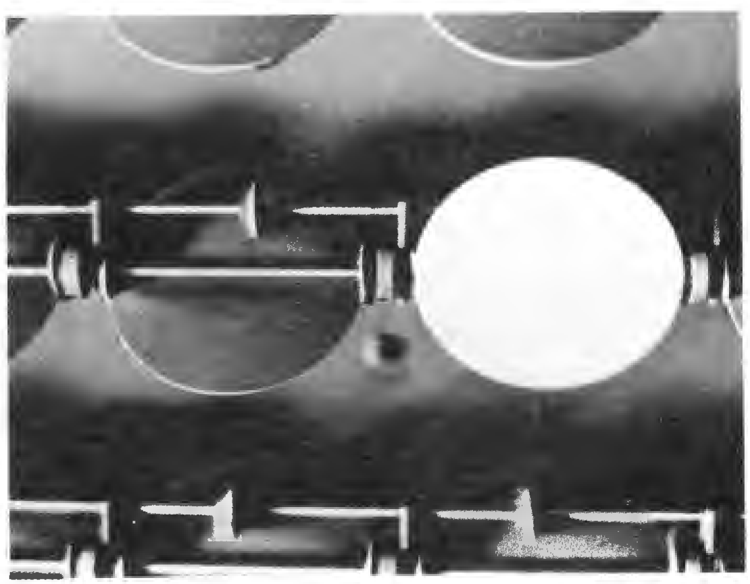


Figure 2-15. Close-Up View of Circular Disk Indicators

Figure 2-16. Sun in Front of Reflective Disk Sign Gives Good Visibility (Ref. 5)

Figure 2-17. Sun Behind Reflective Disk Sign Gives Poor Visibility (Ref. 5)

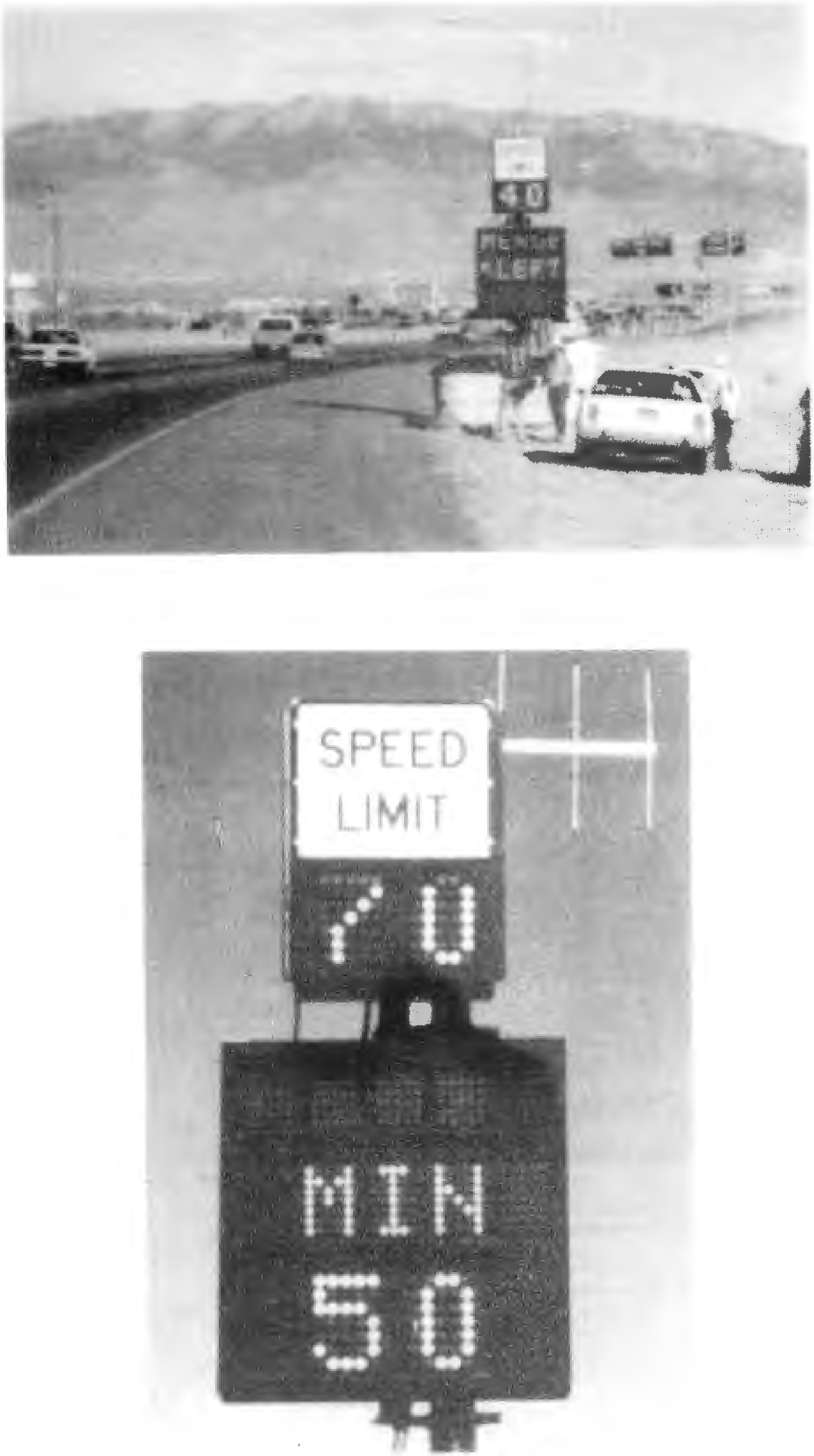


Figure 2-18. Sun Casting Shadows on Sign

Figure 2-19. Extraneous Reflections Using Lexan (Ref. 5)

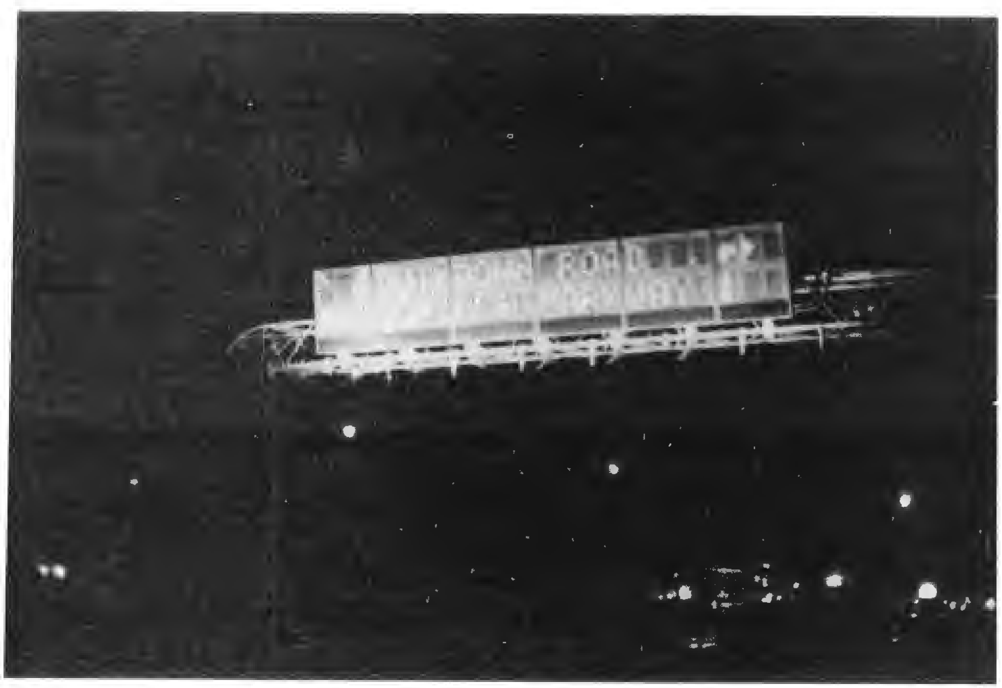


Figure 2-20. Mercury Lighting of Reflective Disk Sign (Ref. 5)

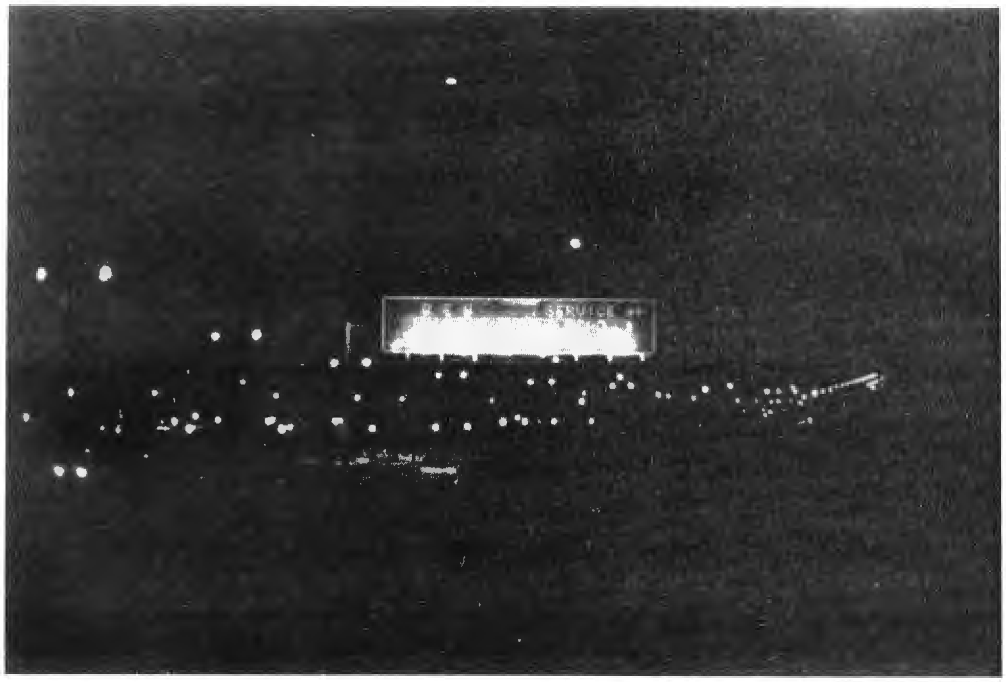


Figure 2-21. High Pressure Sodium Lighting on Reflective Disk Sign With Anti-Glare Lexan (Ref. 5)

Figure 2-22. Detail of Lighting Problem With Anti-Glare Lexan (Ref. 5)

Reflective Disk Matrix Sign - 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.

- 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 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 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 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.

- 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. (5)

Figure 2-23. Rectangular Disk Matrix Sign

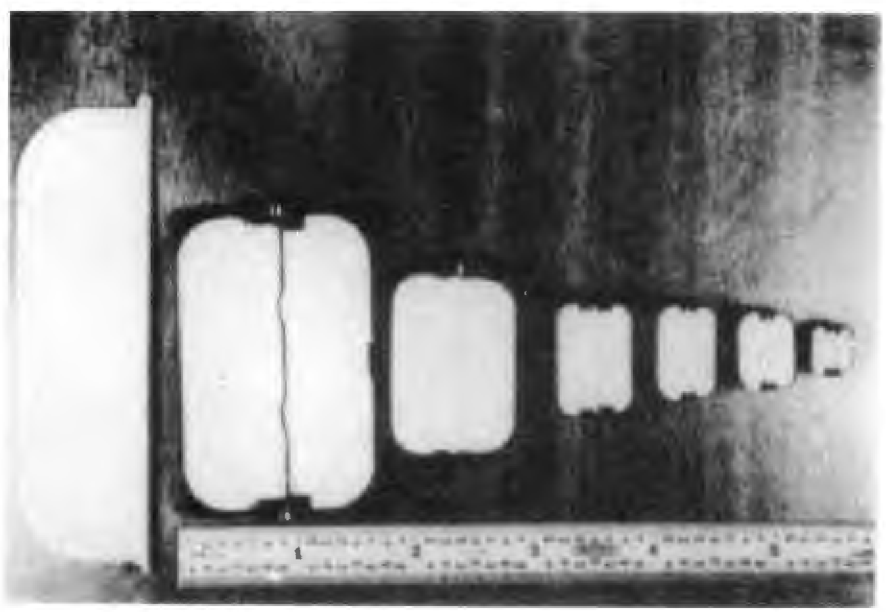


Figure 2-24. Close-Up View of Rectangular Disk Matrix Sign

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 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.

Notes

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

Figure 2-25. Dimensional Square Disk Matrix Sign

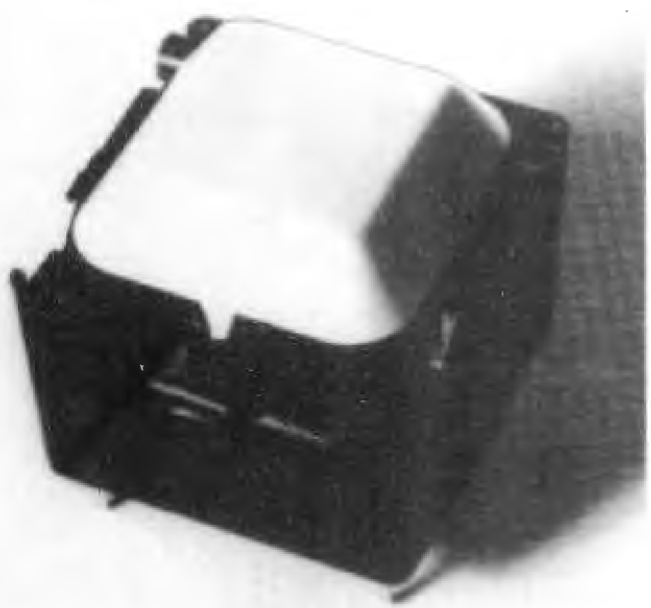


Figure 2-26. Close-Up View of Dimensional Square Disk Matrix Sign

D.7 Flap Matrix Sign

Appearance

- The viewing face is formed by a matrix arrangement of electromechanically actuated flaps.
- Current designs are modular, employing 5 x 7 modules or 31 flap figuregrams.
- Flaps have two positions, up or down, and reveal one of two colors.
- A white-on-black color combination is typically utilized.
- Exact shapes of symbols and lower case letters is restricted with the size of CMSs used for highway applications.

Message Display

- Normally, messages are statically displayed.
- Module-by-module/line-by-line writing is employed to change messages on current designs.
- At least 2.0 seconds are required to change a complete line of copy. Up to 10 seconds are required to change the entire message.
- Unless blanked prior to changing messages, parts of the old and new messages will be visible during the message changing process.
- Character heights from 14 to 18 inches (356 to 457 mm) are available.

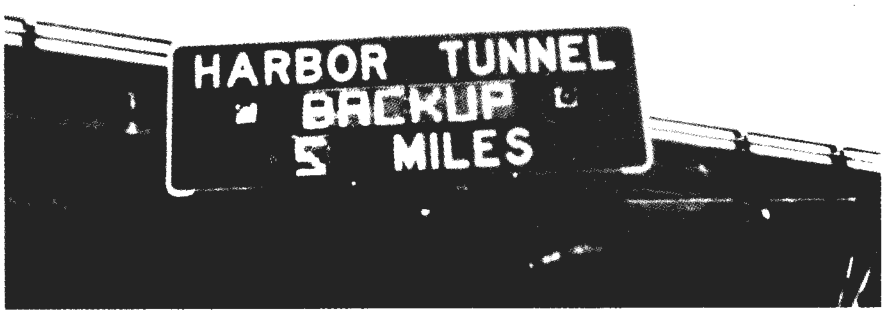


Figure 2-27. Electromechanical Flap Matrix Sign Installed on King Avenue Overpass in Baltimore, Maryland

D.8 Rotating Cylinder/Triangle Element Sign

Appearance

- The viewing face consists of a number of small cylindrical or triangular modules. The modules are closely fitted such that each gives the appearance of a small square with no apparent separation between modules.

- In practice, the operation is almost completely similar to that of the disk or flap signs except that the pixel elements, which are seen as square elements with sides approximately 2 1/2 inches (63.5 mm), are cylindrical (or triangular) and the change of the display is achieved by rotation of the cylinder (or triangle) to show one of the colored surfaces. In the case of triangular elements, one of three colors (e.g., white, fluorescent yellow and matte black) is displayed.

- A typical freeway mounted sign may contain 2,430 elements (90 columns x 27 rows).

Message Display

- Normally, messages are statically displayed.

- Control codes are available to change font size, shape, color, and spacing.

- Font size can be changed to range from 4 wide to 6 wide and 5 high to 9 high. Thus, the following character sizes can be displayed: 4 lines of text with 4x5 font; 4 lines with 4x7 font; 3 lines with 5x7 font; 2 lines with 5x9 font; and double stroke.

- The font fields can be adjusted by the sign operator so that different fonts can be mixed on the same line of text.

- The sign elements can be rotated quickly to provide a pseudo flashing message.

Notes

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

D.9 Vane Matrix (Electrostatic) Sign

Appearance

- The viewing face consists of a number of modules closely fitted such that no separation between modules is apparent; each module contains many irridized aluminum vanes. Each vane is electrostatically moved to one of two positions (up or down) and, depending on vane position, one of two colors is visible.

- Exact shapes of symbols cannot be displayed, but some designs employ 0.5 square-inch (13 square mm) vanes which permit improved shape representation.

Message Display

- Normally, messages are statically displayed; however, some designs permit a flashing mode.

- Changing of messages is usually accomplished by sequential column-by-column writing.

- Depending on the control system, message change times vary from 50 milliseconds to 45 seconds; typical displays applicable for highway use require 30 seconds to change an entire message.

- Letter heights ranging from 2 1/2 to 18 inches (63 to 457 mm) are available.

Figure 2-28. Electrostatic Vane Matrix Sign Used on Highway 99 near Stockton, California

D.10 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.

- Figure 2-29 shows a close-up of the lamps enclosed in reflectors (canisters) to prevent light from lamps which are "on" from reflecting off the glass of lamps which are "off".

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, at a similar pixel size, is the super bright LED cluster. (5)

- 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 as indicated in Figure 2-32. Sound judgement has to be exercised to obtain the optimal voltage (life) to light output (efficacy) ratio. (5)

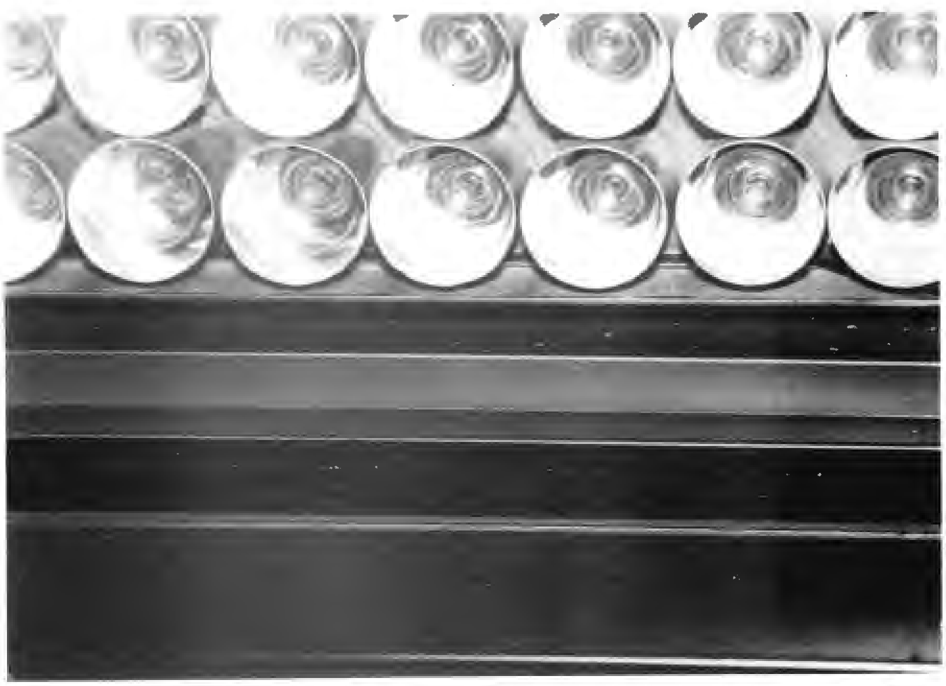


Figure 2-29. 30 Watt Incandescent Bulbs in Canisters (Ref. 5)

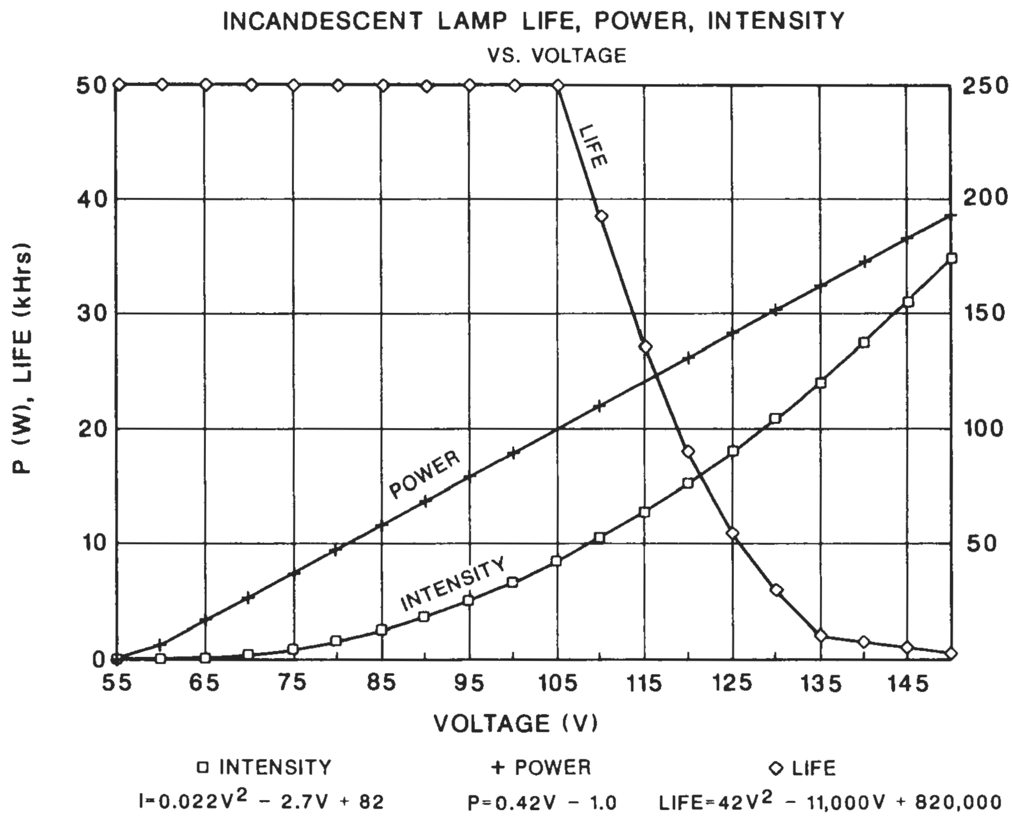


Figure 2-30. Relationships of Incandescent Bulb Life, Voltage and Light Output (Ref. 5)

D.11 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 2-31)
- 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 2-32)
- 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 2-33)
- 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 2-34), or mixedgrid which has a combination of macro and microgrids (Figure 2-35). The microgrid provides a means for more detailed and better presentation of symbols (4).
- 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 2-36 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 of 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.

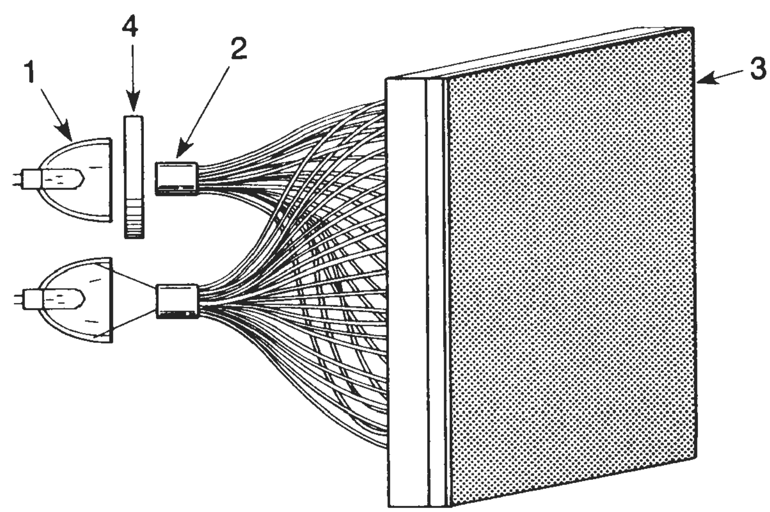
- All stored messages are "hardwired" with each message requiring an individual light source and fiber bundle. Generally, the maximum storage capacity is around 15 separate "hardwired" messages.

Notes

- Selected Standards from France and West Germany are shown in Appendices A and B.

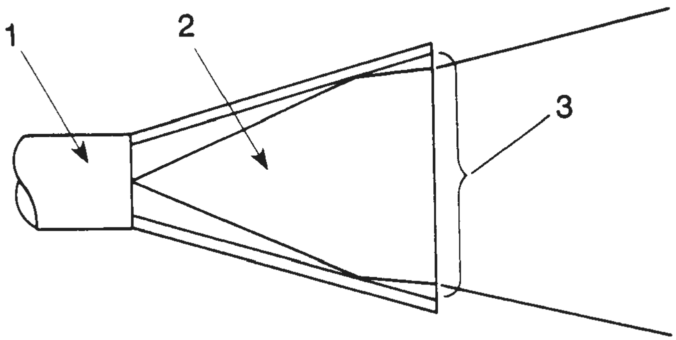
- The fiber bundles can either be sheathed or without a casing. European standards require that the fiber bundles be sheathed. A PVC casing is generally used. No standards are available in the United States where manufacturers generally do not directly cover the fibers, but use a less expensive procedure 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.



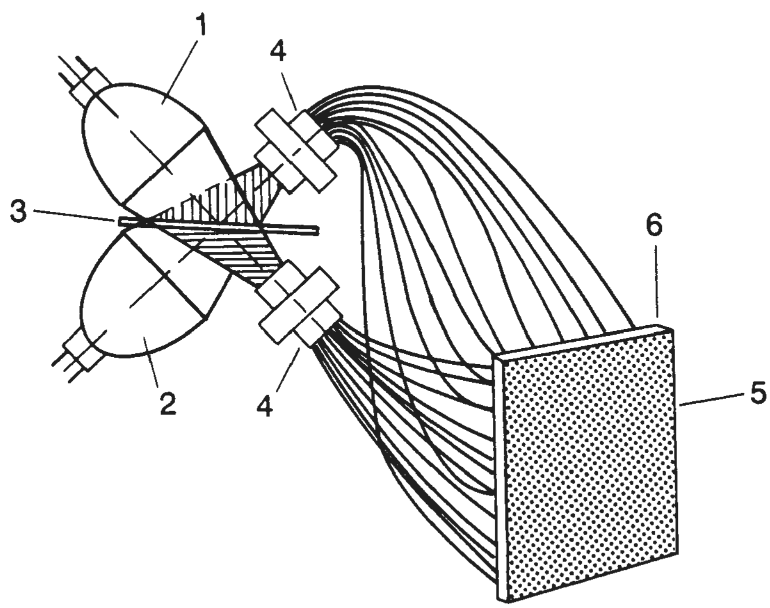
1. Halogen lamp
2. Multi-branched, flexible light guides
3. Screens
4. Filter

Figure 2-31. 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 (4 mm)

Figure 2-32. Fiber Optic Light Guide and Cone



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

Figure 2-33. Fiber Optic Light Beam Splitter

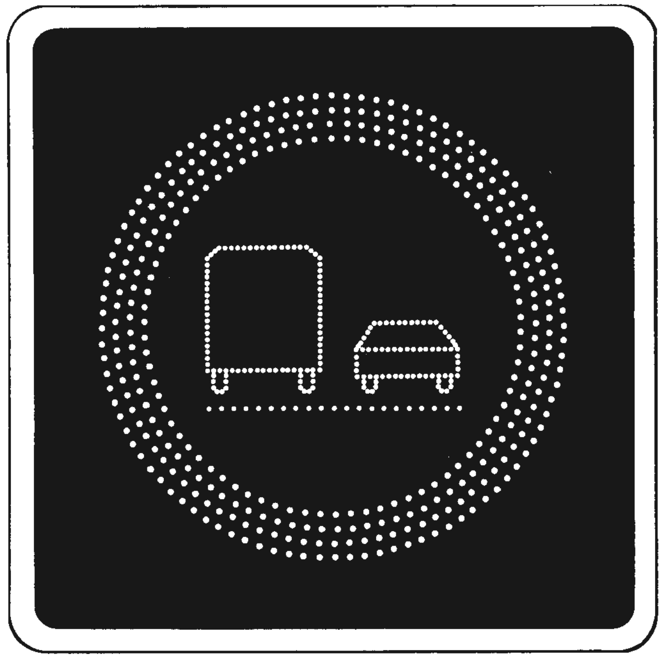


Figure 2-34. Matrix Sign of the Microgrid Type (Ref. 4)

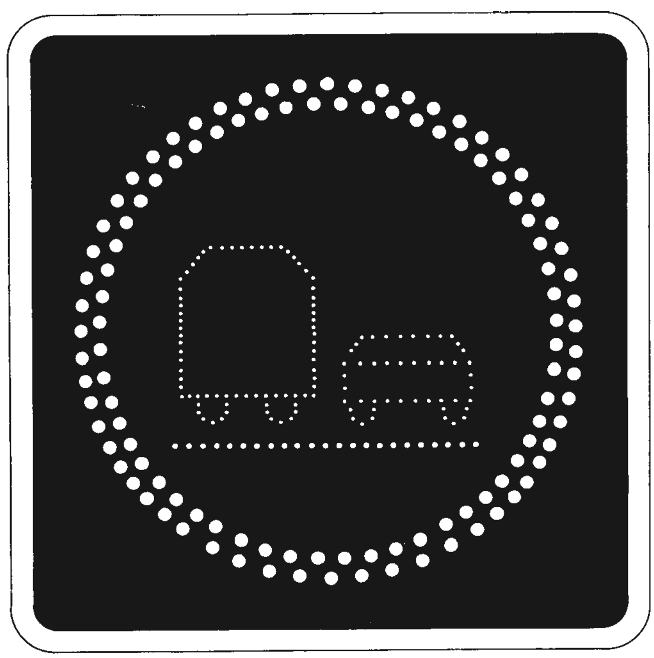


Figure 2-35. Matrix Sign of the Mixedgrid Type (Ref. 4)

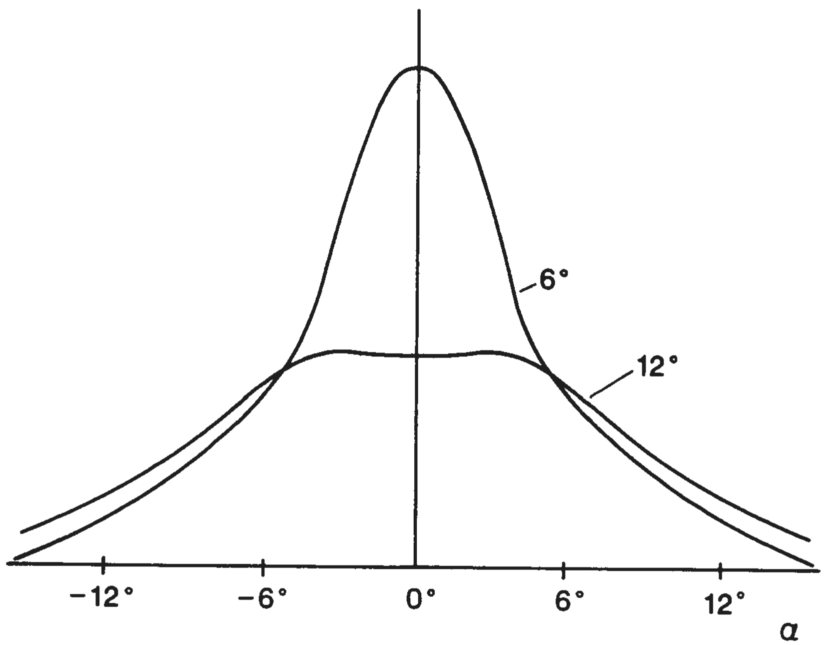


Figure 2-36. Fiber Optic CMS Light Emission Characteristics from Laboratory

D.12 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 2-37 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 2-38.

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 2-39, 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 2-40 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. The cylinder design was calculated to give the best protection from the sun, while permitting the required viewing angle. (5)

- Sun reflectance from Lexan sun shield placed on the front of the CMS can also adversely affect legibility. (5)

- 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. However, manufacturers recommend against its use outdoors due to problems with deterioration from humidity and dirt. (5)

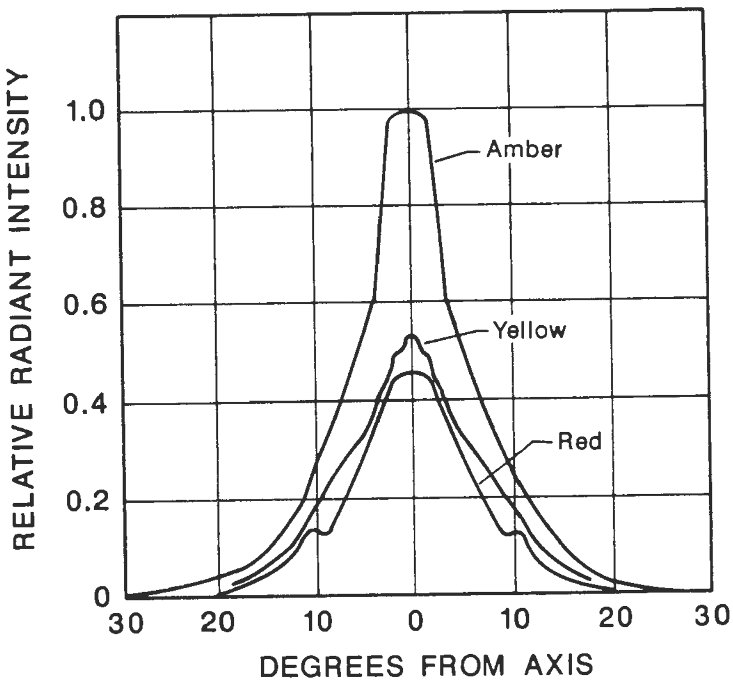


Figure 2-37. LED Cluster Beam Distribution (Ref. 5)

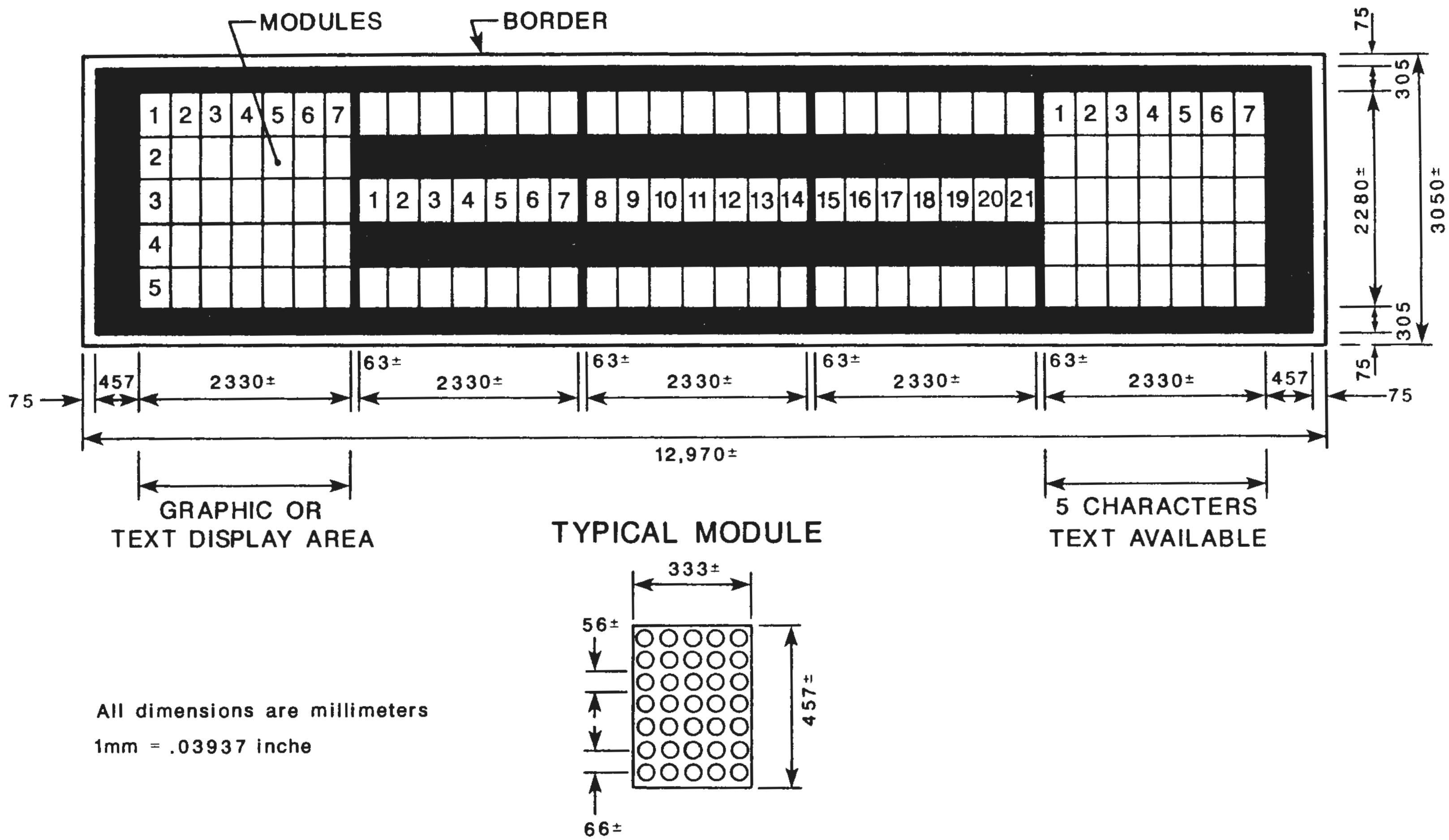


Figure 2-38. Ontario Ministry of Transportation Selected Sign Face (Ref. 5)

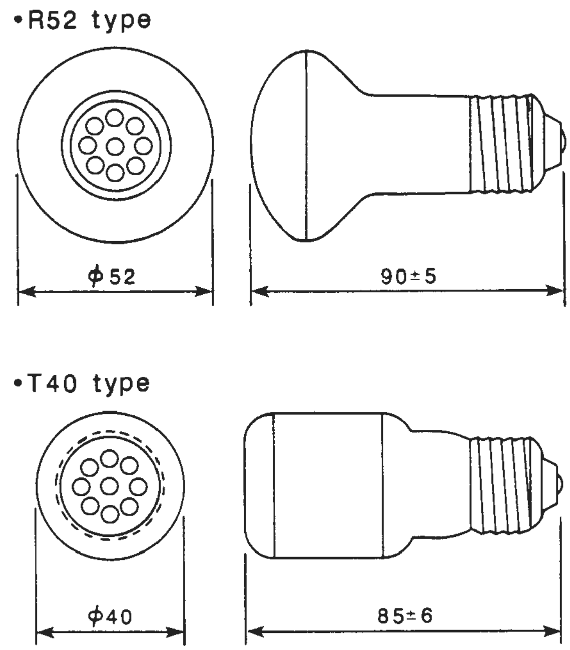


Figure 2-39. LED Cluster in Glass Bulb - Stanley (Ref. 5)

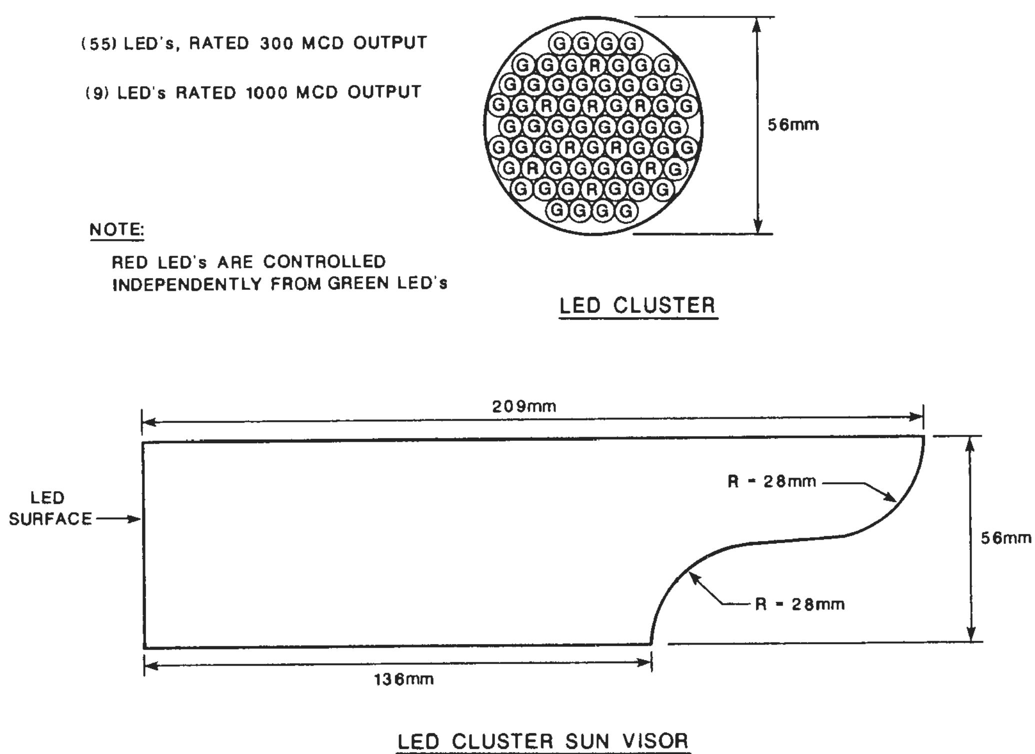


Figure 2-40. LED Cluster with Sun Visor (Ref. 5)

D.13 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 2-41 illustrates the halogen light module and fiber optic bundles connected to a typical three-character module. A shuttered fiber optic CMS is shown in Figure 2-42. Figure 2-43 shows how the message becomes "washed out" under bright sun conditions. Figure 2-44 shows a module mock-up in the "overbright" mode with both lamps and two dots operating.

- 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 as indicated in Figure 2-45.

- The 5x7 matrix array of fibers restricts the presentation of exact symbols and lower case letters.

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. (See Chapter 7, Section B.)

- 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.

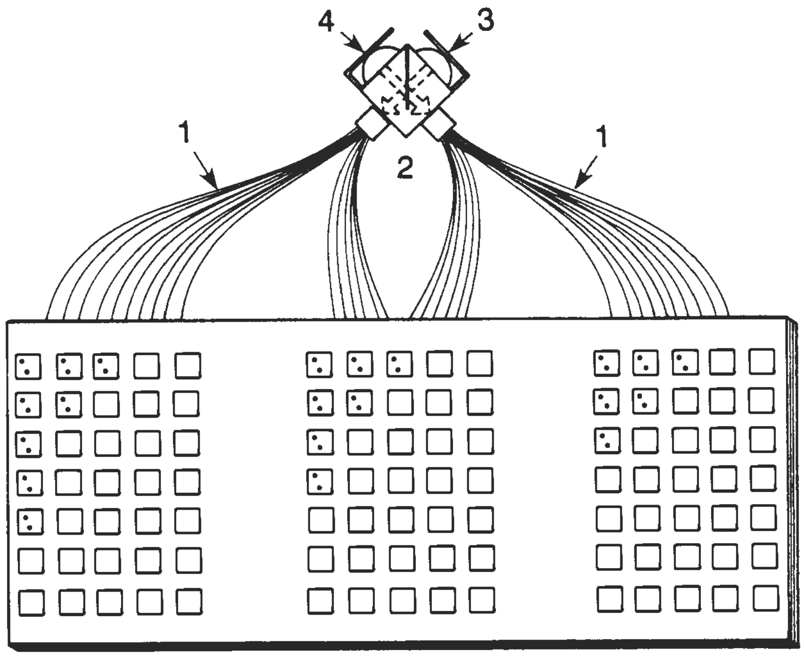
- Each line of message must be increased in units of three characters (e.g., signs can be purchased with 12, 15, 18, etc. characters per line).

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.



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 2-41. Light Module and Fiber Optic Bundles Connected to Typical Three-Character Module

Figure 2-42. Shuttered Fiber Optic Sign (Ref. 5)

Figure 2-43. Shuttered Fiber Optic Sign in Sun (Ref. 5)

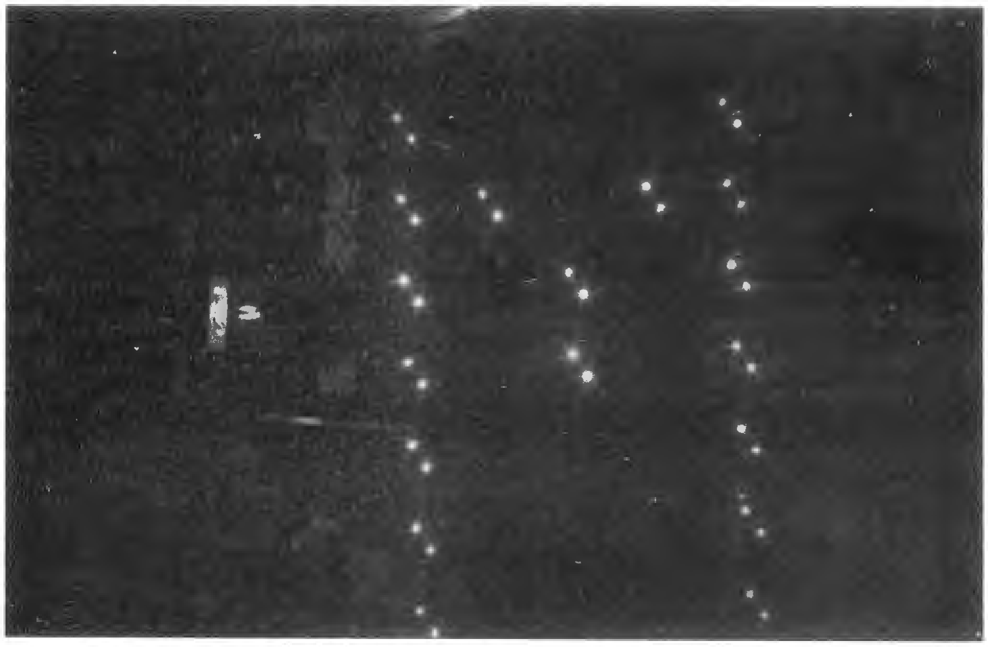


Figure 2-44. Shuttered Fiber Optic Sign Module in Overbright Mode (Ref. 5)

Figure 2-45. Shuttered Fiber Optic Sign Field of View (Ref. 5)

D.14 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 2-46. The pixels in use, therefore, show both the reflective disk and the illuminated fiber optic light. Figure 2-47 indicates a visual comparison of this technology (top line) along with the standard flip disk installation.

- 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.

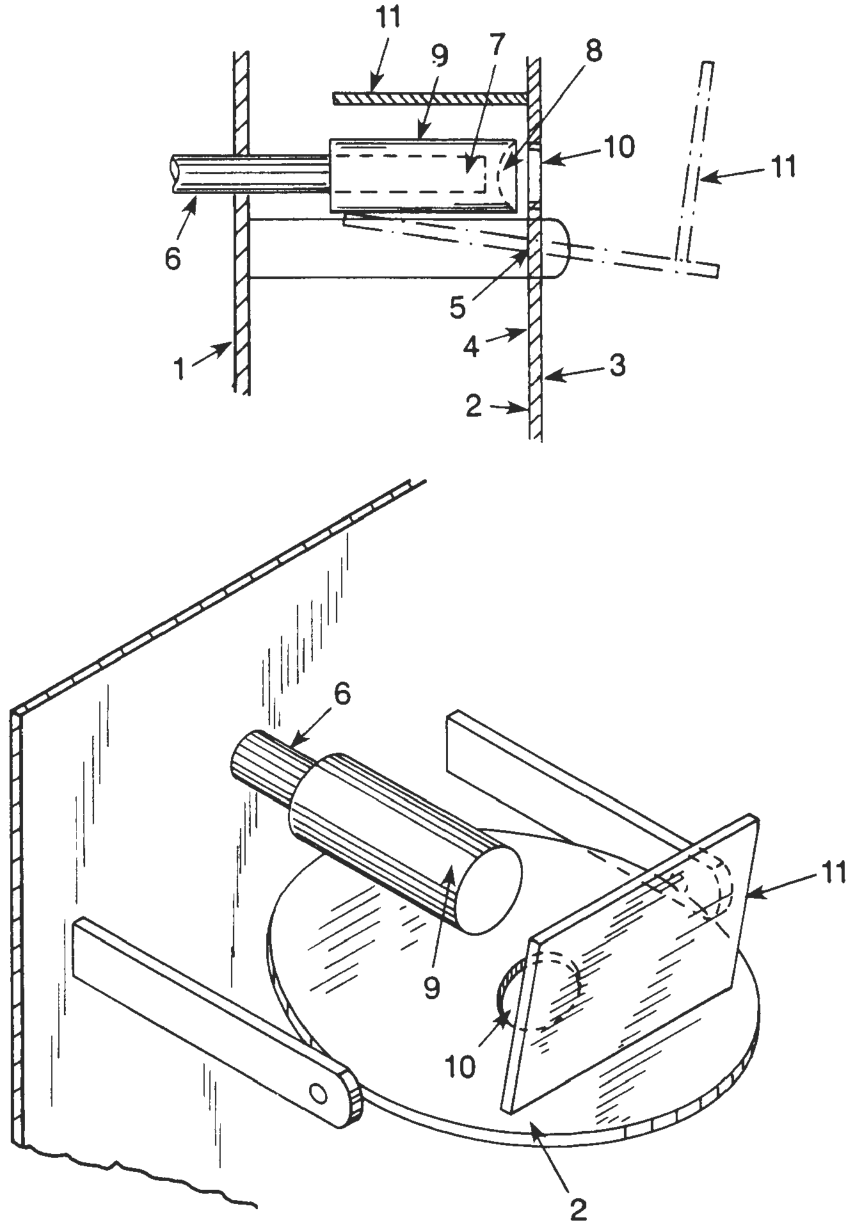
- In the case of power failure, the CMS can rely on the flip disks to revert to either the message under use or to a default message.

- The fiber optic pixels exhibit a directionality similar to the fiber optic CMSs. The effective visual cone is estimated at 20 degrees and is illustrated in Figure 2-48 (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
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 2-46. Mechanics of FO/RD Pixel

Figure 2-47. FO/RD Prototype (Top Line) at Various Distances (Ref. 5)

Figure 2-48. Directional Viewing of FO/RD Prototype (Top Line) (Ref. 5)

D.15 Cloth Sign

General Features

- The most notable use of cloth CMSs for highway applications is by the California Department of Transportation (Caltrans) in the Los Angeles area. Pickup trucks with retractable sign supports are assigned to Major Incident Response Teams. Figure 2-49 illustrates a typical sign used by Caltrans. In addition, cloth signs are used along diversion routes.

Appearance

- Since standard character fonts and colors can be used, the sign can be designed comparable to a normal static sign.

Message Display

- Cloth messages are manually attached to a cloth panel. A nylon hook and pile strip arrangement allows the message panels to be placed on the sign background by hand pressure. Sign message panels are removed by "peeling" them from the background.

- A maximum of four lines of message can be used. Message size is limited by the sign support requirements necessary to fit on the pickup trucks. Message character heights of 10 inch (250 mm) are normally used, although 20-inch (500-mm) characters are sometimes used. Early message panels with 8-inch (200-mm) letters were found to be unsatisfactory.

Figure 2-49. Truck-Mounted Cloth Sign, Caltrans.

D.16 Fold-Out (Type II) Sign

Appearance and Message Display

- In contrast to the type I fold-out signs, fold-out type II displays are manually opened to display a single message.
- The signs can be fabricated by the highway agency to any desirable size using standard characters and colors.

D.17 Removable Panel Sign

Appearance and Message Display

- Sign message panels (usually plywood) are inserted into slots on a fabricated sign support. Different messages can be inserted depending on the signing requirements. The sign support can be fabricated to accommodate several different sizes of message characters.
- Notable examples of this type of sign is the trailer mounted sign used in several highway districts in Texas. Their primary use is for advanced notification of construction or maintenance, or for traffic control during special events.

E. Special Considerations

E.1 Hybrid Displays

A hybrid display results when two or more of the signing techniques discussed in the previous section are incorporated in a single display. Figure 2-50 illustrates typical hybrid displays currently in operation. Hybrid signs typically, though not always, employ a combination of static and changeable elements. Under some circumstances, this combination affords certain advantages:

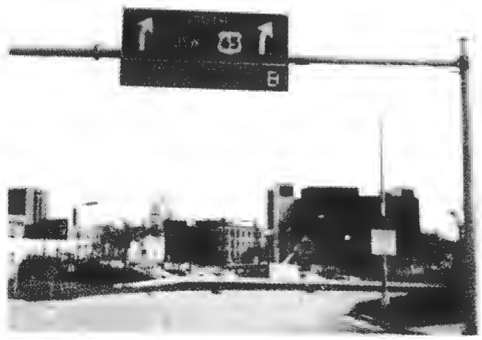
- Some CMSs require one or two lines of copy or a part of a line or lines which do not vary with the message being displayed. By using a static (conventional sign) element for the fixed portion of the message, cost savings related to materials, fabrication, maintenance, and power consumption can be achieved.

- Some CMSs (e.g., bulb and disk matrix signs, fiber optic signs, etc.) have limited shape and color display capabilities. Therefore, a static (conventional sign) element on which desired shapes and colors are displayed can be used in combination with these CMSs.

Hybrid signs also have drawbacks in some applications:

- Invariably, the use of a fixed message element with a changeable message element will reduce the message flexibility of the changeable element and the display as a whole.

- If an internally lighted changeable message element is used with a static (conventional sign) element, the static portion may be washed- out by the intense, internal light source.



Bulb-Type Matrix and Static Sign Elements
Used in Combination in Minnesota

Hybrid Display Used in Philadelphia, Pennsylvania

Figure 2-50. Typical Hybrid Displays

E.2 Transportable Signs

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.

Examples of the use of truck-mounted signs in response to major incidents are the Caltrans Major Incident Response Unit cloth CMS (shown previously in Figure 2-49) and bulb CMS (Figure 2-51). Trailer-mounted signs are used by several Districts of the Texas State Department of Highways and Public Transportation. Although these signs have the capability to respond to unexpected incidents of considerable duration, their primary function is in response to recurring or scheduled events (Figure 2-52). Different kinds of trailer-mounted signs are commercially available (e.g., bulb (Figure 2-53) and reflective disk (Figure 2-54) CMSs. These signs generally display a fixed set of messages.

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.

Figure 2-51. Truck-Mounted Bulb Matrix Sign, Caltrans

Figure 2-52. Trailer-Mounted Changeable Message Sign, Texas State Department of Highways and Public Transportation

Figure 2-53. Trailer-Mounted Three-Line Bulb Matrix Sign

Figure 2-54. Trailer-Mounted Rectangular Reflective Disk Matrix Sign

F. Other Emerging CMS Technologies

F.1 Liquid Crystal Display Matrix Sign (5)

Liquid crystal display (LCD) technology is used for several display systems such as computer monitors, television screens, calculators, watches, clocks, etc., but has not yet been introduced into the highway operations field. It is popular in applications that require low electrical power and where batteries can be used. Experiences with existing uses indicates that considerable improvements need to be made in legibility and other facets before it can become a serious candidate for highway use.

The operation of the LCD is based on optical and electrical properties of materials which crystallize at certain temperatures but remain suspended in liquid. When the voltage is changed, the liquid crystal reorient themselves either to transmit or to block the transmission of light. The viewer, therefore, sees either the crystals or the background behind the liquid.

The LCD display legibility is dependent on the quality of external light to achieve adequate reflectance of incident light on the display. Therefore, night visibility is quite low. Currently, manufacturers are developing high contrast LCDs for outdoor applications.

Another approach being developed is to incorporate internal illumination in the LCD signs. This approach improves night legibility significantly, but greatly increases the power consumption.

F.2 Cathode Ray Tube (Color Video) Sign

Appearance

The color video matrix signs have been mostly installed in for sports events. Therefore, they can be found in stadiums, sports arenas, and race tracks. Typical display surfaces may range in size from which is 125 pixels in width and 100 pixels in height to 224 x 100 pixels.

The video image can be displayed by a variety of ways including fluorescent lights, LEDs, fiber optics and lamps. Each pixel made by one manufacturer, for example, is composed of three fluorescent tubes (blue, red and green). The three tubes are very close together in a cup-like glass which creates a blending of the colors even at short distances. The manufacturer claims that the tubes can be controlled to 32 different light intensity levels to produce more than 32,000 different colors. Another manufacturer uses one red LED chip and one green LED chip sealed in a single glass container. Thus the single LED can be light the red or green, or light both to produce amber.

The light intensity of the color white is more than 3,600 cd/m^2. The manufacturer estimates that the contrast is higher than 8 even in direct sunlight.

The matrix part of the scoreboard is composed of modules of 20 x 64 pixels (height 5 ft [1.5 m], length 15.5 ft [4.8 m]). The fluorescent tubes are mounted on printed circuits with 4 x 4 pixels. On the front side a sun filter is placed along with a 30 percent black surface increases the contrast.

The video sign system comes complete with computers and video equipment (video cameras, tape recorders, etc.). The sign can display still photographs or live pictures.

As of the date of this publication, the cathode ray tube (color video) display has not been used for highway applications primarily because of the very high cost.

3. SOME GENERAL CONSIDERATIONS

A. CMS Criteria

THE PHOTOMETRIC AND PHYSICAL DESIGN REQUIREMENTS FOR CMSs ARE BASED ON THE FOLLOWING FOUR FUNCTIONAL REQUIREMENTS THAT THE SIGNS HAVE TO FULFILL (4):

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.

Conspicuity and legibility issues relative to CMSs are discussed in later chapters of the report. Comprehensibility of messages is covered in detail in the "Manual on Real-Time Motorist Information Displays" (1). Credibility is discussed below.

B. 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.

It is sometimes enticing to display information that exceeds the surveillance capabilities (e.g., displaying point-to-point travel times). In other cases, the operator simply fails to change the messages with changing conditions.

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. Drivers are more receptive to diverting before they get on the freeway (12). 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 USE THE DISPLAYS TO BALANCE DEMANDS WITH AVAILABLE CAPACITY DURING RECURRENT CONGESTION.

There have been attempts 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 (13) and is a good way to lose credibility. Some possible reasons why drivers do not respond to the messages during recurrent congestion situations are:

- Drivers know what delays to expect on the ramp they intend to use and have certain expectations of what conditions they will encounter once on the freeway.

- Drivers are concerned with their individual travel times and are unconcerned with "optimizing" flow in a corridor. Thus, they must realize a significant reduction in their personal travel time. Asking them to drive through additional signalized intersections simply won't work unless it results in a significant improvement in their travel.

- Commuters are not naive drivers. Many have explored alternative routes and have selected routes that appear to be "optimum" for them. Therefore, they must be convinced that the new route will be better for them, and that they are not sacrificing time or comfort for the benefit of other drivers.

BE ON THE ALERT FOR POSSIBLE OPERATOR BOREDOM PROBLEMS (14).

The tendency in many operational systems is to establish a library of messages and then assign the task of displaying the appropriate messages to technicians and assume they do the job properly.

Real-time information displays are basically intended for incident responsive traffic management, that is, response to abnormal conditions such as freeway accidents. The display operators must make timely responses to detected incidents. The major problem inherent in this task is that incidents involve only a small percentage of the time the operator is working. The bulk of his or her time is spent waiting for something to happen. In time, personnel become less motivated and efficient. This leads to failure to display appropriate messages at the proper time and thus, a rapid loss of credibility.

The boredom problem often leads to personnel turnover that requires new people to be trained.

Bogdanoff and Thompson (14) suggest that job enrichment techniques need to be employed to insure job motivation and performance. Surveillance personnel need to function more broadly. This might require using higher grade personnel to both operate and evaluate or upgrade the systems simultaneously. They also suggest that a team concept might be used where teams alternate between operation and evaluation work. Another approach that might be considered is to assign the surveillance personnel additional tasks relating to roadway operations.

C. 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" (1) 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.

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.

D. 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;

- <u>Where</u> the change should take place;
- <u>What</u> degree of driver response is required; and
- <u>How</u> 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.

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.

The examples below serve to illustrate objectives for two CMS systems:

1. An agency in a large city responsible for freeway operations would like to advise approaching drivers of major accidents that occur on a section of an inbound radial freeway. Because of funding, personnel, and surveillance constraints, they want a sign containing a single message to be displayed during the peak and off-peak periods only when major accidents block the freeway for 20 minutes or more. They would like to encourage a portion of the drivers to utilize an adjacent frontage road to bypass the incident and congestion. The display would be operated by local police who would drive to the sign site to activate the display.

2. Same conditions as above, except the agency desires to encourage the freeway drivers to reroute around the incident via a predesignated alternate arterial route.

Although the objectives of the two examples are only slightly different, each necessitates a different signing message.

E. 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 (15).

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. For example, the local driver may be more familiar with local terminology such as freeway names, while the driver passing through may be keying on interstate route numbers. There are also known regional differences in terminology. Local drivers also have the benefit of having seen the sign many times and knowing the type of information displayed, coding conventions, etc. The unfamiliar driver must rely on whatever backlog of experience he has had with similar signs and, in some instances, is entirely dependent on the verbal content of the messages displayed. The local driver may know about alternate or bypass routes with a minimum of advisory information while the visitor may need to be directed by trailblazers along any temporary bypass route designated.

Therefore, 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).

The driving population on a highway segment can be classified in several different ways: familiar/unfamiliar; local/non-local; commuter/non-commuter; large city/small city driver. The familiar, local, commuter, and large city categories of drivers obviously have much in common in terms of their understanding of messages. The unfamiliar, non-local, non-commuter, and small city or rural drivers also have much in common. However, the categories are not synonymous. For example, a driver may be quite familiar with a city through periodic visits, but may not actually live there. In addition, residents of a particular geographic area from both larger cities and smaller cities may use local name conventions while those from other geographic areas may not. Moreover, the city and state agencies may use a terminology on signs not consistent with local usage.

F. 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 (16). 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.

A study (17) of commuters on I-5 in Seattle, Washington found that it is convenient to classify commuters into four major driver groups:

1. Route changers--willing to change route on or before entering the freeway,

2. Non-changers--unwilling to change time, route, or mode,

3. Route and time changers, and

4. Pre-trip changers--willing to make time, mode, or route changes before leaving the house, but unwilling to change en route.

The survey found that route changers (20.6%) in the I-5 corridor in Seattle often divert to an alternate route in the corridor in response to traffic information, and traffic information often influences their route choice prior to leaving, but it does not influence their departure time nor their mode of transportation. Nonchangers (23.4%) rarely divert to alternate routes in the corridor, and rarely or never change the time they leave, transportation mode, or pre-trip route choice. In response to traffic information, time and route changers (40.1%) sometimes divert to an alternate route and often change their departure time or pre-trip route choice. They do not, however, change their mode of transportation. Pre-trip changers (15.9%) often alter the time they leave and pre-trip route choice, but rarely change routes once on I-5.

4. SIGNING ELEMENTS AND CHARACTERISTICS

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.

A. Signing System Elements

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

- Advisory Signs
- Guide Signs
- Advance Signs

Figure 4-1 illustrates a signing system incorporating all three of these elements. The effectiveness of the signing system will in part depend on the relationship of these three elements to each other.

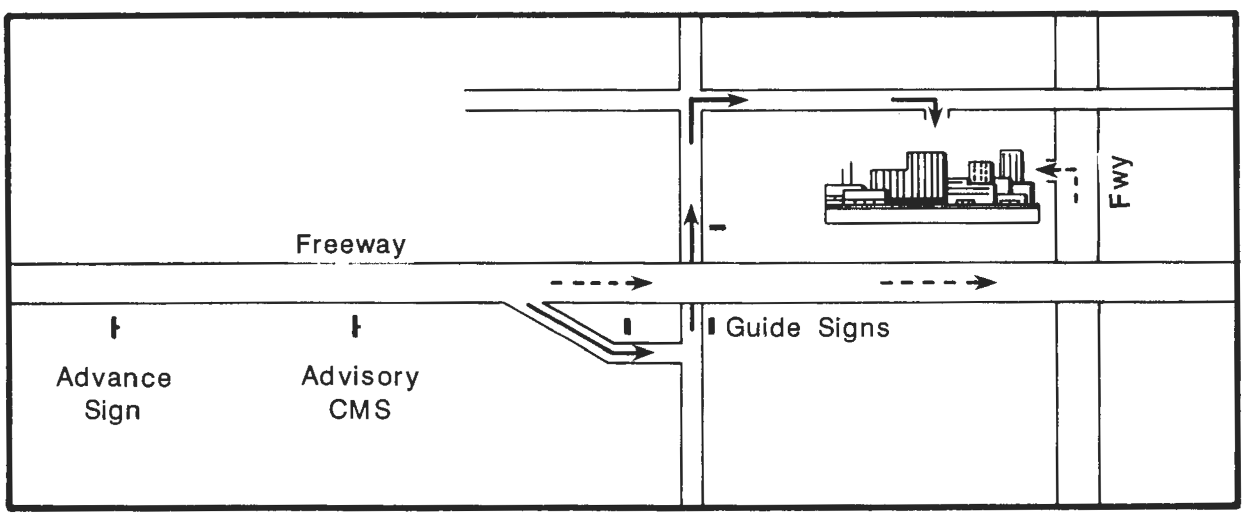


Figure 4-1. Signing System Elements

A.1 Advisory Signs

These are the displays that most people think of when referring to real- time displays. 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.

A.2 Guide Signs

Occasionally, drivers are advised to take a specific alternate route to their destination 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.

A.3 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.

B. Message Content

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

B.1 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.

B.2 Guide Sign Message Elements

Guide signs provide the mechanism for drivers to follow a route other than the intended primary route to their 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 (1).

B.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

Examples of message elements for advance signs used in conjunction with advisory visual displays recommending a route to a specific destination are as follows:

BEST ROUTE TO	◀	**Nature of information**
FAIRGROUNDS	◀	**Destination**
INFORMATION	◀	**Information alert**
AHEAD	◀	**Location of information**

BEST ROUTE INFORMATION	◀	**Nature of information, information alert**
1/2 MILE AHEAD	◀	**Location of information**
70 OR 270	◀	**Route markers**
TO CINCINNATI	◀	**Destination**

C. 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 in Section B.1 serves to illustrate the concept of units of information:

Question	Info. Unit Required
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.

Typically, a unit of information is two words, but a unit could contain one to four words. A unit of information provides an answer to a question which a driver may pose. For example, **ACCIDENT** is a one-word unit relative to a problem. **AT ROWLAND** is a two-word unit; **USE NEXT EXIT** is a three-word unit.

D. Message Format

Message format is the arrangement of the units of information on a sign to form a total message. For example, message units for an advance sign could conceivably be formatted in various ways (not necessarily all acceptable), including:

WASHINGTON BEST ROUTE INFORMATION 1 MILE	BEST ROUTE TO WASHINGTON INFORMATION 1 MILE	INFORMATION 1 MILE FOR BEST ROUTE TO WASHINGTON

Since incident management/route diversion messages typically are longer than normal freeway guide signs, proper formatting is essential for effective communication.

Compatibility must be maintained between words within a line and between message units on a sign. Recommended formats for typical incident management and route diversion messages are presented in the Manual (1).

Another usage of the term **format** is the manner in which word messages are arrayed on the CMS.

D.1 Discrete (Static) Formats

When the entire message is presented at one time, this is referred to as **discrete** or **static display**. Figure 4-2 presents four discrete formats: vertical, compact, chunk extended and message extended.

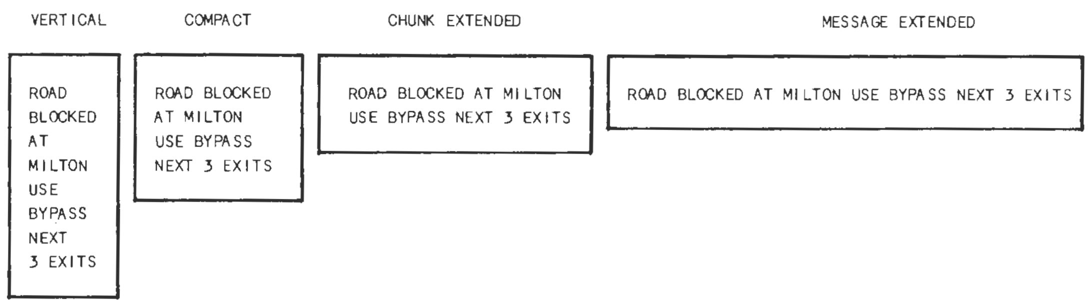


Figure 4-2. Types of Discrete (Static) Formats

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 (18). When volumes and speeds are very low and the driver has unlimited time to view the CMS, then any of the four discrete formats may be used without affecting reading or recall.

D.2 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 4-3. 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 4-3.

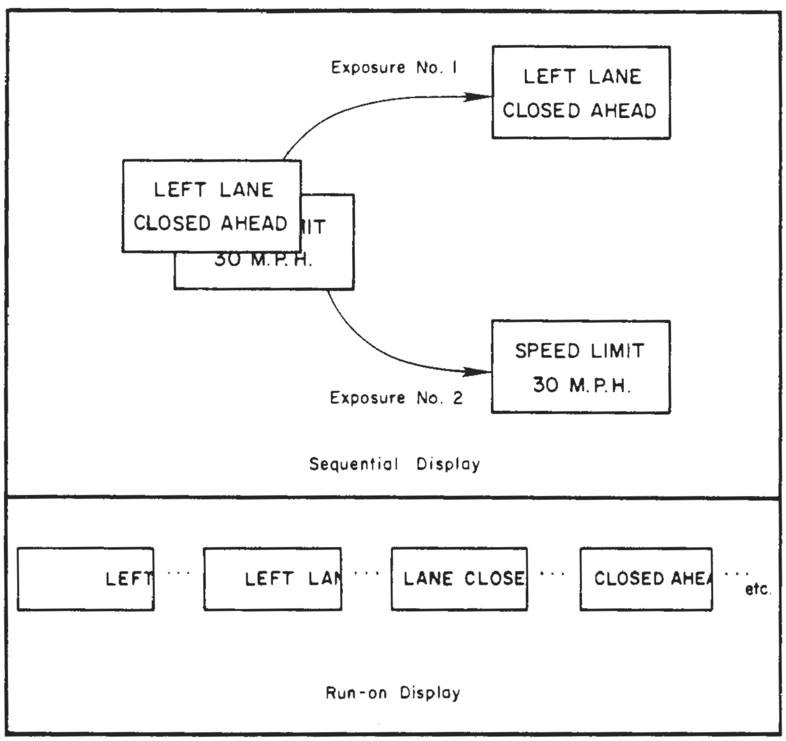


Figure 4-3. Illustration of Sequential and Run-On Display Format

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 (19).

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.

D.3 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 (19). 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 (19). 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 in Section B.1 can be chunked into the following compatible phrases:

ACCIDENT AT MILFORD STREET
HEAVY CONGESTION
UTOPIA TRAFFIC USE WILLIAMS STREET

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.

D.4 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) (18). Word, line and chunk sequencing for an 8-word message are illustrated in Figures 4-4, 4-5, and 4-6.

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.

E. Message Redundancy

E.1 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 in Section D, 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.

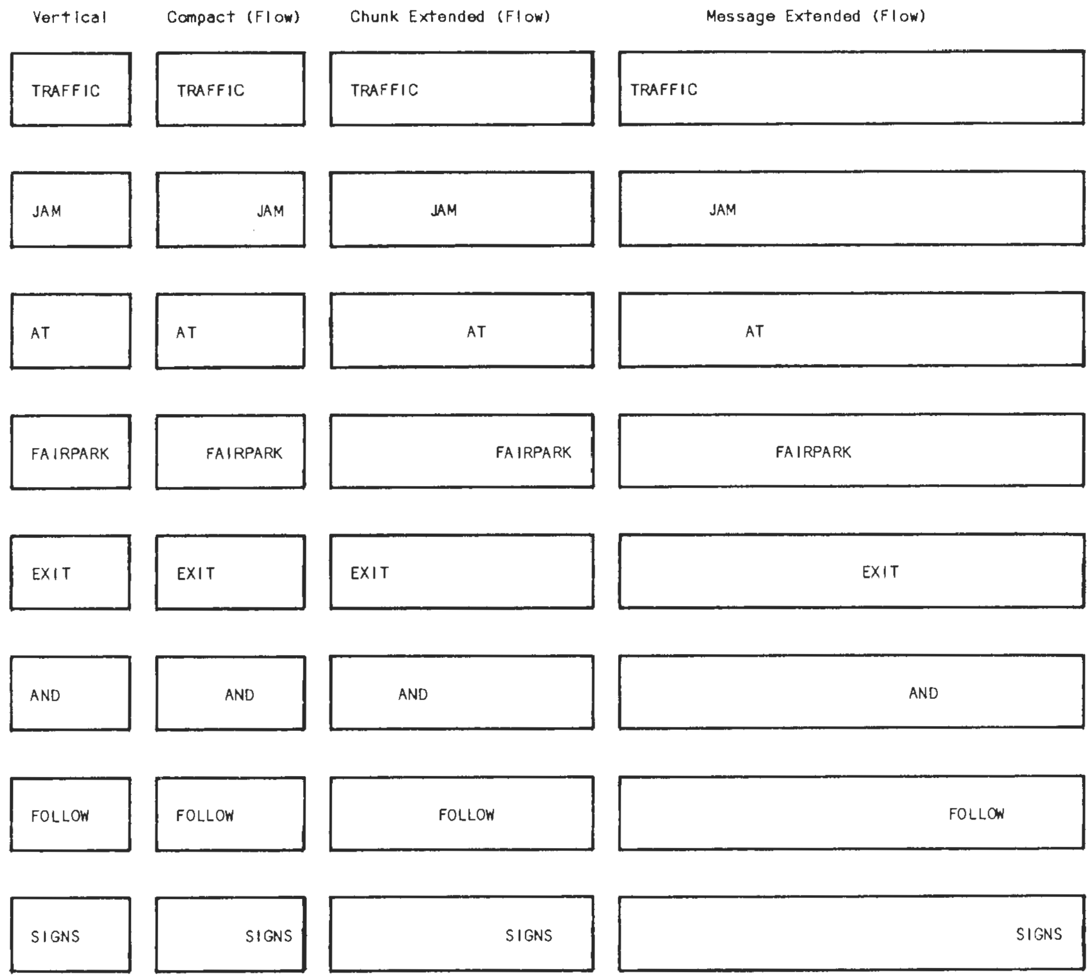


Figure 4-4. Word Sequencing (8 Sequences, 1 Word per Sequence)

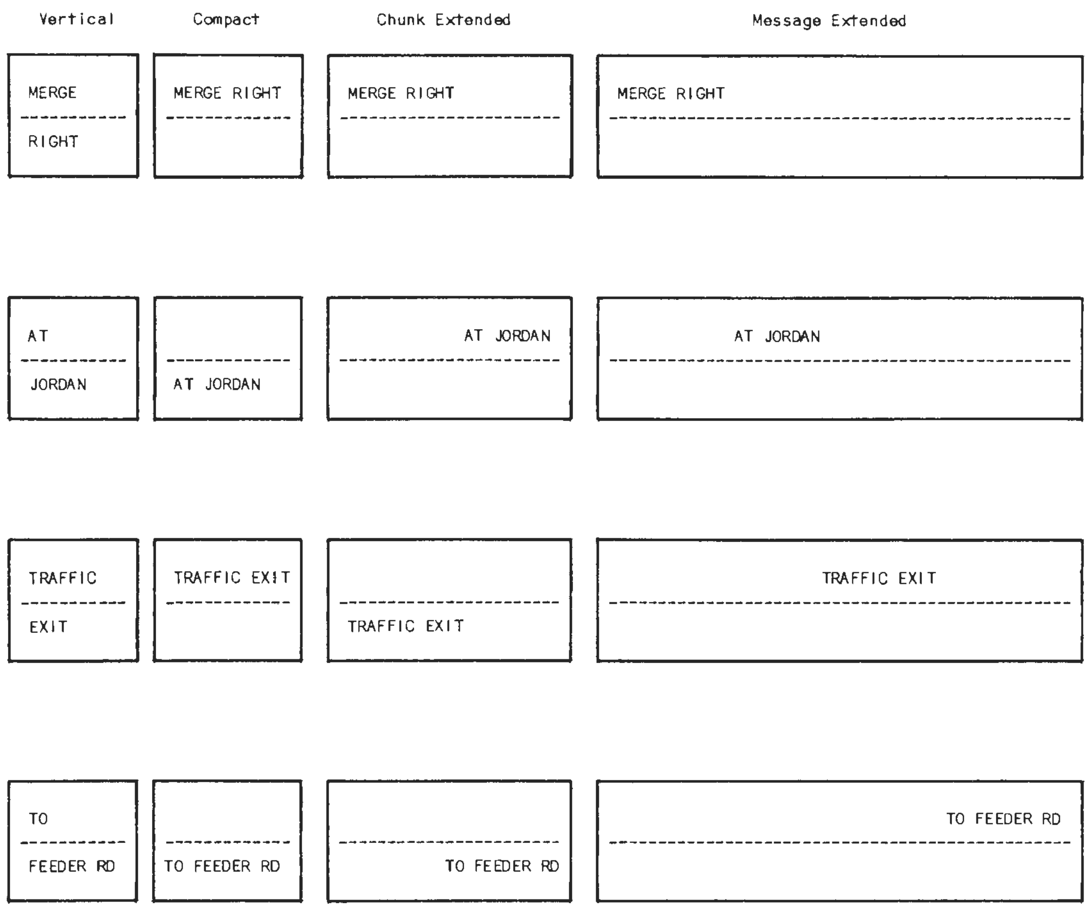


Figure 4-5. Line Sequencing (4 Sequences, 1 Line or Unit per Sequence)

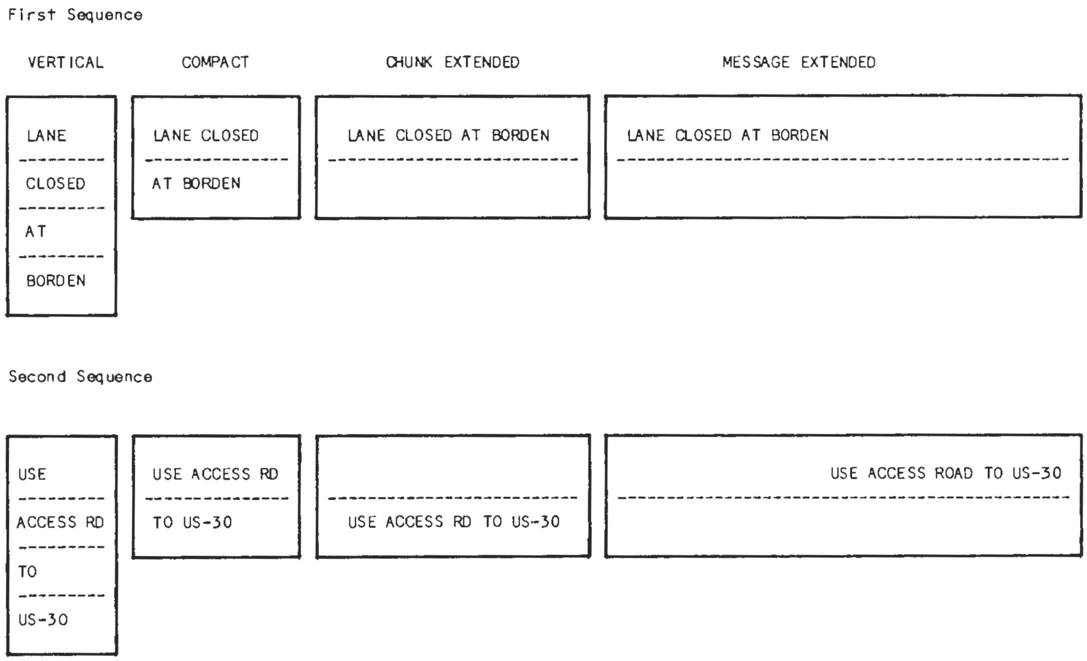


Figure 4-6. Chunk Sequencing (2 Sequences, 1 Chunk per Sequence)

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.

An example of repetition of nearly an entire message on two signs which may be located a mile or more apart is as follows:

FAIRGROUNDS BEST ROUTE USE FITZHUGH AVE	FAIRGROUNDS BEST ROUTE FITZHUGH AVE 1 MILE

In this example, the first part of the message is identical; the second part adds the notation of distance to the exit. Again, the repetition insures that drivers who may have entered the freeway after the first sign or who inadvertently missed it will see the message once. The cross-street **FITZHUGH AVENUE** may be an unfamiliar name to many drivers and its repetition facilitates learning. Thus, the two signs have a certain "continuity" or "compatibility" with key elements repeated as well as new elements added.

E.2 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 <u>or</u> from the red, white, and blue color pattern <u>or</u> from the number.

These cues reduce the amount of visual search required and provide for quicker recognition. Another example of redundancy in the visual cues is as follows:

This 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:

ACCIDENT	◀ white on red
AT KINGMAN	◀ white on green
TAKE TEMP. BYPASS	◀ white on green

The red background of the word message **ACCIDENT** plus the fact that its background differs from that of the other two messages increases 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.

Research has not yet substantiated which color combinations are most effective for advisory CMSs. Agencies in Dallas and Pennsylvania are using white-on-green, black-on-yellow, and white-on-red panels on advisory rotating drum signs to display, in increasing severity, three levels of traffic conditions. The New Jersey Turnpike Authority uses white-on-red panels on signs located on a dual-dual turnpike segment to display regulatory messages designed to close one of the two roadways in a particular direction. Experience by these and other agencies as well as additional laboratory studies should eventually lead to more specific recommendations.

E.3 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 (1)

A. 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.

Driver reading times and consequently, minimum exposure times of CMS messages normally associated with incident management/point diversion, have not been fully researched in a real-world environment. However, some laboratory research on reading times for both static and CMSs have been reported. This research, coupled with limited incident management/point diversion field experiences, enables the authors to provide some preliminary guidelines.

B. 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 familiarity
- Message load
- Display format
- Message length

Design guidelines to account for those factors are presented in the following sections.

It makes no difference what communication mode is used (visual or audio), one cannot tell everything to the drivers in the limited time available. So, discipline must be exerted to prune the message down to the basics alone. Real-time displays can, at most, register up to only two ideas:

- What is the condition
- What should be done

Brevity is not only the soul of wit, it is the heart of effective signing. Remember: 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.

To cope with the moving, busy, and oftentimes distracted driver, outdoor advertisers recommend that words be kept short and to the point. They suggest that outdoor advertising ideas should register in about 6 seconds. Similar principles hold true for real-time driver information displays.

C. 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. Adults can read quite fast while sitting on a recliner reading a novel or newspaper or while sitting in a stopped car reading a sign or billboard. While traveling, drivers cannot always devote full attention to sign reading. Drivers must share their attention between information necessary for the driving task which they receive from the roadway and traffic on the highway with the information displayed on signs. 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.

Drivers search the environment for information needed to perform the various subtasks and shift attention from one information source to another by a process of load-shedding (20). As the complexity of the driving task increases due to extremes in geometrics, heavier traffic volumes, high percentage of large trucks, traffic conflicts, or climatological conditions, load-shedding is required. Drivers will attend to those information needs that they feel are most important to them. The demands on the driver result in less time available to read the sign messages. Thus,

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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.

D. 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 (18, 21). 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.

E. Message Length

Message length refers to the number of words in a message. Although message length is somewhat correlated with message load, load refers to the information content and one unit could consist of one to three words of varying length.

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 (19, 21). SIX UNITS (12 WORDS) GREATLY REDUCE THE ABILITY TO RECALL THE MESSAGE (18).

F. 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).

F.1 Reading and Message Exposure Times for Familiar Drivers

While traveling, drivers must glance from the road to read a sign and back to the road. Forbes (22) states that during this glance the maximum amount of copy which can be read by the ordinary person is three to four familiar words. Mitchell and Forbes (23) recommend that 1.0 second be adopted as the time necessary for a single minimum glance to guarantee adequate time to read the sign twice, unless they are distracted or their vision is obstructed. The relationship between the minimum reading time available and the number of words on a sign are shown in Figure 5-1.

Also shown is the relationship recommended by the British Transportation and Road Research Laboratory (TRRL).

The two relationships are plotted in Figure 5-1 to identify some minimum reading times that should be used for displays. Messages must be legible and exposed to drivers for a period of time not less than that shown in Figure 5-1. Desirably, longer viewing times should be used.

The following examples serve to illustrate driver reading times of selected messages measured in instrumented vehicle studies conducted by Mast and Ballas (24). The data are for familiar drivers (i.e., drivers who had previously viewed similar signs and messages and were thus familiar with the types of signs and messages to expect while traveling on a rural freeway. Reading time distributions for the three selected messages are shown in Figure 5-2.

Sign A contains two units of information composed of five words and numbers. The 85th percentile reading time for familiar drivers traveling on a rural freeway was 2.3 seconds, or slightly more than 1 second per unit of information. The 2.3 seconds reading time is somewhat consistent with the guidelines of Mitchell and Forbes (See Figure 5-1). Note that the message on Sign A is "balanced" vertically and horizontally.

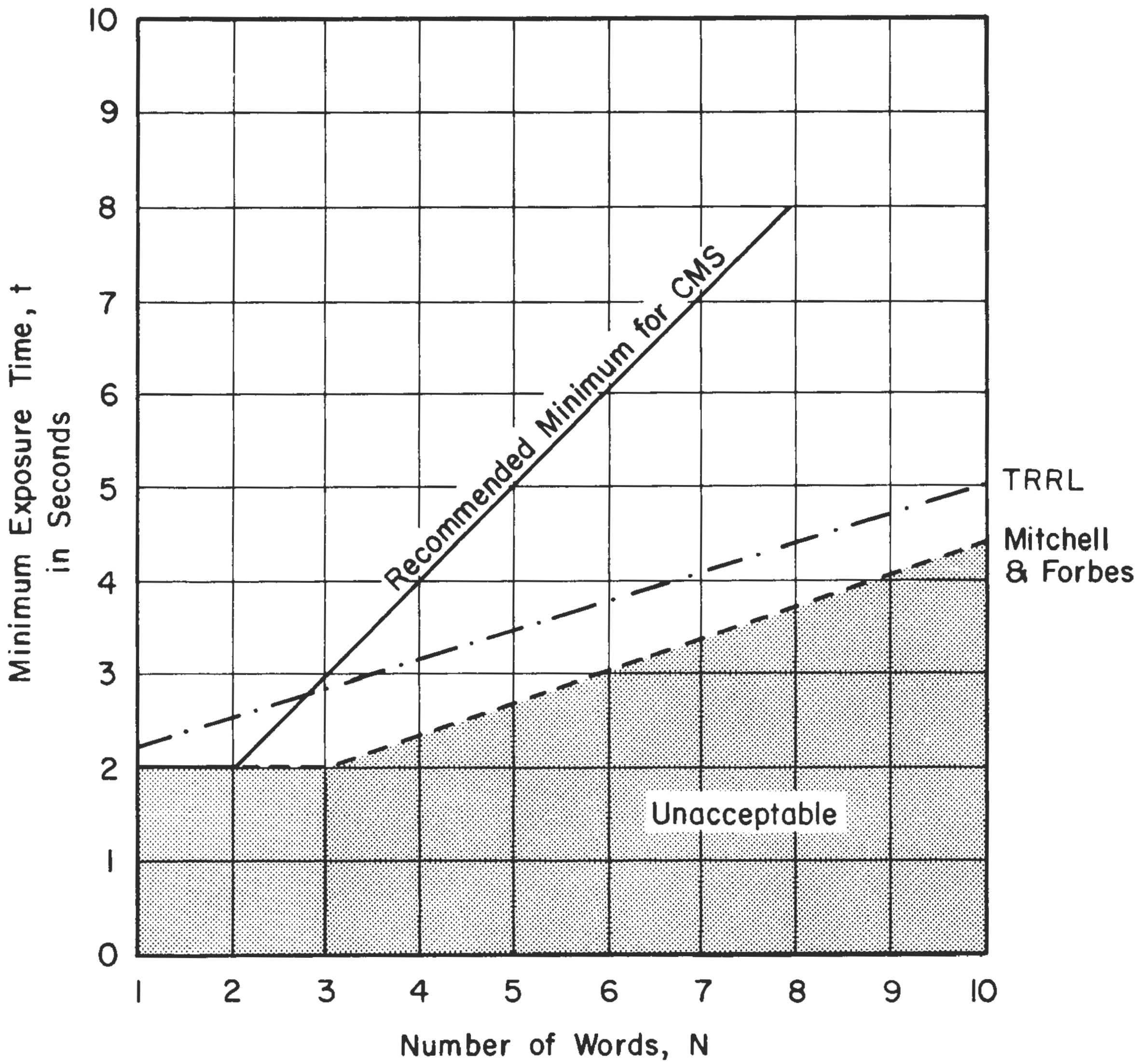

Figure 5-1. Minimum Reading and Message Exposure Times for Short Word Messages

	Message	Number of Words*	Number of Message Units	85th Percentile Reading Time (Seconds)
A.	Heavy Congestion 2 Miles Ahead	5	2	2.3
B.	Traffic Conditions Next 2 Miles Disabled Vehicle on I-77 Use I-77 Bypass Next Exit	13	6	6.7
C.	Traffic Conditions on I-91 Normal on I-91 North Accident on I-91 South Use I-91 South Bypass	13	7	9.8

* Excluding prepositions

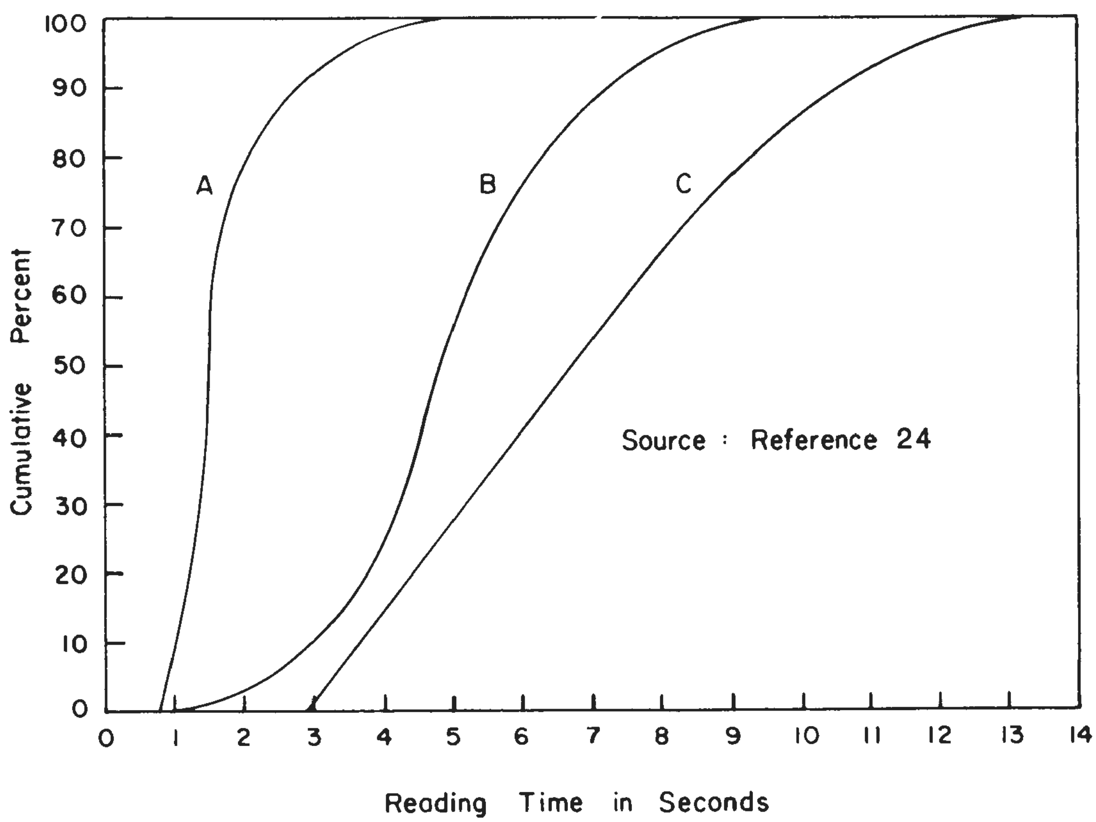

Figure 5-2. Reading Times for Selected Messages

The 85th percentile reading time for the 6-unit message on Sign B consisting of thirteen words was 6.7 seconds. An examination of the message shows that the top two lines of the sign (**TRAFFIC CONDITIONS/NEXT 2 MILES**) actually is a descriptive title for the bottom two lines displaying problem and action messages. The authors speculate that the "familiar" drivers in the study were concentrating on reading the last two lines. Assuming that the test drivers were only reading the bottom two lines, the 85th percentile reading time for the 4-unit, 8-word message (excluding **ON**) was about 1.7 seconds per unit of information (0.8 seconds per word). This reading time is longer than that suggested by Mitchell and Forbes and the TRRL shown in Figure 5-1.

The 85th percentile reading time for the 7-unit, 13-word message shown on Sign C was 9.8 seconds. Assuming that the title on the first line was learned by the test subjects by previously viewing similar signs, the sign message reduces to 5 information units consisting of 10 words. The 85th percentile reading time for the 6-unit, 10-word message was 2.0 seconds per unit of information (about 1 second per word).

It is important to note that all of the instrumented vehicle studies were conducted in very light traffic in a rural area where the drivers were in relatively "unloaded" situations. The reading times would increase under "loaded" driving conditions. Also, the test subjects knew exactly when a sign message was going to be displayed (when they heard the click of the slide projector), and they read a message that was close to them rather than one at a distance. These latter two factors tend to indicate that reading times in a real-world setting would be higher than that resulting from the instrumented vehicle studies (25).

F.2 Reading and Message Exposure Times for Unfamiliar Drivers

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RESEARCH (16, 18, 19, 26) 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 (16,26) has suggested that when an 8-word message is broken into two phrases and the two phrases are sequenced (alternated) an 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.

It is not known how long messages of more than eight words displayed all at once on a 4-line sign should be exposed to the drivers within the legibility distance. Human factors laboratory studies (19) strongly indicate that long messages displayed on one sign tend to overwhelm drivers, so they cannot scan the message quickly. Thus it may take them longer to read the entire message than if it were separated into two smaller phrases.

G. 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.

The appropriate format for a particular situation depends on the type of display, the length of message, and the traffic conditions in which the driver must read the sign. Although not all of the variables associated with display requirements can be quantified, this section provides some guidelines for enhancing the effectiveness of the display.

Loading refers to the work load demands under which a driver must perform. For purposes of simplicity, two categories of loading will be considered: 1) urban area peak period driving (loaded), and 2) urban area off-peak or suburban driving (unloaded). The following descriptions of formats may include references to the loading condition. This is not to suggest that there is some magic cut-off point to the amount of message presented, but rather to indicate that one should give consideration to the loading conditions as the length of message increases.

G.1 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

G.2 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 (19). 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.

ACCIDENT

Minimum 2.0 seconds exposure

ACCIDENT

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 (18).

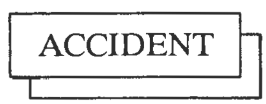
An alternative to the stars is to have a blank time of 1 second delineate the end of message before the sequence is repeated and no more than 0.25 second between sequences (19, 26). Research (18) indicated that the stars are more effective than using a blank time.

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 (18) 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 indicated, 1 sec/word with repetition is recommended.

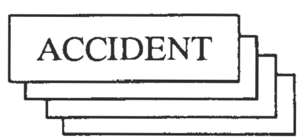
Another feature which must be considered for a sequential message with three or more elements is that many drivers will enter the sign legibility zone and begin reading the sign in the middle of a message sequence. In some cases, the information may not be intelligible unless the drivers read the message 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

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 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



Recommended

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 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 (18, 19) 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 guide- lines are recommended:

Optional	Sign	Recommended
	ACCIDENT AHEAD	**Minimum 2.0 seconds exposure**
Minimum 4.0 seconds exposure (1.0 seconds/sequence element (twice), no star time required) Cycle = 2.0 seconds	ACCIDENT AHEAD	**Minimum 4.0 seconds exposure (2.0 seconds/sequence element, no star time required) Cycle = 4.0 seconds**
	ACCIDENT AHEAD	**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:

Optional	Sign	Recommended
Minimum 4.0 seconds exposure (1.0 seconds/sequence element (twice), no star time required) Cycle = 2.0 seconds	ACCIDENT AHEAD	**Minimum 4.0 seconds exposure (2.0 seconds/sequence element, no star time required) Cycle = 4.0 seconds**
	ACCIDENT AT GRIGGS AVE	**Minimum 8.0 seconds exposure (4.0 seconds/sequence element, no star time required) Cycle = 8.0 seconds**

H. Required Legibility Distance (Side-mounted Signs)

The previous section provided guidelines for message exposure time. The minimum required legibility distance for overhead sign messages can be determined by simply multiplying the operating speed and the minimum exposure time. Keep in mind that the messages on overhead CMSs will no longer be visible to drivers when they are close to the sign--approximately 50 ft (15.2 m) in front of the sign. This loss of legibility must be considered in determining overall message exposure time and legibility distance requirements.

For side-mounted signs, the required legibility distance can also be significantly greater than the product of the speed and minimum exposure time. Comparable to overhead signs, drivers cannot necessarily read the message on side-mounted CMSs when they are near the sign. Mitchell and Forbes (23) found that when a sign is greater than 10°, measured horizontally from the center of the driving lane, the driver's ability to read the sign message is severely diminished. King (27) provides a rather complete development of this concept with respect to lateral sign placement. Figure 5-3 serves to illustrate the effect sign lateral placement has on the nearest distance at which the sign is visible.

In Figure 5-3, point C is the location where drivers can begin to read the message; point B is the location where the message can no longer be read by drivers in the inside lane because the sign falls outside the normal field of vision. The distance at which the sign must become legible is CD which can be expressed for tangent highway sections as:

$$CD = \sqrt{\{tV + [S + (n - 1)L + \frac{2}{3}L + \frac{W}{2}] \cot 10^{o}\}^{2} + [S + (n - 1)L + \frac{2}{3}L + \frac{W}{2}]^{2}}$$

For a 20 ft. (6.1 m) wide CMS, this equation becomes:

$$CD = \sqrt{\{tV + [S + n - \frac{1}{3})L + \frac{20}{2}]\ 5.67\}^{2} + [S + (n - \frac{1}{3}) + \frac{20}{2}]^{2}}$$

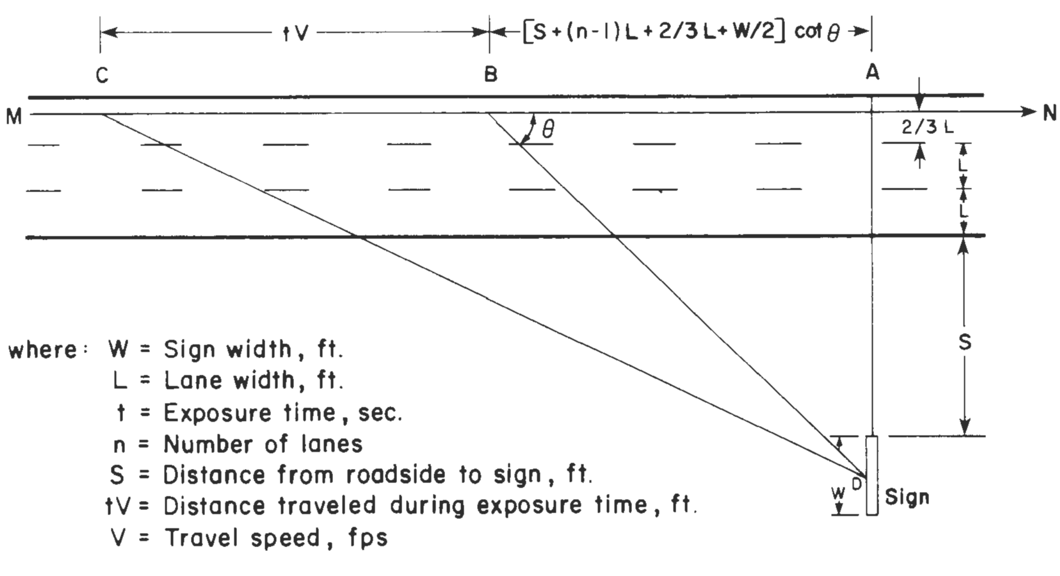


Figure 5-3. Geometry of Sign Location and Horizontal Displacement on a Tangent Section

Table 5-1 provides values for the term inside the brackets. Values for **tV**, the distance traveled during exposure time, are given in Figure 5-4.

Table 5-1
SOLUTION TO THE FUNCTION: $[S + (n - \frac{1}{3})L + \frac{20}{2}]$*
FOR 12 FT. (3.6 m) LANES

n \ s	10	20	30
2	40'	50'	60'
3	50'	60'	70'
4	65'	75'	85'
5	75'	85'	95'

*Note: Assumes 20-ft. (0.6 m) wide sign.

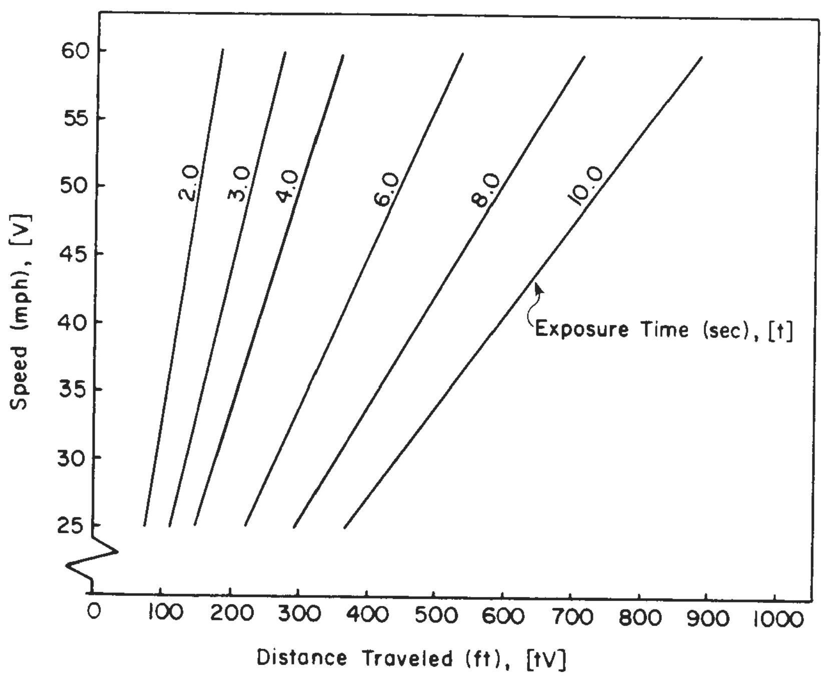


Figure 5-4. Exposure Times for Various Speeds and Distance Traveled

The following example serves to illustrate the use of Table 5-1 and Figure 5-4.

Assume the operating speed is 55 mph (88 km/hr) and the required exposure time is 8.0 seconds. If a 20 ft. (6.1 m) sign is placed 20 ft. (9.1 m) away from the outside lane on a 4-lane freeway, the required legibility distance becomes:

$$CD = \{645 + [75]\, 5.67\}^2 + [75]^2$$

$$CD = 1{,}073 \text{ ft } (326.2 \text{ m})$$

Note that distance CD is the actual required legibility distance. However, the distance parallel to the freeway will normally be the distance most convenient to measure. The difference between the two distances is negligible. Thus, the computed distance CD can be used to measure required legibility distance parallel to the freeway.

6. PRINCIPLES AND CONCEPTS OF VISIBILITY OF SIGNS

A. Visibility (28)

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).

B. Illuminance (29,30)

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 **lumen** (lm) is the unit of flow of light. It is the light from a point source of 1 cd falling on an area of 1 ft^2, where every point on the surface is at a distance of 1 ft. A common unit of illuminance is the **footcandle** (fc). This is the density of light falling on the inner surface of a sphere of 1 ft radius when a point source of light with the intensity of 1 cd is placed at the center of the sphere. One fc incident to a surface equals 1 lm/ft^2.

Current practice is to express distances and areas in metric units. Thus the illumination on a spherical surface of 1 square meter has been defined as 1 **lux** (lx).

1 lux (lx) = 1 lumens per square meter (lm/m^2), a lumen being the unit of luminous flux.

1 lux is approximately 0.1 fc (0.0929 fc).

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.

The human eye responds to a very wide range of illumination levels, from a few lux in a darkened room to approximately 100,000 lx outside in the midday sun. Illumination levels in the open vary between 2,000 and 100,000 lx during the day, whereas at night artificial light of 50-500 lx is normal.

C. 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 $lumen/cm^2$. A ft L is the amount of brightness of an ideally reflecting surface illuminated by one footcandle.

The following equations apply:

1 cd/m^2	= 0.292 footlambert (ft L)
1 footlambert (ft L)	= ca 3.5 cd/m^2
1 millilambert (mL)	= 3.183 cd/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 cd/m^2. Cone vision allows up to over 20,000 fL (70,000 cd/m^2). Fresh snow on a sunny day would be almost 10,000 fL (35,000 cd/m^2). Typical daytime (outdoors) luminance are in the range of 100 to 1,000 fL (350 to 3,500 cd/m^2). The nit is the metric equivalent of the fL. One fL equals 3.4246 nits.

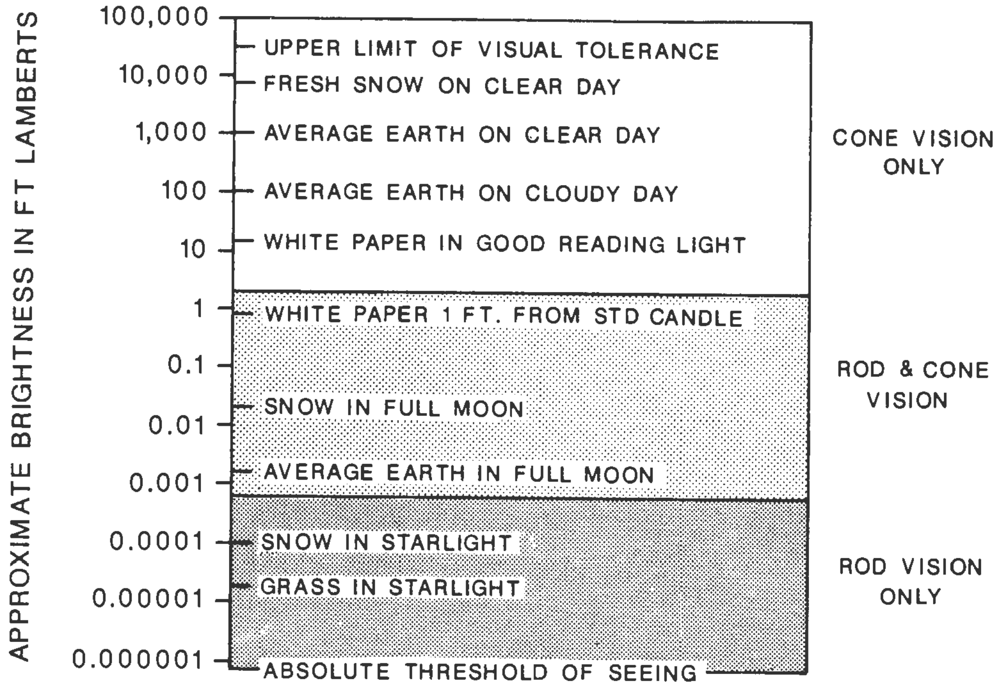


Figure 6-1. Examples of various levels of luminance (Ref. 29)

D. 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:

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

It follows that the average luminance of any surface may be calculated from the formula:

$$\text{Luminance} = \frac{\text{illuminance x refectance (\%)}}{100}$$

As an example, the average reflectance of grass may be 5 percent, and sunlight may be 10,000 fc on a clear day. The brightness of grass would thus be 500 fL. A metric example: 1,000 lx and 9 percent reflectance would produce a surface brightness of 1,000 x $1/\pi$ (.3183) x .09 = 286.5 nits. (Note the $1/\pi$ to convert to a typically flat surface.) (29)

E. 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. Cole and Jenkins (31) give a more quantitative definition: an object is conspicuous if it has a 90% chance of being detected in a very short time (250 ms) against any complex background and in any position with respect to the line of sight.

F. Reading Signs: General (28)

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.

G. Reading Signs by Day

G.1 Luminance (Brightness) Contrast

As previously defined in Chapter 3, 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.

G.2 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

G.3 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:

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

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).

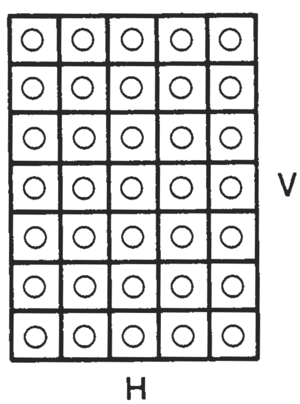


Figure 6-2. A Matrix of 5 x 7 Pixels

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,

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

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. (32) 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 (33).

H. Reading Signs at Night

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

I. 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.

The effects of irradiation of bright letters on printed matter and static signs has been known for many years. This is true even in white paint. In human factors journals, the recommended stroke width of a black line on a white or gray background is 1:6 (1 unit stroke width per six units high). However, the recommended stroke width of a white letter line on a black background is 1:7 or 1:8 (a narrower stroke). In highway applications, a stroke width of 1:5 is used for freeway guide signs.

The white paint irradiates, making the letters appear thicker than they actually are. So 1:8 is essentially equivalent to 1:6 with dark strokes on white. What is true of white paint is even more true with respect to light-emitting sign characters. The bright lights irradiate to the extent that they may cause a blurring or "spilling over" of light into an area which should be dark (e.g., spaces between letters, centers of arced letters, etc.). The bulb matrix signs, for example, are housed in "egg-crate" housings with matte black walls to principally "tone down" the irradiation to desirable dark areas.

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.

J. Reduced Sign Visibility Due to Sun Interference

J.1 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, 2) low level sunlight behind the CMS panel.

J.2 Sun Behind the CMS

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. Figure 6-3 is an illustrates the zone through which the sun passes which would cause a significant visibility problem (5).

J.3 Sun Facing the CMS

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.

J.4 Extent of the Sun Problem

The Ontario Ministry of Transportation conducted studies to determine the extent of the sun problem that they would experience due to the sun positioning for the 20 CMSs scheduled for the initial phase of the Highway 401 system in metropolitan Toronto. The elements of the highway alinement and the sun's path are shown in Figure 6-4. Table 6-1 lists the 20 CMSs and the amount of time during the year that the sun would be in positions behind the CMSs and thus adversely affect legibility of the messages. The column "Interference h/y" lists the hours that the sun would be in the interference zone relative to the particular CMS. The column "Interference Rush h/y" indicates the number of those hours which could be considered to be in the weekday peak period (between 7-9 a.m. and 3-6 p.m.). The two columns under "Longest Duration" list the duration of the sun interference on the worst day of the year for each sign.

The values in Table 6-1 can be put in perspective by considering that peak period hours total 1,304 hrs/yr and that the signs will be in operation 8,760 hrs/yr (i.e., 24 hrs X 365 days). Figure 6-5 is a graphic indication of sun interference periods by the time of

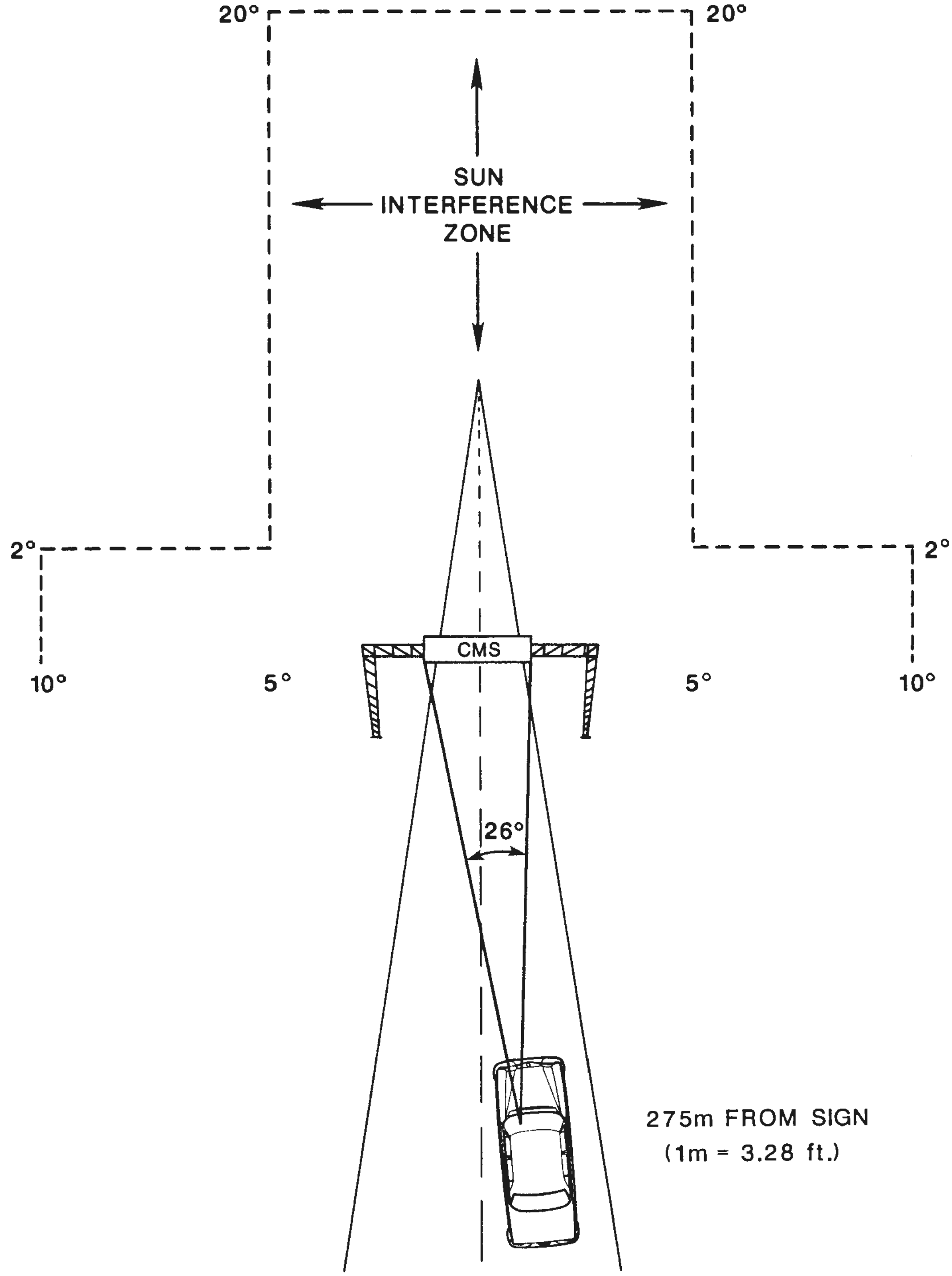


Figure 6-3. Sun Interference With Sign Visibility (Ref. 5)

day and time of year for sign VW0010VEC which will have the most severe sun interference problem of all the signs examined. The interference period of 54 peak period weekday hrs/yr which is 4% of all peak period weekday hours.

Figure 6-5 is also very useful in identifying for each month the periods in the day when measures must be taken to increase the luminance of the CMS legend and reducing the length of the messages.

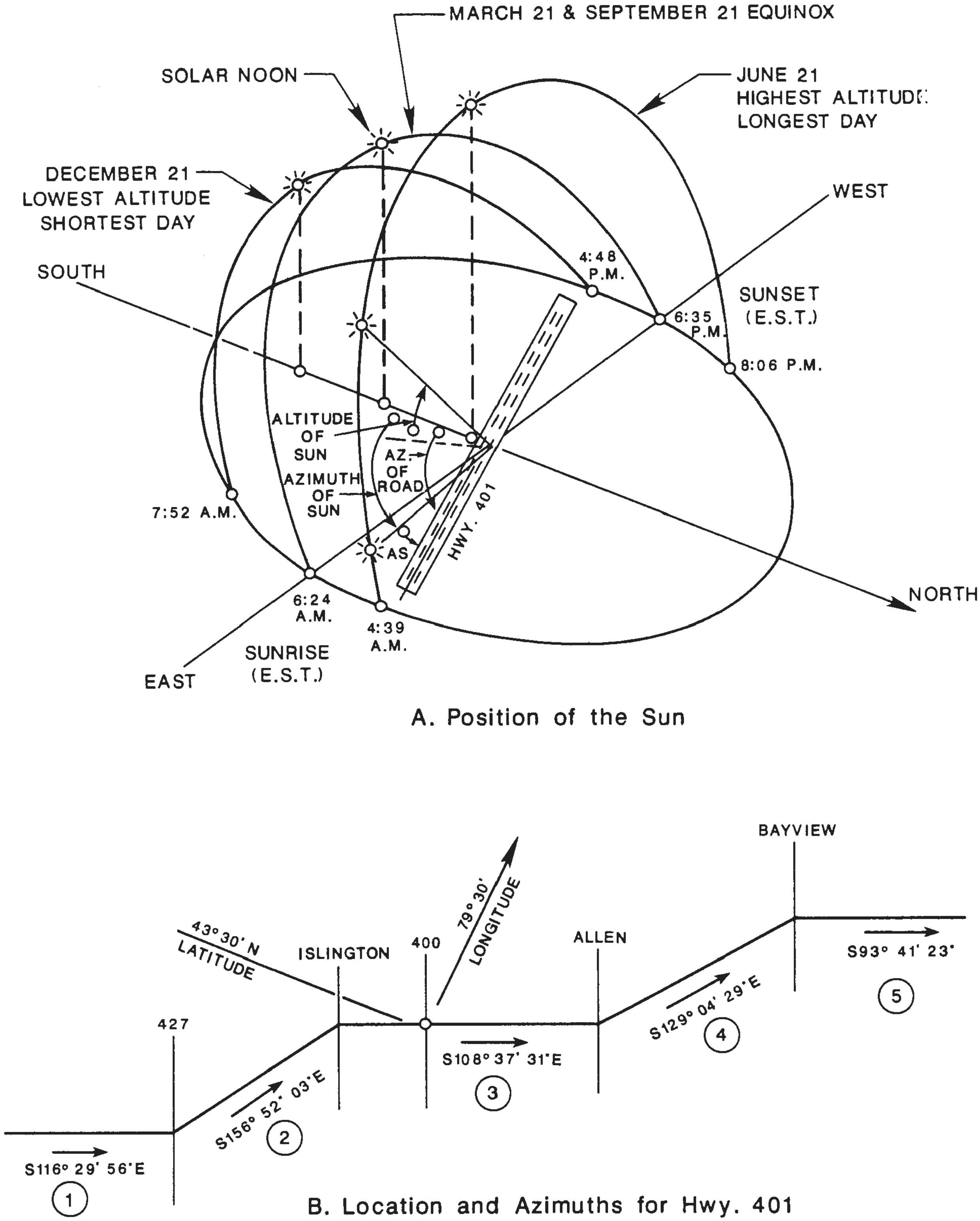


Figure 6-4. Sun Positions with Respect to Highway 401 (Ref. 5)

Table 6-1
SUN INTERFERENCE AT SIGNS (Ref 5)

Sign No.	Location	Viewing Azimuth	Interference h/y	Rush h/y	Longest Duration Overall	& Rush Hour	Blinding Zone 2° x 5°
Eastbound							
VW00020VES	Martingrove	S148° 00'E	0	0	0	0	no
VW00010VEE	West of 400	S 99° 30'E	65	54	175	71	no
VW00010VEC	West of 400	S 99° 30'E	65	54	75	71	no
VE00010VEE	*CNR	S108° 45'E	46	36	60	60	yes
VE00010VEC	W. of Allen	S106° 30'E	47	33	42	42	yes
VE00020VEC	Wilson	S128° 45'E	9	0	20	0	yes
VE00020VEE	W. of Bayview	S106° 30'E	47	33	42	42	yes
VE00030VEC	E. of Leslie	S 93° 30'E	56	50	60	60	yes
VE00030VEE	*E. of Leslie	S 93° 30'E	56	50	60	60	yes
Westbound							
VW00030VWE	*W. of Renforth	S 63° 30'W	10	10	15	15	yes
VW00020VWS	*W. of Mrtngrv	S 23° 00'W	9	9	40	0	yes
VW00010VWC	*Weston Rd.	S 73° 00'W	48	48	43	43	yes
VW00010VWE	*Weston Rd.	S 71° 45'W	48	48	43	43	yes
VE00010VWC	W. of Keele	S 71° 30'W	48	48	43	43	yes
VE00010VWE	Keele St.	S 51° 00'W	48	48	43	43	yes
VE00020VWE	Wilson Ave.	S 49° 00'W	11	11	49	49	yes
VE00020VWC	Wilson Ave.	S 89° 15'W	11	11	49	49	yes
VE00030VWE	Yonge St.	S 85° 00'W	17	17	64	64	yes
VE00040VWC	*Victoria Pk.	S 89° 15'W	54	27	38	33	yes
VE00040VWE	Victoria Pk.	S 85° 00'W	52	30	63	63	yes

Note: 1690 'Rush Hours' per year.
* = Ultimate Phase Signs

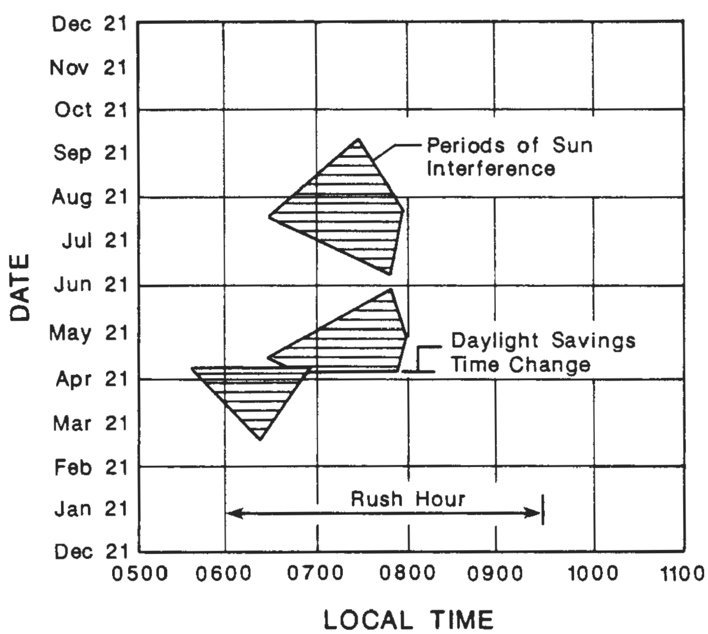


Figure 6-5. Typical Sun Interference Time Graph (Ref. 5)

7. VISIBILITY AND LEGIBILITY CRITERIA - LIGHT-EMITTING SIGNS

A. 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: character height; font style; spacing and size of pixels (character width); spacing of characters, words and lines; size of borders; and contrast (luminance) ratio.

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 (board) 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.

B. 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 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, and 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. (4)

The legibility of light-emitting CMSs, then, is primarily affected by the character height, character width and the contrast ratio (4,32). 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. Information collected by the author which will be 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.

C. 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.

Available data on the legibility of matrix signs are very limited. The results of a legibility study conducted using a bulb matrix sign with 18-inch (457-mm) characters are shown in Table 7-1 (18,19).

These data indicate a mean legibility distance of about 800 ft (243 m) and an 85th percentile legibility distance of about 650 ft (198 m) (36 ft of legibility distance/inch of letter height). In the absence of more definitive data, use 36 ft/in as a guide for determining required letter height.

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. (18,34) 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 8-3. 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 (7) 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 8-3. No published objective data are available concerning the legibility of other kinds of CMSs (e.g., clustered LED, fiber optic, etc.).

As noted in Chapter 2, CMSs in western Europe are used primarily on interurban motorways for 1) speed control and safety (accident avoidance when a queue exists) and 2) lane closures. Generally, a CMS is mounted over each lane. Therefore, the messages displayed in western Europe are not as extensive as those required in most freeway corridor applications in the United States

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 (4). The trend is toward CMSs having character heights of between 15.7 and 18.7 inches (400 to 475 mm) for the speed and lane regulation messages. France (35) 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 (36) specifies character heights between 16.9 and 18.3 inches (430 and 465 mm) for speed control CMSs. The Netherlands (4) requires 17.7-inch (450-mm) character heights. At least one highway agency in France found that although a fiber optic CMS with 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).

The Department of Transport (38), 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 7-2. As noted in Table 7-2, 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 an 17.7-inch (450-mm) character height.

D. 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, a square character font style, or the Lincoln/Mitre character style. The Lincoln/Mitre is best for trained technicians. (1) However, no single style would be expected to have a monopoly on the best design of all characters and numbers. An optimum composite font, based upon two criteria: legibility distance and minimizing character confusions, is suggested by Dudek and Huchingson et al. (18) and is presented in Figure 7-1. The characters were selected from the four different 5 x 7 and 4 x 7 font styles based upon significantly better visual performance. Figure 7-2 shows the font recommended by the International Commission on Illumination which was developed by Lotens and Van Leeuwen (37). The font includes lower case letters. In France, an alphabet shown in Figure 7-3 is used. Figure 7-4 shows the font recommended by the Ontario Ministry of Transportation (5) which is a combination of what they consider to be the best features of the fonts suggested by Dudek and Huchingson et al. and Lotens and Van Leeuwen.

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.

Table 7-1
DAYLIGHT LEGIBILITY DISTANCES FOR 18-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 7-2
CHARACTER HEIGHTS
DRAFT STANDARDS: DEPARTMENT OF TRANSPORT, UNITED KINGDOM (Ref. 38)

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

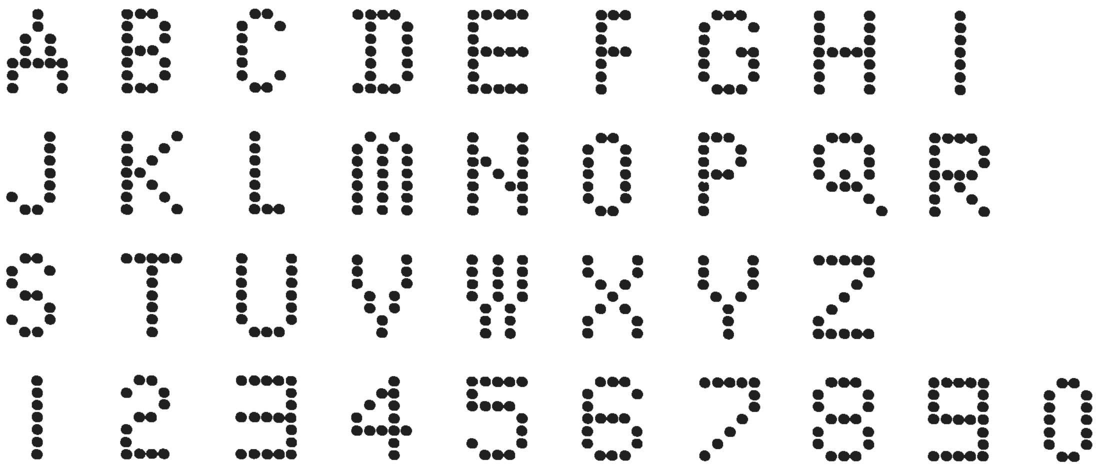


Figure 7-1. Dudek and Huchingson et al. Font (Ref. 1)

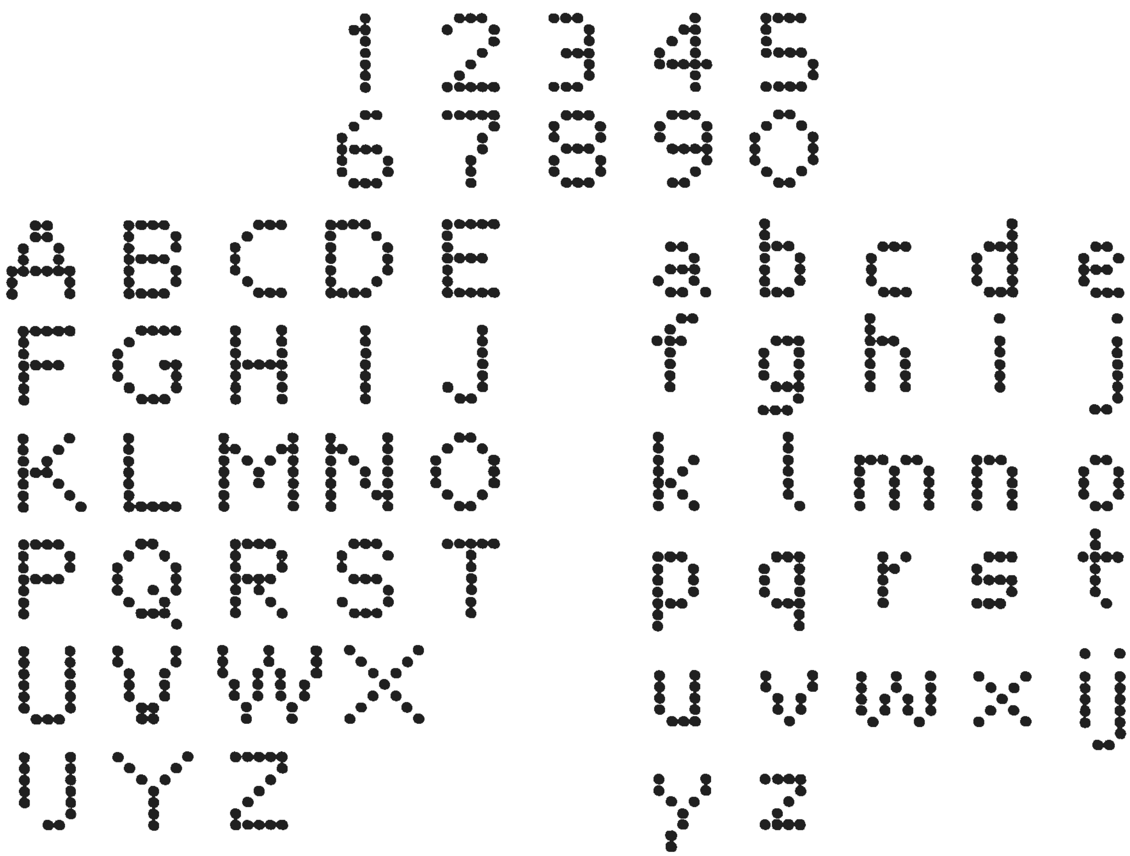


Figure 7-2. CIE Adopted Font (Ref. 5)

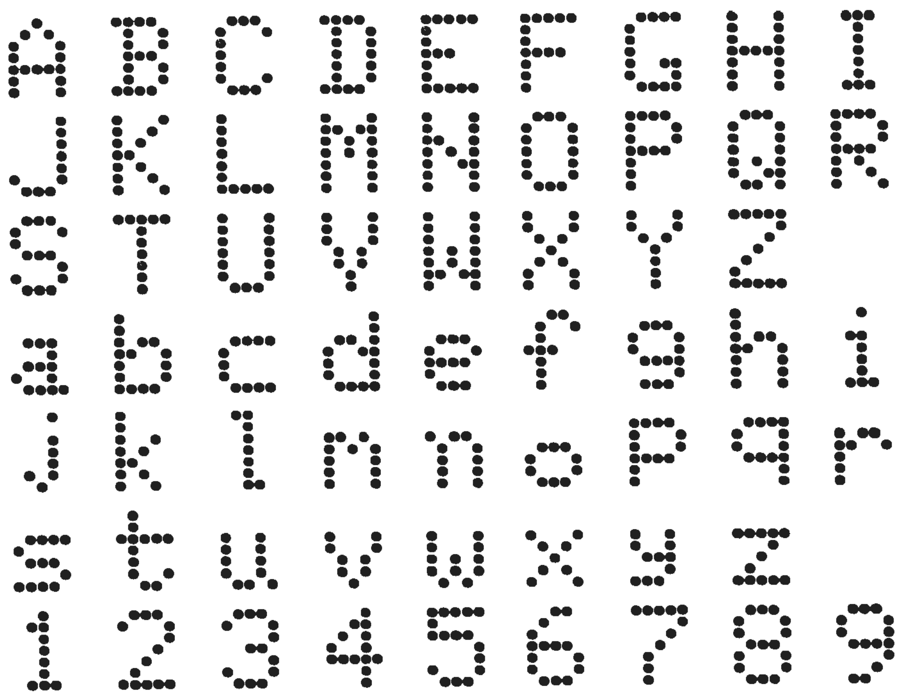


Figure 7-3. Standard Font in France (Ref. 35)

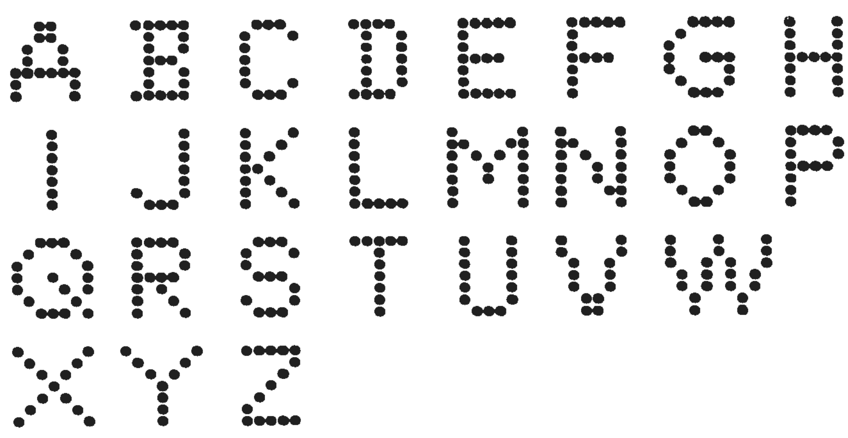


Figure 7-4. Ontario Ministry Of Transportation Recommended Font (Ref. 5)

E. 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 7-3.

One laboratory study conducted by Kerr et al. (32) of CMS character modules indicated that spacing improved performance with lower case letters far more than with upper case characters. One interpretation by Kerr et al. of this difference in effect is that character size is important, and as upper case letters are relatively large, then very little improvement in perceptibility can be expected if size is a component in performance. For the lower case character set, the substantial increase in character size provided by increased spacing clearly has the potential for greater effect. Another interpretation by Kerr et al. is that the improvement in performance that increased spacing provides for lower case characters may arise from better definition of the features of the letters. Lower case letters contain small radius curves, and densely-packed fragments which are generally not found in upper case fonts (e.g. the letters e/E, a/A and s/S). Increasing the spacing between these features would increase their individual discriminability and, therefore, the legibility of each character.

TABLE 7-3
SIZE OF MATRIX ELEMENTS
DRAFT STANDARDS: DEPARTMENT OF TRANSPORT, UNITED KINGDOM (Ref. 38)

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 (255)	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)

F. 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. (38)

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. (35)

G. 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 (39) that the background buffer surrounding the message should be at least one alphanumeric sign line height. Lotens (40) 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 (38). France specifies that the border must be equal to or greater than the character height (35).

H. 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 7-4 (38). 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.

Table 7-4
LIMITS OF CONTRAST RATIO 10^0 AND 20^0 ILLUMINATION DRAFT STANDARDS: DEPARTMENT OF TRANSPORT, UNITED KINGDOM (Ref. 38)

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 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

French researchers, Bry and Colomb (28), 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 (35).

Figure 7-5 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 computed the average luminance of the sign modules during the experiment to be 200 cd/m^2. The luminance of the CMS module characters ranged between 280 and 4,090 cd/m^2.

As shown in Figure 7-5, the percentage of subjects who correctly read the legend rapidly increased from 10 percent to 50 percent as the contrast ratio (C') rose from 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.) Colomb and Hubert stated that their results were perfectly compatible with the results of Padmos et al. (41).

Experiments conducted by Kerr et al. (32) 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. Figure 7-6 shows the reaction time of both old and young subjects in reading CMS modules which were designed to simulate a reading distance of 984 ft (300 m). Measurements were made at contrast ratios of 3, 7, 67 and 100 for upper case and lower case characters using white and yellow light emitters.

Based on the results shown in Figure 7-6, 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. (42) have shown that a contrast ratio in the order of 10 gives optimum visual acuity. The contrast ratio of 10 is supported by Bomier (39).

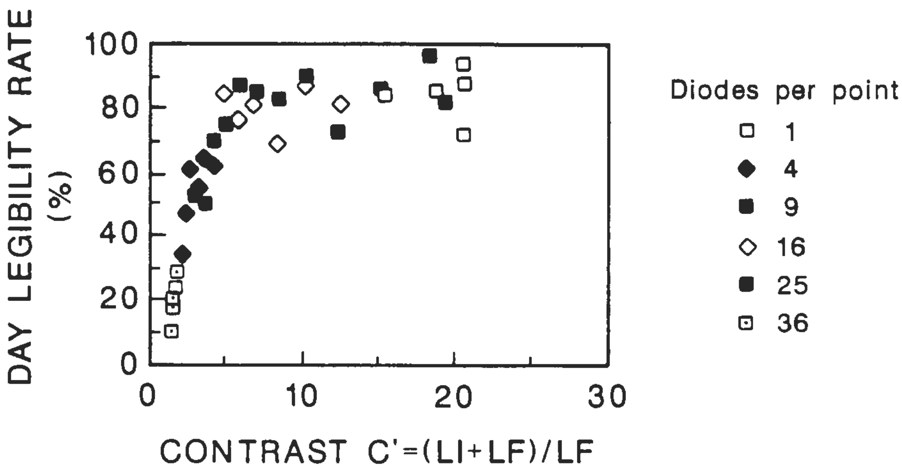


Figure 7-5. Percentage of Letters Correctly Read in Daylight Versus Contrast (Ref. 8)

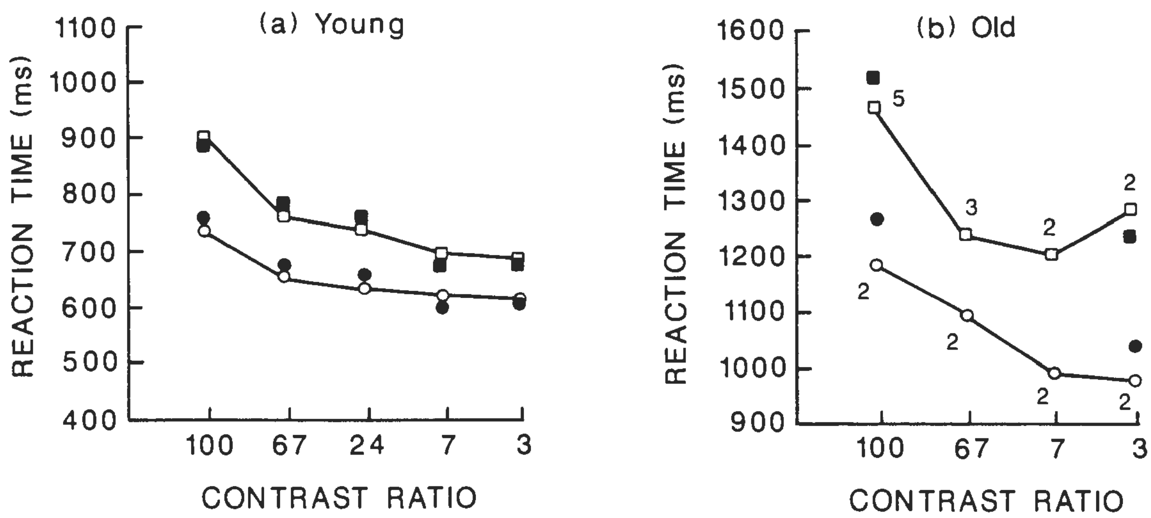


Figure 7-6. Mean reaction time plotted at each contrast ratio for white emitters with lower (■) and upper case (●); and for yellow emitters, lower (□) and upper case (○). Emitter size was 22 mm and emitter spacing was 80 mm. Twelve young subjects (mean age 22.8) and 12 old subjects (74.6) were tested. Bold figures adjacent to data points indicate the number of subjects who could not discriminate letters for that condition (Ref. 32).

Padmos et al. (41) 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 7-7.)

I. 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.

J. Reading CMSs at Night - Luminance Requirements

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 CMS at night (8).

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

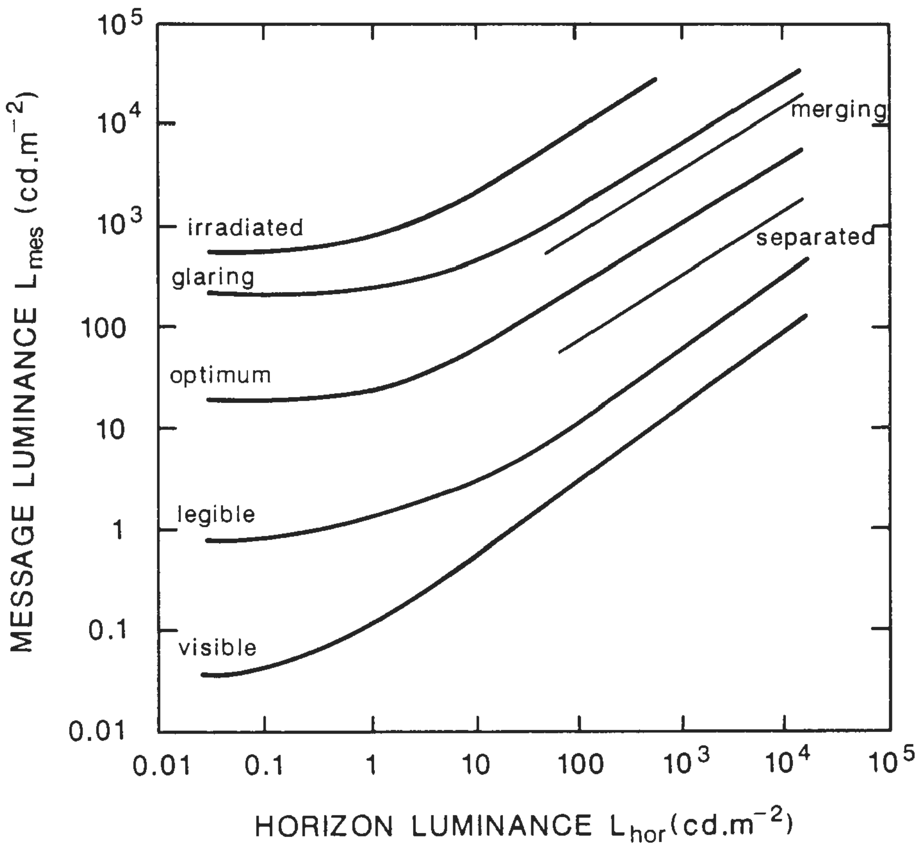


Figure 7-7. Mean Relationships for CMS Legibility Criteria (Ref. 41)

Very limited data are available that help to determine the acceptable sign luminance for nighttime applications. Figure 7-8 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 7-8 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 studied. 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 individuals' 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 (43) 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 (35). 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 (4).

LIMITED RESEARCH SUGGESTS THAT AT NIGHT THE BEST LEGIBILITY RESULTS ARE OBTAINED WHEN THE LUMINANCE OF THE LEGEND IS BETWEEN 30 AND 230 CD/M^2 (8).

K. Irradiation

Character Spacing

Although nighttime irradiation on light-emitting CMSs is a recognized problem, unfortunately little objective information is available which is helpful in establishing stroke width and character spacing guidelines. Experience has indicated, however, 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.

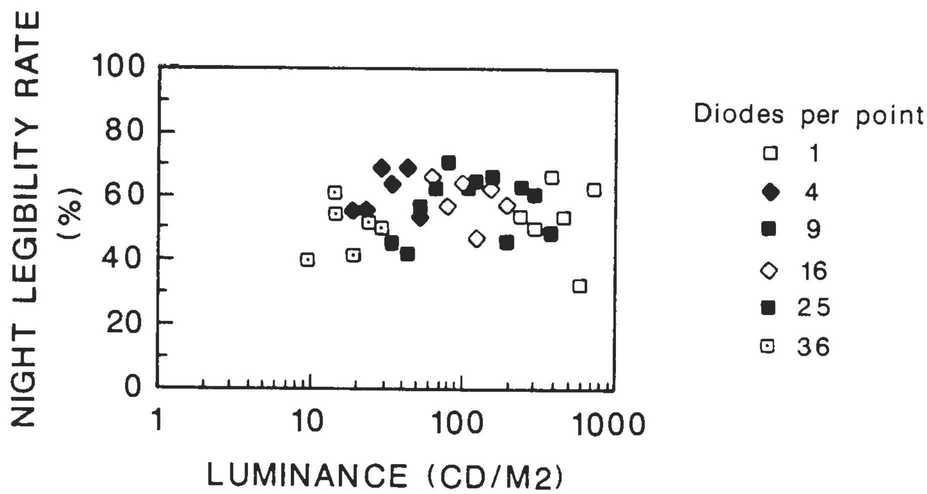


Figure 7-8. Percentage of Letters Correctly Read at Night Versus Contrast (Ref. 8)

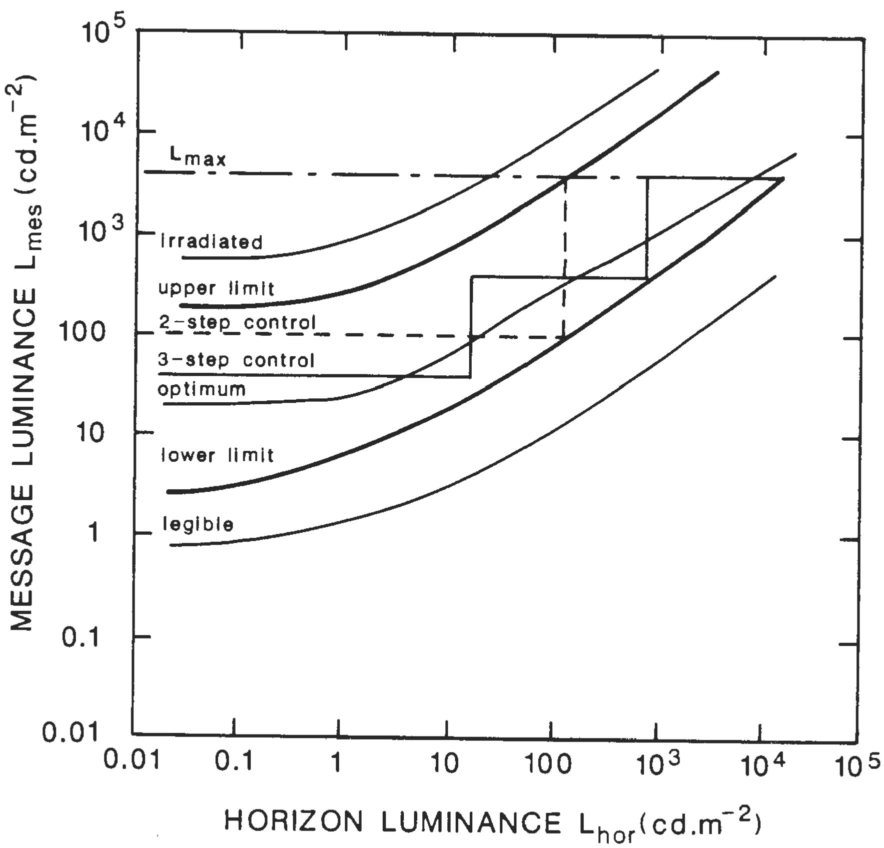


Figure 7-9. Step-Control Schemes to Compensate for Irradiation (Ref. 41)

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. Figure 7-9 illustrates discrete 2-step and 3-step light intensity schemes offered by Padmos et al. (41) for fixed grid fiber optic CMSs which they feel provide sufficiently legible but not too bright messages.

Regardless of which method is used to alleviate irradiation, it is important to test view the display at night and at all expected viewing distances before putting the display into operation.

In Figure 7-9, two limiting curves are shown, within which the fiber optic CMS character luminance should remain. The upper limit was set at a factor of 3 lower than the criterion "irradiated." Padmos et al. indicate that below this limit most observers will not find the sign irradiated. The lower limit is a factor of 3 higher than the criterion "legible." The latter curve was also shifted a factor of 3 to the left in order to account for the impairment of legibility by straylight experienced in practice. Padmos et al. indicate that above this lower limit most observers will be able to read the sign under most practical conditions.

The third boundary condition for the step control was that the maximum value of L_{mes} should not be higher than the lower limit at L_{hor} = 20,000 cd/m^2. According to Padmos et al. a higher L_{hor} rarely occurs. Starting from the maximum value, L_{max} = 4,000 cd/m^2, the two-step and the three-step light control scheme was drawn.

Padmos et al. advise that in order to determine the switching positions for the control in practice, it is better to measure and monitor the average luminance, L_0, of a field of radius 10° around the CMS, as is the practice in tunnel lighting, rather than the luminance of the horizon, L_{hor}. Control through L_0 has the advantage over L_{hor} in that L_0 is less liable to short-term fluctuations caused by passing clouds.

L. 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. The pixels differ among CMSs. In the case of a bulb matrix sign, a pixel is one bulb. The pixel in a fiber optic sign is generally one, two or three fiber points that are illuminated by a lamp. A pixel for a clustered LED sign is a cluster of LEDs.

The loss of pixels forming the characters directly affects the readability of the display. According to research findings with traffic-related words, the maximum tolerable percentages of random pixel loss as indicated by studies of bulb matrix signs are shown in Table 7-5.

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.

Table 7-5
MAXIMUM ALLOWABLE PERCENT BULB FAILURE

Maximum State	Percent Correct Response	
	95% Correct	85% Correct
Unfamiliar	8%	18%
Average	14%	28%
Familiar	28%	44%

Unfamiliar drivers are those who had not previously seen the words in a legible form at the time of testing. Familiar drivers had seen the words previously and the task was one of recognizing them when displayed in a degraded form.

M. Character Height, Stroke Width and Legibility - Lamp Matrix Signs

In addition to sharing the irradiation problem, bulb matrix signs possess other characteristics that merit consideration relative to design configurations. Bulb matrix CMSs generally consist of rectangular arrays of lamps individually surrounded by reflectors or shades. (Details of characteristics may be found in Chapter 2.) These lamp/reflector units are mounted adjacent to each other both vertically and horizontally to form a grid normally seven lamp rows high. The size of the lamp/reflector units and the spacing between them, if any, generally defines the height of the letter. As a single column or row of lamps is used to form the various parts of a letter, the stroke width of each character is essentially the width of the lamp/reflector unit. Although double-stroke characters (two lamp columns used to form vertical letter strokes) are available on some lamp matrix signs, their use should be avoided except when a single simple word is to be flashed.

Bulb arrays used to form character lines can either be a continuous field of bulbs or a fixed number of rectangular matrix modules (small banks of lamps separated by "lampless" areas). Typically, characters are formed by 7 lamp rows and 4 or 5 lamp columns. Various array designs are illustrated in Figure 7-10. These designs are well-suited to the formation of all alphanumeric characters 10 inches or greater in height. Smaller letter heights require smaller, low wattage lamps that are not sufficiently bright for daytime use (44).

N. Reduced Sign Visibility Due to Sun Interference

N.1 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 (39).)

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

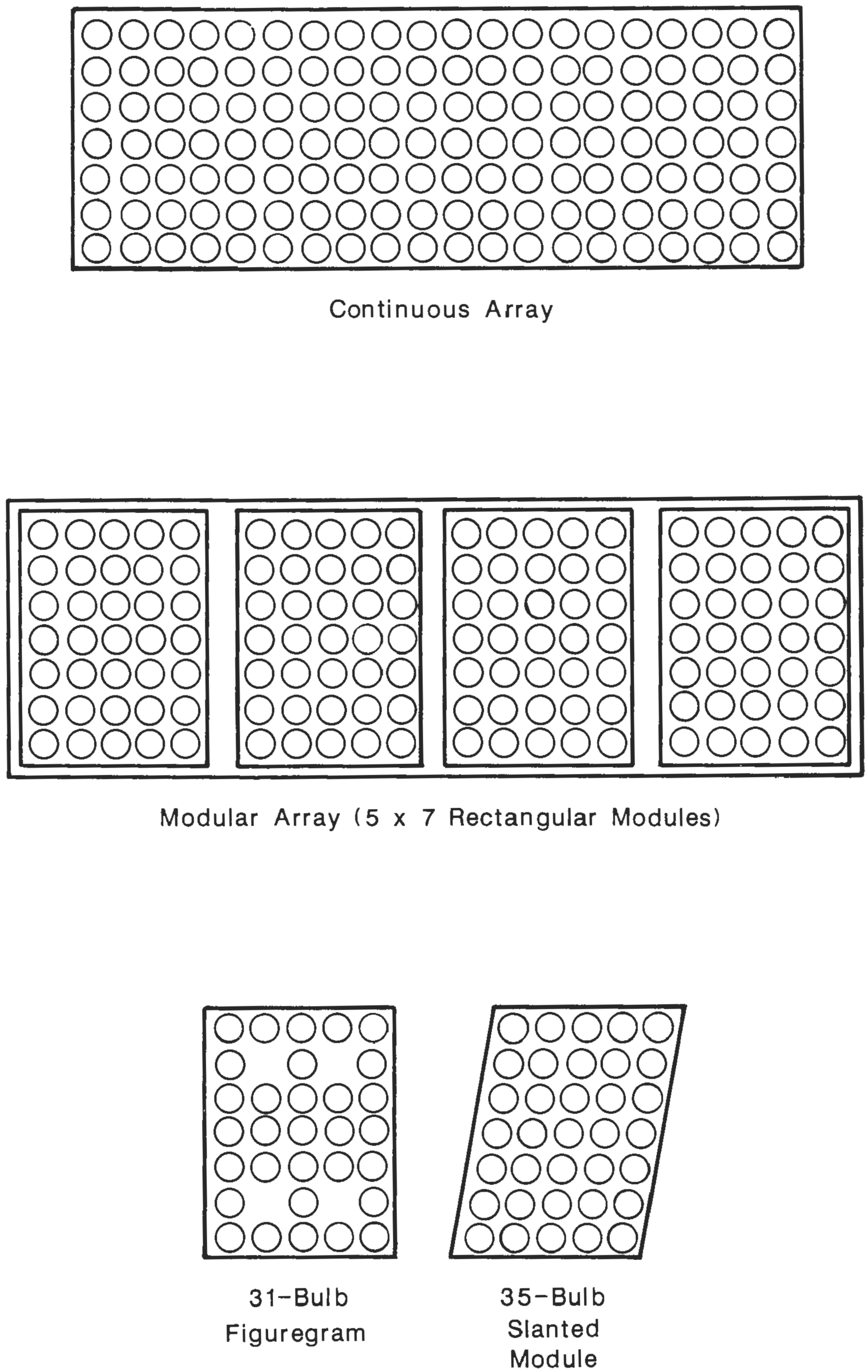


Figure 7-10. Bulb Matrix Arrays (Ref. 1)

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.

N.2 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 things can be done to reduce 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 face, and/or
4. Tilt the sign.

O. Effect of Yellowing of Fiber Optic Guides on Legibility

Kerr et al. (32) found that the yellowing of emitted light caused by the spectral absorption characteristics of certain fiber optic light guides should not affect the legibility of CMSs. It is important, however, that the luminance of the CMS is measured at the point where the light is emitted, to take into account the reduction in luminance also produced by the fiber optics.

P. 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 (18).

8. VISIBILITY AND LEGIBILITY CRITERIA - LIGHT REFLECTING SIGNS

This chapter focuses on factors affecting the target value and legibility of light-reflective CMSs. The first part of the chapter addresses light-reflecting CMSs that resemble static signs in appearance. The second part of the chapter addresses light-reflecting matrix CMSs.

A. Light-Reflecting CMSs

Light-reflecting CMSs can be divided into two groups. The first group includes 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. This group includes the following categories and types of CMSs:

Category	Type
Static w/ beacons	Static message signs with flashing beacons
Electromechanical	Fold-out (type I) Scroll (belt) Rotating drum (prism)
Manual	Cloth Fold-out (type II) Removable panels

The second group of light-emitting CMSs 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. This group of matrix CMSs include the following types:

Electromechanical	Disk matrix Flap matrix Rotating Cylinder/Triangle Vane matrix

B. Character Height and Legibility

Letter size affects the legibility distance of a sign message more than any other single factor. "Rule-of-thumb" estimates, such as 50 ft of legibility distance for each inch of letter height, are not always valid. The legibility distance for static signs varies with the Letter Series (A through F) selected and whether or not the design legibility distance is considered. Design legibility takes into account nighttime viewing conditions and possible 20/40 visual acuity, rather than the ideal 20/20 vision. For Series B through F, design legibility distances vary from 15 ft/in to 27 ft/in, as opposed to 33 ft/in to 60 ft/in for legibility distance.

In general, letter sizes of light-reflecting signs should be designed in accordance with MUTCD requirements and recommendations.

C. Spacing of Characters, Words, and Lines

The MUTCD provides the following guidelines with regard to interline and edge spacing on static signs:

- Interline spacings--three-fourths the average of upper-case letter heights to adjacent lines
- Top and bottom borders--average of the letter heights of the adjacent line
- Side borders--width equal to the height of the largest letter

It should be noted that good spacing in all aspects will significantly improve the readability of the sign.

Avoid these pitfalls:

- Using a letter size too small to do the job.
- Crowding letters and words together to make use of an existing sign blank.
- Crowding a well-spaced message to the edge of a sign to make use of an existing sign blank.

D. Luminance (Brightness) Contrast

The smaller the letter size and/or the longer the viewing distance, the greater the amount of contrast necessary for visibility and legibility.

LUMINANCE (BRIGHTNESS) CONTRASTS OF 40 PERCENT FOR DAYTIME AND 50 PERCENT FOR NIGHTTIME READING ARE RECOMMENDED (45).

Luminance contrasts of 40 percent for daytime and 50 percent for nighttime are readily achieved on static signs by using MUTCD recommended letters and backgrounds. If an agency chooses to use other color combinations, the percent reflectances shown in Table 8-1 should be used to compute the luminance contrasts.

As an example, an agency wishes to use an orange legend on a blue background for a trailblazer. Using Table 8-1, luminance contrast would be $(100)\ \frac{(43-25)}{43} = 41.8.$

This ratio exceeds the 40 percent daytime recommended contrast, but it is less than the 50 percent value recommended for nighttime use.

Table 8-1
REFLECTANCE PROPERTIES OF MUTCD COLORS (Ref. 1)

Color	Percent Reflectance*
Red	79
Black	9
White	79
Orange	25
Yellow	51
Brown	6
Green	7
Blue	7
Purple	12
Light Blue	43
Coral	51
Brilliant Yellow-Green	43

* Relative to flat white magnesium oxide which is considered to have a reflectance of 100 percent.

E. Color Contrast

Table 8-2 shows acceptable color combinations for day and night application based upon luminance contrast.

Adequate luminance contrast for legibility is only one criterion for color selection. Certain color code conventions, which must not be violated in selecting colors, are given in the MUTCD.

For purposes of target value, a light colored sign should not be used against a light background such as the sky, nor should a dark colored sign be used against a dark surrounding. In general, a light green background such as used on U. S. Interstate guide signs appears to provide the best contrast with a variety of possible backgrounds.

Static signs should be reflectorized with sheeting or be externally illuminated.

Table 8-2
ACCEPTABLE SIGN COLOR COMBINATIONS
BASED ON BRIGHTNESS CONTRAST

Background Color \ Legend Color	Red	Black	White	Orange	Yellow	Brown	Green	Blue	Purple	Light Blue	Coral	Brilliant Yellow-Green
Red	■	■	□	□	□	■	■	■	■	□	□	□
Black	■	■	□	□	□	■	■	■	■	□	□	□
White	□	□	■	□	■	□	□	□	□	D	■	D
Orange	□	□	□	■	□	□	□	□	□	□	□	□
Yellow	□	□	□	□	■	□	□	□	□	□	□	□
Brown	□	□	□	□	□	■	■	■	□	□	□	□
Green	■	■	□	□	□	■	■	■	□	□	□	□
Blue	■	■	□	□	□	■	■	■	□	□	□	□
Purple	■	■	□	□	□	□	D	D	■	□	□	□
Light Blue	□	□	□	D	■	□	□	□	□	■	■	■
Coral	□	□	□	□	■	□	□	□	□	■	■	■
Brilliant Yellow-Green	□	□	□	D	■	□	□	□	□	■	■	■

Legend:

- □ Acceptable for Day or Night
- ■ Not Recommended
- D Acceptable only for Day Application or Night w/External Illumination

F. 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 8-3.

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

	Legibility Distance (ft)	
Character Style	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

G. Font Style - Matrix Signs

See Chapter 7, Section D.

H. Spacing of Pixels - Matrix Signs

A schematic of a typical 5 x 7 module for a circular disk matrix CMS was shown earlier in Figure 6-2, page 113. 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. (46)

I. 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. (46)

Also see Chapter 7, Section F.

J. Size of Sign Borders - Matrix Signs

See Chapter 7, Section G.

K. 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 (46).

L. Reduced Sign Visibility Due to Sun Interference

L.1 Sun Behind the Sign

See Chapter 7, Section N.1.

L.2 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 Chapter 7, Section N.2.

M. 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. Section E.6 in Chapter 2 highlights the types of problems that can occur.

N. Accentuation

See Chapter 7, Section P.

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

A. 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. No attempt was made as part of this project to conduct a comprehensive nation-wide written survey of the reliability and maintenance requirements of the various CMS technologies. 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.

A.1 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 to the moving parts. (5)

A.2 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)

A.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. (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. (6)

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)

A.4 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.

B. Maintenance Considerations

NCHRP Synthesis 61 (2) and Synthesis 12 (47) discuss considerations with respect to maintenance. A review of the reports, which were published in 1972 and 1979, indicates that the statements presented in the reports are still valid and are, therefore, repeated below.

> Maintenance problems and costs encountered with CMSs in different installations vary considerably. Therefore, it is difficult to provide guidelines of anticipated maintenance costs...
>
> Unforeseen hardware problems usually do not occur until after the system has been operational for several months. Operating agencies would be well-advised to consider stipulating that the contractor furnish one or two years of maintenance by someone knowledgeable with all parts of the system. During this time, the contractor could train operating agency personnel in all facets of system maintenance. Sometimes the contractor may have only one person familiar enough with the system to provide relatively fast service in correcting failures.
>
> Thus, the operational integrity of the system is hinging upon one individual. This should provide incentive enough for the operating agency to train its own personnel as quickly as possible.
>
> In many cases, the CMS work is done by a subcontractor. The burden thus rests with the prime contractor who may not employ personnel qualified to provide maintenance for the signs and associated hardware.
>
> Whether or not the operating agency decides to eventually do its own maintenance will depend on several factors, including size and complexity of the system, availability of personnel, and location of the system.
>
> Another concern expressed by some agencies is the inadequate supply of on-hand replacement parts to take care of problems resulting from such situations as violent thunderstorms. (One agency reported that it was not uncommon to have one-third of its signs inoperative after severe weather.) The turnaround time in sending defective parts to the manufacturer and

putting the sign back into operation is sometimes excessive. It may require up to two months. The availability of on-hand replacements for those parts that have a high tendency to malfunction will increase the probability of having an operable system, which should, in turn, enhance driver credibility. Lack of funds is normally the impediment to purchasing spare parts after a system is installed. When the system is initially purchased, the highway agency should consider investing in replacements for those parts that have a relatively high tendency for failure.

Still another concern expressed by agencies is the business life of the CMS system supplier relative to the lifespan of the CMS system. A few agencies reported that the CMS system contractors no longer are available to assist the agencies in correcting hardware problems by either furnishing replacement parts or providing system maintenance. Therefore, the tendency by agencies to specify special designs could be a detriment to future operations. There is a need, therefore, to consider designs incorporating more "off-the-shelf" components to enhance the ability of the agency to acquire replacement parts.

The following is a list of several questions that highway officials may wish to 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 knowhow?

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?

C. 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 2-38. Some cost analyses results of interest for several CMS technologies are shown in Table 9-1. The assumed number of service calls per year and the breakdown of labor and materials costs are given in Table 9-2 (5).

Table 9-1
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 9-2
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

D. 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 9-3 presents power consumption estimates made in 1974 for various types of CMSs (2, 48).

The Ontario Ministry of Transportation in 1989 estimated that for the clustered LED CMS under consideration by the Ministry (Chapter 2, Figure 2-38) 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 9-3
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	during face change
	0	other times
Scroll	0.2	during face change
	0.15-0.35	internal lighting
	0.4 -1.2	heat if needed
Drum	0.5 -1.0	during face change
	0.15-0.35	heating each drum, if needed
	0.3 -1.0	external lighting
Vane matrix	0.05-0.1	control unit
	0.1 -0.4	lighting
Disk matrix	0.7	control unit and heater or blower
	0.6	external lighting
Portable bulb matrix	1.0 -1.5	typical message
	2.0	maximum
Bulb matrix	0.011-0.015	each bulb
	2.0 -5.0	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 kW ($0.05/kW-h)(20h/year) + (2 drums x 0.5 kW/drum)($0.05/kW-h) (2000 h/year) + (1.0 kW)($0.05/kW-h)(4000 h/year) = $301/year

10. COMPARISONS OF CHANGEABLE MESSAGE SIGNS BY HIGHWAY AGENCIES

A. Introduction

It would be helpful to a designer of a CMS system if substantial data were available that presents objective evaluations of the various kinds of CMSs, particularly if they were compared side-by-side in the field. Unfortunately, there have not been many reported side-by-side field evaluations of different CMSs. This author was only able to identify three such studies, all of which were conducted outside the United States. Each study was designed to satisfy a local concern. In most cases, the hardware evaluated did not represent the latest or the best equipment available and, therefore, does not represent a totally accurate relative appraisal of the various CMSs. Consequently, the results cannot be easily translated to other locations or to current situations. However, the results are helpful because they identify the rationale for the selection of CMS technology in each case, and provide some information that will be helpful for designers of future systems. The reader must be aware of the limitations of the studies.

This chapter of the report summarizes three reported studies of CMS technologies that were evaluated side-by-side in the field. The field studies are as follows:

1. The Societe des Autoroutes: Paris-Rhin-Rhone (SAPRR) studies of CMSs for freeway applications in 1984,
2. SAPRR studies of CMSs for off-freeway applications in 1989, and
3. Ontario Ministry of Transportation studies of CMSs for freeway applications in 1989.

Two other reports that involved comparisons of CMS technologies are also summarized:

1. Georgia Department of Transportation studies of trailer-mounted CMSs for work zones.
2. FHWA survey of its regional offices concerning CMS operational experiences.

B. Caveat

In reviewing the results of the above and other studies concerning CMSs, it is important to understand the following before generalizations can be made:

1. One must be certain to identify the exact type of CMS technology.

2. One must be certain to identify the exact model and design of each type of CMS evaluated. CMS technology is changing very rapidly and manufacturers continue to make improvements to their products. Below are some examples of some of the sign design differences that can account for reported differences in legibility distances.

Early field studies indicated that messages on CMSs with LEDs were not as legible as other light-emitting CMSs. Some of the newer LED signs have incorporated "super bright" LEDs which have significantly improved legibility. In addition, the number and type of LEDs used by CMS manufacturers differ. One manufacture uses clusters of 8 red and 8 green LEDs. Another manufacturer uses clusters of 9 red and 55 green super-bright LEDs. Similar differences exist for other signing technologies, even among products made by the same manufacturer.

Some CMSs are studied with shade screens, others without screens; some are studied with sun visors, others are studied without visors; etc.

3. One must be certain of the environmental conditions under which the studies were conducted. Some CMSs perform better than others when the sun is directly on the message. Some perform better when the sun is at the zenith, etc.

4. One must be certain of the distances at which measurements are made. The relative quality of CMSs may change depending on the distance observers are upstream from the signs.

5. One must make sure that all conditions are equal among signs when studies are made. For example, it is not appropriate to compare a CMS having a character height of 8 inches (203 mm) with one that has a character height of 18 inches (457 mm) and then make generalizations about the merits of the sign technologies. The results may be attributed to the differences in letter size rather than in the performance of each technology. Different spacings between characters and failure to dim light-emitting signs at night will also adversely affect sign comparisons.

6. One must be certain whether and how luminance was controlled both day and night to optimize contrast and thus legibility. It is necessary to ensure that the luminance of each sign evaluated is adjusted to represent the true operations of the sign.

7. One must be certain that the prototype sign tested truly duplicates the operations of the manufactured CMS.

C. SAPRR Freeway CMSs in 1984 (11)

SAPRR is developing a traffic management assistance system which incorporates a network of alphanumeric remote control information signs. SAPRR is the Paris-Rhine-Rhone Expressway Company in France that manages a network of more than 620 miles (1,000 kms) of mostly 4-lane intercity expressways. The CMSs were to be located on rural expressways upstream of interchanges. The reference speed on the expressways is 81 mph (130 km/hr). The messages were intended for safety information (e.g., warning of slow traffic, reduced speed regulations, etc.) and lane control, and not for diversion.

In 1984, SAPRR asked several CMS manufacturers to install prototype signs side-by-side so that the highway company could select a technology for their CMS system. Reflective disk, scrolls, LEDs and fiber optic CMSs were evaluated.

SAPRR concluded that the reflective disk and scroll CMSs evaluated did not have the necessary target value. LEDs at the time of the evaluations were limited by their power output (only standard LEDs were available; super bright LEDs became available after this evaluation) and did not yield the amount of legibility distances as the fiber optic CMS tested. According to SAPRR, even the existing fiber optic CMS needed improvement to meet the acceptability criteria established by the highway company. SAPRR was able to work with the manufacturer who produced a fiber optic CMS with acceptable target value and legibility distance.

SAPRR purchased fiber optic shuttered CMSs from a manufacturer in France. The fiber optic shuttered signs contained two illuminated fiber optic "dots" in each pixel which were exposed or closed by a rotating shutter. The signs contained four lines of 15 characters measuring 12.6 inches (320 mm). SAPRR evaluated the shutter system under real-world conditions for a year and found it to be very acceptable.

The fiber optic CMSs had characters that were 12.6 inches (320 mm) high. Although SAPRR believes that a 12.6 inches (320 mm) letter is acceptable for their applications on a intercity freeway, they feel that an 18-inch (457-mm) letter would give motorists a more comfortable feeling.

D. SAPRR Off-Expressway CMSs in 1989

SAPRR recently saw the need to present information to motorists before they enter the intercity expressways and was interested in purchasing additional CMSs for installation at route decision points off the expressway. The CMSs would be located at off-expressway sites where the motorists have a choice of different intercity routes. SAPRR felt that the size of the characters would naturally be smaller than that used on the expressway. The reference speed was 56 mph (90 km/hr). It was determined that the legibility distance for the CMS messages they proposed to use should be 328 ft (100 m).

Toward this end, SAPRR conducted field legibility studies of prototype CMSs which were documented by Anthonioz (9). In March 1989, SAPRR launched a public call for the loan of prototype CMSs. Each prototype sign had to be capable of displaying the indication "PMV" (the french equivalent to CMS) and each character had to be approximately 7.9 inches (200 mm). Seven companies supplied at least one prototype sign. The prototype CMSs obtained and field evaluated by SAPRR are shown in Table 10-1.

Unfortunately, the following conditions adversely affected the results;

1. The size of the characters on the CMS prototype were not identical and actually ranged in height from 5.9 to 9.8 inches (150 to 250 mm).

Table 10-1
PROTOTYPE CHANGEABLE MESSAGE SIGNS EVALUATED BY SAPRR (Ref. 9)

Sign	Manufacturer	Technology	Character size mm	Character size inches	Front	Particularities
1	DECAUX LYNX	Fibers + fluo pads	150	5.91	non-reflecting	no day/night adjustment
2	CENTAURE	12 orange diodes per dot	300 (alternating with 200)	11.80	non-reflecting	no day/night adjustment on this proto
2 Bis	CENTAURE	12 orange diodes per dot	200 (alternating with 300)	7.87	non-reflecting	
3	VELEC	Magnetic blinds, yellow paint	225	8.66	non-reflecting glass	2 fluo tubes (top and bottom of unit)
4	SES	Fibers + ribbed front	250	9.84	Wide angle on two letters M V	totally black front except for cutout in front of character spots. Possibility of using one or two fibers per point
5	NEUHAUS	16 Diodes/dot (8 green + 8 red)	210	8.27		no front panel
6	SES	Optical fibers	200	7.87	non-reflecting	
7	SES	Optical fibers + ribbed front face	200		wide angle and non-reflecting	Possibility of one or two fibers per dot (1f or 2f)
8	DECAUX Lynx	Fibers + pads	225	8.86	non-reflecting	no day/night adjustment
8 Bis	DECAUX	Fluo pads	225	8.86	non-reflecting in night lighting	simulation of front, no built
9	EMC2	9 orange diodes/dot	200	7.87	non-reflecting	sorted diodes 400/600 mcd
10	SES	VULTRON fluo pads	180	7.09	transparent non-reflecting	
11	SES	VULTRON fluo pads	180	7.09		
12	LACROIX	13 diodes/dot (4 red + 9 green)	250	9.84	transparent, no non-reflection	"hat" for protection against direct sunshine

2. The signs were evaluated at fixed distances (459, 394, 328, 262, and 164 ft [140, 120, 100, 80, 50, and 30 m]) and the data were not normalized across letter size.

3. Some of the prototype signs did not have any day/night brightness adjustments. Therefore, the luminance could not be optimized for all ambient conditions on every sign.

4. The prototype signs were placed on scaffolding and positioned generally east-west to produce a situation of "sun facing signs" in the afternoon. Unfortunately, because of interference from a nearby building, the "sun behind signs" condition could not be tested.

D.1 General Comments

The following represent general comments provided by Anthonioz (9) based on SAPRR's evaluation of the prototype CMSs shown in Table 10-1:

1. It appears that good legibility cannot be obtained at more than 262 ft (80 m) for characters measuring less than 7.9 inches (200 mm) in size. This translates to 33.3 ft/in of letter height.

2. When the sun was facing the signs, the only techniques which were not adversely affected were those with reflective pads (disks). It will be necessary to increase the luminance for light-emitting signs during this condition.

3. When the sun was facing the LED signs and the contrast ratio between the characters and the background was low, the unlit diodes appeared white.

4. Some of the signs experienced angular legibility problems. At 98.5 ft (30 m) from the sign and an angle of approximately 15° with respect to the general axis, only the messages on the reflective pad and fiber optic with a special "diffusing" front surface prototypes were visible.

D.2 Comments by Sign

DECAUX Lynx (Fiber Optics/Reflective Disk) 5.9-in (150-mm) Characters:

1. The lettering size was far too small for the intended purpose. This equipment is only suitable in urban environments for reading at 164 ft (50 m).

CENTAURE (Light-Emitting Diode) 11.8- and 7.9-in (300- and 200-mm) Characters, 12 Orange Diodes Per Pixel:

1. This equipment obtained relatively good results in spite of the poor background/character contrast. This lack of contrast becomes critical for the sun head on (reading impossible).

2. The treatment of the front face is plain and does not allow the LEDs to show through, which gives good character detachment from the background in spite of the low brightness of the LEDs.

3. The prototype CMS indicates a low manufacturing cost and integrated design and therefore, an economic product.

VELEC (non-fluorescent yellow roller, blinds with internal neon lighting 8.9-in (225-mm) Characters:

1. Poor outdoor results. This product has poor target value. The character brightness is insufficient. By night the two neon (top and bottom of the case) are insufficient to provide the display with the necessary contrast and they generate dazzle.

SES SYLVIA (Shuttered Fiber Optics) 9.8-in (250-mm) Characters:

1. Results were good. This lettering height provided legibility at 328 ft (100 m). With this lettering, it appears necessary to use the 2 optical fiber per character dot version in order to obtain sufficient and continuous lighting yield of the letters.

2. At short distances (164 ft [50 m]), observers found the writing too "light" to read easily.

NEUHAUS (Light-Emitting Diodes) 8.3-in (210-mm) Characters, 8 Red and 8 Green LEDs Per Pixel:

1. The best trade-off of the LED systems tested. The light power remained too weak in strong sunshine, but the contrast has been improved to obtain a very black screen.

2. Angularity characteristic: the message turns red as one moves out of the center line of the sign.

SES, SYLVIA (Shuttered Fiber Optics) 7.9-in (200-mm) Character:

1. The sign messages were dazzling with poorly defined characters. However, these faults can be easily corrected. The diffusing front face reduced the light power of the fiber optic dots in the axis. By doubling the light intensity using two fibers per dot, the improvement was not sufficient. It would appear that there is an optimum yet to be found between the character size and the brightness of the character by optimizing inter-character spacing, etc.

DECAUX (Reflective Disk) and LYNX (Fiber Optics/Reflective Disk) 8.9-in (225-mm) Character:

1. The fiber optic/reflective disk sign resulted in good performance. However, some factors still need to be optimized.

2. Fiber brightness has to be modulated or even eliminated, depending upon the solar illumination. When ambient lighting is strong, it was observed that the reflective disks were sufficient on their own without the fiber optics; the provision of excessive light intensity hinders legibility; the 8.9-in (225-mm) characters with a 7 x 9 dot matrix, which is already bold, becomes dazzling.

3. Similarly, an attempt to optimize the spacing of the characters and the dots with respect to one another should be made.

EMC2 (Light-Emitting Diodes) 7.9-in (200-mm) Characters, 9 Orange Diodes:

1. This product had the lowest density per dot, but was the most powerful of the prototypes.

2. The appearance of the diodes when unlit is white/transparent, which is extremely detrimental to contrast, particularly when ambient lighting is strong and outside the main axis.
3. The target value was weak.

4. The general brightness of the background and the transparent front face were hindrances to legibility.

SES/VULTRON (Reflective disks) 7.1-in (180-mm) Characters:

1. The size of the lettering was far too small for the intended purpose; the visual impact was too weak from long distances and for medium to low ambient brightness. The use of larger characters and another lighting system might improve the system.

LACROIX (Light-Emitting Diode) 9.8-in (250-mm) Character, 4 Red and 9 Green Diodes per Pixel:

1. Prototype sign was rated to be comparable to the NEUHAUS and EMC2.

2. Poor legibility with sun on the front due to the poor contrast on the front face and reflections on the non-treated Plexiglass.

3. Qualitatively, the observers rated this display as being "too red".

D.3 Conclusions and Perspectives

From the comparison of the different CMS modules tested, SAPRR developed basic conclusions and perspectives concerning CMSs for highway applications. These are as follows:

1. To obtain adequate legibility of CMSs for intercity expressways for the signing objectives in France, the effective character size should be greater than 7.9 inches (200 mm). This result is compatible with those of Stockton et al. (44) who found that characters on CMSs located on urban freeway ramps should be at least 10 inches (254 mm) high.

2. Although the type of LEDs tested gave good qualitative results for average ambient brightness, their performance was highly insufficient for all lighting conditions.

3. The brightness of fiber optic CMSs still needs to be optimized (particularly downward), in proportion to the size of the lettering.

4. It will be necessary to have two fibers per dot for any letter size greater than 7.9 inches (200 mm) in order to give "body" to the characters.

5. The diffusing front face, which increases light dispersion, gives very good legibility up to $\pm 20^{o}$ angularity. With a diffusing front face, the light impact in the axis is reduced by about half. (This means that a second fiber per dot would have to be used in order to regain the impact equivalent to a sign with a normal front face). The diffusing front face may require some further optimization with the character brightness.

6. For significant improvements in target value and legibility, LED systems must have significant brightness increases to improve the sign character/background contrast over and above the systems tested. In particular, improvements must be made for conditions when the sun is shinning directly on the CMS.

7. Reflective disk CMSs appear to be very effective when large letters are used, or when used in low speed urban situations (e.g.. intersections, roundabouts).

E. Ontario Ministry of Transportation CMSs in 1989 (5)

The Ontario Ministry of Transportation conducted studies between January 1987 and August 1988 to evaluate CMS technologies for the Highway 401 (Toronto Bypass) Freeway Traffic Management System. The study was carried out to assess all available CMS technologies in terms of performance and benefit/cost aspects, and to determine if there are better alternatives to the reflective rotating disk technology. The study carried out was investigatory, on a broad scope, and did not involve extensive basic research or development. The following conclusions and recommendations were made:

A light-emitting technology is recommended. Light-emitting technologies offer the best brightness and conspicuity compared to reflective technologies and out-perform reflective technologies when the sun is behind, or in front of, the sign (an important consideration on the east-west highway).

The capital costs of light-emitting technologies are high; about two to three times those of reflective technologies. Since the highway is the busiest corridor in Ontario and is currently carrying some 300,000 vehicles per day in a maximum configuration of 16 lanes, the chance of visual confusion and for missing a sign is high. Visual conspicuity and legibility, for important messages, is therefore considered to be imperative. Pure reflective technologies will not provide the required quality.

Most reflective technologies have mechanical components and therefore do not offer the high reliability of some of the light-emitting technologies that use solid state devices.

They recommended that the following technologies be allowed to compete in the contract (listed in order of preference):

1. Light-Emitting Diode (LED) Clusters,
2. Fiber Optic with Reflective Disk (FO/RD), and
3. Shuttered Fiber Optic.

The primary reasons for the recommended technologies are as follows:

LED Cluster:	This is the first choice due to the superior visibility and expected low maintenance costs.
Fiber Optic/ Reflective Disk	This type is visually good with the added flip-disks giving "body" to fiber emissions. The "fail safe" aspects of a power outage are also of value. Unfortunately, the electromechanical aspects are expected to lead to future maintenance problems.
Shuttered Fiber Optic	This type is "acceptable" visually but suffers from a pixel which is too small for proper perspective of the required character size and sun "wash out" under some conditions. Electromechanical aspects are similar to the expected problems of the Fiber-Optic-Reflecting Disk (FO/RD) type.

The advantages, disadvantages and specific features of the acceptable CMS technologies cited are as follows:

E.1 Light-Emitting Diode (LED) Cluster

Advantages

- Complete solid state - no moving parts.
- Long LED life (100,00 hours = 12 years) should mean low maintenance and good reliability.
- Technology continues to be developed; higher outputs, longer lives and lower prices may be expected in the future.
- A low power consumption is important if UPS power backup is needed for energy and cost savings.
- Pixels can be made to mount in a simple lamp or bayonet socket--unsoldering etc. will not be required.
- Power consumption is very low--existing services will suffice.
- Brightness control is infinitely variable from zero to maximum by simple methods.
- A choice of three colors (amber, red alone or yellow/green alone) is easily available by wiring each color of LED separately.
- Several LEDs in each cluster can fail without large consequences.
- Most impressive and most legible of the types studied.
- Used by several authorities in Europe.

Disadvantages

- Unproven in North America (many signs in Japan and Italy).
- Red LEDs give highest output; it is difficult to get the required output in the amber/yellow/green ranges without large number of LEDs per pixel.
- The cluster appears to be more red as the viewer moves farther away or substantially off the light axis.
- Sun reflection from LED plastic encapsulation requires a sun hood over each pixel.
- Lexan front is still required; ordinary LEDs (not encapsulated in resin) are subject to deterioration due to humidity.
- Default messages for power outages would require a UPS.

- Ultraviolet light damages are claimed by some (no substantiation found).

- Ambient temperature affects the quantity of light output and auxiliary cooling (fans) is required.

Features

- Low power consumption.

- Easily changed elements; bayonet mounting of the cluster directly to the printed circuit driver board will enhance rapid modular maintenance.

- Low failure rate; due to estimated life and due to the fact that each cluster contains 64 individual LEDs (several can fail without appreciable deterioration of light output).

- Some site-specific problems bay be encountered with sun reflection from the LED encapsulations.

E.2 Fiber Optic/Reflective Disk (FO/RD)

Advantages

- Uses high-intensity discharge lamps (24,000-hour life) rather than incandescent lamps (6,000)-hour life).

- Illumination is not required under all conditions; the lighting could fail and the display would still indicate the normal flip-disk message.

- Good "punch" equivalent to Sylvia (SES).

- Known manufacturer is local and the leader in the field.

- Can use existing power feeds.

- Can have a default message, using flip-disks only.

Disadvantages

- Research and development still underway; our project would probably be a prototype proving ground as some birthing pains can be expected.

- Mechanical components require maintenance; far too much reliance is put on electromechanical devices rather than solid state devices.

- Lamps require maintenance (although a lamp outage is not 100 percent disastrous).

- Light spillage downwards towards the roadway when the pixel is "off." While not a large concern here, there may be a problem if this sign is used on a non-illuminated roadway.

- Expected maintenance problems with the controller based on past history.

Operational Features

- Expected problems with disks sticking due to moisture and dirt.

- Expected problems with the method of distributing the light from the lamp to the fibers.

- Expected problems with the method of lamp cooling.

E.3 Fiber Optic (Shuttered)

Advantages

- Sign is a quality product; possibly to the point of being overbuilt.

- The "punch" or visibility under sunny conditions, fog, etc. is good.

- Used by several authorities in Europe.

- Can use existing power feeds.

- Local representative for sales and service.

Disadvantages

- Manufacturer insists that 12.6-in (320-mm) characters are satisfactory and has to date not put too much effort into development of 18-in (457-mm) high characters. The proposed module of 16-in (405-mm) characters is a modification of the 12.6-in (320-mm) standard and the spacing of the pixels is less than optimal for good visibility.

- Proprietary materials and methods may make maintenance difficult (all components are European).

- Mechanical components require maintenance.

- Incandescent lamps require maintenance.

- No specific proposals for front opening models have been received.

- Default messages for power outages would require UPS.

Operational Features

- The models examined were considered to be somewhat overbuilt for the highway environment and had what appeared to be "showroom" quality.

- Due to the mechanical nature of the sign, the reliability may be expected to be lower than that of solid state signs.

- The controller is composed of European components and problems with replacement parts acquisition are anticipated. Users, however, report good operational reliability (in Europe).

The Ontario Ministry of Transportation (5) also recommended that the following technologies not be allowed to compete in the contract (in reverse chronological order to that of being dropped as a viable alternative):

1. Lamp (Incandescent),
2. Liquid Crystal Display (LCD) - Internally Illuminated,
3. Light-Emitting Diode (LED) - Board,
4. Reflective Disk,
5. Flap,
6. Rotating Cube/Cylinder,
7. Liquid Crystal Display (LCD) - Externally Illuminated,
8. Liquid Cell (Fluid Cell),
9. Neon Tube (Blank-out),
10. Fiber Optic (Fixed Grid),
11. Cathode Ray Tube (CRT), and
12. Laser Scan.

The advantages and disadvantages of the unacceptable CMS technologies and conclusions reached by the Ontario Ministry of Transportation (5) are as follows:

E.4 Lamp (Incandescent)

Advantages

- Best visual "punch" of all technologies studied.

- Easily dimmed or increased in light output to accommodate to all light levels.

- Old and known technology with well-established methods.

- Economy of capital costs; would attract many bidders and competition would ensure low prices.

- Maintenance is relatively simple and replacement materials are readily available.

Disadvantages

- Energy usage is very high.
- Light source is not directional (sign message could be easily read in adjacent lanes).
- Requires masking or screening to prevent reflection from glass of lamps and from canister reflectors.
- Very hot operating conditions requires open screening or internal ventilation.
- Life of lamps gives a relatively short MTBF.
- Signcase weight would be difficult to keep within the budget of 3000 kg.
- No default message upon power outage.

Conclusions

- The use of incandescent lamp technology would result in the best possible visibility of sign messages (notwithstanding the minor disadvantage of being able to read the signs from the adjacent express/collector lanes).
- The technology meets or exceeds visual and other requirements except for weight and energy usage.
- The use of this technology cannot be justified in view of the policy of energy conservation.

E.5 Liquid Crystal Display (LCD) - Internally Illuminated

Advantages

- Solid state device could be useful and save energy if combined with a concentrated light source.
- Largest advantage would be for use as a shutter for shuttered fiber optic technology, thereby eliminating the electromechanical portions (several under development at the time of writing).

Disadvantages

- Existing signs on the market exhibit very poor contrast and extreme "wash-out" under sun conditions.

- Slow performance in very cold temperatures.
- Cost is not competitive.
- Weight would be difficult to keep within the budget of 3,000 kg.
- No default message upon power outage.

Conclusions

- This technology, in the present form, is unacceptable from the point of view of visibility, cost, weight and temperature performance.

E.6 Light-Emitting Diode (LED) - Board

Advantages

- Low energy usage.
- Red LEDs have high light output; other colors are about 1/3 of the red output; the sign is useful in small sizes where the red color could be tolerated.
- Established technology.
- Relatively economical.

Disadvantages

- Requires internal heating for humidity control.
- Requires internal ventilation for temperature control.
- Requires substantial improvement upon the commercial grade of specification to suit highway conditions.
- Requires screening from sun (either mechanical or as color-tinted anti-glare Lexan).
- Maintenance at board module level only.
- Best in a full matrix configuration; many LEDs would sit idle in the recommended matrix.

Conclusions

- This technology is unsuitable due to the low light output levels in the desired colors and due to anticipated environmental and maintenance problems.

E.7 Reflective Disk

Advantages

- Cost: by far the cheapest capital cost.
- Wide usage: used by many roadway authorities in North America.
- Established technology: materials are easy to obtain.
- Gives reasonable performance in the proper setting; lower speed and less cluttered roads, facing north.
- Local manufacturers.

Disadvantages

- Poor day visibility if sun is not shinning on dots.
- No "punch" to draw attention or provide conspicuity.
- Disks stick frequently, necessitating maintenance.
- Controllers are unreliable (probably as result of a poor specification by users; manufacturers do not provide any quality beyond that specified or they would not be price competitive).
- Unacceptable nighttime visibility where anti-glare Lexan is used.
- Electromechanical devices require preventative and repair maintenance.
- Problems is obtaining service and replacement parts in some cases leave signs out of action for long periods.

Conclusions

- Although many past problems are the result of poor specifications, the general product provided was at the advice of the manufacturers. These products are considered unsatisfactory from a maintenance viewpoint.
- The visibility and conspicuity are considerably inferior to any light-emitting technology.

- Use of this technology in the cluttered visual environment of Highway 401 would be a serious mistake as the sign in much too bland to be effective.

E.8 Flap Matrix

Conclusions

- Advantages, disadvantages and conclusions for the hinged flap technology are similar to those of the reflective disk technology.

- The manufacturers see no point in pursuing bids in Canada as they feel they cannot compete with the local reflective disk manufacturers.

E.9 Liquid Crystal Display (LCD) - Externally Illuminated

Conclusions

- This technology offers some hope of future improvement. If the contrast can be improved and if internal illumination can be provided.

- The reliance on external illumination gives the same problems as those quoted for the reflective disk.

- This technology is not suitable in the present format.

E.10 Liquid Cell (Fluid Cell)

Conclusions

- This technology was dropped from further review due to the large weight, the suspected temperature problems and high cost.

- This technology is more suited to graphic display boards or scoreboards since a full matrix is the standard configuration.

- The technology is considered to be too elaborate for highway use and further consideration is not recommended.

E.11 Neon Tube (Blank-out)

Conclusions

- This technology is not suitable for the planned application.

E.12 Fiber Optic (Fixed Grid)

Conclusions

- This technology would be useful on small Changeable Message Signs where only two to four fixed messages were required. The limited scope will not be satisfactory for use on a large system.

E.13 Cathode Ray Tube (CRT)

Conclusions

- The technology was ruled out as unsuitable since video is not required and due to the large costs.

E.14 Laser Scan

- Presently this technology is limited to indoor or nighttime display. Each display or "show sequence" is a major software and hardware undertaking at this time and this technology was dropped from further study.

F. Georgia Department of Transportation Trailer-Mounted CMS for Work Zones in 1988

Valdez (49) reported on a limited research study in order to provide a quick evaluation of an ADDCO Manufacturing Corporation trailer-mounted flap matrix CMS with 18-inch (457-mm) characters. Static (stationary) legibility distances and sign type characteristics were compared to the more commonly used CMS by the Georgia DOT--the lamp matrix. It should be noted that the studies were conducted using ADDCO CMS Model 905-0100. According to ADDCO, newer models are designed to circumvent some of the deficiencies cited by Valdez.

F.1 Sign Description

The ADDCO flap matrix CMS evaluated by Valdez is constructed of three separate horizontal cases that are tiered. Each self-contained tiered case has a clear polycarbonate, high-impact strength window to protect the electronic and mechanical components from the environmental elements. Within each case there are four 4-ft (1.2 m) black-lite blue tubes which provide illumination during nighttime operations of the sign. The lights can be turned on manually or automatically using photocells.

Each of the three tiered cases contains eight 18-in x 9-in (457 mm x 228.5 m) character modules in 5 x 7 arrays of flaps that independently and electromagnetically expose or cover fluorescent surfaces when opened to form the desired alpha-numeric characters.

F.2 Findings

The daytime static legibility distance of the flap matrix sign under a clear to partly cloudy sky was subjectively established at 900 ft (274 m), and 800 ft (244 m) for the lamp matrix. When the flap matrix sign faced the setting sun, the legibility distance increased to 1,000 ft (305 m). This was a result of the sun reflecting from the fluorescent letter surfaces.

At night, the average legibility distance was 650 ft (198 m) for the flap matrix and 750 ft (229 m) for the lamp matrix. On occasion, the clear polycarbonate protective window on the flap matrix sign reflected headlights of approaching vehicles and adversely affected legibility. Valdez speculated that the decreased legibility distance at night could have been the result of the increased luminance of the sign background caused by the fluorescent lights inside the sign cases.

Valdez reported that the luminance measurements of the sign at night varied because not all the characters were receiving the same amount of illumination. The uneven distribution of light created "dark spots" near both ends of each fluorescent light tube. He speculated that this problem might be corrected by the use of longer light tubes. The middle of each character also received less illumination than the top and bottom areas as the light tubes are located at the top and bottom of each tier.

The legibility of the lamp matrix CMS tested remained fairly constant under varying ambient lighting conditions.

Valdez noted the importance of spacing of characters formed by light-emitting technologies. He stated that the legibility of the lamp matrix CMS could have been increased had the spacing between characters been increased.

G. FHWA Report in 1986

Lavigne (50) called all of FHWA's regional offices in 1986 and asked to discuss the CMS operating experiences by agencies in their regions. Many states have no CMSs. In some cases, division and state contacts were suggested for more detailed information. The following comments are summaries of the reported CMS operating experiences.

G.1 Lamp Matrix

- High maintenance cost
- High electrical operating cost
- Subject to vandalism (shooting bulbs)
- Sign too bright to read at night because dimming circuits non-existent or malfunctioning
- Lamp sockets subject to corrosion
- Highway vibrations cause premature bulb failure
- Great flexibility in creating attention-getting flashing messages
- Used extensively at highway maintenance and reconstruction sites.

G.2 Rotating Drum

- Paint peeling from drum due to temperature changes
- No problems with internally illuminated drum
- Very reliable sign

G.3 Reflective Disk Matrix

- Problem reading tri-color disk sign in daylight
- Sun reflecting off plastic sign face washes out message
- Some corrosion due to high humidity conditions
- Some signs difficult to read at night
- Disk color not always matched with other signs
- Normally very reliable, low power operation, high message flexibility, many signs over nine years old
- Would like to see more uniform disk color from sign to sign; less costly signs; non-reflective cover over sign face; internally illuminated signs.

11. SELECTING THE APPROPRIATE CHANGEABLE MESSAGE SIGN

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. As discussed in Chapter 3, in setting objectives, the agency must first be specific in defining:

- What the <u>problem</u> is that is to be addressed with the CMS,

and then to specify:

- <u>Who</u> is to be communicated with (audience);
- <u>What</u> type of driver response is desired;
- <u>Where</u> the change should take place;
- <u>What</u> degree of driver response is required; and
- <u>How</u> 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" (<u>1</u>) or "Guidelines on the Use of Changeable Message Signs", 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 (<u>1</u>).

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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APPENDIX A

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Ministère des Transports et de la Mer
Direction de la Sécurité et de la Circulation Routières

SPECIFICATION FOR THE APPROVAL OF VARIABLE MESSAGE ROAD SIGNS

Edition Nº 5, August 1988

SETRA - CSTR

This document was produced by the professional-administrative working group organised by SETRA and the LCPC.

SETRA, 46 Avenue Aristide Briand, B.P. 100, 9223 BAGNEUX Cedex, France

LIST OF CONTENTS

PART I - GENERAL

ARTICLE 1 - *General conditions of approval*

The provisions of the order of the 3 May 1978 concerning general conditions for the approval of road equipment also apply to the approval of variable message signs.

This specification establishes the approval procedure applying specifically to variable message signs. Its technical provisions may be subject to some alterations pending final approval of the document.

ARTICLE 2 - *Field of application*

A variable message sign is a road sign where at least two displays can be provided in turn on the same support: a neutral display and one or more signs or messages.

The approval applies to the sign, the displays and any local control facilities. This specification does not however apply to the approval of "shutter" type signs. The provisions for these latter were established by the order of the 26 July 1985 for the approval of category SP signs.

ARTICLE 3 - *Categories of sign*

A distinction is made between 4 categories of sign according to the type of display that is provided:

Category 1: danger or police sign

Category 2: lane allocation sign

Category 3: direction sign

Category 4: information sign

The choice of the technology employed for the signs is left to the initiative of the manufacturer.

ARTICLE 4 - *Request for approval*

4.1 <u>The request</u>

Three copies of a request for approval must be addressed by the manufacturer or importer to:

Ministère de l'Equipement et du Logement
S.E.T.R.A./C.S.T.R.
46 Avenue Aristide Briand
Boite Postale 100
92223 BAGNEUX Cedex

The request must be accompanied by the following documents:

- The request for approval (1).

- A certificate of committment (1).

- A request from abroad for approval of equipments not manufactured in an EEC country can only be accepted where the manufacture has a representative in France who has been accredited to the minister responsible for the national road system. In this case the request, accompanied by a certificate of accreditation of the French representative, must be submitted by that representative. Candidates established in an EEC country can submit their request directly.

- A set of documents giving details of the manufacturer (1)

- A set of documents giving technical details of the equipment (1).

- A report giving results of the tests called for in part IV.

- Design notes

(1) See the appendices for model documents.

ARTICLE 5 - *Granting of approval and follow up action*

5.1 Preliminary approval tests and inquiry

Approval will be granted in accordance with the requirements of this specification or with what are recognised as equivalent requirements in force in another EEC country.

A request for approval must be preceded by laboratory tests and checks carried out by an approved laboratory (see article 7) at the initiative of the candidate. These tests and checks must be carried out in accordance with the procedure given in part IV and be the subject of a resultant report.

The candidate may also be asked to supply the Administration with a sample for additional tests.

In the case of manufacturers who have not yet been approved, a request for approval will give rise to a preliminary inquiry, based on a visit to the manufacturer's premises, concerning the manufacturing and quality control facilities that are available. Such an inquiry will be carried out in accordance with the provisions of article 5 of the order of the 3 May 1978 (see article 23).

Having granted approval on the basis of laboratory tests, tests on an actual site as defined in part IV will be carried out following which the approval will or will not be renewed.

If the tests and verifications are carried out in an EEC country by a laboratory meeting the requirements of article 7 below, the candidate will nevertheless supply copies of the consequent test reports.

Tests may be carried out by these laboratories in accordance with operating procedures that differ from those of the LCPC but such tests will only be accepted where these procedures are recognised as being equivalent to the French ones and on condition that the results are made available to the French administration.

5.2 Granting of approval

Given the results of tests and the preliminary inquiry the Administration will, where applicable, grant approval as follows:

- Approval of the product on issuing one or more technical data sheets valid for 6 years.

- Approval of the manufacturer on issuing an approval certificate which will be renewed annually as a function of the results of checks that will be carried out.

The approval is granted for the product or range of products defined in the technical data sheet and for a given category of sign as defined in article 3. It is valid only for the particular product or range of products within a given category.

5.3 Annual renewal of approval

Each approved manufacturer must submit a request for renewal of some or all of the approvals that have been granted on the 31 January each year. He must also furnish his production figures.

The renewal will be granted on the basis of satisfactory results of tests carried out on actual sites as defined in article 25 and of the checks defined in the following paragraph 5.5.

5.4 Quality control carried out by the manufacturer

The manufacturer must undertake to supply products meeting the requirements of parts II and III and to exercise control of the manufacture of the products in accordance with the requirements of part V.

5.5 Verifications and tests to be carried out by the Administration

The Administration will verify the quality control exercised by the manufacturer and may carry out further checks to confirm that the approved products meet the requirements of parts II and II on selecting samples from within the factory, from stores, from those being delivered or from those already on site.

5.6 Modification of the equipments

Any modification of the approved equipments must have been the subject of a prior request from the party to whom the approval was granted.

Providing that the modification does not affect the characteristics of the approved product, the Administration will issue a new approval on the basis of the documents accompanying the request.

Otherwise the sign will be subjected to some or all of the relevant tests pending reapproval. These tests can be carried out before submitting a request for reapproval and the test report submitted in support of the request.

ARTICLE 6 - *Approval mark*

All products manufactured so as to correspond to the one that will have been approved must be identified by means of an externally visible inscription bearing the following information:

- Series or production number.

- Year of manufacture.

- Approval number.

Details of the required marking are given in appendix 2.

ARTICLE 7 - *Approved laboratories*

Tests and checks must be carried out by the Laboratoire Central des Ponts et Chaussées or by any other laboratory in an EEC country recognised as a suitably independent organisation that can meet the necessary technical and professional requirements in the road equipment field.

ARTICLE 8 - *Payment for the costs of granting approval*

As specified in article 13 of the order of the 3 May 1978 mentioned above, the costs to be met by the companies for the granting of approval will be defined as a result of an annual decision that will be passed on to the candidates.

PART II - GENERAL TECHNICAL REQUIREMENTS

ARTICLE 9 - *Definitions*

The general technical requirements are concerned with:

- The sign itself consisting of:

    - An enclosure designed to take the front face and its display together with any electrical and electronic equipment.

    - Means for fixing the sign in position.

    - A contrasting screen in some cases.

- Local control units in some cases.

Requirements concerning the front face are the subject of part III.

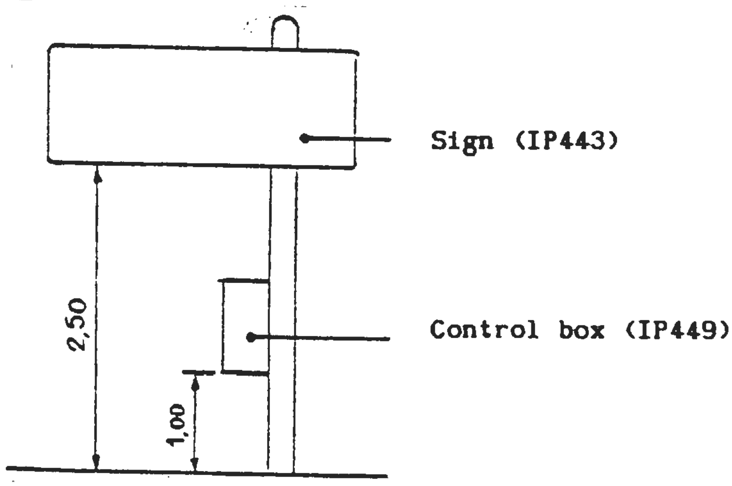
ARTICLE 10 - *Protection index*

The equipments (sign or control boxes) must have a protection rating equal to or not worse than:

- IP443 when the equipment is designed to be installed at a height of more than 2.30m.

- IP449 when the equipment is designed to be installed at a height of 2.30m or less.

Example:



ARTICLE 11 - *Mechanical strength*

The sign and its supports must be designed so as to be capable of withstanding:

- Variable forces due to horizontally applied winds of:

  • 130 daN/m² for signs designed to be installed at a height of less than 2.30m and for which the surface area of the front face is less than 4 m².

  • 240 daN/m² for signs designed to be installed at a height of 2.30m or more and for which the surface area of the front face is more than 4 m².

  Tests will be carried out to confirm that the signs meet this requirement on applying a distributed load to be defined later.

- Resistance to vibration.

  Tests will be carried out to confirm that the signs meet this requirement as is to be defined later.

ARTICLE 12 - *Anti-corrosion protection*

The anti-corrosion design and protection of the different components of the sign, particularly all nuts and bolts, must result in the sign having a life of at least 7 years. The sign must not show any signs of rust during this period.

Visual inspections will be made when carrying out follow-up tests on the signs installed on actual sites.

ARTICLE 13 - *Electrical installations*

The variable message signs must continue to operate and have a satisfactory performance under the following conditions:

- A variation of +10, -15 per cent of the direct or alternating voltage about its nominal value.

- A variation of ± 1 Herz about the nominal frequency.

The performance must not be adversely affected by micro-interruptions that can occur in the electrical power supply to the extent that their duration is always less than 200 ms.

The electrical installation must meet the safety requirements of the NFC 15.100 standard.

Requirements concerning the ability to withstand excess voltages have yet to be defined.

ARTICLE 14 - *Weather resistance*

All parts of the sign and its control unit submitted for approval will be subjected to the following series of climatic tests:

Extreme temperature test:	Temperature range:	$-25 \leq \theta \leq +70$°C
	Duration of test:	3 x 12-hour cycles
	Time at steady temperature: (hot and cold extremes)	3 hours
	Rate of transition:	25°C/hour
Humid heat test:	Temperature range:	$-25 \leq \theta \leq +70$°C
	Duration of test	2 x 12-hour cycles
	Time at steady temperature: (hot and cold extremes)	3 hours
	Relative humidity:	95% for $\theta \geq 5$°C
Rain test:	Identical programme to that for the humid heat test except for water spray sequences in place of the relative humidity ones.	

A solar radiation test is to be developed to partially replace the above tests. The maximum temperature will be reduced to 55°C for this test.

Equipments cooled by a forced circulation of external air will be supplied with air at a temperature of 45°C during these tests.

ARTICLE 15 - *Maintenance*

The sign must be designed so that maintenance operations (cleaning, lamp replacement, etc.) can be carried out on site and such that the colorimetric and photometric characteristics and the performance of the sign continue to be satisfactory from an operational point of view for a minimum life of 7 years.

The instructions must include a list of components whose duration of life is less than 1 year.

ARTICLE 16 - *Operation*

16.1 Basic operation

Signs making use of a matrix of points or segments are considered to be operating satisfactorily when:

- Less than 5% of the points or segments making up a character have deteriorated.

- Less than 2% of the points or segments of the whole sign have deteriorated.

In the case of variable message signs provided with interfaces for remote control or checking, operational tests will be carried out on those interfaces from a simulated control post made available by the manufacturer.

16.2 Degraded operation: failure of the sign

A safety facility must be provided for category 1 and 2 signs such that it is impossible for two different messages to appear at the same time.

Other operational safety provisions must be referred to in the technical data sheet.

16.3 Flashing, alternating and moving displays

Moving text is not acceptable.

Requirements concerning flashing and alternating signs have yet to be defined.

ARTICLE 17 - *Colour of elements other than the front face*

For visible elements other than the front face of a sign, the colours red, yellow, green blue and white as defined in article 22 are not acceptable.

PART III - TECHNICAL REQUIREMENTS CONCERNING THE FRONT FACE OF THE SIGN

ARTICLE 18 - *Definitions*

The requirements for the front face of the sign are concerned with:

- The front face of the enclosure.

- The display.

  The display is made up of the collection of small strips, symbols or characters forming a sign or message.

  The display is considered to be "continuous" when made up of regular lines or surfaces as in the case of fixed road signs (case of rotating prism or internally lit signs) and "discontinuous" when made up of isolated elements (case of matrices of illuminated points or small magnetically operated surfaces).

- A contrasting screen where applicable.

The signs can be luminous or non-luminous. Category 2 signs (lane allocation) are always luminous.

The technical requirements for the front face are classified according to the category of sign and the characteristics of the display.

ARTICLE 19 - *Dimensions and symbols*

19.1 <u>Category 1 signs (danger and police)</u>

- Continuous display signs

The display must meet the requirements of the specification for the approval of fixed SP category signs (order of the 26 July 1985).

- Discontinuous display signs

The standard dimensions for the front faces of the enclosures (in mm) are as follows:

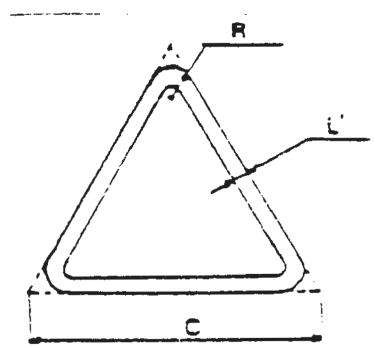
SIZE	SYMBOL ALONE	SYMBOL PLUS PANEL	PANEL ONLY
Very large	1600 x 1600	1600 x 1950	1600 x 350
Large	1300 x 1300	1300 x 1600	1600 x 300
Normal	1050 x 1050	1050 x 1300	1050 x 250

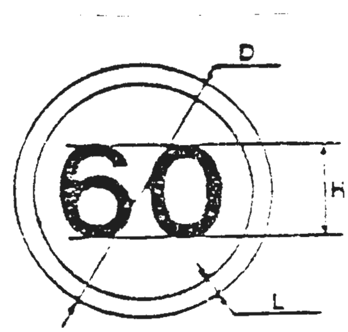
Tolerance on dimensions: ± 2%

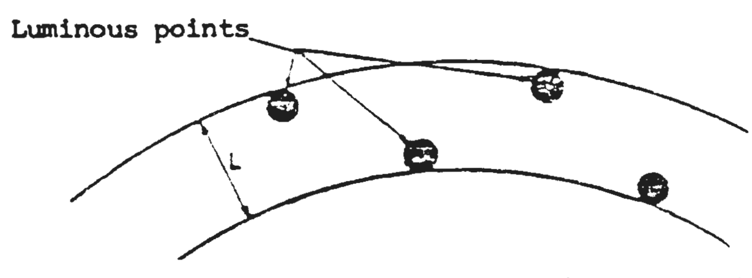
The dimensions of the symbols are as follows:

SIZE	SIGN A			SIGN B		
	C	L'	R	D	L	H (B14)
Very large	1500	55	75	1250	75	475
Large	1250	45	62.5	1050	63	400
Normal	1000	35	50	850	50	325

Tolerance on dimensions:
± 5% for C, D and H
± 10% for L, L' and R



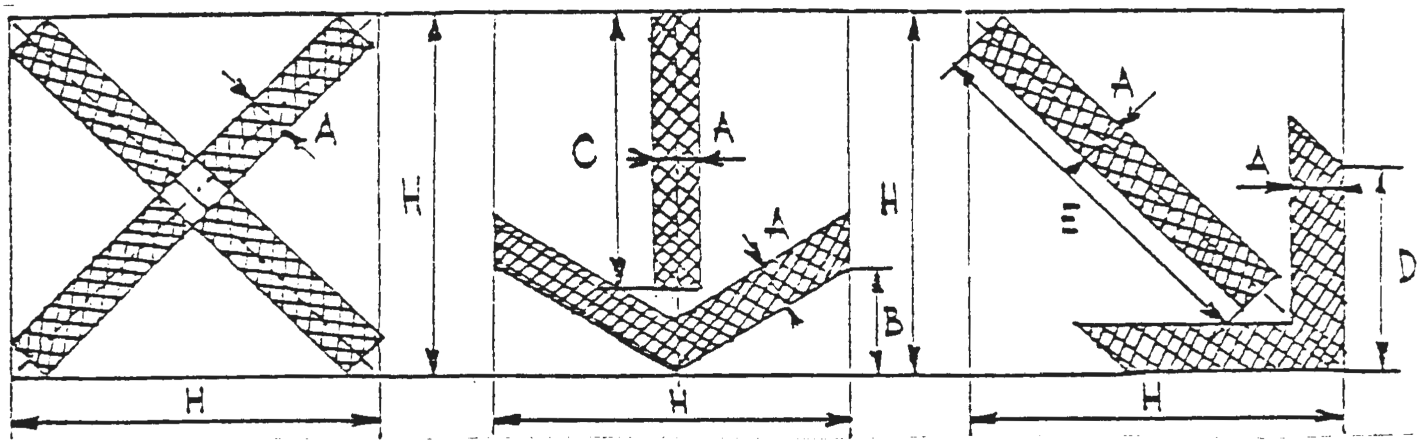




The other geometrical characteristics of the symbols for signs A and B have yet to be defined (except for the height of symbol B14).

19.2 Category 2 signs (lane allocation)

The symbols on these signs are dimensioned as follows:



The symbols are inscribed within a square of side L

L	H	A	B	C	D	E
550 750	300 450	40 60	90 135	225 335	175 260	300 450

Tolerance on dimensions:
± 5% on H, C, D and E
± 10% on A and B

In the case of an installation in a tunnel a contrasting background to the symbols is no longer necessary and the dimension L can be adjusted to suit the remaining space on the sign.

19.3 Category 3 and 4 signs (direction and information)

- Continuous display signs

In the case of category 3 signs the display must meet the requirements of the specification for the approval of fixed category SD signs (order of the 26 July 1985).

In the case of category 4 signs the display must be provided in accordance with the rules for the composition and dimensions given in the inter-ministerial instruction of the 22 March 1982 for direction signs.

In the case of signs consisting of a number of moving elements, the space between adjacent elements must not be greater than 12 mm.

- Discontinuous display signs

  • Dimensions of the enclosures:

For category 3 signs, the dimensions of the enclosures must meet the requirements of the specification for approval of fixed category SD signs.

For category 4 signs, the dimensions of the enclosures must be such that the characters are separated from the outer edges of the sign by a distance that is at least as great as their height.

  • Dimensions of the displays:

The displays consist of alpha-numeric messages. Each alpha-numeric character is made up of separate points or segments.

The important dimensions of the display are as follows:

l: dimension characteristic of the thickness of the line (diameter of a point, thickness of a segment)

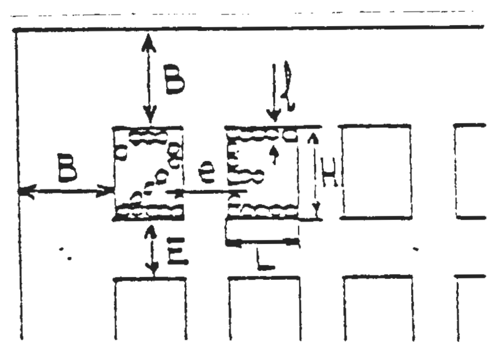
H: height of character

L: width of character

e: space between characters

E: space between rows of characters

B: distance between the text and the edge of the sign or contrasting screen



These dimensions must be such that:

$l \leq H/7$, $L \leq 5H/7$, $e \geq 2H/7$, $E \geq 4H/7$ and $B \geq H$

The minimum and recommended values of H (in mm) are given below according to the type of road on which the sign is installed:

	Minimum value	Recommended value
Motorway	320	400
Open country	200	250
Urban road	125	160

These values can be greater

The alpha-numeric characters must be as like as possible to the characters defined in the inter-ministerial instruction of the 22 March 1982 for direction signs.

The minimum requirements for the alpha-numeric characters as shown in appendix 5 are:

- 5 x 7 point matrix

- ASCII 16 segment matrix

Any set of alpha-numeric characters having a better resolution than this is acceptable.

ARTICLE 20 - *Photometric characteristics*

The required photometric performances are defined with the front face of the sign if any in place.

20.1 Continuous display signs (categories 1, 3 and 4)

- Retroreflecting surfacings

The surfacings employed must be products that have been approved in accordance with the specification in force for the approval of retroreflecting surfacings for road signs and that are included in the list of approved products published in the Bulletin Officiel du Ministère des Transports

- Enclosures lit from within with continuous displays

The brightness of the different colours at all points of the sign during the day and at night must be as follows (a point in this context being regarded as a circle having a diameter corresponding to the smallest dimension of the display):

Colour	Brightness (cd.m^2) *	
	During the day	At night
Black	< 100	< 1
Blue	> 500	4 - 20
Green	> 1000	7 - 45
Yellow	> 3000	25 - 150
Red	> 1000	7 - 45
White	> 5000	50 - 300
Maroon	> 500	4 - 20

* For a perpendicular illumination of 5000 lux

During the day the use of light colours (white and yellow) in combination with a dark one must result in a brightness ratio of between 3 and 25, the recommended ratio lying between 5 and 15.

20.2 Discontinuous display signs (category 1, 3 and 4)

- Non-luminous signs

In the case of category 1 and 3 signs the surfacings employed for the display elements must be products that have been approved in accordance with the specification in force for the approval of retroreflecting surfacings for road signs.

In the case of category 4 signs, surfacings using products not included in the list of approved items will be subjected to artificial ageing tests in accordance with the procedure defined in the specification for the approval of retroreflecting surfacings for road signs. Five flat, 10 x 10 cm samples of each product concerned must be supplied for these tests.

- Luminous signs

The luminous intensity of these signs must meet the minimum requirements given in the following table. These requirements correspond to the results of measurements carried out in a direction perpendicular to the front face of the panel (reference axis).

These requirements are given as a first approach. The products submitted for approval will be the subject of additional visual observations to be made during a transitory period.

Requirements for category 1 signs (danger and police):

Size	Luminous intensity for the complete single-colour display (cd)			
	Red ring or triangle		White symbols	
	Day	Night	Day	Night
Very large	600 to 1200	30 to 60	600 to 1200	30 to 60
Large	450 to 900	25 to 50	450 to 900	25 to 50
Normal	300 to 600	15 to 30	300 to 600	15 to 30

Specifications for category 3 and 4 signs (direction and information)

- During the day

The requirement is based on the luminance contrast.

- The background luminance (L_f) is the luminance of the non-illuminated character, measured under the following conditions:

    - illumination at an angle of 20^o above the reference axis, and measurement of the luminance according to the reference axis
    - the result obtained being related to an illumination of 80000 lux.

- The luminance of the illuminated character (L_c) is obtained by measuring the luminous intensity emitted by all the matrix dots of a character. The measurement is made in the reference axis. The area evaluated is L x H.

The contrast value $C = \frac{L_c + L_f}{L_f}$ must be between 3 and 25.

- At night:

Recommended height of characters (mm)	Luminous intensity per point (cd) *	
	Rural or poorly lit area	Well lit area
Motorway: 400	0.1 to 1	1 to 5
Open country: 250	0.04 to 0.4	0.4 to 2
Urban roads: 160	0.015 to 0.15	0.15 to 0.75

* The point concerned here is considered to be the basic element of the matrix used for the representation of a character. Thus a 5 x 7 matrix contains 35 basic elements. In the case of alpha-numeric characters represented by segments or made up from other than a 5 x 7 matrix, the required range of intensity will be the same as that required for the same character made up from a 5 x 7 matrix.

20.3 Category 2 signs (lane allocation)

These signs must also be luminous. The display can be continuous or discontinuous.

The intensity of illumination during the day or at night in a direction perpendicular to the front face of the sign must be as follows:

- During the day:

H: height of sign (mm)	Luminous intensity of the sign (cd)		
	B_1	B_2	B_3
300	60 to 120	100 to 400	200 to 800
450	80 to 190	200 to 800	400 to 1600

B_1, B_2 and B_3 are as defined in the preceding section 20.2

- At night:

H: height of sign (mm)	Luminous intensity of the sign (cd)	
	Rural or poorly lit area	Well lit area
300	1 to 10	10 to 50
450	2 to 20	20 to 100

20.4 Luminous uniformity

For continuous display signs the uniformity of the brightness must be such that $U = B_{min}/B_{max} > 0.2$ for all points of the sign where a point is defined as a circle whose diameter is equivalent to the smallest dimension of the display.

For discontinuous display signs we define for each single-colour element:

I_{av} = the average luminous intensity per point for each single-colour element

I_i = the average luminous intensity per point of a part of the sign (about 10% of the points selected at random) relative to this single-colour element.

The ratio I_i/I_{av} must lie between 0.60 and 1.40.

The required uniformity for the brightness of the sign has yet to be defined.

ARTICLE 21 - *Viewing angle*

The technical data sheet must refer to the viewing angle with respect to the reference axis for which the photometric performances of the sign are equal to 50% of the minimum requirements on the reference axis.

This angle must amount to at least 7 degrees.

ARTICLE 22 - *Colorimetric characteristics*

The colorimetric performances are referred to here on the understanding that the front face of the sign, if any, is in place.

The colours red, yellow, green, blue and white, as defined in section 22.1, must not be used for parts of the sign other than the display.

Texts and symbols that are shown in black against a white background on a continuous display sign must be in a dark colour on a discontinuous display sign (article 7.2 of the order of the 13 June 1979 on road signs).

The requirements concerning colours are based on I.L.C. recommendations where these exist. In the absence of international recommendations the requirements concerning the following may change on taking account in particular of the results of the tests and checks that are to be carried out:

- Category 3 and 4 signs.

- The "white-yellow" of category 2 signs (move to adjacent lane arrow).

- The "white-yellow" of luminous category 1 signs.

22.1 Non-luminous continuous displays (category 1, 3 and 4 signs)

Retroreflecting and non-retroreflecting surfacings must have a brightness factor and chromatic quality meeting the current requirements given in the specifications for category SP and SD signs and the retroreflecting surfacings intended for use on road signs.

22.2 Non-luminous discontinuous displays (category 1, 3 and 4 signs)

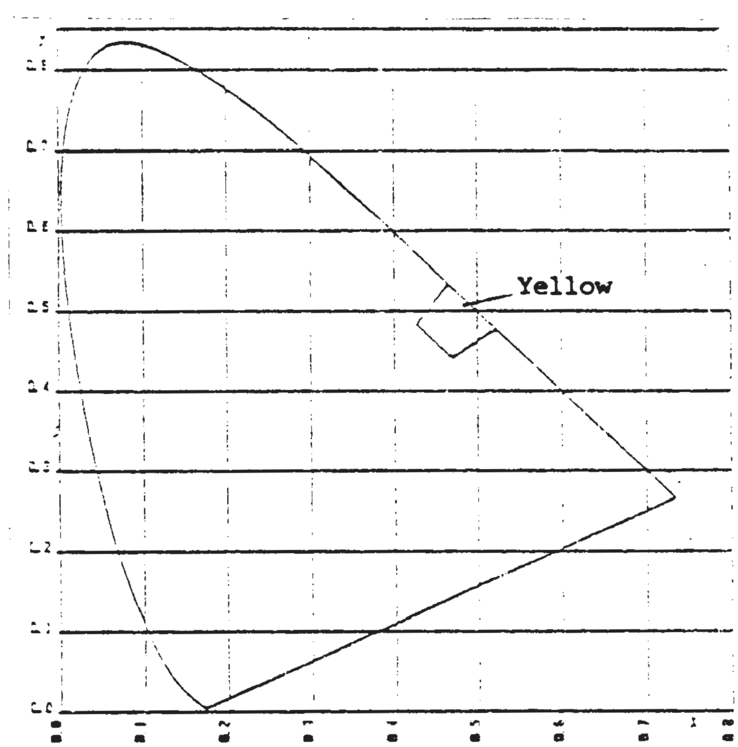
The requirements for category 1 and 3 signs are the same as given in the preceding section.

For category 4 signs, the non-luminous surfacings not defined in the specifications for the approval of category SP and SD signs will be subjected to artificial ageing tests in accordance with the procedure defined in the specification for the approval of retroreflecting surfacings for use on roa signs. Five flat 10 x 10 cm samples must be provided for such tests for each of the products concerned.

The trichromatic x, y coordinates (I.L.C., 1931) of the said surfacings before and after an artificial ageing test must lie within the chromaticity domain defined below.

Coordinates of the vertices of the chromaticity domain of non-luminous, discontinuous display, category 4 signs:

		1	2	3	4
Yellow	x y	0.522 0.477	0.470 0.440	0.427 0.483	0.465 0.534

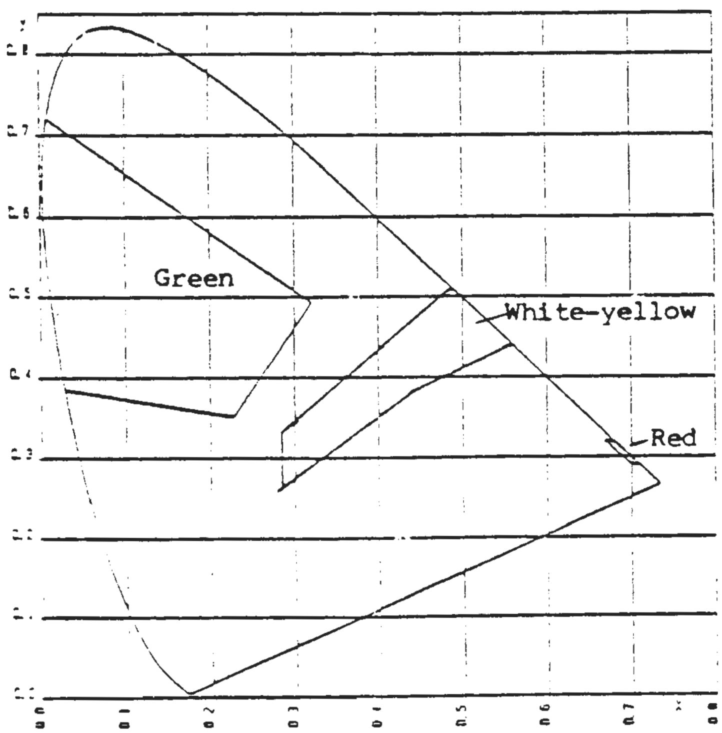


The brightness factor must be as follows: $\beta \geq 0.60$

22.3 Category 2 signs (lane allocation)

Chromaticity coordinates of the colour domain vertices for category 2 signs

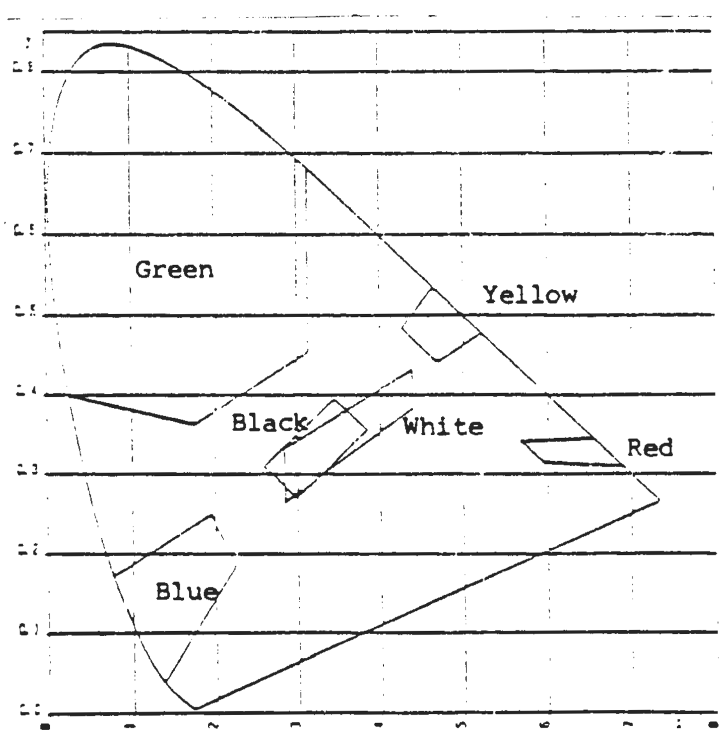
		1	2	3	4	5
Red	x y	0.680 0.320	0.670 0.320	0.700 0.290	0.710 0.290	
Green	x y	0.009 0.720	0.321 0.493	0.228 0.351	0.028 0.385	
White-yellow	x y	0.560 0.440	0.440 0.382	0.285 0.264	0.285 0.332	0.490 0.510



22.4 Luminous, continuous displays (category 1, 2 and 3 signs)

Chromaticity coordinates of the colour domain vertices for transparently illuminated continuous display signs.

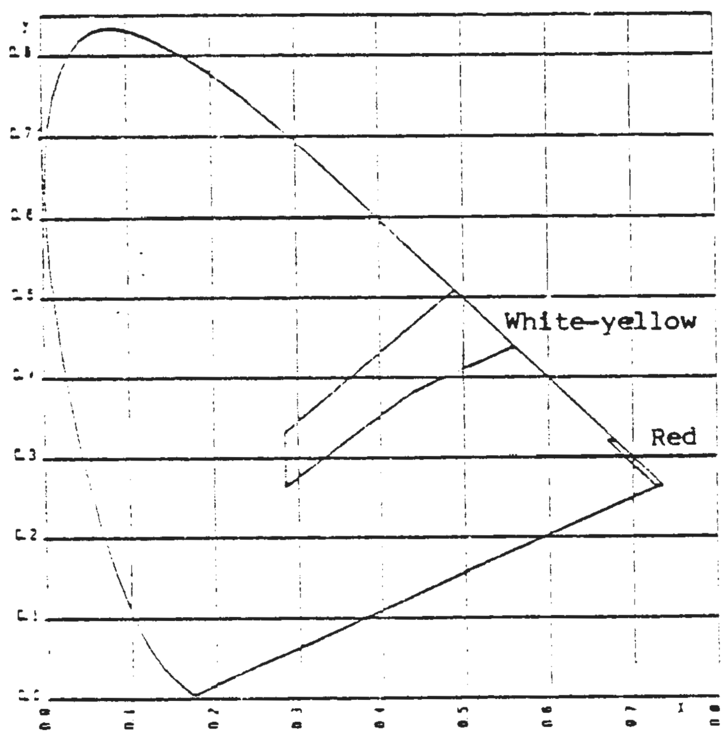
		1	2	3	4
Red	x y	0.690 0.310	0.595 0.315	0.569 0.341	0.655 0.345
Yellow	x y	0.522 0.477	0.470 0.440	0.427 0.483	0.465 0.534
Green	x y	0.313 0.682	0.313 0.453	0.177 0.362	0.026 0.399
Blue	x y	0.078 0.171	0.196 0.250	0.225 0.184	0.137 0.038
White	x y	0.440 0.382	0.285 0.264	0.285 0.332	0.440 0.432
Black	x y	0.285 0.355	0.300 0.270	0.260 0.310	0.345 0.395



22.5 Luminous discontinuous displays (category 1 signs)

Chromaticity coordinates of the colour domain vertices for luminous, discontinuous display, category 1 signs

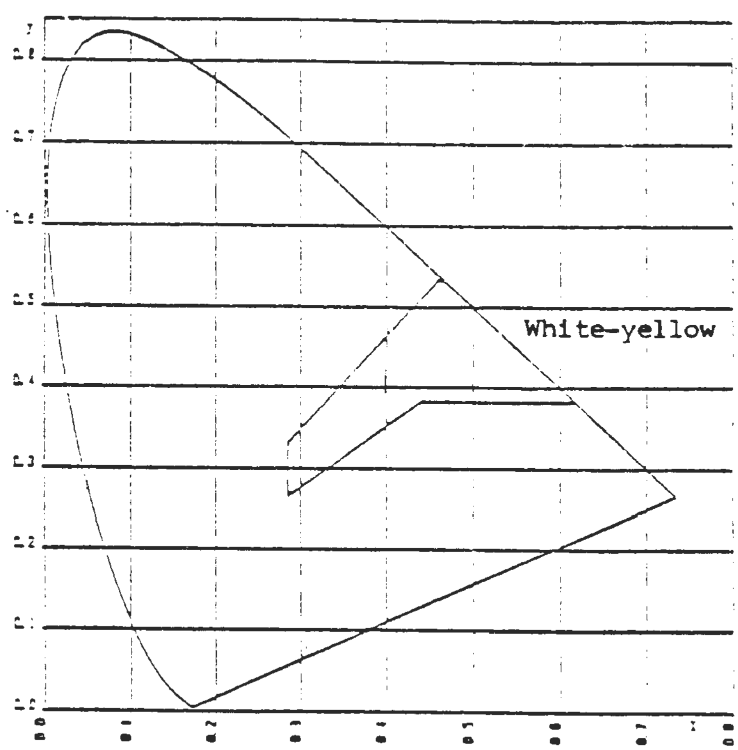
		1	2	3	4	5
Red	x y	0.680 0.320	0.670 0.320	0.728 0.262	0.735 0.265	
White-yellow	x y	0.560 0.440	0.440 0.382	0.285 0.264	0.285 0.332	0.490 0.510



22.6 Luminous discontinuous displays (category 3 and 4 signs)

Chromaticity coordinates of the colour domain vertices for category 3 and 4 signs (direction and information).

		1	2	3	4	5
White-yellow	x y	0.618 0.382	0.440 0.382	0.285 0.264	0.285 0.332	0.465 0.534



PART IV - PRELIMINARY INQUIRY AND APPROVAL TESTS

ARTICLE 23 - *Preliminary inquiry*

The preliminary inquiry will be concerned with:

- The technical and industrial facilities available and the reliability and quality of the company's resources.
- The technical and industrial potential of the company's installations as a whole.
- The existence and organisation of a quality control service and of the corresponding laboratories under the direct control of the director or manager of the factory.

ARTICLE 24 - *Laboratory tests and verifications*

The technical documents supplied by the company will be checked to confirm that they are in accordance with the requirements of the specification. Laboratory tests will be carried out to confirm that the requirements of parts II and III of this specification are met with regard to:

- The dimensions and the arrangements of the symbols.
- Weather resistance.
- Resistance to the effects of vibration.
- Mechanical strength.
- The electrical installation.
- Operation for the variations in supply voltage and frequency mentioned in article 13.
- Operation of the local control units.
- Operation of any safety systems
- The photometric characteristics.
- The colorimetric characteristics.

ARTICLE 25 - *Actual site tests*

The locations where the first 5 signs corresponding to the same technical data sheet are to be installed will be specified by SETRA. Each sign will be the subject of follow-up tests at the end of 1, 5 and 7 years. These tests will be concerned with:

- Proper operation of the sign.

- Corrosion.

- Condition of the displays.

- The photometric performance.

- The colorimetric performance.

The results of the tests must meet the minimum requirements applying to new signs as defined in parts II and III.

PART V - QUALITY CONTROL

ARTICLE 26 - *General*

The provisions of article 9 of the order of the 3 May 1978 concerning the general conditions for the approval of road signs and other equipment concerned with road safety and the use of the roads are completed by the following requirements concerning the continuous quality control to be exercised by the manufacturer and the verifications and tests to be carried out by representatives of the Administration to confirm that it is being properly carried out.

ARTICLE 27 - *Continuous quality control by the manufacturer*

The manufacturer must enter the results of the quality control exercised in his factories in the register that he is obliged to hold in accordance with the application of article 9b of the above mentioned order. This quality control will be concerned with:

- The sources and quality of the basic materials employed.

- Quality control exercised during manufacture.

- The conformity of the finished products.

(to be defined)

ARTICLE 28 - *Verifications and tests to be carried out by the Administration*

28.1 <u>Verification of the quality control being exercised by the manufacturer</u>

The Laboratoire des Ponts et Chaussées will verify that the quality of the products is being properly controlled by the manufacturer. This will be achieved by:

- Obtaining information on the conditions under which the products are being manufactured.

- Verifying that the approval conditions are being met and that the approval marks are being properly applied.

- Verifying that the manufacturer's quality control is operating satisfactorily either on carrying out repeat tests in the factory laboratory (following calibration of the measuring equipment if necessary) or on collecting samples for subsequent testing in the Administration's laboratories.

28.2 On site tests

These tests are carried out periodically for each manufacturer.

The object is to confirm that the products that have been supplied conform to those that will have been approved on the basis of the requirements of parts II and III.

In the event that the results of the tests are unsatisfactory, the replacement of defective elements and any tests carried out by the responsible laboratory will be at the manufacturer's expense.

LIST OF APPENDICES

APPENDIX 1.0

MODEL LETTER REQUESTING APPROVAL

I the undersigned (Christian name and surname)

acting as

request approval of the following products:

manufactured in the following factory (factories):

This request is accompanied by (3 copies of each item):

- A set of documents giving technical details of the manufacturer)
- A set of documents giving technical details of the product including in particular the relevant test reports.
- A certificate of committment

The following individual has been appointed to act as the company's representative in matters concerning this request for approval

Mr

whose address and telephone number are as follows:

Signature

APPENDIX 1.1

CERTIFICATE OF COMMITTMENT

Company ....

Certificate of committment

Article 1 - The signatory or signatories (christian name and surname) declare that they are familiar with:

The order of the 3 May 1978 concerning general conditions for the approval of road sign and road safety equipment and equipment concerned with the operation of the road systems.

The approval specification and its appendices.

They undertake to respect the resulting obligations for the products that they wish to be subjected to the procedure defined in the above mentioned specification with a view to their being approved, without exception or reserve.

These obligations concern in particular:

The operating conditions in the factories where the products are to be produced

The arrangements for submitting requests for approval and for the preparation and supply of the corresponding sets of documents.

The packing and marking of the products.

The factory quality control service.

The verification of the approved products.

Article 2 - The signatory certifies that:

a) The product or products for which he is requesting approval is or are produced (exclusively) by him, under his complete responsibility in the following factory or factories ....
....
....
located at ....
....
and that the company that he (directs, manages, administers) having headquarters located at...
....
is the sole owner of the said factory or factories and their dependencies as well as the equipment therein or that the said company has exclusive rights to the use and operation of the said factory or factories and their dependencies and the equipment therein.

b) Each of the factories is able to make use of its own quality control service for which decisions are taken under the direct responsibility of the (director, manager) of the above mentioned (company, undertaking).

c) The factory quality control service is provided with the necessary facilities and employs the necessary competent staff for controlling the quality of the products.

Article 3 - The signatory or signatories undertake to:

Attach sets of documents giving technical details of the manufacturer and the product to each request and for each product submitted

To provide the authorised representatives of the administration with all facilities to enable them, in the workshops, factories and laboratories concerned with the manufacture of the product, to carry out the necessary verifications for the preparation of every request for approval and in particular for the execution of the preliminary inquiry.

To pay the administration the costs defined in article 13 of the order concerning the general conditions for approval of road equipment.

Article 4 - The signatory or signatories undertake to:

Refrain from carrying out any modification to the composition of products already approved or to the arrangements employed in their manufacture before having obtained the permission of the administration.

The same undertaking applies to every request for approval for which the necessary sets of documents have been supplied.

To inform the administration of every modification carried out after the preliminary inquiry to the elements included in any of the technical, administrative, judicial or financial plans.

Article 5 - The signatory or signatories undertake not to offer for sale, as an approved product, a product having the same commercial designation and bearing the same trade mark, when it is not packed and marked in accordance with the requirements of the specification for approval and the legislation in force concerning health and safety measures.

Article 6 - The signatory or signatories undertake to ensure that the factory quality control is carried out:

As called for by the order concerning the general conditions for approval of road equipment and by the specification for approval.

On inspecting the products with regard to packing and marking.

On taking the necessary measures on completion of the verifications that are made.

On recording the results of the quality control and tests above the signature of the head of the quality control department in the documents placed at the disposal of the representatives of the administration.

Article 7 - The signatory or signatories undertake:

To provide the administration with every facility for proceeding with the verification of the approved products or for having such verification carried out on their behalf.

In the case of a dispute over the results of verifications, to accept the results of repeat tests carried out by a laboratory approved by himself and the administration.

To replace as quickly as possible and in response to a simple request by the administration any supply that fails to meet the specified requirements as revealed by the verifications that will have been made and confirmed by repeat tests if requested.

To withdraw from sale and without any other intervention of the administration any approved product coming from a lot claimed to be defective on conpletion of the verifications made by the administration and confirmed if necessary by the repeat tests mentioned above.

To reimburse the administration for the expenses incurred in carrying out repeat tests in the case of a dispute where the test results confirm the original unfavourable finding; the same expenses, in the contrary case, being met by the administration.

Read and agreed

At .... on the ....

The manufacturer

APPENDIX 1.2

SET OF DOCUMENTS GIVING TECHNICAL DETAILS OF THE MANUFACTURER

1. General information on the company

1.1 Company structure

- Name of company:
- Commercial register Nº:
- Nationality:
- Name of representative in France (obligatory for foreign countries established in a non-EEC country):
- Legal formation of company:
- Group or holding company (indicate if applicable if the company is a subsidiary one or itself has subsidiary companies):
- Headquarters (address, telephone, telex and fax numbers):
- Capital:
- Annual turnover for the last 5 years:
- Types of production and respective turnovers (or percentages of total production) and location of production units:
- Export percentage:
- Number of staff for whole company:
    - Administrative and commercial:
    - Research and development:
    - Production:
- Sub-contractors, if any:
  (names, addresses and respective activities)

1.2 References

- Refer if they exist to any quality certificates obtained for products other than those approved by the Ministère de l'Equipement et du Logement. Give the name of the organisation issuing the certificate.
- Other references if any:

2. Factory manufacturing the products for which approval is being requested

Complete for each factory:

- Name and location of factory:
- Activities of the factory (including activities other than those concerned in this request for approval where applicable):
- Surface area (covered or otherwise):
- Number of staff:
- Name of director and main department heads:
- Production capacity:
- Size of stocks and storage conditions:
- Manufacturing equipment (type, mark, date of acquisition, specific characteristics):

3. Quality control within the factory

3.1 General indications

- Organisation of the quality control (give details of the procedure employed and the attached member of staff or the service responsible for the quality control):
- Name and qualification of the person responsible for the quality control:
- Location of the quality control operations (refer where applicable to requests for a laboratory external to the factory to carry out tests and other quality control operations):

3.2 Quality control procedures and tests

- Quality control of supplies:
    - Nature (basic materials, certificates of conformity provided by the suppliers or the administration):
    - Frequency:
- Quality control exercised during manufacturer:
    - Nature:
    - Frequency:

- Checks carried out on finished products:

    - Nature:

    - Frequency:

3.3 Results of the factory quality control operations recorded in the document provided for this purpose

APPENDIX 1.3

SET OF DOCUMENTS GIVING TECHNICAL DETAILS OF THE PRODUCT

A set of documents must be provided giving the following technical information for each product or range of products being submitted for approval:

- Description and reference Nº of the sign.
- An indication as to whether it is a prototype, a pre-production or a production version.
- Where applicable the number of units sold over the last 3 years as well as the date when the product was first placed on the market.
- A plan of the front face.
- A description of the cooling systems.
- A description of the means for fixing the sign in place.
- Descriptions of component parts of the sign and details of their origins.
- References to paints and other protective products employed.
- Identification of the different options available.
- Electrical power consumption.
- Instructions for use.
- Maintenance instructions.
- Proposed identification marking (see appendix 2.0).
- Test report.
- Technical data sheet corresponding to the attached model which will accompany the approval certificate when the latter is delivered.

VARIABLE MESSAGE ROAD SIGNS

PROPOSED TECHNICAL DATA SHEET - MODEL

Prepared as part of Edition 5 of the specification for approval of the signs

Date: Company:	PRODUCT - Description: - Classification:

TECHNICAL CHARACTERISTICS

- Principle of operation:
- Capacity:
- Enclosure:
- Display elements:
- Safety features:
- Control units:
- Electrical power consumption:

TEST RESULTS

- Tests carried out by:
- Symbols:
- Colour
- Brightness classification:
- Effective viewing angle:

MAINTENANCE

- Preventive maintenance recommended:
- Miscellaneous:

APPROVAL MARKING

-Identifying marking:

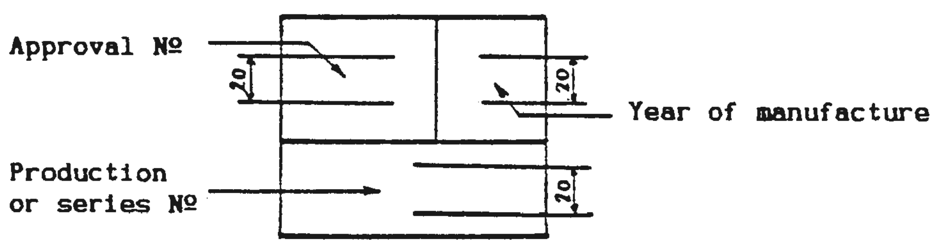
APPENDIX 2.0

APPROVAL MARK

The approval mark on accepted signs must be provided on the back of the equipment as a permanent inscription and bear the following information:

- The approval number for the product.
- The year of manufacture (last two figures).
- The production or series number.

Each figure or letter must appear in a frame and be not less than 20 mm high.



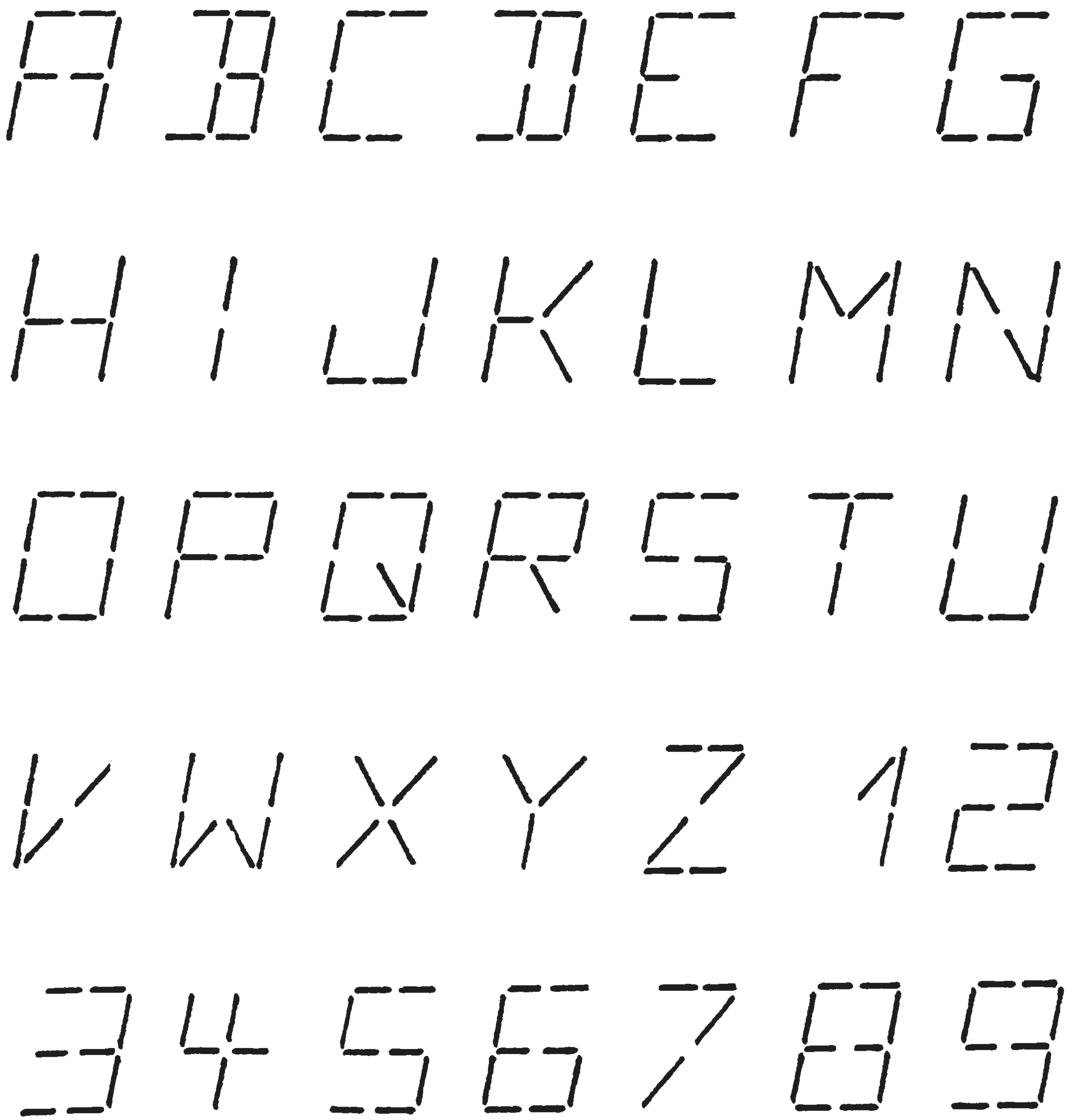
Standard marking

APPENDIX 3.0

AUTHORISED ALPHA-NUMERIC CHARACTERS

5 x 7 matrix characters

ASCII 16 segment characters



APPENDIX B

Translation from German, November 1990

The Federal Minister of Transportation
(West Germany)

GUIDELINES FOR VARIABLE MESSAGE TRAFFIC SIGNS
ON FEDERAL INTERSTATE HIGHWAYS

May 1984 Edition

Content

1 Definitions

(1) Variable Message Traffic Signs (VMSs) are traffic signs that can be shown, changed or turned off when required. They are tools of traffic control with the purpose of regulating the flow of traffic by means of suitable instructions, prohibitions, warnings, and information, or by re-routing traffic in changing weather conditions and fluctuating traffic volume.

(2) The physical devices by means of which VMSs are presented are the Variable Sign Devices (VMSDs). They are only that part of the VMS system visible to the public. The total system consists of the following components:

- devices for data collection and information gathering concerning traffic volume and prevailing environmental condition
- incoming transmission of collected data and outgoing transmission of control commands
- setting up and running of control command programs
- information to the travelling public

Depending on size and capacity of the installation, traffic is controlled

- in a closed loop (i.e., signals are controlled automatically by the computer)
- in an open loop (i.e., the signals are controlled semi-automatically by the computer, leaving command decisions to an operator)
- manually (i.e., without computer; however, data collection and transmission devices may be employed).

Purely manual controls should only be used under exceptional conditions.

2 Areas of Application

(1) The present guidelines are to be used during the planning stage, during installation, and in the operation of traffic control installations with VMSs on Interstate Highways. They are primarily applicable outside city limits.

(2) In addition to these guidelines existing applicable regulations must be observed during installation and operation of Variable Message Traffic Sign Installations (VMS systems), i.e. the Federal Traffic Regulation (StVO) with the corresponding Administrative Regulation (VwV-StVO), the recommendations and regulations of the DIN (Deutsche Industrie Normen; i.e., German Industrial Norms), of the VDE (Verband Deutscher Elektrotechniker; i.e., Society of German Eletro-Technicians), etc.

(3) Basic descriptions concerning VMSs as a means of traffic control, and descriptions concerning technology, problems and questions of economics of installation and operation, and discussions concerning planning can be found in the publication:"Discussion for the Application of Variable Message Traffic Signs (HAW)" [Hinweise für die Anwendung von WVZ (HAW), published by: Forschungsgesellschaft für Straßenwesen, Cologne 1976].

3 Selection of Design

3.1 Types of Design

(1) Depending on the design the following types are to be differentiated

- mechanical VMSDs
- electrically illuminated VMSDs

(2) *Mechanical* VMSDs can show the traffic signs of the Traffic Regulations (StVO) in any size, and accurately according to form and color. They can be lighted either from the outside or from the inside depending on type of design. Among the many possible types, the following should normally be used: prism types, disk types (slit disk), and band types. For VMSs with sizes greater than those of standard traffic signs, those built according to the prism principle should be used.

(3) For *electrically illuminated* VMSDs only the matrix type is to be used. Fiber optic technology is mandated, whereby the picture is constituted of optically formed end points of fiber optics as a matrix (so-called light matrix signs, or matrix signs). Traffic signs may, when technically required, be only set up as black-and-white reversible; otherwise they should follow the colors given in the illustrations of the StVO regulations. They are officially mandated in this manner (see § 39, sect. 1 StVO).

(4) In case both mechanically operated and electrically illuminated types are used, it must be expected that one of the types will dominate over the other so that the quality of the total presentation will be impaired. Therefore, such mixing of types should be used in exceptional cases only.

(5) Switching times for changing signs range between 2 seconds and 20 seconds for mechanical signs; this should be considered in the planning stage. In case of electronically operated matrices, switching times are less than 1 second and may be disregarded.

3.2 Criterion for Deployment

(1) VMSs within traffic control installations should be executed identically within uniform areas of application. This applies especially for the equipment in contiguous road sectors. A uniform design is not only necessary to assure a uniform appearance for

drivers in a particular traffic area, but also for economic requirements of standardization, maintenance, replacement parts, etc.

(2) In choosing a particular design, and when the design for the installation is finally determined, it becomes necessary to consider whether certain pictures of traffic signs should be retained or have to be switched back on when there is a power failure, or when the power supply to a particular sign is otherwise interrupted. Some mechanical VMSDs can switch into a default position. With all other types, a desired predetermined position can be switched on with an auxiliary power supply, a battery buffer, or the like. Because of the considerable financial investment in such an installation, particularly for matrix signs, it will have to be determined in each individual case whether an auxiliary power supply is absolutely necessary. In particularly urgent cases, additional VMSs can be set up which, in case of power failure, are automatically put into a defined position.

(3) During the control of traffic flow along a certain sector (i.e. lane access control), for example,

- traffic control with sector specific information or prohibitions
- warning signs in case of traffic jams
- warning signs under inclement weather conditions

matrix signs are usually to be employed. This is applicable in all cases especially when a high degree of efficacy is imperative with short term application and a high degree of visibility.

(4) During traffic control by detour signs and signals when traffic has to be redirected (variable message road signs), prism switches are to be employed as mechanical VMSDs.

(5) For traffic control at merging points where mandatory redirection applies, mechanically effective sign types should be used as a rule, provided they fit into the sign installation already present.

4. Criteria for the design of street signs

(1) Signs and symbols are to be designed according to prevailing regulations. The pictures of official traffic signs (shape, color) must not be changed in any significant way. In the depiction of letters, DIN 1451 (German Industrial Norm 1451) is to be used. With matrix signs, only the center line of the letters is to be shown as a continuous line.

(2) With matrix signs, the background is to be black. In order for the signs to be clearly visible even in bright daylight, the black background area has to be sufficiently large in relation to the whole picture; if necessary, the total surface has to be enlarged beyond the actual matrix. In order to enlarge the signs optically, and in order to

make them more easily recognizable at the roadside, light matrix signs will always have a black contrast blind with a white border.

(3) *Appendix 1* contains a summary of those standard traffic signs with mechanical and with illuminated electronic VMSDs that are the most essential. The dimensions are to be selected from *table 1* (regulation sizes). On Federal Interstate Highways, the use of oversized letters is advisable, for instance in the case of signs at three-lane sectors where the signs are installed in a somewhat oblique fashion. Minimum sizes and other sizes than those stipulated as regulation sizes may be used only in exceptional cases.

(4) Letters and signs of the *substitutive Variable Message Road Direction Signs* are the same in visual appearance as the usual fixed road signs. If they are set up along Federal Interstate Highways, they must be designed according to the "Guidelines for Direction Signs at Federal Interstate Highways" (RWBA). For all other roads, instructions can be found in the "Pamphlet for Road Signs other than Freeways." This pamphlet deals with the information content, graphic design, as well as the dimensions of the signs.

(5) The signs of the *additive Variable Message Road Direction Signs* are to be designed as white retro-reflective signs with black rim; destination designation and arrows are in black, the detour arrow in orange. For the design of the signs (size, lettering, arrows, etc.), the regulations given in the RWBA are to be followed as far as applicable. Inserts with symbols for additive variable message road direction are illustrated in *appendix 2* of this guideline.

(6) Particular attention is to be given to the following conditions:

- VMSs must be set up in such a way that drivers can recognize and read the signs in time.

- VMSs normally must be visible outside of towns at a distance of 200 m; at this distance it should also be clearly visible what type of sign it is: warning, regulation, or information sign.

- the specific content of the sign (e.g., the type of danger, instruction, recommendation, or text, etc.) should be clearly legible at a distance of 150 m. Additional signs should be legible at a distance of 75 m.

- The visibility of the contents of matrix signs depends on the angle of vision. Signs outside of settled areas should be visible up to a distance of 35 m before they become illegible because of the angle of vision.

(7) These rules are also to be observed when setting up VMSDs
(see section 7).

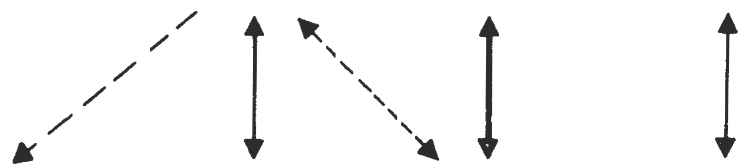
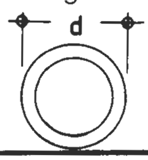
Signs	Regulation Sizes Supersize	Oversize	Normal Size	Minimal Size
Warning Sign 		sl = 1250	sl = 1050	sl = 900
Possible Combinations				
Regulation Signs 	d = 1200	d = 1050	d = 900	d = 750
Possible Combinations				
Height of Letters for Additional Signs		h = 210	h = 210	h = 175
Height for Other Texts		h = 490	h = 420	h = 350
Measurements in mm. Broken lines indicate "only use in exceptional cases".				

Table 1. Measurements of Standard Variable Traffic Signs

5 Electronic Requirements for Lighting

5.1 Variable Message Traffic Signs without Lighting

VMSs without lighting must be retro-reflecting. Colors and light density factors must comply with DIN 6171, section 1: "Surface colors for traffic signs, colors and color limits in daylight conditions." The reflection values of the retro-reflecting materials must comply with DIN 67520, section 2: "Retro-reflecting materials for traffic safety. Minimal requirements for reflecting materials on traffic signs for street traffic." Only materials approved by the Federal Minister of Transportation may be used. Application of types 1 and 2 according to DIN 67520, section 2 is regulated by the ordinance St B13/Stv12/ 38.60.65 -30.07/13022 NS 79 issued by the Federal Minister of Transportation of October 10, 1979.

5.2 Illuminated Variable Message Traffic Signs

(1) Illuminated VMSs are traffic signs with individual illumination. Depending on the type of equipment used, they are either lighted externally, or internally (transparent). For illuminated VMSs, the technical identification are contained in DIN 67521, section 1 "Evaluation of Electronic Illumination of Street Signs. General Remarks", and DIN 67521, section 2 "Evaluation of Electronic Illumination of Street Signs. Signs for Street Traffic."

(2) Externally lighted VMSs are to be made of retro-reflective materials just as those specified for signs without lighting. For these materials the directions and guidelines of section 5.1 are applicable.

(3) Internally lighted VMSs with a total surface of more than 3 m^3 have to comply with the "Preliminary Electronic Guidelines for Internally Lighted Oversized Traffic Sign on Interstate Highways." When electric illumination is used under night time conditions colors of the VMSs have to comply with DIN 6163, section 1 "Colors and Color Limits for Light Signals. General Remarks."

5.3 Light Matrix Signs

(1) Form, size, and intensity of the signs are determined by the need to avoid glare and physiologic blinding under all conditions. For the design of the lettering in a matrix it must be considered that the optically effective dimensions of the numbers, letters, and symbols on the matrix are enlarged by glare while the distances between them are reduced.

(2) In order to obtain the optimal degree of readability at night as well as at daytime, and in order to avoid blinding and glare, a day/night switching should be provided for. The reduction of light intensity during the night is obtained by reducing electric power, and/or by turning off some of the light bulbs. A suitable choice of the light intensity distribution curve can result in excellent readability and will reduce glare and blinding to a minimum.

(3) Colors have to be within the recommended specifications in DIN 6163, section 1.

(4) Reflected "phantom" light (colorless light reflected on the front of the matrix originating from an outside light source) must be controlled by an appropriate window pane (acrylic, or polycarbonate), and/or by flat black blinds about 30-40 cm deep.

6 Technical Specifications

6.1 Signals

(1) The "General Requirements for Approval of Traffic Signs on Interstate Highways" circulated by the Federal Minister of Transportation in a memorandum to the head offices of the road construction departments of the "Länder"[the individual German States of the Federal Republic] (AZ. StB 4/12/16 - 70.22.01/4009 V72 dated June 6, 1972) are applicable also for VMSs, provided the current Guidelines do not explicitly state any deviation.

(2) The signals are those physical parts of the VMSD that carry the individual information signs. These signals are, for example, revolving prisms, revolving surfaces, moving bands, matrices, etc. Signals in WXGs must be smooth, flat, without wrinkles, resistent to abrasion, resistent to UV exposure, and they must be mounted in such a way that they are clearly visible. Enclosures, prisms, and other moving parts must be designed and installed to assure trouble free operation.

(3) Size and distance of the light points on light matrix signals must be suitable to assure clear and unambiguous legibility of the information.

(4) Regulation signal lamps 10 V/50 W or 42 V/65 W are to be used for light matrix signals. They are to be installed in mountings that reduce vibration.

(5) The function of light matrix signals has to be assured even in case of lamp failure. Failure must be automatically signaled to the control center. For each lamp (main lamp) a back-up lamp has to be provided that will be switched on automatically in case of failure. In case conditions do not permit the installation of back-up lamps, care must be taken that the overall sign must still be clearly legible even when an individual lamp should fail. Any possible corruption of the information on the sign must be prevented by appropriate control switches. Whenever bids for light matrix signals are published, a full back-up system for the lamps is to be specified unless expressly stated otherwise.

(6) Suitable provisions must be made to ensure the information carrying devices of mechanically operated VMSDs are securely locked in place so that they do not get stuck half-way when malfunctioning should occur.

(7) Signals should be selected, designed, and constructed in such a way that, even in case of power failure or a malfunctioning of the controls, the signals are fully

functional and legally acceptable in the prevailing traffic situation by switching on or maintaining an appropriate sign. When the failure has been corrected, the installation should automatically return to its normal function without manual re-switching on location.

(8) The enclosures of VMSDs are to manufactured of aluminum or UV-resistent plastic material with the color "Grey"(RAL 7042). They must have a protective coating (IP 54) against water splashes from the road. The insides of the enclosures of light matrix signs are to be painted in flat black. The inside surface must not reflect light. The enclosures must be reinforced so that they can be installed on sign bridges, sign posts, or tripods. Light matrix signs must have a provision to re-direct the signs on all three levels. For this a swivel device is to be used. For direction signs the usual design regulations are to be followed.

(9) Installations requiring maintenance or that must be replaced at regular intervals should be easily accessible. Trap doors should be fastened by hinges like doors only to prevent falling, or they may be secured in some other manner. These trap doors are to be designed to be opened only with special tools.

(10) To prevent water condensation and temperature build-up, vents with insect screens should be provided for. To insure trouble free functioning even at freezing temperatures, a heater controlled by thermostat must be installed.

6.2 Switch Board Boxes

(1) The electronic design has to follow the appropriate DIN and VDE specifications. Particularly to be observed are: VDE 0100, 0800, 0804 and DIN 57832/VDE 0832.

(2) Appropriate measures against lightening must be taken. Particularly, the electronic switches, controls, and the transmission devices have to be protected.

(3) All installations have to be supplied with high voltage protection according to VDE 0100,0800, and 0845.

(4) Switches, control panels and other electronic devices must be installed free of radio interference according to VDE 0875.

(5) Power supply, control panels, switches, and devices for remote control are to be galvanically separated.

(6) The installations have to be operationally safe under climactic conditions specified in DIN 57832/VDE0832.

(7) Other matters to be considered for all parts of the installation:

- condensation inside

- heavy pollution of the surrounding air by dust, smoke, corrosive particles, steam, salt, water spray from vehicles on the road
- effects of excessive heat, for example, by sun radiation, and heating of the road bed; temperature inside the box up to +80°C (176° Fahrenheit)
- influence of botanical or animal organisms
- lightning
- precipitation of all kinds

(8) In addition to temperature effects due to climactic conditions, heating due to operational action must also be considered.

(9) Prism drives for oversized VMSDs (>1.5 m^2) are to be designed in such a way as not to produce a strong jerk at the start and at the end of the turning motion when operated.

(10) VMSDs are to be installed to assure trouble free operation even after prolonged periods of disuse.

6.4 Electric connections

(1) VMSDs are connected to the switch boxes by easily removable extension cables so that the signs can easily be replaced. During repairs they have to be detachable for the power outlets.

(2) VMSDs are to be operated with low voltage safety power, or with 220 V AC. When selecting a particular power supply, attention must be paid to the requirements of the equipment.

(3) In case feed-back messages emanate from the VMSD, insulated connectors have to be inserted.

(4) In case switches are encased within the signal box and these are operated over control cables, low voltage power supply is to be preferred.

(5) The outlets for the power supply as well as the outlets for the control cables and signal transmission have to be clearly identifiable. They must be dustproof and waterproof (protection type IP 65 according to DIN 40 050), and they have to be arranged in such a way that they cannot be damaged during transport.

(6) The outlets for VMSDs must be clearly marked. It is advantageous to provide reserve outlets in case of malfunction or for additional signals to be added later.

6.5 Directives for the bidding process

(1) For the announcements of bids to be submitted for VMSDs as well as for control and switch panels, the following warranty periods are required:

- electronic parts 1 year

- mechanical parts 2 years

7 Arranging Variable Message Traffic Signs at Roadside

7.1 Standard Traffic Signs

(1) In case more than one sign is to be shown simultaneously with a VMSD a suitable choice must be made whether two separate signs should be used, or one common sign of an appropriate size (see illustration 1-3). Whether an integrated design for several simultaneous signs is to be used depends on the particular purpose, and on the construction of the signal. Requirements for maintenance and repair must also be taken into consideration.

(2) Only those combinations of VMSs may be used that are permitted by the appropriate ordinances of StVO and VwV-StVO.

(3) VMSDs are installed normally by the side of the road, and in case of multi-lane one-way highways always on both sides of the road. In case of 4 or more lanes in a given direction, signs are to be installed overhead on sign bridges even when the signs are not lane specific. This is also recommended for three lane roads when there is a chance that signs at roadside may be hidden by moving vehicles, or when signs by the roadside do not offer unambiguous information, or when the median is too narrow.

(4) Whenever information is to be lane specific (e.g., when different lanes require different instructions), the overhead installation of signals for every lane is to be considered for the original installation.

(5) Mechanically operated VMSDs are set up at right angles to the direction of traffic. Light matrix signals have to be directed towards a point at which the sign should be recognized. The reference point is the medium eye level of the driver (height: 1.20m), and a distance of 0.90m from the left stripe of the lane for installation at roadside right, and for the passing lane for installation at roadside left (see illustration 4).

(6) When light matrix signs are installed at bends in the road, good visibility is of primary importance (see section 4).

(7) Light matrix signs on signal bridges must be installed in such a way that they are directed at a point of recognition 150m from the signal bridge and at a height of 1.20m in the center of the lane (illustration 5).

(8) For the arrangement of the VMSDs across a street, the regulations of the VwV-StV and the RWBA are to be observed with respect to the horizontal distances between signs and the vertical clearance over the street.

7.2 (Remains Open...)

7.3 Distances between Variable Message Traffic Signs

(1) The distances between the signs depend on the type of traffic control, the road and traffic conditions at a particular location, traffic density, and possibly other parameters. Even though distances between signs will have to be determined separately for each traffic control situation, a certain standardization of basic distances should be sought. For freeways the following guidelines should apply:

- approx. 1000-2000 m for contiguous installation of street sections. For warning sign equipment (e.g., in case of dangerous weather conditions. As a rule, these distances should be sufficient.

- approx. 500-1000 m for speed controls when speed signs are set up before particular danger zones (e.g., traffic congestion).

(2) As a rule, minimum distances between VMSDs must be wide enough so that only the VMS of the following road sector is legible; this is generally attainable for intervals of more than 300m. For the VMSs at ramp intersections, the particular conditions of ramp alignments and the direction of traffic flow must be considered.

(3) Special attention has to be paid at intersections to the traffic entering the freeway which must be informed of the VMS contents currently valid for the through lanes.

7.4 Installation of VMSs in connection with other traffic signs

(1) VMSs always have to be adjusted to the fixed signs already in place at a location. Signs already in place and newly to be installed VMSs must be clearly recognizable and should not compete with nor contradict each other. Information content of signs already in place must be accounted for during the planning stage for VMS systems location and position.

(2) Whenever necessary, present signs must either be changed, or completely replaced by the new installation. As a rule, a complete and integrated design plan should result at the conclusion of the planning stage.

(3) Whenever VMSs are employed in their function as "additive," in other words, if they are used in combination with an already present fixed set of signs (e.g., in case of traffic detours on alternate routes by means of variable direction signals) special consideration must be given to "sign competition" in the planning stage. This situation is accounted for in the design of variable additive direction signs and their integration into sign installations already present. (see appendix 2).

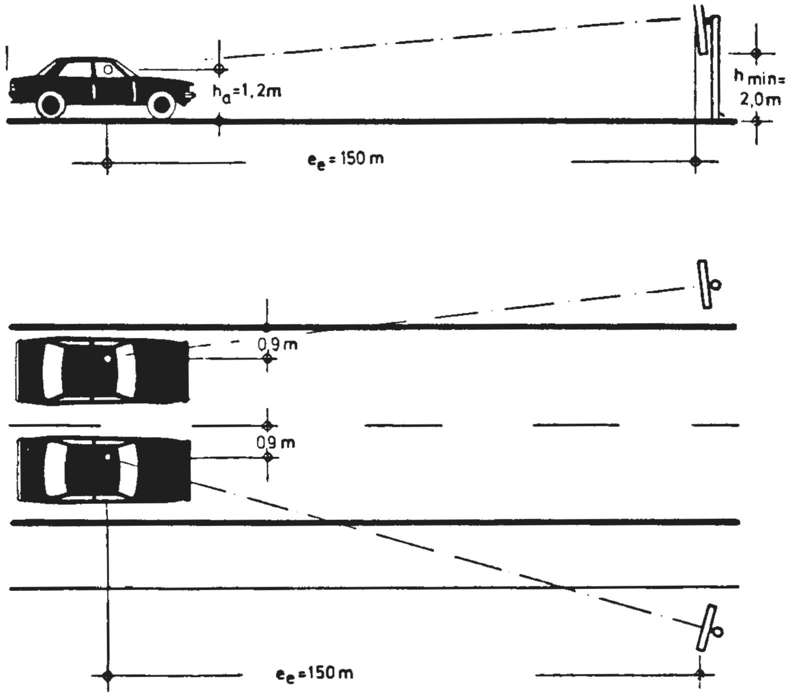


Figure 4. Oblique Positioning of Light Matrix Signs

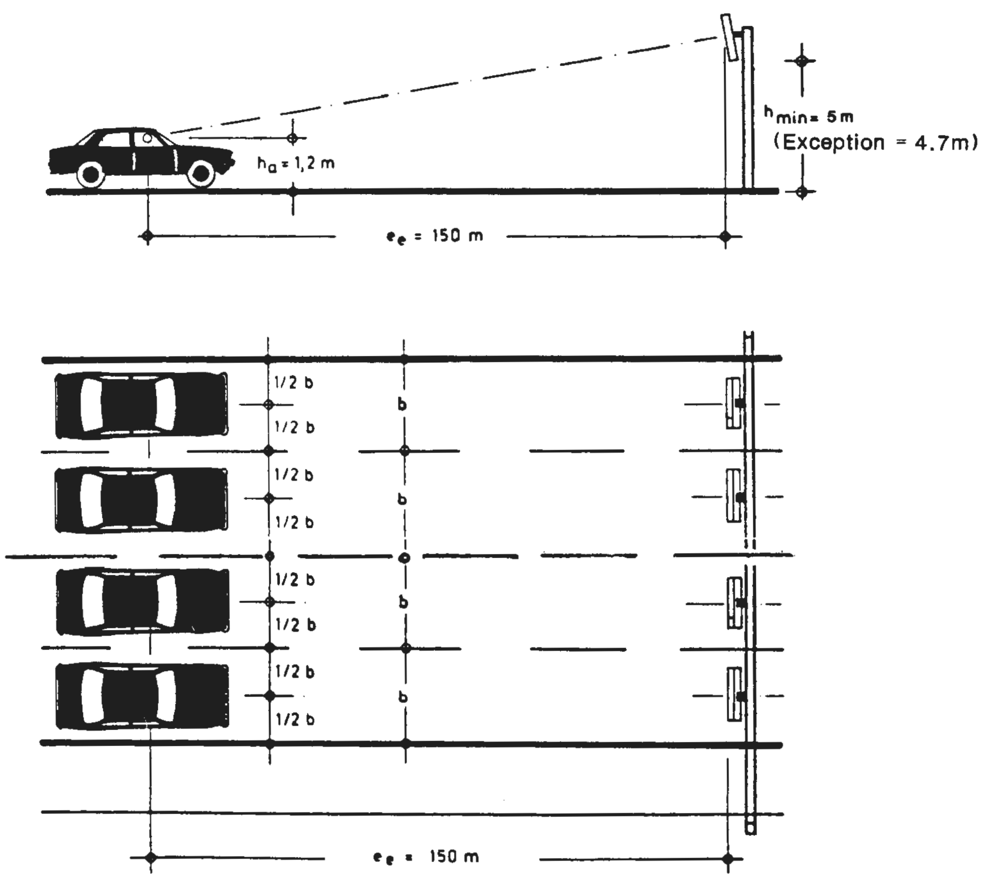


Figure 5. Light Matrix Signs On Signbridges

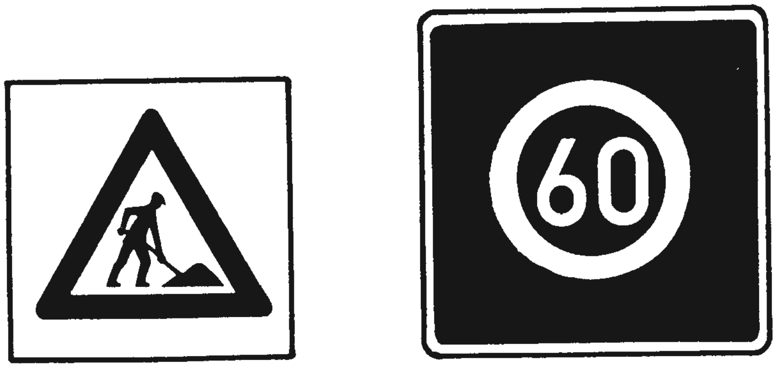


Figure 1. Single Field Signs

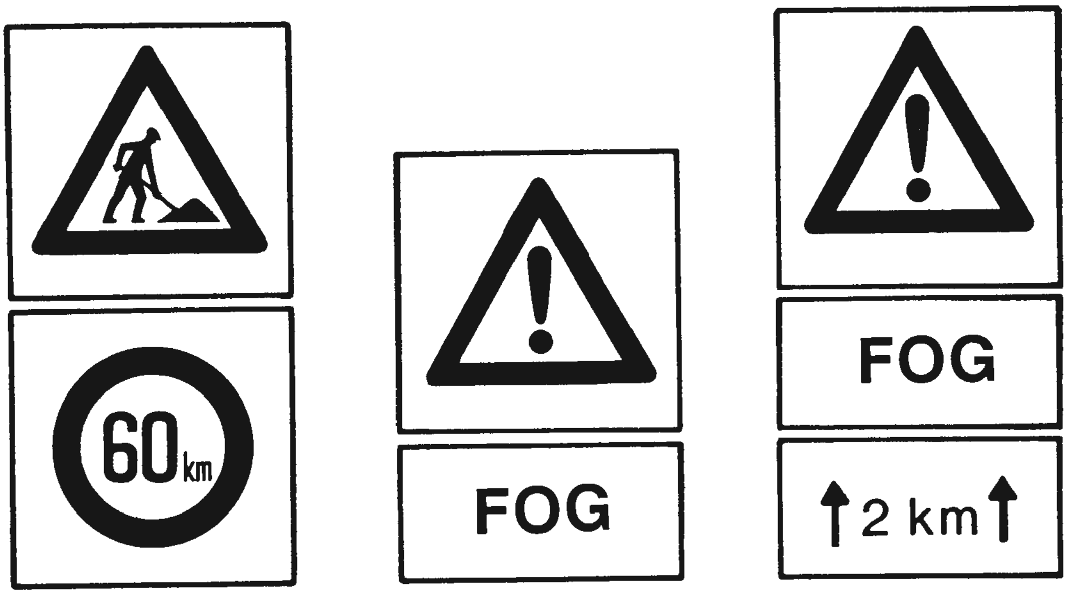


Figure 2. Combination of Single Field Signs

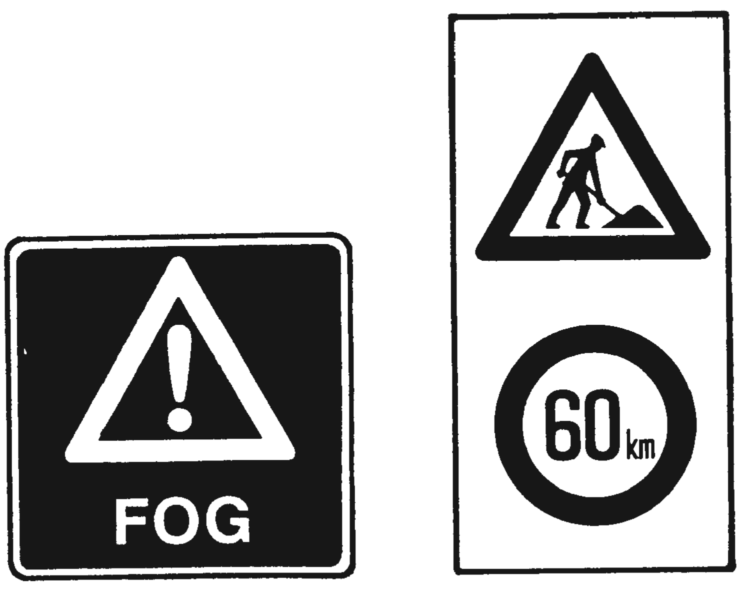


Figure 3. Multiple Signs

8 Operation of Variable Traffic Equipment

8.1 Basic Equipment Requirements

(1) For fully automatic or semi-automatic operation of a VMS system, the following requirements apply as a rule (see also HWA):

- VMSDs with additional control panels in place locally
- data collection systems for traffic and/or other conditions
- transmission equipment for command signals, control signals, and data collection
- control panel and survey installation.

(2) The equipment is to be built up with modules in order to facilitate maintenance and repair. The same goes for all other parts of the installation.

(3) Should a particular VMS system be operated manually, certain parts of section (1) above may be deleted. In that case appropriate measures must be taken to make sure that the operations of the VMS systems are adjusted suitably and in time to prevailing traffic and/or environmental conditions.

8.2 Data Collection

(1) The data collection system must be adjusted to the intended function of the VMS system, to the particular control type, and, if necessary, also to the distances between the VMSs so that the system can furnish the required data. The sensors must be installed at locations critical for the control operations.

(2) Measuring systems have to be backed up with sufficient redundance for self-control and detection of measuring mistakes.

8.3 Signal Transmission Systems

(1) The transmission system for control signals must be adjusted to the individual VMS system. It has to be designed in such a way that it will assure sufficient capacity, a high degree of operational safety, as well as cost-efficiency of the entire installation and its maintenance.

(2) The signal transmission system has to be designed in such a way that the VMSDs can be operated also from a regional location (e.g., a regional control center). In exceptional cases the regional center should be capable of entering into the operation and run its own programs. Moreover, manual operation on location

should be possible in any case, and with absolute priority. The direction of the information flow must not be influenced by this priority switching so that the main control center as well as the regional control centers can receive information signals as much as necessary.

(3) For the secure transmission of control and information data a type of encoding should be used that permits recognition of errors. In order to secure the transmission routes one channel of the transmission line should be loaded with an additional pilot signal that can be controlled from the receiving end. When power is shut off the signal carrier itself may serve as pilot signal.

(4) Size and capacity of the transmission equipment and channels are determined by the amount of information that needs to be transmitted as well as by the demands on the entire system at peak periods. Number and function of the connected VMSDs, of the data collection centers, and possible reserve capacities as well as malfunction and control information determine the volume of information.

(5) In order to save on transmission channels a reduction of collected traffic data should be implemented at the original location of data collection. The picture of the traffic situation and the environmental conditions that have been obtained from the reduced data must, however, describe conditions with sufficient precision to answer the demands of effective control.

(6) For reasons of economic efficiency, the transmission of control and information data must frequently be carried out over the lowest possible number of lines. When information volume is low, systems with multiple frequencies are available. By dividing the frequency range of normal transmissions into several frequency channels, parallel data transmission is made possible. If greater volumes of data transmission have to be accommodated, timed impulse staggering of the data telegrams can utilize multiple sound frequency channels.

(7) Capacity and security of operation are essentially determined by the choice of transmission channels for control and information data. If telephone lines are available ("Ausa"-network, or lines of the Federal Post Office) 600 Baud can be used. Bit error frequencies up to 10^{-6} are to be expected. Transmitter and receiver equipment must adhere to the regulations of the German Federal Post Office. Transmission lines and equipment must also be approved by the Federal Central Office for Telephone and Telegraph Service (FTZ) when lines of the Post Office are used, and by the Federal Railway Central Office when lines of the Federal Interstate Highway System (BZA) are used.

(8) Whenever possible, distances should be differentiated; designated as short lines (cables) are those up to 30 km in length, long distance lines are those over 30 km. For transmission over short distances non-pupinized cables are advantageous because such cables are accessible at any particular sector of the road. In case of VMS systems covering a large area, however, it is better to use pupinized cables in order to increase the transmission range for the data signals. When VMS systems (e.g., VMSDs and data collection installations) are linked up with BAB long distance

cables, the interconnection cables should be kept as short as possible to avoid transmission interference. The length of linking cables should not exceed 120 m.

(9) In case present cables do not have sufficient transmission capacities for a VMS system, decisions have to be made about the types of cables to be laid with all due consideration to the total cable capacities under full load. In case of a new cable installation sufficient back-up and reserve capacities should be provided so that later installations of traffic control equipment such as survey and measuring instruments, VMSs, and the combining of individual VMS systems into larger systems are made possible.

8.4 Operating and Control Equipment

Central operating and control installations have the function to evaluate traffic and environmental data, to generate switch commands for the individual VMSs, and to supervise the operations of the installation in its entirety. To carry out this function at least the following items are normally required

- a traffic display panel showing the current traffic and/or environmental condition, the status of the VMS, and the areas of malfunction
- keyboard or switch board for manual control of the VMS
- computer containing a data bank for data processing, and for operation of the whole installation according to a given program
- installations for recording of the switching operations and for the storing of other important data documentation.

(2) The display screens must be designed in such a way that the operator can easily and quickly see the information about traffic and environmental conditions, as well as the current status of the installation. Indirect status information about the VMS is not permissible.

(3) The equipment is to be secured against unauthorized use, or accidental operations. With the appropriate locks inadmissible signal combinations must be precluded. With appropriate programming the coordination of mutually independent signal operations has to be assured (e.g., by temporal staggering of indicators, and by the set-up of traffic flow regulators).

(4) Operations of VMS systems can be controlled in these manners:

- fully automatic
- semi-automatic (closed loop)
- manually.

Normally, fully automatic systems should be used. It may be advantageous to use manual or semi-automatic controls in some cases as a preliminary stage, or during the construction of a fully automatic system. Such temporary solutions of urgent traffic problems employed when the planning and construction of a fully automatic system takes an inordinate amount of time. In case automatic operations cannot be carried out from the start for technical or economic reasons, one should consider if it is not possible to make at least some preparations that will be necessary for the later incorporation of a fully automatic system.

(5) For the control center, suitably trained personnel must be available. The operators must be able and authorized to supervise the installation, to make decisions in case of malfunctions, and to take the necessary measures. In case this is not possible for technical or organizational reasons, appropriate measures must be taken to supervise the VMS system from another location (another control center nearby, or a regional control center). For this the necessary control equipment must be provided for, as well as equipment for information transmission (telephone lines, etc.), and the appropriate facilities to take action if necessary. At the planning stage for VMS systems, personnel requirements must be investigated.

8.5 Maintenance

(1) VMS systems must be regularly serviced in order to prevent malfunction. The type, extend, and frequencies of the required servicing and maintenance operations must be described in detail and furnished by the suppliers. In case the installation has to be shut down during servicing, such times should be chosen for servicing when, according to experience, the installation does not have to be in operation.

(2) Administrators have to be familiar with the installation of a VMS system at least to the extent that they can judge the extent of the maintenance requirements so that they can coordinate the servicing of the installations. They have to know the measures to be taken in case of malfunction.

(3) Maintenance of a VMS system can mean a considerable financial burden. It should therefore be considered for economic reasons, whether simple maintenance procedures such as changing of lamps and bulbs on matrices, testing of functions etc., should be carried out by personnel of the Highway Department, or whether these services should be turned over to contractors.

(4) As a rule, service contracts have to be awarded. For technically contiguous installations, maintenance should be handled by one contractor. Exact determination of the area to be serviced becomes of prime importance.

(5) The operational regulations to be applied are: DIN 87832/VDE 0832.

The Federal Minister of Transportation

GUIDELINES FOR VARIABLE MESSAGE TRAFFIC SIGNS
ON FEDERAL INTERSTATE HIGHWAYS

APPENDIX 4
(Partial)

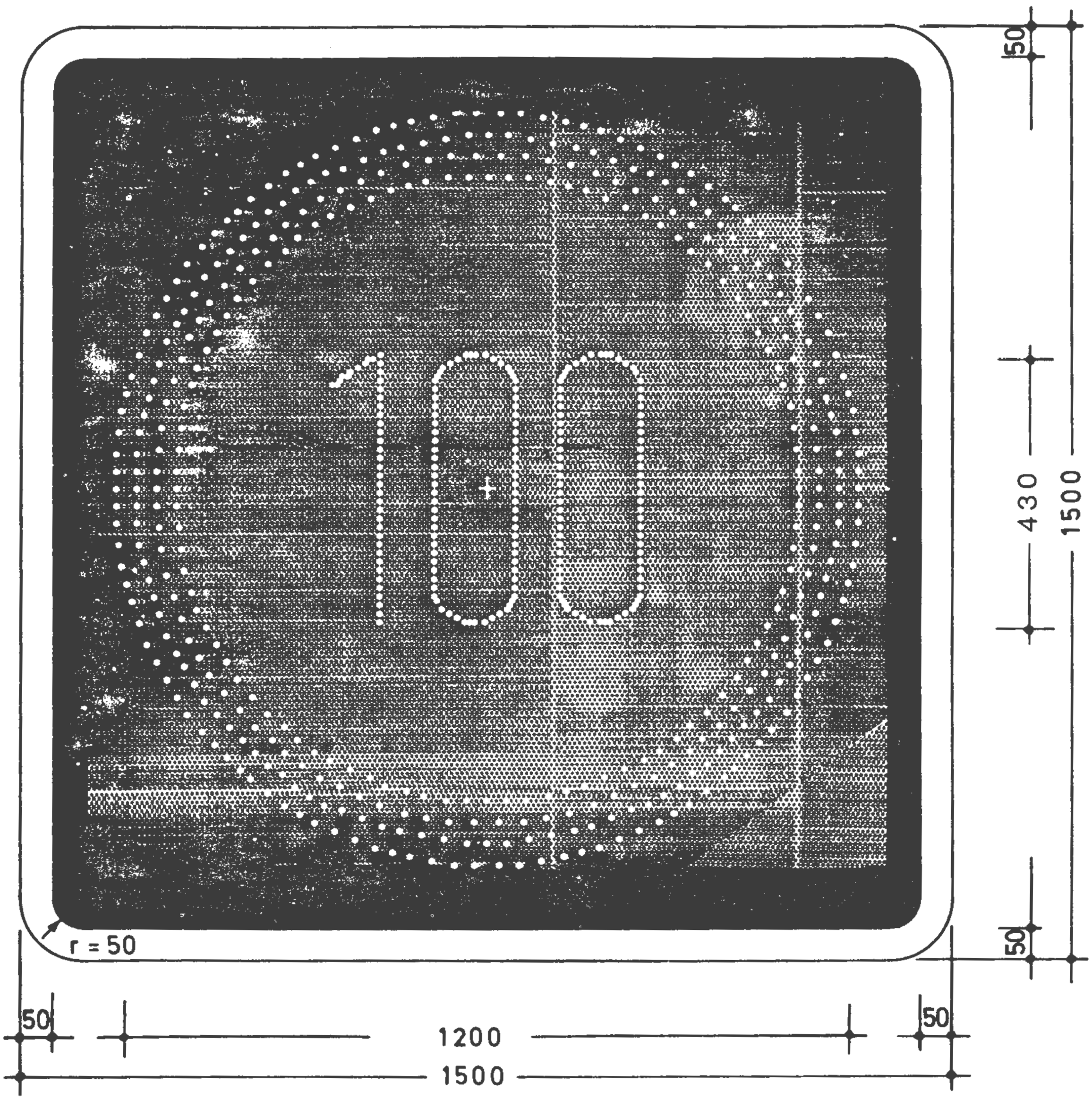
Matrix Signs, Design Samples

MAT 1: Super Size
MAT 2: Over Size
MAT 3: Normal Size
MAT 4: Minimum Size

May 1984 Edition

RWVZ Supplement 4	MATRIX SIGN Z 274 "100" SUPERSIZE	MAT 1 Plate 4a Date: 5/84

SAMPLE



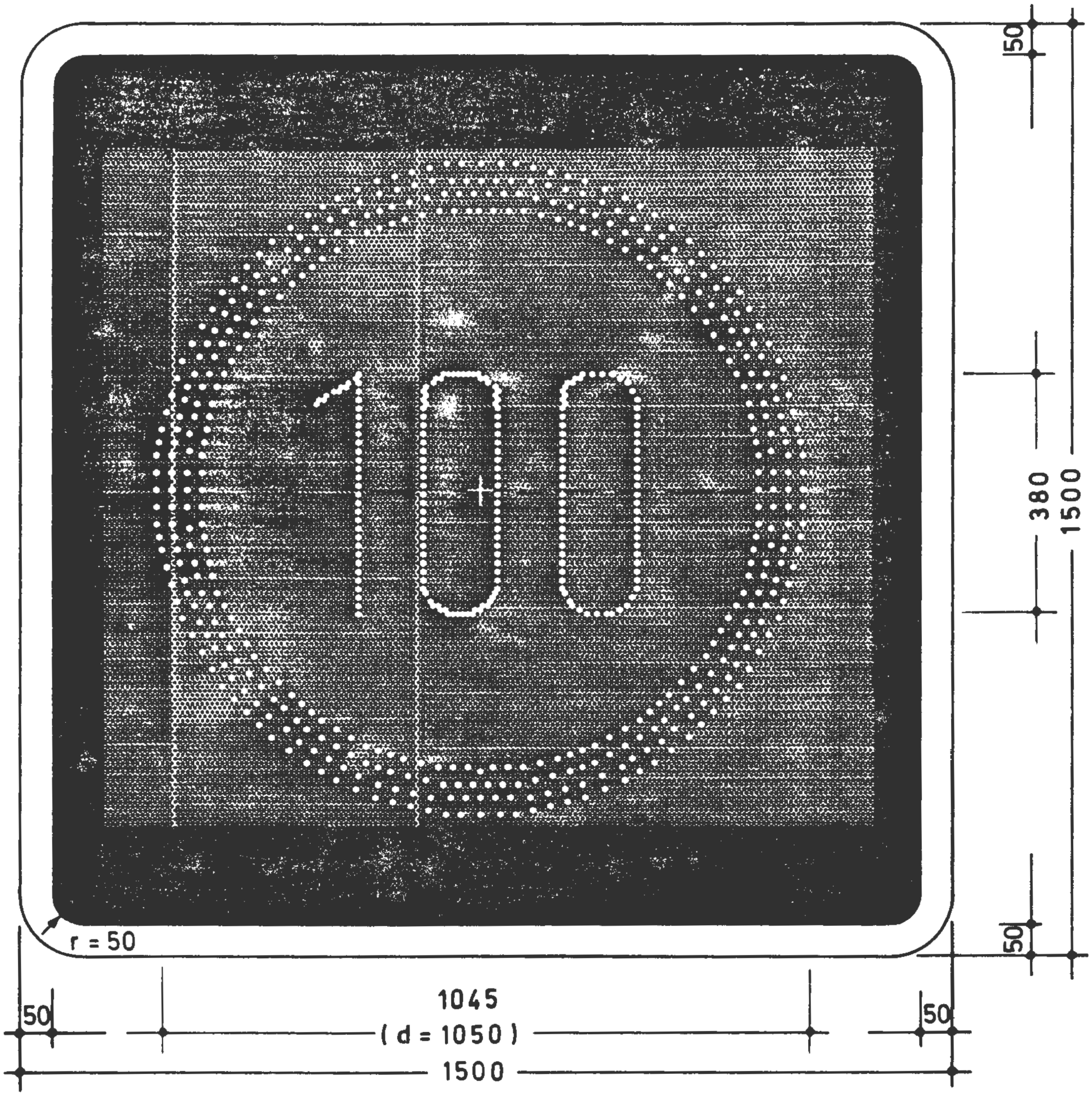
Example for Hexagonal Matrix
(Micromatrix)

Missing light points are due to overlapping. They have to be supplemented when content (information) is reduced.

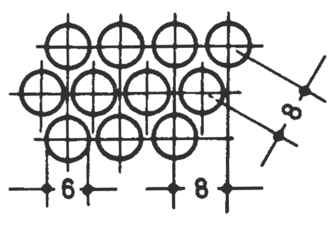
Figures in small letters according to DIN 1451

RWVZ Supplement 4	MATRIX SIGN Z 274 "100" OVERSIZED	MAT 2 Plate 4a Date: 5/84

SAMPLE



Example for Hexagonal Matrix (Micromatrix)

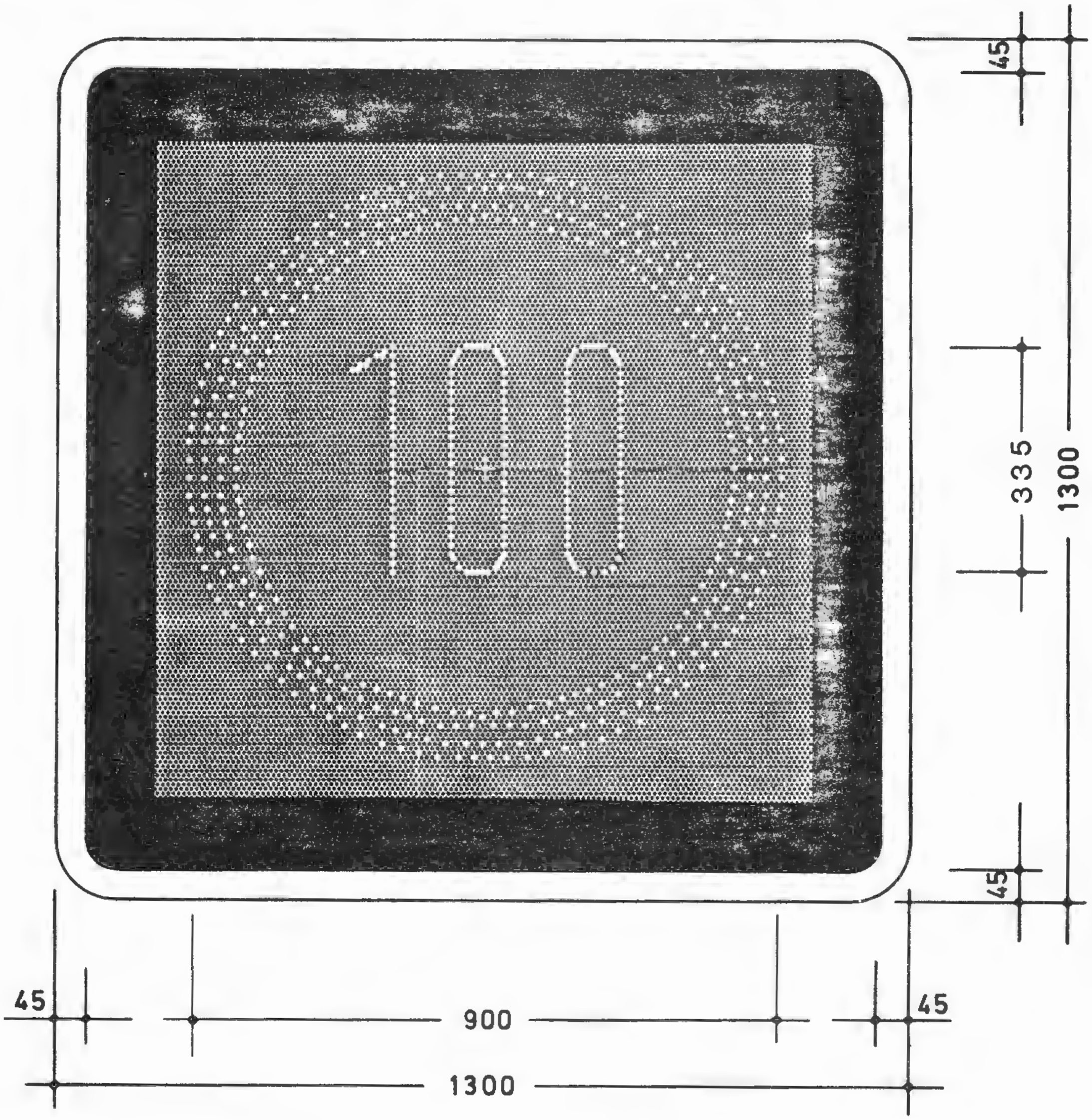


Missing light points are due to overlapping. They have to be supplemented when content (information) is reduced.

Figures in small letters according to DIN 1451

RWVZ Supplement 4	MATRIX SIGN Z 274 "100" NORMAL SIZE	MAT 3 Plate 4a Date: 5/84

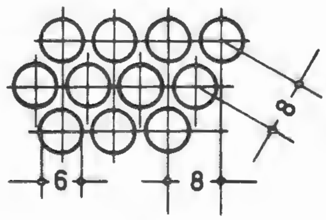
SAMPLE



Example for Hexagonal Matrix
(Micromatrix)

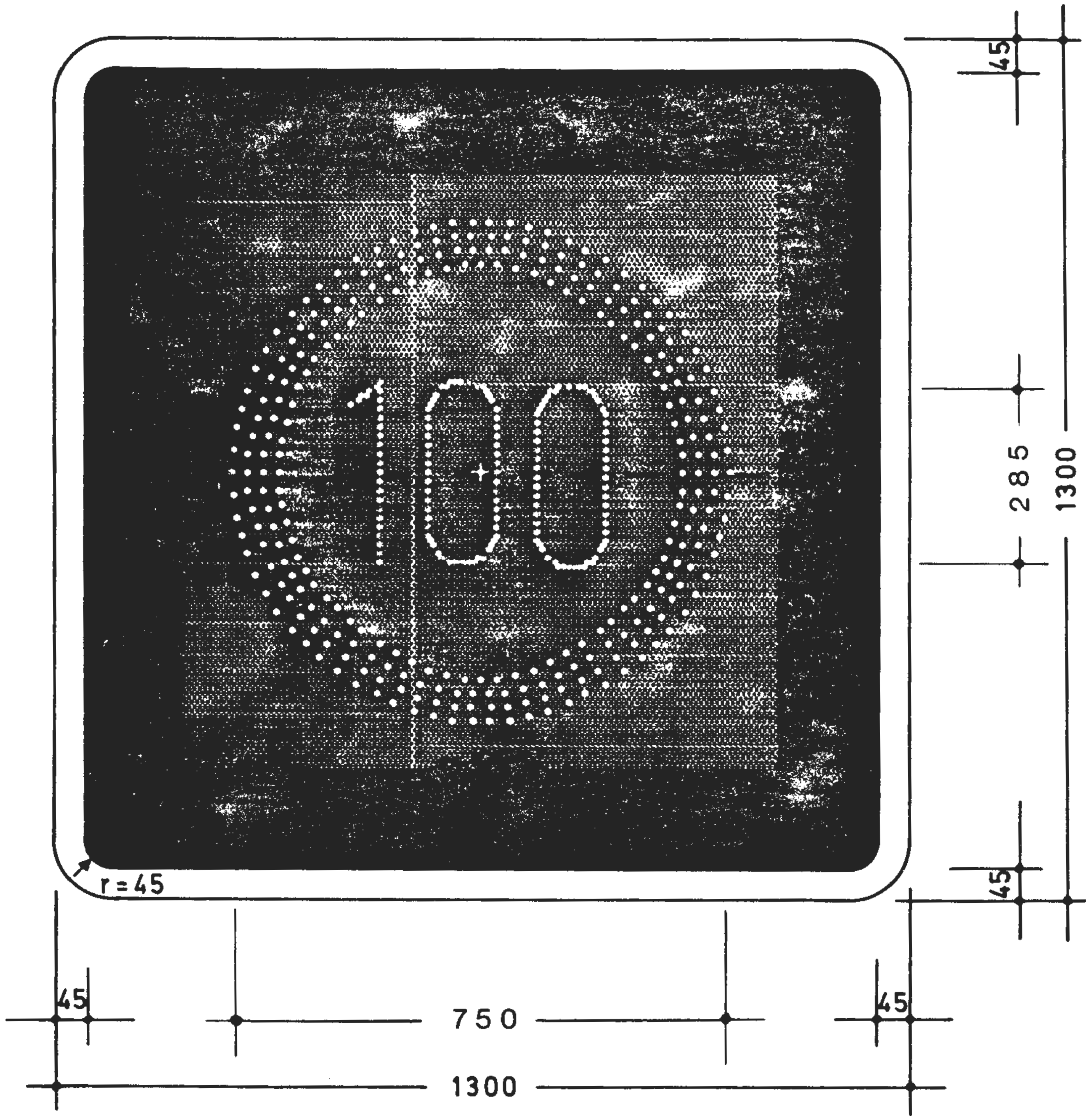
Missing light points are due to overlapping. They have to be supplemented when content (information) is reduced.

Figures in small letters according to DIN 1451

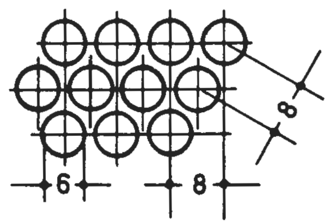


RWVZ	MATRIX SIGN	MAT 4
SUPPLEMENT 4	Z 274 "100" MINIMAL SIZE	PLATE 4a Date: 5/84

SAMPLE



Example for Hexagonal Matrix
(Micromatrix)



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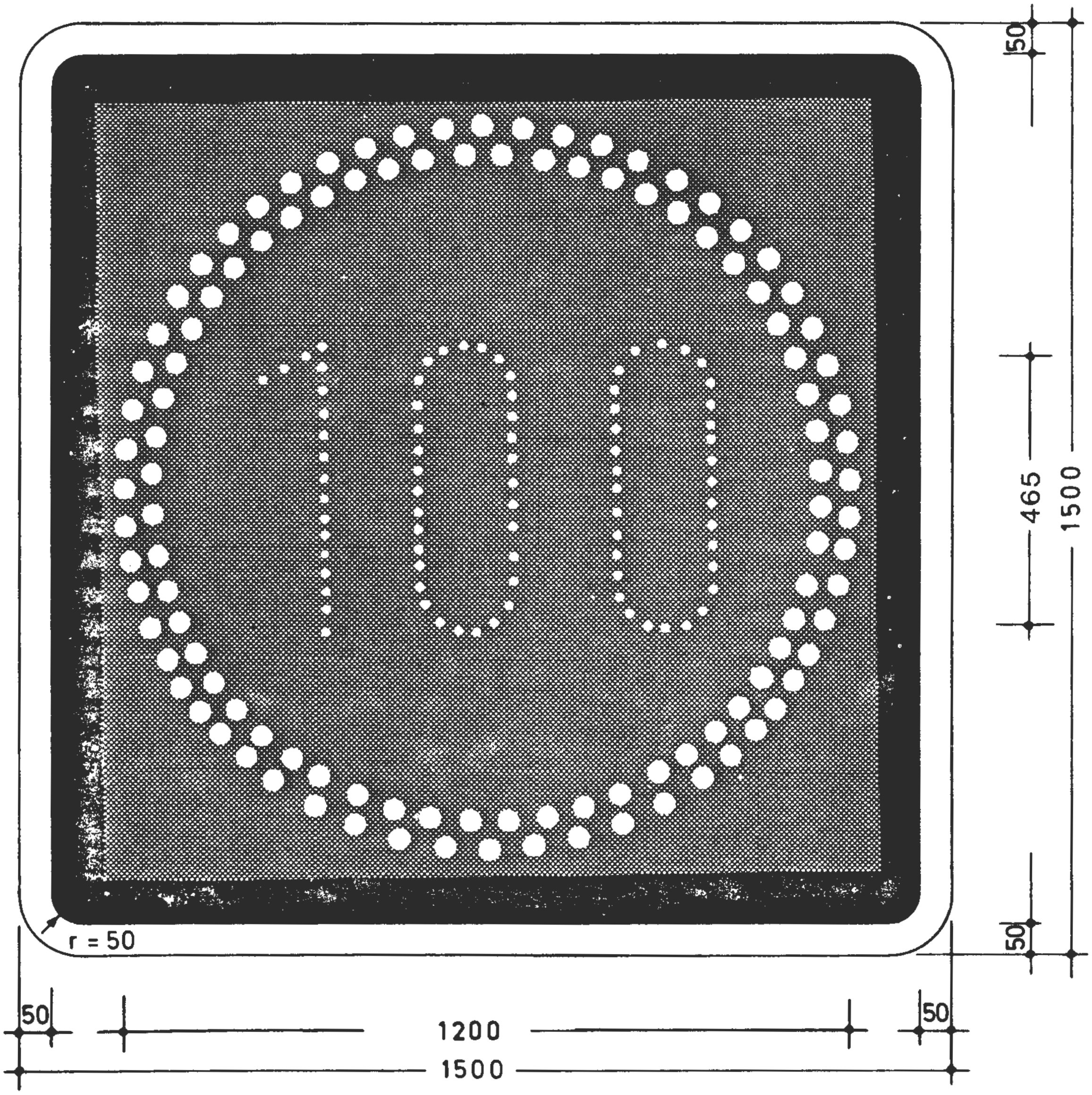
Figures in small letters according to DIN 1451

RWVZ Supplement 4	MATRIX SIGN Z 274 "100" SUPERSIZE	MAT 1 Plate 4b Date: 5/84

SAMPLE



Example of Mixed Matrix

Large Matrix Light Point d=24mm

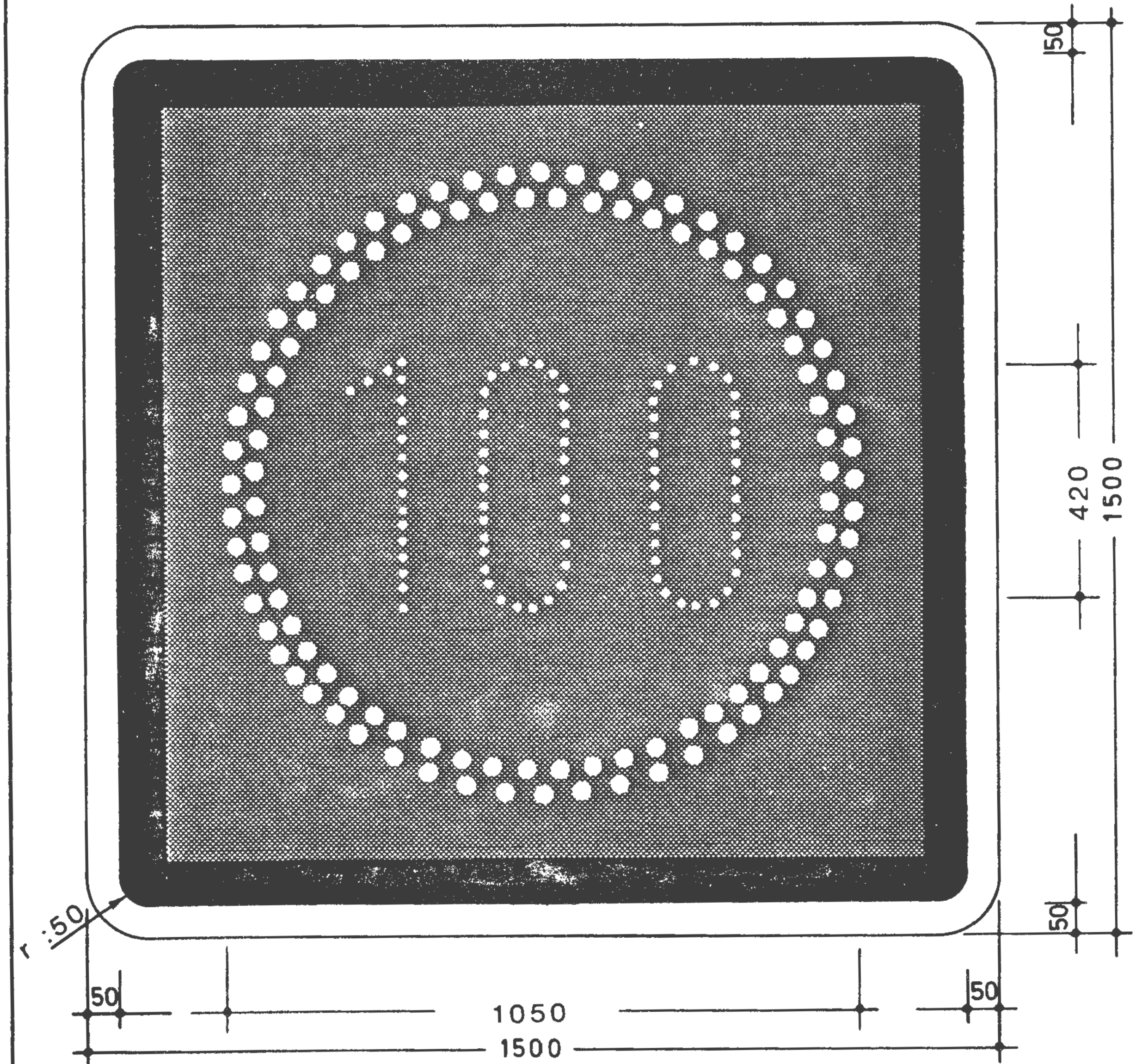
Small Matrix Light Point d=5.5mm

Missing light points are due to overlapping. They have to be supplemented when content (information) is reduced.

Figures in small letters according to DIN 1451

RWVZ Supplement 4	MATRIX SIGN Z 274 "100" OVERSIZED	MAT 2 Plate 4b Date: 5/84

SAMPLE



Figures in small letters according to DIN 1451

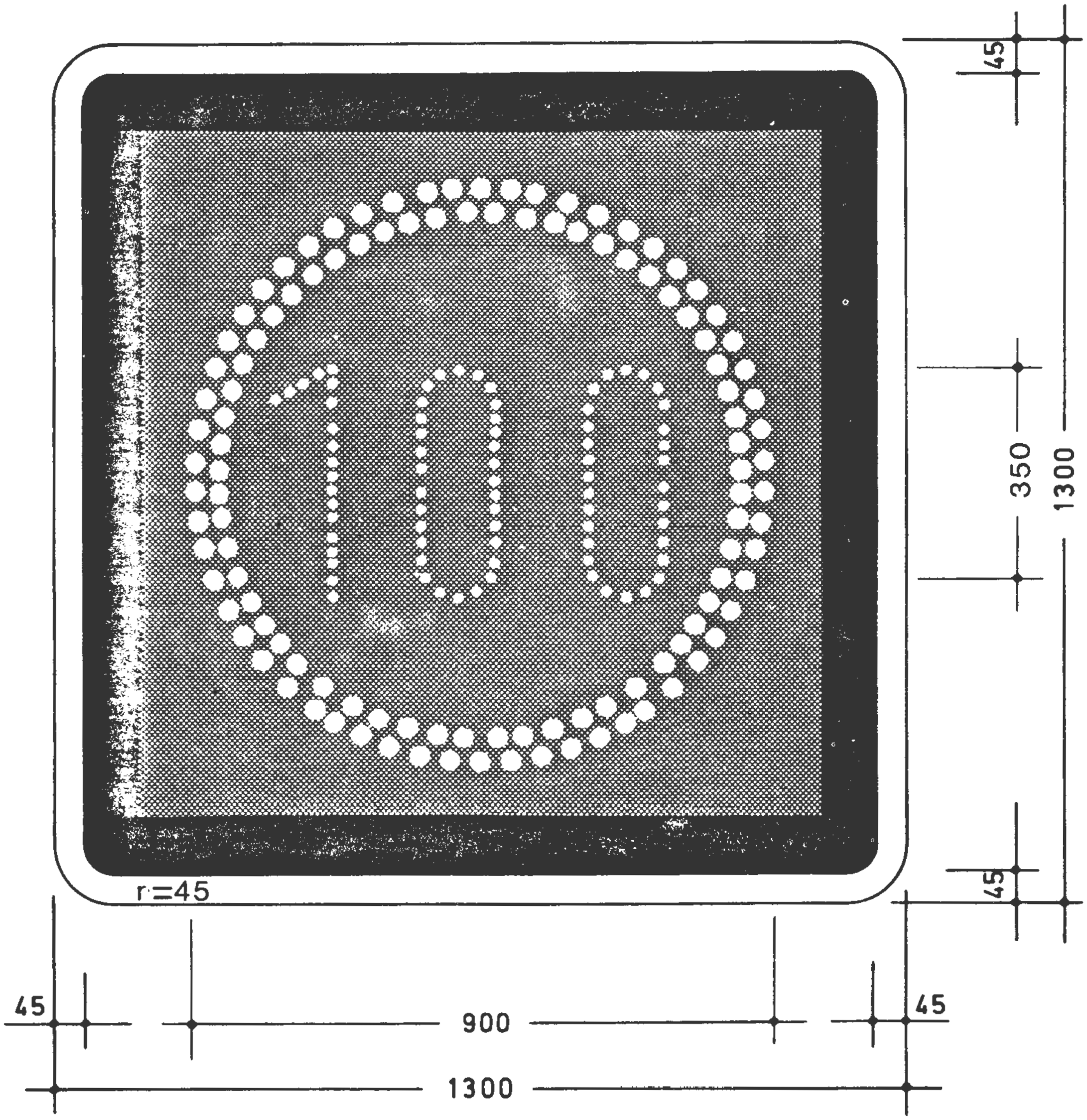
Example of Mixed Matrix

Large Matrix Light Point d=24mm

Small Matrix Light Point d=5.5mm

RWVZ Supplement 4	MATRIX SIGN Z 274 "100" NORMAL SIZE	MAT 3 Plate 4b Date: 5/84

SAMPLE



Example of Mixed Matrix

Large Matrix Light Point d=24mm

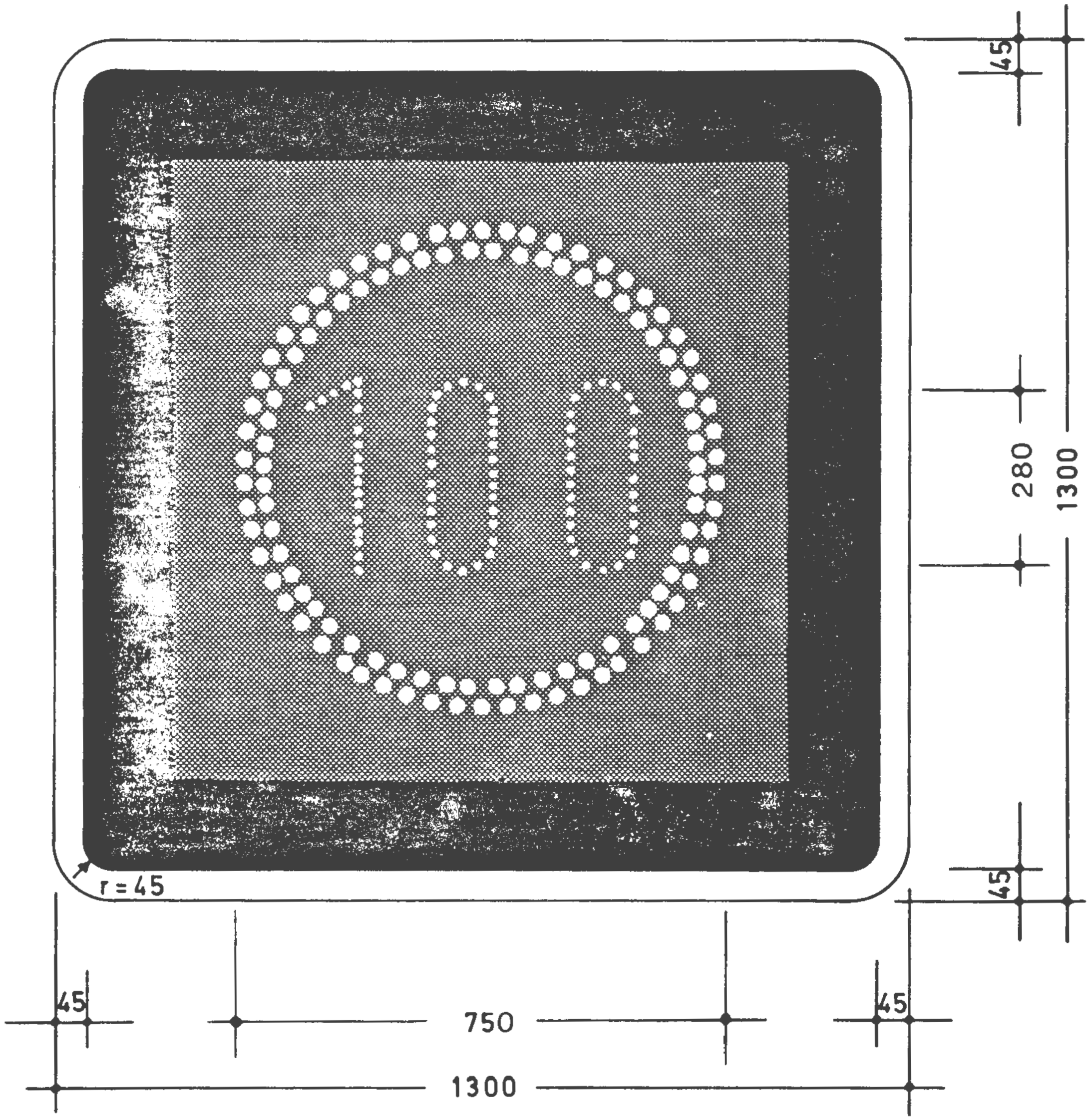
Small Matrix Light Point d=5.5mm

Missing light points are due to overlapping. They have to be supplemented when content (information) is reduced.

Figures in small letters according to DIN 1451

RWVZ Supplement 4	MATRIX SIGN Z 274 "100" MINIMAL SIZE	MAT 4 Plate 4b Date: 5/84

SAMPLE



Example of Mixed Matrix

Large Matrix Light Point d=24mm

Small Matrix Light Point d=5.5mm

Missing light points are due to overlapping. They have to be supplemented when content (information) is reduced.

Figures in small letters according to DIN 1451

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