National Cooperative Highway Research Program

NCHRP Synthesis 237

Changeable Message Signs

A Synthesis of Highway Practice

Transportation Research Board
National Research Council

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Synthesis of Highway Practice 237

Changeable Message Signs

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This report of the Transportation Research Board provides information on the various CMS types in use, their typical characteristics, including the technology types, the character (letters and numbers) types and size, and conspicuity. The synthesis presents a discussion on the types of messages used when there are no incidents. Other aspects, such as procurement, maintainability, and warranties are also discussed. Issues related to the structural design, integrity, and maintenance of CMS sign supports are not included in this synthesis.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the research in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

CONTENTS

Character heights on rotating drum CMSs are generally 406 mm (16 in.) or larger, which is consistent with the *Manual on Uniform Traffic Control Devices* standards for static guide signs used on freeways.

Limited field data indicate that the conspicuity and legibility distances for light-emitting matrix CMSs are superior to light-reflecting matrix CMSs with comparable character heights. A 320-mm (12.6-in.) fiberoptic sign, for example, has a legibility distance about equal to a larger 457-mm (18-in.) character circular reflective disk sign.

Most transportation agencies store a number of messages in the computer. These are supplemented with messages that are created by supervisory personnel when needed.

It is sometimes necessary to use messages that are longer than can be displayed at one time. This situation requires the message to be split into two parts that are sequenced in phases. This is generally accomplished in one of two ways: 1) having sequencing capabilities built directly into the sign, and 2) through the master sign control software.

Message display techniques that have proven useful include automatic pre-timed display of messages and automatic grouping of messages on multiple CMSs.

A majority (about 77 percent) of agencies responding to the survey display messages only when unusual conditions are present on the facility or when specific regulations apply (e.g., for HOV lanes). The CMSs are blank during other times as a matter of policy.

Each type of CMS has unique advantages and features that can provide valuable service, depending on the specific needs of the agency. It is important to be aware of the specific limitations of each technology, and to recognize that what may be considered an implied disadvantage of a CMS technology for one application may be an advantage for another application. The agencies' responses to inquiries about their experiences with selected CMSs are summarized; the categories include: 1) best attributes of the CMSs used; 2) worst attributes (biggest problems); 3) what actions were taken to correct the problems, or if the problems were not corrected, what could be done to correct the problems; and 4) what the agency would do differently in the future.

An interesting report surfaced just prior to the publication of this synthesis. The Maryland State Highway Administration noticed that a certain type of non-prescription sunglasses appeared to block the transmittance of messages on CMSs with amber LEDs used in construction zones. For all practical purposes, this made the message invisible to drivers wearing these sunglasses. This phenomenon was verified by limited laboratory tests by FHWA. The laboratory findings indicate a severe attenuation of the LED emission by some sunglasses. This is due to a notch-filter (a filter that screens out a very narrow band of radiation) in the lenses of these sunglasses in the 580 to 600 nanometer range. Accordingly, on July 15, 1996, FHWA issued a "Policy on the Use of Traffic Control and Warning Devices Based on Amber LED Technology in Traffic Operations and Highway Maintenance Activities."

The anticipated trend in future purchases includes both light-emitting and light-reflecting technologies. A very high percentage of agencies indicated that they definitely would consider light-emitting technologies for future purchases; only about 50 percent indicated that they would consider light-reflecting technologies.

Survey responses indicate that although agencies have improved CMS specifications immensely during the past few years, often in reaction to disappointments with the quality, performance, or relatively poor conspicuity and legibility of some CMS types, most agencies do not have comprehensive CMS standards. In addition, standardization within the industry is lacking. The agencies seem to be much more comfortable with their knowledge of the physical characteristics of CMSs than they are with visibility and legibility issues. There continues to be insufficient data to develop guidelines on the conspicuity and legibility capabilities of the various CMS technologies. At the present time, individual experiences alone lead to improvements in local specifications for future purchases.

Most agencies give substantial consideration to CMS maintainability, that is the ease with which the signs and associated equipment can be accessed for maintenance operations while maximizing the safety of the workers and minimizing disruption to traffic. Several factors enhance maintainability, including sign location, access to the sign controls, and access to the sign components.

A communications protocol (serial bit stream) is necessary between the CMS microcomputer master and the CMS controller. Problems have arisen with transportation agencies being able to easily communicate electronically with a wide variety of CMS types. The only commonality appears to be that most sign communications protocols use a serial data stream of information that is bi-directional between the central controller and the field controller. A common "physical layer" standard supported by most sign manufacturers is the RS-232C series of specifications. However, the embedded information within this physical standard is still unique for each manufacturer of CMS.

In response to the CMS manufacturers' proprietary barriers relative to communications protocols, some transportation agencies have taken aggressive actions. California, Minnesota and Ontario have set their own communications protocols, and require CMS manufacturers to comply with the state standards. Oregon requires that manufacturers provide information on communication protocol in order to sell CMSs in the state.

Of the transportation agencies responding to the survey, 49 percent stated that a national communication protocol is vitally necessary or necessary, another 29 percent stated that a national protocol would be useful. Only 18 percent indicated that a national communication protocol is not needed.

Most agencies responding include at least a 1-year contractor or manufacturer maintenance period in their specifications. After the manufacturer's warranty period, most agencies handle maintenance with state personnel.

One of the complaints expressed by some of the transportation agencies is that the requirement to accept a low bid may result in CMSs with unacceptable quality and performance (e.g., target value, legibility, etc.). Another major concern is the difficulty of integrating newly purchased CMSs into an existing system. Many respondents to the survey expressed the belief that properly written specifications can be a safeguard to ensure quality equipment is purchased.

As previously noted, many agencies are rewriting CMS purchase specifications to be more explicit and complete to ensure quality signs. California, for example, has one specification (Model 500) that all manufacturers must comply with regardless of how low they bid. Arizona uses a procurement process that includes, among other things, the provision that potential suppliers provide a guaranteed life-cycle cost on the equipment for 10 years. The life-cycle costing includes the cost of the signs, a yearly guaranteed electrical cost, and an annual guaranteed maximum repair cost.

It is common practice in each state to test the CMS systems purchased. Of the agencies responding, 38 percent stated that a national test facility is vitally necessary or necessary, and an additional 59 percent indicated that it would be useful. None of the respondents indicated that a national test facility was not necessary.

The survey results indicate that not all state personnel who have the responsibility for CMSs are receiving all of the pertinent reports to assist them in designing and operating CMS systems.

CHAPTER ONE

INTRODUCTION

RATIONALE FOR SYNTHESIS

This report is a synthesis of practice with respect to the use of changeable message signs (CMSs) in the United States and Ontario, Canada to manage traffic, emphasizing congestion reduction and accident prevention in urban and rural settings. It is an update of *National Cooperative Highway Research Program Synthesis of Highway Practice 61: Changeable Message Signs* which was published in July 1979 *(1)*. The report also supplements the Federal Highway Administration 1986 report, *Manual on Real-Time Motorist Information Displays (2)*, and 1991 report, *Guidelines on the Use of Changeable Message Signs (3,4)*.

The 1979 synthesis contains information about the types of CMSs; control systems, surveillance, and interconnect techniques; features of freeway traffic advisory and incident management systems; other traffic management and diversion applications; and technology voids. Much of the information presented in that report is relevant today. However, significant advancements have occurred in computer, electronic, and CMS technologies that offer greater flexibility to CMS users today. In addition to flexibility, newer light-emitting CMS technologies have been shown to provide greater conspicuity and legibility than light-reflecting technologies under certain types of environmental conditions.

The 1986 *Manual on Real-Time Motorist Information Displays* provides practical guidelines for the development, design, and operation of real-time motorist displays (both visual and auditory) for freeway corridor traffic management. The emphasis is on the recommended content of messages to be displayed in various traffic situations; the manner in which messages are to be displayed, including format, coding, style, length, load, redundancy, and the number of repetitions; and where messages should be placed with respect to the situations they are explaining. In comparison, the *Guidelines on the Use of Changeable Message Signs* provides guidance on 1) selection of the appropriate type of CMS display, 2) the design and maintenance of CMSs to improve target value and motorist reception of messages, and 3) design, installation, operation, and maintenance pitfalls to be avoided. In addition, the report updates some of the information contained in the *Manual*.

SYNTHESIS OBJECTIVES

This report documents current practice with respect to the use of CMSs in various applications. The objective of the report was to provide current information on CMSs from state transportation agencies on the following:

- Applications;
- Characteristics;
- Performance measures (conspicuity, legibility, credibility, etc.);
- Message development and operational practices;
- Experiences with CMS technologies;
- Existing technical standards;
- Procurement and testing practices;
- Maintenance experiences;
- Negative effects on traffic;
- Communications/control; and
- Lessons learned.

This synthesis is not intended to be a guideline or manual of practice, but provides information to readers on the state of the practice. Specific applications will require careful consideration of safety and operational effects. This synthesis does not cover issues involved with the structural design, integrity, or maintenance of the supports for changeable message signs. There have been some failures of cantilevered CMS sign supports, and an NCHRP research study, Project 10-38(2) "Fatigue Resistant Design of Cantilevered Signal, Sign, and Light Supports" with particular focus on CMSs, has been initiated.

ANALYSIS APPROACH AND SCOPE

Since the information desired as part of this endeavor was not available in published reports, a questionnaire survey was prepared and mailed to each state department of transportation representative on the American Association of State Highway and Transportation Officials (AASHTO) Subcommittee on Traffic Engineering. Surveys were also sent to one turnpike authority and two Canadian province departments of transportation. The survey, provided as Appendix A, was divided into two parts: Part 1: Permanently Mounted Changeable Message Signs, and Part 2: Transportable Changeable Message Signs. The survey was separated into two parts because it was anticipated that responses would most likely be made by different offices within a given transportation agency.

Thirty-nine state departments of transportation, the one turnpike authority and the two Canadian province departments of transportation (42 agencies) responded to the survey. Forty-two agencies responded to Part 1 and 35 responded to Part 2 of the survey. Table 1 lists the agencies responding. The survey was conducted in the fall of 1992. Part 1 of the survey was updated in the fall of 1995; consequently, the responses summarized in this synthesis for permanently mounted CMSs reflect the state-of-practice as of December 1995. The survey on transportable CMSs was not updated for reasons discussed later in this chapter. Follow-up telephone calls were made to each agency that reported using permanently mounted CMSs.

TABLE 1
TRANSPORTATION AGENCIES RESPONDING TO SURVEY

State Department of Transportation			
Alabama	Illinois*	New Jersey*	Tennessee*
Alaska*	Iowa*	New York*	Texas*
Arizona*	Kansas*	North Carolina*	Utah
Arkansas	Maine*	North Dakota*	Vermont*
California*	Massachusetts*	Ohio	Virginia*
Colorado*	Maryland*	Oregon	Washington*
Connecticut	Michigan*	Pennsylvania	West Virginia*
Georgia*	Minnesota*	Rhode Island*	Wisconsin*
Hawaii*	Mississippi*	South Carolina	Wyoming*
Idaho*	Nebraska*	South Dakota	
Turnpike Authority			
New Jersey*			
Canadian Province			
Ontario*			
Saskatchewan			

* Provided an updated survey response in 1995

TABLE 2
USE OF CHANGEABLE MESSAGE SIGNS BY AGENCIES RESPONDING TO SURVEY

Permanently Mounted CMSs		Transportable CMSs	
YES (29 Agencies)		YES (28 Agencies)	
Alabama	New York	Alabama	New York
Alaska	North Carolina	Arkansas	North Carolina
Arizona	Ohio	California	North Dakota
California	Oregon	Colorado	Ohio
Colorado	Pennsylvania	Connecticut	Oregon
Connecticut	South Carolina	Georgia	Pennsylvania
Idaho	Tennessee	Illinois	South Dakota
Illinois	Texas	Iowa	Tennessee
Iowa	Virginia	Kansas	Texas
Maryland	Washington	Maryland	Virginia
Massachusetts	Wisconsin	Michigan	Washington
Michigan	Wyoming	Minnesota	West Virginia
Minnesota	N.J. Turnpike	Nebraska	Wisconsin
Nebraska	Ontario	New Jersey	Ontario
New Jersey			
NO (13 Agencies)		NO (7 Agencies)	
Arkansas	Rhode Island	Arizona	Vermont
Georgia	South Dakota	Idaho	Wyoming
Hawaii	Utah	South Carolina	Saskatchewan
Kansas	Vermont	Utah	
Maine	West Virginia		
Mississippi	Saskatchewan		
North Dakota			

CURRENT USE OF PERMANENTLY MOUNTED AND TRANSPORTABLE CMSs

Table 2 is a summary of the use of permanently mounted and transportable CMSs by the agencies who responded to the survey. From the table, 27 of the 39 states responding to the survey, the one turnpike authority, and one Canadian province reported using permanently mounted CMSs. Twelve states and one Canadian province reported that they do not currently have permanently mounted CMSs. Twenty-seven states and one province reported using transportable CMSs, whereas, six states and one province do not currently use transportable CMSs.

SYNTHESIS CONTENT AND FORMAT

The results of Part 2 of the survey, Transportable Changeable Message Signs, are not summarized in this synthesis for two reasons. Although 28 agencies reported using transportable CMSs, the responses to specific questions in the survey were not as complete as for the permanently mounted CMSs portion of the survey. Also, it was found that summarizing the available information on transportable CMSs did not add to the information already contained in the discussions on permanently mounted CMSs. Therefore, only the results pertaining to permanently mounted CMSs are addressed here. The responses summarized reflect the state-of-practice as of December 1995.

The synthesis is divided into four chapters. Following the Introduction, the major classifications of CMSs, light-reflecting, light-emitting, and hybrid, are discussed in chapter 2. The results of the survey on permanently mounted CMSs are presented in chapter 3. Conclusions are presented in chapter 4.

TERMINOLOGY

Changeable Message Signs, Variable Message Signs, and Motorist Information Displays

To be consistent with the *Manual on Uniform Traffic Control Devices* (MUTCD) and other major U. S. publications on the subject, the term "changeable message sign" is used here to describe a sign that has the capability of displaying a variety of messages. "Variable message signs" and "motorist information displays" are sometimes used synonymously with "changeable message signs" by some authors and practitioners.

Nominal vs Actual Character Height

In practice, the character height on a matrix CMS is generally indicated by manufacturers and transportation agencies in terms of what is here defined as the sign's nominal character height, rather than the actual physical height. For example, the physical character height may be 445 mm (17.5 inches) but the CMS is referred to as an 18-in.character sign. In one extreme case, as will be discussed later, the actual dimension of a fiberoptic CMS from one manufacturer is 420 mm (16.5 in.), however, it is referred to as an 18-in. sign. Thus, the actual character height on most matrix CMSs will actually be shorter than the nominal character height. To be consistent with practice, all character height dimensions used in this synthesis will be stated in terms of the nominal height dimension.

CHAPTER TWO

CHANGEABLE MESSAGE SIGN TYPES

CLASSIFICATION

CMSs can be conveniently classified into the following three categories *(3):*

1. Light-reflecting,
2. Light-emitting, and
3. Hybrid.

The most flexible of the CMSs form characters and symbols in a matrix format by showing appropriate patterns of the matrix elements. Matrix CMSs are designed in three formats:

1. One or more lines composed of 5 × 7 matrix character modules (Figure 1);
2. One or more lines with continuous matrix lines (Figure 2), and
3. Full matrix display (Figure 3).

The full matrix display is the most flexible but most expensive of the alternatives.

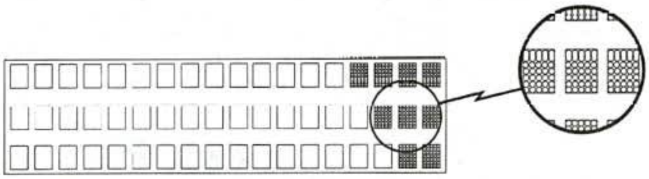


FIGURE 1 Modular character matrix.

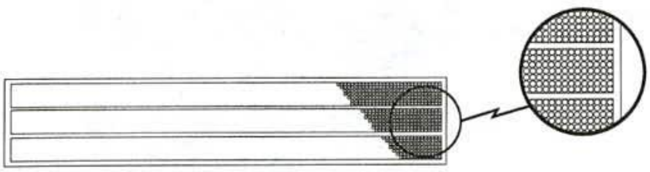


FIGURE 2 Continuous line matrix.

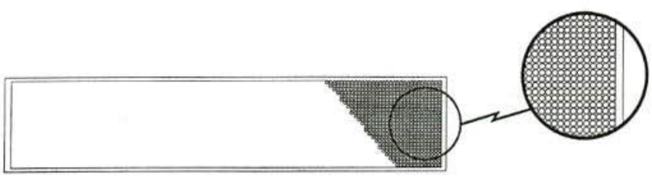


FIGURE 3 Full matrix.

LIGHT-REFLECTING CMSs

Light-reflecting CMSs (e.g., reflective disk, rotating drum) reflect light from some external light source such as external sign lights, vehicle headlights, or the sun. The more common types of light-reflecting CMSs range from the rotating drum sign (Figure 4) with a limited number of messages to the reflective disk matrix sign with infinite message capability. One distinct characteristic of light-reflecting CMSs is that, with the exception of external and internal lighting requirements and requirements for environmental controls (e.g., fans, heaters, etc.), power is required only when a message is changed.

FIGURE 4 Rotating drum CMS.

There are three principal types of reflective disk CMSs:

1. Circular disks,
2. Rectangular disks, and
3. Dimensional square disks.

The viewing face of a circular reflective disk CMS is formed by an array of permanently magnetized, pivoted, 56-mm (2.2-in.) diameter circular indicators inset on a dark background surface (Figure 5). Messages are displayed by electromagnetically rotating appropriate disks to reveal a reflectorized yellow side. The reflective disk sign can be either modular character matrix, continuous line matrix, or full matrix.

The rectangular reflective disk CMS is very similar in operation to the circular disk. The viewing face is formed by an array of permanently magnetized, rectangular disks measuring 43.7 mm (1-5/8 in.) wide by 63.5 mm (2-1/2 in.) high (Figure 6). Each rectangular disk swings like a door 180 degrees on a vertical hinge. When the "door" is open, it presents its yellow side and simultaneously exposes the yellow wall behind the door. When it closes, it shows black for both the flipper door and the wall. The signs are available with either the modular character matrix, continuous line matrix, or full matrix design.

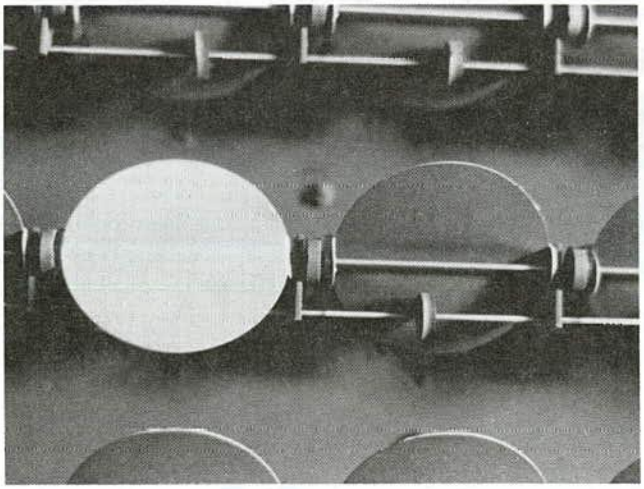


FIGURE 5 Close-up view of circular reflective disk CMS.

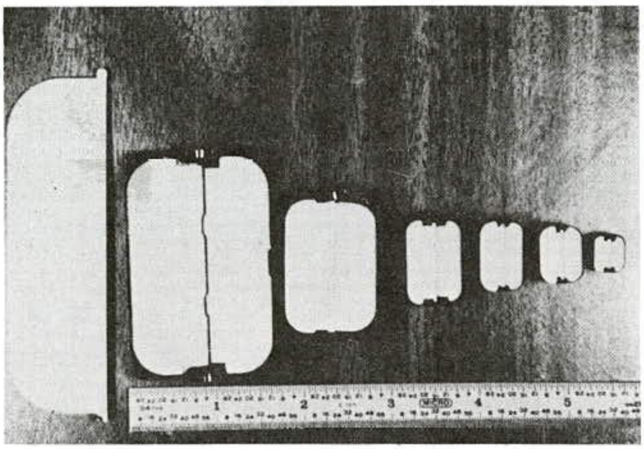


FIGURE 6 Close-up view of rectangular reflective disk CMS.

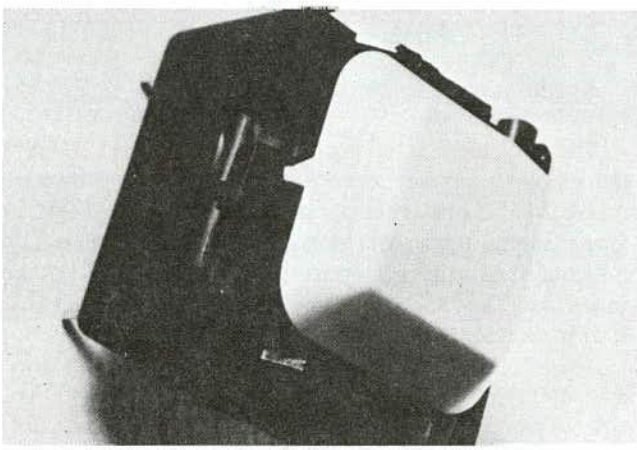


FIGURE 7 Close-up view of dimensional square reflective disk CMS.

The viewing face of a dimensional square disk sign is formed by either a continuous line matrix or a full matrix array of 66-mm (2.6-in.) square elements that rotate to display a side that is either fluorescent yellow (on), or a side that is flat black. (Colors other than fluorescent yellow are available, but are not generally used for highway applications). The elements have sloping sides and are "3-dimensional" thus they provide some depth to the message element (Figure 7). *(3)*

LIGHT-EMITTING CMSs

Light-emitting CMSs generate their own light on or behind the viewing surface. These sign types require power at all times when a message is displayed in comparison to light-reflecting CMSs that require power only when a message is being changed, although both types of signs require power for environmental equipment such as fans and heaters. Light-emitting CMSs are either modular character matrix, continuous line matrix, or full matrix. The more common types of light-emitting signs are bulb (incandescent) matrix, fiberoptic matrix, and light-emitting diode (LED) matrix.

Bulb matrix, sometimes referred to as "lamp matrix," is one of the oldest types of light-emitting CMS used for highway applications. In recent years, advances in technology have resulted in an increased popularity of fiberoptic and LED signs in the United States. Fiberoptic CMSs are either fixed-grid or matrix with shutters. Light radiating from an internal point source (halogen lamp) is directed to the sign's viewing face through a bundle of optically polished glass fibers. For a fixed-grid sign, the points of light (pixels) are arranged to form the specific message(s) (words, numbers, and/or symbols) on the sign face (Figure 8). Thus, a fixed number of messages are available.

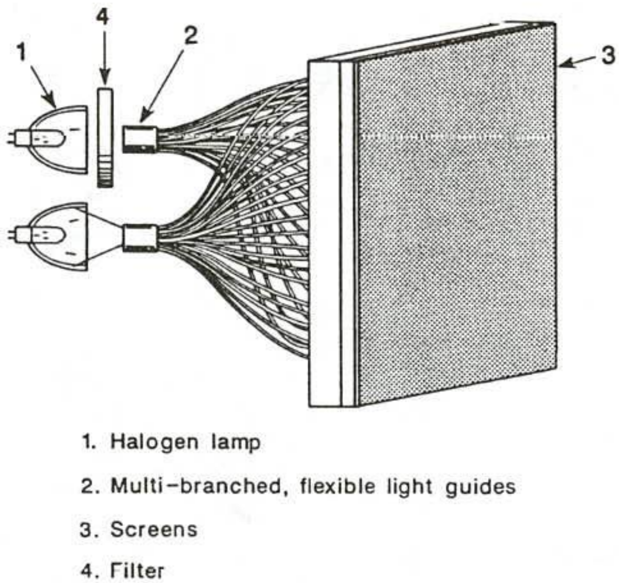
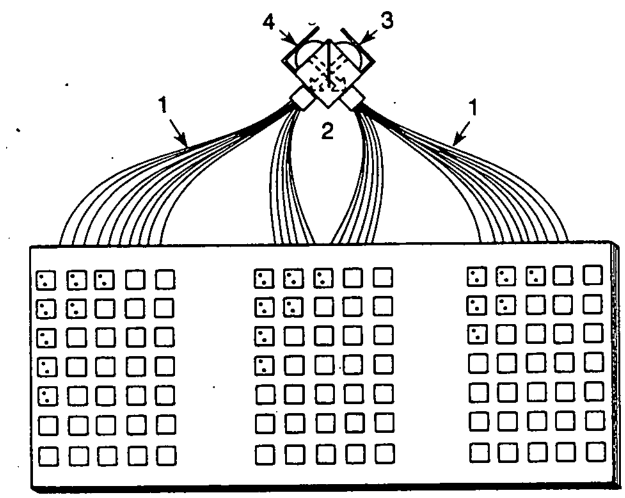


FIGURE 8 Fixed-grid fiberoptic module.

In contrast, the fiberoptic matrix with shutters can display a large number of user-designed messages and thus provides greater flexibility in message selection. Rather than forming specific fixed messages, the fiberoptic glass optical fibers direct light to form 5 × 7 character modules on the sign face. The primary halogen lamp is continuously illuminated; each pixel with two fiberoptic 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, thus forming the message (Figure 9). Since the fixed-grid fiberoptic sign is not generally used for freeway traffic management in the United States (except for lane control signals), all references to fiberoptic CMSs in subsequent sections of this report imply the fiberoptic matrix with shutters.



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 9 Light module and fiberoptic bundles connected to typical three-character module.

The viewing face of an LED clustered CMS is formed in a manner similar to the bulb matrix sign, with the exception that each lighted element is a cluster of LED lamps rather than a single incandescent bulb (Figure 10).

HYBRID CMSs

Hybrid signs combine two CMS technologies to produce displays that exhibit the qualities of both. In the 1970s, transportation agencies inserted bulb matrix into static guide signs. In recent years, manufacturers have integrated fiberoptic or LED with circular reflective disk matrix technologies. The basic operations depend on the established principles of the reflective disk sign technology, which is supplemented with fiberoptics or LEDs. In the case of the former, a single fiberoptic light dot is located behind each reflective disk and radiates through small holes in the disk. The fiberoptic dot shows when the disk is in the "on" position. The pixels in use, therefore, show both the reflective disk and the fiberoptic light. Figure 11 illustrates the principles of one type of design for a fiberoptic enhanced reflective disk CMS.

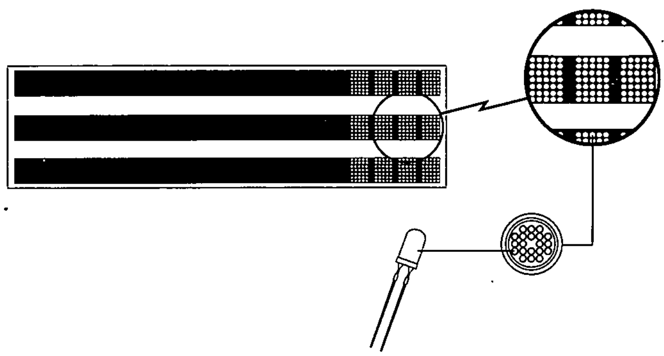
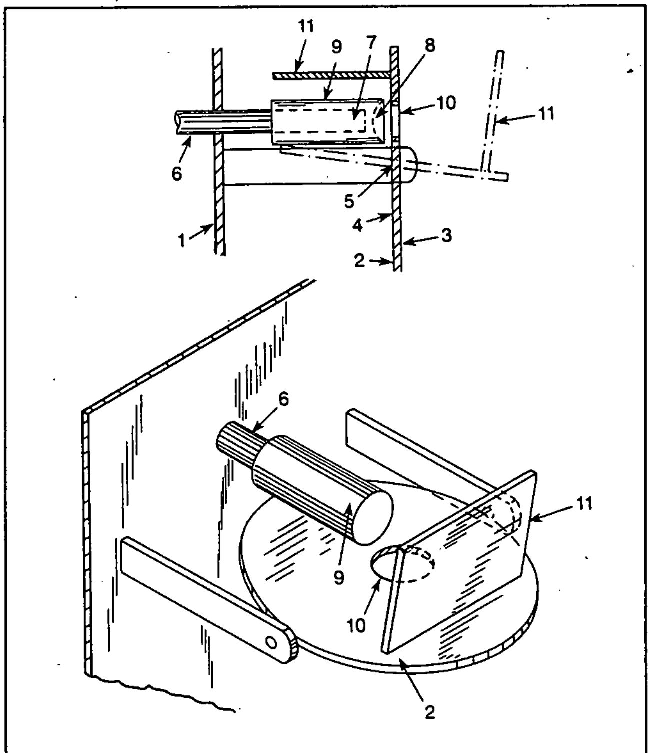


FIGURE 10 LED clusters.



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 11 Mechanics of fiberoptic enhanced reflective disk pixel.

CHAPTER THREE

PERMANENTLY MOUNTED CHANGEABLE MESSAGE SIGNS

A total of 29 agencies—27 states, 1 turnpike authority, and 1 Canadian province—indicated that they have permanently mounted CMSs. This section summarizes the responses from these 29 agencies and represents the state-of-practice as of December 1995.

APPLICATIONS

The results of the survey indicate that permanently mounted CMSs are used primarily for the following nine applications:

- General Traffic Information/Warning,
- Incident/Traffic Management,
- Diversion Information,
- Construction/Maintenance Support,
- High Occupancy Vehicle/Contraflow Lane Information,
- Reversible Lane Control,
- Special Event Traffic Control,
- Fog Warnings, and
- Warnings of Adverse Weather/Road Conditions.

"General Traffic Information/Warning" refers to applications where general information about traffic conditions are displayed. "Incident/Traffic Management" involves display of information about incidents with the intent that some motorists will voluntarily alter their routes. This application is an extension of General Traffic Information/Warning. "Diversion Information" refers to those signing applications where specific instructions about diversion to alternate routes are displayed, thus resulting in a further extension of the first two applications. There is some overlap among these three applications. Agencies operating CMSs as part of urban traffic management centers that display specific diversion information would also display incident information and general traffic information/warning. In contrast, agencies that display diversion information in *rural* areas generally divert traffic because of inclement weather and/or pavement conditions, and do not usually display general traffic information/warning. The remaining applications in the list are self-explanatory.

A comparison of the specific applications among the transportation agencies is shown in Table 3. The applications vary among the agencies ranging from a single purpose (e.g., overhead clearance) to a wide variety of purposes including incident and traffic management and diversion. The number of signs being used for each application by each state is shown in Table 4.

SIGN TYPE

Table 5 summarizes the types of signs purchased by each state during the last three acquisitions. Table 6 is a summary of the most recent CMS purchases classified according to CMS types, which gives a better perspective about the trends in CMS purchases. Most CMS purchases dating from the mid 1970s and early 1980s were light-reflecting technologies—circular reflective disk and rotating drum signs. More recently (since 1989), there has been a trend toward a greater use of light-emitting technologies—fiberoptic, LED, fiberoptic enhanced reflective disk hybrid, and LED enhanced reflective disk hybrid CMSs.

The circular reflective disk CMS was very popular in the 1980s when the agencies began to focus on energy conservation. However, some transportation agencies are beginning to retrofit older reflective disk signs with fiberoptic enhanced reflective disk modules to improve legibility. Only one state (Connecticut) reported using dimensional square reflective disk signs. Many transportation agencies, particularly in the northern part of the United States, continue to find the rotating drum sign appealing even though there is a limitation in the number of messages that can be displayed. Minnesota, for example, has found the six-sided drum suitable for incident management and diversion applications in urban areas.

Although the bulb matrix CMS has not been as popular with most transportation agencies during the last several years, California continues to find the bulb matrix very acceptable and has adopted a full-matrix bulb CMS (96 lamps across by 25 lamps high) as the state standard (*5,6*).

CMS CHARACTERISTICS

Table 7 summarizes specific CMS design characteristics related to message presentation for the most recently purchased CMSs. Shown in Table 7 are the sign type, year purchased, application (freeway, HOV facility, or tunnel), number of lines, characters per line, nominal character height, and legibility distance stipulated in the specifications.

Number of Lines

Matrix Signs

As Table 7 indicates, most matrix CMSs purchased in recent years are line matrix signs with three lines of text. Two transportation agencies (California and Connecticut) purchased full-matrix signs that have the capability of displaying a variety of lines and character heights, ranging from three lines with 457-mm (18-in.) characters to one line with 914-mm (36-in.) characters.

Rotating Drum Signs

Most rotating drum CMSs purchased in recent years have three lines of characters, although some agencies have purchased

TABLE 3

APPLICATIONS OF CMSs

Agency	Application of CMSs									
	A	B	C	D	E	F	G	H	I	Other
Alabama										Overhead Clearance (Tunnel)—3
Alaska		X	X	X						Avalanches
Arizona	X	X	X	X				X	X	Northern part of State: Fog, Ice, Migratory Elk
California	X	X		X		X	X	X	X	Weigh Station Control; Border Crossings
Colorado	X	X								
Connecticut	X	X	X	X	X					Control at Crossings
Idaho			X*							
Illinois	X	X		X		X	X			
Iowa	X	X	X	X			X	X	X	
Maryland	X	X	X	X			X	X	X	Safety, Truck Information
Massachusetts					X					
Michigan	X	X	X**	X			X		X	
Minnesota	X	X	X							
Nebraska									X	
New Jersey	X	X	X	X					X	
New York	X	X	X	X	X				X	
North Carolina		X		X	X	X	X	X	X	Weigh Station
Ohio									X	Tourist Information
Oregon	X	X							X	Earth Slides, Speed Control
Pennsylvania	X	X	X	X						
South Carolina								X		Weigh Station Control
Tennessee								X		Fog Detection & Warning System
Texas	X	X	X	X	X		X	X	X	Bridge Info & Diversion; Toll Road Advisory
Virginia	X	X	X	X	X	X	X		X	Exclusive Lanes; Tunnel Control; Draw Bridge Control; Bridge Opening for River Traffic
Washington	X	X	X	X	X	X	X			Warnings; Weigh Station Control; Variable Speed Limits (future)
Wisconsin		X								Weather; Tunnel Control
Wyoming			X*						X	Tunnel Control
N.J. Turnpike	X	X	X				X	X	X	Speed Limit/Warning; Truck Trailer Ban
Ontario	X	X	X	X						
Percent of Agencies	62%	72%	59%	55%	24%	17%	34%	31%	51%	59%

A—General Traffic Information/Warning; B—Incident/Traffic Management; C—Diversion Information; D—Construction/Maintenance Support; E—HOV/Contra-Flow Lane Information; F—Reversible Lane Control; G—Special Event; H—Fog; and I—Adverse Weather/Road Conditions.

* Due to adverse weather conditions

** Between freeways only

signs with one or two lines for specific applications (e.g., weigh stations).

Character Type and Characters Per Line

Virtually all highway CMSs display messages using all capital letters. Capital letters are especially essential on matrix CMSs because the configuration of the matrix modules (5 × 7) does not lend itself to displaying lower case letters.

The number of characters per line on the most recently purchased CMSs varies from 10 to 24, depending on the message requirements for the sign installation. Table 8 shows the range of message line length, the percentage of agencies using each length, and the percentage of CMSs with each message line length for both matrix and rotating drum CMSs. The two most popular matrix CMS designs have 18 or 20 characters per line. Forty-one percent of the agencies use matrix signs with 18 characters per line; 26 percent use matrix signs with 20 characters per line. Considering the number of signs purchased, 95 percent of the matrix CMSs recently purchased have 15 or more characters per line.

Although CMSs with 15 characters or less per line may be adequate for some applications (e.g., HOV and reversible

TABLE 4

LOCATIONS, APPLICATIONS AND NUMBER OF CMS

Agency	Application	Number of CMSs
Alabama	Overhead Clearance (Tunnel)	3
Alaska	Traffic Advisory/Incident Management/Diversion/Special Events/Adverse Road Weather Conditions/Speed Control/Construction & Maintenance	1
	Traffic Advisory/Incident Management/Diversion/Special Events/Adverse Road & Weather Conditions/Speed Control/Construction & Maintenance/Crossing Control (Avalanches)	1
Arizona	Traffic Advisory/Incident Management/Diversion/Construction & Maintenance	35
	Traffic Advisory/Construction	6
	Traffic Advisory/Construction/ Adverse Weather Conditions	7
California	Traffic Information/Management	150
	Adverse Weather/Road Conditions	15
	Reversible Lanes	12
	Fog	27
	Special Use	4
Colorado	Traffic Management	3
	Tunnel Control	33
Connecticut	Traffic Management/Diversion Warning of Adverse Conditions Control During Construction/Maintenance	14
Idaho	Adverse Weather/Road Conditions	5
Illinois	Traffic Information/Advisory	20
	Reversible Lane	10
Iowa	Traffic Management/Diversion	4
	Fog	3
Maryland	Traffic Advisory/Incident Management/ Adverse Conditions/Construction/ Special Events	33
Massachusetts	Contraflow HOV Lane	1
	Exclusive HOV Lane	1
Michigan	Traffic Information/Advisory	18
Minnesota	Traffic Management/Diversion	63
Nebraska	Adverse Weather/Road Conditions	1
New Jersey	Traffic Advisory/Incident Management/Construction Support	2
New York	Traffic Information/Advisory/Diversion/ Incident & Traffic Management/ Construction and Maintenance Support/HOV Lanes	101
North Carolina	Reversible Lanes/Incident & Traffic Management/Construction & Maintenance Support/HOV Contraflow Lane Information/Special Events/Fog/Adverse Weather & Road Conditions/Weigh Station	1
Ohio	Adverse Road Conditions/Tourist Info	1
Oregon	Incident Management	8
	Adverse Road Conditions	5
	Earth Slides; Speed Control	1
Pennsylvania	Traffic Management & Diversion; Construction/Maintenance	3
South Carolina	Fog	7
	Weigh Station Control	9
Tennessee	Fog Detection & Warning System	30
Texas	Traffic Information/Advisory	2
	Traffic Management	9
	Traffic Management/Diversion	12
	Construction/Maintenance Support	3
	HOV/Contra-Flow Lane Information	37
	Special Events	1
	Bridge Information & Advisory	2
	Toll Road Authority	3
Virginia	HOV/Reversible Lanes/Exclusive Lanes/Traffic Conditions	139
	Tunnel & Bridge Control	69
Washington	Reversible Lanes	20
	Traffic Advisory/Incident Management/Diversion/Special Events	59
Wisconsin	Traffic Management	14
Wyoming	Adverse Weather/Road Conditions	21
	Tunnel Control	2
N.J. Turnpike	Direction	101
	Speed Limit	135
	Incident/Speed Warning	35
	Trailer Ban	1
	Sports Complex Diversion	2
Ontario	Traffic Advisory/Incident Management	25*

* Plus four portable mounted permanent signs.

TABLE 5

MOST RECENT SIGN PURCHASES (As of December 1995)

Agency	Number	Application	Year Purchased
Alabama	4	Bulb Matrix	1976
Alaska	2	Fiberoptic	1989–1990
Arizona	4	Reflective Disk	1980; 1991
	2	Light-Emitting Diode	1991
	33	Fiberoptic	1994–1995
California	51	Bulb Matrix	1992
	88	Bulb Matrix	1992
	52	Bulb Matrix	1993
	42	Bulb Matrix	1994
Colorado	2	Reflective Disk	1986
	1	Reflective Disk	1991
	33	Light-Emitting Diode	1992
Connecticut	1	Fiberoptic	1986
	14	Reflective Disk—Dimensional Square	1990
	2	Fiberoptic	1991
Idaho	2	Rotating Drum	1983
	2	Rotating Drum	1992
	1	Reflective Disk	1992
Illinois	10	Rotating Drum	1975
	1	Reflective Disk	1987
	19	Fiber/Reflective Disk	1992–1995
Iowa	3	Rotating Drum	1992
	4	Fiber/Reflective Disk	1994
Maryland	6	Fiber/Reflective Disk	1992; 1994
	1	Fiberoptic	1992
	4	Fiber/Reflective Disk	1992; 1994
Massachusetts	2	Static/Fiberoptic	1995
	1	Fiberoptic	1994
	2	Fiberoptic	1995
Michigan	12	Reflective Disk	1992
	1	Fiberoptic	1992
	1	Light-Emitting Diode	1992
Minnesota	6	Rotating Drum	1995
	1	LED	1995
	3	Rotating Drum	1994
Nebraska	1	Rotating Drum	1985
New Jersey	2	LED	1994
	1	LED	1995
New York	84	Fiberoptic-Reflective Disk (Retrofitted)	1994
	9	LED	1994
	8	Fiberoptic/Reflective Disk	1994
North Carolina	2	Reflective Disk	1991
Ohio	1	Reflective Disk	1992
Oregon	2	Fiberoptic	1991
	3	Fiberoptic	1992
Pennsylvania	2	Reflective Disk	1976
	1	Rotating Drum	1976
South Carolina	15	Fiberoptic	1991
Tennessee	10	Fiberoptic/Reflective Disk	1993
	10	Fiberoptic/Reflective Disk	1993
Texas	36	Fiberoptic	1995
	10	Fiberoptic/Reflective Disk	1995
	16	Amber LED	1995
Virginia	17	Reflective Disk	1991
	22	Reflective Disk	1992
	19	Reflective Disk	1992
Washington	2	LED/Reflective Disk	1991
	30	Fiberoptic/Reflective Disk	1992
	5	Back-Lit Split Flap	1995
	2	LED (Green/Red)	1990–1992
	14	LED (Amber)	1995
	16	Rotating Drum	1992
	29+	Neon	1972–Present

TABLE 5 (Continued)

Agency	Number	Applications	Year Purchased
Wisconsin	12	Fiberoptic/Flip Disk	1994
	1	LED/Flip Disk	1994
	1	LED	1994
Wyoming	23	Rotating Drum	(No Date Given)
N.J. Turnpike	120	Neon	1984–Present
	120	Flip Matrix	1989
	81	Rotating Drum	1971–1989
	2	LED	(No Date Given)
Ontario	3	Reflective Disk	1987
	13	Light-Emitting Diode	1989
	1	Fiberoptic/Reflective Disk	1989
	2	Fiberoptic/Reflective Disk	1995

lanes), this size may be too small for many locations for incident and congestion management applications. For example, the display of information about the location of an incident, the level of congestion (e.g., *HEAVY CONGESTION*) or temporal information (e.g., *AVOID 20 MIN DELAY*) requires displays with longer message lines.

Dudek (*3*) provides a list of nine recommended steps to selecting the size and type of CMS. The first two steps, 1) clearly establish the objectives of the CMS, and 2) prepare the messages necessary to accomplish the objectives, address the risk that an agency will select a CMS that does not have sufficient character space, and may lack the required legibility distance for the messages that must be displayed.

Long messages or CMSs with insufficient character length often require abbreviations and/or two-phase messages to be used. Dudek and Huchingson (*2*) provide guidelines for abbreviating messages. Although two-phase messages are used successfully by several transportation agencies on permanently mounted and transportable CMSs, Ontario indicated concern that two-phase messages reduce exposure time to each phase by 50 percent. The agency also found that drivers in Toronto sometimes reduce speed when two-phase messages are used on light-emitting CMSs at certain locations. Generally these impacts are temporary, usually as a result of a new sign or message. In the future, Ontario will require a minimum of 2 lines of 21 characters on new CMSs to ensure an entire message can be displayed at one time (*7*).

Guidelines for message length are presented by Dudek and Huchingson (*2, 3*) who caution about the maximum length of message that can be adequately read by motorists at given prevailing speeds. They recommend that messages should be exposed to drivers at a rate not to exceed 1 word of information per second. Thus, when the prevailing speed is 88.5 km/hr (55 mph), the message should not be longer than eight words (excluding prepositions), assuming a typical CMS legibility distance of 198 m (650 ft). If the message is too long, or if the environmental conditions are such that the legibility distance of the CMS is adversely affected, then the message length must be reduced accordingly. When the message is too long for the existing environmental conditions (which can change throughout the day), then motorists must reduce their speeds in order to read the message.

In addition to the required messages that the agency wants to display, selection of a sign line length is sometimes influenced by other physical characteristics inherent in the CMS design. For example, character modules for fiberoptic signs from some manufacturers are typically constructed in increments of three (e.g., signs can be purchased with either 12, 15, 18, 21, etc. characters per line). Thus, if fiberoptics was the desired CMS technology and 16 characters were needed for each line, the agency would have to purchase signs with 18 characters per line, accept the limitations of purchasing signs with only 15 characters per line, or pay the additional cost for specially fabricated modules.

As another example of sign characteristics influencing line lengths, Illinois cautions, in many cases, fewer characters can be displayed on a line of a continuous line matrix CMS than can be displayed on a line with modular characters (i.e., each character is displayed on a 5 × 7 matrix). They advise that, prior to purchase, agencies should carefully evaluate the specific message length capabilities of any continuous line matrix display being considered. Continuous line matrix displays often provide less message capability compared to modular matrix line displays. Whereas a full 20 characters are available on a manufacturer-rated 20-character modular matrix CMS, fewer than 20 characters can be displayed on a 20-character full line matrix CMS in some cases because of the width required for proportional characters. Illinois provides the following two examples of messages that were routinely displayed on a 20-character line modular disk matrix CMS but which were too long to display on a 20-character continuous line matrix CMS (using a desirable 2-pixel spacing between letters and 3- to 5-pixel spacing between words): *ALTERNATE ROUTE INFO* and *USE ALTERNATE ROUTE*. Care must be exercised to ensure that the specifications for continuous line matrix and full matrix CMSs are clear with respect to the number of characters and spacing between characters required on each line.

Character Height and Height-to-Stroke Width Ratio

Studies (*2, 3*) have shown that CMSs used on freeways in the United States should have character heights of at least 457

TABLE 6
MOST RECENT SIGN PURCHASES CLASSIFIED BY CMS TYPE

CMS Technology	Agency	Number Purchased	Year Purchased
Reflective Disk (Circular)	Arizona	4	1980; 1991
	Colorado	3	1986; 1991
	Idaho	1	1992
	Illinois	13*	1987
	Michigan	12*	1992
	North Carolina	2	1991
	Ohio	1	1992
	Pennsylvania	2	1976
	Virginia	58	1991; 1992
	Ontario	3	1987
Rotating Drum	Idaho	4	1983; 1992
	Illinois	10	1975
	Iowa	3	1992
	Maryland	4	1992
	Minnesota	9	1994; 1995
	Nebraska	1	1985
	Pennsylvania	1	1976
	Washington	16	1992
	Wyoming	18	1978–Present
	N.J. Turnpike	81	1971–1989
Fiberoptic	Alaska	2	1989–1990
	Arizona	33	1994–1995
	Connecticut	3	1991
	Maryland	1	1992
	Massachusetts	2	1994; 1995
	Michigan	1	1992
	Oregon	5	1991; 1992
	South Carolina	15	1991
	Texas	36	1995
Light-Emitting Diode	Arizona	2	1991
	Colorado	33	1992
	Michigan	1	1992
	Minnesota	1	1995
	Texas	16	1995
	Washington	14 (Amber)	1995
		2 (Red-Green)	1991
	Wisconsin	1	1994
	Ontario	14	1989; 1994
Fiberoptic/Reflective Disk	Illinois	10	1992
	Iowa	4	1994
	Maryland	6	1992; 1994
	New York	8 New	1994
		84 Retrofitted	
	Tennessee	20	1993
	Texas	10	1995
	Washington	30	1992
	Wisconsin	12	1994
	Ontario	3	1989; 1995
Bulb Matrix	Alabama	4	1976
	California	177	1992; 1993; 1994
Reflective Disk (Dimensional Square)	Connecticut	14	1990
LED/Reflective Disk	Washington	1	1991
	New Jersey	3	1994; 1995
	Wisconsin	1	1994
Back-Lit Split Flap	Washington	5	1995

[a] Some or all signs will be retrofitted with Fiberoptic enhanced reflective disk modules.

TABLE 7

CHARACTERISTICS OF MOST RECENTLY PURCHASED CMSs

Agency	Number	Sign Type	Year Purchased	Application: Fwy	Application: HOV	Application: Tunnel	Number of Lines	Characters Per Line	Nominal Character Height, mm (in.)	Legibility Distance in Specification m (ft)
Alabama	4	Lamp Matrix	1976	X			3	13	457 (18)	
Alaska	2	Fiberoptic	1989–1990	X			3	18	457 (18)[c]	244 (800)
Arizona	4	Reflective Disk	1980; 1991	X			3	18	457 (18)	130–155 (426–507)
	2	Light-Emitting Diode	1991	X			3	18	457 (18)	210–225 (687–738)
	4	Fiberoptic	1991	X			3	18	457 (18)[c]	250–260 (821–855)
California	12	Lamp Matrix	1991	X			3[d]	16[d]	457 (18)[d]	
	51	Lamp Matrix	1992	X			3[d]	16[d]	457 (18)[d]	
	83	Lamp Matrix	1992	X			3[d]	16[d]	457 (18)[d]	
	52	Bulb Matrix	1993	X			3[d]	16[d]	457 (18)[d]	
	42	Bulb Matrix	1994	X			3[d]	16[d]	457 (18)[d]	
Colorado	1	Reflective Disk	1991			X	3	20	457 (18)	
	25	Light-Emitting Diode	1991			X	1	18	457 (18)	
	4	Light-Emitting Diode	1991			X	2	18	457 (18)	
	4	Light-Emitting Diode	1991			X	3	18	457 (18)	
Connecticut	1	Fiberoptic	1986		X		3	12	457 (18)[c]	
	14	Reflective Disk	1990	X			3[b]	11[b]	457 (18)[b]	
	2	Dimensional Square Fiberoptic	1991				3	12	457 (18)[c]	
Idaho	1	Reflective Disk	1992	X			3	18	457 (18)	
	1	Rotating Drum (6)[a]	1992	X			2	16	406 (16)	
	1	Rotating Drum (6)[a]	1992	X			3	16	406 (16)	
Illinois	10	Rotating Drum (3)[a]	1975	X			1/2/3	18	406 (16)	
	1	Reflective Disk	1987	X			3	20	457 (18)	274 (900)
	19	Fiberoptic/Reflective Disk	1992–1995	X			3	21[f]	457(18)	
Iowa	3	Rotating Drum (6)[a]	1992	X			3	18	457 (18)	
	4	Fiberoptic/Reflective Disk	1994	X			3	18	457 (18)	278 (1000)
Maryland	2	Fiberoptic/Reflective Disk	1992	X			3	20	457 (18)	
	1	Fiberoptic	1992	X			3	18	457 (18)[c]	
	4	Rotating Drum (4)[a]	1992	X			3	18	457 (18)	
	4	Fiberoptic/Reflective Disk	1994	X			3	21	457 (18)	
Massachusetts	2	Static/Fiberoptic	1995		X		2		457 (18)	
	2	Fiberoptic	1995		X		3	16	457(18)[c]	
Michigan	12	Reflective Disk	1992	X			3	18	457 (18)	244 (800)
	1	Fiberoptic	1992	X			3	18	457 (18)[c]	244 (800)
	1	Light-Emitting Diode	1992	X			3	18	457 (18)	244 (800)
Minnesota	3	Rotating Drum (6)[a]	1994	X			3	16	406 (16)	
	1	Light-Emitting Diode	1995	X			3	18	457 (18)	
	6	Rotating Drum (6)[a]	1995	X			3	16	406 (16)	
Nebraska	1	Rotating Drum (6)[a]	1985	X			3	24	406 (16)	
New Jersey	2	Light-Emitting Diode	1994	X			3	11	457 (18)	274(900)
	1	Light-Emitting Diode	1995	X			3	15	457 (18)	274(900)

TABLE 7 (Continued)

New York	84	Fiberoptic/Reflective Disk	1994	X	X		3	16	457 (18)	
	8	Led/Reflective Disk	1994		X		2	15	457 (18)	
	1	Led/Reflective Disk	1994	X			3	15	457 (18)	
	8	Fiberoptic/Reflective Disk	1994		X		3	15	457 (18)	
North Carolina	1	Reflective Disk	1991	X	X		3	15	457 (18)	
Ohio	1	Reflective Disk	1992	X			3	20	457 (18)	305 (1000)
Oregon	2	Fiberoptic	1991	X			3	18	457 (18)[c]	366 (1200)
	1	Fiberoptic	1992	X			3	12	320 (12.5)	
	2	Fiberoptic	1992	X			3	18	457 (18)[c]	366 (1200)
Pennsylvania	2	Reflective Disk	1976	X			3	20	457 (18)	
	1	Rotating Drum (4)[a]	1976	X			3	10	305 (12)	
South Carolina	6	Fiberoptic	1991	X			3	15	457 (18)[c]	366 (1200)
Tennessee	20	Fiberoptic/Reflective Disk	1993	X			3	18	457 (18)	244(800)
Texas	12	Fiberoptic	1995	X			3	15	457 (18)[c]	305(1000)
	16	Light-Emitting Diode (Amber)	1995	X			3	18	457 (18)	305(1000)
	6	Fiberoptic/Reflective Disk	1995	X			3	18	457 (18)	305(1000)
Virginia	8	Reflective Disk	1991	X	X		3	11	457 (18)	
	9	Reflective Disk	1991	X	X		3	22	457 (18)	
	22	Reflective Disk	1992	X	X	X	3	22	457 (18)	
Washington	2	Light-Emitting Diode (Red/Green)	1990–1992	X	X		1	7	457 (18)	
	1	Led/Reflective Disk	1991	X	X		2	15	457 (18)	
	1	Fiberoptic/Reflective Disk	1992	X			2	21	457 (18)	
	30	Fiberoptic/Reflective Disk	1992	X			2	21–22	457 (18)	
	16	Rotating Drum	1992	X	X		1–3	Varies	406 (16)	
	14	Light-Emitting Diode (Amber)	1995	X			3	15	457 (18)[g]	280(900)
	5	Back-Lit Split Flap	1995	X			3	15	457 (18)[g]	280(900)
Wisconsin	9	Fiberoptic/Reflective Disk	1994	X			3[g]	21[g]	457 (18)[g]	280(900)
	1	Light-Emitting Diode/Reflective Disk	1994	X			3[g]	21[g]	457 (18)[g]	280(900)
	1	Light-Emitting Diode	1994	X			3[g]	21[g]	457 (18)[g]	280(900)
Wyoming	1	Rotating Drum (6)[a]		X			1	24	406 (16)	
	12	Rotating Drum (6)[a]		X			2	24	406 (16)	
	5	Rotating Drum (6)[a]		X			3	24	406 (16)	
N.J. Turnpike	120	Neon	1989–Present	X			4	21	406 (16)	
	120	Flap Matrix	1989	X			1[h]	2[h]	508 (20)	
	81	Rotating Drum (3)[a]	1971–1989	X			3	20	457 (18)	
	2	Light-Emitting Diode		X			3	20	457 (18)	
Ontario	3	Fiberoptic/Reflective Disk	1994	X			2	20	457 (18)	300 (983)
	1	Fiberoptic/Reflective Disk	1989	X			2	20	457 (18)	300 (983)
	13	Light-Emitting Diode	1989	X			3[e]	21[e]	457 (18)	300 (983)
	2	Fiberoptic/Reflective Disk	1995	X			2	25[f]	457 (18)	300 (983)

[a] Indicates the number of sides for each drum.
[b] Has full matrix. Typically uses 3 lines, 11 characters per line, 457-mm (18-inch) characters.
[c] The physical dimensions is 420 mm (16.5 inches); however, when illuminated, the visual effect, according to the manufacturer is approximately 457 mm (18 inches).
[d] Uses full matrix (96 lamps across, 25 lamps high) with 2400 lamps. Can display up to 3 lines, 16 characters per line, 457-mm (18-inch) characters. Can also display 610–mm (24–inch) characters on 2 lines or 914 (36–inch) characters on 1 line.
[e] Also has 7 x 5 character graphic or text display areas on both right and left side, used for text when displaying 25 characters.
[f] Nominal display length using line matrix; capacity is dependent upon character choice.
[g] Full matrix displays allow several letter heights, sizes, and graphics.
[h] Two-digit speed limit CMSs.

TABLE 8
SUMMARY OF CMS CHARACTERS PER LINE

Number of Characters per Line	Matrix CMSs		Rotating Drum CMSs	
	Percent of Agencies* (n = 27)	Percent of CMSs (n = 676)	Percent of Agencies (n = 9)	Percent of CMSs (n = 129)
10			11.1	0.8
11	11.1	3.6		
12	11.1	0.7		
13	3.7	0.6		
15	22.2	7.7		
16	11.1	48.2	22.2	8.5
18	40.7	20.9	33.4	13.2
20	25.9	1.9	11.1	62.8
21	18.5	9.9		
22	3.7	4.6		
24			22.2	14.7
25	3.7	1.9		
TOTAL		100%	100%	100%

*Does not add to 100% since some states have more than one type.

TABLE 9
SUMMARY OF CMS CHARACTER HEIGHT

Nominal Character Height mm (in.)	Matrix CMSs		Rotating Drum CMSs	
	Percent of Agencies* (n = 28)	Percent of CMSs (n = 684)	Percent of Agencies (n = 10)	Percent of CMSs (n = 145)
≤ 320 (12.5)	3.8	0.1	10.0	0.7
406 (16)	—	—	60.0	38.6
457(18)	100	99.9	30.0	60.7
TOTAL	*	100%	100%	100%

*Does not add to 100% since some states have more than one type.

mm (18 in.) to accommodate message requirements for most applications and audiences and the type of visual noise (e.g., competing commercial electronic advertising signs) usually present in urban and suburban environments. For other than freeway applications, letter heights between 254 and 457 mm (10 and 18 in.) are recommended based on 4.32 m/mm (36 ft/in) legibility index (*2, 3*). Also, it has been strongly recommended that, for highway applications other than freeways, letter heights of 254 mm (10 in.) or greater should be used for bulb matrix CMSs so that bulb brightness is sufficient (*8*). The implications of CMS type on character height are discussed in the following sections.

Matrix Signs

The results of the survey support the earlier research suggesting that a minimum 457-mm (18-in.) character height should be used on matrix CMSs installed on urban freeways. As can be seen in Table 9, all 28 agencies (100 percent) using matrix CMSs specify 457-mm (18-in.) characters. When classified by the number of CMSs, 99.9 percent of the matrix signs that were recently purchased for freeway applications have a 457-mm (18-in.) character height. Experience by Texas and Ontario supported earlier findings that matrix CMSs with 320-mm (12.6-in.) characters are too small.

Early fiberoptic CMS models were only available with a maximum 320-mm (12.6-in.) character height. Following installations, both Texas (Houston District) and Ontario found the 320-mm (12.6-in.) character signs to be too small for urban freeway applications, and are now specifying nominal 457-mm (18-in.) characters.

In practice, CMS character height is specified in terms of nominal character height. In most cases, the actual physical dimension of the character is smaller than the stated nominal character height. For example, Table 10 is a summary reported by Ontario of characteristics for the following types of CMSs: circular reflective disk, fiberoptic, and fiberoptic enhanced reflective disk. As indicated, the actual physical character height dimension for both the reflective disk and the fiberoptic enhanced reflective disk CMSs of 452 mm (17.8 in.) is very close to the cited nominal dimension of 457 mm (18 in.). In contrast, the actual dimension for the nominal 457-mm (18-in.) fiberoptic CMS is only 420 mm (16.5 in.).

The specific character height on light-emitting CMSs is an illusive measurement. A halo or blooming effect of illumination causes the character height of such signs to appear larger than the actual physical dimensions. One CMS supplier stated

TABLE 10
SUMMARY OF DISPLAY CHARACTERISTICS OF SELECTED CMSs USED IN ONTARIO (*7*)

Technology	Circular Reflective Disk	Fiberoptic/Reflective Disk	Fiberoptic	Fiberoptic
Number of lines	2	2	2	3
Characters per line	22	20	21	18
Actual Character height	452 mm (17.8 in)	452 mm (17.8 in)	320 mm (12.6 in)	420 mm (16.5 in)
Nominal character height	457 mm (18 in)	457 mm (18 in)	305 mm (12 in)	457 mm (18 in)
Stroke width	56 mm (2.2 in)	56 mm (2.2 in)	15 mm (0.6 in)	15 mm (0.6 in)
Height-to-width ratio	8:1	8:1	21:1	28:1
Display element color	fluorescent yellow disk	fluorescent yellow disk; yellow light	amber/yellow light	amber/yellow light

that when the sign is illuminated, the visual effect of the 420-mm (16.5-in.) high characters is approximately 457 mm (18 in.). Thus, this sign design is considered by the manufacturer to have a nominal 457-mm (18-in.) character. No objective data are available as of this writing on what effect the halo has on the perceived letter heights of light-emitting CMSs.

The halo effect of light-emitting CMSs also influences the required height-to-stroke width ratio needed to provide legible characters. Reflective disk and fiberoptic enhanced reflective disk CMSs provide height-to-stroke width ratios of 8:1. In contrast, fiberoptic CMSs have ratios of about 28:1. It should be noted that this ratio is much higher (thus producing a thinner character) than MUTCD standards for freeway static guide signs.

Rotating Drum Signs

As previously shown in Table 9, 30 percent of the agencies using rotating drum signs operate with 457-mm (18-in.) characters; an additional 60 percent of the agencies use 406-mm (16-in.) characters. Character heights, height-to-stroke width ratios, and the 406-mm (16-in.) legend are consistent with MUTCD static freeway guide sign requirements. Upper case letters are normally used on rotating drum signs.

Conspicuity (Target Value) and Legibility Distance

The visibility of CMSs depends on the visual capabilities of motorists and the photometric qualities of the signs. Two aspects affect sign visibility: 1) the ease with which the sign is first noticed and can be detected in the driving environment (conspicuity or target value), and 2) the ease with which the message can be read (legibility). The effectiveness of a CMS is largely dependent on the amount of time a motorist has to read the sign. In turn, the time available is primarily a function of the speed of travel, the distance away from the sign at which it is first noticed, and the legibility distance of the sign.

Recognizing that a CMS exists and is displaying a message is essential to obtain a reaction from motorists to the message. The luminance or brightness of a sign is an important factor in its visibility. Luminance is the amount of light emitted or reflected by a surface. The luminance of a sign is affected by time of day and by weather conditions. During a bright sunny day, the luminance must be much brighter for contrast. The problem is much more acute when the sun rays are directly behind or directly in front of the sign face. (*3*)

Specifications

None of the transportation agencies surveyed that purchased rotating drum CMSs indicated that they specified legibility distances in the specifications. Instead, the agencies tend to rely on the known legibility distances of static signs based on the type of character and color combinations chosen. Several, but not all, agencies specified legibility distances for matrix type CMSs—both light-reflecting and light-emitting—ranging, in general, from 229 to 366 m (750 to 1,200 feet).

Objective vs Subjective Evaluations

Most transportation agencies accept in good faith the information furnished by the manufacturers relative to the legibility distance characteristics of CMSs, although some agencies did indicate that they perform subjective assessments using technical staff who view the CMSs from the distances required in the specifications. These subjective evaluations are generally limited in scope and the process generally does not include evaluations under various environmental and lighting conditions (e.g., various sun positions).

Also, subjective evaluations do not assure that the eyesight proficiency of the agency personnel evaluating the CMSs truly represents the driving population as a whole. For example, objective field studies in Pittsburgh (*3*) and Phoenix (*9,10*) determined that the average legibility distance of a reflective disk CMS with 457-mm (18-in.) characters was 221 m (725 ft) and 213 m (698 ft), respectively, during daylight conditions. However, the study in Pittsburgh found the legibility distance of the sign for the 85th-percentile driver to be only 152 m (500 ft). The Phoenix study also found that the average

TABLE 11

DAYLIGHT LEGIBILITY DISTANCES FOR 457-MM (18-in.) BULB AND REFLECTIVE DISK MATRIX CMSs (*3*)

Character Style	Legibility Distance Bulb Matrix m (ft)		Legibility Distance Reflective Disk m (ft)	
	50th Percentile	85th Percentile	50th Percentile	85th Percentile
WORD, single-line, single-stroke	259 (850)	213 (700)	221 (725)	152 (500)
NUMBER, single-line, single-stroke	229 (750)	175 (575)	183 (600)	145 (475)
NUMBER, single-line, double stroke (thick/thin)	259 (850)	213 (700)		
NUMBER, triple line, blocked			244 (800)	145 (475)

nighttime legibility distance was only 108 m (355 ft). As can be seen, these values are much lower than the legibility distance of 229 to 366 m (750 to 1,200 ft) stipulated by many transportation agencies in their specifications.

To date, only a few experimentally controlled studies have been conducted in the United States to provide data concerning the legibility of light-reflecting and light-emitting matrix CMSs. The results of field studies conducted in the early 1980s by Dudek and Huchingson et al. (*11,12*) to measure the legibility distances of bulb and reflective disk matrix CMSs with 457-mm (18-in.) characters are shown in Table 11. These data indicate that legibility distances for bulb matrix CMSs are about 15 percent longer than reflective disk CMSs (for single-line, single-stroke words). Subjective studies by Caltrans (*13*) 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 457-mm (18-in.) letters indicated that messages were readable at a distance of 213 m (700 ft). The 213-m (700-ft) legibility distance is comparable to the average legibility distance of 221 m (725 ft) reported in Table 11, but much higher than the 85th percentile legibility distance of 152 m (500 ft).

TABLE 12

AVERAGE LEGIBILITY DISTANCES FOR LED AND FIBEROPTIC SIGNS UNDER DIFFERENT LIGHTING CONDITIONS (9,10)

Condition	Legibility Distance, m (ft)		
	Reflective Disk	LED	Fiberoptic
Mid-Day	213 (698)	226 (743)	300 (983)
Night	108 (355)	212 (694)	207 (678)
Washout	67 (219)	148 (487)	260 (853)
Backlight	128 (420)	153 (502)	201 (659)

Shown in Table 12 are the results of a field study conducted by Upchurch et al. (*9,10*) in 1991. This study measured the legibility distances of clustered LED (452-mm (17.8-in.) characters), fiberoptic (409-mm (16.1-in.) characters), and reflective disk matrix (457-mm (18-in.) characters) CMSs under four different lighting conditions: daylight, night, washout (sun facing sign), and backlight (sun behind sign). Although the authors did not control the contrast ratios of the signs to produce identical conditions, the studies provide additional insights on legibility distances. Compared against a stated acceptable legibility distance of 207 m (678 ft), the fiberoptic signs provided acceptable legibility distances and performed slightly better than the LED signs tested. Overall, the fiberoptic signs had a significantly higher average legibility distance than the LED or reflective disk signs during mid-day and washout conditions. Also, during backlight conditions, the fiberoptic and LED signs each had significantly higher average legibility distances than the reflective disk signs. At night, the fiberoptic and LED signs had similar legibility distances that were significantly higher than the reflective disk signs. The reader should be aware that LED lamp and sign technologies have improved since the study by Upchurch; additional field evaluations are needed to assess the newer LED CMSs.

Similar results were obtained by Delcan Corporation in 1992 (*7*) through field evaluation studies for Ontario of four CMSs shown in Table 13. Although Delcan indicated that the study design and experimental approach resulted in an apparent overestimate of conspicuity and legibility distances, they were able to make relative comparisons among the CMSs tested. The results of the studies, shown in Table 13, showed that during mid-day and nighttime conditions the average legibility distance of the 457-mm (18-in.) circular reflective disk CMS was not significantly different from the 320-mm (12.6-in.) fiberoptic CMS. The average legibility distance for the 457-mm (18-in.) fiberoptic CMS was not significantly different from the 457-mm (18-in.) fiberoptic enhanced reflective disk CMS. However, the average legibility distances of the 457-mm (18-in.) fiberoptic and the 457-mm (18-in.) fiberoptic enhanced reflective disk CMSs were significantly longer than the 457-mm (18-in.) reflective disk and the 320-mm (12.6-in.) fiberoptic CMSs.

Other legibility criteria have been developed abroad that differ from U.S. practice. For example, the Department of Transport (*14*), 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 14. As noted in Table 14, the United Kingdom requires a minimum character height of 420 mm (16.5 in.) for highway speeds up to 112 km/hr (70 mph). However, they are moving towards specifying a slightly larger 450-mm (17.7-in.) character height.

TABLE 13

COMPARISON OF AVERAGE MID-DAY AND NIGHTTIME LEGIBILITY DISTANCES OF SELECTED CMSs USED IN ONTARIO (*7*)

Technology	Legibility Distance Greater Than Technology Below	Legibility Distance Same As Technology Below
457-mm (18-in) Fiberoptic	457-mm (18-in) Circular Reflective Disk 320-mm (12.6-in) Fiberoptic	457-mm (18-in) Fiberoptic/Reflective Disk
457-mm (18-in) Fiberoptic /Reflective Disk	457-mm (18-in) Circular Reflective Disk 320-mm (12.6-in) Fiberoptic	457-mm (18-in) Fiberoptic
457-mm (18-in) Circular Reflective Disk		320-mm (12.6-in) Fiberoptic

TABLE 14

CHARACTER HEIGHTS DRAFT STANDARDS: DEPARTMENT OF TRANSPORT, UNITED KINGDOM (*14*)

		Minimum Character Heights mm (in.)	
Sign Group	Speed Range km/hr (mph)	Upper Case Only 5 x 7	Upper and Lower Case 7 x 9
Sign Group A			
Warning Signs	up to 112 (70)	420 (16.5)	560 (22.0)
Regulatory Signs			
Lane Control Matrix Signs			
Signs Conveying an enforceable speed limitation of prohibition			
Signs warning of impending hazard			
Sign Group B			
Motorway advisory signals	up to 96 (60)	300 (11.8)	400 (15.7)
Sign Group C			
Directional information signs	up to 80 (50)	200 (7.9)	270 (10.6)
Other informatory signs			
Information complementing Group A or or Group B signs			
Sign Group D			
Others	up to 64 (40)	90 (3.5)	120 (4.7)

Garvey and Mace tested a range of design parameters and CMS hardware types, and in a recent report (April 1996) provide CMS visibility data for both younger and older drivers (*15*).

Western Europe has adopted a legibility criterion of 200 m (656 ft) for light-emitting CMSs that display symbols for speed control and lane control over each lane on interurban motorways (*4*). The trend is toward CMSs having character heights of between 400 and 457 mm (15.7 and 18.7 in.) for the speed and lane regulation messages. France (*16*) specifies character heights between 400 and 475 mm (15.7 and 18.7 in.) for speed control CMSs, and 400 mm (15.7 in.) for information and direction CMSs installed on interurban motorways. Germany (*17*) specifies character heights between 430 and 465 mm (16.9 and 18.3 in.) for speed control CMSs. The Netherlands (*17*) requires 450-mm (17.7-in.) character heights. At least one highway agency in France found that although 320-mm (12.6-in.) fiberoptic CMS characters seem acceptable for the intercity motorways, 457-mm (18-in.) characters would be more comfortable for motorists to read (*18*). In the United States, character heights tend to be higher than those recommended in Europe because the messages are longer and the CMSs need to be more conspicuous against the complex visual backgrounds in urban areas.

MESSAGES

This section of the Synthesis summarizes the responses relative to the policies and practice of 1) developing and storing CMS messages, 2) splitting and sequencing messages, 3) automatic display of messages, 4) display of messages during non-incident conditions, and 5) message security.

Policy and Practice of Developing and Storing Messages

A summary of the authoritative procedure for developing messages is presented in Table 15. The first part of the table summarizes the availability of messages; the second part summarizes the manner in which messages are displayed (i.e., manually, automatically, or both. The data show that 20 of the 28 agencies responding (71 percent) reported operating

TABLE 15

CMS MESSAGE AVAILABILITY AND OPERATION

Agency	CMS Message Availability[a]			CMS Message Operation[a]			
	Computer Library Only	Computer Library and Supervisor Created as Needed	Computer Library and Operator Created as Needed	Automatically Activated	Human Operator Activated	Automatic with Some Operator Intervention	Human Operator with Some Automatic Intervention
Alabama		X					X
Alaska	X		X		X		
Arizona		X	X		X		Future
California		X			X		
Colorado		X			X		
Connecticut		X			X	X	X
Idaho	•	X			X		X
Illinois	X	X	X			X	X
Iowa	X	X	X	X	X		X
Maryland	•	X	X		X		
Massachusetts	X		X	X	X		
Michigan		X					X
Minnesota	•	X					X
Nebraska	•				X		
New Jersey			X	X	X		
New York		X					X
Ohio		X				X	
Oregon	X	X			X		X
Pennsylvania	•	X			X	X	
South Carolina		X					
Tennesee			X	X		X	
Texas	X	X			X		X
Virginia		X			X	X	
Washington		X	X	X	X	X	
Wisconsin			X	Future	X		
Wyoming	•				X		
N.J. Turnpike	X			X	X		
Ontario	X	X		X[b]		X	
	29%	71%	36%	25%	68%	29%	35%

[a] Agencies showing more than one method use different approaches with different systems.
[b] Congestion messages driven automatically by detector system.
• Rotating drum signs with fixed preestablished messages.

CMS systems with messages selected from a computer library, with special messages created as needed by supervisory personnel. Ten agencies (36 percent) reported that they allow trained operators to create messages during emergencies when the library does not contain messages that are necessary for the specific highway/traffic situation.

Nineteen agencies (68 percent) stated that the messages are displayed manually by CMS operators. Ten agencies (36 percent) stated that the signs are activated primarily by the operators but have some form of automatic intervention. Eight agencies (29 percent) operate CMSs automatically with some operator intervention. Seven agencies (25 percent) operate some CMS systems completely automatically.

SPLITTING AND SEQUENCING MESSAGES

Due to the nature of some incidents or diversion situations, it is often necessary to present messages longer than the sign is capable of displaying at a single time. This situation requires the message to be split into two or more parts that are sequenced on the CMS. These messages are referred to as sequenced, alternating, or multi-phased messages. (A sequenced message is actually two or more completely different computer library messages that are continually alternated or sequenced.) An example of sequencing is shown below.

ACCIDENT AT MILFORD AVE	UTOPIA TRAFFIC USE HARDY TOLL RD
Sequence 1	Sequence 2

Sequencing can be accomplished in one of two ways: 1) having sequencing capabilities built directly into the sign, and 2) through the master sign control software. Many CMSs have sequencing capabilities built into the sign. The sequencing capabilities of each sign vary, but may allow for up to six different message phases sequenced at a user-defined rate.

The other method in which sequencing is accomplished, through the master sign control software, can provide advantages in that one message in a library can be used as the first phase on several signs, while the second phase can use a different message from the library on each sign depending on its location.

Some transportation agencies use messages that sequence a single line on a sign. This is accomplished by creating two phases in which the other lines are identical, and only the line of interest is changed. An example is shown below.

Phase 1	Phase 2
ACCIDENT AT MILFORD AVE	ACCIDENT TAKE ROWLAND AVE

Automated Pre-Timed Display Of Messages

A few of the CMS systems allow for some automation in the message activation process. In most cases, this takes the form of pre-timed message actuation. CMS operators program the sign controller to activate or deactivate a display at a preset time. This process is sometimes used in planned situations such as construction/maintenance procedures and special events.

Automatic Grouping of Messages

Some transportation agencies use an automation technique referred to as grouping. Grouping allows the operator to place a certain number of signs into a group and associate a specific message with each sign so that when a single command is issued by the operator, the messages on all the CMSs in the group change appropriately. This further simplifies system operation and helps keep incomplete or conflicting information from being displayed. An example of automatic grouping of messages from Houston is shown in Table 16.

Messages During Non-Incident Conditions

A major issue facing transportation agencies is what should be done with the CMS when not in use for traffic information. As shown in Table 17, of the transportation agencies who responded to the survey, 20 of 26 (77 percent) have a policy of displaying messages only when unusual conditions are present on the facility and leave the CMS blank during other times. One additional agency, New Jersey Turnpike, displays traffic and highway information continuously for a dual-dual freeway facility. In contrast, eight agencies (28 percent) display safety slogans or other information. Five agencies (19 percent) display messages at all times. Alabama and New York display safety messages; Virginia displays day and time information; and Michigan displays the name of the upcoming exit. In Ontario, many of the CMSs were placed at locations typically used for static advanced exit signs. Consequently, in the absence of unusual conditions, the CMSs are used to display advanced exit information. Ontario was recently requested to display safety slogans as well. Maryland has adopted a practice of displaying safety messages about 20 percent of the off time. Three states—Idaho, Michigan, and Texas—do not have statewide policies and the practice varies among the districts, although most districts leave the CMSs blank in the absence of unusual conditions.

In the past, California has displayed public service messages on freeway CMSs in the Los Angeles area. Although these messages were transportation in nature (e.g., NEXT TIME

TABLE 16

AUTOMATIC MESSAGE GROUPING (Houston)

INCIDENT ON U.S. 59 NORTHBOUND NORTH OF IH-610 NORTH LOOP

Sign #1 On U.S. 59 Northbound at Collingsworth	U.S. 59 NORTH ACCIDENT AHEAD	AVOID DELAY USE HARDY TOLL EXIT IH 10 WEST
Sign #2 On IH-610 North Loop Eastbound at Fulton	U.S. 59 NORTH ACCIDENT AHEAD	AVOID DELAY USE HARDY TOLL ROAD
Sign #3 On IH-610 North Loop Eastbound at North Main	U.S. 59 NORTH ACCIDENT AHEAD	AVOID DELAY USE HARDY TOLL OR IH 45 N
Sign #4 On IH-610 North Loop Westbound at Jensen	U.S. 59 NORTH ALTERNATE ROUTE EXIT HARDY TOLL	
Sign #5 On IH-610 North Loop Westbound at Lockwood	U.S. 59 NORTH ACCIDENT AHEAD	AVOID DELAY USE HARDY TOLL ROAD

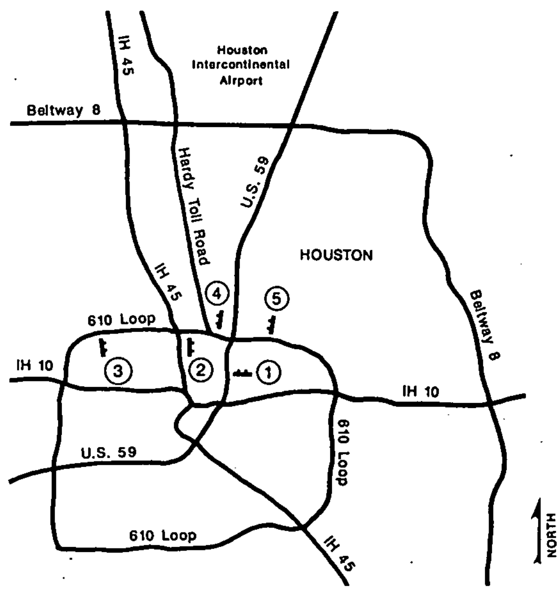


TABLE 17
SIGN STATUS DURING NON-INCIDENT CONDITIONS

Agency	Blank Sign	Safety Slogans or Other Information
Alabama		X
Arizona	X	
California	X	
Colorado	X	
Connecticut	X	
Idaho[a]	X	X
Illinois	X	
Iowa	X	
Maryland	X	X[c]
Massachusetts	X	
Michigan		X[a,f]
Minnesota	X	
Nebraska	X	
New York		X
North Carolina	X	
Ohio	X	
Oregon	X	
Pennsylvania	X	
South Carolina	X	
Tennessee	X	
Texas[a]	X	X
Virginia		X
Washington	X	
Wyoming	X	
N.J. Turnpike[b]		
Ontario		X[d]
	77%	28%

[a] Varies by District.
[b] Displays traffic/roadway information at all times for dual-dual freeways.
[c] Displays safety messages about 20 percent of the time.
[d] Exit information displayed in place of Advance Sign; safety information displayed at times.
[e] Does not add to 100% because some agencies indicated using both blank signs and safety slogans.
[f] Display lower case bottom line message with exit information only.

TRY AMTRAK TO LAS VEGAS; RELIEVE CONGESTION—RIDESHARE; etc.) they did not relate to the operation of the freeway system. Public reaction to the use of the CMSs in this manner was quite negative. There was a belief among the traffic operations professionals that such use led to a public disregard of messages on the CMSs, thus making the signs less effective when traffic operational messages were displayed. The practice has been discontinued; CMSs are now used only for messages pertaining to unusual real-time traffic flow conditions. In contrast, because of construction schedules, the CMSs were installed for the INFORM Project on Long Island more than 18 months before the system became operational. Adverse public reaction to having expensive CMSs sitting idle for several months prompted New York to adopt a policy of displaying some type of message on the freeway CMSs at all times.

Message Security

Measures are generally taken to minimize vandalism and/or improper use of the CMSs by unauthorized personnel. Most agencies have special access codes that are required for operators to create, display, or store messages.

EXPERIENCES WITH CMS TECHNOLOGIES

Each agency was asked about its experiences with the CMSs they had most recently purchased and installed. Information was requested on the following:

1. Best attributes of the CMSs;
2. Worst attributes (biggest problems);
3. What actions were taken to correct the problems; or
4. If the problems were not corrected, what could be done to correct the problems; and
5. What the agency will do differently in the future.

The responses are summarized in tables and discussed in the following paragraphs.

Reflective Disk (Circular)

Circular reflective disk CMSs have been very popular in the United States since the energy crisis in the 1970s, although light-emitting CMSs are currently gaining in popularity. Several positive features of the circular reflective disk CMSs reported by agencies, as shown in Table 18, included low power consumption, relatively low initial cost, and reliability.

Negative attributes of reflective disk (circular) reported by agencies are the low target value and the relatively low legibility under certain environmental conditions, particularly on signs facing east or west directions (although some agencies reported high visibility when the sun is reflecting on the sign face). This problem is exacerbated due to fading of the reflective coating on the flip disks over time in some cases, and problems with glare and deterioration (yellowing) of the plexiglass facing. The reduced contrast ratio between the disk elements and the sign background results in lower target value and legibility distances. Unfortunately, there does not appear to be any practical solution to deteriorating disks other than periodic replacement. The Dallas District in Texas recommended that the disk modules be replaced every two years, particularly on reflective disk signs facing the east and west directions because of the faster disk deterioration due to the sun rays. Also, since the disks are recessed from the sign face, the sun and external bulbs can cast shadows over portions of the message, making it illegible. In addition to target value and legibility concerns, some agencies have been less than satisfied with the mechanical reliability of the flip disk.

To increase the target value and legibility of circular reflective disk CMSs, some agencies (e.g., Illinois, Maryland, New York, Ontario) have retrofitted existing reflective disk signs with fiberoptic enhanced reflective disks. Each of the enhanced individual characters is composed of 35 single fiberoptic light points in a format of 5 light points wide by 7 light points high. The light points are closed or opened by the 90 degree rotation of the circular reflective disk. A hole approximately in the

TABLE 18

ATTRIBUTES OF REFLECTIVE DISK (CIRCULAR) CMSs

Agency	Year	Positive Attributes	Negative Attributes (Problems)	What Was Done to Correct the Problem	What Could Be Done to Correct the Problem
Arizona	1991 1982		Inadequate legibility distance at night, under backlit (by sun) conditions, and under washout conditions	Moved to better low use sites	Enhance disks with fiberoptics or LEDs
Colorado	1991 1986	Reliability. Ease of maintenance. User friendly operation. Legibility in various weather conditions.	Modem control with unreliable phone lines. Power surge on AC line causes signs circuit breaker to "trip"—requires field trip to remote locations of signs. Limited character display capability.	No inexpensive solutions have been found.	
Idaho	1992	Able to create messages on demand. Able to create different fonts, graphics. Remotely accessible. Battery backup.			
Illinois	1987	Reliable performance and cost-effective operations. Minimum maintenance requirements (low down-time). High visibility under high ambient lighting conditions. Low energy consumption.	Low target value (punch). Low visibility under low ambient (night) light.	Now under contract to replace disk modules with state-of-the-art fiber enhanced disk modules.	Change lettering and background colors.
New York	1982	Good visibility under most conditions if properly maintained. Fairly reliable Spare parts have been available for more than 10 years.	Lexan face yellows with age. External luminaries difficult to maintain; lane closures. Flip disks occasionally stick.	Replace lexan facing. Intend to retrofit signs; fiberoptic flip disk enhancement. Exercise all signs for 15 minutes every day.	Signs retrofitted with fiberoptics in 1994.
Ohio	1992	Dependable—no mechanical problems User friendly—easy to operate. Easy and fast installation.	Too small—not enough characters. Not mounted over roadway. Poor visibility under certain lighting conditions. No real-time sign display on controller; no diagnostics software.	Change purchase specifications to include 3 lines with 18-25 characters per line.	Retrofit flip disk to be fiberoptic enhanced.

TABLE 18 (Continued)

Agency	Year	Positive Attributes	Negative Attributes (Problems)	What Was Done to Correct the Problem	What Could Be Done to Correct the Problem
Pennsylvania	1976	Selectability of messages.	No verification feature of message on sign.		
		Relatively maintenance free.	Sporadic blanking out; sign would not always completely blank out.	Overhaul and revamp sign by manufacturer.	
		Target value of display.	Requires high degree of computer skills.	Training.	
		Ease of serviceability.			
Texas	1991	Good message write speed.	Moderate communications failures caused by inadequate line driver design.		Upgrade line drivers to meet environmental requirements.
		Reliable dot operation.	Plexiglass glare problems.	No good solution to plexiglass glare.	
		Controller software very flexible and easy to use.			
		Low power consumption.	Reflective disks fade.	No practical solution; considered inherent in sign design.	
		Relatively low cost.	Frequent failure of disk element.	No practical solution; considered inherent in sign design.	
Washington	1991	Variable character width.	Variable character width can "chop" letters off at end of line.	Better selection of messages.	Moving to either fiberoptic or LED units.
		Cost-effective weigh station control	Mounted on side of road.	Too small to mount over road.	Mount over roadway.
Ontario	1992	Reliability.	Visibility.	Internal illumination; retrofits initiated, but were a failure	Intrinsic to design.
		Cost.	Mechanical reliability.	Convert to fiber/flip disc	Purchase other technology
		Weight.			
		Low power consumption.			

TABLE 19

ATTRIBUTES OF REFLECTIVE DISK (THREE-DIMENSIONAL CUBE) CMSs

Agency	Year	Positive Attributes	Negative Attributes (Problems)	What was Done to Correct the Problem	What Could be Done to Correct the Problem
Connecticut	1990	Full matrix usage.	Cube requires mechanical rotation once each day to prevent sticking.	Test schedule was created to "exercise" all signs daily.	
		Capability to display various character fonts and full matrix graphics.	Cube drivers are located in sign.		
		Rear access for all sign maintenance.	Magnetized cubes require power—in the event of power failure, sign will stay in last state.		
		DOS-based controller software.			

center of each disk permits the passage of light through the disk to the motorist when the disk is in the "ON" position. A shroud mounted on the back of each disk prevents light from passing through the disk when the disk is rotated 90 degrees to the "OFF" position. (*19*)

Reflective Disk (Three-Dimensional Cube)

Only one state (Connecticut) reported using three-dimensional cube reflective disk CMSs for the applications being addressed in this synthesis. The primary advantages summarized in Table 19 are the ability to use the full matrix, providing the capability of displaying various character fonts and sizes and graphics. Experience to date has found this type of sign to have problems with the cubes sticking. To circumvent this problem, Connecticut has developed a daily test schedule to "exercise" the cubes. Other negative attributes cited are that the cube drivers are located in the sign and since the cubes require power, the sign will stay in the last message state when there is a power failure.

Rotating Drum

Ten of the agencies responding to the survey had recently purchased rotating drum CMSs. The rotating drum sign enjoys long-term popularity with several agencies, particularly in the northern region of the United States. Among the positive attributes mentioned by those responding to the survey (Table 20) are low initial cost, good reliability, ease of maintainability, low maintenance cost, good legibility, similarity to normal static signing (although some agencies believe this is a disbenefit), and the ability to incorporate highway route markers into the message. The major limitation of rotating drum CMSs is the lower number of messages that can be displayed in comparison to matrix-type signs. However, Minnesota has been satisfied with the number of messages available using 3-line, 6-sided drum signs for traffic management and diversion.

Bulb Matrix

Table 21 summarizes the attributes of bulb matrix CMSs reported by the two most recent purchasers of this type of sign (Alabama, California). The major advantages cited were that the bulb matrix signs have the best visibility intensity under all environmental conditions, provide a good cone of legibility (a restriction with some light-emitting technologies), and can facilitate the interchange of parts. The major negative attribute to this type of sign is the cost of both power consumption and maintenance (including bulb replacement).

Fiberoptic

A summary of the attributes reported by the eight agencies that recently purchased shuttered fiberoptic CMSs is presented in Table 22. The reports by the agencies have been very favorable. The major positive attributes cited are that they provide good conspicuity (target value) and good legibility. One design characteristic of fiberoptic CMSs that could be considered a negative attribute is the narrower cone of legibility relative to some other types of sign technologies. This requires that extra care must be exercised in placement and positioning of the signs.

Light-Emitting Diodes (LED)

Attributes of LED CMSs are summarized in Table 23. Early installations of LED CMSs in Europe indicated that the characteristics of the standard LEDs were inadequate for highway applications because of their low visibility. The development of super bright LEDs that provide improved outdoor sign luminance in comparison to standard LEDs has spurred interest in LED sign technology in North America in recent years. The first LED CMSs installed in North America used a combination of red and green LEDs to simulate the amber color. Recent technology breakthroughs now allow the use of yellow (amber) LEDs.

TABLE 20

ATTRIBUTES OF ROTATING DRUM CMSs

Agency	Year	Positive Attributes	Negative Attributes (Problems)	What Was Done to Correct the Problem	What Could Be Done to Correct the Problem
Idaho	1983	Easy to select messages. Once message is selected, no mechanical parts to fail.	Limited number of messages. Can only change message at site.		Investigating feasibility of replacing with current technology.
	1992	Computer actuated. Illuminated and flashing beacons.	Limited number of messages. Difficulty in changing the permanent available messages. Cost. Subject to power outage and telephone outage.		May try other types of signs.
Illinois	1975	Reliable operation regardless of weather conditions. Good visibility. Responds well to lighting.	Legend and background color (white on green indistinguishable from routine information/guide signing.		Change lettering
Iowa	1992	Good legibility during all conditions. Low maintenance cost. Low initial cost.	Limited number of messages.		
Maryland	1992	Looks like a normal static sign. Good legibility at long distance with 457-mm (18-in) character height. Interstate shields, etc., can be screened/mounted on sign face in full color (rotating drum changes the route number).	Not versatile (can only be used where diversion choices are limited. Maintenance problems (had prototype sign). Greater power needed to operate (when changing messages and lights and heaters are operating simultaneously).		Use this product for special situations.
Minnesota	1991 1992	Extremely low maintenance requirements; Very reliable. Message legibility is far superior to other technologies. Target value distance. Low capital cost.	Second line message flexibility is limited in some locations.	Careful message design.	
Nebraska	1985	Low initial cost. Good legibility.	Limited number of messages. Inability to change fixed messages.		Replace with different technology.
Pennsylvania	1976	Ease of operation. Ease of serviceability.	Only 3 possible messages. Motorists tend to disrespect.	Closer monitoring by operators.	
Washington	1992	Looks like standard sign. Lower costs.	Messages do not give much information.		

TABLE 20 (Continued)

Agency	Year	Positive Attributes	Negative Attributes (Problems)	What Was Done to Correct the Problem	What Could Be Done to Correct the Problem
Wyoming		Ease of maintenance. Simplicity. Reliability. Visibility.	Fixed messages—not flexible enough to describe all adverse weather conditions. Accuracy of messages compared to actual conditions. Location of signs, conditions at sign may be favorable while sign messages advise of poor weather conditions. Drum utilization—message content on each drum not consistent throughout districts within the state.	Research conducted by local university.	
N.J. Turnpike	1989	Legibility. Standard looking signs. Reliability.	Flexibility—only provides a limited number of messages.	New technology will provide greater flexibility.	

TABLE 21

ATTRIBUTES OF BULB MATRIX CMSs

Agency	Year	Positive Attributes	Negative Attributes (Problems)	What Was Done to Correct the Problem	What Could Be Done to Correct the Problem
Alabama	1976	More noticeable than a regular sign. Able to change the warning message when necessary.	Sign system does not work well in humid climate. Can no longer get parts for the units we have. Very expensive to maintain. Cost of power is $8,000 per year with a $4,400 per year maintenance contract for the computer.		
California	1991 1992	Visibility intensity—best in all environmental conditions. Good cone of vision. Standardization of software—any manufacturer's Model 500 can be operated by Caltrans standardsoftware. Interchangeability—all parts are compatible.	Cost of operation (power consumption). Maintenance.	Districts have been advised that full intensity is not always required. Alternate technologies are under review for use in Model 500. Soft start feature has been added to increase lamp life. Incoming voltage is sensed; Environmental light intensity and clock at site to vary lamp intensity (dim & reduce power); 170 controller does "health check" on sign to know lamp failure, SS switch failure (on & off), and false lamp turn on.	

TABLE 22

ATTRIBUTES OF FIBEROPTIC CMSs

Agency	Year	Positive Attributes	Negative Attributes (Problems)	What Was Done to Correct the Problem	What Could Be Done to Correct the Problem
Alaska	1989 1990	Provide information to traveling public Computer works well	Would be better if they were moveable		
Arizona	1991	Very good legibility distance under all lighting conditions Significantly higher overall average legibility distance than LED or reflective disk signs Much less visual discomfort than LED or reflective disk signs			
Connecticut	1986 1991	No mechanical moving parts	Sharp cut-off; 20° cone of visibility	Used "non leased" bundles which widened the cone	
		Good visibility in adverse weather	Low life of lamps	Used higher voltage lamps—extended life	
Maryland	1992	Good legibility Good conspicuity Good reliability			
Massachusetts	1994 1995	Conspicuity Clarity of meaning Legibility Visibility	Message control	Adjustment of timing of messages	
Oregon	1991 1992	Good legibility	Had to go FHWA experimental project to get best product	No solution other than sole source; can get very inferior products for slightly less cost	Quality & performance are excellent; how do we ensure subsequent signs are equal without going sole source
		Program flexibility Good sign construction Good manufacturer cooperation	Long lead time Modem problems (agency supplied)	No solution—logistics Changed modems—jumpwired	
South Carolina	1991	Good visibility during adverse weather	Narrow cone of vision	Nothing	Additional lighting arrestors
Texas	1992– 1995	Good message visibility	Letters too small 320 mm (12.5 inches)	Purchased signs with larger letters 457 mm (18 inches)	

TABLE 23

ATTRIBUTES OF LIGHT EMITTING DIODE (LED) CMSs

Agency	Year	Positive Attributes	Negative Attributes (Problems)	What Was Done to Correct the Problem	What Could Be Done to Correct the Problem
Arizona	1991	Good legibility distance for daytime and nighttime lighting conditions	Power consumption is high because fan ventilation is required to dissipate heat produced by LEDs.	Number of ventilation fans running continuously was reduced from two to one to reduce power consumption. (Two fans operate when message is displayed.)	
			Transparent panel on face of sign reflects sunlight and headlight illumination; leading to legibility problems and visual discomfort.		Use a flat black matte finish for a background rather than have a continuous transparent cover over the sign.
			Marginal legibility distance under backlit (by sun) and washout lighting conditions.		Increase light output levels of LEDs; Change LEDs with higher light output levels; Change to (now available) yellow LEDs
			Light output decreases at very high temperatures. Smaller cone of legibility (viewing angle) than fiberoptic signs.		
Colorado	1991	Good target value	First signs were too bright	Modified to allow 12 levels of brightness keyed to photocell	
		Minimum maintenance	Color tended to approach orange rather than the desired yellow.		
		Long bulb life			
New Jersey	1994 1995	LED—Amber Color Legibility Conspicuity Site Distance	Cellular phone communication Irregular character formation	Still a problem Board level changes by manufacturer	
Wisconsin	1994	Color No moving parts Back-lit legibility	Unreliable power supply Inconsistent color across the sign	Replacing power supply Replacing LEDs	
Ontario	1989 1995	Visibility	Reliability	Design project follow-up to determine solutions and effectiveness. Next generation sign now under test. Looks very good.	Modifications in specs have already been made to resolve many issues; Implementation of the next generation signs will provide feedback as to its adequacy.
		Solid state design Color capability Fast updates on messages	Power consumption Weight Cost		

The Ontario Ministry of Transportation is considered to be the pioneer transportation agency in the use of LED CMS technology in North America. Thirteen large LED signs were installed by Ontario in 1989. These have provided an important testbed for LED CMS technology. One major advantage cited by the Ministry when this technology was selected was that the sign would be totally solid state and would have no mechanical parts. Thus, the Ministry expected maintenance to be extremely low compared to other existing CMSs. Life expectancy of each LED was 100,000 hours or the equivalent of about 12 years of CMS operation. The signs were specially fabricated since the CMSs are much larger than typical freeway CMSs. In addition to three lines of legend having 21 5 x 7 LED modules for characters on each line, a 7 x 5 matrix of 5 x 7 LED modules is positioned on both the left and right sides of the sign. This results in a matrix of 35 LED modules high by 35 LED modules wide. The side matrices are used to display highway shields, arrows, and other graphics. Each pixel in the 5 x 7 LED modules has a cluster of 63 LEDs—9 red, 54 green—resulting in a total of approximately 300,000 LEDs in each CMS. *(20)*

Experiences by the Ministry were very encouraging, although there have been some development problems—a not too uncommon situation when developing new technology. One of the positive features of the LED signs is their good visibility. However, the reliability has been less than expected and the power consumption greater than expected. The large number of LEDs and their relatively close spacing has caused the signs to occasionally overheat. Also, the initial design of the sign and cooling system caused moisture to be sucked into the sign housing. Another major concern is the inconsistency and the deterioration of LED colors. Because of the heat generated from the LEDs (due to the sign design), the Ministry continues to have difficulty in maintaining the desired amber (yellow) color for the messages using the combination of red and green LEDs. Improvements continue to be made based on the experiences by the Ministry. One new CMS with the new amber (yellow) color LEDs was purchased and will be field-tested. The Ministry speculates that the use of the single color new super bright amber (yellow) will help reduce color uniformity problems associated with mixing red and green colored LEDs. Modifications to specifications have been made to resolve these and other issues. Implementation of the next generation signs will provide additional feedback in the future.

The 33 LED signs in Colorado are more typical of the size used for highway applications and were fabricated by a different manufacturer than the signs used in Ontario. Colorado reports positive results, but is also experiencing some problems. It has been difficult getting the desired United States standard yellow (amber) color using a combination of red and green LED clusters. Another problem experienced by Colorado was that the signs were too bright. This problem was resolved when the signs were modified to allow 12 levels of brightness keyed to photocell readings on the signs.

An interesting report surfaced just prior to the publication of this synthesis. The Maryland State Highway Administration noticed that a certain type of non-prescription sunglasses appeared to block the transmittance of messages on CMSs with amber LEDs that were being used in construction zones. For all practical purposes, this made the message invisible to drivers wearing these sunglasses. This phenomenon was verified in limited laboratory tests by FHWA. The laboratory findings indicate a severe attenuation of the LED emission by some sunglasses. This is due to a notch-filter (a filter that screens out a very narrow band of radiation) in the lenses of these sunglasses in the 580 to 600 nanometer range.

Accordingly, on July 15, 1996, FHWA issued a "Policy on the Use of Traffic Control and Warning Devices Based on Amber LED Technology in Traffic Operations and Highway Maintenance Activities." The sunglasses in question produce visibility problems only in the amber range of the spectrum. Thus the policy applies only to devices that contain amber LEDs. It should be noted that a number of manufacturers distribute hybrid CMS technologies that use LEDs to supplement reflective disks. The policy does not apply to those devices if they are capable of meeting the Department viability requirements without the use of the supplemental LEDs.

Fiberoptic Enhanced Reflective Disk

Manufacturers of circular reflective disk CMSs have incorporated fiberoptic glass or plastic bundles to emit light in the middle of each disk as a means of increasing target value and legibility. Six agencies reported purchasing this type of sign. The limited experience in North America has been very favorable (Table 24). Maryland, Washington, and Ontario reported good conspicuity and legibility in all traffic directions, including east and west. This is a considerable improvement over standard reflective disk CMSs. The agencies also reported good reliability. As a result of the initial experiences, four agencies (Illinois, Maryland, New York, Ontario) reported that they are replacing disk modules with fiberoptic enhanced reflective disk modules on many of their existing circular disk CMSs.

LED Enhanced Reflective Disk

A slight permutation of the fiberoptic enhanced reflective disk CMS is the LED enhanced reflective disk CMS. Two agencies (Washington and Wisconsin) reported using LED enhanced reflective disk signs (Table 25). Washington reported high visibility in all traffic directions. There has not been sufficient experience to provide additional comments regarding the positive and negative attributes beyond the statement of high visibility.

FUTURE CMS TECHNOLOGY PURCHASES

The agencies were asked which CMS technologies they would and would not consider for future purchases. The results, summarized in Table 26, indicate that although some of the agencies will consider light-reflecting CMS technologies, the trend is toward the newer light-emitting technologies. Of

TABLE 24

ATTRIBUTES OF FIBEROPTIC ENHANCED REFLECTIVE DISK CMSs

Agency	Year	Positive Attributes	Negative Attributes (Problems)	What Was Done to Correct the Problem	What Could Be Done to Correct the Problem
Iowa	1994	Good legibility under all conditions	Mechanical failures of disks (not a frequent problem)		Improvement in the shutter device
		Message flexibility compared to rotating drum			
Maryland	1993; 1994	Good legibility Good conspicuity Good reliability			
Tennessee	1993	Good legibility Good target value			
Washington	1992	Highly visible in all directions Mounted over roadway Variable light levels	Unknown at this time		
Wisconsin	1994	Back-lit legibility Front-lit legibility	Too many mechanical parts Too many connected systems, disk drivers, light drivers		
		Light intensity control (using photocells) Full matrix allows graphics			
Ontario	1989	Visibility Reliability Cost Low power requirements	Experimental signs Limited dimming light level range Extensive cooling subsystem Mechanical-electro design	N/A; Prototype sign	Unknown at this time

TABLE 25

ATTRIBUTES OF LED ENHANCED REFLECTIVE DISK CMSs

Agency	Year	Positive Attributes	Negative Attributes (Problems)	What Was Done to Correct the Problem	What Could Be Done to Correct the Problem
Washington	1992	Highly visible at night and better during the day compared to reflective disk Mounted over roadway	Unknown at this time		
Wisconsin	1994	Color Legibility Intensity control	Mechanical switching of LEDs Too many moving parts		

the agencies that responded, approximately the same number would likely consider light-reflecting technologies (reflective disk and rotating drum) as would not consider them. A large proportion (22 out of 26) of the agencies stated that they would not consider bulb matrix technology; whereas, almost all of the agencies would consider other light-emitting technologies (fiberoptic, LED, fiberoptic enhanced reflective disk). (Note: Since the LED enhanced fiberoptic is a very recent introduction in CMS technology, it was not cited by the agencies.) The reasons cited by the agencies concerning purchasing the various CMS technologies are summarized in Tables 27 and 28.

TABLE 26

TYPES OF CMSs THAT WOULD OR WOULD NOT BE CONSIDERED IN THE FUTURE

Type of CMS	Number of Agencies	Would Consider (% Agencies)	Would Not Consider (% Agencies)
Circular Reflective Disk	25	52	48
Rectangular Reflective Disk	25	56	44
Dimensional Square Refl Disk	24	54	46
Rotating Drum	22	32	68
Bulb Matrix	26	12	88
Fiberoptic	27	89	11
Light-Emitting Diode (LED)	26	96	4
Fiberoptic/Reflective Disk	26	81	19

TABLE 27

REASONS CITED FOR CONSIDERING VARIOUS CMS TECHNOLOGIES FOR FUTURE PURCHASES

	Light-Emitting CMSs	Bulb Matrix CMSs	Rotating Drum CMSs
Better legibility in various environmental conditions	X	X	
Better conspicuity (target value)	X	X	
Good legibility			
Lower power cost	X		X
Reliability	X		X
Lower maintenance and maintenance cost	X		X
Ease of repair	X		X

TABLE 28

REASONS CITED FOR NOT CONSIDERING VARIOUS CMS TECHNOLOGIES FOR FUTURE PURCHASES

	Light-Emitting CMSs	Bulb Matrix CMSs	Rotating Drum CMSs
High initial cost	X		
High power cost		X	
High maintenance cost		X	
Some technologies are still not proven	X		
Some technologies have low cone of vision	X		
Limited message capability			X

CMS STANDARDS

Developments by Transportation Agencies

The agencies were asked whether they have developed CMS standards for the following: sign dimensions (including height, length, depth, number of message lines, minimum number of characters per line); target value distance during various environmental conditions; design and installation to optimize target value (contrast ratio between sign and background, external illumination, sign positioning in the field, sign placement); and design to optimize legibility distance (border dimensions, contrast ratio between legend and sign background, character height and width, spacing between lines and characters). The affirmative responses are summarized in Table 29. Most states do not have many statewide CMS standards, and the traffic engineering community is far from achieving nationals standards, although there have been immense improvements in the last few years. One reason for this weakness is that the use of CMSs is still new to many transportation agencies, even though CMSs have been in existence since the early 1960s.

TABLE 29

CMS STANDARDS

	A	B	C	D	E 1	E 2	E 3	E 4	F 1	F 2	F 3	F 4	F 5	F 6	F 7	G	H
Alabama																	
Alaska																	
Arizona																	
California	X	X										X	X	X	X		
Colorado																	
Connecticut	X	X					X	X			X	X	X	X	X	X	X
Idaho																	
Illinois																	
Iowa		X										X					
Maryland	X	X						X	X		X	X	X	X	X	X	
Massachusetts																	
Michigan																	
Minnesota	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Nebraska																	
New Jersey	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X
New York	X	X				X[a]					X	X	X	X	X		
North Carolina																	
Ohio	X	X									X	X	X			X	
Oregon	X	X	X	X					X			X		X	X	X	X
Pennsylvania																	
South Carolina																	
Tennessee	X	X					X	X									
Texas[a]	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Virginia	X	X	X	X		X	X	X			X	X	X	X	X		
Washington																	
Wisconsin																	
Wyoming	X	X							X		X	X	X	X	X		
N.J. Turnpike																	
Ontario	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	
Percent of Agencies	46%	50%	14%	18%	14%	21%	25%	29%	25%	14%	36%	46%	39%	39%	39%	29%	14%

[a] Has state-wide specifications that have been modified by each district.

A. Sign dimensions (height, length, depth).
B. Sign dimensions (number of message lines, max. number of characters per line).
C. Target value distance during various environmental conditions.
D. Message legibility distance during various environmental conditions.
E. Design and installation to optimize target value (conspicuity);
   1. contrast ratio between sign and background
   2. external illumination
   3. sign positioning in field
   4. sign placement

F. Design to optimize legibility distance
   1. border dimensions
   2. contrast ratio between legend and sign background
   3. external and internal illumination
   4. character height
   5. character width
   6. spacing between lines
   7. spacing between characters.

G. Protocol communications with the CMSs.
H. Criteria and field/laboratory procedure for measuring CMS target value and legibility distances during various environmental conditions.

Contrast Ratio and Legibility

The contrast ratio is used to describe the legibility characteristics of signs during daylight conditions. It is the ratio of the luminance of an object to the luminance of the background. For CMS technology, the contrast ratio is the ratio of the sign legend to the legend background (sign panel).

The responses show that the agencies are much more comfortable with their knowledge of the physical characteristics of CMSs than they are with visibility and legibility issues. Almost one-half of the agencies have established standards for sign dimensions and physical characteristics such as character height and width and spacings between lines and characters. Conversely, less than a handful of agencies have standards for contrast ratios.

Interestingly, although the survey indicates a consistent dissatisfaction with the conspicuity and legibility of certain types of CMSs, some agencies do not appear to be moving toward specifying CMS criteria that ensure adequate visual performance. Almost every agency relies on specifying minimum legibility distances that the CMSs must meet. However, as noted elsewhere in this synthesis, most transportation agencies rely on legibility information provided by the manufacturers. Some agencies conduct field evaluations, but generally not to the extent that sufficient objective legibility data are collected. The legibility data provided by manufacturers are, at best, subjective. Until sound objective contrast ratio criteria are established, it is likely that some transportation agencies will continue to install CMSs with less than optimum visual characteristics.

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. Limited research suggests that optimum legibility of light-emitting CMSs is obtained when the contrast ratio between the legend and the sign background is between 8 and 12. Legibility may be regarded as acceptable for contrast ratios between 3 and 25 (*21*). Based on work by French researchers, France specifies that the contrast ratio should be between 3 and 25 for daytime operations (*16*). The criteria proposed by the United Kingdom are shown in Table 30 (*14*). 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.

A problem common to both light-emitting and light-reflecting matrix CMSs is message contrast reduction caused by the reflection of light off the plexiglass sheeting ("glare screen") used to protect the sign face. CMSs with new plexiglass sheeting typically produce appropriate contrast levels; problems occur mainly when the plexiglass is allowed to become dirty or scratched. It is not uncommon with some CMSs for the plexiglass to accumulate dirt on the inside as well as the outside. Regular cleaning of dirty screens, and replacement of those that become excessively scratched is highly recommended.

TABLE 30

LIMITS OF CONTRAST RATIO 10° AND 20° ILLUMINATION DRAFT STANDARDS: DEPARTMENT OF TRANSPORT, UNITED KINGDOM (*14*)

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, and 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, and Signs for car parks

Although the importance of the contrast ratio is recognized, there are no formalized procedures in the United States for measuring the contrast ratio of CMSs when they are purchased. Most transportation agencies subjectively evaluate contrast ratio indirectly by viewing the legibility distances of the signs.

Lessons Learned Relative to Standards and Specifications

The transportation agencies were asked what they would do differently in the future relative to standards, specifications, and maintenance agreements as a result of their experiences to date. The results are summarized in Table 31. About 30 percent of the agencies indicated that in the future, they will improve on the quality and specificity in their standards and specifications. Twenty-one percent of the agencies indicated that they would consider other CMS technologies for future purchases—suggesting the need for more thorough review of the technologies prior to purchase.

CMS FAILURES

One of the few documented analyses of CMS failures relative to light-emitting CMS technologies was conducted by Delcan Corporation for Ontario (*7*). A review of failures was undertaken for the fiberoptic, fiberoptic enhanced reflective disk, and reflective disk CMSs listed in Table 13. The analysis was conducted from periods in 1990 when the signs became operational until mid March 1991.

Although Ontario was able to summarize failure rates and frequencies and durations of down times for each CMS, a lack

TABLE 31

LESSONS LEARNED: CMS PURCHASES

Agency	As a result of your experiences with the above CMSs, what will you do differently in the future relative to standards, specs, maintenance agreements?
Alaska	Make place to pull off road to service the signs. Bring moveable sign to site. Use U.S. made equipment.
Arizona	Tighten specifications.
California	The CMS (Model 500) is very close, if not already, a complete specification. Had it been feasible to work with a prototype, the development standards and specifications would have been made much easier.
Colorado	Upgrade and redesign sign control systems as part of a modernization project for all electronic control systems at the Eisenhower Tunnel.
Idaho	May try other types of signs. Use sign bridge structures (overhead) instead of cantilever structures.
Illinois	Consider color change for reversible lane panels (drum signs).
Iowa	Specify a walk-in enclosure—easier maintenance and fewer lane closures. Require demonstration and pre-approve CMS manufacturers.
Maryland	Specify all maintenance/parts to roadside; provide walk-in enclosures with roadside access to reduce lane closures when maintaining these signs; develop standard specifications for communications and mechanical requirements for all CMSs.
Massachusetts	Nothing
Michigan	Select new equipment with fewer moving parts.
Minnesota	Work with sign manufacturers to develop fiberoptic and/or LED displays.
Nebraska	Consider other types of CMSs.
New Jersey	Never use cellular.
New York	Use newer technology. Fiberoptic enhanced flip disk signs have greatly enhanced visibility and eliminate need for external illumination.
North Carolina	Plan to purchase 11 fiberoptic CMSs. Develop more detailed specifications and plans. Require some type of universal communication protocol and software to enable us to operate signs made by different manufacturers, and in the future have a centralized communication center.
Ohio	Mount 3-line signs, 18-25 characters per line, over roadway. Use fiberoptic-enhanced flip disk signs, LED signs or fiberoptic signs.
Oregon	Quality and performance are excellent; how do we ensure subsequent signs are equal without sole source.
Pennsylvania	Require better environmental enclosure for sign, sign controller and computers; better monitoring systems; provisions for easy and safe access to signs (ladders, steps, etc.); tighten test specifications.
South Carolina	May need to increase size of fiberoptic to increase width of letter.
Texas	Improve testing and inspection procedures; improve specifications; improve detail sheets; try to use light-emitting technology, adopt NTCIP communications protocol.
Virginia	Consider using LED; provisions for easy access to sign (walk-in type) to maintain signs without closing roadway.
Washington	Currently in process of creating standards, specifications. Specifications vary between regions and/or for specific applications. A base specification has been proposed, but is not mandatory and can be modified for sign size, number of characters, number of lines, and to comply with standard protocols. This specification does not call for a particular sign technology. Regions tend to buy one type or from one manufacturer to simplify control and maintenance.
Wisconsin	Require as much solid state electronics as possible, eliminate mechanical switching.
Wyoming	Determine if sign is needed and will be utilized as intended; do a better job of choosing type of flexibility of sign.
N.J. Turnpike	CMS standards are being developed with an interagency group.
Ontario	Use only light-emitting signs. Line matrices have better legibility than individual matrix. Amber LED far superior to red/green mix.

of comprehensive data kept them from determining whether the down time occurrences were strictly a function of CMS failures. Also, Ontario was not able to isolate the effects due to maintenance response times and contractual arrangements for three of the CMSs. Because of these reasons, the quantitative data provided by Ontario (to their own admission) may not be a fair assessment of the relative frequency of problems among the four CMSs studied. Therefore, the comparative data among the four CMSs are not reproduced here. The reader is referred to the report by Delcan Corporation (7) that presents comparative quantitative data with discussions of the study limitations. More complete data were available for one of the signs—457-mm (18-in.) fiberoptic—and are shown in Table 32.

The data in Table 32 show that there were 84 down-time occurrences during the 14-month analysis period between 1990 and 1991. Of these 84, 45 percent of the recorded failures were due to communication failures, 30 percent to bulb outage failures, 13 percent to power failures, and 12 percent to miscellaneous causes. Failures due to bulb outages occurred primarily when the backup bulb failed, resulting in the CMS automatically shutting down with no message display possible. On a failure duration basis, the communication and bulb outage failures comprised 38 percent and 37 percent of total failure times recorded.

MAINTAINABILITY

Maintainability is the ease in which the signs and associated equipment can be accessed for maintenance operations while maximizing the safety of the workers and minimizing disruption to traffic. Several different factors enhance maintainability, including sign location, access to the sign controls, and access to the sign components. Following is a brief narrative of the provisions reported by the transportation agencies for enhancing maintainability. It is conceivable that other transportation agencies not mentioned may use similar procedures but did not explicitly identify them in the survey. Also, there are likely other approaches to enhancing maintainability that were not explicitly identified by the respondents.

Location and Design of Sign Controlle Cabinet

Connecticut, Maryland, Ohio, Oregon, Pennsylvania, Virginia, and Washington place the CMS control cabinets at ground level for ease of maintenance. Connecticut locates the control cabinets on roads adjacent to the freeway. One district in Texas where the signs are located in the freeway median, generally places the sign controller cabinets along the frontage road. Minnesota, which uses rotating drum CMSs rather extensively, reported that the control cabinet is actually located inside the CMS that has a walk-in housing.

Illinois reports the use of cabinets with screened air exhaust openings under the roof overhang. Most agencies reported the use of environmentally sealed cabinets.

Access to Sign Components

Access to matrix CMSs for maintenance is usually through the front or rear of the sign. The primary advantage of front access is that maintenance personnel can see the sign face as it is tested during maintenance procedures. Some reflective disk CMSs have sliding panels; however, the general consensus is that hinged panels are better. Sliding panels require track space which is susceptible to corrosion, while hinges can be corrosion resistant. There are differences of opinion, however, over whether the panels should be hinged at the top, or at the bottom. The advantage of top-hinged panels is that maintenance personnel do not have to reach across the panel to perform the maintenance. However, provisions must be made (e.g., wider walkway scaffolding) to ensure that maintenance personnel can conveniently access the bottom panel, particularly when a 3- or 4-line CMS is used. The advantage of bottom-hinged panels is that a catch mechanism is not necessary to prop open the panels.

Walkway Scaffolding

Since CMSs are generally mounted on either overhead or cantilever structures, provisions should be made to maintain

TABLE 32
FAILURE DATA FOR 457-mm (18-in.) FIBEROPTIC CMS DURING 14-MONTH PERIOD IN ONTARIO (7)

Failure Type	Number of Occurrences (out of 84 total)	Total Duration (hr) of Occurrences[a]	Percent of Total Failure Time	Failure Time as a Percent of Total 14-month Test Period[b]
Communications	38 (45%)	161.7	38	1.6
Bulb Out and Off	25 (30%)	156.8	37	1.5
Power Failure	11 (13%)	84.6	20	0.8
Other	10 (12%)	23.1	5	0.2
TOTAL	84 (100%)	426.2	100%	4.2%

[a] There were 426.2 hours of total failure time during the 14-month test period.
[b] Assumes 24 hour per day operation.

the signs while minimizing disruption to traffic. Most agencies incorporate walkway scaffolding and handrails in the structures to provide access to the signs without having to disrupt freeway traffic. Texas recommends that the scaffolding should be 4 feet wide instead of the standard 2 or 3 feet normally used to provide working space for personnel when the hinged sign panels are propped open. The scaffolding may have to be offset to ensure maintenance personnel can conveniently open the bottom panel door of a multi-line CMS.

Walk-in Sign Cabinets

Some CMS manufacturers provide an optional walk-in sign cabinet that allows maintenance personnel to enter the sign cabinet and perform maintenance on the components. It is a design feature used by several agencies including Iowa, Maryland, Minnesota, and Virginia for safety purposes and to prevent lane closures during sign maintenance. The walk-in enclosures are particularly attractive in cold weather areas. Walk-in cabinets have been available with rotating drum CMSs for some time; some manufacturers now offer the walk-in sign cabinet option for matrix CMSs, both light-reflecting and light-emitting.

Line Drivers

A line driver is a device, similar to an amplifier, that enables the controller to "drive" the electronic signal the required excess distance. Line drivers are needed when the sign controllers are located more than 300 feet from the CMS. This situation sometimes occurs when the CMS is located in the median. The Fort Worth District in Texas reported several problems with line drivers, particularly in hot weather, that resulted in communications problems with the signs and thus rendered the CMSs inoperable. In the future, the District plans to locate the controller cabinets at distances from the CMSs that are within the manufacturer's specifications in order to eliminate the need for line drivers.

COMMUNICATIONS PROTOCOL

A communications protocol (serial bit stream) is necessary between the CMS microcomputer master and the CMS controller. Some CMS users have in the past complained that the lack of standards in the CMS industry makes it extremely difficult and expensive to incorporate several different types of CMSs within a corridor. Agencies have complained that CMS manufacturers are reluctant to provide information about communications protocol for their sign systems. The only commonality appears to be that most sign communication protocols use a serial data stream that is bi-directional between the central controller and the field controller. A common "physical layer" standard supported by most sign manufacturers is the RS-232C series of specifications. However, the embedded information within this physical standard is still unique and proprietary for each CMS manufacturer.

Table 33 summarizes comments received from the transportation agencies relative to communications protocol standards or problems. Several of the agencies currently operate only one type of CMS and have not encountered the problems with controlling multiple CMS types. Some agencies using multiple sign types are taking aggressive actions to minimize the difficulty in communicating with signs having different communication protocols. California, Minnesota, and Ontario, for example, have set their own communications protocol and require CMS manufacturers to comply with their standards. Oregon requires manufacturers to provide the state with communications protocol information. If the manufacturer refuses, the state does not consider the bid.

Responses to an inquiry about whether a national standard communications protocol is necessary are summarized in Table 34. Fifteen of the 28 agencies responding to the survey (53 percent) stated that a national communications protocol is necessary or vitally necessary; an additional eight agencies (29 percent) indicated that it would be useful. The results emphasize the concern that the majority (82 percent) of the transportation agencies have about this issue. Only five agencies (18 percent) indicated that a national communications protocol was not necessary. It is interesting to note, however, that those users that had relatively many signs generally stated that a national communication protocol was vitally necessary or necessary.

WARRANTIES

Table 35 summarizes the warranty periods stipulated and the post warranty maintenance practices by each agency. Most specify 1-year warranties for their CMSs. California specifies an 18-month warranty period; six agencies specify only a 6-month warranty. Following the manufacturer's warranty period, the large majority of the agencies handle maintenance with agency personnel, except for certain special provisions and situations.

PROCUREMENT AND TESTING

Procurement

One of the complaints expressed by some of the transportation agencies is that the requirement to accept a low bid may result in CMSs that are not acceptable from the standpoints of quality and desirable sign characteristics (e.g., target value and legibility). The low bid process coupled with pressures from sign manufacturers at times result in situations where the CMSs may be supplied by inexperienced or questionable manufacturers. Occasionally, sign manufacturers go out of business, thus leaving the agency with CMSs that cannot be easily repaired because parts are not available. In addition, software problems occur that cannot be fixed.

Another problem often encountered is the difficulty in maintaining system compatibility when new CMSs need to be

TABLE 33

PROTOCOL STANDARDS OR POLICIES

Agency	Most Recent Sign Types	Comments
Alabama	Bulb Matrix	None
Alaska	Fiberoptic	None
Arizona	Reflective Disk Light-Emitting Diode Fiberoptic	We use phone lines leased from telephone company. We have more problem with software differences. Must meet software specifications for all future signs.
California	Bulb Matrix	This has been solved by setting one communications protocol called "signview" which was developed by the state. This is a standard by which all signs (Model 500) must operate. There is work on making this a standard for all CMSs.
Connecticut	Fiberoptic Reflective Disk— (Dimensional Square)	No standard developed.
Idaho	Rotating Drum	No problem yet, but would like standards. In this district, we are just starting to purchase newer signs. So far we are using software that is 100% IBM compatible to run our signs, so we can maintain only one type of machine to operate all other signs.
Illinois	Rotating Drum Reflective Disk Fiber/Reflective Disk	Disk Signs; no protocol standards exist and vendors have historically treated such information as proprietary which has always resulted in compatibility problems when mixing various vendor applications.
Iowa	Rotating Drum Fiber/Reflective Disk	We have not experienced problems yet. We have not gotten to the point where we need to expand the system. We have not established standards on communication protocol.
Maryland	Fiber/Reflective Disk Fiberoptic Rotating Drum	Lack of standardization can hurt vendors. Some states without CMSs might invest in sign systems if standardization existed (similar to early computer compatiblity). Have developed a standard protocol for the CHART system which all vendors must meet.
Michigan	Reflective Disk Fiberoptic Rotating Drum	No standard developed for the State.
Massachusetts	Static/Fiberoptics Fiberoptics	None
Minnesota	Rotating Drum Light-Emitting Diode	We specify the sign control and do all software required. Each sign controller is a 170 type controller with our software and communications to the central sign controller and PCs used for sign control. LED sign control is married to the drum sign control and PCs.
Nebraska	Rotating Drum	No standards.
New York	Fiberoptic/Reflective Disk	
North Carolina	Reflective Disk Fiberoptics	No standards.
Ohio	Reflective Disk	None yet, only have one sign.
Oregon	Fiberoptic	No problem. We required manufacturers to provide protocols with software. No protocols = no sale.
Pennsylvania	Reflective Disk Rotating Drum	Both flip disk signs are same sign. We have no such problems. We have no standards.
South Carolina	Fiberoptic	
Tennessee	Fiberoptic/Reflective Disk	In order to specify a proprietary item, a justification would be submitted to FHWA if their funding was involved. Typically, compatibility is an acceptable justification.
Texas	Reflective disk Fiberoptic Fiber/Reflective Disk	No statewide standards.
Virginia	Reflective Disk	Yes, we have the same problems and are developing a protocol communications for the CMSs.
Washington	Reflective Disk LED/Reflective Disk Fiber/Reflective Disk	Setting our own communications protocol—Now each type has own computer communications protocol. Varies by region to fit specific control scheme.
Wisconsin	Fiberoptics/Reflective Disk Light-Emitting Diode Fiberoptics/Reflective Disk	Need an open national communications & control protocol.
Wyoming	Rotating Drum	
N.J. Turnpike	Rotating Drum	Our computer department has created a remote device interface software which allows communication between our headquarters and any type of sign so that it can communicate with any vendor's sign.
Ontario	Light-Emitting Diode Fiber/Reflective Disk	Product specific protocol required use of "legal tools" for release of this information for others to emulate. Recent sign contract specified our own protocol. Industry acceptance of protocol yet to be determined.

TABLE 34
NATIONAL PROTOCOL NEEDS

	National Protocol				
Agency	Vitally Necessary	Necessary	Useful	Not Necessary	Absolutely Not Necessary
Alabama		X			
Alaska				X	
Arizona	X				
California				X	
Colorado			X		
Connecticut			X		
Idaho			X		
Illinois			X		
Iowa		X			
Maryland		X			
Massachusetts				X	
Michigan		X			
Minnesota					X
New Jersey	X				
New York			X		
North Carolina	X				
Ohio	X				
Oregon		X			
Pennsylvania				X	
South Carolina		X			
Tennessee			X		
Texas	X				
Virginia	X				
Washington	X				
Wisconsin	X				
Wyoming			X		
N.J. Turnpike			X		
Ontario	X				
Percent of Agencies[a]	32%	21%	29%	14%	4%

[a] Two agencies (7%) did not respond to inquiry about the national protocol.

purchased to add to an existing system. Traffic management systems are usually developed and implemented in stages because of funding and other constraints. Accordingly, CMSs for traffic management systems are purchased over a period of years under separate contracts. One of the major concerns expressed by some agencies is the difficulty of integration of the new CMS equipment into an existing system. The low bid process may require a state to accept CMS hardware that is not directly compatible with the existing system.

It is the belief of most respondents to the survey that measures can be taken to rectify these type problems. Properly written specifications can be a safeguard to ensure quality equipment is being purchased. Therefore, many transportation agencies are rewriting CMS purchase specifications to be more explicit and complete rather than using general or generic specifications. For example, the specifications can include explicit CMS performance requirements, clauses for performance and experience of the manufacturer and contractor, and pre-award inspection of the signs. California has one specification (Model 500) that all manufacturers must comply with regardless of how low the bid. California is considering implementing a Qualified Products List for CMS system manufacturers. The agency expects that this will reduce bonding requirements.

Some transportation agencies write very general specifications because they may not be knowledgeable about the most recent CMS developments in this rapidly changing technological area. Unfortunately, if the specification is too generic, the agency may obtain equipment that does not perform satisfactorily, but nevertheless, meets the specifications.

Some agencies develop general specifications because of their concern about unintentional sole sourcing. United States Code Title 23, Section 112(b)(1) requires the states to foster competition in bids when federal money is involved; however, the law does allow sole-source procurement in emergencies and when it is in the best interest of the public. The federal regulation states that, in projects using federal monies, a public agency shall award contracts through competitive bidding, unless the agency demonstrates a more cost-effective method of bidding or an emergency exists. The transportation agency can use this federal regulation to its advantage by adopting criteria that bring in quality products. One method to accomplish this goal is to accept the lowest adjusted bid, which includes a life-cycle cost analysis similar to the method used by Arizona. (*22*)

TABLE 35

WARRANTY PRACTICE

Agency	Warranty Period			Post Warranty Period				Comments
				Agency	Private		Varies Among	
	18 Months	12 Months	6 Months	Personnel	Per Call	Other	Districts	
Alabama		X						
Alaska				X				
Arizona		X		X				Flip disk parts hard to get
California	X						X	
Colorado		X		X				
Connecticut			X			18 mo		
Idaho		X		X				Parts only
			X			12 mo		Limited warranty
Illinois			X		X			
Iowa		X		X				
Maryland	*	*	*	X				
Massachusetts		X			X			
Michigan				X				
Nebraska		X		X				
New Jersey		X			X			
North Carolina			X	X				We may contract maintenance by manufacturer after warranty period.
Ohio		X		X				Will use contractor in future
Oregon		X		X				
Pennsylvania						X		Initial: gen contractor Now: manufacturer
South Carolina				X				
Tennessee		X						Maintenance under annual contract
Texas		X					X	
Virginia			X	X				Initially: construction contractor
Washington		X**	X	X				
Wisconsin						X		Contractor maintains for 2 years; Probably let a new contract for PM and critical maintenance.
Wyoming		X		X				
N.J. Turnpike		X		X				
Ontario†						X		Post warranty maint. contracted out

* Depends upon type of funding; federal funding limits most warranties to six months. However, the Intermodal Surface Transportation Efficiency Act provides up to 24 months of operational support.
** New specification.
† Up to 5 years.

The Arizona Example

Marston (*22*) describes part of the procurement process used in Arizona, which was designed to ensure that quality CMSs were purchased. The Arizona procurement process provides a good example of the way that a transportation agency can effectively approach CMS procurement. In 1992, Arizona bid for 19 CMSs to be installed and integrated into the Freeway Management System. The bid requested fiberoptic, LED, or fiberoptic enhanced reflective disk technologies. Arizona also required from every potential supplier a declaration of guaranteed parts and an independent laboratory certification of acceptability of color output, environmental condition adequacy, line transients, and of rated lives for character modules, halogen lamps, LEDs, sign control units, and communications units. The proposal had to include at least three customer references of installed, outdoor CMSs meeting specific criteria.

Arizona requested that the potential suppliers provide a guaranteed life-cycle cost on the equipment for the 10-year life of the project. The life-cycle costing included the cost of the signs, a yearly guaranteed electrical cost, and an annual guaranteed maximum repair cost.

The electrical and repair guarantee was a unique way to control Arizona's cost of ownership during the project. For the electrical guarantee, the potential supplier had to estimate the total cost of operating one sign for eight hours a day, on various settings, at a fixed cost per kilowatt-hour. This quantity was then multiplied by 365 to estimate the yearly cost of operation. When Arizona receives the signs, it will randomly select signs for testing. If there is a discrepancy between the Arizona estimate of total operating cost and the supplier's estimate, then the difference will by multiplied by 10 (10-year project life). This amount will then be subtracted from the amount paid to the supplier for each sign. No monies will be withheld from or awarded to the supplier if the Arizona estimate is lower than the supplier's estimate. For guaranteed yearly maintenance, if the cost of maintenance, including traffic control costs, should exceed the maximum, then the supplier is responsible for paying the excess regardless of who performs the maintenance—Arizona, supplier, or private firm.

Marston (*22*) summarized several aspects that a transportation agency may consider when developing specifications for CMSs (Table 36). She states that a specification for CMSs is unique and must be written to address the individual needs of the agency. Although specifications from different agencies

TABLE 36

KEY ASPECTS WHEN SPECIFYING CHANGEABLE MESSAGE SIGNS (*22*)

Function	Practices	Aspects to Consider
Communication	Fiberoptic cable Twisted wire pair Cellular Radio Coaxial cable	Common interfaces Data rates and formats Frequency of communication Control software Terrain and environment
Maintenance	Supplier provided Contractor provided Inhouse	Bonding Response time Sign & software access Proprietary information Start of maintenance period
Operations	Functional specifications User interfaces	Message failure rates Legibility Message verification Ease of use Graphics and/or text Color and font
Testing	Inhouse Independent (labs) Certification acceptance Contractor field tests	Acceptance criteria Environmental criteria Certificates Approved listing
Cost	Life-cycle Just-in-time delivery	Initial capital costs Lifetime electrical cost Lifetime maintenance cost Storage of signs Transportation of signs
Quality Assurance	Pre-qualifications Post-qualifications Approved bidders list Warranties Guarantees	Past performance Bonding of equipment Deployed signs Company history

can be similar, the detail must be specific to the user. Some of the major functional areas that may be considered include communication, maintenance, operations, testing, cost, and quality assurance. These areas are fairly broad, and as can be seen in Table 36, there are many different practices and aspects that may be selected.

Testing

Testing CMSs is one of several methods available to ensure that quality CMSs are purchased. In some European countries, products are tested in government approved laboratory facilities. For example, in France, a potential CMS supplier must provide a typical sign to the Laboratoire Central des Ponts et Chaussées, a laboratory in Paris, for rigorous testing. If the CMS passes the tests, a certificate of quality is issued to the supplier, which then has the approval to sell the sign for use on highways in France.

No national testing facility exists in the United States. Instead, it is up to each individual state to test the CMS systems purchased. The process used by Texas will be summarized here as a representative of the types of tests conducted by most other transportation agencies.

It is current Texas policy to require performance testing of materials and equipment not previously tested and approved. Four series of CMS tests are conducted: a design approval test, a factory demonstration test, a stand-alone test, and a system test.

Design approval tests are conducted to determine if the design of the equipment meets the requirements of the specification. The tests conducted as part of the design approval are a temperature and condensation test, a test of primary power variation, and a relative humidity test. The design approval test may be foregone with certification of approval from an independent testing lab. The factory demonstration tests include an examination of the product design and construction, wiring continuity tests, and an operational test. The stand-alone test occurs after the equipment has been installed in the field but prior to connection with the rest of the system. The final system test occurs after connection with central equipment. The test exercises all remote control functions and displays the return status codes from the controller for a minimum of 72 hours. Failure of any tests results in required correction and/or substitution of equipment.

The Fort Worth District in Texas requires more extensive "burn-in" and system integration tests. After the initial 72 hour burn-in during which time control functions are repeatedly activated to ensure that the system software and hardware are

TABLE 37
NATIONAL TEST FACILITY NEEDS

Agency	National Test Facility				
	Vitally Necessary	Necessary	Useful	Not Necessary	Absolutely Not Necessary
Alabama		X			
Alaska			X		
Arizona	X				
California			X		
Colorado			X		
Connecticut	X				
Idaho			X		
Illinois			X		
Iowa			X		
Maryland		X			
Massachusetts		X			
Michigan			X		
Minnesota			X		
Nebraska			X		
New Jersey		X			
New York			X		
North Carolina	X				
Ohio	X				
Oregon			X		
Pennsylvania			X		
South Carolina			X		
Tennessee			X		
Texas		X			
Virginia	X				
Washington		X			
Wisconsin				X	
Wyoming			X		
N.J. Turnpike			X		
Ontario			X		
Percent of Agencies[a]	17%	21%	59%	3%	0%

operating satisfactorily, 180 days of standard field operation are required, followed by a final 72 hour burn-in test. Tests demonstrating compatibility with the existing system (integration tests) are also required by the District.

National Test Facility

Because of the time and expense required for each agency to test any CMS it purchases, it has been suggested that a national testing laboratory might be established. In response to an inquiry in the survey discussed herein, 17 agencies (59 percent) indicated that a national facility to test CMS hardware and performance would be useful, 6 agencies (21 percent) indicated that a national test facility is necessary, and 5 agencies (17 percent) indicated the test facility is vitally necessary (Table 37). In contrast, only one of the agencies stated that a national test facility was not necessary.

RESOURCE MATERIAL

In response to an inquiry in the survey discussed herein, 10 of the 24 agencies (42 percent) responding indicated that they were not familiar with research and publications that provide guidance on 1) message selection, 2) message design, 3) CMS placement, 4) legibility requirements, 5) legibility of various types of CMSs, and 6) character size. These results indicate that not all state personnel who have the responsibility for the CMSs are receiving and/or using all of the pertinent reports that are available to assist them in designing and operating CMS systems.

CHAPTER FOUR

CONCLUSIONS

Although the results of the survey indicated that improvements have been made in recent years in CMS technology, the results also indicate that not much progress has been made in certain aspects of CMSs since the earlier synthesis on changeable message signs was published in 1979. Research and activities that are necessary to gain better understanding and use of CMSs and consistent quality include the following (some of which are repeated from the 1979 synthesis):

- Some agencies are taking aggressive actions to ensure that quality equipment is purchased. Functional quality and not necessarily low price is considered. One approach to ensure quality is to prepare CMS purchase specifications that are explicit and complete, rather than using general specifications. The specifications can include explicit CMS performance requirements, clauses for performance and experience of the manufacturer and contractor, and pre-award inspection and evaluation of the signs.
- Another means to ensure quality is for agencies to consider requiring potential CMS suppliers to provide a guaranteed life-cycle cost on the equipment for a specified period (e.g., 10 years), similar to Arizona's approach.
- The survey results point to the need for a national standard communications protocol. This could be accomplished by cooperative efforts of industry and transportation agencies to develop standards consistent with the needs of the agencies to easily communicate with a variety of CMS types. Currently, some state agencies are independently taking aggressive actions to minimize the problems resulting from CMSs that use different communications protocols.
- Objective data are lacking on the performance characteristics of alternative CMS technologies, in spite of the existence of some technologies for more than 20 years. Field and proving ground tests are needed to quantify performance characteristics (e.g., target value, legibility distances, maintenance frequencies, etc.) of CMSs for the benefit of all the agencies.
- Side-by-side evaluations of alternative CMS systems is an approach to quantify differences in performance characteristics among existing and emerging CMS technologies. However, it is a process that currently must be duplicated by several transportation agencies. Based on the survey, there is a strong interest by transportation agencies in the United States to have a national testing facility.
- Transportation agencies that document the operational efficiency of the various CMS technologies, in particular, maintenance problems, frequencies, and actions taken to circumvent the problems, will have a strong impact on future designs and improvements.
- Procedures could be improved to ensure that the latest reports and information are being forwarded to the individuals within state and local transportation agencies who have responsibility for designing and preparing specifications for CMS systems.
- Better and faster exchange of experiences with alternative CMS technologies, particularly when new technology is introduced for highway applications, would benefit transportation agencies.
- Research and experience indicate the need for a minimum character height of 457 mm (18 inches) for matrix CMSs used for freeway applications.
- Additional field studies to evaluate message effectiveness in terms of motorist response would be useful. The number of documented studies that measured motorist response to CMS messages in real-world operational settings is extremely small and most were conducted in the mid 1970s.
- Research in terms of human behavior and standardization of practice concerning whether CMSs messages should be displayed during nonincident conditions and whether non-traffic-related messages should be displayed on CMSs would be useful.
- Field studies could objectively determine the reasons motorists occasionally reduce speed at certain CMS locations when messages are displayed.
- Studies to determine the optimum surveillance techniques for various types of CMS system objectives would be useful.
- Studies of transportable CMSs to evaluate the operational issues encountered by transportation agencies and the overall effectiveness of these devices are needed.

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APPENDIX A

Survey

Agency______________________________

NCHRP PROJECT 20-5, TOPIC 23-11
CHANGEABLE MESSAGE SIGNS
Survey Form
PERMANENTLY MOUNTED CHANGEABLE MESSAGE SIGNS

Contacts

1. Name, agency, address, telephone & fax numbers of person(s) completing Part 1 of this survey. ______________________________

____

2. Name, address, telephone & fax numbers of person(s) in your organization to contact for additional information if different from above.

____

____

____

____

Permanently Mounted Changeable Message Signs (CMSs)

3. Attached Table A is a listing of CMSs that were reported by your State in a survey by TRB in 1978 and published in NCHRP Synthesis of Practice 61 - CHANGEABLE MESSAGE SIGNS. In Table 1 below, please list your current applications or make the necessary changes and additions to reflect current applications of permanently mounted CMSs. Use attached Table B as a guide to identify specific types of applications.

Table 1. KNOWN APPLICATIONS OF PERMANENTLY MOUNTED CMSs (1992)

Known Application	Location
1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	
9.	
10.	
11.	
12.	
13.	
14.	
15.	
16.	
17.	
18.	
19.	

*Agency*______________________________

4. For each application you listed in Table 1, list the approximate number (#), types (flip disk, fiber optic, LED, etc.) and manufacturer of the permanently mounted CMSs.

Table 2. NUMBER, TYPES AND MANUFACTURER OF PERMANENTLY MOUNTED CMSs

Appl	# Signs	Type	Manufacturer
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			

5. List the type of permanently mounted CMSs (flip disk, fiber optic, LED, etc.) acquired during the last three purchases.

Sign A__________	Sign B__________	Sign C__________
Model No. or Name______	Model No. or Name______	Model No. or Name______
Year Purchased______	Year Purchased______	Year Purchased______
Number of Signs Purchased___	Number of Signs Purchased___	Number of Signs Purchased___
Cost per Sign______	Cost per Sign______	Cost per Sign______

6. For each CMS type listed in 5, please check whether the following information is available and send the information to Conrad L. Dudek:

<u>Info Available</u>

a. sign dimensions (height, length, depth) ___Yes ___No
b. sign dimensions (number of message lines, max. number of characters per line) ___Yes ___No
c. target value distance during various environmental conditions ___Yes ___No
d. message legibility distance during various environmental conditions ___Yes ___No
e. design and installation to optimize target value (conspicuity)
  1. contrast ratio between sign and surrounding background ___Yes ___No
  2. external illumination ___Yes ___No
  3. sign positioning in field ___Yes ___No
  4. sign placement ___Yes ___No
  5. others *(please specify)* ____________________ ___Yes ___No

*Agency*________________________________

f. design to optimize legibility distance
   1. border dimensions __Yes __No
   2. contrast ratio between legend and sign background __Yes __No
   3. external and internal illumination __Yes __No
   4. character height __Yes __No
   5. character width __Yes __No
   6. spacing between lines __Yes __No
   7. spacing between characters __Yes __No
   8. others *(please specify)* ____________________ __Yes __No

g. sign placement to enhance driver's ability to read and respond to message __Yes __No

h. message design (words and symbols, length, abbreviations, display duration, number of sequences, sequencing speed, etc) __Yes __No

i. message use for traffic management and diversion
   1. displaying messages during peak periods in the absence of incidents __Yes __No
   2. displaying messages during off peak periods in the absence of incidents __Yes __No
   3. displaying diversion messages __Yes __No
   4. displaying safety and other slogans __Yes __No

j. protocol communications with the CMSs __Yes __No

k. criteria and field/laboratory procedure for measuring CMS target value and legibility distances during various environmental conditions __Yes __No

7. For permanently mounted CMSs please check whether State standards (either formal or de facto) have been developed relative to the following;
Send copies of the standards to Conrad L. Dudek:

<u>Standards Developed</u>

a. sign dimensions (height, length, depth) __Yes __No

b. sign dimensions (number of message lines, max. number of characters per line) __Yes __No

c. target value distance during various environmental conditions __Yes __No

d. message legibility distance during various environmental conditions __Yes __No

e. design and installation to optimize target value (conspicuity)
   1. contrast ratio between sign and background __Yes __No
   2. external illumination __Yes __No
   3. sign positioning in field __Yes __No
   4. sign placement __Yes __No
   5. others *(please specify)* ____________________ __Yes __No

f. design to optimize legibility distance
   1. border dimensions __Yes __No
   2. contrast ratio between legend and sign background __Yes __No
   3. external and internal illumination __Yes __No
   4. character height __Yes __No
   5. character width __Yes __No
   6. spacing between lines __Yes __No
   7. spacing between characters __Yes __No
   8. others *(please specify)* ____________________ __Yes __No

g. sign placement to enhance driver's ability to read and respond to message __Yes __No

h. message design (words and symbols, length, abbreviations, display duration, number of sequences, sequencing speed, etc) __Yes __No

i. message use for traffic management and diversion
   1. displaying messages during peak periods in the absence of incidents __Yes __No
   2. displaying messages during off peak periods in the absence of incidents __Yes __No
   3. displaying diversion messages __Yes __No
   4. displaying safety and other slogans __Yes __No

j. protocol communications with the CMSs __Yes __No

k. criteria and field/laboratory procedure for measuring CMS target value and legibility distances during various environmental conditions __Yes __No

8. List in order the four best attributes of the CMSs listed in 5.

Sign A:

1.____

2.____

3.____

4.____

Agency ______________________

14. Please discuss whether the sign supplier provided a warrantee period; whether you purchased a maintenance agreement; how you handle maintenance after the warrantee period; how you will handle maintenance in the future (e.g., in-house vs contract; if on contract, per call or blanket agreement; time period).

15. Describe the provisions you specify in order to gain access to the CMS components for maintenance (e.g., front vs back access; hinged vs sliding panels). State the merits and disadvantages of each approach from your perspective.

16. Describe any adverse driver reaction to the CMSs (e.g., drivers slowing, drivers not responding to message, etc) and describe the reasons for the negative reaction; what did you do to improve the situation? What was the most common public complaint; what did you do to improve the situation?

17. Some agencies have complained that they must purchase CMS based on low bid only; therefore, operations personnel are not always happy with the quality of the CMSs that they receive. Has this been a problem in your State? What have you done to resolve the problem? Can you purchase CMSs on sole source contracts in order to ensure quality?

18. Suppose you have several CMSs of a certain type that were purchased from a specific vendor. What procurement problems, if any, would you encounter if you wanted to add more CMSs of the same type to your system? If you would encounter problems, please describe what should be done at the state or national level to allow you to purchase similar CMSs so that the system would appear to be consistent from the driver's perspective?

19. What procedures and resources do you use to sort through all of the options when purchasing CMSs, particularly when technology changes so rapidly?

*Agency*__________________________________

20. A communications protocol (serial bit stream) is necessary between the CMS microcomputer master and the CMS controller. Some highway agencies have complained that because of lack of standards in the CMS industry it is extremely difficult and expensive to incorporate several different types of CMSs within a corridor. Also, vendors are reluctant to provide information about the communications protocol for their CMS systems. There appears to be a need to establish protocol standards. Please discuss your problems, if any, with communications protocol. Discuss whether your State has established standards and/or what your State has done to alleviate the problems.

____

____

____

21. If the answer to #19 is "no", do you believe that a <u>national</u> standardized communications protocol is
___vitally necessary ___necessary ___would be useful, but not necessary ___not needed ___absolutely not necessary

22. What types of tests and demonstrations do you feel are needed prior to procurement of CMS systems?

____

____

23. Do you field evaluate or test different types of CMSs, particularly with respect to target value and legibility distances before you complete your specifications or purchase the signs? ___Yes ___No
Please comment

____

____

24. Do you believe that a <u>national</u> facility to test CMS hardware and performance is
___vitally necessary ___necessary ___would be useful, but not necessary ___not needed ___absolutely not necessary

25. Manufacturers and suppliers provide adequate technical and performance information. ___Yes ___No

26. I am aware of research and publications that provide guidance on

a. message selections	___Yes	___No
b. message design	___Yes	___No
c. CMS placement	___Yes	___No
d. legibility requirements	___Yes	___No
e. legibility of various types of CMSs	___Yes	___No
f. character size	___Yes	___No

27. Would you consider the following type of CMS for future purposes?

a. Bulb matrix	___Yes	___No	___Unfamiliar
b. Disk matrix with fiber optics	___Yes	___No	___Unfamiliar
c. Fiber optics	___Yes	___No	___Unfamiliar
d. Flap matrix	___Yes	___No	___Unfamiliar
e. Light-emitting diode (LED)	___Yes	___No	___Unfamiliar
f. Reflective disk - circular	___Yes	___No	___Unfamiliar
g. Reflective disk - dimensional square	___Yes	___No	___Unfamiliar
h. Reflective disk - rectangular	___Yes	___No	___Unfamiliar
i. Rotating drum	___Yes	___No	___Unfamiliar
j. Rotating cylinder/triangle element	___Yes	___No	___Unfamiliar
k. Rotating scroll (tape)	___Yes	___No	___Unfamiliar
l. Vane matrix	___Yes	___No	___Unfamiliar
m. Others (*please specify*) ____________________	___Yes	___No	___Unfamiliar

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