FINAL REPORT

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Policies for Use of Changeable Message Signs in Highway Work Zones

Project VE-H2, FY 97

Report No. ITRC FR 97-1

Prepared by

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16. Abstract

Portable Changeable Message Sign (PCMS) systems used in work zones are programmable supplementary traffic control devices that display messages composed of letters, symbols or both and provide information and instructions to the traveling public approaching work zone activities. The study seeks to develop warranties and criteria for PCMS deployment in Illinois highway work zones.

It is recommended that PCMS systems be used during long- and intermediate-term stationary work, for traffic control through incident areas, and in projects where advance-time notification is needed. The discussion focuses on spacing criteria, number of signs required, sign visibility and message legibility, text alignment, distance criteria, message length, duration and type, project-level operational guidelines, message storage and dissemination, repair, maintenance and utility costs, as well as control and coordination issues.

The study concludes that additional research is needed in order to: Develop a comprehensive standardized statewide database of messages and message abbreviations; develop a comprehensive repository with information about the technology of the various components of the PCMS units; coordinate PCMS units used in highway work zones with a corridor or regional ATMS system; maintain information about the use of a PCMS unit in a work zone project and possibly integrate it with other relevant information in a management system.

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POLICIES FOR USE OF CHANGEABLE MESSAGE SIGNS IN HIGHWAY WORK ZONES

Illinois Department of Transportation

Illinois Transportation Research Center

Project VE-H2, FY 97

Final Report

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Executive Summary

POLICIES FOR USE OF CHANGEABLE MESSAGE SIGNS IN HIGHWAY WORK ZONES

Project VE-H2, FY 97

Report No. ITRC-FR 97-1

This study represents a continuing effort in the State of Illinois toward the understanding and improvement of traffic safety at highway work zones through the use of Portable Changeable Message Sign (PCMS) systems. These systems are programmable supplementary traffic control devices that display messages and provide information and instructions to the traveling public approaching work zone activities.

The objectives of this study were sixfold: (1) develop warrants for the use of PCMS systems on Illinois Department of Transportation (IDOT) highway projects; (2) evaluate PCMS systems as a safety improvement; (3) develop criteria for the number, placement and spacing of PCMS systems in advance of highway work zones; (4) determine optimal message length, optimal duration of a given message and optimal message type; (5) evaluate the effectiveness of "real-time" information displayed on PCMS systems and the process required to transmit real-time messages from the source to the CMS; and (6) identify and discuss the human factors which impact the foregoing.

We accomplished these objectives through seven tasks: (1) a literature review; (2) a motorist survey; (3) a survey of the IDOT Districts Traffic Engineers; (4) an analysis of accident reports; (5) development of warrants for PCMS systems use on highway projects; (6) development of criteria for PCMS deployment in highway work zones; and (7) a final report on the findings in the previous tasks.

In the literature review we compiled information from several dozens of publications, as well as telephone conversations, electronic mail and faxes with a select set of states traffic operations engineers. In the motorist survey we obtained a scientific sample of motorist attitudes on different operational characteristics of PCMS systems including message length, message duration and message type. In the survey of the IDOT Districts Traffic Engineers we collected information about existing guidelines and determined the number of PCMS systems currently in use, perceived problems or benefits, and existing policies governing use and placement and message choice. In the absence of suitable accident data we investigated through the literature the potential to increase safety in highway work zones by means of

using PCMS systems. In the development of warrants for PCMS systems use on highway projects we employed federal guidelines, experience from other state Departments of Transportation and ongoing research. In the development of criteria for PCMS deployment we investigated spacing, number of signs required, distance in advance of the work zone, optimal message length, duration and type based on motorist response characteristics.

The study produced several interesting findings. Upon evaluating the effectiveness of PCMS systems in highway work zones, we found that familiarity with the construction area and time of day jointly affect PCMS visibility. In addition, among commercial drivers, those under 40 years or over 60 years of age were more likely to notice the sign. Moreover, motorists were more likely to recall PCMS messages that contain "action" statements. Finally, motorists recalled almost two times easier those message components (a "problem" or "action" statement) that they desired to see when approaching a work zone.

The implications of these findings for PCMS deployment in highway construction zones are that, in situations where the use of portable units is warranted, particular attention should be given to sign visibility and message legibility issues. Moreover, motorists' preference for "action" statements imply that messages should be short enough (two panels at most) without compromising motorists' information needs. The small amount of time (a few seconds) available to read a message should be utilized to display only the information with the highest impact potential and not information which is also conveyed by other traffic control safety devices deployed in a construction zone.

We also found that accidents occur most frequently at work zones when activities are in progress, the rate of increase depending on factors related to traffic, geometry and the environment. Moreover, accident frequency increases at short work zones with short durations compared to long work zones with long durations. Furthermore, nighttime accidents at work zones tend to occur more often at taper areas that emphasizes the need for adequate lighting and suitable channelization in these areas.

The study has important implications for the use of PCMS in state-wide highway projects because it has produced warranties and criteria for development that can be adopted and implemented immediately. In particular, we recommend the use of PCMS systems in long-term (more than three days) and intermediate-term (up to three days) stationary work, while the need during short-term stationary work (up to twelve hours) should be conditional on seasonal, climatic and visibility situations.

We recommend that PCMS systems be deployed first in urban highway work zones because of high speeds and traffic volumes and closer spacing of entry and exit ramps. On the other hand, PCMS use in work zones situated in rural highways with low traffic volumes (e.g., ADT less than 10,000) and high speeds may warrant additional placement considerations to accommodate device conspicuity and message legibility requirements due to higher speeds.

PCMS systems could also be used for advance time notification for ramp closures, lane closures or lane shifts, multi-lane highway projects requiring cross-over, run-arounds or detours, planned maintenance work, any project with a marked detour and an ADT > 10,000, or any projects with an ADT > 10,000 and traffic delays expected. Moreover, PCMS systems should be considered in blasting zones and for traffic management of major incidents. Finally, PCMS systems should not be used to replace lighted arrows, to advance notice of new traffic signal or sign, for advertising, or to replace the Illinois Manual of Uniform Traffic Control Devices requiring static signing or pavement markings.

The study has also produced detailed criteria for deployment of PCMS systems in highway work zones. PCMS systems used for construction projects should have specific placement locations listed in the Traffic Control Plan included in the project plans. Moreover, we recommend two signs per direction of traffic in work zones longer than two miles and for rural head-to-head construction projects. Urban or fringe area head-to-head projects will generally require the use of more units.

PCMS systems should be activated 1,000 feet, and in situations of heavy truck traffic three to five miles in advance of a work zone. When two units are needed they should be placed on the same side of the roadway, separated by at least 1,000 feet. PCMS units should not be placed near ramps, intersections or lane-closure tapers.

PCMS systems should not be obstructed by other signs or other objects. Furthermore, the units should be placed in the most level area possible or be leveled both horizontally and vertically. The units should be placed on the outside shoulder of the roadway not closer than 6 feet or farther than 20 feet from the edge of the travelway. The bottom of the sign should be 7 feet above the elevation of the edge of the roadway when in operation. The unit should be turned approximately 3 degrees outward from perpendicular to the edge of pavement.

We recommend that PCMS units be visible for at least one half-mile under ideal daytime and nighttime conditions. Messages should be legible for a minimum of 750 feet for traffic on all lanes and should remain legible for at least 650 feet from the nearest travel lane up to 100 feet from the message panel. No more than two message screens should be used and every effort should be made to restrict the message to one screen. PCMS systems closer to the work zone should be used to display warning messages. Units furthest out from the project area should display diversion messages. Generic messages should not be displayed. When not in use a PCMS should be turned off.

We recommend that the entire message cycle should be readable at least twice at the posted speed. A minimum exposure time of one second per short word (four to eight characters) or two seconds per unit of information should be allotted. In any case the message should not be scrolled any faster than 1.5 seconds per screen. On high speed roadways standard messages should be given two seconds and complex messages three seconds per message panel. Messages should not scroll horizontally or vertically across the face of the sign. Blank screens should not be used unless the device is turned off.

We found several areas where there is no uniform application of PCMS systems in IDOT highway work zones. These areas include: highway construction projects of similar nature; situations that warrantee the use of publicly or privately owned PCMS systems; placement of the units before, during and after the construction period; use of a standardized database of messages and abbreviations; use of an established methodology to compose messages; sequencing and duration of longer messages; policies regarding updating, modifying or discontinuing messages; maintenance guidelines; understanding of the pros and cons of different PCMS technologies; coordination of PCMS systems and other intelligent transportation systems technologies.

As a result, we recommend additional research in four areas: Development of a comprehensive standardized statewide database of messages and message abbreviations; development of a comprehensive repository with information about the technology of the various components of the PCMS units owned and operated by the districts; coordination of PCMS units used in highway work zones with a corridor or regional ATMS system; maintaining information about the use of a PCMS unit in a work zone project and possibly integrate it with other information related to the individual PCMS unit and the work zone project in a management system.

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DISCLAIMER

The contents of this report strictly reflect the views of the authors who are responsible for the facts and the accuracy presented herein. The contents do not necessarily reflect the official views of the Illinois Department of Transportation. This report does not constitute a standard, specification or regulation.

Contents

List of Figures

List of Tables

1 Introduction

1.1 Background

The control of roadway traffic is essential to the safe and efficient movement of vehicles and pedestrians. Among locations that appear to present a challenge for safe traffic control are highway construction zones. These sites are potential sources of congestion, delays, motorist confusion, frustration and accidents. The rate and severity of traffic accidents in highway work zones are significantly higher than those on normal roadway sections (Ullman and Riesland, 1990). Excessive speed and driver inattention/confusion are among the contributing factors most often reported for work zone accidents (Ullman and Riesland, 1990).

The Office of Highway Safety (OHS) at the Federal Highway Administration (FHWA) reports that fatalities in work zones rose by nearly 20% from 1992 to 1993 to a total of 762 (from 647). They rose again in 1994 to an all-time high of 833, while in 1995 the total was 771 (38 in Illinois) and 771 in 1996 (29 in Illinois). In 1993, OHS estimated 37,800 disabling injuries were the result of work zone accidents. At the same time the annual estimated societal cost of work zone accidents was $3.04 billion (Work Zone Highway Safety Web Page: http://www.ohs.fhwa.dot.gov/workzone/index.html).

Warning drivers in advance of upcoming work zones may lessen congestion and delays by providing the drivers with the option to alter their route. Such information may also improve safety as motorists are alerted to current roadway conditions, speed reductions and other hazards. A recent study in Illinois (Benekohal et al., 1995) reported that a large number of drivers had concerns about bad driving conditions in work zones, particularly in advance warning and transition areas. Large-truck drivers seem to be more sensitive to work zone traffic control because their share of work zone fatalities is 68% higher than the rest of the vehicle fleet (Benekohal et al., 1995).

One of the means available to roadway authorities to alert drivers of upcoming work zones is the *Changeable Message Sign* (CMS). CMS units used in highway construction zones are electronic devices that are portable, versatile, and highly visible in both daytime and nighttime hours. These signs seem to be effective in attracting drivers' attention and are believed to be a positive influence in work zone safety.

A considerable amount of CMS-related research has been conducted nationally and internationally, the bulk of which has dealt with the physical specifications of the signs rather than operational issues. As a result, few research findings have found their way into the design and deployment of CMS systems under the wide range of possible work zones conditions.

1.2 Study Objectives and Research Approach

By commissioning a study of this nature the Illinois Department of Transportation (IDOT) recognized the need to understand the impact of properly using CMS systems in highway work zone activities and eventually formalize the research findings into statewide guidelines. As a result, this study was set forth to achieve a number of objectives:

1. Develop warrants for the use of CMS systems on IDOT projects;
2. Evaluate CMS systems as a safety improvement;
3. Develop criteria for the number, placement and spacing of CMS systems in advance of highway work zones;
4. Determine optimal message length (single or multiple screens), optimal duration of a given message (in days) and optimal message type (specific or generic);
5. Evaluate the effectiveness of "real-time" information displayed on CMS systems and the process required to transmit real-time messages from the source to the CMS; and
6. Identify and discuss the human factors which impact the foregoing.

The study proposed to accomplish these objectives through seven tasks:

1. **Task A: Literature Review.** A comprehensive review of the current literature on human factors in traffic engineering as related to CMS systems.
2. **Task B: Motorists Survey.** A survey to obtain motorist attitudes on different operational characteristics of CMS systems including message length. message duration and message type.
3. **Task C: IDOT District Traffic Engineers Survey.** A survey to collect information about existing guidelines and determine the number of CMS systems currently in use, perceived problems or benefits, policies governing use and placement and message choice.
4. **Task D: Accident Rates with and without CMS Systems.** An analysis of accident reports to determine whether it can be established that accident rates are affected by the presence or absence of CMS systems.

5. **Task E: Warrants for CMS Systems Use.** Development of warrants for CMS systems use on projects of long and short duration, as well as projects involving lane closings, lane width restrictions, blasting zones and incident management.

6. **Task F: Criteria for CMS Systems Deployment in Highway Work Zones.** Development of criteria for spacing, number of signs required, distance in advance of the work zone, optimal message length, duration and type based on motorist response characteristics, manufacturer's specifications, sight distance, traffic volume, speed and other considerations.

7. **Task G: Final Report.** A Final Report on the findings in the previous tasks.

1.3 Organization of the Report

This report is organized into 9 chapters (sections) and 6 appendices. After this introductory section a list of definitions relevant to work zone traffic control terminology is presented in Section 2. A literature review is presented in Section 3. The implementation and analysis of the motorists' survey is presented in Section 4. Results from the survey of IDOT Traffic Engineers are presented in Section 5. A literature review of accident rates in highway work zones with and without portable changeable message signs deployment is presented in Section 6. Warrants for portable changeable message signs are discussed in Section 7, while criteria for deployment is in Section 8. Concluding remarks and recommendations for future research are made in Section 9.

A list of messages that exemplify the New York State DOT "template" approach to composing messages is compiled in Appendix A in Section 10. Virginia's DOT modular approach to composing messages is given in Appendix B in Section 11. Lists of portable CMS messages compiled from various sources are presented in Appendix C in Section 12. The motorists survey questionnaire can be found in Appendix D in Section 13. The IDOT Traffic Engineers survey questionnaire is presented in Appendix E in Section 14. Finally, experiences from State Departments of Transportation regarding the development of guidelines for the use of portable CMS systems in highway work zones are presented in Section 15.

2 Terminology, Definitions and Acronyms

The term "changeable message sign" is not universally accepted and some of the reasons are presented in Section 2.1. Definitions relevant to the highway work zone environment are presented in Section 2.2. Finally, the acronyms used throughout this report are given in Section 2.3.

2.1 Terminology

To exemplify the dynamic nature of research in this rapidly changing area of traffic control devices, even the terminology for the main device under study is in question. In particular, three different acronyms are used to describe highway signs that can display different messages using various technologies:

1. **CMS (Changeable Message Sign):** This was the first term used to describe non-static signs, such as rotating drum and neon displays. The term has also been used to describe modern LED, fiber optic and flip-disk signs. It is argued by many researchers that CMS should only refer to those signs that support a limited number of fixed messages. These would include blank-out, lane-use and rotating drum signs. There seems to be a consensus that CMS systems are dynamic message signs in which a *finite* number of messages may be displayed due to physical limitations in the sign's technology. Examples are drum-type signs, lane-use signs, and so-called "blank-out" signs. CMS systems may be LED, fiber optic, or other technology.

2. **VMS (Variable Message Sign):** This term was intended to describe increased flexibility created by new sign technologies. Many researchers agree that VMSs should only refer to those signs that allow the user to activate or download new messages via software. These would include character matrix, line matrix and full matrix signs. There seems to be a consensus that VMSs are dynamic message signs in which an *infinite* variety of messages may be displayed. Examples are LED, fiber optic, flip -disk/fiber optic hybrid, or any technology not limited by the sign's physical format.

3. **DMS (Dynamic Message Sign):** This new acronym was developed as a part of the NTCIP[1] effort to create a standard flexible enough to support both signs with a

[1] National Transportation Communication for ITS Protocol is the product of the joint effort of the public and private sectors of the ITS industry to develop a suite of common communications protocols for use in communication and management of traffic and transportation systems and devices

common set of data. In this regard, DMS is a new term applicable to either CMS or VMS.

Nationwide the terms CMS and VMS are used interchangeably, while in Europe VMS is clearly the term of choice. Nevertheless, all three terms are defined in the industry approved standard and are used appropriately within the standard. Whether or not people in the industry adopt the use of the term DMS remains to be seen. Following the official term adopted in the 1993 revision of FHWA's Manual on Uniform Traffic Control Devices (USDOT, 1993) the term CMS will be used throughout the study.

2.2 Definitions

In this section we define terms that will be used throughout this report in alphabetical order. For established terms most of the definitions given are consistent with those of AASHTO (AASHTO, 1968 and 1984) and the *Manual on Uniform Traffic Control Devices* (USDOT, 1993). Additional information is given in Lewis(1989).

Activity Area: The activity area is the portion of the roadway in which any closure is in effect and where work is taking place. It is the portion of the traffic control zone that commences at the downstream end of the transition area and extends to the beginning of the termination area.

Advance Warning Area: The advance warning area gives road users adequate time to respond to conditions. It may vary from a series of signs starting a mile in advance of the work area to a single sign or flashing lights on a vehicle. The length of the area varies between one-half mile and one mile for freeways.

Buffer Space: The buffer space is an optional feature in the activity area that provides a recovery space for errant vehicles and separates traffic flow from the work activity or potential hazard. This short section of clear roadway between the cone taper and the work area can provide an extra margin of safety for both traffic and workers.

Changeable Message Sign (CMS): CMS systems are electronic traffic control devices whose message can be changed manually, electrically, mechanically, or electromechanically to provide motorists with information about traffic congestion, traffic accidents, maintenance operations, adverse weather conditions, organized events or other highway features such as drawbridges, toll booths and weigh stations, and notification of construction zones.

Detour Route: When a road is closed and a detour is established the traffic control zone includes the area in which a detour route begins. The detour route extends beyond the zone to divert traffic around the site and return it to the original route.

Fiber Optic: A bundle of fiber optic cables are fastened to a lens at the face of the sign to create a dot (pixel). Typically, the light source is a single 50-watt tungsten bulb for every three characters and a second bulb for bright conditions, fog and also as a backup. *Advantages:* high visibility. *Disadvantages:* small cone of vision (not visible at close range) and high maintenance cost due to short life span of bulb.

Flip-Disk: Rectangular or circular leaves or flaps with one side reflective yellow and the other side black. These flaps independently expose or cover various fluorescent painted light-reflective surfaces in order to form the desired alpha-numeric character. Major benefits of a flip-disk type of sign is its ability to default to a pre-programmed message as it suffers from power failure. *Advantages:* low power requirements, excellent tolerance to the environment and a successfully proven technology. *Disadvantages:* sun glare, fading of disks and nighttime visibility.

Influence Zone: The influence zone for a work operation is the portion of the highway network over which traffic is routed or diverted because of traffic restrictions at the work site. This is the zone in which traffic control procedures may be used to advise motorists of congestion and alternative routings.

Light Emitting Diode (LED): A cluster of solid state diodes are mounted in a socket which makes up a pixel. *Advantages:* low maintenance and long life due to no moving parts. *Disadvantages:* sensitivity to heat and humidity, required cooling in cabinet and small viewing angle.

Portable Changeable Message Sign (PCMS): PCMS systems are portable CMS units used in temporary traffic control zones in a variety of different scenarios.

Road Users: Road users are all those who may be using any portion of the highway right-of-way and its immediate environs. The term includes vehicle operators and passengers, cyclists, pedestrians, bystanders and workers.

Roadway: The roadway is the portion of a highway intended and available for vehicular use. It includes the traveled way and the shoulders. A divided highway has two or more directional roadways.

Shoulder: A shoulder is the portion of the roadway contiguous with the traveled way used in emergencies by stopped vehicles and providing lateral support of the pavement.

Termination Area: The termination-area cone taper provides a short distance for traffic to clear the work area and return to normal operation. It is the final portion of the traffic control zone that begins at the downstream end of the activity area.

Traffic Control: Traffic control is the process of regulating, warning and guiding road users and advising them to traverse a section of highway or street in the proper manner.

Traffic Control Device: Traffic control devices are signs, signals, markings or other devices placed on or adjacent to a street or highway by authority of a public body or official having jurisdiction to regulate, warn or guide road users. At work sites, other traffic control devices are commonly employed such as channelizing and delineating devices.

Traffic Control Plan: A traffic control plan is a plan for handling traffic through a specific highway or street work zone or project.

Traffic Control Zone: A traffic control zone at a work site is the entire section of the roadway over which control related to the work operation is exercised and in which any temporary traffic control devices are placed.

Traffic Lane: A traffic lane is that portion of the traveled way for the movement of a single line of vehicles.

Traffic Sign: A traffic sign is a device mounted on a fixed or portable support to convey an official message by means of words or symbols; it is officially erected for the purpose of regulating, warning or guiding traffic.

Transition Area: The transition area channelizes traffic from normal highway lanes to the path required to move traffic around the work area. It contains the tapers that are used to close the lane. It is the portion of the traffic control zone that commences at the downstream end of the advance warning area and extends to the beginning of the activity area.

Traveled Way: The traveled way is the portion of the roadway designated for the ordinary movement of vehicles; it extends from edge line to edge line.

Washout Conditions: A testing condition (Upchurch, 1992) that includes all observations taken while the sun was shining in front of the sign.

Work Zone: Work zone, work area and work site denote the general location of work activity or the subject of work-area traffic control.

Work Space: The work space is that portion of the activity area set apart exclusively for workers, equipment and material storage and is delineated to exclude vehicular and pedestrian traffic.

2.3 Acronyms

The following acronyms are used throughout this report:

AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
ATSSA	American Traffic Safety Services Association
CMS	Changeable Message Sign
DMS	Dynamic Message Sign
FHWA	Federal Highway Administration
HAR	Highway Advisory Radio
IDOT	Illinois Department of Transportation
LED	Light Emitting Diode
INDOT	Indiana Department of Transportation
IADOT	Iowa Department of Transportation
ITS	Intelligent Transportation Systems
MIDOT	Michigan Department of Transportation
MNDOT	Minnesota Department of Transportation
MUTCD	Manual on Uniform Traffic Control Devices
NCDOT	North Carolina Department of Transportation
NCHRP	National Highway Cooperative Research Program
NHS	National Highway System
NTCIP	National Transportation Communication for ITS Protocol
NYSDOT	New York State Department of Transportation
ODOT	Oregon Department of Transportation
OHS	Office of Highway Safety
PCMS	Portable Changeable Message Sign
PTMS	Portable Traffic Management System
PSA	Public Service Announcement
SHRP	Strategic Highway Research Program

TCP	Traffic Control Plan
TMA	Truck-Mounted Attenuator
VDOT	Virginia Department of Transportation
VMS	Variable Message Sign
WISDOT	Wisconsin Department of Transportation
WSDOT	Washington State Department of Transportation
Y2K	Year 2000 (Problem)

3 Literature Review

A vast amount of information on changeable message signs exists as a result of research studies and the successful application of solutions to the problems faced by practitioners in their daily work. Unfortunately, this information often is not concentrated conveniently or evaluated properly. The literature on portable changeable message signs in relation to the highway work zone operations is considerably smaller. As a result, few of the research findings have made their way into state guidelines.

For these reasons, this literature review is the result of a compilation of several dozens of publications including articles, reports and working papers, personal communication with state traffic engineers (including several hours of telephone conversations), regular and electronic mail and faxes, as well as extensive web searches and library visits.

A brief reference to the various types of changeable message signs is discussed in Section 3.1. Components of portable changeable message signs are discussed in Section 3.2. Motorists experience with respect to various attributes of PCMS systems is detailed in Section 3.3. Utilization and placement of PCMS units are discussed in Sections 3.4 and 3.5, respectively. Some general advantages and disadvantages of CMS units use in work zones are presented in Section 3.7. Human factors as related to PCMS units are discussed in Section 3.8. Finally, human factors specifically related to older drivers are presented in Section 3.9.

3.1 Types of Portable Changeable Message Signs

Although there are many types of CMS systems on the market, they can be categorized into three different groups: light-reflecting (reflective disk, rotating drum), light-emitting (bulb incandescent matrix, fiberoptic matrix, light-emitting diode matrix) and hybrid. Briefly, light-reflecting signs reflect light received from an external source such as headlights, the sun or illuminators. Light-emitting signs create light, either on or behind the viewing surface, with lamps located within the sign housing. Some sign suppliers have combined characteristics of both reflective and emitting technologies to create hybrid signs (Dudek, 1991a).

The light-emitting diode (LED) clustered matrix is a grouping of solid state devices that glow when voltage is applied. Very little power is needed to use an LED. However, because of the limited brightness and small sizes of the LEDs, many must be used to produce an effective message. Since LEDs are low voltage they need high currents to illuminate them.

A problem with LEDs is that the intensity of light tends to decrease over time due to material deterioration and constant high temperatures, especially with increased exposure to bright sunlight. To add to the problem, as an LED begins to degrade it inherently draws more current, furthering the degradation process. LED clusters have an added limitation in that when a single LED within a cluster fails the complete cluster must be replaced.

Therefore, LED clusters must be well-ventilated to maintain color brightness (Dudek, 1991a). LEDs are most commonly found in green, red and amber hues; white, which contrasts the best with a black background, is not available. Light-emitting CMS displays are at their best in low-light conditions, at night or on cloudy days. They are at their worst in bright daylight because the light emitter must be capable of overpowering the brightness of sunlight.

Advantages of LED technology include:

- solid state (no moving parts require less maintenance)
- good visibility and legibility under most lighting conditions
- life span of 10-12 years requiring less maintenance
- choice of colors

Disadvantages of LED technology include:

- sensitivity to heat and humidity
- required cooling within the sign enclosure
- small viewing angle (6 to 12 degrees)

Reports indicate that new draft European standards for CMS systems. covering both physical (i.e., light output) and communications activities (i.e., roadside links to and from signs) are supportive of LED technology.

Reflective-disk CMS units use disks — circular, rectangular and three-dimensional – made of a reflective color, usually yellow, on a dark background. The disks are permanently magnetized, pivoted and arranged in an array so that when an electromagnet is used to flip the disk a message is shown. Reflective disks can be internally illuminated — for example, fluorescent lights within the sign housing – or externally illuminated by the sun, headlights or bottom-mounted lighting. If the sign is internally lit power is necessary whenever a message is displayed. If the sign is not light emitting, then power is only needed when the disks are rotated or flipped (Marston, 1993).

Reflective CMS displays are at their best in bright daylight. Since they are diffuse-reflective they reflect back the sunlight, becoming brighter as the sun gets brighter. During nighttime and dark days, they require some sort of illumination.

Advantages of flip-disk technology include:

- lower power requirements
- excellent tolerance to the environment
- unaffected by high temperatures
- wide viewing angle (40 degrees)

Disadvantages of flip-disk technology include:

- higher maintenance costs due to sticking disks
- collects dust which reduces legibility
- reflective tape will eventually become bleached by sun
- low visibility from long distances, especially at night

The hybrid CMS displays seek to combine the best of the two worlds, that is to yield the best overall daytime and nighttime visibility. The hybrid CMS units incorporate either LED or fiber optics with reflective disks (Marston, 1993). In this sign technology, the reflective disk, which is black on one side and yellow — or similar contrasting color — on the other side, is used as a shutter for a light source, typically LED or fiber optic. When the shutter is "on" the yellow side of the reflective disk and the light emitter can be seen. When the shutter is "off" the light emitter is covered by the disk and the black side of the disk is seen. The hybrid signs require less light from the emitter, as they are not attempting to overcome the power of the sun. The reflectors are given more visibility with the incorporation of the LED or fiber optics while still reflecting the sun, headlights or internal illumination.

Advantages of hybrid technology include:

- high visual display and legibility
- can still operate even if light source fails
- can have default message with flip disk
- unaffected by high temperatures

Disadvantages of hybrid technology include:

- high maintenance cost associated with disk
- reflective surface bleaches in sun
- small viewing angle
- collects dust which reduces legibility

3.2 Components of Portable Changeable Message Signs

The three components that need to be addressed based on the Manual on Uniform Traffic Control Devices (MUTCD) Standards (USDOT, 1993) are the message sign panel, control system and power source.

Message Sign Panel: When developing guidelines it is important to realize that not all PCMS systems are the same. According to the American Traffic Safety Services Association (ATSSA) guidelines (ATSSA, 1994) this variation should be taken into consideration when discussing element colors, size, character modules, visibility and various light source conditions.

Control System: ATSSA has suggested that the system should include the following features in order to ensure successful use based on the MUTCD Standards (USDOT, 1993): (a) a display screen to review messages before displaying on a CMS screen; (b) provision of automatic programmed messages in case of power failure; and (c) a back up battery to maintain memory when power is unavailable.

Power Source: Based on ATSSA's guidelines (ATSSA, 1994) it is essential that the PCMS unit be fully equipped with a power source as well as a battery to ensure that if power problems should arise the motorists will still receive the information.

The New Jersey Department of Transportation is developing what is believed to be the world's first commercial use of fuel cells to power CMS units. The fuel cells are the same source used to supply power to all NASA space vehicles. The by-products of fuel cells are heat and water, making it the cleanest and most efficient energy producing technology known (ITS World, 1998).

3.3 Motorist Experience with CMS Systems

Motorist experience with CMS units is extremely crucial in order to determine the future needs and study areas regarding CMS utilization. The information source, accuracy, timing and relevancy are important concerns from the motorist's perspective.

Source of Information: The CMS units are an extremely important form of information about road conditions (particularly when coupled with radio information). Pouliot and Wilson (Pouliot and Wilson, 1992) have shown that CMS units are a very useful form of information, but are typically more suited for local drivers. Table 1 shows information sources used by the local and truck groups gathered from this study.

	Percent Utilization	
Source of Information	Local Drivers	Truck Drivers
Road and Travel Phone	80	23
CMS	69	40
Radio	61	63
Television	50	21
CB Radio/Other Drivers	24	72
Others	< 30	< 40

Source: Pouliot and Wilson (1992).

Table 1: Information sources used by local and truck drivers.

Accuracy of Information: Since drivers expect the information displayed on CMS units to be accurate it is crucial that the correct information be displayed. For example, proper description of roadwork will prepare the motorist for potentially difficult road conditions due to construction. Incorrect information could be detrimental to the effectiveness of CMS units. Based on the user survey by Benson (Benson, 1996), more than 30% of the 500 survey respondents said they experience inaccurate or out-of-date information on CMS units.

Timeliness of Information: CMS units must communicate not only the intended action for motorists but also the timeliness for the proper action. CMS units are extremely useful in giving information about alternate routes in a timely manner. This can potentially help to avoid confusion and accidents. Miller (Miller et al., 1995a) showed that information like the message LANE/CLOSED/AHEAD is insufficient because it fails to tell motorists what they should do and when they should do it. The message LFT LANE/CLOSED/1000 FT, however, tells motorists which lane they need to avoid and how soon this lane closure will occur.

Pertinence of Information: Motorists do not need unnecessary information and are more likely to respond to messages and speed advisories based on real-time conditions (Garber and Patel, 1994). CMS units primary purpose have been to advise drivers of unexpected traffic and routing conditions and of special speed control measures.

Type of Information Needed: Focus groups have indicated a need for particular information but preferences are confounded. Some motorists, for example, feel that information about when congestion dissipates is unnecessary while other motorists feel it is very valuable. In fact, negative comments of CMS systems were matched with the same number of positive comments in a recent study (Benson, 1996). Those motorists who felt negatively towards the CMS units felt the information was irrelevant and a nuisance. The positive comments came from those who felt that CMS systems were useful in providing notification of construction ahead, lane shut down and location of upcoming exit lanes.

Message Length: Focus groups (Miller et al., 1995b) are divided on the maximum number of screens allowed. Participants did agree that multiple message signs were difficult to read as a result of poor visibility, large vehicles blocking the view of the CMS, encountering the CMS in the middle of a message or placement of the CMS on the opposite shoulder. Moreover, a 3-line message was rated as being more helpful and more likely to provide necessary information than either a 1- or 2-line message (Hanscom, 1981).

Blank Screens: CMS units should be left blank if there are no unusual traffic conditions to report (Miller, 1995a). Survey respondents (Miller, 1995a) felt a blank CMS meant that there were no unusual traffic conditions to report, while a CMS that displayed the date and time was both a waste of taxpayer resources and a distraction.

3.4 Utilization of CMS Systems

Pigman and Agent (1988) evaluated different traffic control devices and recommended the following: (a) supplemental signs for all long-term closures on high-volume, high-speed four-lane roadways, (b) CMS units when one-way hourly volumes exceed 1,000 (ADT exceeds 20,000) and (c) application of rumble strips if other devices do not reduce late merges and there is excessive congestion.

It was found that substantial savings in flagger labor costs could be achieved by using a PCMS with only a minimal increase in motorist delay costs (Ullman and Levine, 1987). Conservative estimates of the savings ranged from $9 to $14 per hour. The study also suggested that the potential for vehicle accidents within the work zone may be higher with PCMS systems because of occasional driver noncompliance with these traffic signals. The trade-off between this possible increase in vehicular accidents and the reduction in flagger accidents could not be estimated from that study.

In a recent study (Benson, 1996), half of the survey respondents were skeptical on the accuracy of travel time during heavy congestion. Among the participants in the focus groups many expressed skepticism about the value of such estimates, whether they were quantitative or descriptive. Motorists also felt that congestion warnings could cause people to slow down and cause accidents.

Survey participants in the study (Benson, 1996) agreed that CMS units should include traffic and road condition information. Two-thirds of the respondents indicated that specific safety messages are a good idea to post. For example, LIGHTS ON/IN BAD/WEATHER was preferred to TAILGATING/DEADLY. This is clearly against the IDOT's policy to post messages only when needed because not essential messages would lessen the effect of essential messages.

One of the major contributors to accidents in work zones is a large speed differential among vehicles, especially in work zones where the speed limit has been reduced. Garber and Woo (1990) found that the accident rates during the construction period were significantly higher than those before the work zone was installed. Benekohal and Shu (1992) concluded that using two CMS units within the work zone was the most effective way to reduce speeds for both trucks and cars. In addition, Hanscom (1982) found that CMS units tend to improve traffic flow and reduce speeds, which is safer for construction workers.

Hanscom (1982) conducted before and after studies of CMS application versus non-CMS application at freeway construction sites with lane closures to determine the effectiveness of CMS units on operational traffic behavior. The study concluded that the use of CMS units resulted in increased preparatory lane-change activity, smoother lane-change profiles, significantly fewer late exits and reduced speeds at the lane closure point. In particular, CMS units used for advanced warning at lane closure work zones reduced average speeds by up to 7 mph.

There was an overwhelming amount of support by motorists (Benson, 1996) for posting the precise location of an accident to show where to divert from the freeway. For example, the message ACCIDENT AHEAD/ALL LANES OPEN/MAINTAIN SPEED, posted when the after-effects of an accident could be seen alongside the road but all travel lanes had been cleared, had very strong support.

The study conducted by Benson (1996) indicated a reluctance on the part of some respondents to follow the alternative routes suggested by the CMS units. Four reasons for the reluctance were given: (a) fear of getting lost, (b) belief that congestion would be bad on the alternative route, (c) belief that alternative route would not be any faster and (d) the motorist already had an alternative route.

3.5 Placement of PCMS Units

The placement of PCMS units in advance of a work zone or in a work zone can be crucial in the motorist's reaction time and speed reduction time. Early research (Richards, 1986) showed that CMS units should be first activated 500 to 1,000 feet upstream of the hazardous location within the work zone. This ensures that drivers have adequate time to react and the message will still be fresh in their minds when they reach the potential hazard. The same study recommended that CMS units should not be placed in high driver work load areas such near ramps, intersections or lane-closure tapers.

Dudek and Ullman 1989) investigated reduced traffic control sign treatments for short-duration maintenance operations involving lane closures on four-lane divided highways with traffic volumes of 30,000 or fewer vehicles per day. The study indicated that CMS placement 1,500 feet before the cone taper influenced drivers to exit the closed lane farther upstream from the work zone than the other candidate sign treatments.

Hanscom (1981) recommended an advance placement 3/4 mile from the closure. On the other hand, Benekohal et al.(1995) found that truck drivers prefer an advance warning sign 3 to 5 miles.

3.6 Effectiveness of CMS Systems

Hanscom (1981) observed increased advance preparatory lane change activity, smoother lane change profiles and significantly fewer late exits (exit from closed lane within 100 feet of closure), especially with advance placement 3/4 mile from the closure as opposed to a 2000-feet advance placement. Moreover, reduced average traffic speeds approaching the taper were observed at locations characterized by preexisting speeds in excess of 48 miles per hour (mph).

Benekohal and Shu (1992) examined the effectiveness of CMS systems to reduce speed in a construction zone. The study conclude the following:

- *Experiment A — One CMS in advance of the work zone:* Displaying speed limit and information messages on a CMS placed in advance of a work zone reduced the average speed of cars and trucks by 2.8 mph and 1.4 mph, respectively, at the beginning of the traffic control zone.
- *Experiment B — One CMS inside the work activity area:* Displaying information in the work zone was effective at reducing the average speed of cars an additional 1.7 mph near the CMS (about 1000 ft. from it) but was not effective far from the CMS (about 2 miles but still in the work zone). On the other hand, the CMS was not effective at reducing average speeds of trucks near the CMS, but it produced a 3.7 mph additional speed reduction 2 miles from the CMS.
- *Experiment C — Two CMS units inside the work activity area:* Displaying information on two CMS devices in the work zone activity area reduced the average speeds of both cars and trucks. Net reduction near the first CMS were 4.6 mph for cars and 3.7 mph for trucks. The net reduction near the second CMS were 4.7 mph for cars and 2.6 mph for trucks.

Overall, the study found that not only did the signs reduce average speeds but also the percentages of vehicles with excessive speeds.

3.7 General Advantages and Disadvantages of CMS Use

Previous research (Richards and Dudek, 1986) has indicated that the general advantages of using CMS systems in work zones are:

1. Relatively inexpensive for both short- and long-duration applications
2. Agency or contractor has direct control over performance
3. Little or no disruption to traffic flow
4. Quick and easy to implement and remove
5. Suitable for all types of highways and work zones
6. Effective at night and in inclement weather
7. May be used in combination with other techniques for best results.

The general disadvantages of using CMS systems in work zones are:

1. Only modest speed reduction possible (no greater than 10 mph (Richards and Dudek, 1986; Richards et al., 1996; Hanscom, 1981 and 1982).
2. Constrained by availability of signs
3. Effectiveness may decrease with continuous use
4. Sign maintenance and repair may require technical expertise.

3.8 Human Factors and CMS Systems

The effectiveness of PCMS systems, gauged in terms of observable driver behaviors that traffic management procedures are designed to elicit, rests upon a set of reasonably well-understood human factors. A motorist information system must be rational, relevant and reliable. Driver sensory/perceptual and cognitive capabilities must be thoughtfully considered to ensure that a message will be acquired and then understood, recalled and applied by the driver within a desired time frame; the message must seem to clearly apply to the driver and to reflect current conditions to be credible; and it must be accurate in describing what the driver experiences downstream. The credibility of a highway advisory message certainly depends in part upon a presentation strategy that is "rational," but it also must be perceived to be relevant to the individual motorist and reliable to the point of being virtually error-free. Reliability requirements — being dependent on real-time data on operations as input to the traffic control system — are most difficult to meet, but probably the most important if high rates of compliance in drivers' vehicle control decisions are ever to be realized. A motorist's ability to use highway information is governed by:

1. information acquisition or how well the source can be seen or heard and
2. information processing or the speed and accuracy with which the message content can be understood and its ease of recall by the motorist after message presentation is completed.

In the acquisition of PCMS information, a visual task, the key factors are:

1. its conspicuity or "attention-getting value" to the motorist;
2. the size, brightness (contrast), stroke width-to-height ratio and spacing of individual characters of text which together determine the legibility of the message;
3. the placement of the PCMS device — overhead versus one side versus both sides of the highway — which affects its likelihood of being blocked from a motorist's view by other vehicles, as well as the "eyes away from the road" time required to fixate upon the message; and
4. the exposure time or available viewing time, of each message phase presented on a PCMS.

Human factors have come to play an increasing part in the design and use of CMS units. Several criteria must be met for CMS systems to be effective. Initially, CMS units must command attention or be easily detected by drivers. They must be legible at the appropriate distance (in time to take the necessary action) and must be legible when seen for a very brief period (glance legibility). At busy highway locations, CMS units can easily be hidden by large vehicles and seen only briefly. CMS messages should also be quickly understood as drivers often have only a second or two to interpret and respond to the message. This may pose a problem given that drivers may require 10.2 to 11.7 seconds to detect, recognize, make a decision and execute a proper maneuver for a lane change in a construction zone (Warren and Robertson, 1979).

The relative importance of these various design criteria has not been established in a definitive manner. They are not all of equal importance and can be in conflict. In an attempt to determine the relative weighting that ought to be attributed to the main criteria for traffic sign symbols Dewar (Dewar, 1988) solicited the views of sign experts in four countries (Australia, Canada, New Zealand and the United States) and found that comprehension was most important, followed by conspicuity, reaction time and legibility distance.

A great many human characteristics and individual differences influence the ability of drivers to obtain information from CMS units. How will those who design and deploy CMS systems take into account driver abilities and limitations? Knowledge of the human factors associated with driver abilities is essential to decisions about issues such as:

1. number of screens to be used,
2. duration of a given message,
3. type of message (specific or generic),
4. message legibility and conspicuity,
5. speed of response to the message,
6. effects of environmental conditions (e.g., darkness, fog),
7. individual differences (e.g., age, education) and
8. information overload.

In spite of the considerable amount of research that has been done on these topics, some of which is outlined in Henderson (1987), little has been successfully applied to the design and use of CMS systems in work zones. More detailed accounts of human factors research on driver characteristics are available elsewhere (Dewar, 1992; Evans, 1991) and traffic signs in general (Dewar, 1989). A good summary of traffic engineering practice related to traffic control devices in general can be found in the latest edition of the Traffic Engineering Handbook (Pline, 1992). The problems faced by older drivers as related to traffic control devices have been outlined by Staplin *et al.* (1987). Some of the foregoing issues were also addressed in a design guide by Dudek *et al.* (1978) and an applications guide by Dudek (1991a).

In Section 3.8.1 research experience regarding CMS visibility and message legibility is presented. In addition, two criteria affecting CMS legibility are further considered in Sections 3.8.2 and 3.8.3.

3.8.1 CMS Visibility and Message Legibility

The ease with which a CMS sign can be seen depends on roadway factors such as grade, curvature and placement relative to other signs or structures and the structure of the unit.

The unit should be visible for several seconds before the message becomes legible so that the motorist is aware that there is a message to be read.

The other aspect of CMS visibility is message legibility, that is the ease with which the message can be read. Legibility can be affected by factors such as message characteristics, angle of light emissions and lighting conditions. Light-emitting CMS units can be initially seen at a longer distance than light-reflecting signs, but are harder to see at distances close to the sign. This is very important on high-speed highway locations and during inclement weather conditions.

Legibility of a sign can change due to a different lighting conditions, such as day, night, washout and backlight. Table 2 gives the average legibility distances for different technologies and lighting conditions as reported in (Upchurch et al. 1992).

Condition	Reflective Disk	LED	Fiberoptic
Midday	698	743	983
Night	355	694	678
Washout	420	487	853
Backlight	219	502	659

Table 2: Average legibility distances (in feet) under different conditions.

Research findings regarding the legibility and presentation of the message include:

- A minimum exposure time of one second per short word (four to eight characters) or two seconds per unit of information (Dudek, 1992).
- For freeway applications CMS units should have characters at least 18 inches in height (Dudek, 1992).
- Benekohal et al. (1992) concluded that 40% of drivers have difficulty in reading light-embodying CMS units at night.
- Flip-disk signs have the highest discomfort rating of all four types analyzed by Upchurch (1992). This was true for all four lighting conditions stated in the study.
- Fiber-optic signs have the lowest discomfort rating of all three types analyzed by Upchurch et al. (1992) during the midday and washout conditions.

According to the 1993 Revision to Part VI of the MUTCD (USDOT, 1993) the following factors should be taken into consideration when messages are designed:

- No more than two displays should be used within any message cycle.
- Each display should convey a single thought.
- Messages should be as brief as possible.
- When abbreviations are used they should be easily understood.
- The entire message cycle should be readable at least twice at the posted speed, the off-peak 85th percentile speed prior to work starting or the anticipated operating speed.
- Messages should not scroll horizontally or vertically across the face of the sign.

Another study (Mace, 1988) recommended the following character/message variables for CMS visibility:

1. **Color:** Optimal: Matching MUTCD color-coding specifications; Acceptable: Red, Amber/Yellow, White, Orange.
2. **Contrast:** Optimal: $5 < (Lt - Lb)/Lb < 50$; Acceptable: $(Lt - Lb)/Lb = 5$ [2].
3. **Contrast orientation:** Optimal: Light letters on a darker background; Acceptable: Light on black; Light on colored.
4. **Font and matrix form:** Optimal: Alphanumerics that most closely approximate Standard Highway font; Acceptable: Any reasonable non-serif font using at least a 5×7 matrix or equivalent.
5. **Letter height:** Optimal: 18.1 in; Acceptable: 12.0 in if legibility < 400 ft is acceptable.
6. **Width:height:** Optimal: W:H=0.8; Acceptable: W:H=0.6 to 1.0.
7. **Stroke width:height:** Optimal: SW:H=0.13; Acceptable: SW:H=0.1 to 0.18.
8. **Inter-letter spacing:** Optimal: Three times Standard Alphabet Series E or 1/2 the letter height; Acceptable: 3/7 the letter height.
9. **Inter-word spacing:** Optimal: Equal to letter height; Acceptable: Equal to 5/7 the letter height.

[2]Lt – luminance of a character module with all the elements "on"; Lb – luminance of a character module with all the elements "off".

10. **Inter-line spacing:** Optimal: 70% of letter height; Acceptable: 20% of letter height with two-line CMS units.

Two criteria affecting CMS legibility are further considered. Distance in Section 3.8.2 and letter fonts and style in Section 3.8.3.

3.8.2 Distance Considerations

VDOT's guidelines (see Section 11, Module 4) state that a CMS message should use no more than two (flip-disk) screens, although a message with only one screen is preferred. There are two key reasons for using a maximum of two screens:

1. The MUTCD guidelines state that portable CMS systems should use no more than two screens.
2. In order for a CMS message to be effective, motorists must have enough time to read the entire message. In light of this fact, the MUTCD guidelines also state that motorists should be able to read the entire message twice if traveling at the posted speed limit. Due to limited legibility distances of CMS units, motorists will rarely have sufficient time to read a message twice that is longer than two screens.

It is worthwhile, therefore, to compute the amount of time motorists will have to read a CMS. Figure 1 is used for the following discussion. If a motorist notices a CMS from far away the CMS message may not be legible. However, as the motorist approaches the CMS, the message becomes legible at point A. The motorist is then able to read the message as he or she travels from point A to point B. At point B, however, the motorist may no longer comfortably read the CMS. This occurs because the CMS is located to the side of the road and is outside the motorist's cone of vision, unless the motorist lifts his/her eyes from the road. Therefore the motorist may only safely read the message while traveling between points A and B. One may then use this distance between points A and B in order to compute the amount of time which the motorist has to read the CMS.

Dudek (Dudek, 1992) begins with the premise that a laterally-mounted PCMS will cease to be comfortably readable when the angle between the CMS and the road centerline is greater than 10 degrees, which occurs as the motorist gets closer to the CMS (King, 1970). Reading the CMS becomes difficult because of the combination of psychological factors involved in driving and the disappearance of the CMS from the normal field of vision. The distance,

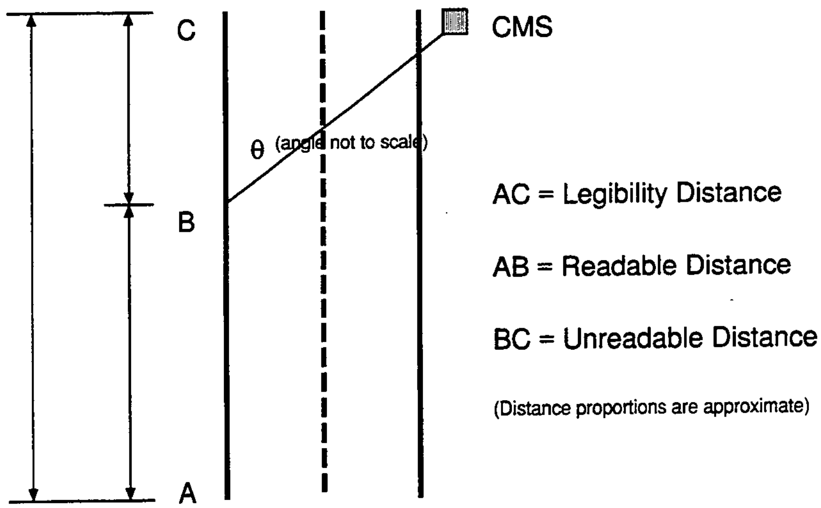


Figure 1: An illustration of various distances used to determine CMS legibility.

D_u, from the CMS to the point at which it is no longer comfortably readable is given by:

$$D_u = 5.67[S + (N - 0.33)L + 0.5W] \tag{1}$$

where, $S =$ distance from the side of the road to the CMS in feet;
$N =$ number of lanes;
$L =$ width of lanes in feet;
$W =$ width of the CMS in feet.

Given the distance, D_l at which the CMS becomes legible (from the literature), the distance, D_r, at which the CMS becomes readable is then given by:

$$D_r = D_l - D_u \tag{2}$$

The difference may then be divided by the travel speed, v, in order to compute the time, t_r, for which the CMS is readable, namely,

$$t_r = \frac{D_r}{v} \tag{3}$$

This readable time then limits the maximum number of different message screens which may be used.

Numerical Example: Assume that a CMS is mounted such that, as calculated by (1), it has an unreadable distance D_u =200 feet. Table 3, taken from VDOT's report (VDOT,

Distance from close side of CMS to edge of road (ft)	Four Lanes of traffic	Three Lanes of traffic	Two Lanes of traffic	One Lane of traffic
0	281	213	145	77
2	292	224	156	88
4	303	235	167	99
6	315	247	179	111
8	326	258	190	122
10	337	269	201	133
12	349	281	213	145
14	360	292	224	156
16	371	303	235	167
18	383	315	247	179
20	394	326	258	190
22	405	337	269	201
24	417	349	281	213
26	428	360	292	224
28	439	371	303	235
30	451	383	315	247

Table 3: Distances (in feet) at which a CMS becomes unreadable.

1995), gives the values for D_u in various situations. The literature (Mace, 1988) states that in daytime conditions a flip-disk CMS has a legibility distance D_l=650 feet. The readable distance, D_r, can then be computed from (2) to be 650 feet - 200 feet = 450 feet. A travel speed of 55 mph is equivalent to approximately 81 feet per second. From (3) it can then be determined that the readable time, t_r, is approximately six seconds (450 feet/81 feet per second = 5.6 seconds).

Assume now that a CMS has three lines, eight characters per line and the capability to display alternate message screens. If a reading time of two and a half seconds per message screen is allowed then it will take approximately two and a half seconds to read one screen, five seconds to read two screens and 7.5 seconds to read three screens, the last of which is not possible at 55 mph (over 5.6 seconds).

The limitation is reinforced by the MUTCD standards (USDOT, 1993) which specify the following:

- no more than two message screens should be used by portable CMS systems.
- motorists should be able to read the entire CMS message twice while traveling at the posted speed.

The MUTCD standards suggest that even two screens might be too much for motorists to process, which leads to the conclusion that one should use additional message screens very judiciously.

3.8.3 Letter Fonts and Style

Miller *et al.* (1995) report that for flip-disk PCMS systems double-stroke lettering has a 25% smaller legibility distance than single-stroke lettering. Certain lower-case letters are difficult to make with the current PCMS units, especially hanging letters such as "g", "y" or "p".

There is evidence (White, 1988, pp. 30-32) to suggest that viewers may comprehend mixed-case words more quickly than upper-case words, assuming the viewer is close enough to read the text. However, in the case of CMS systems there is the additional consideration of the distance at which one can read the message. The height of the letter affects the legibility distance, which explains the general attempt to use letters that are as tall as possible in a CMS message. Mixed-case words may be slightly more legible than upper-case words, but the loop height of the lower-case letters must be the same height as that of the upper-case letters. To achieve this equality, the lower-case letters would have to be wider than the upper-case letters, which is not possible with most of today's CMS units. Secondly, the differences found in the legibility distances were small; 50 feet for high-contrast and 16 feet for low-contrast materials, with the average legibility distance being around 600 feet (Garvey and Mace, 1996).

The current portable CMS units are estimated to have 650-foot legibility distances under good daytime conditions and 350-foot legibility distances under nighttime conditions. If the legibility distances of CMS systems currently in use are too small to be reduced further for a questionable gain in recognition speed from mixed-case letters, then it might be better to use only upper-case letters in cases where legibility distance is not an issue.

3.8.4 PCMS Placement

PCMS placement affects information acquisition under heavy traffic conditions where a center lane driver's view of a roadside device may be obscured for lengthy intervals. If a facility has more than two lanes a consideration may be given to placement of a portable PCMS in the median (space permitting). Placement in the median minimizes glare from opposing vehicles due to a large glare angle, unlike on the right shoulder.

3.8.5 Message Duration

A motorist's reading time for a CMS message dictates the required exposure time at a given speed. Exposure time is the length of time a driver is within the legibility distance of the message. The minimum recommended exposure time per page (phase) for a three-line CMS is 3 seconds, without consideration of any particular set of driver characteristics. While some jurisdictions have selected shorter exposure times, the increasing numbers of older drivers on limited-access highways makes an even stronger case for the 3-second minimum per page. Reading time is the time it actually takes a driver to read a sign message. In instrumented vehicle studies conducted in light traffic with familiar drivers on a rural freeway, reading times averaged 1 to 1.5 seconds per unit of information (Mast and Ballas, 1976). Reading times under "loaded" driving conditions would be higher, such as under extreme geometry, heavy traffic volumes, large volume of truck traffic, traffic conflicts or poor climatological conditions.

More recent field research using drivers not familiar with the highway has indicated that a minimum exposure time of 1 second per short word (four to eight characters) or 2 seconds per unit of information, whichever is larger, should be used (Carvell et al., 1978). A unit of information is a data item given in a message that can answer one of the following questions: (1) what happened? (2) where? (3) what is the effect on traffic? (4) for whom is the advisory intended? and (5) what driver action is advised? Thus, the exposure time for a three-line message could vary from 3 seconds to as long as 6 seconds, with each phase of a PCMS at the lower end of this range and with each permanent CMS phase (page) at the upper end, due to differences in the number of characters per line. Reducing the exposure time per phase is warranted only when information is being repeated. For example, a three-line message may be displayed for only 2.5 seconds if it is a second phase of a two-phase message which repeats one or two lines from the first phase. If the second phase presents new information the recommended minimum exposure time for both phases remains 3 seconds (Staplin et al., 1998).

For a given operating speed, exposure will increase with increasing legibility distance. For example, an overhead sign message legible at 650 ft (198 m) will be exposed to drivers traveling at 55 mph (88 km/h) for approximately 8 seconds. With a legibility distance of 1,000 ft (305 m), the message will be exposed for about 12 seconds. Legibility distances for PCMS systems vary from the minimum of 650 ft (198 m) specified by the MUTCD Part VI and ATSSA to over 1,000 ft (305 m), depending on the technology. Permanent CMS systems generally have legibility distances in the higher range of 900–1,200 ft (274-366 m). However, there is a point at which a sign becomes unreadable during a driver's approach to a CMS, reducing the legibility distance, particularly for side-mounted CMS units. This unreadable distance, which is dependent on the number of lanes and the sign technology as well as how far the sign is placed from the roadway edge or how high above the roadway it is mounted, ranges from 280 ft to 420 ft (85 m to 128 m). In an existing system, therefore, required exposure times dictate the maximum length of message that can be displayed and in all cases it is desirable that motorists be able to read the entire message on an (unobstructed) CMS twice (Staplin et al., 1998).

The calculated maximum exposure duration of a message should not exceed 9 seconds (Staplin et al., 1998). For two-phase messages a separate requirement is needed to meet the needs of drivers. In this case, 3 seconds is added to the required exposure time because of the asynchrony between the time the driver can read the CMS and the onset of the CMS phase displayed. In other words, the phase that the driver reads initially may have already been displayed for 2 seconds by the time he or she can read it. Thus, the driver will not have enough time to read this phase and will need to view that phase again. The net result is that 3 seconds needs to be added to the required exposure time to allow drivers to read the phase that first came into view a second time. Since the maximum recommended exposure time is 9 seconds only 6 seconds of actual message reading time is allowed on a two-phase CMS, whereas the full 9 seconds can be used for a single-phase message. The important point here is that single-phase messages can more efficiently convey information to drivers. When use of a single-phase CMS is not possible because of message length, multiple devices with a single phase on each device will be superior with respect to drivers' limitations for message acquisition. Part VI of the MUTCD (para. 6F-2) specifies that when multiple CMS units are used they shall be placed on the same side of the roadway, separated by at least 1,000 ft (305 m).

For these reasons, the maximum number of phases used to display a message on a permanent CMS should be two (Staplin et al., 1998). The most effective format for CMS message presentation is a single phase which consists of a maximum of three units of information, but if two are required, each should be worded so that it can stand alone and still be understood. Portable CMS devices, though limited to fewer characters per line, should also be restricted to two phases (Staplin et al., 1998). At high speeds above 55 mph (88 km/h), a driver may only have 2.8 to 4.6 seconds to read a message on a side-mounted CMS, depending on the available legibility distance. For this reason, messages should be restricted to one phase at high speeds (Staplin et al., 1998).

3.9 Older Drivers

The legibility of a CMS is influenced by the same factors influencing character and message legibility of static signs, including the key factor of driver visual performance capability (Staplin et al., 1998). This section essentially reports on the literature search found in (Staplin et al., 1998).

Letter acuity declines during adulthood (Pitts, 1982) and older adults' loss in acuity is accentuated under conditions of low contrast, low luminance and where there is crowding of visual contours (Adams et al., 1988). In any event, the legibility for current CMS systems is determined primarily by the technology and the device configuration (numbers of rows, characters per row and number, size and spacing of pixels per character) as fabricated by a given manufacturer and for all practical purposes can be treated as a fixed factor — modified by environmental considerations — in considering whether a particular system will meet motorists' needs.

3.9.1 Legibility Distance

For any given speed, older drivers' needs dictate a legibility distance that permits the entire CMS message to be read twice in its entirety. As a general rule, at least 1,000 ft (305 m) of legibility distance for a motorist with 20/40 visual acuity should be provided on a 55-mph (88-km/h) facility. Of the studies that assessed various character matrix forms (number of elements per character cell), most found a 7×9 element matrix to be necessary when using lowercase letters because of the descenders and ascenders, but a 5×7 font was generally deemed acceptable with uppercase-only lettering. The MUTCD specifies a minimum legibility requirement of 650 ft (198 m) under both day and night conditions for PCMS units. Given that the most common format for a portable sign is 18-in (450-mm) tall characters arranged in three lines of eight characters, this provides for a legibility distance of 36 ft/in (0.44 m/mm) of letter height. Thus, letter sizes of at least 18 in (450 mm) should be used to accommodate older drivers' diminished visual acuity. Other variables found to significantly effect CMS legibility for older observers are font, letter width-to-height ratio, contrast, orientation, letter height, case and stroke width (Jenkins, 1991; Mace et al., 1994). The most consistent finding across studies evaluating CMS design elements was that the results for older drivers were quantitatively, but not qualitatively, different from those of their younger counterparts. That is, if a manipulation of a variable resulted in an improved score for younger observers, it almost invariably improved older observer performance.

The "target value", legibility and viewing comfort of light-emitting diodes (LED's) and fiber-optic CMS technologies were compared with flip-disk and conventional overhead guide signs in a field study (Upchurch et al., 1992). Younger (ages 18-31) and older (ages 60-79) subjects in this study demonstrated mean daytime target values for fiber-optic, LED and flip-disk technologies that all were significantly better (longer) than the values for conventional overhead signs. Under nighttime conditions, however, the poorest performances (shortest distances) were demonstrated by both age groups for the flip-disk technology, falling below the conventional sign values as well. The fiber-optic and LED signs again exceeded the conventional signs based on nighttime mean target value, with the fiber-optic technology showing a slight superiority for older drivers. Under backlight (sun behind sign) and washout (sun behind driver) conditions, target values for all sign types decreased substantially and the differences among sign types diminished, although the fiber-optic technology still resulted in the best overall performance across age groups.

Legibility distance results tended to favor conventional signs, followed by fiber-optic signs, LED signs and flip-disk technology. Mean daytime legibility distances for each sign type in this study were as follows:

- fiber-optic: 61 ft/in (0.74 m/mm)
- LED: 42 ft/in (0.51 m/mm)
- flip-disk: 39 ft/in (0.47 m/mm)
- conventional: 88 ft/in (1.07 m/mm).

Under nighttime conditions, the conventional signs again could be read at the longest mean distances, followed closely by the fiber-optic and LED signs, with the flip-disk technology showing the poorest performance. Backlight conditions favored the fiber-optic technology and washout conditions favored the conventional signs; in both cases, however, the flip-disk technology resulted in the shortest legibility distances. Using a threshold for minimal acceptable legibility distance of 628 ft (191 m), the study concluded that flip-disk signs are deficient under all conditions except midday daytime viewing, LED signs are deficient under both backlight and washout sun conditions and fiber-optic signs are deficient only with the sun glare present under backlight conditions.

Mean discomfort ratings were consistent with these patterns of results. Fiber-optic and conventional signs were assigned the best (lowest discomfort) ratings under daytime conditions, by younger and older drivers alike. LED signs caused slightly more discomfort for older subjects and flip-disk signs resulted in the highest discomfort ratings, especially for older drivers. Under nighttime conditions only the flip-disk technology resulted in high discomfort ratings. Discomfort ratings were more even and much higher, across sign types under backlight conditions, though flip-disk signs still were rated the worst by both age groups. Under washout conditions subjects reported little discomfort for either the fiber-optic or conventional signs, but much greater and roughly equivalent levels of discomfort with the LED and flip-disk technologies.

Table 4 contains legibility distances from the Upchurch et al. study (1992). For older drivers, the legibility distances are lower due to the well-documented degradation of visual performance with age. Unfortunately, this is the only study that has assessed legibility distances for older observers. The legibility distances for conventional bulb matrix and LED/flip-disk hybrid CMS units were estimated from the results of the Upchurch data and data cited in (Dudek, 1991a). The results suggest that flip-disk CMS units should not be used at night along roadways where average speeds reach or exceed about 55 mph (88 km/h).

	Daytime Legibility Distances		Nighttime Legibility Distances	
Sign Technology (Character Height, in)	Younger Observers	Older Observers	Younger Observers	Older Observers
Fiber Optic (16 in)	1006	959	687	667
LED (17.8 in)	812	681	794	602
Flip-disk (18 in)	731	667	363	348
Bulb matrix	800	671	750	569
Hybrid LED/flip-disk (18 in)	731	667	794	602

Table 4: Day and night predicted legibility distances for various sign technologies (in feet).

Although the bulb matrix CMS was assessed by the Upchurch et al. study (1992), no legibility distances for that sign were reported. Legibility distances for this type of CMS systems have been obtained; however, it is unknown whether any older observers have been used in assessing legibility distances. Dudek (1995) cited a study in which bulb matrix CMS systems provided legibility distances of 800 ft (244 m) during the day and 750 ft (229 m) at night. These distances are similar to the legibility distances obtained by Upchurch et al. (1992) for LED-type CMS systems using younger observers. Until psychophysical data can be obtained for older observers viewing bulb matrix signs the legibility distances for older observers are assumed to be roughly 671 ft (204 m) during the day and 569 ft (173 m) at night. These estimates are based on applying the ratio of older-to-younger legibility distances for the LED-type display (Staplin et al., 1998).

There are also a number of hybrid CMS systems that were not included in the Upchurch et al. study (1992). Hybrid CMS systems apply various combinations of sign technologies listed in Table 4 within a single sign. Product literature for one manufacturer's hybrid LED/flip-disk sign states that the sign provides 900 ft (274 m) of legibility distance during the day and greater than 900 ft (274 m) at night, using character heights of 18 in (450 mm). Unfortunately, the methods used to obtain these legibility distances are unknown. Since the sign uses the reflective flip-disk technology during daytime and the LEDs at night, the legibility distances for older observers for the daytime flip-disk in Table 4 (667 ft [203 m]) should be used as a more realistic estimate of legibility distance with LED/flip-disk hybrids (Staplin et al., 1998). For nighttime viewing, the nighttime LED legibility distance (602 ft [183 m]) in Table 4 should be used (Staplin et al., 1998).

3.9.2 Cognitive Ability

Work zones constitute driving situations that require a high amount of controlled processing and data show that cognitive ability scores that measure processing efficiency decline with age (Ackerman, 1987). In fact, sensory memory, working memory and divided attention all show a decline with aging and must be considered in the display of messages on CMS units. Sensory memory is a high-capacity, briefly accessible register from which information is lost through decay or interference. While there is evidence that older adults require slightly more time to establish a legible "icon" in sensory memory, another set of findings suggests that with advancing age images are instead more susceptible to masking by other (successive) stimuli (Walsh et al., 1978). This suggests that a message should be limited to a single phase or certainty no more than two, because multiple phases will interfere with message comprehension. There is also considerable evidence that older adults have poorer working memory function than younger adults (Salthouse, 1991; Salthouse and Babcock, 1991). This suggests that message length be limited to the fewest, most relevant units possible. Finally, older adults are particularly disadvantaged when they are required to use working memory to manage multiple tasks (Ponds et al., 1988). Van Wolffelaar et al. (1990) found that older drivers made more tracking (steering) errors when required to attend and respond to a dot-counting task and a task that required them to monitor peripheral events. In another study (Staplin et al., 1998), older adults also showed a dramatic increase in the rate of nonresponding on the dot-counting task under multiple task conditions, compared to younger subjects. Van Wolffelaar et al. (1990) concluded that there is a disproportionately greater problem for older adults in divided attention situations and directly linked this to a higher accident rate for older adults in time-pressured, complex traffic situations.

3.9.3 Message Guidelines

The minimum required information for traffic management includes: (1) a statement of the problem and (2) action statement(s) — i.e., a driver needs to know what to do and one good reason for doing it. Additional elements are included as needed for a specific situation. The key here is not to burden the driver with unnecessary information. Only about two-thirds of drivers are able to recall completely four pieces of information (problem, effect, attention and action); however, 80-90 percent can recall the action message (Huchingson et al., 1978). Two problems in message presentation must be avoided: (1) providing too much information in too short a time and (2) providing ambiguous information that leaves either the intent of the message or the desired driver response uncertain.

The first problem does not refer solely to reading-time difficulties, as discussed above; instead, it refers to the number of ideas or "information units", contained in a message. Certainly, the number of words displayed on a sign is important, but so is the manner in which words are grouped. Units containing one word (DELAY), two words (DELAY AHEAD) or many words (MAJOR DELAY AT HIGH STREET) are equally difficult to remember when the display is no longer in sight. However, a series of six units, for example, of information in a message displayed on a permanent CMS will be easier to remember if presented in two phases of three units each than if all six units are presented on a single phase. Studies have concluded that no more than three units of information should be displayed on one sequence when all three units must be recalled by drivers (Huchingson et al., 1978; Gish, 1995).

Gish (1995) conducted a human factors laboratory study addressing the perceived timeliness, accuracy and credibility of CMS messages using both younger (ages 16-33) and older (ages 65-84) test subjects. Results showed that correct recall of the first CMS phase (a downstream speed advisory) was nearly 100 percent for both age groups. However, successive phases of information (containing downstream delay and route diversion information) were recalled less accurately. For the delay information (second phase), correct recall for the younger subjects was about 82 percent, versus 60 percent for the older subjects. For route numbers (third phase), correct recall was 55 percent for the younger subjects and 19 percent for older subjects. These results reinforce the earlier recommendation that a maximum of two phases should be used.

When a message must be divided into two phases it is desirable to repeat key words from the first phase in the second phase to provide assurance that all drivers see the message at least once. This also allows information rehearsal, as provided by an additional "learning trial", which will facilitate message recall when the device is no longer in sight. A recommended standard practice is therefore to put the problem on line one, the location on line two and alternate either the effect and action or diversion information on line three, repeating lines one and two on both phases.

The second type of problem can occur when an unfamiliar word or abbreviation is used, when a word is hyphenated or a phrase is divided inappropriately or when an abbreviation or a word can mean different things in different word pairings or contexts. Ambiguity occurs, for example, when CENTER LANE is used on a freeway with four or more lanes in one direction. Another example is the use of LANE CLOSED versus LANE BLOCKED to denote a prolonged closure for construction or maintenance versus a temporary blockage due to an accident or stall. To foster the most simple and consistent practice for motorists LANE CLOSED is recommended under both roadwork and incident conditions because at the time of display the lane is effectively closed. Finally, neither FREEWAY BLOCKED nor FREEWAY CLOSED should ever be used when at least one lane is open to traffic.

Abbreviations also have the potential to be misunderstood by some percentage of drivers, exacerbating message comprehension problems for individuals with age-related diminished capabilities. It has been determined that certain abbreviations are understood by at least 85 percent of the driving public independent of the specific context (e.g., BLVD = boulevard). A second category of abbreviations are understood by at least 75 percent of the driving population but only with a prompt word (e.g., LOC means "local" when shown with TRAFFIC). Other abbreviations are prone to be frequently confused with another word (e.g., WRNG could mean either "warning" or "wrong") and should be avoided (see Appendix A).

3.10 Approaches to Composing PCMS Messages

Message content and composition may be the most critical aspect of CMS operation. In spite of the apparent simplicity of a CMS there is a deliberate thought process that should be followed to ensure that the messages displayed are credible and give clear, concise information to the motorist.

Two approaches to composing standard CMS messages are described below; the Virginia Department of Transportation (VDOT) "modular" approach and the New York State Department of Transportation (NYSDOT) "template" approach. Both are useful because by deconstructing a message they allow the development of effective CMS messages by means of a standard procedure for building messages from essential components. However, given the limited information capabilities of flip-disk PCMS systems, in many situations it would be impossible to create a message long enough to contain all of those elements yet brief enough to be understood.

In the interest of space, particularly on PCMS units, operators are encouraged to use abbreviations wherever practical and where their use will not be confusing to the motorist. A list of standard abbreviations (and a list of abbreviations that should not be used) can be found in Appendix C in Section 12.

3.10.1 VDOT's Modular Approach

A user manual for CMS systems is typically more useful than a set of canned messages. Variations in traffic conditions and available information render suggested messages ineffective in responding to unforeseen applications. Furthermore, only messages that apply to changed traffic conditions should be used as general safety statements — greetings are ignored by motorists.

The Virginia PCMS Operator's Manual VDOT, 1995) is organized into 17 Modules that guide an operator through a step by step process, with each module representing a distinct decision. This system is well thought out and comprehensive and may be used to provide guidance in composing CMS messages, especially when circumstances allow plenty of time to devote to the process. A copy of the manual is presented in Appendix B in Section 11.

3.10.2 NYSDOT's Template Approach

The template approach assumes that CMS messages contain the following basic elements:

- problem statement
- location
- effect
- attention
- action
- diversion

For clarity and to ensure uniform motorist understanding throughout the state, it is strongly suggested that CMS messages be constructed from the standard words for each element in the tables in Appendix A.

Because portable signs provide only 8 characters per line, two screens may be required to display information that would otherwise be possible to present on one screen on a permanent sign that typically can display three lines of 18 to 24 characters per line. When a portable sign is used to display a message in two phases, the problem and location statements should be displayed in screen one and the effect or action statement during screen two. For example, screen one could read ROADWORK/NEXT/2 MILES and screen two could read LEFT/LANE/CLOSED. If legibility distance restrictions rule out a two screen display, the use of abbreviations plus elimination of the problem statement is the recommended strategy to allow for the presentation of the entire message on one phase: "LFT LANE/CLOSED/NEXT 2MI". Note that the "/" symbol is used to indicate the separation of lines of a CMS message and should not be included in the actual message. Standard words for each element of the CMS message are shown in Tables 33, 34, 35, 36, 37, 38, 39 in Appendix A. Use of messages which vary substantially from those made up of an appropriate combination of the above approved message components should be avoided. When necessary, non-standard messages should be reviewed thoroughly.

4 Motorist Survey

As IDOT actively searches for ways to improve safety in highway work zones it is more likely that motorists' reactions towards the deployment of PCMS systems in highway work zones will provide the necessary feedback to make PCMS use more effective and efficient for the driving population, the ultimate customer of traffic information. Consequently, a survey effort was undertaken to obtain motorist attitudes on different operational characteristics of CMS systems including message length, message duration and message type.

The rich body of relevant information from the literature, reported in Section 3, enabled us to reduce the number of questions that could be effectively administered to motorists, while at the same time ensuring a satisfactory level of statistical accuracy (note that the fewer the questions asked for the same sample size, the more reliable the statistical information obtained). This section describes this effort starting with the site selection in Section 4.1 and a description of the work zone environment in Section 4.2. Questionnaire development issues are discussed in Section 4.3. The procedure to identify suitable PCMS messages is presented in Section 4.4 and the messages selected for testing in Section 4.5. The survey pretest is described in Section 4.6 and the actual survey in Section 4.7. The survey analysis is presented in Section 4.8 along with a discussion of the human factors affecting the behavior of motorists driving through highway work zones. Finally, concluding remarks are made in Section 4.9.

4.1 Survey Site Selection

The highway work zone used for the survey was located northwest of Morris between Illinois 47, exit 112 and Mile Post 107 on Interstate Route 80. The proposed improvement consists of the removal and replacement of the superstructures and abutments on two structures carrying Interstate Route 80 over Nettle Creek and the east fork of Nettle Creek.

At the time of the survey the project was in Stage I construction which involved diverting the westbound traffic to the eastbound lanes. The traffic was separated by a temporary concrete barrier. Two PCMS units were utilized and located approximately 2.5 miles (4 kilometers) in each direction from the project limits. This distance was certainly far greater than the recommended 600-1,000 ft. probably because of heavy truck traffic and the preference of truck drivers for PCMS advance placement (3 to 5 miles as reported in Benekohal et al., 1995). Note, it was not possible to account for the distance impact on the interpretation of the survey results because moving the PCMS unit closer to the work zone could interfere with the site's traffic control plan.

During the survey period weather conditions varied from clear/sunny to partly cloudy to overcast/light drizzle. The PCMS unit was placed off the outside shoulder of the highway. The unit was almost level and angled approximately perpendicular to the edge of the pavement. The visibility of the message was not affected by the sun glare, which was critical given the east-west orientation of the travel way. In addition, the visibility of the unit was not obstructed by any fixed object in the vicinity or roadway geometrics. These and other details regarding the layout of the PCMS unit and other traffic control devices can be seen in a series of pictures in Figures 4, 5, 6 at the end of Appendix E.

For the purposes of the survey, in consultation with the project technical review panel (TRP) the rest area just east of the Morris site was selected for a number of reasons:

1. Survey activities could be conducted comfortably and safely in the rest area.
2. The traffic volumes in the period during which the staff conducted the survey were high enough (the daily traffic volume ranges from 15,000 to 18,000) to permit the collection of the requisite number of responses efficiently.
3. The construction site warranted the operation of PCMS units because (similarly to VDOT's approach):
   (a) drivers were required to change travel speed and lanes;
   (b) the PCMS unit could provide a work zone advisory message and
   (c) the PCMS unit could be sited properly at a suitable distance from the construction zone so that it could be seen in a timely manner.

4.2 Work Zone Environment

PCMS systems are supplementary (category 4) traffic control devices used with other signs, such as arrow boards, drums and other warning signs. An illustration of the various traffic control devices deployed in the surveyed work zone (one mile before and after) is presented in Figure 2. The message sign was deployed 2.5 miles in advance of the work area and does not appear in the figure.

It is interesting to observe the absence of the location of the PCMS unit in the Traffic Control Plan (TCP) for the work zone. Perhaps this study will encourage the state guidelines to include PCMS systems in the TCP in the same way as other traffic control devices.

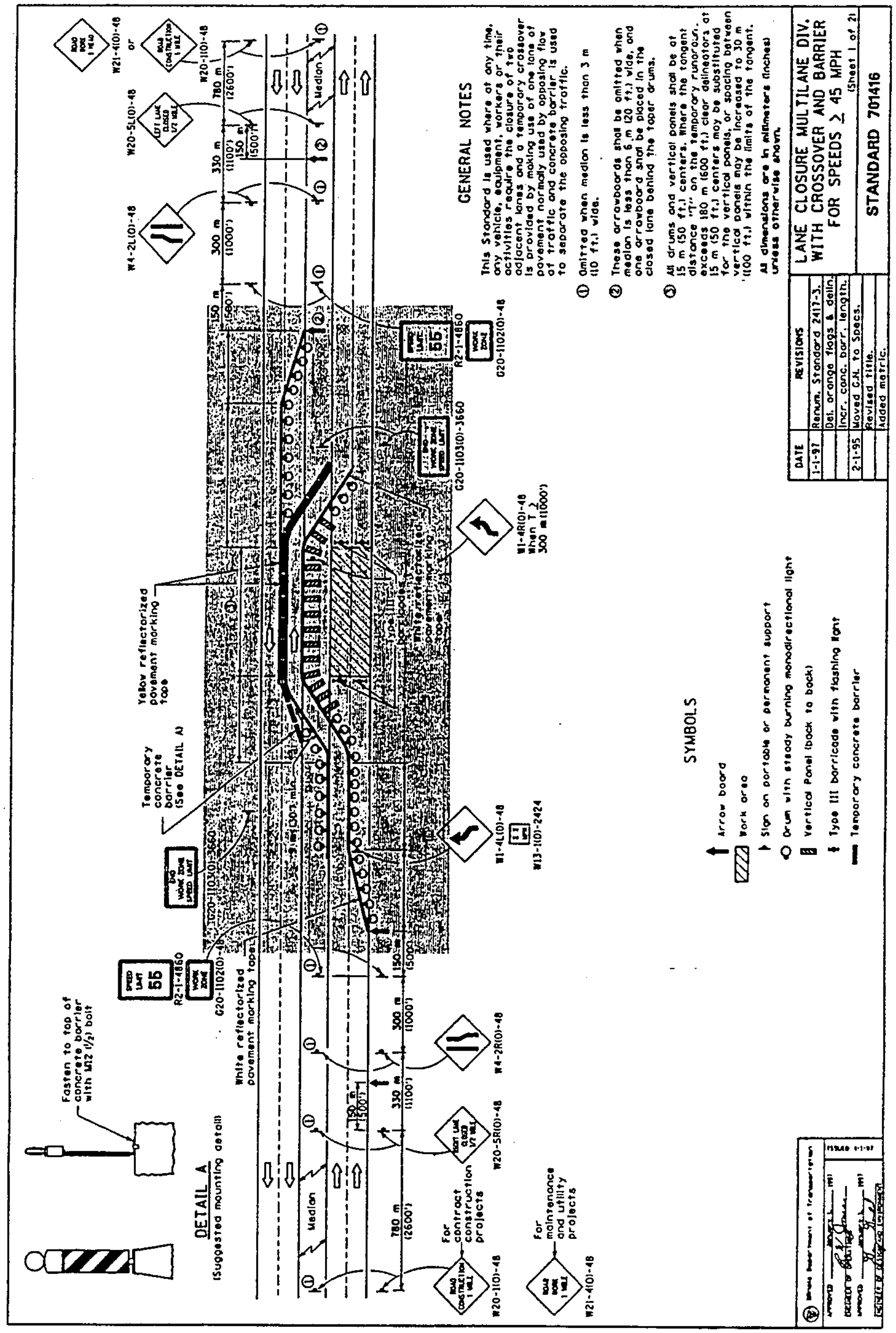


Figure 2: Various traffic control devices deployed in the surveyed work zone.

4.3 Questionnaire Development

The project team developed the survey instrument in consultation with the project TRP. In addition to basic demographic information, the questionnaire asked about the visibility of the PCMS, understanding of the message and perceptions about the suitability of the instructions given. The questionnaire contained 16 closed-ended variables, two other-specify variables and one open-ended variable and took, on average, three minutes to administer. The four-member Questionnaire Review Committee (QRC) at SRL reviewed and approved a draft version of the survey instrument to ensure compliance with ethical practices and basic principles of questionnaire construction. The draft was sent to the project TRP for review and comments that were then incorporated into the final version shown in Appendix E.

4.4 Identifying Suitable PCMS Messages

During the identification of suitable PCMS messages for testing, the project team made the following resolutions in agreement with the experience reported in the literature:

1. The message should be restricted to two screens maximum (with the help of acceptable abbreviations).
2. The message should include a problem component, a distance-to-the-construction-site component and an instruction component.
3. The message should give the distance in miles to the beginning of the work zone.
4. The message should be sequenced (if necessary) into meaningful segments in order to minimize confusion to the motorist.
5. If necessary, the message should be scrolled no faster than 1.5 seconds per screen.
6. The message should pass the drive-through test[3] before it is activated.

4.5 Messages Tested

We tested the following three messages:

[3]the field supervisor tests the message in a 'dry run' by driving through the work zone at the new lower speed limit and ensuring the message is visible, legible and appropriate

Number	Message	Panel
M1 (Control)	ROAD/CONST./AHEAD	First
M1	LEFT/LANE/CLOSED	Second
M1	TWO-WAY/TRAFFIC/AHEAD	Third
M2	MERGE/RIGHT/2.5 MI	First
M3	LEFT/LANE/CLOSED	First
M3	MERGE/RIGHT	Second

Message M1 was the only one used by IDOT at the time the survey was taking place.

4.6 Survey Pretest

During a study-specific training session, SRL trained the field staff in techniques for establishing professional rapport, answering potential questions, maintaining cooperation of respondents, proper ways to ask each question, how to record responses and how to probe, as well as safety issues. SRL also supervised the interviewers and debriefed them after the pretest had been concluded. The pretest was monitored by the field supervisor and by the SRL project coordinator. Interviewers worked closely with IDOT officials so that the message could be changed when the requisite number of interviews had been attained.

The survey pretest occurred on August 5, 1998. The questionnaire was structured so that the interviewer would skip the substantive questions whenever a driver could not remember seeing the changeable message sign on site. During the pretest, 12 drivers passed this criterion (the "yes" responses) and 14 drivers did not pass (the "no" responses). The results by message are as follows:

Responses	M1	M2	M3	Total
Yes	2	6	4	12
No	2	5	7	14
Total	4	11	11	26

The distribution of the yes/no responses was not found to be statistically associated with the message displayed ($\chi^2 = 0.756$). This issue is revisited in the actual survey.

Moreover, the pretest gave the researchers the opportunity to consider that the variety of traffic control devices and warning messages at the construction site has the potential to create cognitive difficulties for drivers. For example, once a driver recalled having seen a sign he/she was asked what the sign said. A sample of the responses for each message follows.

Message	Responses
Message 1	Stay in right, left ending
	Lane drop
Message 2	Left lane closed
	Work ahead & mileage
	2.5 miles to construction area
	Left lane ends, expect delays
	Warning 2.5 miles
	Lane ends 2 miles
Message 3	Construction ahead, left lane closed, speed limit 55
	Construction for next 5 miles
	Left lane ends, merge right, 55 miles speed limit
	Merge right 1 mile ahead

The sample responses give an early indication that the second (one-panel) message is the least confusing. This is not surprising given the findings in the literature, but needs to be considered within particular contexts (e.g., traffic environment or human factors). This is the scope of the investigation in the next section.

4.7 Actual Survey

The actual survey took place on September 1, 2, 3 and 12, 1998, during daylight hours under the same guidelines followed during the pretest. Based on the experience acquired during the pretest the survey questionnaire was finalized in both content and appearance to be more effective (see Appendix E).

4.7.1 Message Schedule

More than twenty hours of survey work produced 403 usable responses. The message schedule is shown in Table 5.

Date	Time of Day	Message
Tuesday, 9/1	1315-1400	M2
	1410-1500	M2
	1510-1600	M1
	1715-1800	M3
	1800-1900	M3
Wednesday, 9/2	815-900	M3
	910-1000	M3
	1010-1100	M2
	1235-1300	M2
	1310-1400	M2
	1410-1500	M3
	1615-1700	M1
	1710-1800	M1
	1810-1900	M1
Thursday, 9/3	730-800	M1
	810-900	M2
	910-1000	M3
Saturday, 9/12	900-1000	M1
	1000-1100	M1
	1110-1130	M2

Table 5: Survey schedule.

4.7.2 Coding Issues

During the survey period 403 motorists were interviewed, of which 297 recalled having seen the PCMS in the construction zone and 106 did not. The responses to the open-ended Questions 3, 5 and 6 varied considerably. For example, Question 3 asked: "When you're approaching a construction area, what are the most important things that you want to know about (mention more than one)?"

The responses were coded as follows:

1. What is the speed limit
2. How much delay to expect
3. What are the alternative routes/how to get there
4. Which lane will be closed/lane to be in/what to do
5. Is there adequate clearance/lane width for trucks
6. How far ahead is the construction area
7. What is the length of the construction area
8. Advance warning for construction area coming up
9. What are the safety hazards
10. Are there people working
11. Other (e.g., sign accuracy, police in the vicinity)

Question 5 asked: "What did the sign say (mention more than one)?" Most of the responses can be summarized by message as follows:

<u>Message</u>	<u>Responses</u>
Message 1	Merge left/right (in x miles)
	Lane closed in x miles
	Speed instructions
	Caution
	Construction ahead (in x miles)
	Other
Message 2	Construction ahead (in x miles)
	Speed instructions
	Merge left/right (in x miles)
	Two-way traffic
	Caution
	Other
Message 3	Lane change ahead (in x miles)
	Merge left/right (in x miles)

Speed instructions
Construction ahead (in x miles)
Caution
Other

Given the variation in the responses the responses for Question 5 were coded as follows:

1. Merge left/right (in x miles)
2. Lane closed/change (in x miles)
3. Speed instructions
4. Caution
5. Construction ahead (in x miles)
6. Two-way traffic (in x miles)
7. Other

The last open-ended Question 6 asked: "What other information would you have liked to have gotten from the sign (mention more than one)?" The responses were coded as follows:

1. How long is the delay
2. Speed instructions/what to do
3. Lane change
4. Are there working people
5. How far ahead/how long is the construction area
6. Other (traffic directions, police in the vicinity, sign brightness, hazards)

4.8 Survey Analysis

Tabulations of the motorists' responses are discussed in Section 4.8.1. The factors affecting the ability to notice the PCMS device are investigated in Section 4.8.2. A discussion on the relationship between human factors and message content is presented in Section 4.8.3. Finally, statistical model building is described in Section 4.8.4.

4.8.1 Motorists' Responses

During the first step of the analysis simple tabulations of the motorists' responses were created. These tabulations follow the order and format of the survey instrument and revealed the following information:

1. More than 50% of the respondents thought they were delayed less than three minutes, while a sizable 24% did not feel any delay at all (Table 6).
2. The overwhelming majority of the respondents thought the delay they experienced was reasonable (Table 7).
3. Interestingly (see Table 8), when approaching a construction area the motorists were mostly concerned about which lane will be closed, what lane to be in or what to do (39.2%), the speed limit (32%), the length of the construction area (21.8%), the presence of people working (17.1%) and much less with instructions about alternate routes (2.7%) and details about the safety hazards (5.2%). The latter is probably due to the familiarity with the construction site.
4. Almost three out of four motorists recalled having seen the PCMS (Table 9)[4].
5. Of those who recalled having seen the PCMS, perceptions about the message contents varied widely (Table 10; the previous footnote applies). Nearly one-third (30.3%) said the message warned them about lane closure or lane change ahead (some also gave a distance number). A quarter of respondents (24.9%) said the message warned them about merging left or right (again, with or without a distance number). Only few mentioned that the message was about speed instructions. Further analysis, later, will compare the responses with the actual messages displayed.
6. The question regarding additional information needed from the message generated little enthusiasm among those who recalled having seen the PCMS (Table 11; the previous footnote applies).
7. Most (90%) of those who recalled having seen the PCMS said that the amount of information on the sign was about right (Table 12).
8. Of those who recalled having seen the PCMS, 88.7% said they were able to read the entire message before they passed it (Table 13) and 95.4% claimed that the letter font of the message was large enough to read easily (Table 14).

[4]multiple answers allowed

9. Of those who recalled having seen the PCMS, 92.9% said the message sequencing was about right (Table 15) and 84.5% thought that the distance from the sign to the construction site was about right (Table 16).
10. Of the 403 motorists interviewed, 52.9% were commercial drivers (Table 17).
11. Of the 403 motorists interviewed 75.2% said they lived more than 25 but less than 100 miles away from the construction site (Table 18).
12. 57.1% of the motorists interviewed had passed the same construction site again during the 30-day period prior to the day of the interview (Table 19). Almost all of those had passed the site more than 10 times (Table 20).
13. Almost half of the motorists interviewed were found to be between 40 and 59 years of age (Table 21).
14. The vast majority of those interviewed were male drivers (Table 22).

Response	Frequency	Percent
Less than 3 minutes	214	53.1
4 to 10 minutes	75	18.6
11 to 15 minutes	13	3.2
More than 15 minutes	1	.2
None/No Delay	97	24.1
Don't Know	3	.7
Total	403	100.0

Table 6: Amount of time delay

Response	Frequency	Percent
Yes, reasonable	290	72.0
No, not reasonable	11	3.6
Don't Know	5	1.6
Total	306	100.0

Table 7: Was the delay reasonable

4.8.2 Ability to Recall PCMS

The sample size was large enough to perform a number of contingency table analyses. At first, the investigation focused on whether the ability to recall having seen the PCMS is

Information Needed	Percent
Which lane will be closed/lane to be in/what to do	39.2
What is the speed limit	32.0
What is the length of the construction area	21.8
Are there people working	17.1
Other (sign accuracy, police, etc.)	15.4
How much delay to expect	8.9
How far ahead is the construction area	7.2
Advance warning for construction area coming up	7.2
What are the safety hazards	5.2
Is there adequate clearance/lane width for trucks	4.0
What are the alternative routes/how to get there	2.7

Table 8: Important information needed when approaching a construction site

Response	Frequency	Percent
Yes, recall seeing one	297	73.7
No, does not recall	106	26.3
Total	403	100.0

Table 9: Saw portable changeable message sign

Stated Message Content	Percent
Lane closed/change (in x miles)	30.3
Merge left/right (in x miles)	24.9
Other	22.6
Construction ahead (in x miles)	17.2
Two-way traffic (in x miles)	3.7
Speed instructions	3.4
Caution	3.0

Table 10: Stated message content

Other information Needed	Percent
Other (traffic directions, police, sign brightness, hazards)	4.2
How long is the delay	3.5
Speed instructions / what to do	3.0
How far ahead / how long is the construction area	3.0
Lane change	2.2
Are there working people	1.0

Table 11: Other information needed

Response	Frequency	Percent
Too much information	1	0.4
Too little information	20	8.4
About right	215	90.0
Don't know	3	1.3
Total	239	100.0

Table 12: Amount of information on sign was . . .

Response	Frequency	Percent
Yes	212	88.7
No	20	8.4
Don't know	7	2.9
Total	239	100.0

Table 13: Able to read all of sign before passing

Response	Frequency	Percent
Yes	228	95.4
No	1	.4
Don't know	10	4.2
Total	239	100.0

Table 14: Were the letters large enough

Response	Frequency	Percent
Too fast	6	2.5
Too slow	5	2.1
About right	222	92.9
Don't know	6	2.5
Total	239	100.0

Table 15: Did the message move . . .

Response	Frequency	Percent
Too close	16	6.7
Too far back	17	7.1
About right	202	84.5
Don't know	4	1.7
Total	239	100.0

Table 16: Was sign too close to construction

Response	Frequency	Percent
Commercial	213	52.9
Private	190	47.1
Total	403	100.0

Table 17: Driving vehicle for commercial/private use

Response	Frequency	Percent
10 to 25 miles	7	1.7
26 to 100 miles	93	23.1
More than 100 miles	303	75.2
Total	403	100.0

Table 18: How far from here do you live

Response	Frequency	Percent
Yes	230	57.1
No	173	42.9
Total	403	100.0

Table 19: Driven down stretch of road within past 30 days

Response	Frequency	Percent
Once or twice before	77	33.5
3 to 5 times	66	28.7
6 to 10 times	38	16.5
More than 10	48	20.9
Don't Know	1	.4
Total	230	100.0

Table 20: About how many times . . .

Response	Frequency	Percent
Under 21	5	1.2
21 to 39	93	23.1
40 to 59	197	48.9
60 or older	107	26.6
Refused	1	.2
Total	403	100.0

Table 21: Are you . . .

Response	Frequency	Percent
Male	369	91.8
Female	33	8.2
Total	402	100.0

Table 22: Respondent's gender

affected by a number of factors such as time of day, message content, gender, age, type of vehicle, familiarity with the construction site.

a. Impact of time of day and message content: For analysis purposes (mainly to ensure that certain statistical tests could be employed) the survey effort was divided into 5 time periods, each one containing almost 20% of the responses. The time periods are:

1. 7:40 a.m. to 9:00 a.m.
2. 9:10 a.m. to 10:35 a.m.
3. 10:45 a.m. to 2:00 p.m.
4. 2:10 p.m. to 4:00 p.m.
5. 4:10 p.m. to 6:55 p.m.

In each time period statistical tests were carried out to determine whether the distribution of the motorists who recalled having seen the PCMS was affected by the specific message that was on at the time they were driving.

The two variables of interest here are: (a) the number of motorists who recalled (or did not recall) having seen the PCMS, and (b) the specific message (one of M1, M2, M3) that was on display (or was not on display) at the time they were driving. Both variables are *categorical* with two categories each; hence these variables are called *binary* variables. The statistical test involved is *the Chi-square test of association (dependence)* between these two binary variables.

If the Chi-square statistic (denoted by χ^2 oftentimes) is relatively large, then there is an association between the two variables, that is, one can be predicted from the other. Here, the two binary variables form a 2×2 (contingency) table. In this case, the Chi-square statistic must be larger than 3.84 at the 5% significance level, or 6.63 for the 1% significance level.

The Chi-square statistic can range from 0 to the sum of occurrences for each variable (in each time period). The latter means the variables are perfectly associated. However, this can occur in two directions: (a) all drivers recalled the message when it was on display, and nobody recalled the message when it was not on display; (b) all motorists recalled the message when it was not on display, and nobody recalled the message when it was on display.

The size of the Chi-square statistic does not tell the direction of the association. It does not tell (in general) whether motorists who recalled the message are associated with the message being on display or not. In this particular example of the two binary variables it would be trivial to determine the direction by counting the occurrences in each of the four categories; but the direction is not so obvious in more complex situations. In a later section, another measure of association, the *Odds Ratio*, which does show the direction of the association, will be discussed.

Table 23 shows that in each time period (recall the survey was conducted only during daylight hours) the ability to recall having seen the PCMS is statistically independent of the message content (a Chi-square statistic value less than 3.84).

The column with the probabilities indicate the probability (denoted as p oftentimes) of obtaining a Chi-square value greater than the value reported. For example, in the first time period, the probability of obtaining a Chi-square value of greater than 1.848 is almost 40%, which is substantially higher than 1% or 5%.

Time of Day	χ^2	Probability
7:40 a.m. to 9:30 a.m.	1.848	0.397
9:00 a.m. to 10:35 a.m.	1.365	0.505
10:35 a.m. to 14:00 p.m.	0.090	0.764
14:00 p.m. to 16:00 p.m.	3.223	0.200
16:10 p.m. to 18:55 p.m.	0.054	0.817

Table 23: Impact of time of day and message content on the ability to recall having seen the PCMS.

b. Impact of gender: Again, the two variables of interest are binary (male/female; did/did not recall the message). Using the same test as above, *the effect of gender difference on the ability to recall having seen the PCMS is not statistically evident* ($\chi^2 = 0.898, p = 0.343$). Due to the high prevalence of male drivers this analysis was not validated by time period of day.

c. Impact of age: To study the impact of age, drivers were categorized into three groups: under 40, 40 to 60 and over 60 years of age. Hence the contingency table analysis is conducted in this case on a 2×3 table (the critical values for the Chi-square statistic here are 5.99 and 9.21 for the 0.05 and 0.01 significance levels, respectively) and obtained a value of 2.671 for the Chi-square statistic. The associated probability obtained under the null hypothesis of no association is 0.263, which is substantially higher than 0.01 or 0.05. Since higher values for the Chi-square statistic can be obtained in more than 26% of the cases, the null hypothesis cannot be rejected on statistical grounds. Therefore, *the age factor did not seem to affect the ability to recall having seen the PCMS.*

This fact also applies for each time period of day as can be seen in Table 24. Indeed Chi-square values are not sufficiently high (at least at the 0.05 significance level) to reject the null hypothesis of no association between age and ability to recall having seen the message.

However, *the age factor was found to be significantly associated with the ability to notice the PCMS for commercial drivers* ($\chi^2 = 9.191, p = 0.010$), while for private drivers the frequencies observed are very close to those expected under the null hypothesis of no association ($\chi^2 = 0.424, p = 0.809$). Particularly *among commercial drivers, those under 40 years or over 60 years of age were more likely to notice the sign; on the contrary, those between 40 and 60 years of age were less likely to observe it.*

Time of Day	χ^2	Probability
7:40 a.m. to 9:30 a.m.	1.509	0.470
9:00 a.m. to 10:35 a.m.	0.386	0.824
10:35 a.m. to 14:00 p.m.	0.820	0.664
14:00 p.m. to 16:00 p.m.	5.020	0.081
16:10 p.m. to 18:55 p.m.	5.175	0.075

Table 24: Impact of time of day and age on the ability to recall having seen the PCMS.

d. Impact of type of vehicle: Overall, the type of vehicle (commercial vs. private) in each time period does not seem to affect the ability to recall having seen the PCMS (Table 25). The table summarizes the results obtained after performing a contingency table analysis on each of the 2×2 tables (two categories of vehicles and two categories of recalled/did not recall having seen the message) for each of the five time periods. Indeed in each time period, the Chi-square values are lower than the critical values of 3.84/6.63 at the 0.05/0.01 significance level to reject the null hypothesis of no association. Recall, however, the previous observation for commercial drivers.

Time of Day	χ^2	Probability
7:40 a.m. to 9:30 a.m.	0.553	0.457
9:00 a.m. to 10:35 a.m.	0.000	1.000
10:35 a.m. to 14:00 p.m.	0.812	0.367
14:00 p.m. to 16:00 p.m.	0.357	0.550
16:10 p.m. to 18:55 p.m.	0.112	0.738

Table 25: Impact of time of day and type of vehicle on the ability to recall having seen the PCMS.

e. Impact of day of week: The survey was carried out over four days; Tuesday, Wednesday, Thursday and Saturday. The Chi-square test in this case was carried on a 2×4 contingency table. The critical values for the Chi-square statistic are 7.81 and 11.34 at the 0.05 and 0.01 significance levels, respectively. In this respect, the null hypothesis of no association cannot be rejected ($\chi^2 = 2.184, p = 0.535$). Therefore, *no statistical proof was found showing recall of PCMS varies by the day of the week.*

f. Impact of familiarity with the area: Familiarity with the area was defined to be represented by the distance from the construction site the driver lived (less than 10 miles, 10 to 25 miles, 26 to 100 miles or more than 100 miles). The Chi-square statistic critical values for this 2×4 contingency table are 7.81 and 11.34 at the 0.05 and 0.01 significance levels, respectively. The results obtained ($\chi^2 = 7.094, p = 0.029$) indicate that *familiarity with the area seems to affect the ability to recall having seen the PCMS*, at least at the 0.05 significance level.

g. Impact of familiarity with the construction site: Familiarity with the construction site was defined to be represented by driving through the construction area in the last 30 days prior to the interview date. At first it appeared that familiarity with the construction site bears no impact on the ability to recall having seen the PCMS ($\chi^2 = 1.578, p = 0.209$). Indeed the Chi-square statistic obtained was lower than the critical values of 3.84/6.63 at the 0.05/0.01 significance level for this 2×2 contingency table setup.

On second investigation and after the previous test was carried out for each of the five time periods, *the period 16:10 p.m. to 18:55 p.m. was found to have an impact on the ability to recall having seen the PCMS.* Indeed the Chi-square statistic obtained for this time period was 4.08 (Table 26), which is higher than the critical value of 3.84 at the 0.05 significance level. Note that the hypothesis that significant rush hour traffic speed changes may have influenced driver awareness in this time period was not tested due to the lack of data on traffic speeds.

Time of Day	χ^2	Probability
7:40 a.m. to 9:30 a.m.	2.067	0.151
9:00 a.m. to 10:35 a.m.	0.067	0.796
10:35 a.m. to 14:00 p.m.	0.426	0.514
14:00 p.m. to 16:00 p.m.	0.930	0.335
16:10 p.m. to 18:55 p.m.	4.080	0.043

Table 26: Impact of time of day and familiarity with the construction site on the ability to recall having seen the PCMS.

h. Impact of the frequency driving through the construction site: The frequency driving through the construction site in the last 30 days prior to the interview date was categorized into four strata (once or twice, 3 to 5 times, 6 to 10 times or more than 10 times). The 2×4 contingency table setup gave $\chi^2 = 0.987, p = 0.912$ for the Chi-square statistic and the associated probability, respectively. Recall the critical value of the statistic at the 0.05 significance level is 7.81. As a result, *the frequency driving through the construction site did not appear to have any effect on recalling having seen the PCMS.*

i. Impact of the weather conditions: Weather conditions were categorized into three strata (clear/sunny, partly cloudy/overcast, light drizzle). The Chi-square statistic and associated probability computed for this 2×3 contingency table setup were $\chi^2 = 0.110$ and $p = 0.740$. Recall the critical Chi-square statistic is 5.99 at the 0.05 significance level. As a result, *weather conditions (at least those prevailing during the survey period) did not seem to affect the ability to recall having seen the PCMS.*

4.8.3 Human Factors and Message Content

In general, motorists who saw the PCMS thought that the information on display was adequate, that the letter fonts were large enough, that the sequencing of the message was good enough and that the location of the sign was about right. These motorists were almost equally split between commercial and private drivers, live great distances from the work zone, and almost half of them did not drive by frequently.

Subsequently, the investigation focused on whether the *stated* message (the message the respondent stated he/she observed) reflected the *actual* message (the message that was on display at the time the respondent was driving by). Messages M1 (ROAD / CONST. / AHEAD — LEFT / LANE / CLOSED — TWO-WAY / TRAFFIC / AHEAD) and M3 (LEFT / LANE / CLOSED — MERGE / RIGHT) were on display 37% of the time; message M2 (MERGE / RIGHT / 2.5 MI) was displayed the remaining 26% of the time. It was found that 51% of the motorists who remembered a message sign could recall something relevant to the message when M1 was on display while they were driving by. Twenty one percent could recall the message M2 and 67% could recall the message M3. Although it appears that information related to the two-panel message M3 was recalled more frequently, the influence of the other traffic control devices, many of which indicated similar warnings/actions, is unclear. As a case in point, when examining whether the messages M1, M2 or M3 provided the information that was most desired when approaching a work zone, the message M2 was preferred by 34.5%, followed by the messages M1 at 31.8% and the message M3 at 30.7%.

Recall now the three messages tested:

Number	Message	Panel
M1 (Control)	ROAD/CONST./AHEAD	First
M1	LEFT/LANE/CLOSED	Second
M1	TWO-WAY/TRAFFIC/AHEAD	Third
M2	MERGE/RIGHT/2.5 MI	First
M3	LEFT/LANE/CLOSED	First
M3	MERGE/RIGHT	Second

In the M1 message the first panel represents a "problem" statement (see Appendix A), the second panel an "effect" statement and the third panel an "attention" statement. In the M2 message the panel represents a combined "action" and "location" statement. Finally, in the M3 message the first panel represents an "effect" statement and the second panel an "action" statement. In this light, the previous analysis provided evidence that **motorists are more likely able to recall messages that contain action statements**, that is, messages that inform them what to do. This is in agreement with the literature.

In an attempt to better understand stated and revealed preferences with respect to the message content the analysis focused on the "problem" and "action" components of the messages that were desired and observed. The analysis produced some useful insights.

Out of 210 respondents, 31.0% wanted an "action" statement when approaching the work zone and recalled an "action" statement in the PCMS message. In addition, 27.1% wanted a "problem" statement and recalled a "problem" statement, 18.6% wanted an "action" statement and recalled a "problem" statement and 23.3% wanted a "problem" statement and recalled an "action" statement. As a result, there is a strong evidence ($\chi^2 = 5.602, p = 0.018$) that motorists recall better those message components they desire when approaching a work zone (recall the critical Chi-square statistic for the 2×2 contingency table setup is 3.84 at the 0.05 significance level).

In addition, it was found that the ability to recall or want a "problem" or "action" component in the message does not seem to vary with age. Indeed, 368 respondents (for which the cross-tabulation was relevant) did not show any age-specific preference in regard to these two components ($\chi^2 = 0.534, p = 0.766$; the critical Chi-square statistic for the 2×3 contingency table setup is 5.99 at the 0.05 significance level). Moreover, 230 respondents (for which the cross-tabulation was relevant) did not show any age-related evidence for selectively recalling any of the above components ($\chi^2 = 0.027, p = 0.986$).

4.8.4 Model Fitting

The previous section discussed the investigation of statistical association, primarily by testing the hypothesis of no association. This section shifts the focus to statistical models, methods aimed at describing the nature of the association in terms of a parsimonious number of parameters.

a. Statistical background: In this section the terms *odds, probabilities, and logits* will be heavily used. All three of these terms describe how often something happens relative to its opposite happening. Thus, they all deal with a special case of *nominal* measurement scales: dichotomous (binary) outcome measures.

Table 27 shows the difference between the three terms. *Odds* are one category divided by the other. For example, the odds for observing an action statement is $(a+b)/(c+d)$, the reciprocal of the odds for observing a problem statement, $(c+d)/(a+b)$. Similarly, the odds for desiring an action statement is $(a+c)/(b+d)$, the reciprocal of the odds for desiring a problem statement, $(b+d)/(a+c)$. Odds can range from zero to infinity, with the odds of 1 indicating neutrality, or no difference.

The *logits* are simply the natural log of the odds. Note that the two logits are always symmetrical (they sum to zero). They range from minus infinity to plus infinity, but because they are logarithms, the numbers usually range from +5 to -5, even when dealing with vary rare occurrences.

The probabilities are one category divided by the total. For example, the probability of observing an action statement is $(a+b)/(a+b+c+d)$ and a problem statement $(c+d)/(a+b+c+d)$. Note that the two probabilities sum to 1. Similarly, the probability of desiring an action statement is $(a+c)/(a+b+c+d)$ and a problem statement $(b+d)/(a+b+c+d)$. The range of probabilities is zero to one. Note that when a very small number is in the numerator and a very large number is in the denominator, odds almost equal probabilities.

Briefly, an *odds ratio* is the ratio of two odds, while *relative risk* is the ratio of two probabilities. *Effectiveness* is merely 100 * (1 - relative risk). Note than unlike the simple Chi-square test of association, a direction is implied with odds ratios and relative risk.

The logits have an advantage over odds or probabilities. Their neutral point is zero and

		Desired		
		Action	Problem	Total
Observed	Action	a	b	a+b
	Problem	c	d	c+d
	Total	a+c	b+d	a+b+c+d

Table 27: An example to illustrate statistical terms.

they are symmetrical about zero. This is not true for odds or probability.

When odds are transformed into logits and logistic regression is used, we assume the resulting function is linear, and the problem can be treated, roughly, like linear regression[5]. This way, the problem of computing odds or probabilities that are less than zero is avoided. This is not the case if odds or probabilities are used as raw data in a regression analysis. Thus *logistic regression* allows *nominal* outcome variables to be compared with multiple covariates, which can be any measurement scale, nominal through ratio.

b. Observed versus desired message components: At first the analysis posed the following question: *If there is such an effect, what is the effect of the desire for an action or problem message statement on the ability to recall an action or problem message statement?.* Since both the *response* and the *explanatory* variables are categorical, the following logistic regression was built:

$$\theta_h = \frac{\exp\{\alpha + \beta_1 x_{h1}\}}{1 + \exp\{\alpha + \beta_1 x_{h1}\}} \tag{4}$$

where,
θ_h — the probability that a motorist who desired an action or problem statement (h=1 for action and 2 for problem message statement) observed an action message statement;
α — the intercept parameter;
x_{h1} — the explanatory variables for the desired component (h=1 for action and 2 for problem message statement) and
β_1 — the regression parameter.

This particular model represents a 2×2 contingency table for which one measure of association is the *odds ratio.* In this case, the odds ratio compares the odds of the proportion of

[5]Maximum likelihood parameter estimation is required (as opposed to ordinary least squares (OLS) estimation) because the logit transformation violates the Gauss-Markov conditions of the classical linear regression model. In particular the presence of heteroscedasticity implies that if OLS is used, then the OLS estimators of the parameters will remain unbiased and consistent but will no longer be the most efficient estimators. Moreover, the estimated variances will be biased estimators of the true variances of the parameters, and if these are used then the statistical tests commonly used in regression analysis will be incorrect

the *desired* action statement to the odds of the proportion of *observing* action statements. It was found that the odds for observing an action statement is almost two times higher (an odds-ratio value of 1.939) for those desiring an action statement than a problem statement.

Using the above parameterization it is easy to compute the odds of recalling an action or problem statement, because equation (4) is equivalent to

$$\log \frac{\theta_h}{1-\theta_h} = \alpha + \beta_1 x_{h1} \tag{5}$$

and the left-hand side is the log of the odds (the *logits* as explained above). The Analysis of Variance (ANOVA) Table[6] for this model is shown in Table 28.

Once the model has been applied an assessment is made how well it fits the data. Test statistics that assess fit in this manner are known as *goodness-of-fit statistics*. They address the differences between observed and predicted values, or their ratio, in some appropriate manner. Departures of the predicted proportions from the observed proportions should be essentially random. The test statistics have approximate chi-square distributions. If they are larger than a tolerable value, then additional factors should be introduced into the model to better explain the variation in the data.

The model has an explanatory capacity at the 0.01 level as can be attested by a 5.629 value of the -2 log L statistic. This statistic is a log likelihood statistic (associated with the likelihood surface evaluated during the maximum likelihood parameters estimation) that tests whether the explanatory variables are jointly significant relative to the chi-square distribution).

Variable	Parameter Estimate	Standard Error	Wald χ^2	Pr > χ^2	Odds Ratio
Intercept	1.1729	0.4495	6.8083	0.0091	.
Desired	-0.6621	0.2810	5.5499	0.0185	0.516

Table 28: Odds of recalling an action message statement — ANOVA table.

The interpretation of the results is shown in Table 29. In logistic regression odds ratios as functions of the model parameters are obtained. As a result, it can be seen again from Table 29 that the odds for observing an action statement are 3.2313/1.6666, or 1.939, times

[6]This table is routinely produced by standard statistical software packages. The table summarizes the arithmetic calculations when performing analysis of variance, a method to partition the variance of the sample data into several components and ascertain the magnitude of the contributions of these components to the total variation.

higher for those desiring an action statement than a problem statement. This fact may imply that in situations where both action and problem statements can be used but only one panel can be displayed, action message statements are better candidates than problem statements.

Desired Statement	Logit Probability θ_h	Odds of Observing Action Statement
Action	$e^{1.1729}/(1+e^{1.1729})$	$e^{1.1729} = 3.2313$
Problem	$e^{1.1729-0.6621}/(1+e^{1.1729-0.6621})$	$e^{1.1729-0.6621} = 1.6666$

Table 29: Odds of recalling an action statement.

c. Observed versus desired message components and familiarity with the area:

The previous model can be improved if the motorists' familiarity with the construction area is taken into account. The model fit has the following form:

$$\theta_{hi} = \frac{\exp\{\alpha + \beta_1 x_{hi1} + \beta_2 x_{hi2}\}}{1 + \exp\{\alpha + \beta_1 x_{hi1} + \beta_2 x_{hi2}\}} \tag{6}$$

where,
θ_{hi} — the probability that a motorist who desired an action or problem statement (h=1 for action and 2 for problem message statement) and is familiar or not familiar with the construction site (i=1 if familiar and 2 if not familiar) observed an action message statement;
α — the intercept parameter;
x_{hi1} — the explanatory variables for the desired component (h=1 for action and 2 for problem message statement) and familiarity with the construction site (i=1 if familiar and 2 if not familiar); and
β_1, β_2 — the regression parameters.

The odds for observing an action message for the hith group is:

$$\frac{\theta_{hi}}{1 - \theta_{hi}} = \exp\{\alpha + \beta_1 x_{hi1} + \beta_2 x_{hi2}\} \tag{7}$$

In this *incremental effects* parameterization, parameter α is the log odds of observing an action statement for motorists who desire an action statement and are familiar with the construction site. Since this group is described by the intercept it is called the *reference cell* in this parameterization. The parameter β_1 is the increment in log odds for motorists desiring a problem statement and the parameter β_2 is the increment in log odds for motorists unfamiliar with the construction site. The ANOVA table for this model is shown in Table 30.

Variable	Parameter Estimate	Standard Error	Wald χ^2	Pr > χ^2	Odds Ratio
Intercept	1.9459	0.5937	10.7408	0.0010	.
Desired	-0.6167	0.2844	4.7016	0.0301	0.540
Familiar	-0.6011	0.2897	4.3061	0.0380	0.548

Table 30: Odds of recalling an action message statement — ANOVA table.

Table 31 displays the probabilities and odds predicted by the model based on parameter estimates shown in Table 30. The model has an explanatory capacity at the 0.006 level as can be attested by a 9.967 value of the -2 log L statistic.

Desired Statement	Familiar	Logit Probability θ_{hi}	Odds of Observing Observed Action Statement
Action	Yes	$e^{\alpha}/(1+e^{\alpha})$	e^{α}
Action	No	$e^{\alpha+\beta_2}/(1+e^{\alpha+\beta_2})$	$e^{\alpha+\beta_2}$
Problem	Yes	$e^{\alpha+\beta_1}/(1+e^{\alpha+\beta_1})$	$e^{\alpha+\beta_1}$
Problem	No	$e^{\alpha+\beta_1+\beta_2}/(1+e^{\alpha+\beta_1+\beta_2})$	$e^{\alpha+\beta_1+\beta_2}$

Table 31: Odds and predicted probabilities of recalling an action statement.

It is easy now to compute various odds ratios. For example, the odds ratio of observing an action statement for motorists desiring a problem statement versus an action statement accounting for familiarity with the construction site is $\exp\{\alpha+\beta_1\}/\exp\{\alpha\} = \exp\{\beta_1\}$ or $\exp\{\alpha+\beta_1+\beta_2\}/\exp\{\alpha+\beta_2\} = \exp\{\beta_1\}$, or 0.540. That is, motorists have 1.85 times higher odds to observe an action statement when they desire an action statement rather than a problem statement.

Similarly, the odds ratio of unfamiliar versus familiar motorists is determined by forming the ratio of the odds of observing an action message for motorists desiring either an action or a problem statement, $\exp\{\alpha+\beta_2\}/\exp\{\alpha\} = \exp\{\beta_2\}$ or $\exp\{\alpha+\beta_1+\beta_2\}/\exp\{\alpha+\beta_1\} = \exp\{\beta_2\}$, or 0.548. That is, motorists familiar with the construction site have 1.82 higher odds to observe an action statement than motorists unfamiliar with the site.

4.9 Concluding Remarks

The main findings from the motorists survey were the following:

1. the motorists' ability to notice a PCMS device seems to be affected by the joint effect of the familiarity with the construction area and the time of day (between 4 p.m. and 7 p.m. during the survey period[7]);

2. among commercial drivers, those under 40 years or over 60 years of age were more likely to notice the sign; on the contrary, those between 40 and 60 years of age were found to be less observant;

3. the motorists' ability to notice a PCMS device did not seem to be affected by the separate effect of factors, such as the time of day (daylight period), message content, gender, age, vehicle type, day of the week and weather conditions (light drizzle to sunny);

4. motorists (both commercial and private drivers) believed that information on the PCMS (from all messages tested) was adequate, that the letter font (18 inches) was large enough, that the sequencing of the message (2 seconds) was good enough and that the location of the sign (2.5 miles ahead from the construction site) was about right;

5. motorists were more likely able to recall PCMS messages that contain action statements;

6. motorists recalled better (almost two times easier) those PCMS message components that they desired to see when approaching a work zone;

7. motorists' ability to recall or want a "problem" or "action" component in a PCMS message did not seem to vary with age;

The implications of these findings for PCMS deployment in highway construction zones are that, in situations where the use of portable units is warranted. particular attention should be given to sign visibility and message legibility issues so that motorists' attention is maximized for:

1. drivers familiar or unfamiliar with the construction site

2. commercial or private drivers

3. drivers of different age groups

[7]Recall the survey period started at 7:40 a.m. and ended at 6:55 p.m.

4. driving conditions, especially in late afternoon hours (nighttime conditions were not tested).

Moreover, motorists' preference for "action" statements (independently of age group, gender or vehicle type) imply that PCMS messages could be short enough (two panels at most) without compromising motorists' information needs, while at the same time avoiding redundancy which not only is not desired, but also affects the impact of the critical (and desired) portion of the message on the driving behavior. In other words, the small amount of time (a few seconds) available to read a message should be utilized to display only the information with the highest impact potential and not information which is also conveyed by other traffic control safety devices deployed in a construction zone.

5 IDOT District Traffic Engineers Survey

IDOT has been increasingly using PCMS systems in highway work zones, yet the district traffic engineers do not share the same experiences from the deployment of PCMS units in various projects. In order to facilitate the communication of these experiences among IDOT engineers, as well as to examine the possibility that these experiences can be summarized to provide a basis for developing guidelines, a survey effort was undertaken.

The purpose of the survey was to gather information about maintenance of traffic policies for highway construction zones regarding

1. monitoring and controlling construction zone activities
2. policies to reduce speed limits in construction zones
3. design/performance criteria for construction zone traffic control
4. various types of portable CMS systems used in highway construction zones and the experience with their effectiveness
5. communication protocols of PCMS systems
6. performance characteristics (e.g., target value, legibility distances, and maintenance frequencies) of PCMS systems
7. policies governing PCMS use
8. placement and message choice
9. recommendations about changes to existing policies, practices and applications to PCMS systems devices.

After some background information in Section 5.1, the district traffic engineers responses are presented in Section 5.2. A synthesis of the responses is developed in Section 5.3. Finally, concluding remarks related to the survey effort are presented in Section 5.4.

5.1 Background

There are nine Highway Districts within the State of Illinois. These districts and each of the counties they contain can be seen in Figure 3. Selective highway statistics are shown in Table 32.

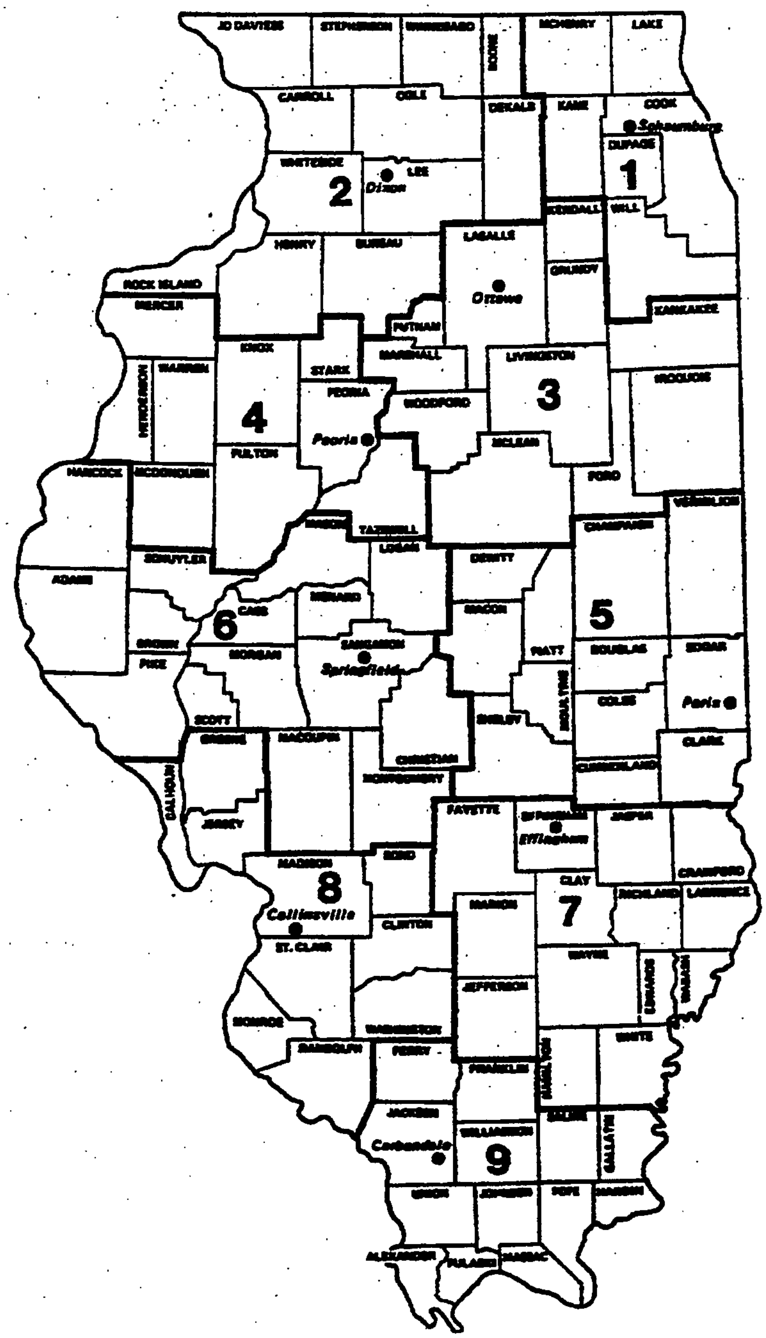


Figure 3: IDOT Highway Districts.

Highway District 1: It encompasses six counties in northeastern Illinois and includes the city of Chicago, suburban Cook County and the collar counties of DuPage, Kane, Lake, McHenry and Will. The district operates a network of 23,994 centerline miles with 52,780 million annual vehicle miles traveled (AVMT).

Highway District 2: It encompasses twelve counties in northwestern Illinois and includes the cities of Rockford, Rock Island-Moline, Princeton, Geneseo, Rochelle, DeKalb, Dixon, Freeport, Spring Valley, Belvidere, Kewanee, Sandwich and Sterling-Rock Falls. The district operates a network of 16,841 centerline miles with 8,157 million AVMT.

Highway District 3: It encompasses eleven counties in east-central Illinois which include the major cities of Bloomington-Normal, Kankakee, LaSalle-Peru, Mendota, Morris, Ottawa, Pontiac and Watseka. The district operates a network of 16,710 centerline miles with 6,436 million AVMT.

Highway District 4: It encompasses nine counties in west-central Illinois and includes the following cities: Peoria, Canton, Chillicothe, Galesburg, Macomb, Monmouth and Pekin. The district operates a network of 11,533 centerline miles with 4,615 million AVMT.

Highway District 5: It encompasses twelve counties in eastern Illinois and includes the cities of Decatur, Champaign-Urbana, Danville, Charleston and Mattoon. The district operates a network of 16,042 centerline miles with 5,678 million AVMT.

Highway District 6: It encompasses fifteen counties in west-central Illinois and includes the following cities: Springfield, Quincy, Jacksonville, Lincoln and Taylorville. The district operates a network of 18,619 centerline miles with 5,506 million AVMT.

Highway District 7: It encompasses fourteen counties in southeastern Illinois and includes the cities of Effingham, Mount Vernon, Vandalia and Centralia. The district operates a network of 14,867 centerline miles with 3,598 million AVMT.

Highway District 8: It encompasses ten counties in southwestern Illinois and includes the following cities: East St. Louis, Alton, Bellville, Edwardsville, Jerseyville, Highland, Greenville, Mascoutah and Chester. The district operates a network of 11,507 centerline miles with 6,960 million AVMT.

Highway District 9: It encompasses thirteen counties in southern Illinois and includes the cities of Carbondale, Murphysboro, Harrisburg, West Frankfort, Marion, Benton and Cairo. The district operates a network of 8,991 centerline miles with 3,007 million AVMT.

District	AVMT[a]	MH&S[b]	AADT[c] per mile[d]	AADT per state mile[e]	AADT per inter. mile[f]
1	52,780	23,994	6,010	29,140	99,939
2	8,157	16,841	1,323	6,375	16,707
3	6,436	16,710	1,052	5,840	18,634
4	4,615	11,533	1,093	5,716	18,995
5	5,678	16,042	967	5,853	17,283
6	5,506	18,619	808	4,695	15,082
7	3,598	14,867	661	5.076	15,437
8	6,960	11,507	1,653	8,476	31,138
9	3,007	8,991	914	5,244	16,485
Statewide	96,737	139,104	1,897	10,246	33,907

Source: Illinois Highway Statistics Sheet (1996), Illinois Department of Transportation, Office of Planning and Programming.

[a] AVMT: Annual Vehicles Miles of Travel (in millions).
[b] MH&S: Miles of Highways and Streets.
[c] AADT: Annual Average Daily Traffic.
[d] AADT per mile includes centerline mileage in the state, county, township and municipal road network.
[e] AADT per state mile includes centerline mileage in the state road network.
[f] AADT per interstate mile includes centerline mileage in the interstate road network.

Table 32: Some Illinois highway statistics.

5.2 IDOT District Traffic Engineers Survey Responses

The project team in consultation with the project Technical Review Panel developed a questionnaire consisting of nine clusters of multiple-choice and open-ended questions. The final version of the survey instrument is appended in Section 13. On February 24, 1998, the survey questionnaire was sent to the district traffic operations engineers.

This section summarizes the responses to the IDOT Traffic Engineers Survey. In those cases where questions have multiple parts the question is decomposed into more elemental questions and responses to those elemental question are presented.

5.2.1 Question 1

The first question had three parts:

1. How many CMS systems are currently in your inventory in your district?
2. In what occasions do you use CMS systems from private inventories?
3. Are there any differences in the policies for CMS operation between publicly and privately-owned CMS units?

IDOT currently owns 40 PCMS units. These units are allocated to District 1 (one unit), District 2 (five units), District 3 (nine units), District 4 (three units), District 5 (seven units), District 6 (five units), District 7 (four units) and District 9 (six units).

Interestingly, the units used by District 2 are owned by Iowa DOT. These units are activated by Iowa DOT when congestion levels on the Iowa part of the highway system is believed to affect congestion on the Illinois part of the system.

The districts use PCMS systems from private inventories in a variety of situations, such as

- during weekend and around-the-clock lane closures
- during activities that will delay traffic
- in traffic flow changes during construction
- for detour during emergency closures
- in construction projects
- in road and bridge contracts awarded by IDOT.

As a general rule, there are no differences in the policies for CMS operation between publicly and privately-owned CMS units. However, since private units are not under state jurisdiction, they are not required to display traffic information only, and not advertising messages.

5.2.2 Question 2

In the second question the respondents were asked to identify examples of PCMS applications in each district. The following (non-exhaustive) list of situations was provided to assist their choices:

1. detours
2. changes to detours and bypasses
3. a lane drop where a continuous lane once existed
4. advance warning for work zone speed limits
5. in lieu of flaggers on freeways and expressways
6. lane closures where sight distance is restricted and/or congestion occurs
7. road closures
8. accident and incident management requiring display of special message
9. advisories and advance notice of construction activity
10. other (please specify)

All districts use PCMS systems during road closures and for advisories and advance notice of construction activity. Seven districts use PCMS systems for detours. Six districts use PCMS systems during lane closures where sight distance is restricted and/or congestion occurs and in situations where accident and incident management requires the display of special messages. Five districts use PCMS systems for a lane drop where a continuous lane once existed and for advance warning for work zone speed limits. Four districts use PCMS systems for changes to detours and bypasses. One district uses PCMS systems to warn about width restrictions, inform about congestion and notify about changes in alignment or surface conditions. One district uses PCMS systems in advance warnings of special event detours. Finally, another district uses PCMS systems to warn about new signal turn-ons.

5.2.3 Question 3

In the third question, respondents were asked how long before or after an activity period they had deployed units and at what locations with respect to the work zone site for situations where they had planned to use PCMS systems. The answers here vary widely, pointing to the lack of specific guidelines for uniform PCMS use.

IDOT districts deploy PCMS units from three days to one month prior to the beginning of the work zone activity. All of the districts agree that PCMS units should be placed before other traffic control signs, at locations that are the most visible to motorists and suitably in advance of the work zone area to allow for possible detours. None of the districts, however, indicated the number of PCMS units used and the exact placement of the units with respect to the work zone area.

5.2.4 Question 4

In the fourth question, respondents were asked what policies are in place for the proper operation of CMS systems. In situations where the use of *standard* sign messages (i.e., those included in the Manual on Uniform Traffic Control Devices) is warranted, there is no unanimous agreement regarding the use of a particular reference for the composition of the message. Two of the districts follow the guidelines they have developed that resemble closely those found in the MUTCD manual (USDOT, 1993) with additions borrowed from the experiences of other states.

In situations where there is a need for customized messages, some of the districts do not adhere to a particular policy. Those districts that have a set of guidelines in place adhere to those guidelines and compile messages from a set of pre-programmed lists customized to fit each case. A few districts give this responsibility to the traffic operations engineer in charge of the design of the traffic control plan for the work zone area. In addition, half of the districts use a standard inventory of sign messages for different work zone situations including resurfacing, pavement patching, and bridge reconstruction.

When asked about policies for designing a customized message, some of the districts follow the ATSSA guidelines (ATSSA, 1994) and the standards found in the Manual on Uniform Traffic Control Devices (USDOT, 1993), while others apply their own guidelines (which are compatible with the MUTCD manual). Some districts do not apply particular guidelines for designing messages.

Longer messages require additional planning and design. Districts responded that they usually split longer messages into three-panel (at most) three-line (at most) stand-alone phrases. For even longer messages districts use additional units.

Sequencing longer messages requires further consideration regarding cycle times and message duration. Some districts responded that they use 2-3 seconds/cycle with 6-9 seconds message duration. Others limit sequencing to three messages allowing 1.2-1.5 seconds per message. Few of the districts agree that message sequencing depends on the speed and the volume of the approaching traffic.

Situations which require more detailed and thus longer messages necessitate the use of abbreviations. All districts are using abbreviations. Some districts said they are using abbreviations to limit a message to three panels. When the use of abbreviations is called for, some districts use a set of abbreviations which is not always compatible with the list of abbreviations recommended by ATSSA (ATSSA, 1994). The latter list is by no means an exhaustive list of message abbreviations. Clearly, there is a need for a comprehensive standardized statewide database of messages and message abbreviations. Responses regarding updating, modifying or discontinuing a message varied from "bimonthly" to "as conditions change" to "when message is no longer effective or relevant".

Maintenance of PCMS units not in use seems to vary across districts as well. Some districts use in-house mechanics while hardware parts are replaced by the manufacturer. Others require the contractor to maintain the privately-owned units according to manufacturer's specifications for the duration of the project.

5.2.5 Question 5

In the fifth question the respondents were asked what type of CMS systems they use. The districts responded that they use a variety of CMS technologies as follows:

District	*Type of PCMS used*
D1	Light-reflecting flip disks
D2	Light-reflecting rectangular disks
D3	Light-reflecting PCMS
	Light-emiting PCMS
D4	Light-reflecting rectangular disks
D5	Light-reflecting PCMS
	Light-emitting PCMS
D6	Light-reflecting rectangular flip disks
	Light-emitting LED matrix
D7	Light-reflecting circular and rectangular disks
	Light-emitting bulb matrix and LED matrix
D8	Don't know
D9	Light-reflecting flip disks
	Light-emitting LED matrix

None of the districts seem to be using hybrid CMS systems that combine both technologies. This is probably due to the fact that hybrid technology is newer and not as well tested.

The responses clearly indicated that the development of a comprehensive repository with information about the technology of the various components of the PCMS units owned and operated by the districts would clearly facilitate the deployment effort of the new technology.

5.2.6 Question 6

In the sixth question, respondents were asked about their experiences with the CMS technology they have used. The responses show that the experience with the reliability of different CMS technologies varies. Some of the districts have found that solar-powered light-emitting diode CMS systems are more reliable while older light reflecting rotating-drum CMS units last only three hours. One district reported problems with hardware and engines and that reliability increases when contractors use their own PCMS systems. The particular experience of the districts with the duration of the different PCMS components was not conclusive.

Other districts observed that solar powered units appear to be more reliable and that older diesel engines are costly to maintain (a yearly average cost of $10,000 was quoted). A few districts mentioned that the initial set-up costs are high (prices of $20,000 to $30,000 are not uncommon) and that despite the costs, the systems were not user-friendly.

5.2.7 Question 7

In this question, respondents were asked about their experiences regarding PCMS use in coordination with a traffic management/monitoring system, highway advisory radio or intelligent transportation systems technologies. The majority of the districts (4 out of 7 responding districts) did not report having any experience at all. Some districts reported that they don't use PCMS systems for traffic management using instead permanent CMS units.

Only one district reported a good working experience with coordination with some kind of traffic management system (did not specify). Finally, one district reported that their PCMS units were owned and activated by Iowa DOT.

Coordination of PCMS units used in highway work zones with a corridor or regional ATMS system is a direction that IDOT could look into in the near future to benefit from the advancement of ITS technologies.

5.2.8 Question 8

District traffic engineers' experience with the effectiveness of CMS systems in controlling vehicle speeds in work zones appears to be rather consistent with the findings in the literature. Stand-alone PCMS units do not reduce speeds. Units used in combination with a radar gun seem to be effective in reducing the speed temporarily (for a number of days).

Most of the districts reported that PCMS systems fail to communicate convincingly the approaching hazardous environment and thus speed reduction does not occur until the driver is close to the work area. In addition, a third of the districts do not use PCMS units as a speed-control traffic device.

5.2.9 Question 9

The last question of the survey asked whether district traffic engineers maintain records or logs on when and where CMS units are used. This information can potentially be related with accident reports to evaluate the effect of CMS usage on traffic safety.

The majority of the districts do not keep any records at all. Only District 1 maintains records of the dates, messages and location of PCMS units used. District 2 reported that this type of information is kept only in construction projects where contracts require specifically the use of PCMS systems.

The ability to record this type of information could facilitate future studies about the effectiveness of PCMS units in work zones. There is clearly a need for maintaining this information and possibly integrate with other information related to the individual PCMS unit and the work zone project in a management system.

5.3 A Synthesis of Survey Responses

The acquired experience on the use of PCMS systems in highway work zones was synthesized based on the responses from the survey as well as private communication with IDOT staff. Overall this synthesis is compatible with the information obtained during the literature review in the first task of the study.

PCMS systems are traffic control devices with the flexibility to display a variety of messages to fit the needs of highway workers. PCMS systems are best used in conjunction with conventional signs, pavement markings and lighting and can be applied, in addition to highway projects, to all types of streets and highways. Situations in which alignment and traffic routing problems require advance warning and information are good candidates for PCMS usage.

Messages should be visible from one-half mile and legible from 650 feet under both day and night conditions. The message must be short enough so it can be read in its entirety and provide proper description of road work or incident location. Delay messages should accurately reflect actual delay time. Messages should not scroll horizontally or vertically. It is desirable to use standard sign messages (see Sections 10, 11 and 12 for details) or customized messages as needed (see Section 3.10 for approaches to compose messages). Finally, public information messages are not advisable.

The use of more than two to three messages per PCMS should be avoided so that messages are still visible by drivers traveling at the posted speed limit. Moreover, the message should be modified bimonthly to maintain the interest of the driver.

PCMS units are placed in advance of other signing. When used to divert traffic, the PCMS may also be placed in advance of a major interchange so as to allow drivers adequate time to select alternate routes if available.

PCMS units are normally placed on the shoulder of the roadway. However, placement farther from the traveled lane is desirable. The sign should be turned approximately three degrees away from perpendicular to the edge of the roadway to reduce glare.

PCMS units should only be placed on one side of the roadway — either left or right depending on the needs. When two signs are needed, they should be placed on the same side of the roadway and should be separated by at least 1,000 feet.

5.4 Concluding Remarks

IDOT districts are involved in a wide range of highway work zone activities and their use of PCMS systems vary depending on the nature of the activity. There are situations, however, where during similar work zone activities the deployment and application pattern of the PCMS units is not consistent across districts. In particular, this survey of district traffic engineers has shown that areas where there is no uniform application of PCMS systems include:

1. highway construction projects of similar nature
2. situations where use of publicly or privately owned PCMS systems is warranted
3. placement of the units before, during and after the construction period
4. use of a standardized database of messages and abbreviations
5. use of an established methodology to compose messages
6. sequencing and duration of longer messages
7. policies regarding updating, modifying or discontinuing messages
8. maintenance guidelines
9. understanding of the pros and cons of different PCMS technologies
10. coordination of PCMS systems and other intelligent transportation systems technologies.

In addition, the IDOT District Traffic Engineers survey revealed the need for improvement in four areas:

1. Development of a comprehensive standardized statewide database of messages and message abbreviations
2. Development of a comprehensive repository with information about the technology of the various components of the PCMS units owned and operated by the districts
3. Coordination of PCMS units used in highway work zones with a corridor or regional ATMS system
4. Maintaining information about the use of a PCMS unit in a work zone project and possibly integrating it with other information related to the individual PCMS unit and the work zone project in a management system.

6 Accident Analysis

Because relevant traffic accident data were not available this accident analysis chapter contains only a review of the literature. For example, the lack of consistent traffic volume data (before, during and after the construction period) did not permit the computation and comparison of the true accident rates before and during construction. Therefore, one might question whether any apparent increase in traffic accidents during construction was actually due to a growth in travel. In the absence of volume data it is not possible to answer this question with certainty.

Work zone safety is currently a major concern to transportation and highway engineers because of the relatively high rates of accidents in these areas. This is due to the combination of heavy traffic volumes and the disruptive nature of work zone activities. The issue is receiving more and more attention because of changing priorities at the national and state levels that place more emphasis on maintenance and rehabilitation of the existing highway system than on the construction of new highways. As a result the frequency of work zone activities will increase and consequently, unless effective measures are taken, a significant increase in accident rates will occur.

A clear understanding of work zone accident characteristics and traffic control devices is needed to facilitate the development of effective guidelines that will significantly improve safety at highway work zones. The purpose of this section is to discuss the effectiveness of PCMS systems in improving the safety of both motorists and working personnel in such an environment.

Previous research has shown that a high percentage of work zone accidents occur during daylight hours in good weather conditions and during the summer months. This suggests that accidents occur most frequently at work zones when activities are in progress (Richards and Faulkner, 1981). Nighttime accidents at work zones tend to occur more often at taper areas that emphasizes the need for adequate lighting and suitable channelization in these areas.

The rate of increase of work zone accidents varies significantly from study to study as factors related to traffic, geometry and the environment change (Hall and Lorenz, 1989; Hargrove and Martin, 1980; Rouphail et al., 1988; Ha and Nemeth, 1995). Other studies have shown that increases in accident rates at work zones also depend on the duration and length of the construction zone. Higher increases were observed at short work zones with short durations than at long work zones with long durations (McGee et al., 1982).

Average speed and speed variances are two main characteristics of traffic flow that significantly affect accident rates and/or severity. It has been shown that one of the major problems at work zones is the large speed differential among vehicles, especially at work zones where speed limits have been considerably reduced from the normal speed limit (Paulsen et al., 1978). The posting of a much lower speed limit usually does not result in most drivers reducing their speeds to the new limit because drivers tend to drive at a speed that in their opinion is suitable for the prevailing conditions, regardless of the posted speed limit (Garber and Gadiraju, 1988).

Highway construction and maintenance zones deserve special consideration with respect to older driver needs because of their strong potential to violate driver expectancy. Driver expectancy is a key factor affecting the safety and efficiency of all aspects of the driving task (Alexander and Lunenfeld, 1986). Consequently, it is understandable that accident analyses consistently show that more accidents occur on highway segments containing construction zones than on the same highway segments before the zones were implemented (Graham et al., 1977; Nemeth and Rathi, 1983; Paulsen et al., 1978; Garber and Woo, 1990; Hawkins et al., 1992).

In an accident analysis at 20 case-study work zone locations, among the most frequently listed contributing factors were driver attention efforts and failure to yield the right-of-way (Pigman and Agent, 1990). Older drivers are most likely to demonstrate these deficits. Research on selective attention has documented that older adults respond much more slowly to stimuli that are unexpected (Hoyer and Familant, 1987), suggesting that older adults could be particularly disadvantaged by changes in roadway geometry and operations characteristic of construction zones. There is also research indicating that older adults are more likely to respond to new traffic patterns in an "automatized" fashion, resulting in more frequent driver efforts (Fisk et al., 1988). To respond in situations that require decisions among multiple and/or unfamiliar alternatives with unexpected path-following cues, drivers' actions are described by complex reaction times that are longer than reaction times in simple situations with expected cues. In Mihal and Barrett's (1976) analysis relating simple choice and complex reaction time to crash involvement, only an increase in complex reaction time was associated with accidents. The relationship with driver age was most striking: the correlation between complex reaction time and accident involvement increased from 0.27 for the total analysis sample (all ages) to 0.52 when only older adults were included. Such data suggest that in work zones situations, where there is increased complexity in the information to be processed by drivers, the most relevant information must be communicated in a dramatic manner to ensure that it receives a high priority by older individuals.

Compounding their exaggerated difficulties in allocating attention to the most relevant aspects of novel driving situations, diminished visual capabilities among older drivers are well documented (Pitts, 1982; Wood and Troutbeck, 1994). Deficits in static and dynamic acuity and contrast sensitivity, particularly under low luminance conditions, make it more difficult for them to detect and read traffic signs, to read variable message signs and to detect pavement markings and downstream channelization devices. Olson (1988) determined that for a traffic sign to be noticed at night in a visually complex environment its reflectivity must be increased by a factor of 10 to achieve the same level of conspicuity as in a low-complexity environment. Mace (1988) asserted that the minimum required visibility distance — the distance from a traffic sign required by drivers in order to detect, understand, make a decision and complete a vehicle maneuver before reaching a sign — is increased significantly for older drivers due to their lessened visual acuity and contrast sensitivity, coupled with inadequate sign luminance and legend size. Other age-related deficits cited by Mace (1988) include lowered driver alertness, slower detection time in complex roadway scenes due to distraction from irrelevant stimuli, increased time to understand unclear messages such as symbols and slower decision making.

7 Warrants for CMS Use

PCMS systems are traffic control devices and must be placed and used with the same care as traffic signs, speed limit signs or stop signs. PCMS units should be placed and used primarily to convey information which:

- is critical in nature
- requires motorists to alter their driving in some manner and take specific action as a result
- will enable motorists to safely and conveniently reach their destinations on current or future trips
- will assist in the protection of personnel in construction and maintenance work zones or inspection sites.

The primary purpose of using PCMS systems in temporary traffic control zones is to advise the driver of unexpected traffic and routing situations. Some typical applications include advising the traveler of:

- significant delays
- changes in alignment or surface conditions
- special speed control measures
- lane closures where sight distance is restricted and or congestion occurs
- road closures
- accident and incident management requiring display of special messages
- advisories and advance notice of construction activities.

As such warning and guiding traffic control devices, PCMS systems should be used only where needed and warranted for maximum effectiveness. The warrants discussed in this section should contribute toward the development of sound guidelines and serve as an aid in preventing PCMS misuse.

This section discusses the need for deployment and development of warrants for PCMS use in various situations. The discussion is organized as follows. In Section 7.1 the need for PCMS use on projects of varying duration is presented. The roadway-type effect is discussed in Section 7.2. Advance-time notification guidelines for different projects are recommended in Section 7.3. Sections 7.4 and 7.5 discuss the need for PCMS use in projects with obstructed view and traffic backups, respectively. Situations where PCMS systems should not be deployed are presented in Section 7.8. The use of PCMS systems for traffic control through incident areas is discussed in Section 7.7. PCMS use in blasting zones is discussed in Section 7.6. Finally, concluding remarks are presented in Section 7.9.

7.1 Duration of Work

Work duration is a major factor in determining the need for PCMS deployment in highway work zones. The periods of relevance here seem to be long- and intermediate-term stationary work, while the need for PCMS systems during short-term stationary daytime work is conditional on seasonal, climatic and visibility situations. Furthermore, in situations of short-duration work that occupies a location up to one hour it may not be cost efficient to deploy PCMS units. During mobile operations PCMS systems may be used to enhance the visibility of vehicles deployed.

7.1.1 Long-Term Stationary Work

Long-term stationary work occupies a location more than three days (USDOT, 1993). During this period there is ample time to realize benefits from the full range of traffic control procedures and devices available for use. PCMS units can attract attention so that they are less likely to be displaced or tipped over that is an important consideration during those periods when the work crew is not present. Furthermore, as long-term operations extend into the nighttime, the conspicuity potential of PCMS units add to the range of traffic control devices that can be safely deployed during this period.

7.1.2 Intermediate-Term Stationary Work

Intermediate-term stationary work occupies a location from overnight to three days (USDOT, 1993). During this period it may not be feasible or practical to use procedures or devices typically deployed for longer period projects (e.g., pavement markings or barriers). The increased time to place and remove these devices may increase the life of the project.

In other instances there might be insufficient payback time to make more elaborate traffic control economically attractive. In these situations using PCMS systems as an additional warning device might prove to be both an effective and efficient option that certainly needs proper consideration.

7.1.3 Short-Term Stationary Work

Short-term stationary daytime work occupies a location from one to twelve hours (USDOT, 1993) mostly for maintenance and utility operations. These cases may warrant the deployment of PCMS systems to accommodate varying seasonal, climatic and visibility situations.

7.2 Roadway Type

As a general recommendation, if it is necessary to prioritize the need of PCMS use in highway work zones (due to limited resources), then urban highway work zones should be at the top of the list because of high speeds and traffic volumes and closer spacing of entry and exit ramps. On the other hand, PCMS use in work zones situated in rural highways with low traffic volumes (e.g., ADT less than 10,000) and high speeds may warrant additional placement considerations to accommodate device conspicuity and message legibility requirements due to higher speeds as discussed in earlier chapters.

7.3 Advance Time Notification

PCMS systems may be warranted for advance time notification in the following highway work zones:

- **Ramp Closures.** The message should be displayed three to seven days prior to the closure. For weekend closures on freeways with high seasonal/tourist travel, the message should be displayed longer (up to ten days) including two Thursdays prior to closures.
- **Lane Closures or Lane Shifts.** The message should be displayed two weeks prior to construction during lane closures if traffic delays are expected or two weeks prior to and the first week during any lane closure or traffic control changes if traffic delays are not expected. When a side road intersects the highway within the temporary traffic

control zone an additional unit may be needed on the side road to provide advance notification.

- **Multi-Lane Highway Project Requiring Cross-Over, Run-Arounds or Detours.** The message should be displayed two weeks prior to construction; or two weeks prior to the run-around being opened to traffic; or the first week during lane closures or changes; or during periods run-arounds are in effect and if traffic delays are expected.

- **Planned Maintenance Work.** The message should be displayed a maximum of one week prior to planned work.

- **Any Project with a Marked Detour and an ADT > 10,000.** The message should be displayed two weeks prior to and the first week of detour; or two weeks prior to opening a previously closed road.

- **Any Project with an ADT > 10,000 and Traffic Delays Expected.** The message should be displayed two weeks prior to and during construction.

7.4 Notice of Operations — Obstructed View

PCMS systems may be warranted in situations of unusual roadway geometrics, as an advanced warning device in conjunction with static signing for fixed or moving operations. Unusual geometrics, such as curves or hills, provide an obstructed view to motorists coming upon the operation and the PCMS may give additional attention.

7.5 Construction Zone Traffic Backups

PCMS systems may be warranted in construction zone traffic backups. This involves monitoring congestion and backups (real time) and requires constant updating and extensive resources. The traffic backup must be monitored every 15 to 30 minutes depending on the situation. The PCMS messages on delay times must be accurate.

7.6 Blasting Zones

Radio frequency energy can cause the premature firing of electric detonators used in blasting zones. Drivers are advised to turn off mobile radio transmitters and cellular phones. The same holds true with PCMS units both remotely or manually operated. It seems possible, however, that newer hybrid PCMS systems could display a message while their power supply is off.

PCMS systems (if their operation do not interfere with electric detonators) may be used to direct operators of mobile radio equipment to turn off transmitters in the blasting area. A minimum safe distance of 1,000 feet should be used for PCMS placement.

The following message guidelines for PCMS units in blasting zones are similar to those found in the MUTCD manuals (USDOT, 1988 and 1993):

1. The message BLASTING / ZONE / X MILES should be used in advance of any work space where explosives are being used. The message TURN OFF / ELECTRIC / DEVICES should be used in sequence with the previous message at least 1,000 feet before the beginning of the blasting zone.
2. The message END BLASTING ZONE should be placed a minimum of 1,000 feet past the blasting zone.
3. On a divided highway the signs should be mounted on both sides of the directional roadways.
4. Whenever a side road intersects the roadway between the PCMS units displaying the messages BLASTING ZONE AHEAD and END BLASTING ZONE or a sign road is within 1,000 feet of any blasting cap, similar messages as on the mainline should be displayed on the side road.

Composition and display of these and other messages should follow the guidelines provided for other PCMS messages as indicated elsewhere in this report.

Advance notification (no longer than a week before) should also alert drivers of the coming event. If traffic delays due to the blasting activities are expected then this should be reflected in the message.

7.7 Control of Traffic through Incident Areas

The primary function of traffic control at an incident area is to move traffic safely and expeditiously through or around the incident (USDOT, 1993). Examples of incidents or major emergencies during which PCMS systems could be deployed include major traffic accidents blocking the traveled way and hazardous chemical spill closing a highway.

The control of traffic through incident areas is essential for fire and enforcement operations. PCMS systems could assist the effort to maintain good public relations by keeping the motoring public well informed.

In addition, PCMS units could be deployed along with (but not instead of) other regulatory signs and warning signs for incident management. In all occasions, criteria for PCMS deployment for incident management should conform with those discussed in Section 8.

7.8 Prohibited PCMS Use

PCMS use should be prohibited in the following cases:

- lighted arrow replacement: the lighted arrow board is more visible, recognizable and understood than a PCMS
- advance notice of new traffic signal or sign
- advertising of any kind
- replacement of the Illinois Manual of Uniform Traffic Control Devices requiring static signing or pavement markings.

7.9 Concluding Remarks

Prescribing warrants for PCMS deployment in highway work zones is not an exact science since both the state-of-the-art in research and technology development are continuously evolving. Apparently, each highway work-zone situation would ideally require specific consideration to fully assess the need for PCMS deployment. Given the limited scope of this study, federal guidelines, states' experience and ongoing research were employed to contribute to the synthesis presented in this chapter. This research may assist the decision-making ability of state highway officials and advance the level of understanding regarding the conditions that warrant PCMS use in highway work zones.

8 Criteria for PCMS Deployment

In the foregoing the different factors affecting PCMS deployment in highway work zones have been discussed in detail. These factors will assist the effort of drafting the functional requirements for deployment. In this section criteria are developed for spacing, number of signs required, distance in advance of the workzone, optimal message length, duration and type based on motorist response characteristics, manufacturer's specifications, sight distance, traffic volume, speed and other considerations.

The criteria developed in this section are a synthesis of federal guidelines, selected states' experience and ongoing research. The presentation begins with the spacing requirements in Section 8.1. The number of signs required is the issue of Section 8.2. Sign visibility and message legibility criteria are presented in Section 8.3. Text alignment issues are discussed in Section 8.4. Distance considerations are presented in Section 8.5. Issues related to message length are discussed in Section 8.6. Message duration and type are the issues of Sections 8.7 and 8.8. Project-level operational guidelines are provided in Section 8.9. Message storage and dissemination are discussed in Sections 8.10 and 8.11, respectively. Repair, maintenance and utility costs are discussed in Section 8.12 and control issues in Section 8.13. Coordination issues are discussed in Section 8.14. The section concludes in Section 8.15.

8.1 Spacing, Placement and Installation

8.1.1 Spacing

When two signs are needed to communicate multiple messages they should be placed on the same side of the roadway, separated by at least 1,000 feet so that the first message is understood before the second message is observed.

8.1.2 Placement

PCMS systems should be activated 1,000 feet in advance of a work zone so that drivers have adequate time to react and the message will be still fresh in their minds when they reach the potential hazard. In situations of heavy truck traffic an advanced placement of three to five miles may be warranted.

PCMS systems in the vicinity of a work zone should be placed in advance of any other temporary traffic control zone signing and should not replace any required signing. Further, the units should not be placed near ramps, intersections or lane-closure tapers since motorists' attention is on weaving traffic. Moreover, the devices should be placed in locations accessible by maintenance vehicles.

PCMS systems used for construction projects should have specific placement locations listed in the Traffic Control Plan included in the project plans. These locations may be changed slightly in the field, within 500 feet, if necessary.

When used for route diversion, PCMS units should be placed far enough (no less than a mile) in advance of the work site to allow traffic ample opportunity to exit the affected highway. In this case the unit should be placed prior to an interchange preceding the construction project.

8.1.3 Installation

PCMS units should not be obstructed by other signs, poles or other objects. Further, the units should be placed in the most level area possible or be leveled (e.g., using leveling jacks at all four corners of the trailer) both horizontally and vertically so that displayed messages can be easily read.

PCMS units are normally placed on the outside shoulder of the roadway. If possible, the device should not be placed closer than 6 feet or farther than 20 feet from the edge of the travelway. A sign placed closer than 6 feet from the edge of the travelway becomes an obstruction which causes a reduction in traffic flow. A sign placed farther than 20 feet from the edge of the travelway becomes unreadable for many motorists.

However, if practical, placement further from the traveled lane is desirable. If a paved shoulder is the only option the device should be clearly delineated by channeling devices such as cones, barricades or barrels in accordance with Traffic Control Plans for shoulder closures.

The bottom of the sign should be 7 feet above the elevation of the edge of the roadway when in operation. The unit should be turned approximately 3 degrees outward from perpendicular to the edge of pavement. This angle reduces glare from reflected sunlight, vehicle headlights or the internal sign illumination itself.

8.2 Number of Signs Required

Research findings are not conclusive regarding the optimum number of signs required to be deployed in different work-zone situations. Two signs per direction of traffic may be warranted in work zones longer than two miles to reduce speed variance, but otherwise the gains in speed reduction are modest (not more than 10 mph and more often than not less than 5 mph).

State experience recommends two PCMS units per direction of traffic for rural head-to-head construction projects. Urban or fringe area head-to-head projects will generally require the use of more units due to the increased number of alternate routes and interchanges close to the project limits.

8.3 Sign Visibility and Message Legibility

It is generally recommended that PCMS units be visible for at least one half-mile under ideal daytime and nighttime conditions. Messages should be legible for a minimum of 750 feet for traffic on all lanes and should remain legible for at least 650 feet from the nearest travel lane up to 100 feet from the message panel.

Legibility of a sign can change due to a different lighting conditions such as day, night, washout and backlight. Table 2 gives the average legibility distances for different technologies and lighting conditions.

In addition, the following character/message variables are recommended:

Variable	Optimal	Acceptable
Color	Matching MUTCD color-coding specifications	Red, Amber/Yellow, White, Orange
Contrast	$5 < (Lt - Lb)/Lb < 50$	$(Lt - Lb)/Lb = 5$
Contrast orientation	Light letters on a darker background	Light on black; Light on colored
Font and matrix form	Alphanumerics that most closely approximate Standard Highway font	Any reasonable non-serif font using at least a 5×7 matrix or equivalent
Letter height	18.1 in	12.0 in if legibility < 400 ft is acceptable

Width:height	W:H=0.8	W:H=0.6 to 1.0
Stroke width:height	SW:H=0.13	SW:H=0.1 to 0.18
Inter-letter spacing	Three times Standard Alphabet Series E or 1/2 the letter height	3/7 the letter height
Inter-word spacing	Equal to letter height	Equal to 5/7 the letter height
Inter-line spacing	70% of letter height	20% of letter height with two-line CMS units

Given the specific PCMS technology used, if the legibility distances are too small to be reduced further for a questionable gain in recognition speed from mixed-case letters, it is better to use only upper-case letters. This is definitely a possibility especially in cases where legibility distance is not an issue. Moreover, the sign should automatically reduce its light output under low ambient lighting conditions in order to meet the legibility requirements and not impair drivers' vision.

8.4 Text Alignment

Each line of text can be aligned to the left, the right, the center or justified outward to both sides. The MUTCD manual makes use of center alignment on all signs except for those that display distances which are presented with justified outward text. While center alignment is probably the easiest to read, the use of left alignments for PCMS units located on the right side of the roadway would bring the text closer to the motorist.

8.5 Distance in Advance of the Work Zone

Motorists should be able to read the entire message twice while traveling at the posted speed (see argument in Section 3.8.2). Tables 3, 48 and 49 give the distances in feet at which PCMS units become unreadable for various types of highways and PCMS distances to the edge of the road. Ideally, upstream sight distance to the device should be between 650 and 1,000 feet.

When giving a location or distance, then:

- For familiar drivers select the term (cross street, landmark or exit number) best known to the local population.

- If the route is an interstate and the exits are numbered sequentially (i.e., they do not correspond to mile markers) then give the distance in miles. If the latter is not true and there is an exit (or a static sign indicating the distance to an exit) give the location as an exit number; otherwise give the distance in miles.

Decimal fractions should not be used to express distances. Metric distances should be shown in whole kilometers or if less than one kilometer, in whole meters (rounded to the nearest 10 meters). Distances in English units may incorporate the fractions one-fourth, one-half or three-fourths of a mile. Distances less than one-fourth of a mile shall be shown in feet (rounded to the nearest 100 feet). The use of English units, metric units or both should be determined by current IDOT guidelines and/or policy.

8.6 Optimal Message Length

It is generally recommended that no more than two message screens be used and that every effort should be made to restrict the message to one screen (e.g., using abbreviations). With a two-screen message a motorist might view the message out of sequence (i.e., read the second screen first). Messages should be composed so that an out-of-sequence message will not confuse the driver.

When PCMS units are used to display messages in two phases the **problem** and **location** statements should be displayed in screen one and the **effect** or **action** statement during screen two. For example, screen one could read ROADWORK/NEXT/2 MILES and screen two could read LEFT/LANE/CLOSED. If legibility distance restrictions rule out a two-screen display the use of abbreviations plus elimination of the **problem statement** is the recommended strategy to allow for the presentation of the entire message on one phase: LFT LANE/CLOSED/NEXT 2MI. Standard words for each element of the CMS message are shown in Tables 33 through 39 in Appendix A in Section 10.

8.7 Message Duration

The following criteria should be considered with respect to message duration:

- The entire message cycle should be readable at least twice at the posted speed, the off-peak 85-th percentile speed prior to work starting or the anticipated operating speed.

- A minimum exposure time of one second per short word (four to eight characters) or two seconds per unit of information should be allotted. In any case the message should not be scrolled any faster than 1.5 seconds per screen.
- On high speed roadways standard messages should be given two seconds per message panel and complex messages should be given three seconds per message panel.
- Messages should not scroll horizontally or vertically across the face of the sign.
- Blank screens should not be used unless the device is turned off.

8.8 Message Type

In general, PCMS units closer to the work zone should be used to display warning messages. Units farthest out from the project area should display diversion messages. Generic messages should not be displayed, unless in situations when power is lost where a default message DRIVE SAFELY may be displayed. When not in use a PCMS should be turned off.

More specific message-design criteria are provided below. In all cases, time displayed in messages should relate to the standard 12-hour format using "a.m." and "p.m." designation and express local time. Moreover, public service announcements and advertising messages should not be displayed.

8.8.1 Advisory Messages for Work in Progress

- Each advisory message for current must contain (or imply) a problem, a location and an instruction statement (see Table 40).
- Sensational incident information should be avoided.
- Descriptors such as DELAY or CONGESTED are not used unless a distance or location follows.
- The word AFTER is preferred to AT and BEFORE when it provides additional information by indicating a possible point of diversion.
- The word AHEAD is used only if it is needed to clarify the message.
- The message does not contain both the words RIGHT and LEFT unless absolutely necessary.

- If a merge is required but not imminent the amount of time or distance motorists have to complete the merge is displayed.

8.8.2 Route Diversion Messages

- A diversion message should contain an *audience* component and an *instruction* component. A *time saved* component may also be included if necessary.
- The *audience* component is included if needed. It answers the question, "To whom is the message directed?" If no audience is specified then it is understood that the message applies to all traffic. When there is a mixture of local and through traffic, however, then the unit may need to qualify to whom the message is directed. Example *audience* components are given in the leftmost column of Table 41.
- The *time saved* component is included **ONLY** if the following criteria are met (example *time saved* components are shown in the middle column of Table 41):
  - inclusion of the time saved component will not result in a message which is longer than two screens.
  - diversion is an option, rather than a requirement, for motorists.
  - the amount of time motorists may save by diverting can be **accurately determined** (within 15 minutes). Note that this time saved is **not** simply the amount of time motorists might sit in traffic; it also accounts for the extra time motorists spend diverting to another route. Thus traffic conditions on both the main route and the diversion route must be monitored.
  - the message can be updated when necessary.
- The *instruction* component answers the question "What should motorists do?" and should be a single statement. If multiple instructions are necessary then they should be supplied by static signs, additional units or HAR. Example *instruction* components are in the right-most column of Table 41.
- The phrases ALT ROUTE or DETOUR are used correctly. The word DETOUR implies that an alternate route has been marked with static signs to guide the unfamiliar motorist. The phrase ALT ROUTE implies that motorists have to find such a route on their own.

8.8.3 Advisory Messages for Future Work

- Each advisory message for future work must contain a *condition & location*, a *time* and an *instruction* component (see Table 43).
- The *condition & location* component indicates construction or closure. If the message is referring to a location other than the road where the CMS is situated then that location needs to be specified. Example *condition & location* components are shown in the left-hand column of Table 43.
- The brief and concise *time* component indicates when the new traffic conditions will be in effect. This component may refer to a time of day, day of the week or day of the month. Example *time* components are shown in the middle column of Table 43.
- The *instruction* component that may often be implied, alerts motorists as to how they should react to the change in traffic conditions, such as to use an alternate route or to expect delays. Example *instruction* components are shown in the right-hand column of Table 43.
- The message does not describe future conditions more than one week in advance.
- If the change in traffic conditions has already occurred then it is important to verify that the message is still applicable and reword the message if necessary. If the situation is a long term one then static signs should be used.

8.9 Operation

The IDOT District Traffic Operations Engineer should authorize the use of all PCMS systems, both state-owned and contractor-furnished. Each PCMS should have a person designated by the District Engineer to be responsible for the authorization of messages to be displayed and for the care, maintenance and security of the device. This person may delegate certain responsibilities in regard to the PCMS but should ensure that any personnel given access to the PCMS understands and adheres to this policy. Access to the PCMS should only be given to responsible individuals.

Project inspection staff or contractor's surveillance staff should be used to activate the PCMS units for congestion relief and warning messages. Contractor surveillance staff may be allowed to activate a PCMS unit after approval of the Resident Engineer. Only maintenance staff should activate diversion messages since diverting highway traffic includes local maintenance personnel helping direct traffic in conjunction with the Illinois State Police.

Local maintenance personnel may be needed to quickly erect additional diversionary or trailblazing signs to smoothly redirect the diverted traffic.

Any project that is utilizing PCMS units to display congestion relief, warning or diversion messages needs to have close communication between construction and maintenance personnel. It is especially important for the Highway Maintenance Supervisor to be involved with all communications relating to project traffic control and incident handling.

The incident management diversion route map and a list of pre-approved messages should be kept in a weatherproof folder secured inside the PCMS unit. This folder should also include a brief step-by-step set of instructions detailing the remote start-up operation requirements of the PCMS unit. Copies of the incident management diversion route and pre-approved messages should also be filed with the Resident Engineer, Highway Maintenance Supervisor, local maintenance garage, and the District Traffic Operations Engineer.

8.10 Message Library

It is appropriate that a global message library containing all messages for all PCMS be maintained on a central computer server at the agency responsible for the PCMS. Individual message libraries or sub-libraries that are subsets of the global library, should also be maintained for handling messages that may only be applicable to the unique needs of specific PCMS locations. As such, the central computer server should reference library entries via indexes into the library and should have the ability to add, modify and delete library information on PCMS, including individual library entries tagged with size and date information so that a central computer server can verify library version information.

8.11 Message Dissemination

In situations where PCMS deployment is warranted (see Chapter 7) the PCMS software should be able to utilize operator inputs and links with the above message libraries so that it can suggest messages to display. If confirmed, then the messages can be immediately sent via wireless communication to the appropriate PCMS. As a result, the message on the portable unit can avoid conflicting with the message displayed on a nearby permanent unit.

However, in the event a suggested message is inappropriate, interaction with the PCMS software would allow the person in charge to compose a limited-scope ad hoc message based on combinations of existing pre-approved words and phrases in the above PCMS library.

When the library does not contain the desired keywords a freehand message composition should be available to the appropriate agency supervisor via special password verification.

8.12 Repair, Maintenance and Utility Costs

PCMS systems should be maintained as recommended by the manufacturer. Routine visual checks can help determine if the sign is operating properly and some system-driven signs can be internally checked. In any case, manufacturer's maintenance schedules and operating procedures should be closely followed, especially for units under warranty.

Currently, portable CMS units are either solar or diesel powered. Diesel powered units require daily maintenance such as refueling and check engine lubrication system. Solar powered units should be checked weekly, even if they have been exposed to regular sunshine, to make sure that the batteries are being charged properly.

As a security measure, if a portable CMS is to be stationed in one location for any length of time (even overnight, in some areas) it should be secured to an immovable fixed object. The wheels on portable units can be removed to discourage theft.

Repair parts and labor costs for PCMS units used on construction projects are eligible for project funds. Fuel and oil costs can also be charged against project funds. Appropriate utility costs, such as telephone land lines or cellular telephone charges, are also eligible project costs. An external voucher charged against project funds can be used for repair costs. Technical support for PCMS units will be available through a designated repair facility.

8.13 Control

Signs are capable of having manual on-site control or remote control. The manual on-site control allows a project engineer or maintenance supervisor to program the sign using the on-board computer keyboard. There are two methods of remote control: (1) utilizing a car cellular telephone and (2) utilizing a central base computer. The car cellular telephone would be most applicable if the project engineer wanted control of the sign without having to travel to the sign location.

However, the car cellular option is very restrictive since the programmer can only use the cellular number pad to program various functions. This limits the different features that can normally be used on the computer keyboard.

A central base computer (Y2K compatible) should be set up at the state level to address computer-based remote control issues. Either hard-wire telephone lines or cellular telephone services may be used to communicate with the signs in the field. The base computer will consist of personal computer, modem and printer. A dedicated telephone number must be arranged for the base station and each sign. Hard-wired telephone lines are preferred if lines are available close to the sign locations. While cellular telephone provides savings in hard-wire installation, the system is not entirely reliable. Near larger cities, peak-hour business calls often over-saturate the system, not allowing acceptance of additional calls. Also, cellular service may not be available, particularly in rural areas. Users should verify the availability of cellular phone services in specific locations.

8.14 Coordination Issues

To avoid causing confusion to motorists by having conflicting messages on portable and permanent units, coordination should include, but not be limited to, the contractors owning PCMS systems and local governing agencies operating nearby permanent CMS systems. An additional benefit of coordination is the potential to address liability issues in a unified manner. Coordination can be facilitated through the use of an automated system that controls the display of both portable and permanent CMS systems.

8.15 Concluding Remarks

PCMS systems can be an effective tool for communicating essential information to the traveler before and during a highway construction period. When used properly they can help motorists make informed decisions about how to navigate through highway work zones more safely.

This section has provided criteria for deployment. These criteria are not definitive, but reflect the state of the practice as research continues.

9 Conclusion and Future Research

This study has covered a wide range of issues related to the PCMS deployment in highway work zones. The major findings are presented in Section 9.1 followed by recommendations for future research in Section 9.2.

9.1 Major Findings of the Study

The control of roadway traffic is essential to the safe and efficient movement of vehicles and pedestrians. Among locations that appear to present a challenge for safe traffic control are highway construction zones. These sites are potential sources of congestion, delays, motorist confusion, frustration and accidents. One of the means available to roadway authorities to alert drivers of upcoming work zones is the PCMS. This study assessed the need to use PCMS systems in highway work zones and suggested criteria for deployment after a research effort with a number of major findings.

The study revealed that accidents occur most frequently at work zones when activities are in progress, the rate of increase depending on factors related to traffic, geometry and the environment. Moreover, accident frequency increases at short work zones with short durations compared to long work zones with long durations. Furthermore, nighttime accidents at work zones tend to occur more often at taper areas, which emphasizes the need for adequate lighting and suitable channelization in these areas. In addition, it has been shown that one of the major problems at work zones is the large speed differential among vehicles, especially at work zones where speed limits have been considerably reduced from the normal speed limit.

Highway construction and maintenance zones deserve special consideration with respect to older driver needs due to age-related deficits (i.e., lowered driver alertness, slower detection time in complex roadway scenes due to distraction from irrelevant stimuli, increased time to understand unclear messages such as symbols and slower decision making). The study found that older drivers are quantitatively but not qualitatively different from their younger counterparts.

IDOT districts are involved in a wide range of highway work zone activities during which the use of PCMS systems vary depending on the nature of the activity. There are situations, however, where during similar work zone activities the deployment and application pattern of the PCMS units is not consistent across districts. The study identified several areas where there is no uniform application of PCMS systems, such as highway construction projects of similar nature; situations where use of publicly or privately owned PCMS systems is warranted; placement of the units before, during and after the construction period; use of a standardized database of messages and abbreviations; use of an established methodology to compose messages; sequencing and duration of longer messages; policies regarding updating, modifying or discontinuing messages; maintenance guidelines; understanding of the pros and cons of different PCMS technologies; coordination of PCMS systems and other intelligent transportation systems technologies.

In addition, the IDOT District Traffic Engineers survey revealed the need for improvement in the following areas:

1. Development of a comprehensive standardized statewide database of messages and message abbreviations
2. Development of a comprehensive repository with information about the technology of the various components of the PCMS units owned and operated by the districts
3. Coordination of PCMS units used in highway work zones with a corridor or regional ATMS system
4. Maintaining information about the use of a PCMS unit in a work zone project and possibly integrate it with other information related to the individual PCMS unit and the work zone project in a management system

The human factors dimension of PCMS deployment was investigated during a motorist survey. The analysis revealed that, in situations where the use of portable units is warranted, particular attention should be given to sign visibility and message legibility issues so that motorists attention is maximized for drivers familiar or unfamiliar with the particular construction site, for commercial and private drivers, for drivers of different age groups and for driving conditions, especially in late afternoon hours (and probably nighttime conditions, although the latter was outside of the scope of work).

Moreover, motorists preference for "action" statements (independent of age group, gender or vehicle type) imply that PCMS messages could be short enough (two panels at most) without compromising motorists information needs, while at the same time avoiding redundancy which not only is not desired, but also affects the impact of the critical (and desired) portion of the message on the driving behavior. In other words, the small amount of time (a few seconds) available to read a message should be utilized to display only the information with the highest impact potential and not information which is also conveyed by other traffic control safety devices deployed in a construction zone.

The previous research effort led naturally to a needs assessment. Prescribing warrants for PCMS deployment in highway work zones is not an exact science since both the state-of-the-art in research and technology development are continuously evolving. Each highway work-zone situation would ideally require specific consideration to fully assess the need for PCMS deployment. Federal guidelines, state DOTs' experience and ongoing research were employed to contribute to the synthesis presented in this study. PCMS systems can be an effective tool for communicating essential information to the traveler before and during a highway construction period. When used properly, they can help motorists make informed decisions about how to navigate through highway work zones more safely.

This study is expected to assist the decision-making ability of state highway officials and advance the level of understanding regarding the conditions that warrant PCMS use in highway work zones. The research team believes that this report will be of interest to state and local traffic engineers responsible for the design and operation of efficient highway systems and especially to traffic operations engineers in charge of the design of the traffic control plan for the work zone area. It may also be useful to consulting traffic engineers, sign manufacturers and vendors in the private sector who assist governmental clients in the deployment of changeable message signs in highway projects.

9.2 Future Research

Traffic technology as related to PCMS deployment in highway (and arterial) work zones is changing rapidly. PCMS systems are traffic control devices which need to be considered within the greater area of advanced traffic management systems and therefore purchasing, procurement and deployment decisions need to bear this in mind. A natural extension of this project is to fill the need for additional improvements as discussed earlier by means of designing and deploying "intelligent" PCMS systems which will:

- improve traffic flow through the work zone
- provide real-time traffic flow information to motorists approaching the work zone
- increase public safety for motorists and construction personnel
- be truly portable and adaptable to various construction projects
- have state-of-the-art display technology
- have open architecture compatible with the NTCIP protocol

- be integrated with local traffic management systems
- promote public acceptance by providing pertinent and true real-time traffic information
- adhere to the needs of various segments of motorists
- be cost effective
- be the product of strategic cooperation between public-private interests.

The objectives of the new study would be to develop functional requirements, specifications, design and general deployment strategy for such an advanced PCMS system demonstration. This work would consider requirements and options relative to data collection and processing, communications and dissemination technologies and outline a general deployment strategy, including a prioritized list of potential demonstration site locations/configurations.

Today's evolving display technologies require state agencies to remain flexible. A decade ago the market consisted of three basic technologies: lamp bank, reflective disk and rotating drum PCMS systems. These technologies are considered mature and are still in use. Within the last five years, however, the demand for PCMS systems as an integral part of the ever-expanding ITS industry has prompted the development of new display technologies. With these in mind, decisions about deployment of PCMS devices should consider the following issues:

1. **PCMS systems are a customer interface.** Motorists (the paying customers of the transportation system) judge the overall quality of the ITS based on CMS display. In particular situations where guidance is certainly appreciated, such as work zones, any system problems affecting PCMS systems are immediately and publicly advertised. In this respect PCMS failure may evaporate the public and political support for ongoing or expanded ITS funding.
2. **PCMS importance.** The penalty for PCMS failure or malfunction typically involves embarrassing negative media coverage.

10 Appendix A: NYSDOT's "Template" Messages

ACCIDENT
DELAY(S), MAJOR/DELAYS
DISABLED/VEHICLE
TRAFFIC/BACKUP
ROADWORK
ROAD/MAY BE/(SLIPPERY, ICY, WET, etc.)
RAMP/MAY BE/(SLIPPERY, ICY, WET, etc.)
BRIDGE/MAY BE/(SLIPPERY, ICY, WET, etc.)
SHOULDER/MAY BE/(SLIPPERY, ICY, SOFT, BLOCKED, etc.)
CONST, ROADWORK, SLIPPERY, SNOW, ICING, DRIFTING, FLOODING, FOG, HIGH WINDS, TRUCKS ENTERING, etc.
SLOW/TRAFFIC, 1 (or 2) WAY/TRAFFIC
LANES/DIVIDE
ROADWORK/CONST/TONIGHT, TODAY, TOMORROW, DATE, etc.
SINGLE/LANE
ONE LANE/BRIDGE
SOFT/SHOULDER
LOOSE/GRAVEL
FRESH/OIL
HOV LANE
TRAFFIC/SIGNAL
MOVING/WORK/ZONE, WORKERS/IN/ROADWAY, FLAGGER
UNEVEN/LANES
LANES/NARROW, SHIFT, MERGE, etc.
NO/SHOULDER, NO/PASSING
NO/OVERSIZE/LOADS
HAZMAT/SPILL
EMERG/VEHICLES/ONLY
TRAFFIC/EMERG/TUNE TO/540/1610 AM

Table 33: Standard problem statement messages.

_ /MILES/AHEAD
AT/ _ /ST
AT EXIT/ _
AT/(LANDMARK)
NEAR/(LANDMARK)
EXITS/ _ TO _
_ /ST TO/ _ ST
NEAR/ _ /ST
AFTER/ _ /ST EXIT
NEXT/ _ /MILES

Table 34: Standard "location" messages.

LEFT/LANE/CLOSED
RIGHT/LANE/CLOSED
CENTER/LANE/CLOSED
CENTER/LANES/CLOSED
2 RIGHT/LANES/CLOSED
2 LEFT/LANES/CLOSED
ROAD/CLOSED
LEFT/SHOULDER/CLOSED
RIGHT/SHOULDER/CLOSED
OFF RAMP/CLOSED
EXPECT/DELAYS
DELAYS/AHEAD
SLOW/TRAFFIC
SPEED/LIMIT/ _ MPH
_ MINUTE/CLOSURES/ MIDNIGHT/ TO _ AM,PM
_ MILE/BACKUP

Table 35: Standard "effect" messages.

ALL/TRAFFIC
CARS
TRUCKS
(ROUTE #)/ NORTH (SOUTH) (EAST) (WEST)
LOCAL/TRAFFIC
THRU/TRAFFIC
BUSES
CARPOOLS
WIDE (OVERSIZE)/LOADS
EMERG/VEHICLES/ONLY
VEHICLES/WITH/TRAILERS
SINGLE/AXLE/TRUCKS

Table 36: Standard "attention" messages.

MERGE/RIGHT (LEFT)
KEEP/RIGHT (LEFT)
STAY ON/ _
(attention statement)/ MERGE TO/RIGHT (LEFT) (CNTR) LN (S)
(attention statement) /MERGE TO/RIGHT (LEFT) (CNTR) LN (S)
DO NOT/LEAVE/VEHICLE
PREPARE/TO STOP
PREPARE/TO MERGE
SLOW TO/ _ MPH
REDUCE/SPEED
(attention statement) /KEEP RT (LFT)
DO NOT/PASS
STAY/IN LANE
PROCEED/WITH/CAUTION
USE/CAUTION
WATCH/FOR/FLAGGER
USE/RIGHT(LEFT)(CENTER)/LANE(S)

Table 37: Standard "action" messages (for non-diversion situations).

TUNE/RADIO/540 (1610) AM
AVOID/DELAYS/USE _ EXIT/ _ MILES
AVOID/DELAYS/USE _
USE/NEXT/EXIT
USE/DETOUR/ROUTE
CONSIDER/ALT/ROUTE
(action statement)/USE _
USE/ _ ROAD (STREET)(AVE)(BLVD.)/VIA _
USE ALT/ROUTE
USE NYXX/TO XX W/ TO XX E/TO I-95
USE/I-95 SO/TO RTE /XX EAST/AVOID/DELAYS
DELAYS
USE/ROUTE XX/NORTH/AS ALT/ROUTE
FOLLOW/ALT/ROUTE

Table 38: Standard "action" messages (for diversion situations).

BEST/ROUTE TO/(VENUE)
AVOID/DELAYS
USE/ _ /STREET (ROUTE)(AVE)(BLVD) etc.
ARENA (STADIUM) (RACE TRACK) (CASINO)
(RESORTS) (BEACH) (ZOO) (AQUARIUM)
(CONCERT)(EMPIRE/STATE/GAMES)(WESTCHESTER/OPEN)
(US OPEN)(OTB CLASSIC) etc.
(VENUE)/TRAFFIC

Table 39: Acceptable message elements for special events.

11 Appendix B: VDOT's Portable CMS Operator's Manual

11.1 Module 1: Should a CMS be used?

A CMS is a tool for grabbing the motorist's attention. Therefore it should be used only when there is a specific message that needs to be conveyed to motorists: overuse of a CMS will cause motorists to ignore it and lessen its effectiveness.

All of the following statements should be true if a CMS is to be used.

T F Drivers are required to do something in response to the message such as:

- change travel speed,
- change lanes,
- divert to a different route or
- be aware of a change in current or future traffic conditions.

T F Where applicable, static signs which can effectively convey this message are not readily available. CMS systems should be used to supplement, *rather than replace*, static signs that are required by law.

T F The CMS does not tell drivers something they already know.

T F Message accuracy can be confirmed from a reliable source such as State Police, a credible commercial traffic reporter or visual inspection.

T F Traffic conditions may be monitored to detect significant changes such that the CMS may be removed or the message may be changed as soon as events warrant.

IF all answers are true, then proceed to Module 2.

IF any answers are false, then stop.

11.2 Module 2: What is the purpose of the CMS?

Select a purpose of the CMS from one of the four categories below.

<u>Current Operations</u> **(events occurring NOW)**

A. Incident work zone advisory message:

- accident
- congestion
- construction
- poor visibility
- slippery surface
- road/lane/bridge/shoulder closure
- pedestrians or bicyclists

B. Diversion message to an alternate route in conjunction with a *current incident or work zone advisory* message by itself.

C. Guidance message for a special event

- control traffic (such as lane control)
- guide traffic
- alert to highway advisory radio

<u>Future Operations</u> **(events occurring in the future)**

D. Advisory message for a future event

- **work zone**
  - road/lane/bridge closure
  - roadwork or maintenance
- special event (e.g. parades or sporting events)

IF a category has been selected, then proceed to Module 3.

IF no category has been selected, then reconsider use of CMS systems.

11.3 Module 3: Where should the CMS be located?

All statements in A, B and C should be true.

A. Placement requirements to enhance CMS readability

T F The sight distance of the CMS is acceptable.

Ideally, the sight distance should be at least 1,000 ft. If this is not possible, then the sight distance should be long enough for motorists who are not expecting a CMS to both become aware of its presence and read the message.

T F The CMS is not obstructed by signs, poles or other objects.

T F The CMS is placed in the most level area possible.

T F The CMS is not located within a major intersection or interchange.

T F If two CMS units are used for the same traffic stream (i.e. traffic traveling in the same direction) they are separated by at least 1,000 ft.

This 1,000 ft separation distance applies whether the CMS units are on the same side or opposite sides of the road. If the CMS units are on the same side, then drivers will need time to digest the first CMS message before reading the second CMS's message. If the CMS units are on opposite sides of the road, then drivers may try to read both units simultaneously unless the units are 1,000 ft apart.

B. Placement requirements to give motorists sufficient time to react.

T F The CMS is located prior to major decision points (intersections and interchanges where drivers may change their travel path).

T F The CMS is placed prior to present and expected future traffic backups.

T F If used on an interstate to divert drivers, the CMS is placed no less than one mile prior to the interchange where drivers need to divert.

T F If advising drivers to take a detour, the CMS is used in conjunction with trailblazing signs.

C. Where should the CMS be placed in relation to the edge of the road?

T F If possible the CMS is placed off the shoulder.

Placing the CMS on the shoulder or next to the guardrail should be avoided as the unit may then block emergency access or be too close to traffic.

T F Group II channelization devices are used in conjunction with the CMS.

T F The CMS is placed in a location that will be accessible to maintenance vehicles even if the traffic queue grows.

IF all answers are true, then proceed to Module 4.

IF any answers are false, then consider a different location or other methods of communications, such as HAR or a flagger.

11.4 Module 4: What is the maximum number of screens that may be used?

Motorists must have enough time to read, digest and react to the entire message. Large vehicles, driver inattention, unfamiliarity with the area and complex messages hamper motorists' ability to assimilate information provided by the CMS. The element of surprise of encountering a CMS further lessens the amount of time available to read a message. Finally, note that flip-disk CMS legibility deteriorates severely at night.

- Therefore it is strongly recommended that only one screen be used if at all possible.
- However, if more than one screen is necessary, then a maximum of two screens should be used.

Three-screen messages should not be used.

IF you believe that more than two screens are required for a particular CMS message, then see Table 3 and submit the message to the Regional Traffic Engineer or Safety Officer for comments.

OTHERWISE go to Module 5.

11.5 Module 5: What is the message type?

The message content is directly dependent on the type of message selected in Module 2. This message type determines which module should be examined next. Recall the type of message selected in Module 2 and proceed to the decision box below:

(A) incident or work zone advisory message (current event)

OR

(B) diversion message to an alternate route (current event)

OR

(C) guidance message for a special event (current event)

OR

(D) advisory message for a future event

IF A (incident or work zone advisory message) then go to Module 6.

IF B (diversion message to an alternate route) then go to Module 7.

IF C (guidance message for a special event) then go to Module 8.

IF D (advisory message for a future event) then go to Module 9.

11.6 Module 6: What is the message? (current incident/work zone advisory)

A. Message components for current incident/work zone advisory messages

Each current incident/work zone advisory message must contain a *problem* component, a *location* component and an *instruction* component. A component may be in the form of a statement or it may be implied.

T F The *problem* component is included or implied.

The problem component describes the specific traffic condition, such as an accident a delay, congestion, an icy road, construction or pedestrians. Example *problem* components are shown in the left-hand column of Table 40.

T F The *location* component is included or implied.

The *location* component indicates where the traffic condition occurs, such as an exit location, a landmark or a distance from the motorist. Example *location* components are shown in

PROBLEM	LOCATION	INSTRUCTION
TRAFFIC/SLOWS	AFTER/EXIT 100B	INFO/540 AM
LFT LANE/CLOSED	2 MI	MERGE RT
CNTR LN/CLOSED	NEXT 2MI	MERGE/LFT
RT LANE/CLOSED	DUKE ST/TO ELM	REDUCE/SPD
2 RT LNS/CLOSED	BEFORE/DUKE ST	STOP AHD
2 LFT/LANES/CLOSED	AFTER/DUKE ST	PREPARE/TO STOP
RT SHLDR/CLOSED	AT DUKE	a diversion message – see Module 7
LEFT/SHLDR/CLOSED	AHD	implied (see below)
PEOPLE/CROSSING	ON MOUNT	
ACCIDENT	ON BRIDGE	
ROAD/CLOSED	implied (see below)	
EXIT 5/CLOSED		
LEE HWY/CLOSED		
TRAFFIC/CLEARS		
FOG		
ICE		
SNOW		
implied (see below)		

* The components shown are examples only: other words are permitted. Furthermore, it is not necessary that each component be on a separate screen. Note that the forward slash '/' indicates a separate message line.

Table 40: Current incident/work zone advisory message components.

the middle column of Table 40.

T F The *instruction* component is included or implied.

The *instruction* component declares what the motorist should do, such as change lanes, divert to an alternate route or prepare for a sudden decrease in speed. Example *instruction* components are shown in the right-hand column of Table 40 and examples of how the instruction component may be implied are shown below.

- Note that components may be *implied* (see below.)

The message MERGE RT/2 MI implies a *problem:* there is a change in traffic conditions resulting from an accident or roadwork.

The message EXIT 5/CLOSED/USE EX 6 implies a *location:* exit 5.

The message RT LANE/CLOSED 1 1/4 MI implies an *instruction:* motorists must merge into the left lane.

IF all of the answers on section A are true, then continue with section B.

IF any answers on section A are false, then reword the message.

B. Additional requirements for current incident/work zone advisory messages

All of the statements should be true.

T F Sensational incident information such as CAR FIRE, VEHICLE OVERTURNED or TRUCK ACCIDENT has been avoided. Instead, words such as ACCIDENT have been used, if applicable.

T F Descriptors such as DELAY or CONGESTED are not used unless a distance or location follows, such as CONGESTED 3 MI or DELAY AT DUKE ST.

T F If applicable, the word AFTER has been used appropriately.

The word AFTER is preferred to AT and BEFORE when it provides additional information by indicating a possible point of diversion. For example, ACCIDENT AFTER DUKE ST indicates that drivers may use Duke Street as an alternative route to avoid the accident.

T F The word AHEAD is used only if it is needed to clarify the message.
A more precise location than AHEAD is preferred.

T F The message does not contain both the words RIGHT and LEFT unless absolutely necessary. Messages which contain both the words right and left, such as RIGHT LANE CLOSED MERGE LEFT may confuse the motorist.

T F If a merge is required but the merge is not imminent then the amount of time or distance motorists have to complete the merge is displayed.

T F If the words TRAFFIC CLEARS are used then they are followed by a location or distance equal to or greater than the distance to the end of congestion. Thus if the congestion clears in 2.2 or 2.9 miles, then the CMS should read TRAFFIC CLEARS 3 MI.

IF all answers are true, then go to Module 7.

IF any answers are false, then reconsider the message.

11.7 Module 7: What is the message? (route diversion)

IF using a message for *diversion to an alternate route* then complete this section.

OTHERWISE go to Module 10.

The following module outlines appropriate *diversion messages* for diverting motorists to an alternate route. These diversion messages may be used:

1. as an *instruction* component of the current advisory messages in Module 6 or

2. as a separate message.

A diversion message should contain an *audience* component and an *instruction* component. A *time saved* component may also be included if necessary.

All of the following statements should he true.

T F The *audience* component is included if needed.

The *audience* component answers the question, "To whom is the message directed?" If no audience is specified then it is understood that the message applies to all traffic. When there is a mixture of local and through traffic, however, then the CMS may need to qualify to whom the message is directed. Destinations and events are useful for designating this audience. Example *audience* components are given in the leftmost column of Table 41.

T F The *time saved* component is included **ONLY** if the following criteria are met:

- inclusion of the time saved component will not result in a message which is longer than two screens.

- diversion is an option, rather than a requirement, for motorists.

- the amount of time motorists may save by diverting can be **accurately determined** (within 15 minutes). Note that this time saved is **not** simply the amount of time motorists might sit in traffic; it also accounts for the extra time motorists spend diverting to another route. Thus traffic conditions on both the main route and the diversion route must be monitored.

- the CMS can be updated when necessary.

AUDIENCE	TIME SAVED	INSTRUCTION
LOCAL/TRAFFIC	SAVE/40 MIN	USE/LEE HWY
THRU/TRAFFIC	AVOID/40 MIN/DELAY	FOLLOW/DETOUR
BEACH	SAVE 1 HR	USE ALT/RTE
SYRACUSE	AVOID/1 HR/DELAY	USE EX15
CONCERT		
COLISEUM		
implied (see below)		

* The components shown below are examples only: other words are permitted.

Furthermore, it is not necessary that each component be on a separate screen.

Table 41: Diversion message components.

Example *time saved* components are shown in the middle column of Table 41.

T F The *instruction* component is included.

The *instruction* component answers the question, "What should motorists do?" and should be a single statement. If multiple instructions are necessary then they should be supplied by static signs, additional CMS units or HAR. Example *instruction* components are in the right-most column of Table 41.

T F The phrases ALT ROUTE or DETOUR have been used correctly, if applicable.

The word DETOUR implies that an alternate route has been thought out and marked with static signs to guide the unfamiliar motorist. The phrase ALT ROUTE implies that motorists have to find such a route on their own.

• Note that the *audience* component may be implied to all traffic. For example, the message SAVE 1HR/FOLLOW/DETOUR is acceptable and applies to all traffic.

IF all answers on the past two pages are marked true, then go to Module 10.

IF any answers are marked false, then review the message.

11.8 Module 8: What is the message? (guidance for a special event)

Special event guidance messages alert motorists when traffic conditions change as the result of a special event, such as a concert, parade or sports event. These messages may guide motorists attending the event or direct other traffic to avoid congested areas.

AUDIENCE	INSTRUCTION
BSA/PKRNG	EXIT 100A
BSA TRAF	FIRST RT
CONCERT	FIRST/LEFT
FOOTBALL/GAME	RIGHT LN
FOOTBALL	LEFT LN
BILLS/GAME	FOLLOW/SIGNS
implied (see below)	

* The components shown are examples only: other words are permitted.

Furthermore, it is not necessary that each component be on a separate screen.

Table 42: Special Event message components.

A guidance message for a special event should have two components:

1. audience
2. instruction

All of the following statements should be true.

T F An *audience* component has been included.

An *audience* component alerts all motorists or a group of motorists to a change in traffic conditions. Examples include the name of a special event, the destination of that event or a certain portion of the traffic stream. Example *audience* components are given in the left column of Table 42.

T F An *instruction* component has been included.

An *instruction* component indicates how motorists should react to the new traffic condition. Example *instruction* components are given in the right column of Table 42.

T F Event or destination names which the unfamiliar motorist will recognize have been used.

For example, if the musical group "U2" is playing at a concert at the Nassau Coliseum the message U2 PKING FIRST RIGHT may be understood by more travelers than COLISEUM PKING FIRST RIGHT. Depending upon the situation, it may be better to display the name of the event rather than the name of the destination.

IF all answers on the previous module are marked true, then go to Module 10.

IF any answers are marked false, then review the message.

11.9 Module 9: What is the message? (advisory for a future event)

Advisory messages for a future event alert motorists to future changes in traffic conditions, usually as a result of roadwork or special events. The advantage of such a message is that it allows motorists to make alternate arrangements themselves.

However, the disadvantage of an advisory message for a future event is that motorists may tend to ignore the CMS if they become accustomed to seeing the same message.

Each advisory message for a future event must contain a *condition & location* component, a *time of condition* component and an *instruction* component.

All of the following statements should be true.

T F A *condition & location* component has been included.

The *condition & location* component indicates construction, a closure or a special event. If the message is referring to a location other than the road where the CMS is situated then that location needs to be specified. For example, a CMS situated on a major arterial could be used to alert motorists to future construction on a nearby interstate. Example *condition & location* components are shown in the left column of Table 43.

T F A brief and concise *time* component has been included.

The *time* component indicates when the new traffic conditions will be in effect. This component may refer to a time of day, day of the week or day of the month. Example *time* components are shown in the middle column of Table 43.

T F An *instruction* component has been included or implied.

The *instruction* component alerts motorists as to how they should react to the change in traffic conditions, such as to use an alternate route or to expect delays. Example *instruction* components are shown in the right column of Table 43. Note, however, that *instruction* components may often be implied as explained below.

For example, the message EXT 5 CLOSED DEC 4 – 7 is acceptable because it *implies* an instruction for motorists to use an alternate route.

T F The message does not describe future conditions more than one week in advance.

CONDITION & LOCATION	TIME	INSTRUCTION
EXIT5/CLOSED	DEC 4-7	INFO/540 A.M
BRADDOCK/CLOSED	5/9 – 5/12	USE / RTE 301
RT LANE/CLOSED	9 AM – 5 PM	implied (see below)
ROADWORK/ON I-90	TUES/9AM-5PM	
ROADWORK		
CONCERT		
BOWL/GAME/AT RICH		
PARADE/MAIN ST		

* The components shown below are examples only: other words are permitted. Furthermore, it is not necessary that each component be on a separate screen.

Table 43: Components of an advisory message for a future event.

T F If the change in traffic conditions has already occurred, than verify that the message is still applicable and reword the message if necessary. If the situation is a long term one then static signs should be used.

• Note that the *instruction* component may be implied. For example, the message EXIT 5 CLOSED DEC 4 – 7 is acceptable and implies that motorists must find another route.

IF all answers in Module 9 are marked true, then go to Module 10.

IF any answers are marked false, then review the message.

11.10 Module 10: How should distances and locations be conveyed?

IF a distance **or** a location is part of the message, then complete this module.

OTHERWISE go to Module 11.

When giving a location or distance, the question arises as to whether the operator should give a distance in miles (ACCIDENT 3 MI), an exit number (ACCIDENT AFTER EX 100), or the name of a prominent landmark (ACCIDENT AT BROAD STREET). In order to make this decision, complete this module.

T F The message applies **ONLY** to familiar drivers.

IF true, then consider the use of cross streets, landmarks and exit numbers and select the term that is best known by the local population. Go to Module 11.

IF false, then continue with this module.

T F The route is an interstate.

IF true, then continue with this module. IF false, then give a distance in miles. Go to Module 11.

T F The exits are numbered sequentially (i.e. they do not correspond to mile markers).

IF true, then give the distance in miles. Go to Module 11. IF false, then continue with this module.

T F At least one of the following are located within one mile after the CMS:

- an exit or
- a static sign indicating a distance to an exit.

IF true, then give the location as an exit number. Go to Module 11. IF false, then give the distance in miles. Go to Module 11.

11.11 Module 11: Are the words "traffic" and "ahead" used correctly?

The statement below should be true.

T F The words "traffic" and "ahead" have been used only as necessary.

Pay careful attention to use the words "traffic" and "ahead" only when necessary. Some examples are listed here for a three-line CMS with eight characters per line:

- The two-screen message

first screen	second screen
JONES	USE
BEACH	EXIT 150
TRAFFIC	

should be shortened to a one-screen message

JONES
BEACH
EXIT 150

• The message

first screen	second screen
ACCIDENT	PREPARE
3 MI	TO STOP
AHEAD	AHEAD

should be shortened to

ACCIDENT
3 MI
STOP AHD

IF the above answer is true, then go to Module 12.

IF the above answer is false, then review the message.

11.12 Module 12: Is the word "next" used only as necessary?

IF the word "next" is used to designate an exit or turn, then complete this module.

OTHERWISE go to Module 13.

Historically, the word "next" has generated confusion. For example, if motorists read the message USE NEXT EXIT and soon after the message they see an exit, it may not be clear whether motorists should take that exit or take the following exit. In order to avoid using the word "next", complete this module.

T F The CMS is used on an interstate.

IF True, then use a name or route number rather than NEXT. For example, USE I-81 or USE EX 34" can replace USE NEXT EXIT. Go to Module 13.

IF false, then continue with this module.

T F The exit or turn which motorists should use is clearly marked with static signs.

IF true, then use the name or number expressed by static signs rather than NEXT. For example, the message LEFT AT / ELMWOOD can replace USE NEXT / LEFT. Go to Module 13.

IF false, then continue with this module and notify the Regional Traffic Engineer that the street is not well marked.

T F The exit or turn which motorists should use is visible from the CMS.

IF true, then use THIS instead of NEXT. For example, the message USE THIS/RIGHT should replace USE NEXT/RIGHT. In this case, do not use the abbreviation RT as motorists may believe it means ROUTE. Go to Module 13.

IF False, then use FIRST instead of NEXT. For example, the message USE/FIRST/ RIGHT should replace USE NEXT/RIGHT. In this case, do not use the abbreviation RT as motorists may believe it means ROUTE. Go to Module 13.

11.13 Module 13: How should the CMS message be sequenced?

IF the message will fit on one screen, then go to Module 14.

IF the message will not fit on one screen, then complete this module.

The following statement should be true.

T F The message is clear even if the motorist encounters the second screen first or is able to read only one of the screens.

Individual message screens must be compatible and make sense when read separately. For example, suppose there is an accident at exit 150 which will delay motorists for about an hour and the CMS operator wishes to route traffic to I-295 in order to bypass the accident. The operator would not want to sequence the message as follows:

first screen	second screen
ACCIDENT AT/EXIT 150 SAVE/1HR	USE I295

because the motorist might be confused by the connection between saving one hour and an accident. Instead, the operator should choose the following format:

first screen	second screen
ACCIDENT AT/EXIT 150	SAVE/1HR USE I295

IF the answer is true, then go to Module 14.

IF the answer is false, then rearrange the message or shorten it to fit on one screen.

11.14 Module 14: Is the message acceptable?

The message should communicate essential specific traffic information concisely and accurately. Therefore, the answer to all of the following questions should be true.

T F Standard abbreviations are used where necessary. (See Appendix C for a list of standard abbreviations.)

T F Unnecessary screens have been eliminated.

Consider the following three-screen message:

screen 1	screen 2	screen 3
NEW	BEGINS	USE
TRAFFIC	TUESDAY	CAUTION
PATTERN	12-10-94	

The first two screens convey all the essential information, while the third screen steals valuable time from the important part of the message. Therefore in this example the third screen should be eliminated.

T F The message is consistent with local signing.

For example, if you wish to divert drivers to Route 244 (Columbia Pike), whether or not you use COLUMBIA PIKE or RTE 244 depends upon how local signs refer to that road.

T F The message is clear to the driving population.

T F Message lines make sense when read in the order shown.

The order in which message lines are displayed affects the readability of the message. For example, the message 8 MI/ACCIDENT/USE RT50 may confuse motorists simply because it is displayed in an unfamiliar order. Instead, one should use the message ACCIDENT/8MI/USE RT50.

IF all of the above answers are true, then go to Module 15.

IF any answers are false, then consider rewording the message, using a second CMS or employing another means of communication such as HAR or static signs.

11.15 Module 15: How should the message be displayed?

All of the following statements should be true:

T F The correct amount of time for displaying each message screen has been determined.

Ideally, motorists who are unfamiliar with the area should have approximately one second per eight character word or three seconds per screen, assuming screens have three lines and approximately eight characters per line, in order to read the CMS message. The reading time, however, is dependent upon a variety of factors, such as motorists' familiarity with the CMS, motorists' familiarity with the area, the complexity of the message, traffic conditions and the difficulty of negotiating the road. Therefore this recommended time of three seconds per screen may be altered based upon the effect of these factors and the results of the "drive-through" test in Module 16, but the messages should not be scrolled any faster than 1.5 seconds per screen.

T F Single stroke fonts are used. (Double stroke fonts should be avoided, as these have a smaller legibility distance than single stroke fonts.)

T F All letters are displayed in upper-case only.

T F Blank or unnecessary screens are not used.

IF all of the above answers are true, then go to Module 16.

IF any answers are false, then reevaluate the message display format.

11.16 Module 16: Does the CMS pass the drive-through test?

The CMS should now be activated and set to display the desired message. However, before leaving the site, complete the remaining two modules.

T F A drive past the CMS indicates that it is being used effectively.

The operator should drive past the CMS at least once, as would a motorist in order to verify that the CMS is accomplishing its intended purpose. The following should be considered:

- Is the CMS plainly visible, even for a motorist who is not expecting to encounter it?
- If using more than one message screen, is the display time set such that the message does not scroll too fast or too slow?

- Is there enough time to read, understand and react to the message after accounting for trucks blocking the CMS, travelers unfamiliar with the area and driver inattention?
- Does the message convey the essential information that motorists need?
- Will the message continue to be accurate and necessary until an operator can alter the message or remove the CMS?
- Is the CMS situated so that it does not hinder the flow of traffic or emergency vehicles nor constitute a safety hazard?

IF the above answer is true, then go to Module 17.

IF the above answer is false, then reconsider the message content, how the message is displayed, the placement of the CMS or the use of other means of communication.

11.17 Module 17: When should the message be updated, modified or discontinued?

Information on a CMS must be accurate and up-to-date. Effective use of a CMS requires that the operator update the CMS as soon as any of the following conditions are true:

T F A change in driver response is no longer required.

T F The message accuracy may no longer be verified.

T F Static signs that can convey the information just as effectively have become available.

T F Most or all of the drivers already know the information being conveyed by the CMS.

T F Most or all drivers appear to be ignoring the message.

T F The amount of delay being displayed by the CMS changes by more than 15 minutes.

T F The best alternate route changes.

IF any of the above answers are true, then change the message or remove the CMS.

IF all of the above answers are false, then continue to display the message.

12 Appendix C: A Synthesis of Message Abbreviations

The message abbreviations in this appendix are a synthesis of those found in the American Traffic Safety Services Association (ATSSA) guidelines (ATSSA, 1994), FHWA publications and state DOTs' guidelines.

Word	Abbrev.	Word	Abbrev.
Alternate	ALT	Left	LFT
Avenue	AVE	Maintenance	MAINT
Boulevard	BLVD	Normal	NORM
Bound	BND	Parking	PKING
Can Not	CAN'T	Right	RT
Center	CNTR	Road	RD
Do Not	DON'T	Service	SERV
Emergency	EMER	Shoulder	SHLDR
Entrance, Enter	ENT	Slippery	SLIP
Expressway	EXPWY	Speed	SPD
Freeway	FRWY, FWY	Street	ST
Highway	HWY	Traffic	TRAF
Information	INFO	Travelers	TRVLRS
It Is	IT'S	Warning	WARN
Junction	JCT	Will Not	WON'T

Table 44: Standard abbreviations easily understood.

Abbrev.	Possible Words	Abbrev.	Possible Words
ACC	Accident or Access	LT	Left or Light
CLRS	Clears or Colors	PARK	Parking or Park
DLY	Delay or Daily	RED	Reduced or Red
FDR	Feeder or Federal	POLL	Pollution or Poll
L	Left or Lane	STAD	Stadium or Standard
LOC	Location or Local	WRNG	Warning or Wrong
TEMP	Temporary or Temperature		

Table 45: Abbreviations that should not be used.

Word	Abbrev.	Prompt	Word	Abbrev.	Prompt
Access	ACCS	Road	Mile	MI	[Number]*
Ahead	AHD	Fog*	Minor	MNR	Accident
Blocked	BLKD	Lane*	Minute(s)	MIN	[Number]*
Bridge	BRDG	[Name]*	Oversized	OVRSZ	Load
Cardinal Directions	N,E,S,W	[Number]	Prepare	PREP	To Stop
Chemical	CHEM	Spill	Pavement	PVMT	Wet*
Commercial	COMM	Vehicle	Quality	QLTY	Air*
Construction	CONST	Ahead	Route	RTE	Best*
Exit	EX, EXT	Next*	Signal	SGNL	Traffic, Ahead
Express	EXP	Lane	Turnpike	TRNPK	[Name]*
Hazardous	HAZ	Driving	Vehicle	VEH	Stalled*
Interstate	I	[Number]	Upper	UPR	Level
Lane	LN	Right, Left, Center	Lower	LWR	Level
			Work	WRK	Road
Major	MAJ	Accident			

* Prompt word given first

Table 46: Abbreviations understood in conjunction with a particular word.

Word	Abbrev.	Prompt	Word	Abbrev.	Prompt
Condition	COND	Traffic*	Northbound	N-BND	Traffic
Congested	CONG	Traffic	Roadwork	RDWK	Ahead [Distance]
Downtown	DNTWN	Traffic	Southbound	S-BND	Traffic
Eastbound	E-BND	Traffic	Temporary	TEMP	Route
Frontage	FRNTG	Road	Township	TWNSHP	Limits
Local	LOC	Traffic	Westbound	W-BND	Traffic

* Prompt word given first

Table 47: Abbreviations understood with a prompt word by about 75% of drivers. Public education prior to usage is recommended.

13 Appendix D: IDOT District Traffic Engineers Survey Instrument

The survey questionnaire was sent to the district traffic operations engineers accompanied by the following cover letter which explains the purpose of the survey:

The Urban Transportation Center at the University of Illinois at Chicago is conducting a study sponsored by IDOT on the use of Changeable Message Signs (CMSs) in highway work zones. We are therefore only interested in **portable** *CMSs. One of the tasks requested by IDOT is to survey IDOT district traffic engineers to determine the number of CMSs currently in use, perceived problems or benefits, policies governing use, placement and message choice and recommendations.*

In this regard, we are asking your help to answer the questions below that apply to CMS use in your district. Please complete this survey form and fax it back to us by March 10, 1998. If the space provided in the survey instrument is not enough please attach your answer in a separate sheet and send it back with the rest of the survey.

We will call you in approximately a week to discuss your experience with CMSs that cannot be conveyed in this survey instrument.

1. How many CMSs are currently in your inventory in your district? In what occasions do you use CMSs from private inventories? Are there any differences in the policies for CMS operation between publicly and privately-owned CMS units?

2. Indicate examples of applications of CMSs in your district including but not limited to (please circle):
   (a) detours
   (b) changes to detours and bypasses
   (c) a lane drop where a continuous lane once existed
   (d) advance warning for work zone speed limits
   (e) in lieu of flaggers on freeways and expressways
   (f) lane closures where sight distance is restricted and/or congestion occurs
   (g) road closures

(h) accident and incident management requiring display of special message

(i) advisories and advance notice of construction activity

(j) other (please specify)

3. In situations during which you have planned to use CMS units how long before or after the construction period do you have them deployed and at what locations relative to the construction site?

4. What policies do you have in place for the proper operation of CMSs? In particular,

   (a) Are you using *standard* sign messages (i.e., those included in the Manual on Uniform Traffic Control Devices)?

   (b) In situations where you need to use *customized* messages,

      i. How do you obtain them?

      ii. Do you use a standard inventory of sign messages for different work zone situations such as resurfacing, pavement patching, bridge reconstruction?

      iii. What guidelines do you use for their design?

      iv. How do you display longer messages (multiple units or sequencing on a single unit)?

v. What is your district policy regarding cycle times and message duration?

(c) In what situations do you use abbreviations? In those cases, do you have a standard set of abbreviations? What abbreviations do you recommend avoiding?

(d) When do you update, modify or discontinue a message?

(e) How do you maintain the CMS unit when not in use?

5. What type of CMSs do you use:

(a) Light-reflecting CMSs (i.e., circular disks, rectangular disks or square disks)

(b) Light-emitting CMSs (i.e., bulb matrix, fiber optics, light-emitting diode matrix or fiber optics with shutters)

(c) Hybrid matrix CMSs

(d) other (please specify)

6. What is your experience regarding the CMS technology
   (a) reliability

   (b) requirements and costs?

7. What is your experience with the coordination of CMS units in work zones within a traffic management/monitoring system, highway advisory radio or intelligent transportation systems technologies?

8. What is your experience with the effectiveness of CMSs in controlling vehicle speeds in work zones?

9. We need to evaluate the effect of CMS usage on traffic accidents. Do you keep records or logs on when and where CMS units were used, so that we can relate this information with accident reports?

14 Appendix E: Motorists Survey Instrument

Hello, we're doing a study on road signs for the Department of Transportation and I would like to ask you a few questions.

First of all, were you the driver coming here?

- Yes
- No (THANK PERSON AND GO ON TO ANOTHER RESPONDENT)

Have you been driving eastbound on I-80 for at least ten miles?

- Yes
- No (THANK PERSON AND GO ON TO ANOTHER RESPONDENT)

1. You just drove through a construction area. About how much time do you think that construction delayed you? Would you say . . .
   - Less than three minutes,
   - 4 to 10 minutes,
   - 11 to 15 minutes or
   - More than 15 minutes?
   - NONE/NO DELAY (SKIP TO Q. 3)
   - DON'T KNOW
2. Do you think this was a reasonable delay or not?
   - Yes, reasonable
   - No, not reasonable
   - DON'T KNOW

3. When you're approaching a construction area, what are the most important things that you want to know about it? (AFTER EACH MENTION, ASK): What else?

-
-
-
-
-
- DON'T KNOW/NOTHING

4. Do you recall seeing a Changeable Message Sign during the last ten miles of your drive? Here's a picture of what they look like. (IF NECESSARY): A Changeable Message Sign is an electronic panel that is about 4 feet square and is put on a portable trailer. It displays a series of messages that can be changed as the need arises.

- Yes, recalls seeing one
- No, does not recall seeing one/DON'T KNOW (SKIP TO Q.12)

5. What did the sign say? (AFTER EACH MENTION, ASK): Anything else?

-
-
-
-
-
- DON'T KNOW/NOTHING (SKIP TO Q.12)

6. What other information would you have liked to have gotten from the sign? (AFTER EACH MENTION, ASK): What else?

-
-
-
-
-
- NOTHING
- DON'T KNOW

7. Do you think there was too much information on the sign, too little information or was it about right?
    - Too much information.
    - Too little information.
    - About right
    - DON'T KNOW
8. Do you think you were able to read all of the sign before you passed it?
    - Yes
    - No
    - DON'T KNOW
9. Were the letters large enough for you to read them easily?
    - Yes
    - No
    - DON'T KNOW
10. Did the message move too fast, too slow or about right?
    - Too fast
    - Too slow
    - About right
    - DON'T KNOW
11. Do you think the sign was too close to the construction, too far away or about right?
    - Too close
    - Too far back
    - About right
    - DON'T KNOW
12. We want to be sure to talk to all kinds of drivers, so I'd like to finish by asking you a few questions about yourself. Are you driving your vehicle for commercial or private use?
    - Commercial

- Private
- BOTH
- REFUSED

13. How far from here do you live? Would that be . . .

    - Less than 10 miles,
    - 10 to 25 miles,
    - 26 to 100 miles or
    - More than 100 miles?
    - REFUSED

14. Before today, had you driven down this stretch of road in the past 30 days?

    - Yes
    - No (SKIP TO Q.16)
    - DON'T KNOW (SKIP TO Q.16)

15. About how many times, one-way, in the past 30 days? Would you say . . .

    - Once or twice before,
    - 3 to 5 times,
    - 6 to 10 times or
    - More than 10 times in the past 30 days?
    - DON'T KNOW

16. Are you . . .

    - Under 21, (SKIP TO TY)
    - 21 to 39, (SKIP TO TY)
    - 40 to 59 or (SKIP TO TY)
    - 60 or older? (SKIP TO TY)
    - REFUSED

17. (INTERVIEWER: IF REFUSED AGE, TAKE A GUESS.)

    - Under 21,
    - 21 to 39,

- 40 to 59 or
- 60 or older?

TY — Those are all the questions I have. Thank you for your time and have a safe trip!

INTERVIEWER: NOW FILL IN THE FOLLOWING INFORMATION:

18. RESPONDENT GENDER:
    - Male
    - Female
19. DATE:
20. DAY OF WEEK:
    - Monday
    - Tuesday
    - Wednesday
    - Thursday
    - Friday
    - Saturday
    - Sunday
21. TIME OF DAY: (24-HOUR CLOCK)
22. APPROXIMATE TEMPERATURE
    - 50s
    - 60s
    - 70s
    - 80s
    - 90s
    - 100s
23. GENERAL WEATHER CONDITIONS: (CIRCLE ONE)
    - Clear/sunny
    - Partly cloudy/overcast

- Foggy
- Light drizzle
- Rainy
- Heavy rain/thunderstorms

GO BACK THROUGH THE QUESTIONNAIRE TO MAKE SURE EVERYTHING IS FILLED IN.

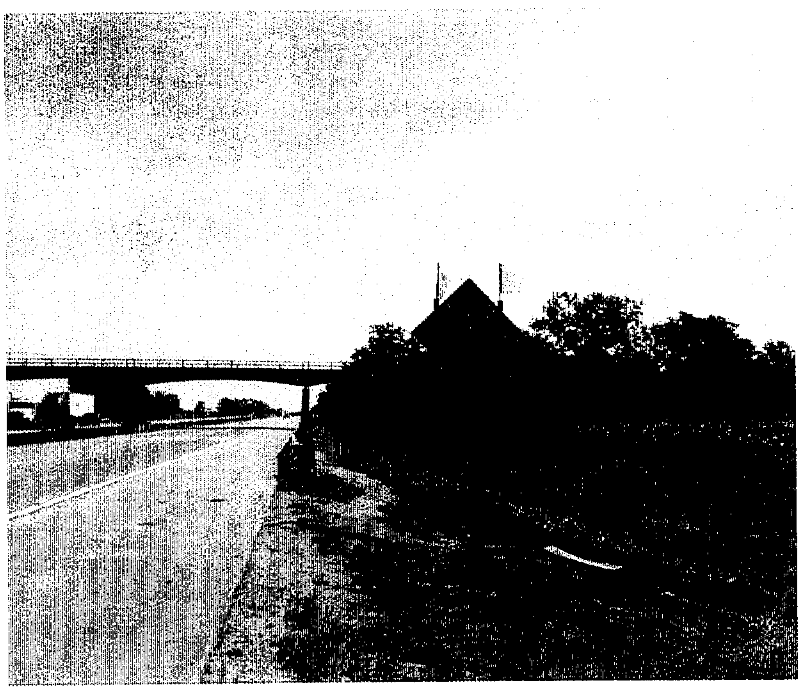
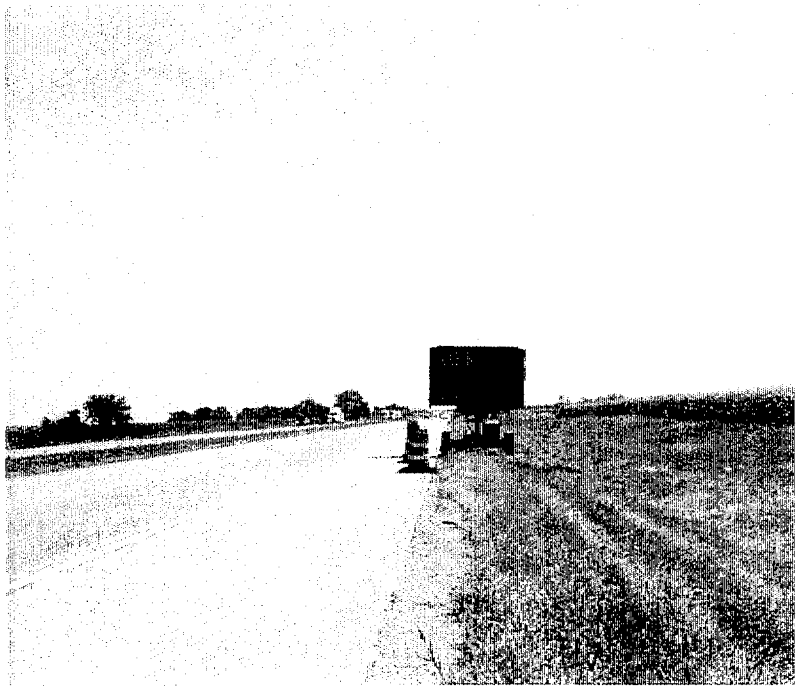


Figure 4: Traffic control devices in the work zone area.



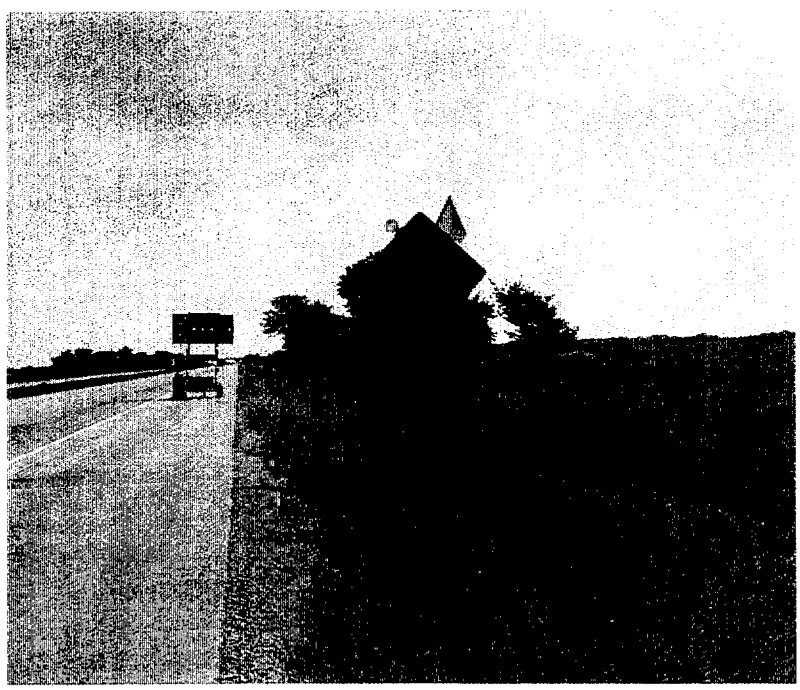


Figure 5: Traffic control devices in the work zone area (continued).

Figure 6: Traffic control devices in the work zone area (continued).

15 Appendix F: State Departments of Transportation Experiences

During the literature search, a number of state departments of transportation were contacted to request their experiences of using CMS systems in highway work zones. Although many of state DOTs routinely make use of PCMS units in construction zones, only few of them have established specific policies and guidelines. In this appendix information collected from selective state DOTs is presented.

15.1 Indiana Department of Transportation

The Indiana Department of Transportation (INDOT) uses the following guidelines for PCMS systems (INDOT, 1998):

Definition: A PCMS used in a construction area is a supplemental traffic control device. Its intended use is to provide nonstandard, appropriate and timely information to the motorist. It is not to be used instead of or in place of, standard traffic control devices.

Placement: A PCMS is normally suggested for placement on the right side of the roadway unless there is a relatively sharp curve to the right and the sign would be more visible if placed in the median. A PCMS should never be dual mounted (i.e. one on each side of the roadway) facing the same direction. Spacing between portable changeable message signs should be 300 meters (1000 feet) or greater and on the same side of the roadway. The bottom of the sign should be 2 meters (7 feet) above the elevation of the edge of the roadway. It is desirable to place the PCMS behind a guard rail or as far from the travel lane as is feasible while providing visibility and conspicuity. The PCMS must be level both vertically and horizontally.

Operation: A normal PCMS in a construction area consists of: 18-inch characters, 8 characters per line and 3 lines per screen. The message is programmed to be displayed over one, two or three sequencing screens. Message content should be limited to two screens, with a maximum of three screens for unusual conditions. The recommended sequence rate for the entire message (one, two or three screens) is such that the motorist can view the message twice upon approach to the sign. The suggested duration for a simple or standard message is two seconds per message screen and three seconds per screen for a complex message. The sequence rate necessary for the motorist to view the message twice is not feasible with a three screen message. Multiple changeable message signs may be needed to convey the full message content to the motorist. Each changeable message sign, however, must contain its own complete message.

Messages should be short and concise. They should answer the questions: when, what and where. Oftentimes one or more of the questions are intuitively understood by the motorist. Special care shall be taken when considering the use of abbreviated words. Abbreviated words used in the message should be limited to common abbreviations understood by the motorist. Abbreviated words should not be used unless their use reduces a multi-screen message by a screen or reduces a single screen message by a line of text.

The message must be accurate and timely. Inaccurate or untimely messages only antagonize the motorist and leads to disregard of other messages or traffic controls that are applicable.

A PCMS should not display generic messages such as DRIVE SAFELY or HAVE A NICE DAY. When a message is no longer applicable the message should be changed to an applicable message or the changeable message sign should be turned off. When no message is displayed at night the PCMS is to be delineated to advise the traveling public of its position.

15.2 Iowa Department of Transportation

The Iowa Department of Transportation (IADOT) uses the following guidelines for portable CMS systems (IADOT, 1994):

- **Project Development Steps:** The Preliminary Traffic Control Committee in the Office of Design will review all head-to-head or other complex projects to determine the need for CMS units. Inventory and allocation of CMS units are handled by the State Traffic Engineer, Office of Maintenance. Reservations to use CMS units on a construction project are made by the Design Section Engineer, Office of Design.

  Once a need has been determined for the use of CMS units on a construction project the Traffic Control Engineer, Office of Design; the Construction Field Engineer - Traffic Control, Office of Construction; and representatives from the appropriate Resident Maintenance Engineer Office, Resident Construction Engineer Office and Transportation Center will determine the number and location of CMS units to be used. This team will also determine the specific congestion relief and warning messages needed for CMS units proposed for the construction project. These project-specific congestion relief and warning messages will be listed in the Traffic Control Plan included in the project plans.

Diversion messages will be determined based on the incident management plan for the section of highway proposed for construction. Incident management plans have been developed according to Maintenance IM 1.255 (Freeway Incident Management). To promote uniform diversion message content statewide, the Resident Maintenance Engineer should provide the State Traffic Engineer a proposed list of messages to be used on CMS units reserved for the construction project in their area. This message list will then be reviewed and an approved list of messages will be provided to the Resident Maintenance Engineer.

Other specific traffic control plan such as design detail sheets or standard road plans may also include messages to be used for a CMS unit. An example of this is Design Detail Sheet 521-15A. When a project plan includes a Design Detail Sheet requiring a CMS unit the messages displayed should be as shown on the Design Detail Sheet. After a project is under construction and a need for additional motorist warning is determined, it may be necessary to add additional CMS units to the project Traffic Control Plan. Use of additional CMS units should be confirmed by the State Traffic Engineer so that availability of a CMS unit can be assured. Appropriate message content for these additional units should be approved by the State Traffic Engineer.

- **CMS Placement:** CMS units used for construction projects will have specific placement locations listed in the Traffic Control Plan included in the project plans. These locations may be changed slightly in the field, within 150 meters (500 feet), if necessary.

  Typically, four CMS units are used for a rural head-to-head construction project. Two CMS units are located for each direction of traffic for the construction project. The two units closer to the project are used to display congestion relief and warning messages. The two units furthest from the project area are used to display Diversion messages. These advance CMS units should be placed prior to an interchange preceding the construction project temporary traffic control zone to aid in traffic diversions.

  Urban or fringe area head-to-head projects will generally require the use of more CMS units due to the increased number of alternate routes and interchanges close to the project limits.

  CMS units are placed in advance of project related traffic control signing and should not replace any other signing required by the contract documents. A CMS used in conjunction with any temporary traffic control zone should be visible for at least 800 meters (1/2 mile) under both daytime and nighttime conditions. Messages should be legible for a minimum of 200 meters (650 feet).

  CMS units should be located off of the outside shoulder and should be installed level so that displayed messages can be easily read. Leveling jacks are available at all four corners of the CMS trailer to level the CMS unit. The bottom of the CMS message panel shall be a minimum of 2 meters (7 feet) above the surface of the roadway when it is in operation. The CMS unit should be turned approximately three degrees from perpendicular to the edge of pavement. This angle reduces glare from reflected sunlight, vehicle headlights or the internal sign illumination itself.

A CMS should be placed by itself off the outside shoulder of the highway. CMS units should never be located in pairs, on either side of the highway, since the oncoming motorist will be unsure what unit to read and may then miss an important message completely. When two separate CMS units are needed for a particular situation they should be placed on the same side of the roadway at least 300 meters (1,000 feet) apart so that one message can be understood before the next message is observed.

- **Message Design:** The primary purpose of using CMS units in temporary traffic control zones is to advise the motorists of unexpected traffic and routing situations. The following information is included as a guide to promote statewide uniformity of message content for CMS units.

  Department-owned CMS units are capable of a panel display consisting of three lines of eight characters each. It is desirable that messages used on CMS units are readily understood by motorists and allow adequate time to react. Messages should be designed taking into account the following factors:

  - no more than two panels should be used for any message cycle
  - each panel should convey a single thought
  - messages should be as brief as possible
  - abbreviations should be easily understood
  - the entire message cycle should be readable at least twice by motorists traveling at operating speeds
  - messages shall not scroll horizontally or vertically across the face of the sign.

  The entire CMS unit message should be legible at least twice at the prevailing operating speed. For example, a driver traveling at 90 kph (55 mph) has only about eight seconds to read a given message. This requires a message to be no longer than two panels when the prevailing speed is 90 kph (55 mph).

  On high speed roadways standard messages should be given two seconds per message panel and complex messages should be given three seconds per message panel.

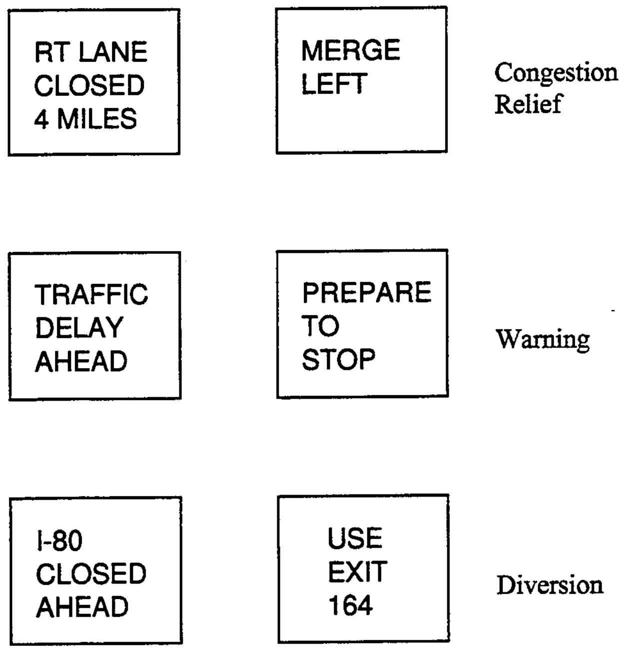


Figure 7: Typical CMS messages for congestion relief, warning or diversion during construction projects.

- **Typical CMS Messages:** Typical messages for construction project use are divided into three categories:

  1. congestion relief
  2. warning
  3. diversion.

  Sample messages are shown in Figure 7. The top message in Figure 7 helps alleviate congestion occurring at the lane merge location by giving advance notice to the motorist that a lane is closed ahead, encouraging motorists to merge into the appropriate lane well in advance of the actual merge area.

  When traffic starts to back-up, due to traffic loadings exceeding lane capacity of the single available lane through the traffic control zone, the middle message in Figure 7 warns approaching motorists that congestion at the lane merge is starting to cause backups. Motorists are advised by this message to watch for stopped vehicles on the highway ahead.

  When capacity problems start to occur on the mainline it is recommended that interchange on-ramps located within a head-to-head project be temporarily closed. Closure of on-ramps will eliminate a potential motorist conflict area while also relieving added traffic congestion. It is recommended that on-ramps be closed only when traffic congestion problems occur. After the congestion is relieved the on-ramps should be reopened.

When capacity of the open lane in the traffic control zone has reached its maximum and the backed-up queue extends beyond the ROAD CONSTRUCTION AHEAD advance warning signs, a diversion is necessary. The bottom message in Figure 7 relays to approaching motorists information that the highway is closed ahead and an alternate incident management route is to be used. The Iowa State Patrol is involved in relieving traffic congestion during diversions. The Iowa State Patrol may have closed the highway and are forcing all motorists to exit and follow the previously trailblazed route around the construction project.

- **Project Level CMS Operation:** Project inspection staff or contractor's surveillance staff should be used to activate the CMS units for congestion relief and warning messages. Contractor surveillance staff may be allowed to activate a CMS unit after approval of the Resident Construction Engineer. Only maintenance staff should activate diversion messages since diverting highway traffic includes local maintenance personnel helping direct traffic in conjunction with the Iowa State Patrol. Local maintenance personnel may be needed to quickly erect additional diversionary or trailblazing signs to smoothly redirect the diverted traffic.

  Any project that is utilizing CMS units to display congestion relief, warning or diversion messages must have close communication between construction and maintenance personnel. It is especially important for the Highway Maintenance Supervisor to be involved with all communications relating to project traffic control and incident handling.

  The incident management diversion route map and a list of pre-approved messages should be kept in a weatherproof folder secured inside the CMS unit. This folder should also include a brief step-by-step set of instructions detailing the remote start-up operation requirements of the CMS unit. Copies of the incident management diversion route and pre-approved messages should also be filed with the Project Inspector, Highway Maintenance Supervisor, local maintenance garage, Resident Construction Engineer Office and Resident Maintenance Engineer Office.

- **CMS Applications:** The primary purpose of CMS units in temporary traffic control zones is to advise the motorist of unexpected traffic delays or diversions ahead. Repeat motorists (i.e., familiar drivers) become accustomed to a static message after a period of time and will ignore the stale message. When a static message is later changed to describe a newer condition on the construction project, these repeat motorists may not read the new message. Prolonged operation of a CMS displaying a static message will reduce its effectiveness.

CMS units should not be used where a standard black-on-orange road work sign could be used. Incorrect use of CMS units include advertising special events, regulatory speed limits, replacing an advance arrow panel or happy messages such as HAVE A GOOD DAY or DRIVE SAFELY.

CMS units should only be operated when a message is needed for information purposes. Routine long-time operation of a CMS unit with a static message shown will impair the overall operation of CMS units since a static message can be effectively displayed on a permanent post mounted sign. A CMS unit is intended to be used to display messages that are timely and responsive to actual field conditions occurring at the time of the display.

When traffic problems have advanced beyond the need to display a congestion relief message it is imperative to immediately change the displayed message to a warning message. Also, when traffic congestion problems require a diversion the diversion message should be shown as soon as forces are available to activate the traffic diversion onto the preplanned incident management route. Around-the-clock display of a static message defeats the purpose of flexible message displays from a CMS unit.

- **CMS Repair, Maintenance and Utility Costs:** Repair parts and labor costs for CMS units used on construction projects are eligible for project funds. Fuel and oil costs can also be charged against project funds. Appropriate utility costs, such as telephone land lines or cellular telephone charges, are also eligible project costs. An external voucher charged against project funds can be used for repair costs. Technical support for CMS units is available through the repair shop in Ames.

15.3 Michigan Department of Transportation

The Michigan Department of Transportation (MDOT) uses the following guidelines for PCMS systems (MDOT, 1998):

- **Advance Time Notification:** Advance time notification should be displayed in the following cases.
  - **Ramp Closures.** The message should be displayed three to seven days prior to the closure. For weekend closures on freeways with high seasonal/tourist travel,

the message should be displayed longer, up to ten days, including two Thursdays prior to closures.

- **Lane Closures**. See Ramp Closures above.
- **Freeway Closures.** The advance notice message notes the temporary closure (short duration) of freeways for planned work such as bridge beam installations.
- **Planned Maintenance Work.** The message should be displayed a maximum of one week prior to planned work.

The message during the closure/work will differ from those displayed prior to the event.

- **Information During Existing Events:** Information during existing events should adhere to the following guidelines.
  - **Detour or Alternate Routes.** The message should recommend detours or alternate routes during ramp, lane, or freeway closures.
  - **Special Event Traffic Conditions.** Sporting or charity events which generate unusual vehicle and/or traffic patterns are examples for PCMS use.
  - **Incident Management.** Freeway closures due to crashes and/or incidents which can not be dealt with static signing alone.
  - **Notice of Operations — Obstructed View.** Within unusual roadway geometrics a PCMS may be used as an advanced warning device in conjunction with static signing for fixed or moving operations. Unusual geometrics, such as curves or hills, provide an obstructed view to motorists coming upon the operation and the PCMS may give additional attention.
  - **Construction Zone Traffic Backups.** This involves monitoring congestion and backups (real time). This is potentially an ideal use for PCMS systems, but requires constant updating and extensive resources. The traffic backup must be monitored every 15 to 30 minutes depending on the situation. The PCMS messages on delay times must be accurate.
- **Prohibited PCMS Use:** PCMS use should be prohibited in the following cases.
  - Lighted arrow replacement: The lighted arrow board is more visible, recognizable and understood than a PCMS.
  - Advance notice of new traffic signal or sign.
  - Advertising of any kind.

- Replacement of Michigan Manual of Uniform Traffic Control Devices requiring static signing or pavement markings.

- **Message Guidelines:** Drivers must be able to see, read and comprehend the message on the CMS. The basic principles to ensuring the proper operation (read) and providing the proper messages (comprehend) are message objective, message timing and the message itself.

  - **Message Objective.** PCMS users should clearly establish the message objective by considering questions, such as: What happened? Where? What is the effect? Who is affected? What is advised? The message should be designed to use the most important information and be condensed, as much as possible, to meet the requirements of message timing.
  - **Message Timing.** Sequencing messages is typically used when situations dictate the need for more messages that can be displayed at one time on a PCMS. The cycle time and duration of the message used is related to the operating speed of the highway. All message sequences shall consist of a maximum of two messages and a maximum of two-second display time for each message. If additional sequences are needed a second PCMS shall be placed on the same side of the roadway, separated by at least 300 meters.
  - **Message.** When operating a PCMS it is essential to use messages that are readily understood by drivers. It is important to properly describe the road work or incident location. The PCMS shall provide a 460 mm character height with a maximum eight characters per line and three lines per message. While commuters are familiar with street names, tourists may not be able to identify the route name. When providing dates avoid using numbers for words whenever possible. For example, use the format JUL 24 instead of 7/24/94.
  - **Default Messages (Power Lost).** All message boards allow for default messages to be displayed when power is lost to the PCMS. The default message shall be DRIVE SAFELY.
  - **PCMS Is Not in Use.** When a PCMS is not in use it shall be turned off.

- **Abbreviations:** Because of limitations to PCMS size or the message length, it is sometimes necessary to abbreviate words. The use of abbreviations should be kept to a minimum. Tables of message abbreviations in different cases are presented in Appendix A.

15.4 Minnesota Department of Transportation

The Minnesota Department of Transportation (MNDOT) uses the following guidelines for PCMS systems (MNDOT, 1998):

- **Usage:** A portable CMS (PCMS)
  - should be used in conjunction with conventional signs, pavement markings and lighting
  - shall not replace any required signing
  - used on freeways shall be capable of presenting three lines of message copy
  - should not be used for advertising, to replace an arrowboard, or for regulatory messages.
- **Placement** Placement of PCMS units should adhere to the following.
  - The bottom of the message sign panel shall be a minimum of 7 feet above the roadway when it is in the operating mode.
  - PCMS units are typically placed on the shoulder of the roadway. However, if practical, placement further from the traveled lane is desirable.
  - PCMS units should be placed only on one side of the road, either right or left. When two PCMS units are needed they should be placed on the same side of the roadway and should be separated by at least 1,000 feet.
  - The sign shall be placed to be visible from 1/2 mile.
  - The message shall become legible for a minimum of 750 feet for traffic on all lanes of the roadway. The message shall remain legible for at least 650 feet from the nearest travel lane (up to 100 feet from the message panel).
- **Operation:** PCMS units should be operated so that
  - PCMS has reliable up-to-date information
  - delay messages accurately reflect traffic delay time
  - no more than two displays are used with any message cycle
  - the entire message is readable twice at the posted speed prior to working starting
  - the work or incident location is accurately described
  - abbreviations are easily understood, or words are spelled out

- each message contains a single thought
- messages do not scroll horizontally or vertically across the face of the sign.

- **Standard Abbreviations for Use on PCMS Systems:** Standard abbreviations easily understood are presented in Appendix A. Other abbreviations are easily understood whenever they appear in conjunction with a particular word commonly associated with it. These words and abbreviations are also presented in Appendix A. Moreover, there are abbreviations (see also Appendix A) that should not be used because they represent several words that could be abbreviated in the same manner.

As part of its Intelligent Transportation System (ITS), MNDOT applied its Portable Traffic Management System (PTMS) (Nookala et al., 1996) to a work zone environment. The intent of this experiment was to provide real-time information to motorists about the traffic conditions as they approached and passed through the work zone, improve safety for motorists and construction personnel, and minimize the work zone related delays experienced by motorists. Off-the-shelf full-size CMS units (permanently installed or trailer-mounted) or custom-made one-foot by one-foot LED units that can be attached together to form a CMS were used as part of the Driver Information Subsystem of the PTMS. The evaluation of the PMTS in a work zone environment was conducted in four phases (SRF Consulting Group, 1997):

1. **Phase One:** Focused on the effect of PTMS on traffic operations within a work zone by analyzing the change in the relative uniformity of the speeds, change in travel time, change in number and severity of accidents and change in traffic volumes to assess the effect of the PTMS on traffic volume passing through the work zone. The results of this test showed:
   - a significant increase in traffic volume through the work zone when PTMS was in operation, attributed to driver confidence in PTMS
   - 70% decrease in the variability in speed for traffic traveling through the work zone
   - 9 mph decrease in the average speed for traffic approaching the work zone.
2. **Phase Two:** Focused on the overall operational aspects of the PTMS within the work zones, particularly the portability of the system, the level of effort needed to install and operate the PTMS traffic control center and the system reliability after the initial development and debugging. The results of this test were the following:
   - the PTMS can be deployed easily given the complexity of the equipment

- the overall system operation was deemed successful in work zones with special traffic needs.

3. **Phase Three:** Evaluated the user reaction to the PTMS work zone, particularly the reaction of the motorists, system operators, construction personnel, transit operations personnel and a focus group of persons who traveled though the work zone. The following summarizes the results of this test:

   - 66% of those surveyed remembered seeing the lighted PTMS CMS messages.
   - most of the previous group remembered specific messages and felt more informed about traffic conditions
   - a high percentage of the messages remembered was considered easy to read, easy to understand and usefully and correctly reflected traffic conditions
   - system operators indicated that the PTMS could be mastered in two to three hours and that it was easy to operate and reliable
   - the PTMS provided real-time traffic information that was easy to read.

4. **Phase Four:** Evaluated the cost of deploying the PTMS in work zones. This includes the cost of the system and the cost to locate the system in the field and set it up.

15.5 New York State Department of Transportation

The New York State Department of Transportation (NYSDOT) guidelines are (see for a full description (NYSDOT, 1996):

- **CMS Policy Statement:** CMS systems are traffic control devices and must be placed and used with the same care as traffic signs, speed limit signs or stop signs. CMS units should be placed and used primarily to convey information which:
  - is critical in nature
  - requires motorists to alter their driving in some manner and take specific action as a result
  - will enable motorists to safely and conveniently reach their destinations on current or future trips
  - will assist in the protection of personnel in construction and maintenance work zones or inspection sites.

Each region should establish a committee to ensure that CMS systems are used in such a manner as to accomplish this policy.

- **Default:** The messages displayed on a CMS screen are generated by and stored on a computer. A collision, power failure or other malfunction can cause an erased or garbled message.

  As a safeguard, CMS systems include a feature allowing the operator to input a default message that warns operators and law enforcement personnel that the machine is malfunctioning — much like the time display on a VCR that flashes after there has been a power interruption.

  To take advantage of this feature, the committee must select a standard default message to be used by both the department and contractors employed by the department that is descriptive enough for the operator but which does not alarm or confuse motorists and cause them to drive dangerously or irresponsibly. This standard default message should be programmed into the machine to prevent unauthorized or unacceptable messages (which are often used at the factory or at construction staging yards to test the devices) from being displayed.

- **Regulation of the Private Use of CMS Systems:** Concerns have been expressed about the private use of CMS systems that may conflict with the use of CMS systems for the benefit of the public. This concern comes from the experiences encountered when the department started using flashing arrowboards in its maintenance and construction operations about the same time as flashing arrows became economical for commercial establishments to use to attract customers. As technology advances and the cost of CMS systems comes down, it is conceivable that these systems could be used for commercial purposes.

  This concern has been noted and the Traffic Engineering and Safety Division will monitor the situation and take appropriate action if it becomes necessary, probably under Section 1114 of the Vehicle and Traffic Law.

- **Liability with Regard to the Use of CMS Systems:** CMS systems are traffic control devices and as such are governed by the same considerations as traditional traffic control devices such as signals, signs, pavement markings with regard to liability. Therefore it is essential to carefully consider the implications of the use of a CMS; placement, reliability and the display messages should all be weighed in making a determination on their use.

- **Maintenance and Security Guidelines:** CMS systems should be maintained as recommended by the manufacturer. Routine visual checks can help determine if the sign is operating properly and some system-driven signs can be internally checked. In any case, manufacturer's maintenance schedules and operating procedures should be closely followed, especially for units under warranty.

Currently, PCMS units are either solar or diesel powered. Diesel powered units require daily maintenance (e.g., refueling and checking engine lubrication system). Solar powered units should be checked weekly, even if they have been exposed to regular sunshine, to make sure that the batteries are being charged properly.

As a security measure, if a PCMS is to be stationed in one location for any length of time (even overnight, in some areas), it should be secured to an immovable fixed object. The wheels on portable units can be removed to discourage theft.

- **Siting Considerations:** Siting/location is another important element in the deployment of CMS units. The devices should be far enough upstream from a diversion point so motorists can take necessary action relative to an incident or congestion and yet not be located so far in advance that the impact of their message is lost.

  They must be legible that, in some cases, makes their location dependent upon the type of technology each device employs (e.g., character matrix, line matrix, full matrix) and the time of day it will be operational. They must be accessible for maintenance yet placed in a safe position relative to traffic.

  Most of the literature recommends that if a CMS is used to inform of a traffic diversion it should be located at least one mile in advance of the interchange or intersection. On more rural and secondary highways, however, operators should use their judgment and discretion applying appropriate flexibility as conditions demand.

  If multiple CMS units are used in sequence there should be at least 1000 feet between them and they should be located on the same side of the highway so motorists do not have to search to locate them.

  PCMS units should be located along the right side of the roadway if at all possible. They should be placed as level as possible along tangent sections, with an uphill grade preferred over a downhill grade. They should be turned three degrees inward toward the centerline to reduce glare.

  CMS devices require protection such as a guiderail or barriers. If they must be placed in an unprotected area, they should be located outside of the clear recovery area and they still should be legible to traffic. The least desirable unprotected location is on a paved shoulder. If that is the only option the device should be placed as far as possible from the edge of the travel lane and should be clearly delineated by channeling devices such as cones, barricades or barrels in accordance with Traffic Control Plans for shoulder closures.

- **General Operating Considerations for CMS Use:**

  CMS systems should require the motorist to do something in response to a specific message, such as:

  - change travel speed
  - change lanes
  - take a different route
  - be aware of a change in current or future traffic conditions.

  In addition:

  - CMS units should supplement, rather than replace, static signs that are required by the MUTCD, law or regulation, particularly in work zones.
  - CMS units should not tell motorists something that they already know.
  - CMS messages should be as clear and concise as possible. Refer to the Standard Approved Message and Standard Approved Abbreviations Appendices for uniform messages that can be used without obtaining further approval. Messages that deviate substantially from those in the directory should be reviewed by a committee prior to deployment.
  - Messages should generally be composed using all upper case letters. Mixtures of upper and lower case letters have less legibility.
  - PCMS units are usually limited to a maximum of 8 characters per line with 3 lines per screen. Permanent CMS units can accommodate between 18 and 24 characters per line and 3 lines per screen.
  - CMS units should not display unnecessary information. Messages that simply say PLEASE BE CAREFUL, DRIVE SAFELY do not tell motorists specifically what they need to do and should therefore be avoided unless used as the standard default message as determined by a committee.
  - CMS messages should not display information which is so specific that it may give motorists a false sense of security. Weather-related conditions are probably the best example of this. SNOW AND ICE CONDITIONS AHEAD is a better message to display than ICING AT EXIT 5. A general message allows for a variety of conditions to exist which require driver caution over a non-specific area. A specific message, while it may be accurate, probably would not account for all of the area covered by the condition; for example, someone might assume that icing was only occurring at Exit 5 while it may also be present at Exit 4.

- **CMS Systems and Speed Detection Radar:**

  There are differing points of view in the traffic engineering community regarding the use of CMS units equipped with speed detection radar that tells drivers how fast they are traveling. Some experience indicates that some motorists will speed up just to see how high a speed they can register. There is also some evidence that CMS/radar units quickly lose their effectiveness. However, there are circumstances where this temporary use may be desirable, such as in situations where a new speed limit is established or approaching or within a work zone, where radar-equipped CMS units may be a useful tool in educating motorists to a changed condition. Therefore, such use should be carefully considered and closely coordinated with local officials and law enforcement agencies to maximize the impact of such an application. It is also suggested that such a deployment be short term in nature.

- **CMS Systems and Special Events:**

  When CMS systems are used in conjunction with a special event, mass gathering, emergency/major traffic incident or complex construction project, the committee should critique their effectiveness afterwards to see if the CMS was deployed properly, if it functioned as designed or if the messages were clear and understandable. Notes on lessons learned should be shared with other CMS operators by way of distribution through a system yet to be established for disseminating operations-related information.

  In general, the CMS operator should exercise his or her good judgment as to the use of a CMS in terms of siting it and composing appropriate messages. Final authority for their use should rest with the committee.

- **CMS Operations Guidelines:** The following guidelines pertain to CMS operations:

  1. CMS units should be visible from 1/2 mile under ideal day and nighttime conditions.
  2. Ideally, "upstream" sight distance to the CMS should be between 650 and 1000 feet.
  3. Messages should be legible from all of the lanes of traffic that the CMS faces for at least 650 feet[8] in advance of the sign (the legibility zone).

[8] 650 feet is the minimum legibility distance described in the Federal MUTCD Varying distances, up to 1200 feet, are currently recommended in the department's MUTCD. For all practical purposes, operators should use the 650 foot distance as the general minimum standard, given the somewhat limited legibility capabilities of CMS equipment presently available on the market.

4. The sign should automatically reduce its light output under low ambient lighting conditions in order to meet the legibility requirements and not impair drivers' vision.
5. If two or more CMS units are used for the same traffic stream they should be separated by at least 1000 feet and located on the same side of the roadway.
6. CMS units should be located and messages should be composed so that the motorist can view the entire message twice while driving within the legibility zone at normal operating speeds.
7. To give motorists time to read, digest and react to the CMS message it is recommended that only one screen (three lines) be used if at all possible and that every effort be made to limit longer messages to a maximum of two screens.
8. For a two screen message, the display time allowed for each two screen message should be two seconds. Longer times (up to a maximum of three seconds) can be used if a drive-by review indicates that additional time is necessary for motorists to understand the message.
9. With a two screen message a motorist might view the message out of sequence (i.e. read the second screen first). Messages should be composed so that an out-of-sequence message will not confuse the motorist.
10. As soon as possible after a message is activated, a reliable source should confirm that the proper message is in fact being displayed.
11. To maintain the message's credibility, the CMS message must be accurate and up-to-date. As soon as conditions change the message should be removed or changed. In general, messages should not reference the length of time or how long an incident, congestion or delays might last.
12. If a CMS is deployed for incident response in an area where Highway Advisory Radio (HAR) is available, the CMS should be programmed to refer motorists to HAR for further information related to the incident to supplement static HAR signs. Without that prompt motorists may not receive important information regarding alternate routes available to avoid whatever caused the incident.
13. When a CMS will remain at a location for any significant duration without being operated it should be turned off, the sign panel should remain blank or in the case of a portable sign, the sign panel should be turned so that it is parallel to the roadway.
14. In general, the CMS units operator should exercise his or her good judgment as to the use of a CMS in terms of siting the unit and composing appropriate messages. Final authority for their use rests with the committee.

NYSDOT has also developed a template approach to compose messages (Section 3.10.2).

15.6 North Carolina Department of Transportation

In July, 1995, a formal policy was adopted by the North Carolina Department of Transportation (NCDOT) outlining the use of permanent and portable CMS systems. In this section, the main points of this policy are documented. A more complete description is given in (NCDOT, 1996).

- **Policy Statement:** This policy provides specific guidelines for the use of stationary and portable CMS systems used on the North Carolina highway system. Messages displayed shall convey pertinent information to motorists that assists in their driving decisions. Messages shall be conveyed in a standard, nonconfusing manner that allows drivers to both perceive and react to the information given in a timely fashion.

- **Purpose:** CMS systems can be used to effectively reduce congestion caused by planned or unplanned incidents such as excessive daily traffic, accidents, detours, construction delays or special events. Once a driver population has gained confidence that messages are reliable and relay pertinent information that assists in reducing delays, CMS units can be used to convey information to alter traffic patterns or modes of transportation.

- **Authorization:** The Division Engineer will authorize the use of all CMS systems both state-owned and contractor-furnished. Each CMS shall have a person designated by the Division Engineer to be responsible for the authorization of messages to be displayed and for the care, maintenance and security of the CMS. This person may delegate certain responsibilities in regard to the CMS but should ensure that any personnel given access to the CMS understands and adheres to this policy. Access to the CMS shall only be given to responsible individuals. The Division Engineer will ensure that efforts are coordinated such that motorists are informed of the most critical information based on the priority of messages listed below.

- **Display of Messages on Portable CMS Systems:** Messages shall be displayed on portable CMS units in accordance with the below listed priorities. When the portable CMS is not being used to display one of the below listed message types, it shall remain blank.

  Types of messages conveyed on portable CMS units have the following priority:

1. Emergencies such as evacuations or closures required by the NCDOT, the Department of Emergency Management, local law enforcement or the military. Examples include:
   - the Department of Emergency Management conducting a hurricane, nuclear or hazardous material evacuation
   - the military requiring road closure for major troop/equipment transport
   - closure of facility due to accident involving damaged structure or toxic spill.

   In the event of such an emergency another agency would most likely be in command of the situation and may direct specific use of CMS systems. In all likelihood this agency would rely on NCDOT for locating and programming signs and developing the exact wording of messages.

2. Hazardous and/or uncommon road conditions that require motorists to alter their driving such as severe weather conditions, accidents or work zone activities. The majority of information relevant to motorists would fall into this category; therefore it is extremely important for all parties to cooperate and ensure that motorists are receiving the most important information at any particular time. Examples include:
   - extreme weather such as ice, snow, fog, flooding or rockslide
   - unusual roadway conditions for the roadway type such as lane shifts, rough pavement or narrow lanes on a freeway due to construction or maintenance
   - lane/shoulder closures or blockages
   - accident and/or emergency vehicles in a lane or on the shoulder
   - workers or construction equipment in close proximity to an open travelway
   - severe congestion causing reduced speeds.

3. Short term detours (mandatory) for a partial audience for which no other signing is in place. If detours are planned to be in place for more than a week plans should be made to use conventional detour signing. Any message displayed on a CMS will loose its effectiveness if it is not changed frequently. If the detour was not planned, the CMS should be used as an alternate to conventional signing; however, if the detour is expected to remain in place for more than a month conventional signs should be ordered as soon as possible. Examples include:
   - detour for specific audience such as over-width vehicles that cannot traverse a construction zone with barriers
   - overnight ramp closure for which no detour is given
   - temporary weight restriction due to maintenance of structure.

4. Traveler information and suggested alternate routes for delays and/or congestion caused by planned or unplanned incidents. By giving the motorists as much information as possible about real-time traffic conditions, it is assumed that individual motorists will make intelligent decisions as to how to avoid congestion and delays. In order for motorists to react to this type of information they must trust that it is accurate. Examples include:
   - expected delay; allow motorists to determine their alternate route
   - suggested alternate route(s)
   - combination of the above
   - suggested routes to a large traffic generator
   - alternate modes of transportation available (van-pool, carpool, transit or HOV lanes);
   - preventative actions.
5. Advance notice for scheduled incidents such as lane closures, road closures or special events. If a planned event/ incident is expected to occur motorists should be warned ahead of time to avoid that area during the event. Examples include:
   - large, traffic-generating sports event
   - scheduled lane closure with a heavy traffic impact
6. Other public information which assists the department in improving highway safety and reducing congestion may be displayed after careful consideration. However, the message must require motorists to alter their driving and direct approval by the Division Engineer must be received prior to displaying the message. Example:
   - license, DUI, seat-belt or weight check by law enforcement officials.

CMS units shall not display messages that in any way advertise commercial events or entities. CMS units shall only display messages that pertain to highway safety or congestion reduction. CMS units should not be used to convey a message for an extended period of time that could be conveyed with a conventional warning sign.

- **Applications of Portable CMS Systems:** The primary purpose of CMS systems is to advise the driver of unexpected traffic and routing situations. Their most frequent use is on high-density roadways but they have applications on all types of streets and highways. Examples of effective CMS uses include providing notice of:
  - accident and incident management
  - ramp, lane or roadway closures

- significant expected traffic delays
- expected decrease of traffic speed
- new detours
- changes to detours
- adverse environmental conditions
- advance notice of construction activity
- changes in alignment or surface conditions.

- **Message Priority:** Relaying multiple messages and special highway safety messages should be done as follows:

  1. **Multiple Messages.** It may be necessary to relay multiple pieces of information to motorists. This can be accomplished with some creative message design. For instance, if a segment of I-95 is closed due to an overhead bridge which has partially collapsed, it will definitely qualify as a priority 1 message situation. If, at the same time, the truck that hit the bridge is on fire and billowing smoke onto the alternate route, US 301, it will qualify as a priority 2 message situation.
  2. **Special Highway Safety Messages.** PCMS units may be used to display messages "which assist the department in improving highway safety and reducing congestion." Examples of this type of message include advance notification of checkpoints since the slowed traffic is an abnormal traffic condition or work zone awareness campaign messages.

- **Message Override Based on Priority:** Numerous persons may have access to a CMS and authority to place messages on the CMS. These agencies and individuals include Division Incident Management personnel, Division Construction staff, Maintenance staff, contractors, city Traffic Engineering staff and possibly law enforcement or Emergency Management staff. Any individual and/or agency with these privileges shall be aware of and adhere to the policy. Most divisions have procedures (written or unwritten) for placement of messages on CMS units by any person other than the one individual delegated the responsibility for the sign from the Division Engineer. If one individual or agency wants to replace an existing message being displayed on a CMS with another it shall only be replaced with a message of higher priority. For example, the message I-85 CLOSED that is most likely a priority 1 emergency message, would never be replaced with WORK ZONE STAY ALERT that is a priority 6 public information message. The standard procedure in most areas of the state is that persons wanting to display a message should verbally inform the one person responsible for that CMS. That individual physically enters or changes the message, if appropriate or verbally authorizes the requesting individual to reprogram the CMS.

Common sense and courtesy dictate that if an individual or agency replaces an existing message on a CMS:

- the message shall be the most pertinent information to the majority of motorist (highest priority as mandated by the policy)
- the person responsible for the sign shall be informed as soon as possible (in many areas the division policy states the one individual to be informed prior to placement).

- **Message Types to Avoid:** Message types that should not be displayed include:

  1. CMS units shall not display messages that in any way advertise commercial events or entities.
  2. CMS systems should not be used to convey a message for an extended period of time that could be conveyed with a conventional warning or guide sign. A classic example of this is ROAD/WORK/AHEAD. Stock piles of standard signs are maintained by division forces or can be fabricated and should be used in situations which necessitate the conveyance of a standard message for an extended period of time.

- **Sign Placement and Installation:** The following pertain to sign placement and installation:

  1. **Sight Distance.** The signs should be visible from 1/2 mile under ideal day and night conditions. Each sign message should be legible from all lanes at a distance of 1000 feet according to the NCDOT Standard Specifications, although research indicates that many drivers cannot read a sign at a distance greater than 650 feet. In the field the CMS should be sited and aligned to optimize visibility.
  2. **Horizontal and Vertical Alignment.** The CMS should not be placed in sags or just beyond crests. The CMS should be level and angled approximately three degrees away from perpendicular to the travelway to minimize glare. The signs, if facing either the east or west, should be checked at sunrise and sunset to ensure that their reflection of the sun does not blind motorists.
  3. **Delineation and Positive Protection.** Where possible the CMS should be placed behind existing rigid or semi-rigid protection (barrier or guardrail). This will help to avoid potential injury to errant motorists, while simultaneously aiding in the protection of the equipment. When CMS systems are required for long

terms in locations where no protection exists temporary guardrail or barrier should be considered.

Where positive protection is not feasible CMS units should be delineated with drums. If a CMS is placed on a 10-foot shoulder a shoulder closure should be installed. If a CMS is placed adjacent to a 4-foot shoulder it should be delineated with a minimum of three drums. If possible, CMS units should not be placed closer than 6 feet or farther than 20 feet from the edge of the travelway. A sign placed closer than 6 feet from the edge of the travelway becomes an obstruction that causes a reduction in tra ffic flow. A sign placed farther than 20 feet from the edge of the travelway becomes unreadable for many motorists.

4. **Placement.** Placement in advance of the temporary traffic control zone or incident should, as much as possible, take into account the following factors:
   - CMS units will typically be placed in advance of any other temporary traffic signing and should not replace or duplicate any required warning or guide signing.
   - Where used for route diversion, CMS units should be placed far enough in advance of the intersection or interchange to allow traffic ample opportunity to exit the affected highway. CMS units should not be placed within an interchange since motorists' attention is on weaving traffic.
   - Visual clutter should be avoided when placing CMS systems.
   - CMS units should be placed in advance of predicted queues (backups).
   - CMS units should be placed in locations accessible by maintenance vehicles.
   - CMS units are normally placed on the right shoulder of the roadway.
   - When two signs are needed to communicate multiple messages they should be placed on the same side of the roadway, separated by at least 1,000 feet.
   - The sign should be turned three degrees away from perpendicular to the travelway to reduce glare.
   - The sign shall be installed such that it has a 7 feet minimum vertical clearance to reduce glare, enhance sight distance and increase visibility.
   - The sign should be leveled with the use of the leveling jacks which support most of the weight of the sign. When leveling a sign on wet or soggy ground, use $2'' \times 2' \times 2'$ blocks to balance the sign.

- **Message Development:** When designing a message sequence enough information needs to be given to the motorists to spur them to make a decision. If this is not done the message may be ignored. The message can be broken down into the 5 Ws (what, where, when, who and why). All of these components are not necessarily needed for every message. They may often be implied.

1. **What? (and How?)** What action is required by the motorist? This is the instruction you want motorists to follow. Examples include instructions to reduce speed, divert to a specific route or begin to merge. The motorists will tend to ignore a simple WHAT statement unless they are also given a HOW. Motorists need to have as much information as possible so they can make an informed decision. The WHAT component of a message may be implied. The WHAT component is the most important piece of information given which will affect drivers' decisions. Both components must be clear, comprehensible and recognizable. WHATs include MERGE RIGHT, MERGE LEFT, KEEP RIGHT, KEEP LEFT, PREPARE TO STOP, REDUCE SPEED, DO NOT PASS, STAY IN LANE, SLOW TO xxMPH, STAY IN VEHICLE, TUNE RADIO 530 AM, EXIT 1 MILE, FOLLOW DETOUR, FOLLOW ALT ROUTE,

2. **Where?** Where is the decision point at which motorists must take an action?
   - When giving a location only, use major points of reference such as exit numbers. Do not use overpass or underpass names.
   - When the majority of motorists are interstate travelers who are not familiar with the names of local cross-street locations should be described in distances to the nearest 1/2 mile.
   - If the majority of motorists are local, use the local street names. Most urban drivers are more familiar with street names than route numbers or SR numbers.
   - AHEAD is not a WHERE; it's a filler word. When giving notice of an incident, lane closure or heavy congestion, give an actual distance instead of using the word AHEAD. This will give the driver a point of reference and the opportunity to divert based on his knowledge of the area. WHERE includes xx MILES AHEAD, AT MOREHEAD ST. NEAR (LANDMARK), EXITS xx TO xx.

3. **When?** When will an event occur for which drivers should change their actions? For future events give specific data for its traffic disruption only if it is certain to occur. An example is a major traffic-generating sports event. Do not make the message specific if real-time information cannot be kept current. This type of message is usually required to be combined with a WHERE. The CMS will lose their credibility if they advertise traffic conditions that never occur. WHEN can be a date, time, holiday or wweekend.

4. **Who?** If only a partial audience is required to take an action, who are they?
   - over-width vehicles
   - motorists with a particular destination, such as in a secondary road or ramp closure detour situation.
   - traffic in route to a specific event.

   WHO includes ALL TRAF, CARS, TRUCKS, BUSES, WIDELOADS, EMER VEH / ONLY, ROUTE NO with a direction, LOCAL/TRAFFIC.

5. **Why?** Additional information given to assist and/or spur motorists' decision making. This is the carrot to entice motorists to make a change to their driving and follow the message instruction. WHY includes LEFT LANE CLOSED, RIGHT LANE CLOSED, RAMP CLOSED, xx MILE BACKUP, xx MIN DELAY, SLOW TRAFFIC, RT SHOULDER CLOSED, CHAINS REQ'D, EXPECT DELAYS.

- **Word Usage:** Avoid filler words such as AHEAD or CAUTION. Both of these words can be implied in most instances. Drivers will realize that if you are giving a warning you are also advising caution. They will also assume that they would only be advised of situations ahead of them. The word TRAFFIC when addressing a specific audience, can usually be deleted as well. Instead of two panels displaying GAME / TRAFFIC /USE / LEFT / LANES, a single panel displaying GAME / LEFT /LANES is sufficient.

  When using more than one panel repeat key words. Do not use both LEFT and RIGHT in same sequence, such as RIGHT LANE CLOSED / MERGE LEFT. Unalert drivers will scramble the message.

  Use standard abbreviations familiar to the driver population. Express lanes, for instance, are unfamiliar to North Carolina motorists, so the message THRU / TRAFFIC / USE EXPRESS / LANE would only confuse the motorists.

- **Legibility:** Most matrix signs are limited in alphabet to upper-case letters. The arrangement of the matrix makes it difficult to form some of the parts of lower case letters. This is especially true for letters with loops, such as "g" or "q". In general, the practice of using upper case letters should be followed. If a word needs to be emphasized it can be flashed or placed in bold print.

- **Flash Rate:** Slowly flashing the problem statement (the WHY or WHAT) should attract attention. Do not flash a large portion of text. Do not flash at a fast interval rate. It will distract the motorist and decrease the message's legibility.

- **Flip Rate and Number of Message Panels:** The 1993 revision to Part VI of the MUTCD (USDOT, 1993) states:

  "Messages should be designed taking into account the following factors:

  1. No more than two displays should be used within a message cycle.
  2. Each display should convey a single thought.
  3. Messages should be as brief as possible.
  4. When abbreviations are used they should be easily understood.
  5. The entire message cycle should be readable at least twice at the posted speed, the off-peak 85th percentile speed prior to work starting or the anticipated operating speed.
  6. Messages shall not scroll horizontally or vertically across the face of the sign.

  If more than one panel is used the message programmer should read the message, using each panel as the first, to ensure that motorists will not misinterpret them.

  The literature states that a word requires one second to read and a simple phrase two seconds. Thus a panel could take from 3 to 6 seconds to read. According to Tables 48 and 49 (which have been computed using the equations in Section 3.8.2) there is not enough time to display three panels. Therefore, only two panels should be used to display messages.

- **Programming Sheet:** A sheet similar to that shown in Figure 8 that is site specific to each area and type of sign, shall be developed because different sign types require different message ratings.

Distance from CMS to edge of road (ft)	Four Lanes at 65 MPH	Three Lanes at 65 MPH	Two Lanes at 65 MPH	Four Lanes at 55 MPH	Three Lanes at 55 MPH	Two Lanes at 55 MPH	Three Lanes at 45 MPH	Two Lanes at 45 MPH
2	3.8	4.6	5.3	4.5	5.4	6.3	6.6	7.7
6	3.6	4.3	5.1	4.3	5.1	6.0	6.3	7.3
10	3.4	4.1	4.8	4.0	4.8	5.7	5.9	7.0
20	2.8	3.5	4.2	3.3	4.1	5.0	5.0	6.1
30	2.1	2.9	3.6	2.5	3.4	4.3	4.2	5.2

Table 48: Reading time (in seconds) of a CMS assuming it first becomes legible at 650 feet.

PROGRAMMING SHEET FOR
PORTABLE CHANGEABLE MESSAGE SIGNS

LOCATION OF BOARD : ______________________________

USED: FROM _ _ _ AT ___ ___AM/PM

TO _ _ _ AT ___ ___AM/PM

MESSAGE PROGRAMMED BY: ______________________________

MESSAGE 1

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

MESSAGE 2

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

MESSAGE 3

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

TIMING

MESSAGE 1 WILL RUN ___ ___ SECONDS

MESSAGE 2 WILL RUN ___ ___ SECONDS

MESSAGE 3 WILL RUN ___ ___ SECONDS

Figure 8: Programming sheet for portable CMS systems.

Distance from CMS to edge of road (ft)	Four Lanes at 65 MPH	Three Lanes at 65 MPH	Two Lanes at 65 MPH	Four Lanes at 55 MPH	Three Lanes at 55 MPH	Two Lanes at 55 MPH	Three Lanes at 45 MPH	Two Lanes at 45 MPH
2	7.6	8.4	9.1	9.0	9.9	10.7	12.1	13.1
6	7.4	8.1	8.8	8.7	9.6	10.5	11.7	12.8
10	7.1	7.9	8.6	8.4	9.3	10.2	11.4	12.4
20	6.5	7.3	8.0	7.7	8.6	9.4	10.5	11.5
30	5.9	6.7	7.4	7.0	7.9	8.7	9.6	10.7

Table 49: Reading time (in seconds) of a CMS assuming it first becomes legible at 1000 feet.

15.7 Oregon Department of Transportation

The Oregon Department of Transportation (ODOT) guidelines are (ODOT, 1996):

- **Conditions Warranting Message Display (Priority):** The purpose of a CMS is to provide information for motorists to make rapid decisions in response to traffic and/or adverse weather conditions. To the degree possible CMS use should enhance ODOT's first priority, that of public safety. CMS messages should normally be displayed only when some response or decision by motorists is required. The following will typically determine the relative priority of displayed messages:

  1. Drawbridge operations, road and/or ramp closures and emergency situations
  2. Incident/accident
  3. Construction/maintenance operations
  4. Adverse weather or environmental conditions events
  5. Traffic operations information associated with special events such as car shows or sports events
  6. Public service announcements (Rev. 11/96)

  Changing needs, with respect to daily and seasonal occurrences. may alter the relative priority for displaying messages.

- **Sign Control and Operation Techniques:** Under Oregon Revised Statute 810.200, uniform standards for traffic control devices, uniform system of marking and signing highways and subdelegation orders from the Oregon Transportation Commission, the

State Traffic Engineer (hereafter called Traffic Engineer) is responsible for exercising authority with respect to the use of traffic control devices. Therefore, the control and operation of signs herein that are traffic control devices, will be under the authority of the Traffic Engineer.

These guidelines allow the Traffic Engineer to make separate agreements for an individual sign or type of sign. Messages displayed shall be subject to the provisions set forth below. Sign control and operation will follow the *Guidelines on the Use and Operation of Changeable Message Signs*, Report No. FHWA/TX-92/1232-9, Chapters 3, 4 and 5 (Dudek, 1992). Additional guidelines for PCMS have been provided by the American Traffic Safety Services Association, Inc. (ATSSA) (ATSSA, 1994).

The operation of portable signs will be according to the manufacturer's instructions with consideration of the following:

1. Portable signs should be placed at a location where they can be observed by the affected traffic. For example, where there is sufficient room, a sign displaying LEFT LANE CLOSED, MERGE RIGHT should be placed on the left side of traffic flow. The same message may be displayed at other locations as deemed necessary.
2. It may be advisable to pre-approve sign messages for possible incident management.
3. PCMS systems used for incident management, maintenance or construction operations shall be operated under the authority of the District Manager, Construction Project Manager or designated representatives of these persons.

- **Determination and Approval of Text:** The following guidelines apply for routine, programmed, non-routine and special messages.
  - Routine and/or programmed messages:
    1. All routine or frequently recurring messages shall be pre-approved by the Traffic Engineer. Approved message lists will be compiled, published and sent to region and district offices for their information.
    2. Message elements, characteristics, length, exposure times, and display format shall follow the *Guidelines on the Selection and Design of Messages for Changeable Message Signs*, Report Number FHWA/TX-92/1232-10 (USDOT, 1992). Attention is directed to the following:
       (a) Eliminate unnecessary words (e.g., a, an, the), use common abbreviations and eliminate the use of the period when the meaning or intent of the message is not sacrificed.

(b) The message length should be limited to eight words of about 4 to 8 characters.

(c) The minimum exposure time should be the greater of one second per word or two seconds per line of information.

(d) On highways where the prevailing speeds are greater than 55 mph (90 kph), messages should not be separated into more than two sequentially displayed phrase panels, each consisting of not more than two lines. (See Guidelines on the Use and Operation of Changeable Message Signs (USDOT, 1992, pp. 48-50)

- Non-routine and special messages: A list of personnel authorized to compose and/or approve non-routine messages will be developed jointly by the Region Manager and the Traffic Engineer for each sign, exclusive of those signs within a construction zone. The list should include personnel who are professional engineers especially qualified in traffic engineering and may include persons outside the agency.

- **Displaying, Altering and Removing Messages:** The following guidelines apply for displaying, altering and removing messages.

  1. Messages displayed should not deliberately cause traffic pattern changes which could adversely impact a facility operated or maintained by another jurisdiction without prior consent of the responsible person of that jurisdiction.
  2. Operators of other permanent CMS locations should be informed before displaying, changing or removing messages from a CMS which may affect such locations. Restoration of earlier messages may be required when a current message display is ended.

- **Determination of Speeds, Distances and Times:** The following guidelines apply for determining speeds, distances and times.

  - Speed:

    1. Numeric speeds as a part of the message(s) should be avoided unless specifically authorized by the Region Traffic Operations Supervisor or the Traffic Engineer. Speeds on a CMS are advisory or warning rather than regulatory.
    2. The use of messages like SLOW or REDUCE SPEED are preferable because they tell an action that the driver should take. A CMS should be used as an advisory or warning sign rather than a regulatory sign.

  - Distance:

1. Decimal fractions should not be used to express distances. Metric distances shall be shown in whole kilometers or if less than one kilometer, in whole meters (rounded to the nearest 10 meters). Distances in english units may incorporate the fractions one-fourth, one-half or three-fourth of a mile. Distances less than one-fourth of a mile shall be shown in feet (rounded to the nearest 100 feet). The use of english units, metric units or both shall be determined by current ODOT guidelines and/or policy.
2. Reference to an exit number or NEXT EXIT, 2nd EXIT etc., may be preferable to actual distances. Local names or landmarks should be avoided as much as possible.

- Time:
  1. Time displayed in CMS text shall relate to the standard 12-hour format using "a.m." and "p.m." designation and express local time.
  2. CMS text should not project road conditions more than 24 hours in advance because of expected extreme weather.
  3. Information on extended road or lane closures for construction or maintenance activities should be displayed prior to, but generally no more than one week in advance of the closure.

- **Restrictions (Rev. 11/96):** PSAs and advertising messages shall not be displayed on a PCMS. Test messages on a PCMS should not be displayed to traffic.

15.8 Virginia Department of Transportation

The Virginia Department of Transportation (VDOT) appears to be the only state DOT in the country that has developed manuals for the effective use of CMS systems. This research effort reported in (Miller et al., 1995a and 1995b) produced two manuals; one for the operation of permanent and another for the operation of portable CMS systems (VDOT, 1995). This last document describes a modular approach to compose PCMS messages and is presented in Appendix B.

15.9 Washington State Department of Transportation

The CMS system is part of the Washington State Department of Transportation (WSDOT) Traffic Management System. Depending on the specific location, CMS systems provide lane control, regulatory information such as variable speed limits and driver information on unusual traffic conditions. However, the system may also be used for other traffic-related purposes on a limited basis.

- **Responsibility for Operation of the CMS System:** The WSDOT regional Traffic Office is responsible for the operation of the CMS system.
- **Coordinating Organization:** The regional Traffic Office will coordinate CMS operations with other agencies and WSDOT organizations.
- **Requests for Messages:** Requests to post a message should follow the guidelines for each type of message listed below. Requests from coordinating organizations for messages in emergency situations should be routed through Region Radio Operations. Requests for messages relating to maintenance or construction activities should be routed through the Construction Traffic Coordination Office (CTCO) in advance of the requested service. Requests for public service announcements (PSAs) should be routed through the Region Traffic Office.

  Information required by the Traffic Office and Radio Operator must include justification for the CMS usage, the CMS location/geographical coverage required for the request, description of the activity, the intended dates and times of activity and a contact person and phone number for message cancellation. The operations staff shall develop the message and display sequencing for consistency.
- **Documentation of CMS Usage:** It is important to document CMS benefits as operational needs increase and resources dwindle. As a minimum, operations staff must maintain a log of CMS usage for traffic restrictions, incidents, construction and maintenance activities and PSAs. Regulatory and lane control signs are operated full time, but documentation of when messages are changed is critical if enforcement is to be supported and for possible tort defense.
- **CMS System Priorities:** The following priorities are discussed:
  1. *Dedicated lane control and regulatory CMS systems:* CMS systems dedicated to these functions, including variable speed limits must be used for that purpose. Some of these signs can simultaneously display messages that will be displayed according to the remaining priorities.
  2. *Safety-related:* WSDOT's first priority is safety. Therefore, aside from dedicated signs, this means that any messages that are directly related to safety are given first priority for display. Notable examples of this type of message are an emergency tunnel or highway closure and flammable restrictions for tunnels.

3. *Roadway closures:* The third CMS system priority is the display of road or ramp closures, regardless of the reason for the closures (e.g., accident, construction). This information is important because closures directly impact the route a driver would take.
4. *Minor traffic impacts:* The fourth priority is information on minor traffic impacts. Minor traffic impacts include construction lane closures, blocking incidents and delay information.
5. *Public service announcements:* The last priority for the CMS system are PSAs. These messages do not directly impact drivers and therefore are not critical to the efficient operation of the transportation system.
6. *Test Messages:* Test messages may be used check sign operation for maintenance and prior to new signs being placed into service.

- **Procedure for Changing these Guidelines:** These guidelines have been and will continue to be, developed over time. Factors such as changing areas of responsibility, new CMS technologies and changing personnel and philosophies will necessitate the revision of these guidelines. Any revisions should be well thought out and discussed with all involved parties, including coordinating organizations and adjacent regions or states that need to maintain compatible CMS operations, prior to implementation. Fundamental changes should be coordinated with the WSDOT Traffic Office. Prior to implementation all parties involved with operation of the CMS system should be notified of the revision. As a minimum, these guidelines should be reviewed annually to identify any weaknesses or ambiguities. Suggestions for revisions to these guidelines may be directed to the WSDOT Region Traffic Engineer.

- **Traffic Conditions for CMS Usage:** The manner in which the CMS system is used will vary depending on the nature of the associated traffic condition. Various categories of traffic conditions are described below, along with specific information on the appropriate use of the CMS system.

  1. *Regulatory and Lane Control:* Some CMS units are installed specifically to provide long-term lane control, such as near the entrance to express lanes. These CMS units may only be used for that purpose as they are a part of the highway signing and are not reinforced with fixed signing. Other CMS systems have been installed for the purpose of providing variable speed limits (VSL) in areas which have an approved traffic regulation. These must display speed limits as the fixed signing has been removed. Additional space on the VSL can be used for messages in accordance with the remaining priorities.

2. *Traffic Restrictions:* In this context traffic restrictions refer to the prohibition of vehicles from using a roadway. These restrictions may be planned or unplanned, of short or long duration and specific or general. Requests for traffic restriction messages generally come from WSDOT or local agency maintenance offices.

3. *Road Closures:* Restriction request initiated by a maintenance or construction office. CMS systems can be used for warning of road closures for either emergencies or for scheduled maintenance operations.

4. *Bridge Draw Span Openings:* Usually SR 520 Evergreen Pt. or SR 104 Hood Canal openings for boat traffic or weather conditions.

5. *Flammable Restrictions:* Enacted when SR 5 Convention Center, SR 90 Mt. Baker Tunnel or SR 90 Mercer Island Lid fire control systems are inoperable.

6. *Weight, Height, Width Restrictions:* Restriction request initiated by a maintenance or construction office. CMS use only appropriate in emergency situations (e.g. earthquake damaged bridge) or short term use (e.g. construction-related height restriction).

7. *Incidents:* The use of the CMS system for incident information requires close monitoring by responsible personnel. The use of the system for incident information has the greatest potential for increasing or decreasing WSDOT's CMS credibility. If we are accurate and timely with our CMS usage we increase our credibility and vice versa.

8. *Disabled Vehicles and Accidents:* CMS systems used only when incident is visually confirmed or when requested by coordinating organizations, in this case usually WSDOT Incident Response Team (IRT) or Washington State Patrol (WSP) Communication with coordinating organizations should be through Radio Operations Messages are to be removed once the incident is no longer blocking. Messages describe the general nature of the situation (e.g. ACCIDENT AT MERCER) and traffic impacts (e.g. CONGESTION FROM NORTHGATE TO SHIP CANAL BRIDGE). Specific alternate routes included only if alternate is another State Route or with approval from route operator (e.g. City of Seattle) Messages describing severe incident-related traffic conditions may be continued at the discretion of the operator (e.g. CONGESTION FROM NORTHGATE TO SHIP CANAL BRIDGE DUE TO EARLIER ACCIDENT), however, CMS units should not be used to describe recurrent congestion (normal day to day backups).

9. *Road and Driving Conditions:* CMS systems should not be used to display weather conditions or driving conditions (e.g. icy roadway under near-freezing

temperatures). The Travel Aid Project, across Snoqualmie Pass, is allowed an exemption to this guideline due to the experimental nature of the operational test. Special Events CMS units may be used to manage freeway traffic destined for high impact special events (e.g. Seahawks game at Husky stadium) when traffic conditions warrant. Special event related CMS systems for freeway management should be coordinated prior to the event with the Regional Traffic Office. Message information should be limited to description of event-related traffic impacts and their duration.

10. *Construction and Maintenance Information:* The CMS system can be an effective supplement to construction traffic control but should not be used in lieu of adequate traffic control planning. Anticipated CMS use for construction and maintenance should be included in traffic control plans and scheduled in advance with the Regional Traffic Office. The CMS system should be used when construction activities require drivers to perform complex maneuvers, for major impacts or in cases where traditional signing methods are impractical. The WSDOT CMS system may be used to display information on

    - lane, ramp or road closures
    - detours
    - advanced notice for high-impact closures.

    Construction-related CMS use should be coordinated with the Construction Traffic Coordination Office (CTCO). The message information should be limited to the nature of the construction impact and the effect on drivers. Impacts include:

    - LEFT LANE CLOSED
    - EXIT XXX CLOSED.

    Driver effects include:

    - USE CAUTION
    - USE ALTERNATE ROUTE
    - FOLLOW DETOUR (only if signed detour provided)
    - EXPECT DELAYS (no specific duration).

    Non-WSDOT CMS use should be coordinated with the Region Traffic Engineer or designee.

11. *Public Service Announcements:* Only freeway or transportation related events or services of regional or state-wide significance should be considered for PSAs. The CMS system should not be used for public service announcements that are not directly related to transportation (i.e., carpool or transit info). PSAs should only

be used randomly and sparingly so as to not degrade the warning nature of the sign, otherwise motorists may disregard the sign thinking there is just another non-emergency message displayed. Operational limitations of some CMS units, such as overheating and degradation, may be considered when scheduling PSAs.

12. *Commuter Info Line:* CMS units may be used to display the phone number(s) of the WSDOT Commuter Info Line. Advertisement of commuter information lines on CMS units informs travelers of the resources available to them to enhance their mobility. CMS units may be used to display phone numbers for carpool matching or public transit information or phone numbers. CMS units may also be used to display the phone numbers of privately-sponsored commuter information lines, so long as the firm has a written agreement or contract with WSDOT stipulating the service to be provided. The PSA shall be generic and not include any private company names or trade-mark indications. Messages should be displayed on a rotating schedule, no beacons and in compliance with CMS usage priorities.

13. *Approved Rideshare Promotions:* The "Oil Smart Wednesdays" and "Rideshare Week" promotions are approved for state-wide CMS usage. Messages encouraging regional participation in rideshare/transit usage are displayed on consecutive Wednesdays in March. Messages of this type may be unique for the particular event but should focus on long-term traveler behavior. An example is the message "Upgrade Your Commute The Only Smart Way - Call METRO Ridematch 625-4500" that does not specify the name or date of the event, but conveys the option and the means to set up a ridematch, anytime. These messages are intended to benefit transportation system by encouraging drivers to use alternate modes of transportation and encourages travelers to utilize alternative modes of transportation and the freeway HOV system. Messages are displayed on selected signs, with no beacons and in compliance with CMS usage priorities.

14. *Other PSA Messages:* Messages other than traffic related should be avoided.

15. *Test Messages:* It can be necessary to run test messages on a CMS sign in order to assure correct operations or to "burn-in" a new sign. It is vital that test messages not misdirect traffic, so non-message formats or otherwise acceptable PSAs will be used. Acceptable test messages should either state TEST MESSAGE, display a portion on the alphabet or a sequence of numbers or non-message test patterns such as moving columns or rows. Other test messages should be reviewed by the Region Traffic Office.

15.10 Wisconsin Department of Transportation

The Wisconsin Department of Transportation (WISDOT) has issued the following guidelines for the application of PCMS systems (WISDOT, 1994):

Applications

Since they are dynamic signs PCMS systems must only be used to display real-time or changing condition information. This could-include expected delay times in a queue situation, ramp or lane closures, advisory speeds and alternate route advisories. The signs may be used to advise travelers to use a signed construction bypass route.

PCMS systems should not be used to replace static warning or regulatory signs; they may be considered as a supplemental device to a required static sign. In the case of a ramp or lane closure, the PCMS would supplement the static warning signs informing motorists of the closure.

If traffic is flowing smoothly options are to indicate EXPECT NO DELAYS or TRAFFIC MOVING SMOOTHLY or have the screen blank.

The use of nonstandard words such as DANGER, HAZARDOUS or CAUTION should be avoided. These words do not contribute any information and may overly concern drivers as they approach the work zone.

The use of generic messages that do not pertain to the specific work zone or special event should be prohibited. These types of messages would include BUCKLE UP, WELCOME TO WISCONSIN or DRIVE SAFELY. Use of these types of generic messages will tend to lead to motorist disregard of critical work zone messages.

In regard to using PCMS systems for weather-related advisories to motorists, several states have been contacted and some very strongly advise against trying to give information about a specific site at a given time because of the likelihood of being inaccurate, both in regard to the actual condition and in regard to the timeliness of the advice.

Local agencies may wish to have special event messages displayed on the state highway system. They may wish to have the district supply the PCMS with or without compensation. Conceivably they may wish to station their own machines on our system. None of these options are wrong, provided the following provisions are met:

1. the event will generate enough traffic to cause congestion and/or guidance problems

2. the message will be made up of advisory content, not advertising for the event
3. the state-owned machines are not required at work-zone sites at the time
4. the local agency has given the district ample notice
5. if the local agency is to supply the machines the locations and other details are to be approved by the district beforehand
6. any district may elect not to allow this type of activity for reasons such as lack of personnel, or to make arrangements or monitor
7. the content of the message shall be pre-approved by the district office.

Purchase

Generally, the signs are acquired through a highway improvement contract. Bid items for the signs and remote control equipment is included. The specs are written to indicate that the signs will become the property of the state upon completion of the project.

It is also possible to purchase the signs through the state procurement process with approval to charge the purchase to the construction project. The state procurement process is preferred since it allows the state more direct control as to the acceptance of the sign.

Another option which should be considered is to require the contractor to supply the sign as part of the contract, similar to the providing of flashing arrow board, drums and barricades. The state would not assume ownership.

Power Source

Most signs are powered with a large battery pack. The battery pack is recharged, using either 110-volt AC power or an on-board diesel engine generator. The 110-volt AC power is preferred if power lines are convenient to the project site. If used, the on-board diesel engine will require much more maintenance and repair than the AC power alternative. Solar-powered signs, as well as any other emerging technical features, shall be given full consideration.

Maintenance

Arrangements should be made using state forces, county or contractor to maintain the signs while in use. Usually on an improvement contract the maintenance is included as a bid item. The contractor would be required to check the sign at regular intervals. If the sign is running on AC power, a check of battery water levels is necessary at least twice a week. If using the diesel generator, the fuel, oil, belts, hoses, as well as the battery level, should be checked daily. If the signs are purchased new a warranty period is usually provided requiring the supplier to repair any failures or breakdowns of the sign.

Lateral Placement

Signs should be placed as far away from the live traffic lanes as possible. In advance of interstate construction projects the signs should be placed on the backslope beyond the ditch. The location selected should be at or slightly above the elevation of the roadway. This improves the visibility, minimizes the chance of a vehicle hit and also improves safety for the sign maintenance worker. For intermittent maintenance work, such as freeway lane closure, the signs may be placed on the shoulder. The sit e should be visited to assure visibility, safety and maintenance considerations.

Control

Signs are capable of having manual on-site control or remote control. The manual on-site control allows a project engineer or maintenance supervisor to program the sign using the on-board computer keyboard. There are two methods of remote control: (1) Utilizing a car cellular telephone and (2) utilizing a central base computer. The car cellular telephone would be most applicable if the project engineer wanted control of the sign without having to travel to the sign location.

However, the car cellular option is very restrictive since the programmer can only use the cellular number pad to program various functions. This limits the different features that can normally be used on the computer keyboard.

The central base computer remote control has been widely used in the state. The base computer is generally located at the local State Patrol headquarters. Either hard-wire telephone lines or cellular telephone services are used to communicate with the signs in the field. The base computer consists of personal computer, modem and printer. A dedicated telephone number must be arranged for the base station and each sign. Hard-wired telephone lines are preferred if available close to the sign locations. While cellular telephone provides savings in hard-wire installation, the system is not entirely reliable. Near larger cities peak-hour business calls often over-saturate the system, not allowing acceptance of further calls. Also, cellular service may not be available, particularly in rural areas. Users should consult with C.O. Traffic or the Telecommunications Unit in the Division of Business Management regarding the availability of cellular phone services in specific locations.

Training

Training for state patrol operators, project engineers and maintenance contractors is available. Provisions can be included in the purchase specifications that would require the supplier to provide a certain number of hours training during the warranty period. Beyond warranty period, the training would be available for a fixed fee.

Messages

The signs are generally capable of sequencing up to six frames. However, at normal highway speeds usually only two or three frames are used. It is desirable for the driver to be able to read the entire message sequence twice as they pass by the sign. For an interstate highway application, the total viewing time is about ten seconds. Each frame is usually displayed for 2 seconds. Additional time required to change the frames brings the total time to over 9 seconds.

It is recommended that the first frame describe the traffic condition ahead that the motorist may encounter. The second frame would be used to advise the driver of an appropriate action. Examples are:

1. 1 HOUR/DELAYAHEAD USE/BYPASS/ROUTE
2. TRAFFIC/STOPPED/AHEAD PREPARE/TO/STOP
3. LANES/BLOCKED/AHEAD PREPARE/TO/DETOUR

If the State Patrol will be operating the signs for a specific project, a set of message guidelines should be prepared for use by the operators. This will provide consistency in the messages being displayed while various shifts of operators or troopers are working the project.

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