Use of Color Changeable Message Signs – Current Practices and Research

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16. Abstract

Two overarching objectives of the *Use of Color Changeable Message Signs (CMSs) – Current Practice and Research* project are (1) to understand how agencies are displaying messages and using CMSs capable of displaying color, and (2) provide information on illuminated color displays from research reviewed that may help in establishing future color Changeable Message Sign (CMS) display policy and practice. This report presents information based on available literature, research, and current practices from the limited number of States using colors on CMSs. This report may assist transportation agencies with identifying the range of issues to consider and possible implications with integrating color in the display of different types of messages (e.g., combination of text and symbols, symbols only) on color CMSs. The information in this report may also assist with supporting the identification of issues to address in future efforts to develop technical resources, procedures, policies, or research in support of the use and display of messages on color CMSs.

This report does not alter or supersede the national standards for the use and display of CMSs set forth in the Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD). Messages displayed on CMSs within roadway or highway rights-of-way in the United States are required to follow the provisions in the MUTCD. Though many provisions throughout the MUTCD apply to the operation of CMSs as a traffic control device, Chapter 2L of the MUTCD provides standards and guidance unique to the use and display of messages specific to the characteristics and capabilities of CMSs.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS				
SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: volumes greater than 1000 L shall be shown in m^3			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS				
SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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CHAPTER 1. INTRODUCTION

Changeable message signs (CMSs) are one of the tools a transportation agency has for communicating information to the traveling public. They allow for the display of time-sensitive or location specific regulatory, warning and guidance information. This information may affect travel, allow drivers to make choices, or require drivers to take an action. CMSs benefit motorists by providing pertinent information that can result in increased safety and reduced travel delay.

This report summarizes the results of a literature review of published research and practices of the few agencies that are presently operating and displaying messages on a color Changeable Message Sign (CMS). The information in this report is a synthesis of literature and the limited current practices. This report makes no claim to the effectiveness of the practices identified. This report does not alter or supersede the Manual on Uniform Traffic Control Devices (MUTCD) for Streets and Highways, which is the national standard for all traffic control devices used on roadways open to public travel[1].

Manufacturers are building CMSs for transportation use that comply with industry standards (e.g., National Transportation Communications for Intelligent Transportation Systems (ITS) Protocol (NTCIP) and National Electrical Manufacturers Association (NEMA)) to enable the sharing of information and not using proprietary protocol specific to each company. However, many of these devices are capable of displaying messages that would not be consistent with the Standards and Guidance found in the MUTCD for using CMSs on streets and highway. Therefore, care should be taken to ensure message content (e.g., use of color, layout, symbols), design, and display are consistent with the provisions of the MUTCD.

The CMSs used for transportation generally use light-emitting diodes (LEDs), some with pixels as small as 0.79 inches (20 mm). Each pixel of a full-color CMS is made up of red, green, and blue LEDs. Such signs may display color images with symbols that closely match the MUTCD color specifications.

Only a few transportation agencies are using colors and graphic-aided messages on CMSs, and those are being used on an experimental basis. The current (2009, Revision Numbers 1 and 2) edition of the MUTCD provides guidance and sets standards on the use of colors and symbols on a CMS.[2] Although researchers have noted the general advantages of using symbols and graphic-aided messages on traffic signs, their usage on CMSs is still limited in the United States.

This report presents information on the issues to consider when displaying messages using color on CMSs based on standards and guidance in the MUTCD, a review of the literature, and available information gleaned from early use of color CMS by agencies. Some of the material cited in this report may contradict provisions in the MUTCD and are provided for information

[1] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. §1A.07

[2] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Chapter 2L.

purposes only. Messages displayed on CMSs within highway rights-of-way are required to follow the provisions in the MUTCD.[3]

Full-matrix color technology on CMSs allows pixel spacing to as low as 20 mm which provide the opportunity to present more information to the motorists (colors, symbols, font variation, message layout, etc.). Therefore, information is needed across a range of CMS attributes and not just simply the use of color, to consider when preparing and displaying messages. The attributes and issues covered in this report include:

- Planning and operation of CMSs
- Dynamic display of messages
- Visual design
- Luminance, luminance uniformity, and luminance contrast
- Legibility Distances of display elements
- Color contrast
- Typography
- Message composition
- Message length

The literature review identified a lack of research results on full-matrix color CMSs. Most of the extensive research conducted on CMSs was on 64 mm yellow/amber sign displays. In preparing this report, literature was reviewed to find information documenting agency experiences with using color CMSs.

[3] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Section 2L.01.

CHAPTER 2. PLANNING AND OPERATION OF CMSS

Introduction

Attentive planning for and operation of Changeable Message Signs (CMSs) is critical to ensuring messages are effectively conveyed to the traveling public. Messages displayed on a Changeable Message Sign (CMS) should follow the following five basic requirements for an effective traffic control device:[1]

1. Fulfill a need
2. Command attention
3. Convey a clear, simple meaning
4. Command respect from road users
5. Give adequate time for proper response

Agencies looking for opportunities to improve the operation and use of CMSs should review, update, or develop policies and procedures governing how CMSs are managed and operated. These policies and procedures should address as a minimum:

- What is appropriate content for messages on CMSs
- Design and layout criteria for messages
- Timing and duration of message display
- Primacy of messages when multiple messages of different types are being considered
- Vetting and hierarchy for approving new messages or content.
- Other factors determined necessary to appropriately control message content, design and timing.

CMS use within public rights-of-way is only allowed as a traffic control device. [1] The operation and display of messages on CMSs should be managed with the same expectations as traffic control devices. Well written and thought-out policies and procedures help ensure the content and display of messages on CMSs meets the same standards as other traffic control devices, while also meeting the expectation of road users.

Operation and Use of Messages on Color CMSs

The following issues were identified in the literature review as topics that agencies may consider when developing or displaying messages on color CMSs:

- Agency Policies:
  - Issues specific to the display of messages with color on a CMS
  - Development and display of messages on a CMS
  - Management and operation of all types of a CMS

[1] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. §1A.02

- Compliance with MUTCD provisions (23 C.F.R. § 655.603(a))

- Agency Procedures and Day-to-Day Practices:
  - There is insufficient empirical data to support suggestions for when to add color elements to messages displayed on CMSs nor to suggest certain colors be used in certain messaging applications.
  - Developing uniform messages and using those messages consistently in similar situations aids driver expectancy and comprehension.
  - Because CMS-related hardware and software can vary based on a number of factors (e.g., vendor, when manufactured), the display of messages should be tested before being used the first time under active traffic conditions to verify the capability of a CMS to accurately replicate text layout, graphics and colors.

CMS Policy

The Manual on Uniform Traffic Control Devices (MUTCD) recommends that States and local agencies develop and establish a policy regarding the display of messages on CMSs;[2] however, the literature review conducted for this project identified fewer than half of the State Departments of Transportation (DOTs) currently have a written policy that governs the use of CMSs. This review of DOTs with policies, identified only a fraction specifically addressing the design and use of color in messages being displayed on CMSs. Operational policies and procedures should consider issues specific to the use of color in messages being displayed on CMSs, to ensure consistency among all types of traffic control devices. Some State DOT policies reviewed include a reference that "all graphic displays used on a CMS shall be in compliance with the MUTCD" as a reminder of this requirement.

For example, the Florida DOT makes templates for the use of color in messages developed and made available to operators to aid the consistent development of different types of messages.[3] In another example, the Rhode Island DOT provides a set of message development rules.[4] As a third example, the Wisconsin DOT uses a message library that can store common messages and graphics for use on their CMSs.[5] Regardless of the approach used, having examples or procedures on the issues to consider for the development of different types of messages should help ensure consistency when they are displayed on color and non-color CMSs.

When to Use a Color CMS

Research on the use of color (i.e., non-amber or -white) lettering in messages dates to the 1990s, with more substantial research occurring in the early 2000s. However, there is limited research or information on practices with the use of color messages or graphics on full matrix color CMSs.

The focus of much of the available research attempted to determine if a letter color could be viewed and understood at a greater distance, with mixed results. Other research confirmed the use of amber as a top performing color for word messages,[6,7] where others found green to be as

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[2] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Section 2L.02.

[3] Florida Department of Transportation (2012). *Color Dynamic Message Sign Support Concept of Operations*. Tallahassee, FL: Florida Department of Transportation. Retrieved from http://sunguidesoftware.com/sunguidesoftware/documentlibrary/DragAndDropFTP/621Color-DMS-ConOps.pdf

[4] Wreh, M. and Nordstrom, W. (2016). Draft Message Policy for Dynamic Message Signs. Providence, Rhode Island: Rhode Island Department of Transportation.

[5] Wisconsin Department of Transportation (2015). Wisconsin Traffic Engineering Operations and Safety Manual. Madison, WI: Wisconsin Department of Transportation. Retrieved from http://wisconsindot.gov/dtsdManuals/traffic-ops/manuals-and-standards/teops/17-01.pdf

[6] Aylward, D., & Valentine, T. (1995). Application Of Light Emitting Variable Messages Signs To Convey Information To Motorists On High Speed Highways. Vermont South, Victoria. Retrieved from https://trid.trb.org/View/642033

[7] Shao, D., & Wang, J.-H. (2002). Study Of The Human/ITS Interface Issues On The Design Of Traffic Information Bulletin Board And Traffic Control Signal Displays. Kingston, RI: University of Rhode Island Transportation Center. Retrieved from https://trid.trb.org/View/697987

or more effective than amber.[8,9] Currently, there is not sufficient research to empirically support recommendations for when to use color in messages displayed on a CMS.

Consistency between the MUTCD provisions and the design of messages containing color or symbols displayed on a CMS, beyond being a requirement,[10] helps meet motorist's expectations for the type of message being displayed and therefore should enhance quicker recognition and better understanding of the message. Currently, some State DOTs are using the colors in the development of messages that match the requirements listed in Table 2A-5 (Common Uses of Sign Colors) of the MUTCD.[11] Some State DOTs are also using graphics in messages that contain an image of a standard road sign with colors that match Table 2A-5. Figure 1 presents an example of a route shield on a color CMS matching the color specifications from the MUTCD.

Figure 1. Photo. Route shield on a full-matrix color changeable message sign (CMS).
Source: Florida Department of Transportation

The MUTCD states "Legibility distances for negative-contrast changeable message signs are likely to be at least 25 percent shorter than those of positive-contrast messages. A negative-contrast sign or message has a darker color legend on a lighter color background. In addition, the increased light emitted by negative-contrast changeable message signs has not been shown to

[8] Wang, J.-H., Hunter, C., & Cao, J. (2002). A Design Of Experiment Approach To Study The Display Of Variable Message Signs. Providence, RI: Rhode Island Department of Transportation. Retrieved from https://trid.trb.org/View/731157
[9] Lai, C., Yen, K., & Wang, D. (2007). Effects of Chinese Font Style and Color on Variable Message Signs. Fourth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design (pp. 167-173). Iowa City, IA: University of Iowa. Retrieved from https://trid.trb.org/View/814533
[10] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Overview.
[11] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Section 2A.10.

improve detection distances."[12] For example, the conventional speed limit sign (R2-4) has black lettering on a white background in the MUTCD, which by definition is a negative-contrast sign display. [13] However, the New Jersey Turnpike Authority has found the use of a white background on a full matrix color CMS is too bright in low-light scenarios. As such, this agency has reversed the colors using white lettering on a black background for these messages when they are displayed on a CMS.

In general, messages developed incorporating color by different agencies in the United States are similar, as they often mimic the colors and graphics as shown in the MUTCD, but there are differences in how and which messages are being used. Some agencies have few message types that use color and/or symbols (e.g., travel times). Other agencies have incorporated more color in messages displayed on color CMSs.

The number and type of messages a State DOT displays on CMSs is often constrained by the agency's operational policies and procedures. These policies and procedures change and evolve as research is conducted and the lessons learned or practices of other agencies become available. However, these policies and procedures are not always backed by empirical data or research to support these practices.

Other differences in agency practices result from the variability in capabilities of the software and infrastructure specific to each CMS. For example, some agencies have CMSs installed that were manufactured by different vendors at different time periods, where each has different capabilities. Specific messages for the same application may need to be developed for each CMS based on the capabilities of the individual CMS. Other agencies may have software limitations, which limits their traffic management systems ability to communicate with and change the messages that can be displayed on different types of CMSs. Regardless of the agency's circumstances, it is important that all messages used for the same application be as consistent in content and design as possible to avoid any driver confusion when seen at various points along the roadway.

[12] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Section 2L.04.
[13] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Section 2B.13.

CHAPTER 3. USE OF MESSAGES ON COLOR CMSS

Introduction

There is extensive literature and research available on the use of color on visual displays. This information, however, is generally for computer displays, cockpit displays, map displays, and displays used in advertising. Information specific to the display of color on Changeable Message Signs (CMSs) in the public right-of-way for surface transportation system applications is very limited. Because the display of information in the highway environment is very different and can create substantial safety risk for road users, much of the literature and research does not translate directly to displays used on traffic control devices, and therefore does not support the development of agency policies, procedures, or messages to display on a Changeable Message Sign (CMS).

The synthesis of previously completed research captured in this chapter is intended to be consistent with the allowed use of color on CMSs, as specified in the Manual of Uniform Traffic Control Devices (MUTCD) for Streets and Highways.[1]

Physiology of Seeing Color

In Europe and North America, approximately eight percent of the adult male population and one percent of the adult female population is color deficient to some degree. This means that, on average, 1 in every 20 individuals will not see colors in the same way as the majority. The most common kind of color deficiency is dichromatism, where a person lacks one of the three normal cone pigments. Absence of the red pigment is known as protanopia, absence of the green pigment as deuteranopia, and absence of the blue pigment as tritanopia. Dichromats have difficulty discriminating hues corresponding to the missing pigment from combinations of the other two pigments.[2] For a comprehensive review of the physiology of color vision, see the research conducted by P. Lennie (2003).[3]

Using Color

Table 1 has a summary of the allowed uses of color on signs in the MUTCD.[4]

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[1] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Chapter 2L.
[2] G.W. Meyer and D.P. Greenberg, (1988). Color-Defective Vision and Computer Graphics Displays, IEEE Computer Graphics and Applications, Vol. 8, No. 5, pp. 28-40.
[3] P. Lennie (2003). The physiology of color vision. In S.K. Shevell (Ed.), The science of color (2 edition, pp. 217-246), New York, Elsevier.
[4] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Section 2A.10.

Table 1. Sign background colors

Color	Main Purpose
Black	Regulatory
Blue	Road User Services, Evacuation, Information,
Brown	Recreational and Cultural Interest
Fluorescent Pink	Incident Management
Green	Guidance and Recreation
Fluorescent Yellow-Green	Warning for Pedestrians, Bicyclists, Schools, and guide
Orange	Temporary Traffic Control
Purple	Electronic Toll Collection and Account Information
Red	Stop or Prohibition
White	Regulation
Yellow	Warning

Considerations for Displaying Messages on Color CMSs

The following items were identified in research and the literature review conducted for this project, and are not requirements of the MUTCD, when displaying messages on color CMSs.

1. Use color sparingly and for a specific purpose.[5]
2. Use of color in the background of messages displayed on CMSs should only be used to categorize the type of information (e.g., blue sign background for road user services guidance only).[6]
3. Use of color should be as a redundant attribute, i.e. if color were to be removed from the display, other attributes (size, shape, text, etc.) would still convey the intended meaning of the display. Symbols and controls should have unique shapes or labels. Text layouts should have sufficient spatial and typographic cues to be easily readable without color categorization. Using color in this manner may tend to mitigate the potential problems for drivers with color perception deficiencies.[7]
4. Use color consistent with convention. Red should only be used for a prohibition regulatory messages such as "stop" or "do not enter," and amber only for "caution or "alert"[8] i.e. a warning message or message element. Use color in messages displayed on CMSs that conforms to current use of color on highway signs per the MUTCD,[9] as shown above on Table 1.
5. Use color consistently throughout all signs used.[10]

[5] M. Stone, S.J. Laskowski, S. Z. Lowry (2008). Guidelines for Using Color in Voting Systems, National Institute of Standards and Technology, Report # NISTIR 7537.
[6] Ibid
[7] Ibid
[8] Ibid
[9] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Section 2A.10.
[10] https://colorusage.arc.nasa.gov/luminance_cont.php. Web site accessed on 6/4/2018.

6. Use of color in messages are most effective when the number of colors used is very small.[11]
7. Do not use colored text, borders, backgrounds, or patterns for purely decorative or aesthetic purposes. They can add complexity and may visually conflict or be confused with colors used functionally.[12]
8. Colors used should not interfere with text or symbol legibility.[13] Luminance contrast should be at least 10:1. For a description and discussion of luminance contrast see the information NASA has made available: https://colorusage.arc.nasa.gov/luminance_cont.php
9. Avoid placing colored text or symbols on a colored background.[14] Either the text or the background should be black or white. Luminance contrast and legibility is difficult to predict when using color-on-color, especially for people with color vision deficiencies.[15]
10. Use only white or yellow for text on a black background.[16] Colored text on black (or very dark) backgrounds can be difficult to read, especially if the text is a dark, saturated color (such as blue or red). This may be true even if there is a 10:1 legibility ratio in the message being displayed.[17]
11. When using color for labeling, use wide lines or blocks of color, instead of thin lines or colored text.[18] When used, symbols should be blocky and simply colored.[19]

Display of messages on CMSs

Recent research employing driving simulation suggests that regardless of what information was displayed on the CMS, drivers, on average, will glance twice at the CMS for durations of 0.5 seconds or less.[20] The study included the presentation of pictures of faces on the CMSs, and under these conditions, the mean glance duration was still 0.5 seconds or less. The results of this driving simulation study suggests that the operation of CMSs may not be generally distracting to drivers, but also suggests that short and simple messages are needed to convey information to road users. Further research is needed to verify the validity of this finding.

However, the amount of information, time, and how a message is displayed (e.g., dynamic attributes) may still cause driver distraction or create an inability to read and comprehend the message. The display of messages in phases is necessary when the text identified as critical for conveying a message does not fit on the sign. In this case, instead of displaying the entire message, the CMS cycles through phases. Due to the limited time available for motorists to read

[11] M. Stone, S.J. Laskowski, S. Z. Lowry (2008). Guidelines for Using Color in Voting Systems, National Institute of Standards and Technology, Report # NISTIR 7537.
[12] Ibid.
[13] Ibid.
[14] Ibid.
[15] https://colorusage.arc.nasa.gov/luminance_cont.php. Web site accessed on 6/4/2018.
[16] M. Stone, S.J. Laskowski, S. Z. Lowry (2008). Guidelines for Using Color in Voting Systems, National Institute of Standards and Technology, Report # NISTIR 7537.
[17] https://colorusage.arc.nasa.gov/luminance_cont.php. Web site accessed on 6/4/2018.
[18] M. Stone, S.J. Laskowski, S. Z. Lowry (2008). Guidelines for Using Color in Voting Systems, National Institute of Standards and Technology, Report # NISTIR 7537.
[19] https://colorusage.arc.nasa.gov/luminance_cont.php. Web site accessed on 6/4/2018.
[20] Inman, V., Bertola, M.-A., & Philips, B. (2015). Information as a Source of Distraction. Washington, DC: Federal Highway Administration. Retrieved from https://www.fhwa.dot.gov/publications/research/safety/15027/15027.pdf

messages on CMSs based on the speed they are traveling and the legibility distance of the sign, the MUTCD restricts CMSs to display no more than two message phases.[21]

Flashing is when a sign or elements of a message displayed alternates between an illuminated and a non-illuminated state. *Animation* is when an object is made to change in size or location over time when it is displayed on a CMS. The research cited below was conducted using monochrome CMSs, but there is little reason to believe it is not applicable to color CMSs. This information is most useful for supporting research to assess issues specific to the development of messages that use color.

Considerations for the Display of Messages on CMSs

The following issues were identified in the literature review as topics agencies may want to consider as they contemplate displaying messages on color CMSs:

- Dynamically displaying messages:[22]
  - Do not flash parts of, or the entire CMS message[23,24]
  - Do not use scrolling text or symbols in the CMS message[25]
- Phase timing:
  - Consider using 2 seconds per information unit OR 1 second per 4-8 character words (excluding prepositions), whichever is longest[26] (See Chapter 12: Message Length)
  - For two-phase messages, a blank screen should be displayed between phases 1 and 2 of not more than a 0.3 seconds[27,28]
  - Consider displaying blank time between multi-phase message cycles to help drivers identify phrase order[29]

Safety-critical messages should be tailored to minimize demands on drivers' attention for message readability and comprehension, especially in locations that are likely to have high

[21] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Section 2L.05.
[22] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Section 2L.04.
[23] Dudek, C. L., and Ullman, G. L. (2002). Flashing messages, flashing lines, and alternating one line on changeable message signs. Transportation Research Record, 1803, 94-101.
[24] Dudek, C. L., Schrock, S. D., and Ullman, G. L. (2005). Impacts of using dynamic features to display messages on changeable message signs (Report No. FHWA-HOP-05-069). Washington, DC: Federal Highway Administration.
[25] Greenhouse, D. (2007). Optimizing comprehension of Changeable Message Signs (CMS) (Report No. UCB-ITS-PRR-2007-24). Berkeley: University of California Partners for Advanced Transit and Highways (PATH).
[26] Dudek, C. L. (1992). Guidelines on the use and operation of changeable message signs (Report No. FHWA-TX-92-1232-9). College Station: Texas Transportation Institute.
[27] Greenhouse, D. (2007). Optimizing comprehension of Changeable Message Signs (CMSs) (Report No. UCB-ITS-PRR-2007-24). Berkeley: University of California Partners for Advanced Transit and Highways (PATH).
[28] Federal Highway Administration. (2009). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Section 2L.05.
[29] Dudek, C. L. (1992). Guidelines on the use and operation of changeable message signs (Report No. FHWA-TX-92-1232-9). College Station: Texas Transportation Institute.

driving demands (e.g., weaving section, highway diverge).[30] Do not use flashing messages (i.e., one-phase CMS messages that flash the entire message or contain one flashing or blinking line, often the last line).[31] This design may increase reading time and reduce comprehension.[32,33] Do not use looming; i.e. animation effects where text or symbol size increases over time. Looming may distract drivers and negatively affect message clarity.[34,35]

The MUTCD[36] indicates that for two-phase portable CMS messages, each phase should be displayed for a minimum of 2 seconds. Additionally, the total message (the sum of both phase display times) should not exceed 8 seconds. Figure 2 provides an example of a 2-phase message, with the message in the top photograph preceding the message in the bottom photograph. [37]

Figure 2. Photo. An example of a multi-phase message displayed on a changeable message sign (CMS).

Source: Shari Hilliard, Kansas Department of Transportation

[30] Inman, V., Bertola, M.-A., & Philips, B. (2015). Information as a Source of Distraction. Washington, DC: Federal Highway Administration. Retrieved from https://www.fhwa.dot.gov/publications/research/safety/15027/15027.pdf
[31] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Section 2L.05.
[32] Dudek, C. L., and Ullman, G. L. (2002). Flashing messages, flashing lines, and alternating one line on changeable message signs. Transportation Research Record, 1803, 94-101.
[33] Dudek, C. L., Schrock, S. D., and Ullman, G. L. (2005). Impacts of using dynamic features to display messages on changeable message signs (Report No. FHWA-HOP-05-069). Washington, DC: Federal Highway Administration.
[34] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Section 2L.05.
[35] Dudek, C. L. (1992). Guidelines on the use and operation of changeable message signs (Report No. FHWA-TX-92-1232-9). College Station: Texas Transportation Institute.
[36] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC.
[37] Dudek, C. L., Schrock, S. D., and Ullman, G. L. (2005). Impacts of using dynamic features to display messages on changeable message signs (Report No. FHWA-HOP-05-069). Washington, DC: Federal Highway Administration.

CHAPTER 4. DEVELOPING MESSAGES TO DISPLAY ON CMSS

Introduction

The visual design of a message to be displayed on a Changeable Message Sign (CMS) refers to the visual features of the legend, which may aid message comprehension. These features include text, symbols, borders, and other details. The "layout" refers to how text and symbols are positioned in a message, "symbol shape" refers to the shape of a symbol's outside edge creating its form, and "symbol detail" is the graphical detail necessary to recognize a symbol as intended.

Considerations for Developing Messages to Display on a CMS

The following issues were identified in the literature review as topics agencies should consider as they contemplate displaying messages on a color CMS:

- Message:
  - If symbols are used along with text, place symbols on the left-hand-side of the message text for large signs.[1]
  - The use of symbols and text should be avoided on smaller signs, as there is generally not enough room to display both adequately. [2]
- Symbol shape:
  - Symbols shaped like those used on standard warning traffic signs convey the hazard level of the message.[3]
  - Relatively solid shapes may be better than thin or dotted line edges unless the element in question depicts action or movement.[4]
  - Use closed figures without discontinuous lines, outlines, or disjointed elements that can result in a fragmented figure.[5]
  - Enclose all parts of the symbol within a single boundary.[6]
- Symbol detail
  - Include only details that contribute to the meaning of a symbol.[7]
  - Omit details that distract from the objectives of recognition and comprehension.[8]

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[1] Wang, J., Hesar, S., & Collyer, C. (2007). Adding Graphics to Dynamic Message Sign Messages. Transportation Research Record: Journal of the Transportation Research Board, No. 2018, 63-71. Retrieved from https://trid.trb.org/View/802093

[2] Ibid

[3] Campbell, J. L., Richman, J. B., Carney, C., and Lee, J. D. (2004). In-Vehicle Display Icons and Other Information Elements Volume I: Guidelines (Report No. FHWA-RD-03-065). Washington, DC: Federal Highway Administration.

[4] Ibid

[5] Ibid

[6] Ibid

[7] Campbell, J. L., Richman, J. B., Carney, C., and Lee, J. D. (2004). In-Vehicle Display Icons and Other Information Elements Volume I: Guidelines (Report No. FHWA-RD-03-065). Washington, DC: Federal Highway Administration.

[8] Ibid.

Some research suggests drivers may respond more quickly to, and may prefer, symbol-aided messages compared to text-only messages displayed on a CMS.[9] This general preference should not be applied indiscriminately. For example, some symbols may act as flankers, delaying the reading and comprehension of text placed next to the symbol.[10] Additionally, the *Use of Color Changeable Message Signs (CMSs) – Human Factors Study* findings indicated the addition of symbols to messages did not improve sign legibility or comprehension. At least three State DOTSs (Florida, Virginia, and Wisconsin) report their current practice supports placing the symbol to the left of the message text when displaying messages on CMSs.[11]

The structural properties of a symbol (e.g., the lines, curves, and graphics that make up a symbol) are important determinates of its perceptibility; they provide the contextual cues that define the meaning of a symbol.[12] The shape of a symbol's outside edge or border may call attention to the hazard level being communicated and enhance driver's interpretation of symbols. This strategy takes advantage of global superiority effect,[13] in which the perception of global features in a figure, such as outline shape or the figure-ground relationship, is more rapid than the perception of local features, such as the depiction of specific objects within the symbol.

Using consistent symbols can also facilitate rapid recognition.[14] Research has found that drivers perceive octagon, diamond, and inverted triangle shapes as the most hazardous, while they perceive circle, square, and rectangle shapes as the least hazardous.[15,16,17] These preferences are consistent with cultural stereotypes of American road signage displayed in the MUTCD.

[9] Wang, J., Hesar, S., & Collyer, C. (2007). Adding Graphics to Dynamic Message Sign Messages. Transportation Research Record: Journal of the Transportation Research Board, No. 2018, 63-71. Retrieved from https://trid.trb.org/View/802093

[10] Perez, W.A., Kennedy, J.F., & Katz, B.J. (2012). Sports Logo Evaluation Report. Technical Memorandum to FHWA Human Factors Team, McLean, VA.

[11] Wang, J., Hesar, S., & Collyer, C. (2007). Adding Graphics to Dynamic Message Sign Messages. Transportation Research Record: Journal of the Transportation Research Board, No. 2018, 63-71. Retrieved from https://trid.trb.org/View/802093

[12] Banard, P., & Marcel, T. (1984). Representation and understanding in the use of symbols and pictograms. In R. Easterby & H. Zwaga (Eds.), Information design: The design and evaluation of signs and printed material (pp.37-75). New York: J. Wiley & Sons.

[13] Pomerantz, J.R. (1983). Global and local precedence: Selective attention in forma and motion perceptions. Journal of Experimental Psychology: General, 112, 516-540.

[14] Rogers, Y. (1989). Icon design for the user interface. International Reviews of ergonomics, 2, 129-154.

[15] Cochran, D.J., Riley, M.W., & Douglas, E.I. (1981). An investigation of shapes for warning labels. Proceedings of the human Factors and Ergonomics Society 25th Annual Meeting, 395-399.

[16] Riley, M.W., Cochran, D.J, & Ballard, J.L. (1982). An investigation of preferred shapes for warning labels. Human Factors, 24(6), 737-742.

[17] Collins, B.L. (1983). Evaluation of mine-safety symbols. Proceedings of the Human Factors and Ergonomics Society 27th Annual Meeting, 947-949.

CHAPTER 5. LUMINANCE, LUMINANCE UNIFORMITY, AND LUMINANCE CONTRAST

Introduction

Luminance is the amount of light that passes through or is reflected from an area. Luminance uniformity refers to the consistency of luminance values across a symbol, text element, or the entire display. Luminance contrast is the ratio of foreground luminance elements to their backgrounds. To measure luminance uniformity, use a photometer to measure within two areas on the display, or within two locations of a symbol segment or text element with a spot size small enough to fit inside the segment. To measure luminance contrast, use a photometer to measure two areas on a display and take the ratio of the higher to lower luminance areas.

Agencies typically specify the required luminance uniformity and contrast in the specifications and contract documents when procuring Changeable Message Signs (CMSs). The following issues were identified in the literature review that agencies may want to consider as they contemplate including luminance uniformity in the procurement of color CMSs, verify vendor-supplied information, or assess the luminance performance of an existing (i.e., already purchased and operational) CMS over time to determine that it is still performing as intended.

Considerations for Luminance Characteristics

The following aspects of CMS design are important to consider when designing and testing CMS message luminance characteristics. These are expanded on further in the discussion section.

- Suggested luminance values differ based on condition and driver age (Table 2)
- Consider providing no more than 33 percent Element Nonuniformity (Figure 3) within an individual symbol or text element.[1]
- Consider providing no more than 50% Display Nonuniformity across the entire field of view of the display.[2]
- The optimal contrast ratio range is 8 to 12[3].

[1] Schaeffer, M. S. (1987). Hologram luminance study (HAC IDC Ref. No. 061187.MSS). El Segundo, CA: Hughes Aircraft Company.
[2] Ibid.
[3] Dudek, C. L. (1997). Changeable Message Signs. (NCHRP Synthesis Report 237). Washington, DC: Transportation Research Board.

$$\%\ Element\ Nonuniformity = \frac{|(Luminance_{min}) - (Luminance_{max})|}{(Luminance_{max})}$$

$Luminance_{min}$ = luminance emitted by the area or element of smaller intensity
$Luminance_{max}$ = luminance emitted by the area or element of greater intensity

Where:

$$Contrast\ ratio = \frac{(Luminance_{max})}{(Luminance_{min})}$$

Figure 3. Image. Equation to calculate the percent element nonuniformity

Table 2. Suggested luminance values for younger and older drivers in different conditions (reported in cd/m2)[4]

Age of Driver	Sun Overhead	Overcast/Rain	Nighttime
Young (16-40)	850	350	30
Old (65+)	1,000	600	30

Luminance

Driver age and sun position significantly affect the luminance of CMSs.[5] Generally, greater luminance is suggested for older drivers at a given distance.[6] The luminance values and contrast ratios provided above should lead to adequate legibility, as long as other message design parameters, such as symbol and text size, are sufficient. Older drivers generally have poorer visual acuity than do younger drivers. Thus, all other factors being equal, luminance and luminance contrast that meet the legibility needs of older drivers should meet the legibility needs of younger drivers.

Luminance Uniformity

[4] Garvey, P.M. and Mace, D.J. (1996). Changeable Message Sign Visibility. (Report No. FHWA-RD-94-077). Washington, D.C: Federal Highway Administration.
[5] Ibid.
[6] Ibid.

The American National Standards Institute suggests that luminance nonuniformity remain below 50 percent.[7] The MIL-STD-1472D, Military Standard[8] indicates that while the preferred limit for luminance nonuniformity across optical projection displays is 33 percent, at luminance nonuniformity is problematic 66 percent. The nonregulatory design objectives provided above reflect a composite of the information provided by references.[9,10,11] Specifically, if luminance differences up to 37 percent are not always noticed by observers, and if 33 percent represents a preferred limit, then 33 percent may be used as a limit for small-area luminance nonuniformities (i.e., within an individual symbol or text element).[12] A 50 percent value was identified as a conservative potential limit for luminance nonuniformity across the field of view, based on the research that was conducted and referenced in the Hologram luminance study.[13] Moderate nonuniformities in luminance may only lead to the perception, by the driver, that the display is of poor quality.[14] However, with great nonuniformities in luminance, drivers may not have sufficient luminance and contrast to ensure adequate legibility in certain areas of the display.[15]

The photometric and physical properties of signs directly affect the legibility of the sign elements. Luminance can be reduced by dirty or scratched protective plexiglass sheeting.[16] Weather conditions such as rain and fog can affect luminance and contrast of signs by reducing the illumination coming from the sign or light reflected by the sign. Luminance and contrast needs vary by time of day and lighting conditions. Light-emitting CMSs have minimum contrast ratios on sunny days, when light falling is at a minimum, or when the sun increases the background sign luminance.[17] The following information has been synthesized for how different conditions may influence these design variables.

Daytime Contrast

[7] MIL-D-87213A. (1986). Military specification displays, airborne, electronically/optically generated. Washington, DC: U.S. Government Printing Office.
[8] MIL STD 1472D. (1989). Human engineering design criteria for military systems, equipment and facilities. Washington, DC: U.S. Government Printing Office.
[9] American National Standards Institute. (1988). American national standard for human factors engineering of visual display workstations. Santa Monica, CA: Human Factors and Ergonomics Society.
[10] MIL STD 1472D. (1989). Human engineering design criteria for military systems, equipment and facilities. Washington, DC: U.S. Government Printing Office.
[11] Farrell, R. J., & Booth, J. M. (1984). Design handbook for imagery interpretation equipment. Seattle, WA: Boeing Aerospace Company.
[12] Campbell, J. L., Carney, C., & Kantowitz, B. H. (1998). Human factors design guidelines for advanced traveler information systems (ATIS) and commercial vehicle operations (CVO) (No. FHWA-RD-98-057).
[13] Schaeffer, M. S. (1987). Hologram luminance study (HAC IDC Ref. No. 061187.MSS). El Segundo, CA: Hughes Aircraft Company.
[14] Ibid.
[15] Ibid.
[16] Dudek, C. L. (1992). Guidelines on the Use and Operation of Changeable Message Signs. (Report No. FHWA-TX-92-1232-9). College Station: Texas Transportation Institute.
[17] Dudek, C. L. (2004). Changeable Message Sign Operation and Messaging Handbook. (Report No. FHWA-OP-03-070). College Station, TX: Texas Transportation Institute.

Research on symbols found a contrast of 1.2:1 may be sufficient for young military pilots.[18] Research conducted by Blackwell[19] investigated contrast needs for both younger and older subjects under laboratory conditions. The data indicate that 1.4:1 contrast may be sufficient for older drivers under laboratory conditions.[20] High brightness increases detection and legibility in daytime fog and was rated as more urgent, but also more glaring.

Daytime Luminance

Garvey & Mace[21] found that during extreme backlit (sun behind the CMS) and washout (sun directly on the CMS) conditions, 1,000 cd/m2 is a desirable minimum luminance value for drivers. Some drivers, however, cannot be accommodated under these visibility conditions, at 650 feet, at any luminance level. Williams, Gibbons, Medina, & Connell found an ambient background luminance of 8,565 cd/m2 is considered a representative "worst case" background luminance for daytime driving .[22]

Nighttime Contrast

Schaeffer[23] found that with a minimum background luminance of 0.03 cd/m2, older individuals will need 2:1 contrast, and that with a background luminance of 30 cd/m2, older individuals will need at least 1.6:1 contrast. Mourant & Langolf[24] investigated contrast needs for both younger and older subjects under low luminance laboratory conditions. The research conducted by Mourant & Langolf[25] indicated that older drivers need a contrast of 2:1 under low luminance conditions; adequate legibility was not obtained at contrast levels below 2:1 (i.e., 1.25:1).

Nighttime Luminance

If luminance values are too high at night, CMS symbols or text may appear to irradiate or bleed onto the background and blur due to the extreme contrast.[26] Setting luminance values too high may cause irritation to motorists or reduce the legibility of the sign or message displayed on a CMS.

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[18] MIL-D-87213A. (1986). Military specification displays, airborne, electronically/optically generated. Washington, DC: U.S. Government Printing Office.
[19] Blackwell, O. M., & Blackwell, H. R. (1971). Visual performance data for 156 normal observers of various ages. Journal of the Illuminating Engineering Society, pp. 3-13.
[20] Ibid.
[21] Garvey, P.M. and Mace, D.J. (1996). Changeable Message Sign Visibility. (Report No. FHWA-RD-94-077). Washington, D.C: Federal Highway Administration.
[22] Williams, B., Gibbons, R., Medina, A., & Connell, C. (2015). Visibility of a Color Variable Message Sign in the Fog. Proceedings of the 94th Annual Meeting of the Transportation Research Board. Washington, DC: Transportation Research Board. Retrieved from https://trid.trb.org/View/1337302
[23] Schaeffer, M. S. (1987). Hologram luminance study (HAC IDC Ref. No. 061187.MSS). El Segundo, CA: Hughes Aircraft Company.
[24] Mourant, R. R., & Langolf, G. D. (1976). Luminance specifications for automobile instrument panels. Human Factors, 18(1), pp. 71-84.
[25] Ibid.
[26] Dudek, C. L. (1992). Guidelines on the Use and Operation of Changeable Message Signs. (Report No. FHWA-TX-92-1232-9). College Station: Texas Transportation Institute.

Legibility of Messages on CMSs

Since travelers may view CMS devices at a broad range of distances. Symbol height can be defined as the *visual angle* subtended by a symbol or unaccented letter or number (at the driver's eye) in minutes of arc. Display element size, background color, and sign technology all affect the distance at which information on the sign is legible.

The following aspects are important to consider when designing a message and considering its legibility when it is displayed on a CMS. These are expanded on further in the section on issues to consider which may affect message legibility:

- CMS should be legible for up to 650 ft.[27]
- Both blue and black backgrounds have acceptable legibility distances.[28]
- Consider how symbol height, distance, and visual angle affect legibility (Figure 4).[29]

  Where:
  $Symbol\ Height = Distance\big(Tan(Visual\ Angle)\big).$
  Symbol Height = the height of the symbol
  Distance = distance from viewer's eye point to the display
  Visual Angle = angle in degrees
  Height and Distance use the same unit of measure

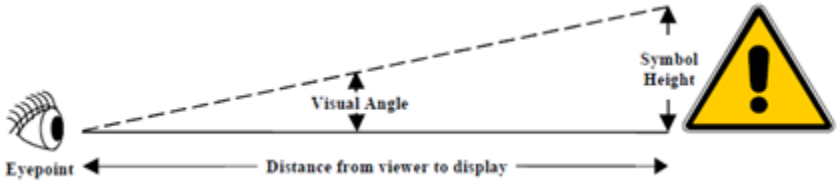

Figure 4. Illustration. Relationship between viewing distance, symbol height, and visual angle.

The following issues should be considered as they may affect message legibility:

Symbol Height. The necessary symbol height can be calculated from the distance at which the sign should be legible (e.g., at least 650 ft for a CMS). A driver traveling at 60 miles per hour (mph) would be able to view a CMS for 7.4 seconds at that speed and distance.[30] However, this

[27] Dudek, C. (2002) Guidelines for changeable message sign messages. Presentation at the TMC Pooled-Fund Study Annual Meeting, Arlington, VA. Retrieved on July 21, 2006, from http://tmcpfs.ops.fhwa.dot.gov/meetings/mtg)detail.cfm?id=10
[28] Chrysler, S., Carlson, P., Brimley, B., & Park, E.-S. (2017). Effects of Full Matrix Color Changeable Message Signs on Legibility and Roadway Hazard Visibility. Journal of the Transportation Research Board, No. 2617, 9-18. Retrieved from https://trid.trb.org/View/1438308
[29] Campbell, J. L., Carney, C., & Kantowitz, B. H. (1998). Human factors design guidelines for advanced traveler information systems (ATIS) and commercial vehicle operations (CVO) (No. FHWA-RD-98-057).
[30] Dudek, C. (2002) Guidelines for changeable message sign messages. Presentation at the TMC Pooled-Fund Study Annual Meeting, Arlington, VA. Retrieved on July 21, 2006, from http://tmcpfs.ops.fhwa.dot.gov/meetings/mtg)detail.cfm?id=10

does not mean the driver would be able to read the CMS message for this full duration as the message display becomes unreadable before the vehicle is adjacent to the sign due to the limiting effect of the LED viewing angle.

Sign Legibility Distance. In a closed course study on the legibility distances of travel time signs or safety signs with black backgrounds, a slight decrease in legibility distance was observed for safety signs with blue backgrounds. In all cases, the legibility distance for tested signs was greater than 50 feet of legibility for every inch of letter height.[31]
LED signs have the potential for a negative interaction with sunglass filters. Some sunglasses have a notch-filter in the lenses, which attenuates light emissions in the same range that amber LEDs emit light.[32] This reduces the brightness of the LED, decreasing the contrast and making it difficult to read messages on CMSs. The MUTCD has additional information on the legibility and visibility issues agencies should consider with displaying messages on CMSs.[33]

Color Contrast

Contrast refers to the relationship between the luminance of a symbol and of its background. *Color contrast* refers to the relationship between the luminance of a symbol and background associated with chromatic differences such as hue and saturation.

The information provided in this chapter can be used by agencies to integrate color contrast considerations into the development of specifications for a vendor-supplied CMS. The integration of color contrast provisions into these specifications will allow agencies to verify vendor-supplied specifications, to select appropriate color combinations of individual elements of a CMS, and to assess the color contrast performance of an existing (i.e., already purchased and operational) CMS over time, to verify it is still performing as required.

The following aspects of CMS design are important to consider when designing for color contrast on CMSs. These are expanded on further in the discussion section:

- Highly saturated blue (i.e., approximately 450 nanometers) should be avoided.[34,35]
- If colored elements are shown against a colored background, the color contrast between the elements should be a minimum of $100\Delta E(CIE\ Yu'v')$ distances (Figure 5).[36]

[31] Chrysler, S., Carlson, P., Brimley, B., & Park, E.-S. (2017). Effects of Full Matrix Color Changeable Message Signs on Legibility and Roadway Hazard Visibility. Journal of the Transportation Research Board, No. 2617, 9-18. Retrieved from https://trid.trb.org/View/1438308
[32] Halloin, D. M. (1996). Impediments to the effective use of portable variable message signs at freeway work zones. In C. Dudek (Ed.). Compendium of Graduate Student Papers on Advanced Surface Transportation Systems (p. Ci-C34). College Station: Texas A&M University.
[33] Federal Highway Administration. (2009). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Section 2L.03.
[34] Murch, G. M. (1987). Visual perception basics. Society for Information Display Seminar Lecture Notes, 1, pp. 2–1-2–36.
[35] Donohoo, D. T., & Snyder, H. L. (1985). Accommodation during color contrast. Digest of the Society for Information Display, pp. 200-203.
[36] American National Standards Institute. (1988). American national standard for human factors engineering of visual display workstations. Santa Monica, CA: Human Factors and Ergonomics Society.

$$\Delta E(CIE\ Yu'v') = \left[\left(155\left(\frac{\Delta Y}{Ym}\right)\right)^2 + (367\Delta v')^2 + (167\Delta v')^2\right]^{0.5}$$

$\Delta E(CIE\ Yu'v')$= the color contrast metric
ΔY = difference in luminance between text (symbology) and background
Ym = the maximum luminance of the text (symbology) or background
$\Delta u'$= difference between u' coordinates of text (symbology) and background (per the 1976 CIE UCS, see note below)
$\Delta v'$= difference between v' coordinates of text (symbology) and background (per the 1976 CIE UCS, see note below)

Figure 5. Image. Equation for color contrast metric [36]

Note the American National Standards Institute[37], a non-governmental organization, states the discriminability of pairs of colors depends on their differences in chrominance and luminance. While an entirely satisfactory metric which combines these attributes into a single assessment of total color difference does not exist, an estimate can be derived by calculating the weighted difference between the locations of the colors in the 1976 CIE UCS (CIE UCS L*u*v*).

Note the color contrast estimate should be used only to ensure discriminability of colors of relatively high luminance.

The MUTCD[38] has identified the color combinations to consider when displaying messages on CMSs table 2A-5 of the 2009 MUTCD. The MUTCD[39] states that, if a black background is used, the color used for the legend on a changeable message sign should match the background color that would be used on a standard sign for that type of legend (such as white for regulatory, yellow for warning, orange for temporary traffic control, red for stop or yield, fluorescent pink for incident management, and fluorescent yellow-green for bicycle, pedestrian, and school warning signs).

The MUTCD[40] states if a green background is used for a guide message or when a blue background is used for a motorist services message on a CMS, the background color shall be provided by green or blue-lighted pixels such that the entire CMS would be lighted, not just the white legend. The MUTCD[41] also states a CMS should not display symbols or route shields unless they can do so in the appropriate color combinations.

[37] Ibid.
[38] Federal Highway Administration. (2009). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC.
[39] Federal Highway Administration. (2009). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Section 2L.04.
[40] Federal Highway Administration. (2009). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Section 2L.04.
[41] Ibid.

Williams et al.[42] investigated using color CMS messages in a 2015 study. They found that participants rated amber on black, black on white, and white on black signs as having greater legibility distances, white on black causing the least glare, and red on black as high urgency (though red on black had lower legibility distances).

The New Jersey Turnpike Authority (NJTA)[43] noted that the main reason for selecting the different message colors is to follow the MUTCD provisions. For regulatory signs, it found that using black lettering on a white background was too bright, so they used white text on a black background. The neon tube CMS signs that were previously on the New Jersey Turnpike had red lettering; red was selected because it was the neon color most visible in inclement conditions. On the current CMS signs, NJTA has found that yellow text on a black background seems to be most visible in inclement conditions.

Typography

Typography is the technique of arranging text in a message to maximize visibility and legibility. The issues and attributes or capabilities of a CMS, which will influence the typography agencies may consider in the design of messages to display on CMSs, include: width-to-height ratio, stroke width-to-height ratio, symbol spacing, symbol font, word spacing, and line spacing.

The following issues are important to consider typography when designing messages to display on CMSs:

- The typical width-to-height ratio of the sign characters is between 0.7 and 1.0. The typical stroke width-to-height ratio is 0.2.[44] The typical ratio between stroke width to character height ratio should be between 1:8 and 1:6 (1:6 is better).[45] The typical stroke width-to-height ratios for black on white symbols are 1:6to 1:8 and ratios for white on black symbols of 1:8to 1:10.[46,47]
- The typical spacing in practice between characters in a word is between 25 to 40 percent of the letter height.[48]

[42] Williams, B., Gibbons, R., Medina, A., & Connell, C. (2015). Visibility of a Color Variable Message Sign in the Fog. Proceedings of the 94th Annual Meeting of the Transportation Research Board. Washington, DC: Transportation Research Board. Retrieved from https://trid.trb.org/View/1337302
[43] New Jersey Turnpike Authority. (2017). Guideline For Use Of VMS Systems For Construction Within Work Zones. Woodbridge, NJ: New Jersey Turnpike Authority. Retrieved from http://www.state.nj.us/turnpike/documents/NJTA-Guideline-VMS-Systems-2017-03-20.pdf
[44] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Section 2L.04.
[45] Sanders, M. S., & McCormick, E. J. (1993). Human factors in engineering and design (5th ed.). New York: McGraw-Hill.
[46] MIL STD 1472D. (1989). Human engineering design criteria for military systems, equipment, and facilities. Washington, DC: U.S. Government Printing Office.
[47] American National Standards Institute. (1988). American national standard for human factors engineering of visual display workstations. Santa Monica, CA: Human Factors and Ergonomics Society.
[48] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Section 2L.04.

- Use an easy-to-read and simple font. The use of fonts should replicate the FHWA Standard Alphabets for Traffic Control Devices to the extent possible. When used to replicate a standard sign, then standard FHWA alphabets should be used.[49]
- Word spacing should be 75 to 100 percent of letter height (100 percent is better).[50] Line spacing should be 50 to 75 percent of letter height (75 percent is better).[51]

The above information on typography provides adequate symbol ratios so that 95 percent of drivers can comfortably and quickly read the symbol 95 percent of the time.[52]

This information is also consistent with the symbol width-to-height ratio suggested by standard human factors reference sources.[53,54,55] Sanders et. al.[56] indicates that, while a symbol width-to-height ratio of 1:1 is supported by empirical data, a symbol width-to-height ratio of 0.6:1 may be used without serious loss in legibility. In general, optimum ratios for black symbols on a white background are lower than those for white symbols on a black background, due to a phenomenon called irradiation. Sanders et. al.[57] also recommended a stroke width-to-height ratio for black-on-white symbols of 1:6 to 1:8 and ratios for white on black symbols of 1:8 to 1:10.

Spacing

The spacing agencies consider using between text on messages displayed on CMSs should allow drivers to recognize words as items rather than series of individual letters and lines as separate entities. Crook et. al.[58] indicated a space-to-symbol-height ratio of 0.1:1 was adequate for direct viewing of most displays. Larger spacing (up to 0.25:1) reflect data obtained under suboptimal conditions or reduced contrast.[59,60] Word spacing should be 75 to 100 percent of letter height, so

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[49] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Section 2L.01.
[50] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Section 2L.04.
[51] FIbid.
[52] Campbell, J. L., Carney, C., & Kantowitz, B. H. (1998). Human factors design guidelines for advanced traveler information systems (ATIS) and commercial vehicle operations (CVO) (No. FHWA-RD-98-057).
[53] MIL STD 1472D. (1989). Human engineering design criteria for military systems, equipment, and facilities. Washington, DC: U.S. Government Printing Office.
[54] Sanders, M. S., & McCormick, E. J. (1993). Human factors in engineering and design (5th ed.). New York: McGraw-Hill.
[55] Farrell, R. J., & Booth, J. M. (1984). Design handbook for imagery interpretation equipment. Seattle, WA: Boeing Aerospace Company.
[56] Sanders, M. S., & McCormick, E. J. (1993). Human factors in engineering and design (5th ed.). New York: McGraw-Hill.
[57] Sanders, M. S., & McCormick, E. J. (1993). Human factors in engineering and design (5th ed.). New York: McGraw-Hill.
[58] Crook, M. N., Hanson, J. A., & Weisz, A. (1954). Legibility of type as determined by the combined effects of typographical variables and reflectance of background (Report No. WADC T-53-0440). Wright-Patterson Air Force Base, OH: Wright Air Development Center (DTIC No. AD-043309).
[59] Meister, D. (1984). Human engineering data base for design and selection of cathode ray tube and other display systems (NPRDC TR 84-51). San Diego, CA: Navy Personnel Research and Development Center (DTIC No. AD-A145704).
[60] Boff, K. R., & Lincoln, J. E. (Eds.). (1988). Engineering data compendium: Human perception and performance. Wright-Patterson Air Force Base, OH: Armstrong Aerospace Medical Research Laboratory.

each word is clearly legible, and they do not run together. [61] Width-to-height, stroke width-to-height, and space-to-height ratios can have an impact on legibility, particularly under conditions in which some design parameters (i.e., character height, contrast, or luminance) do not meet suggested thresholds.[62]

The MUTCD states,[63] "The spacing between characters in a word should be between 25 to 40 percent of the letter height. The spacing between words in a message should be between 75 and 100 percent of the letter height. Spacing between the message lines should be between 50 and 75 percent of the letter height."

Font

The intent of using a symbol font is to avoid extensive flourishes and embellishments of the symbols. Most conventional fonts that are clear and simple will be legible if other symbol parameters, such as character size and contrast, are adequate.[64,65,66] The MUTCD provides specific guidance[67] about letter height, minimum legibility distance, and other characteristics. The MUTCD[68] states that portable CMSs mounted on trailers or large trucks should have a minimum letter height of 450 mm (18 in), and on service patrol trucks should have a minimum height of 250 mm (10 in).

When all capital letters are used in messages displayed on CMSs, they are more difficult for people to read than mixed or lowercase letters.[69] People are more accustomed to reading mixed or lowercase letters and can identify word shapes using the ascenders and descenders. On the other hand, Inman et al. conducted several studies looking at driver response to CMSs, and regarding letter style, found that all performance differences between uppercase and lowercase were non-significant.[70] The MUTCD allows mixed cased letters (an initial upper-case letter followed by lower-case letters) only for names of places, streets, and highways.[71]

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[61] Federal Highway Administration. (2009m Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Section 2L.04.
[62] American National Standards Institute. (1988). American national standard for human factors engineering of visual display workstations. Santa Monica, CA: Human Factors and Ergonomics Society.
[63] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. §2L.04
[64] MIL STD 1472D. (1989). Human engineering design criteria for military systems, equipment, and facilities. Washington, DC: U.S. Government Printing Office.
[65] Sanders, M. S., & McCormick, E. J. (1993). Human factors in engineering and design (5th ed.). New York: McGraw-Hill.
[66] American National Standards Institute. (1988). American national standard for human factors engineering of visual display workstations. Santa Monica, CA: Human Factors and Ergonomics Society.
[67] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Chapter 2L, Changeable Message Signs.
[68] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Section 6F.60.
[69] Proffitt, D. R., and Wade, M. M. (1998). Creating Effective Variable Message Signs: Human Factors Issues. (Report No. VTRC 98-CR31). Charlottesville: Virginia Transportation Research Council.
[70] Inman, V., Bertola, M.-A., & Philips, B. (2015). Information as a Source of Distraction. Washington, DC: Federal Highway Administration. Retrieved from https://www.fhwa.dot.gov/publications/research/safety/15027/15027.pdf
[71] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. §2A.13

Studies have found that amber and green lettering performed well in terms of faster driver response time and higher accuracy.[72,73,74,75] The use of monochromatic yellow lettering in messages at an approximate wavelength of 575-600 nanometers may have advantages, as it may refract evenly (where its color is not affected by the intensity at which it is emitted), allowing its color to be more easily discriminated from similar colors, as it retains its color in a saturated environment.[76] In general, participants in this research preferred text to graphics and showed preference for using red lettering, which was also the quickest and most accurate response times when viewing graphics and amber lettering in the driving simulator.[77]

Message Composition

The formatting of messages to be displayed on CMSs will affect the time drivers require to read and understand the messages. Drivers have a limited amount of time to comprehend the information and make decisions. Messages that are easy to comprehend reduce the amount of time required to read and grasp the meaning of the message, which can facilitate decision-making and promote faster responses, while potentially reducing the incident of erratic maneuvers by vehicle operators.

Messages that are easy to read and understand and are not distracting improve the ability for drivers to comprehend the information displayed and make the necessary decisions or actions. If drivers are unfamiliar with a word or symbol, or a phrase is not understood or intuitive, it may be less effective and take more time to comprehend.

The following aspects are important to consider when designing messages to display on CMSs. The basic CMS message content is often determined using the acronym PLA (Table 3),[78] which stands for Problem, Location, and Action.

[72] Boff, K. R., & Lincoln, J. E. (Eds.). (1988). Engineering data compendium: Human perception and performance. Wright-Patterson Air Force Base, OH: Armstrong Aerospace Medical Research Laboratory.
[73] Heglin, H. J. (1973). NAVSHIPS display illumination guide: II. Human factors (NELC/TD223). San Diego, CA: Naval Electronics Laboratory Center.
[74] Lai, C., Yen, K., & Wang, D. (2007). Effects of Chinese Font Style and Color on Variable Message Signs. Fourth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design (pp. 167-173). Iowa City, IA: University of Iowa. Retrieved from https://trid.trb.org/View/814533
[75] Inman, V., Bertola, M.-A., & Philips, B. (2015). Information as a Source of Distraction. Washington, DC: Federal Highway Administration. Retrieved from https://www.fhwa.dot.gov/publications/research/safety/15027/15027.pdf
[76] Boff, K. R., & Lincoln, J. E. (Eds.). (1988). Engineering data compendium: Human perception and performance. Wright-Patterson Air Force Base, OH: Armstrong Aerospace Medical Research Laboratory.
[77] Clark, A., Wang, J., Maier-Speredelozzi, V., & Collyer, C. (2007). Assisting Elder Drivers' Comprehension of Dynamic Message Signs. Kingston, RI: University of Rhode Island Transportation Center. Retrieved from https://trid.trb.org/View/848458
[78] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Section 6F.60.

Table 4 shows a potential order for message elements. Note that only a limited number of elements should be included in a single message:[79]

- Words should be simple, and messages standardized with nontechnical, common vocabulary.[80]
- Command style messages should be used for safety-critical information that requires immediate response.[81]
- Notification style messages should be used for presenting low criticality information.[82]
- Messages should not be prefaced with a single word such as: Danger, Warning, Caution, unless it is part of a recommended action (e.g., "Use Caution").[83] Regardless, such words generally do not add specific actionable information to the message and overuse can diminish any positive effects.
- Consider referencing specific diversion or incident location information if it is available.[84]
- Consider using the phrase "THIS EXIT" instead of the phrase "NEXT EXIT" to refer to an upcoming exit that is within sight of the CMS.[85]

Table 3. Definitions and examples of a problem, location, and action (PLA) (adapted from Dudek[86]).

Content	Definition	Example
Problem	Provides information about the situation that the driver will encounter	Flooding
Location	Describes the location or distance to the situation	At US-23
Action	A recommendation for the driver in response to the problem and location	Use I-280 East

[79] Dudek, C. L. (2004). Changeable Message Sign Operation and Messaging Handbook. (Report No. FHWA-OP-03-070). College Station, TX: Texas Transportation Institute.
[80] Pedic, F., and Ezrakhovich, A. (1999). A literature review: The content characteristics of effective VMS. Road & Transport Research, 8(2), 3-11.
[81] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC.
[82] Dudek, C. L. (2004). Changeable Message Sign Operation and Messaging Handbook. (Report No. FHWA-OP-03-070). College Station, TX: Texas Transportation Institute.
[83] Pedic, F., and Ezrakhovich, A. (1999). A literature review: The content characteristics of effective VMS. Road & Transport Research, 8(2), 3-11.
[84] Dudek, C. L. (2004). Changeable Message Sign Operation and Messaging Handbook. (Report No. FHWA-OP-03-070). College Station, TX: Texas Transportation Institute.
[85] Benson, B. G. (1996). Motorist attitudes about content of variable-message signs. Transportation Research Record, 1550.
[86] Dudek, C. L. (2004). Changeable Message Sign Operation and Messaging Handbook. (Report No. FHWA-OP-03-070). College Station, TX: Texas Transportation Institute.

Table 4. Potential order for message elements (adapted from Dudek[87]).

Message Element	Element Description
1. Incident/Roadwork/ Closure Descriptor	Description of the unusual situation (use closure descriptor when all lanes on the roadway or ramp are closed)
2. Incident/Roadwork/ Closure Location	Location of the unusual situation
3. Lanes Closed/Blocked	Description of the exit ramps or lanes that are closed or blocked, can be used instead of Element 1
4. Effect on Travel	Description of the severity of the situation to help the driver decide whether or not to divert (e.g. delay or travel time)
5. Audience for Action	Used when the action applies to a subset rather than all drivers
6. Action	Tells drivers what to do
7. Good Reason for Following the Action	Gives drivers confidence that following the action will improve safety or save time

The following are issues to consider when composing messages to display on CMSs.

Problem, Location, Action

There are two caveats for the PLA method to develop messages to display on CMSs. The first is that there can be other elements to consider when determining what information to consider including in a message, such as a specific audience. The second is there may not be a prescribed action element for a driver. An example is a message may simply be descriptive of a condition. Alternatively, the action element may be a more general statement such as "SLOW DOWN" or it may provide a different sort of recommendation like "Expect Delays."

Jargon

Technical language should not be used, as it is more likely to be misunderstood by drivers. Examples of terms or words to avoid could include: Technical: "Right Turn Prohibited", "Reduce Velocity"; Nontechnical: "No Right Turn", "Reduce Speed". Leaving out signal words (e.g., excluding words such as Danger, Warning, and Caution) can reduce reading time, conserve sign space, prevent driver confusion and does not affect performance.[88]

Element Order

[87] Dudek, C. L. (2004). Changeable Message Sign Operation and Messaging Handbook. (Report No. FHWA-OP-03-070). College Station, TX: Texas Transportation Institute.
[88] Pedic, F., and Ezrakhovich, A. (1999). A literature review: The content characteristics of effective VMS. Road & Transport Research, 8(2), 3-11.

The MUTCD[89] states that for use on portable message signs, "If the message can be displayed in one phase, the top line should present the problem, the center line should present the location or distance ahead, and the bottom line should present the recommended driver action." This structure of messages aligns with the order of message elements suggested by Dudek, on the previous page.[90]

Effect on Travel

This information informs travelers of the severity of the situation. The message may identify or quantify a delay or travel time increase, in an attempt to help travelers form expectations about their trip or decide to change their travel (e.g., switch route). Examples of this message element could include "Major Delay," or "# Min Delay."

Audience for Action

Audience information is included when the *Action* message element applies to a specific group of travelers rather than everyone passing the DMS. Examples of this message element include "Eastbound Traffic," or "KC Metro Area."

Good Reason for Following the Action

This information gives a traveler confidence that following the advice on the DMS will result in safer travel and/or significant savings in time. Examples of this message element include "Best Route to I-5," or "Avoid # Min Delay."

Message specificity

Wang, Collyer, and Yang[91] found that more specific messages (i.e., CRASH AT EXIT 12/MAJOR DELAYS TO BOSTON/USE ROUTE I-295) are preferred to less specific messages (i.e., CRASH AT EXIT 12/MAJOR DELAYS/USE OTHER ROUTES). Survey data shows that travelers preferred precise location information, so drivers could make informed decisions about exiting/re-entering the roadway.[92] When expressing exit information, travelers preferred "THIS EXIT" instead of "NEXT EXIT.".[93] However, the message "THIS EXIT" only makes sense when the exit is clearly visible at the time the message is read on the sign.

Command/Notification Style

[89] Federal Highway Administration. (2009). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Section 6F.55.
[90] Dudek, C. L. (2004). Changeable Message Sign Operation and Messaging Handbook. (Report No. FHWA-OP-03-070). College Station, TX: Texas Transportation Institute.
[91] Wang, J.-H., Collyer, C. E., and Yang, C.-M. (2005). Enhancing Motorist Understanding of Variable Message Signs. (Report No. FHWA-RIDOT-RTD-06-1). Providence: Rhode Island Department of Transportation.
[92] Benson, B. G. (1996). Motorist attitudes about content of variable-message signs. Transportation Research Record, 1550.
[93] Ibid.

Command style messages inform drivers of a situation and suggest an action to take (e.g., "Slow Down," "Move to Right Lane"). Notification style messages simply inform drivers and allow them to determine the appropriate action on their own (e.g., "Vehicle Ahead," "Crash ½ mile"). The importance of a message should determine the message style used.[94] For critical messages, command style should be used to increase compliance. Limiting the use of command style messages to only when urgent action is necessary will help maintain respect and therefore compliance with this type of message. For less critical messages, notification style may be used.

Symbols

Results from several studies indicate that, while drivers may prefer symbols to text-based messages, they can recognize text only messages on CMSs faster and from further away than the corresponding symbol based signs.[95,96,97,98] Specific types of symbol-only messages may provide better recall over a short time than text only.[99] Drivers may be more inclined to comply with some, but not all, types of symbols than with text-only messages.[100,101] However, symbol meaning may not be easily understood as text. Familiarity and intuitiveness are key attributes associated with symbol comprehension levels. Internationally accepted symbols alone or in conjunction with variable text signs can improve the effectiveness of a sign.[102] Only symbols found in the MUTCD are acceptable to include in messages or display on CMSs. New symbols must be tested and approved by the FHWA prior to their introduction.[103]

Message Length

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[94] Dudek, C. L. (2004). Changeable Message Sign Operation and Messaging Handbook. (Report No. FHWA-OP-03-070). College Station, TX: Texas Transportation Institute.
[95] Dudek, C. L. (2004). Changeable Message Sign Operation and Messaging Handbook. (Report No. FHWA-OP-03-070). College Station, TX: Texas Transportation Institute.
[96] Proffitt, D. R., and Wade, M. M. (1998). Creating Effective Variable Message Signs: Human Factors Issues. (Report No. VTRC 98-CR31. Final Contract Report. Project No. 9816-040-940). Charlottesville: Virginia Transportation Research Council.
[97] Wang, J., Hesar, S., & Collyer, C. (2007). Adding Graphics to Dynamic Message Sign Messages. Transportation Research Record: Journal of the Transportation Research Board, No. 2018, 63-71. Retrieved from https://trid.trb.org/View/802093
[98] Clark, A., Wang, J., Maier-Speredelozzi, V., & Collyer, C. (2007). Assisting Elder Drivers' Comprehension of Dynamic Message Signs. Kingston, RI: University of Rhode Island Transportation Center. Retrieved from https://trid.trb.org/View/848458
[99] Ullman, B., Trout, N., & Sun, D. (2012). Truck-mounted Changeable Message Signs with Symbols for Work Zone Operations. Transportation Research Record: Journal of the Transportation Research Board, No. 2272, 78-86. Retrieved from http://trrjournalonline.trb.org/doi/abs/10.3141/2272-09
[100] Bai, Y., Huang, Y., & Schrock, S. L. (2011). Determining the Effectiveness of Graphic-aided Dynamic Message Signs in Work Zone. Ames, IA: Smart Work Zone Deployment Initiative/IDOT/FHWA. Retrieved from https://kuscholarworks.ku.edu/handle/1808/19837
[101] Choocharukul, K., & Wikijpaisarn, S. (2013). Modeling Impacts of Traffic Information on Driver's Route Choice Decision: An Empirical Analysis of Bangkok Expressway's Motorists. Journal of the Eastern Asia Society for Transportation Studies, Vol. 10, 600-611. Retrieved from https://trid.trb.org/View/1284154
[102] Aylward, D., & Valentine, T. (1995). Application Of Light Emitting Variable Messages Signs To Convey Information To Motorists On High Speed Highways. Vermont South, Victoria. Retrieved from https://trid.trb.org/View/642033
[103] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Section 2A.06.

CMSs should display messages that drivers have the time to comprehend as they approach the sign. The length of a message is important, because there is a limited amount of time to present information to drivers. Message length is described not only by the number of words used, but by the number of *information units* the words convey.

Information units are a measure of the message load, or total amount of information in the message. Information units are often defined as the answers to basic questions (e.g., what, where, who). If there are too many words or information units in a message, it may need to be split into two *phases*. A *phase* is defined as the information displayed on a CMS at a single point in time.

The following aspects are important to consider when designing a message and determining the appropriate length for display on a CMS. Device format should permit maximum amount of information display at a glance. Keep messages as short and concise as possible. Messages may reference other sources containing additional information (e.g., 511).

Information Units (Units) are a measure of the information presented in terms of facts used to make a decision (e.g., Table 5). A single information unit consists of one to four words. Examples of information units from Dudek[104] are:

- Eight units: Road Construction on Interstate 5 next 10 miles. Take Highway 99
- Four units: Road Construction Ahead at Jaspertown

The MUTCD[105] recommends using no more than:

- One unit per line
- Three units per phase
- Four units max per message read at speeds greater than 35 mph
- Five units max per message read at speeds less than 35 mph

Table 5. Examples of one information unit from Dudek.[106]

Question	Answer **(1 information unit)**
What is the problem?	MAJOR CRASH
Where is the problem?	AT US-23
Who is the message for?	NEW YORK
What should they do?	USE I-280 EAST

Length refers to the number of words or characters in a message, excluding prepositions (Figure 6). Based on the required reading time of 1 second per 4-8 character word (excluding

[104] Dudek, C. (2002) Guidelines for changeable message sign messages. Presentation at the TMC Pooled-Fund Study Annual Meeting, Arlington, VA. Retrieved on July 21, 2006, from http://tmcpfs.ops.fhwa.dot.gov/meetings/mtg)detail.cfm?id=10

[105] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Section 2L.05.

[106] Dudek, C. (2002) Guidelines for changeable message sign messages. Presentation at the TMC Pooled-Fund Study Annual Meeting, Arlington, VA. Retrieved on July 21, 2006, from http://tmcpfs.ops.fhwa.dot.gov/meetings/mtg)detail.cfm?id=10

prepositions) or 2 seconds per information unit, whichever is longest, Dudek[107] recommends using no more than:

- 8 words per message for drivers on a 55-mph road
- 7 words per message for drivers on a 65-mph road

Figure 6. Photo. Prepositions such as "to" do not count toward message length.
Source: Dudek.[108]

Phases are similar to pages of a book; a phase is the text that is displayed in a single point in time:

- The MUTCD[109] requires
  - Two phases max per message.
  - Each phase must be understandable alone.
- The MUTCD[110] recommends
  - One line should not contain parts of two units, but may contain two whole units.
  - When dividing messages between two phases, compatible units should be kept on the same phase (e.g., Figure 7).
- Dudek[111] suggests to not use alternating line messages.

[107] Ibid.
[108] Dudek, C. (2002) Guidelines for changeable message sign messages. Presentation at the TMC Pooled-Fund Study Annual Meeting, Arlington, VA. Retrieved on July 21, 2006, from http://tmcpfs.ops.fhwa.dot.gov/meetings/mtg)detail.cfm?id=10
[109] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Section 2L.05.
[110] Ibid.
[111] Dudek, C. (2002) Guidelines for changeable message sign messages. Presentation at the TMC Pooled-Fund Study Annual Meeting, Arlington, VA. Retrieved on July 21, 2006, from http://tmcpfs.ops.fhwa.dot.gov/meetings/mtg)detail.cfm?id=10

Poorly designed message:

Improved message:

Figure 7. Photo. The top row shows a 2-phase poorly designed message, the bottom row shows the improved 2-phase message
Source: Dudek. [111]

Information Units

One unit of information equals one answer for one question. Research and operational experience indicate that no more than four units of information should be included in a message to display on a CMS when the traffic operating speeds are 35 mph or more, or no more than five units for speeds less than 35 mph. In addition, no more than three units of information should be displayed on a single message frame.[112] The maximum number of information units per message includes the information units in all phases of the message. If the message is too long to be read at normal speeds, some drivers may slow down to read, creating a potential safety hazard. In general, message length should be reduced as much as possible without losing its intent. This can be accomplished by using the following methods:[113]

- Omit evident or redundant information.
- Delete "dead" words. Examples of "dead" words are "street," "avenue," or "boulevard" following a familiar arterial name. The word "ahead" may also be unnecessary when the road weather condition is occurring on the same freeway as the CMS.
- Use appropriate abbreviations.

Length

Dudek[114] states that the appropriate absolute message length is affected by:

- the amount of time that the driver is in the legibility zone of the CMS, considering travelling speed and environmental conditions;
- the driver workload for all driver activities; and

[112] Dudek, C. (2002) Guidelines for changeable message sign messages. Presentation at the TMC Pooled-Fund Study Annual Meeting, Arlington, VA. Retrieved on July 21, 2006, from http://tmcpfs.ops.fhwa.dot.gov/meetings/mtg)detail.cfm?id=10
[113] Ibid.
[114] Ibid.

- message familiarity.

The length of a message may be expressed as a count of individual words. The eight-word maximum for high-speed roadways is based on the driver speed legibility distance. This assumes drivers are traveling at 55 mph and the legibility distance of the sign is 650 ft (which is the approximate legibility distance for a lamp matrix sign with 18-inch character heights).[115] The lighting conditions, sun position, vertical curvature, horizontal curvature, spot obstructions, rain, fog, and trucks in the traffic stream and speeds higher than 55 mph may affect this distance.[116] If the legibility distance of a message on a CMS is reduced, then the driver's reading time is also reduced, which may suggest a necessary reduction in the number of information units contained on the sign.

Phases

Drivers have difficulty reading CMS messages that are on more than two phases.[117] Since either phase 1 or phase 2 may be read first by a passing driver, each phase should make sense by itself by providing the appropriate message regardless of sequence order read. This may be accomplished by keeping compatible information units in the same phase. In alternating-line messages, a portion of the message is held constant between the two phases, and the other portion alternates. Research on this method[118,119] showed comprehension was not affected by these alternating lines, but reading time increased. The MUTCD[120] states messages shall be limited to no more than two phases, with no more than three lines of text per phase. If more than two phases are needed, multiple CMSs may be used appropriately spaced apart from each other. Sometimes, it may be appropriate to coordinate messages to be displayed on CMSs with other forms of traveler information that may have the ability to share larger amounts of information (e.g., "TUNE RADIO TO XX AM" where XX is the radio station).[121]

[115] Ullman, G.L., Ullman, B.R., Dudek, Cl., Williams, AA., and Pesti., G. (2005) Advanced Notification messages and use of sequential portable changeable message signs in work zones. College Station, Texas A&M University.
[116] Dudek, C. (2002) Guidelines for changeable message sign messages. Presentation at the TMC Pooled-Fund Study Annual Meeting, Arlington, VA. Retrieved on July 21, 2006, from http://tmcpfs.ops.fhwa.dot.gov/meetings/mtg)detail.cfm?id=10
[117] Dudek, C. L. (2004). Changeable message sign operation and messaging handbook (Report No. FHWA-OP-03-070). College Station, TX: Texas Transportation Institute.
[118] Dudek, C. L., and Ullman, G. L. (2002). Flashing messages, flashing lines, and alternating one line on changeable message signs. Transportation Research Record, 1803, 94-101.
[119] Dudek, C. L., Schrock, S. D., and Ullman, G. L. (2005). Impacts of using dynamic features to display messages on changeable message signs (Report No. FHWA-HOP-05-069). Washington, DC: Federal Highway Administration.
[120] Federal Highway Administration. (2009, Revision Numbers 1 and 2). Manual on Uniform Traffic Control Devices for Streets and Highways. Washington, DC. Section 2L.05.
[121] Dudek, C. (2002) Guidelines for changeable message sign messages. Presentation at the TMC Pooled-Fund Study Annual Meeting, Arlington, VA. Retrieved on July 21, 2006, from http://tmcpfs.ops.fhwa.dot.gov/meetings/mtg)detail.cfm?id=10

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