Field Evaluation of Full-Matrix Color Changeable Message Signs

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INTRODUCTION

As technology and capabilities in Changeable Message Signs (CMSs) have evolved, traffic engineers are now able to install electronic signs with high resolution and can closely mimic static traffic signs. The MUTCD allows for the use of electronic signs; however, there remains a need to understand the types of messages, font styles, and backgrounds that are most effective to communicate information. The Federal Highway Administration (FHWA) through the Traffic Management Center (TMC) Pooled Fund Study (PFS) sponsored a project to develop recommendations for considerations related to the use of Color CMSs. This paper documents the field evaluation procedures and results portion of the project.

PURPOSE

The purpose of this evaluation was to determine road user understanding of and reaction to a variety of messages displayed on color, full-matrix Changeable Message Signs (CMSs). More specifically, the research team assessed the impacts that the signs have on motorists including:

- Do text and background colors influence legibility?
- Does font influence legibility?
- What are considerations for displaying CMS messages in daytime versus nighttime?
- What are participant preferences for various sign design features, and do these design features affect subjective ratings?
    - Are borders helpful on CMS messages?
    - Is there an optimal placement of symbols on CMS messages?
    - Does the use of color (i.e., color-coding) help to convey messages more easily?
- Does color influence participant feedback on sign brightness?

BACKGROUND

Chapter 2L of the Manual on Uniform Traffic Control Devices (MUTCD) (Federal Highway Administration, 2009) provides standards and guidance related to the use of CMSs. However, the MUTCD does not provide extensive guidance on the use of traffic control devices, rather it provides boundaries within which the device may be used. For some devices with a wide variety of uses, such as CMSs, additional guidelines are often necessary to further refine the best uses of these traffic control devices, as long as these guidelines fall within the Manual's boundaries.
In light of this, there is a need for further research and guidelines to better assist transportation agencies who either use full-matrix CMS or are considering their use. The information included in guidelines must identify what messages are most effective, when to use them, and which format should be used (graphics versus text). The development of said guidelines and best practices requires an in-depth analysis by professionals who thoroughly understand effective traffic control device design, understand the development and application of research designs that will result in achieving useful results, and have experience working with practitioners to determine current practice and to ensure that the guidelines developed will be in a format useful to practitioners.

A limited number of guideline and policy documents have been developed that cover using color CMSs, both within the United States and internationally. Within the United States, the bulk of these documents were developed at the state level. International documents have been collected and reviewed from a number of countries, with the bulk from agencies within Europe and Australia. Most of the policies and guidelines do not incorporate the capabilities of more modern signs.

Dudek (2004) authored the *Changeable Message Sign Operation and Messaging Handbook* for FHWA. This document is similar to others Dudek authored at the state level (e.g., New Jersey, Texas). Although this document provides the reader with a significant amount of information on CMS operation and message design, there are few details about using colors, symbols, and graphics in the document because “until highway agencies can afford to install stadium and arena type full-matrix, full-color signs, use of graphics and symbols will be limited” (pg. 5-41). The only guidance on this topic within the document is to ensure that using graphics does not compromise the size of letters in the text message (Dudek, Changeable Message Sign Operation and Messaging Handbook, 2004).

Lichty et al. developed guidance for disseminating road weather advisory information for USDOT’s Research and Innovative Technology Administration in 2012. While this document did not focus on CMS, specific guidance was written in the document for displaying messages on CMSs. Specifically, the authors recommended using different colors on the CMS: green to communicate clear or normal; yellow to communicate caution, warning, slow moving areas of traffic; and red to communicate danger, emergencies, and extremely slow traffic. The authors also recommended using red lettering or background, as well as increasing the size of the symbols and, if possible, showing the consequences of not responding appropriately when communicating highly urgent messages (Lichty, Richard, Campbell, & Bacon, 2012).

While there has been much research into using color and symbols on CMSs, there have been few studies looking into message design, especially on full-matrix CMSs. Common practice in the United States is to include a single graphic on the left-hand side of the sign and the worded message on the right-hand side; however, the literature scan shows a mixture of different message design practices used successfully outside of the United States.

From the practitioner’s perspective, a major challenge in deploying and fully using color, full-matrix CMS signs is the lack of updated and detailed guidance. Many of the guidelines developed for CMSs, both on the state and Federal level, were developed in past years where this technology was rather new and the cost for the equipment was high. As color, full-matrix CMS equipment technology has matured and costs decreased, more agencies are purchasing these devices, but guidelines have not been updated or, in some cases, developed.

While some of these guidance documents are very detailed, many others simply provide general language stating that the symbols/graphics shall be in conformance with the MUTCD. New research in this area, coupled with highlighting existing best practices and developing a concise set of detailed guidelines for using colors and symbols on full-matrix CMSs will be beneficial to both those agencies looking to update their dated documents, as well as new agencies looking to develop new guidelines. Therefore, this evaluation aims to address some of these considerations.

METHOD

In order to address the research questions, the field study was organized into two parts. The first part investigated sign legibility using different fonts and different color combinations for the sign legend and background. The second part investigated participant preferences for different sign design elements.

Part 1 – Legibility

Ten different sign designs were developed for the legibility testing. These signs varied in legend color, background color, and font. Five background colors were tested (black, green, white, orange, and yellow) and five legend colors were tested (black, red, yellow, green, and white), though not every background color and legend color were tested together. Three different fonts were evaluated: Series D, Series E, and an LED-style font. Although the Series D and Series E styles cannot be exactly recreated on a CMS as they are on static signs, the high resolution of the CMS used for this study enabled the fonts to be displayed so they visually appear the same as those used on static signs. The LED-style font represented the font style that is traditionally used on CMSs. The three different fonts were evaluated on a single legend/background color combination; all other signs were developed using Series D font. Figure 1 shows the 10 sign designs that were developed for field legibility testing.

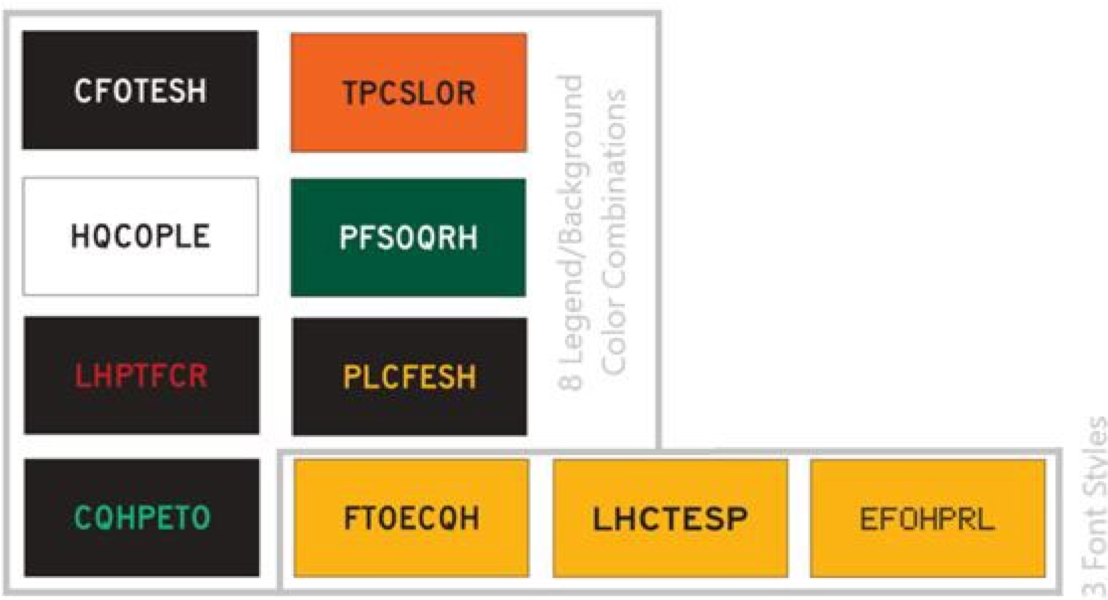


Figure 1. Example Signs Tested During the Field Study Part 1

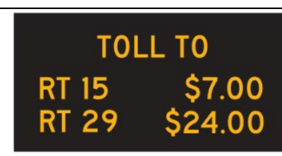
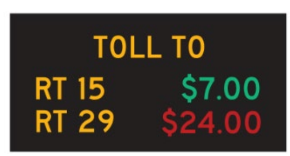
The legend and background color combinations were selected to include both positive contrast (e.g., white text on black background, hereafter referred to as "white-on-black") and negative contrast (e.g., black-on-white) signs. The white-on-green, yellow-on-black, black-on-yellow, and black-on-orange color combinations were included because these are common color combinations used on static signs and newer color CMS signs. Some participants in the laboratory study indicated that it was difficult to see red text on a black background, therefore, the red-on-black color combination was included in the field study in order to determine if there were similar findings when using a real CMS sign. The green-on-black color combination was included because this was the green included on the color-coded Travel Time and Toll Cost signs included in the laboratory study.

Each of the 10 sign designs displayed a string of seven uppercase letters. None of the messages formed a word in the English language, rather, they appeared as a random sequence of letters similar to an eye chart used for vision screening. The research team created three versions of each of the 10 signs, for a total of 30 signs. Each version of a sign included the same 7 letters that are shown on the signs in Figure 65, but presented in a different random order. For example, the white-on-black sign always included the letters C, F, O, T, E, S, and H, but versions one, two, and three of that sign had those seven letters presented in a different order. This was done to prevent participants from becoming familiar with the order in which letters were presented, thus reducing the chances that participants could recite letters by memory (rather than relying solely on reading the sign). The order of the signs displayed was developed to prevent participants from viewing signs with the same color and letter combination in succession. All participants viewed the signs in the same sequence.

Part 2 – Subjective Feedback

The second part of the field test gathered participant preference for different sign design elements including messaging with color (i.e., color-coding), border presence, and symbol placement. This entailed the participants viewing seven groups of signs. Six of these seven sign groups investigated participant preferences for different sign designs within each group of signs. Two groups of signs were used to test each of the three sign design elements of interest (symbol placement, border presence, and color-coding). The sign messages and testing goals are shown in Table 1.

Table 1. Signs Tested During the Field Study Part 2

Sign Message and Testing Goal	Sign Design		Sign Message and Testing Goal	Sign Design
ROAD WORK AHEAD Investigate participant preference for a sign border	 		RAMP CLOSED TO I-95 NORTH Investigate participant preference for the inclusion and placement of a symbol.	  
RAMP CLOSED TO I-95 NORTH Investigate participant preference for a sign border	 		TRAVEL TIME Investigate participant preference for a legend with multiple colors.	 
NO TRUCKS Investigate participant preference for the inclusion and placement of a symbol.	  		TOLL COST Investigate participant preference for a legend with multiple colors.	 

The seventh group of signs all had the same message: ROAD CLOSED AHEAD (Figure 2). This group of signs varied in background color (black, white, and yellow) as well as legend color (white, red, and black). During this part of the study, experimenters showed participants one sign at a time and asked participants to provide feedback on each sign's brightness level (e.g., sign is too bright, sign is too dim). Each sign was shown at the sign's brightest level, which was the sign's default setting.

Figure 2. Signs Studied for Brightness

Apparatus

The CMS used for this experiment was a 4 foot by 8-foot high-resolution, full color sign. The CMS had a pixel pitch of 4 millimeters, a pixel density of 62,500 pixels per square meter, and a cabinet resolution of 640 x 320 pixels. The research team mounted the sign to the side of a trailer for portability. The CMS set-up is shown in Figure 3.

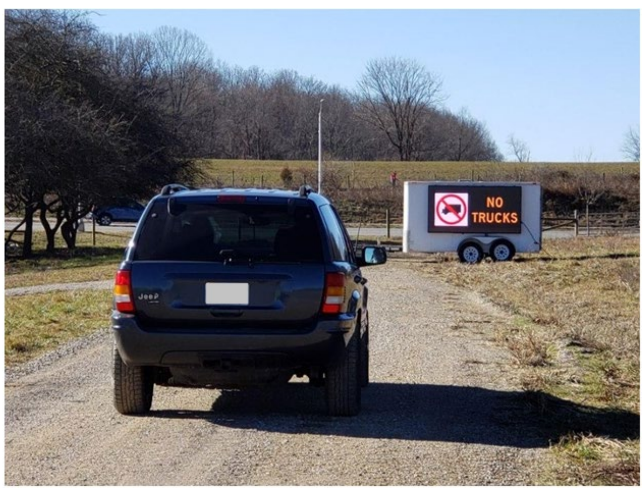


Figure 3. Photo. Experimenter and Participant during the Field Test Part 2

Participants

A total of 27 people participated in the field study, though only 26 participants produced usable data; one participant arrived late and was unable to provide responses to many of the questions, so was excluded from the data analysis. Of the 26 participants with usable data, 15 completed the study during the day and 11 completed the study at night. Participants ranged from 19-67 years old with an average age of 43 years. Forty-one percent (41%) of the participants were male (average age 53 years) and 59% were female (average age 37 years). Participants were required to be at least 18 years of age in order to participate. Their vision was scored using a Snellen Eye Chart. All participants had at least 20/40 vision in one or both eyes, corrected if necessary.

Participants were primarily recruited through an online advertisement placed on Craigslist, as well as by word-of-mouth. The advertisement provided general information about the study with a link to an online form that people could complete to submit their interest to the research team. The experiment was reviewed and approved by an Institutional Review Board (IRB).

Field Data Collection

The field study was conducted in Blacksburg, Virginia on an access road that was closed to normal traffic and provided a controlled environment where participants could not be distracted by other traffic. The access road was approximately 2000 feet long, and the section of road used as the test road for the study was approximately 800' in length with a small vertical curve and no horizontal curves. This configuration gave participants an unobstructed view of the CMS throughout the entire duration of the study.

Field data was collected between 7:30 a.m. ET and 9:30 p.m. ET each in order to analyze legibility in both daytime and nighttime conditions. As mentioned previously, a light meter was used to measure the amount of ambient lighting at the time that each participant started the study.

The participants did not drive the research vehicle; the experimenter and participant were only seated in the front seat of the research vehicle in order to view the signs and stay out of the cold. The experimenter administered a vision screening using a Snellen Eye Chart mounted inside the CMS trailer. Participants were asked to stand at a marked location that was 10' from the eye chart and asked to read the lowest line they could easily see. Participants' vision scores were recorded on a form. All participants had at least 20/40 vision in one or both eyes, corrected if necessary.

After the vision screening, the experimenter used the light meter to establish the amount of ambient lighting. The measurement was recorded on the vision screening form. The experimenter would then power on the sign and drive the participant to the furthest marked distance from the sign, which was 900'.

Once the experimenter and participants were situated at the farthest marked distance from the sign, the sign program began, and the participants viewed each of the ten signs shown in Figure 1. Participants viewed one sign at a time and were instructed to read the letters on the sign aloud, as they could see them, similar to what they might do for an eye chart. The experimenter recorded the letters read by the participants into a spreadsheet on a laptop computer. The experimenter advised participants to let him/her know if they could not see a letter or to let the experimenter know if they thought they could see a letter but were partially guessing. If participants were undecided between two letters (e.g., O or Q), the experimenter would ask them to make their best decision. After responding to the first sign, the participants repeated that process for all 10 signs.

After viewing all 10 signs at the farthest distance, the experimenter and participants moved to the next closest distance from the sign and repeated the same process of viewing all 10 signs. This process occurred at six different pre-determined distances from the sign: 900 feet, 750 feet, 600 feet, 525 feet, 450 feet, and 300 feet.[1] The order of the letters on the signs, and the order of the signs within a group were randomized and differed at each distance.

After the participants concluded the legibility testing at all six distances (Part 1), the experimenter and participants remained at the 300-foot distance for Part 2 of the field study. The second part of the field study consisted of showing participants seven different sets of signs and asking for their subjective feedback and preference for different sign designs within a given group of signs. The 300-foot distance was selected because it was a comfortable viewing distance from which the sign would be clearly legible to participants.

During this part of the testing, participants were asked questions about the signs in order to determine preferences for design elements. Participant preferences were measured for the following sign elements: border presence, symbol presence, symbol placement, color coding, and sign brightness. Each set of signs included at least two different sign designs that incorporated one of the sign elements being tested in different ways. The participants viewed each sign within a sign group twice and then the experimenter would ask the participants if they noticed any differences between the signs. The experimenter recorded participant responses on a laptop computer. Next, the experimenter told the participants the intended meaning of the current signs they were viewing and asked the participants to rate each sign alternative within that sign group. The participants saw each sign again and rated each one on a scale of 1 (would not work at all) to 5 (would work very well) to indicate how well they thought the sign conveyed the intended meaning.

[1] The distances were initially set to 900’, 750’, 600’, 450’, 300’ and 150’ but, based on an initial analysis of data, the research team decided to remove the 150’ distance due to the high level of accuracy achieved at the 300’ distance, and add the 525’ distance due to the large disparity in accuracy between the 600’ and 450’ distances.

After recording the participant's ratings, the experimenter asked participants if they preferred one sign design over the other(s), or if they had any additional feedback that they wanted to provide about the signs they just viewed. The research recorded any feedback or information that the participants provided. This process was repeated for each of the six sign groups described in Table 1. The seventh set of signs (Figure 2) was used to gauge participants' reactions to brightness levels. During this part of the study, participants saw the Road Closed Ahead sign in four different text and background color combinations. Each time a sign appeared, the participants were asked for their feedback on the brightness level (i.e., if the sign was too bright or too dim). The experimenter recorded the participants' feedback on each sign's brightness level, and this concluded their participation in the study.

RESULTS

For the legibility testing, participants were shown a sign at each of the six marked distances and asked to read the letters out loud. These were then compared against the actual letters to calculate a score for each trial ranging from 0% (0 of 7 letters correctly identified) to 100% (all 7 letters correctly identified). The maximum distance at which each participant could correctly identify all letters was found and used as the dependent variable in statistical models. There were 11 cases in which participants could not do so at any distance; these cases were assigned a legibility distance value of 0 feet. Mixed effects linear models were fit to allow for fixed effects of light (daytime vs. nighttime) and colors (and their interaction), and random effects of vision and participant-specific intercepts. Various response distributions were assessed, but the Normal always performed best. The results of the field testing are organized by the findings related to each of the field study research questions.

Do legend and background colors influence legibility?

Figure 4 shows the mean accuracy for each sign at each distance. The black-on-orange color combination garnered the longest average legibility distance (484 ft) and was statistically significantly greater than that of all other signs with the exception of black-on-yellow and white-on-black. The shortest legibility distance was observed for green-on-black (262 ft), which was not statistically different from white-on-green (290 ft).

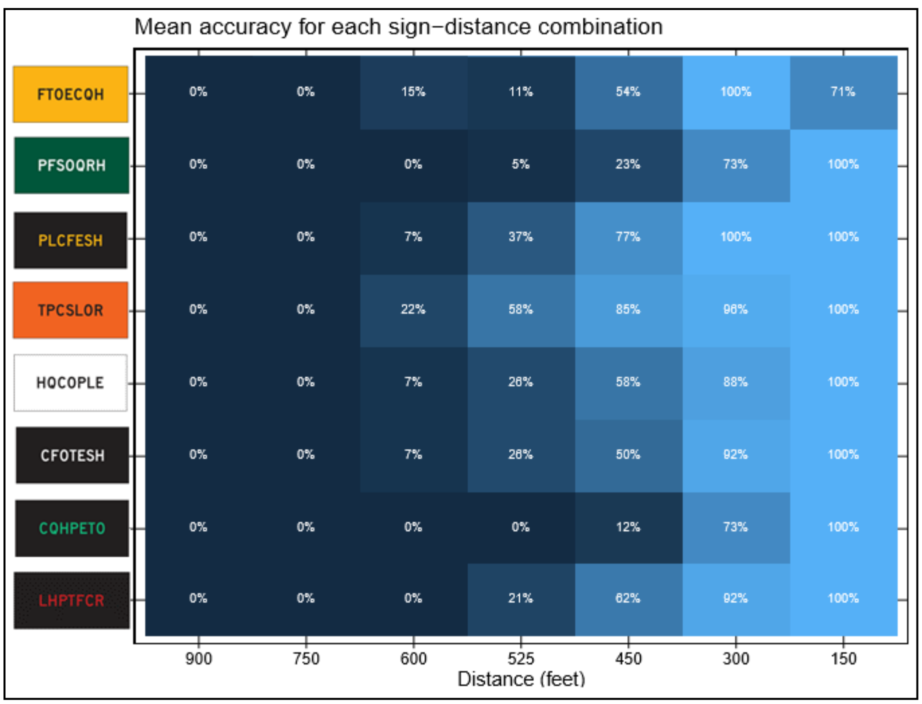


Figure 4. Mean accuracy for each sign alternative at each distance. The percentages represent the percentage of participants who were fully correct (i.e., correctly identified each letter on the sign).

The CMS used for the field testing was a 4 foot by 8-foot sign, and therefore font size was scaled to 10.4-inch letters in order to fit properly on the signs. The overall effect of light (daytime vs. nighttime) was insignificant ($p > 0.05$), but the legibility of one-color combination was affected. For yellow-on-black, daytime legibility averaged 495 feet versus 392 feet at night (difference = 103 feet, $p < 0.05$).

Does font influence legibility?

Series E garnered the longest legibility distance (509 ft), which was statistically significantly greater than the distance associated with Series D (406 ft, difference = 103 ft, $p<0.01$) and LED (439 ft, difference = 69 ft, $p<0.01$). The effect of light was not statistically significant.

Do various design features affect subjective ratings?

Participants were shown six different sign categories, each with 2-3 sign alternatives (as shown in Table 1). Each sign category was used to investigate one of three design features: border presence, the use of color-coding, and symbol placement. Participants rated each stimulus from 1 (would not work at all) to 5 (would work very well). Similar mixed effects statistical models were estimated here, using the numeric rating as the dependent variable. Participants were also given an opportunity to provide open-ended feedback on each sign category, including preference for different sign designs or any other feedback they wished to provide.

Border Presence - "Road Work Ahead" and "Ramp Closed" signs included alternatives with and without borders. The border alternative garnered higher subjective ratings of the Road Work Ahead signs (mean without border = 3.9, mean with border = 4.5, difference = 0.6, $p < 0.01$). The Ramp Closed sign ratings were not affected by the presence of a border.

The Road Work Ahead sign was used as an example where there was less text and more space between the legend and the horizontal edges of the sign, whereas the Ramp Closed sign was used as an example where there was very little background space remaining between the text and the horizontal edges of the sign. Although the average ratings for the sign with a border were similar for Road Work Ahead (4.53) and for Ramp Closed (4.47), the ratings for the signs without borders were slightly higher for Ramp Closed (4.22) than they were for Road Work Ahead (3.91). Additionally, 70% of participants indicated that they preferred the Road Work Ahead sign with the border, compared to 56% who indicated that they preferred the Ramp Closed sign with the border (even though more participants noticed the border on the Ramp Closed signs than they did on the Road Work Ahead signs). These findings could be an indication that participants may gravitate toward a border particularly when there is excess free space on a sign, however, further research would be required to examine this. The laboratory study findings did not indicate that participant ratings were influences by border presence, but rather were influenced by symbol use/placement or text/background color. The effect of light was insignificant for both signs.

Color Coding - “Travel Time” and “Toll Cost” signs included alternatives with yellow text and multi-colored text. The yellow-only alternative garnered higher subjective ratings of the Travel Time signs (mean with yellow text = 4.2, mean with multi-colored text = 3.6, difference = 0.6, $p < 0.05$). However, this difference only appears among the daytime participants (difference = 0.9, $p < 0.05$; at night: difference = 0.4, $p > 0.05$). The Toll Cost sign ratings were not affected by text color or light ($p>0.05$).

Although participants in the laboratory were not asked their preference for the Travel Time or Toll Cost signs, they were asked what they thought the colors (i.e., color-coding) were trying to tell them. For the Toll Cost signs, about 54% of participant responses indicated a general understanding of the intended meaning of the color-coding (indicating amount of traffic and/or cost relative to normal). For the Travel Time signs, about 71% indicated a general understanding of the intended meaning (indicating amount of traffic and/or travel times relative to normal times). With participant preference for Toll Cost and Travel Time signs at 52% and 56%, respectively, and participant understanding of the meaning behind the color-coding (54% and 71%, respectively), it is possible that preference for signs (yellow-only vs. color-coded) could be influenced by their understanding of the color-coding.

Symbol Placement - “Ramp Closed” and “No Trucks” signs included alternatives with three different symbol placement options. The presence of a symbol (whether placed in the center or on the left) garnered higher subjective ratings of the Road Closed signs (mean without symbol = 3.2, mean with symbol in center = 4.1, mean with symbol on left = 4.5; difference between no symbol and center = 0.9, $p<0.01$; difference between no symbol and left = 1.3, $p<0.01$; difference between center and left = 0.4, $p>0.05$). Center-placement (symbol-only) garnered lower ratings of the No Trucks alternatives (mean symbol in center = 3.0, mean with symbol on left = 4.2, mean with symbol on right = 4.5; difference between center and left = 1.2, $p<0.01$; difference between center and right = 1.5, $p<0.01$; difference between left and right = 0.2, $p>0.05$). The effect of light was insignificant for both signs.

For the No Trucks sign group, participants were asked if they had any preference for certain signs over the others. Eighty-two percent (82%) of participants preferred a sign with both the symbol and the text, as opposed to the symbol-only sign. Approximately 42% of participants specified that they particularly prefer the symbol to the right of the text, whereas 19% specified that they prefer the symbol to the left of the text. The findings are similar to the laboratory findings regarding No Trucks signs. Participants rated the signs with both symbols and text higher than the symbol-only signs.

Participants were also asked to indicate if they had any preference for certain signs in the Ramp Closed sign group. Thirty-five percent (35%) of participants indicated that they prefer the sign with the route shield to the left of the text, 31% preferred the sign with the route shield within the text, 15% preferred either sign that included a route shield, 15% preferred the sign with text only, and 4% had no preference. The participants (35%) who preferred the route shield to the left of the text liked that this sign had both the symbol (route shield) and the test. They also tended to like that the route shield was larger on this sign, which they reported was helpful if you are looking for I-95, and also helpful if you are not looking for I-95 because you would see the route shield first, know that the sign doesn't apply to you, and thus not have to read the rest of the sign. The participants (31%) who preferred the sign with the route shield within the text liked that this sign had both text and symbol (route shield), but generally thought that this sign "flowed" the best. They liked that it included both the symbol (route shield) and the text but indicated that it seemed less crowded than the sign with the route shield to the left of the text. Participants liked that this sign could be read like a sentence and was more intuitive than the sign with the route shield on the left because in that scenario they have to connect what the symbol and words are saying. They also felt like the sign with the route shield within in text didn't feel as cramped as the sign with the route shield to the left of the text. The participants (15%) who preferred the sign with only text indicated that this sign was simple and easiest to read. These findings were similar to the Ramp Closed findings from the laboratory study. Although reaction times were slightly higher than average for the symbol-center and slightly lower than average for the symbol-right, the rankings indicated that participants preferred either sign that included the symbol with the text over the sign than included text-only.

In general, the laboratory and field study findings regarding symbol placement are similar in that participants prefer signs that include both symbols and text more than text-only signs or symbol-only signs.

Participant Feedback on Sign Brightness for Different Legend and Background Colors

Participants were shown four different legend/background color combinations for a Road Closed Ahead sign and provided feedback on the brightness of each sign. Participant responses were coded into one of three categories based on the feedback they provided about the sign brightness: "too bright" (+1), "good level of brightness" (0), and "too dim" (-1).

A mixed effects linear model was fit to allow for fixed effects of light and colors (and their interaction), and random effects of vision and participant-specific intercepts. The findings indicated that text/background color combination influences how bright participants feel a sign is. The black-on-white sign alternative was rated as the brightest color combination (mean rating = 0.64, 95% CI: 0.45, 0.83), while the red-on-black was rated as the dimmest (mean rating = -0.28, 95% CI: -0.48, -0.07). Black-on-white was rated as significantly brighter than all other combinations ($p < 0.05$). Red-on-black was rated as significantly dimmer than black-on-white (difference = 0.9, $p < 0.01$) and black-on-yellow (difference = 0.5, $p < 0.01$), but not white-on-black (difference = 0.3, $p > 0.05$). Black-on-yellow and white-on-black were not statistically significantly different from one another ($p > 0.5$).

An analysis was conducted to determine if perception of brightness for each sign varied by time of day (daytime vs. nighttime). Overall, the signs rated during the night were rated as brighter than those rated during the day (difference = 0.3, $p < 0.01$). However, the statistical significance of this difference disappears when examining each sign individually ($p > 0.05$).

CONCLUSIONS AND RECOMMENDATIONS

Symbol Use and Placement -

Participant subjective ratings indicated that signs with both text and symbols (with the symbols presented either to the left or right of the text) are preferred over other sign alternatives across all sign categories that were tested with symbols. Further research would be required to determine if sign comprehension is influenced by symbols for different sign messages other than the seven sign messages that included symbols in this study. For example, research on other sign messages not included in this study may indicate that sign messages that are not as comprehensible could benefit from the use of a symbol (e.g., to benefit non-native English speakers).

Use of Color -

The field study indicated that the black-on-orange signs resulted in the longest average legibility distance and was significantly greater than all other signs except for the white-on-black and black-on-yellow signs. The field study also indicated the shortest legibility for green-on-black signs, followed by white-on-green signs. The field study yielded no statistically significant differences between the white-on-black, yellow-on-black, black-on-white, and black-on-yellow signs.

When examining the concept of color-coding, participant field ratings of the Travel Time and Toll Cost signs garnered higher ratings for the yellow-only (not color-coded) alternatives for Travel Time signs (for daytime participants only), with no difference for Toll Cost signs. For both the Travel Time and Toll Cost categories, more participants (52% and 56%, respectively) furthered mentioned that they preferred the yellow-only signs than those who mentioned they preferred the color-coded sign (26% and 30%, respectively), with 19% (in both sign categories) indicating no preference.

Use of Borders -

In the field study, participant subjective ratings for the Road Work Ahead signs were significantly higher for the sign with the border than the sign without the border. And, although more participants noticed the border for the Ramp Closed signs than they did on the Road Work Ahead signs, fewer participants mentioned that they prefer the sign with the border for the Ramp Closed signs than for the Road Work Ahead signs. These findings could be due to the amount of text that is included on the signs. The Ramp Closed sign has more text that extends to the edge of the border, whereas the Road Work Ahead sign includes more free space between the text and the edge of the border. However, the signs were also presented in different text/background color combinations. Additional research, focused on the presence of borders, would be required to better understand why borders might improve legibility and to further examine the effects of background color and amount of text on preference for borders.

Considerations for Use of CMS in Daytime versus Nighttime -
Legibility distances in the field study did not vary significantly in the daytime versus nighttime, except for yellow-on-black signs. For these signs, legibility distance was significantly longer during the daytime than at nighttime. Participant subjective ratings of signs with varying design features (border presence, color-coding, symbol placement) were not affected by light (daytime vs. nighttime), except for the Travel Time signs. For these signs, participants rated the yellow-only signs significantly higher than the signs with multi-colored text, but only during the daytime.

Participants were shown four different legend/background color combinations (black-on-white, black-on-yellow, red-on-black, white-on-black) for a text-only sign and provided feedback on the brightness of each sign. Overall, the signs rated during the night were rated as brighter than those rated during the day. However, the statistical significance of this difference disappears when examining each sign individually.

Font Style -
The findings indicated that Series E had the longest average legibility distance, which was significantly longer than Series D and the LED-style font. This is not a surprising finding, as Series E has wider letters and was designed to be seen further than Series D, even on static signs. A more comprehensive font study could also examine the effects of mimicking signs using mixed-case on CMSs.

Limitations and Future Research -
A limitation of the current study is that font style was only evaluated using one text/background color combination. This preliminary look into font on CMSs showed that different font styles may be more effective than others on full matrix color CMSs, however, a more comprehensive study looking at legibility of various fonts would be useful. A secondary study could evaluate fonts using various text and background color combinations. Additionally, although the current study included a preliminary evaluation of the effects of color on perception of sign brightness, a study focused specifically on brightness and lighting could evaluate optimal levels of brightness under varying lighting conditions. Additionally, due to the design of the current field study, the CMS (which was mounted to a trailer) essentially resembled a ground-mounted sign. The current study did not evaluate what the impacts would be if the sign was overhead.

Additional research would be needed to determine which symbols are highly recognizable to motorists and which are not. Though some research has been conducted on symbol signs using static signs, additional research would be required, followed by deployment and use, to determine what factors make a symbol highly recognizable to motorists.

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