pennsylvania
DEPARTMENT OF TRANSPORTATION

# Evaluation of Colored VMS Boards

FINAL REPORT

July 20, 2018

By S. Ilgin Guler, Kristin Kersavage
and Martin T. Pietrucha

The Pennsylvania State University PennState College of Engineering | LARSON TRANSPORTATION INSTITUTE

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF TRANSPORTATION

CONTRACT # 4400015622
WORK ORDER # 004

Technical Report Documentation Page

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| PA-2018-007-511601 WO 004 | | |

| 4. Title and Subtitle | 5. Report Date<br>July 20, 2018 |
|---|---|
| Evaluation of Colored VMS Boards | 6. Performing Organization Code |
| **7. Author(s)**<br>S. Ilgin Guler, Kristin Kersavage and Martin T. Pietrucha | **8. Performing Organization Report No.**<br>LTI 2018-10 |
| **9. Performing Organization Name and Address**<br>The Thomas D. Larson Pennsylvania Transpiration Institute<br>Department of Civil and Environmental Engineering<br>The Pennsylvania State University<br>201 Transportation Research Building<br>University Park, PA 16802-4710 | **10. Work Unit No. (TRAIS)**<br><br>**11. Contract or Grant No.**<br>4400015622 |
| **12. Sponsoring Agency Name and Address**<br>The Pennsylvania Department of Transportation<br>Bureau of Planning and Research<br>Commonwealth Keystone Building<br>400 North Street, 6th Floor<br>Harrisburg, PA 17120-0064 | **13. Type of Report and Period Covered**<br>Final Report 12/12/2017 – 7/20/2018<br><br>**14. Sponsoring Agency Code** |

**15. Supplementary Notes**

Contracting Officer's Technical Representative: Jerome Frederick, jerfrederi@pa.gov, 717-265-7557

**16. Abstract**

Variable message signs (VMS), often referred to as changeable message signs or dynamic message signs, present traffic information to motorists in either real-time or asynchronous static conditions. Typically installed on freeways, VMS can communicate information to motorists that includes early warning messages, advisory messages, or alternative route messages. The Pennsylvania Department of Transportation (PennDOT) is in the process of installing new, permanent VMS along several corridors throughout the state. Some of these signs are capable of presenting full-color messages to approaching drivers. PennDOT wishes to exploit their use for roadway users so that drivers will be better able to plan their travel and select the best travel routes in real time. The objective of the research project described herein was to evaluate the visibility and comprehensibility of a series of alternate VMS sign designs to provide PennDOT with research-based guidance to format optimal sign designs. A subset of monochromatic VMS (amber in color), representing current usage in Pennsylvania, was also included in the study to determine the best way to convey information using this type of sign. The results of the study show that the best design for comprehensibility and visibility of VMS signs would entail the following: (1) messages would display only time information, not travel distance information; (2) route numbers would be displayed by numbers rather than shields; (3) monochromatic signs would be used, but if colored VMS are used, the best use of color would be to display a congested travel time in red; and (4) the background would be black. Following these guidelines would result in the best comprehensibility of signs with no significant difference in the gender, age, or colorblindness of travelers.

| 17. Key Words | 18. Distribution Statement |
|---|---|
| Variable message signs, changeable message signs, dynamic message signs, early warning messages, advisory messages, alternative route messages, sign visibility, sign comprehensibility | No restrictions. This document is available from the National Technical Information Service, Springfield, VA 22161 |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | 51 | |

**Form DOT F 1700.7** **(8-72)** **Reproduction of completed page authorized**

## Disclaimer

# Table of Contents

# List of Figures

# List of Tables

# 1. Introduction

Variable message signs (VMS), often referred to as changeable message signs (CMS) or dynamic message signs (DMS), present traffic information to motorists in either real-time or asynchronous static conditions. Typically installed on freeways, VMS can communicate information to motorists that includes early warning messages, advisory messages, or alternative route messages (Dudek, 2004). While real-time traffic congestion condition status is the preferred information to be included on VMS, asynchronous or static information can also be displayed, such as safety messages. The Manual on Uniform Traffic Control Devices (MUTCD) offers some guidance and provisions for VMS and mentions numerous applications for these signs, such as (FHWA, 2009):

- Control at crossing situations,
- Destination guidance,
- Incident management and route diversion,
- Lane, ramp, and roadway control,
- Priced or other types of managed lanes,
- Special event applications associated with traffic control or conditions,
- Speed control,
- Traffic regulations,
- Travel times,
- Warning of adverse weather conditions, and
- Warning situations.

As of 2015, the Federal Highway Administration (FHWA) reported that 76 cities or towns (n.b., each dot may signify multiple jurisdictions/locations within the area designated by that dot) in the United States provided travel times to drivers using dynamic message signs, and an additional 8 cities or towns had plans to provide travel times to users, as shown in Figure 1.1 (FHWA, 2015).

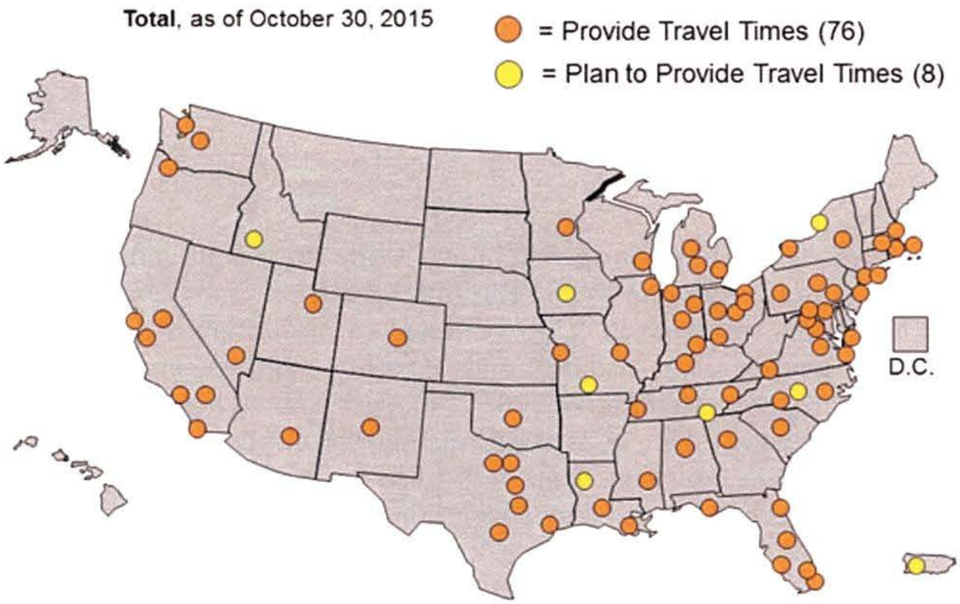



**Figure 1.1.** Status of travel times displayed on dynamic message signs in 2015 (FHWA, 2015).

As described above, while VMS have been used extensively within the United States for many years, changes to the signing technology now allow for great use and variety of colored fonts, backgrounds, and ancillary information (e.g., route markers/shields) on these signs. While it is anticipated that the use of color on these signs could yield performance gains, little research has been done to examine this idea.

The Pennsylvania Department of Transportation (PennDOT) is in the process of installing new, permanent VMS along several corridors throughout the state. Some of these signs are capable of presenting full-color messages to approaching drivers. PennDOT wishes to exploit their use for roadway users so that drivers will be better able to plan their travel and select the best travel routes in real time.

The objective of the research project described herein was to evaluate the visibility and comprehensibility of a series of alternate VMS travel time message formats to provide PennDOT with research-based guidance to format optimal sign designs. A subset of monochromatic VMS (amber in color), representing current usage in Pennsylvania, was also included in the study to determine the best way to convey information using this type of sign.

This report details the research completed by the Thomas D. Larson Pennsylvania Transportation Institute at Penn State to fulfill the objectives stated above. The work described herein covers a literature review, expert interviews, and extensive laboratory human factor-based analyses.

# 2. Literature Review

This section synthesizes the literature pertaining to VMS messaging and state department of transportation (DOT) practices using VMS. The first subsection discusses the various types of messages that have been included on VMS or tested to be displayed on VMS. The second subsection presents guidance for visibility and legibility requirements of VMS. The third subsection discusses the design characteristics of VMS, such as front height and width. The fourth subsection examines message length, units of information, and display time for messages on VMS. The fifth subsection presents typical methods used when analyzing data from VMS experiments. The sixth and final subsection offers some conclusions related to the findings of the literature review report.

## 2.1 Types of Messages on VMS

VMS can be used to display many different types of messages and provide users with multiple bits of information; however, not all messages are considered useful by motorists. When choosing messages to display on VMS, the needs of the users should be considered so that the most effective information is disseminated, especially real-time travel information. In addition to the applications of VMS messages listed in the MUTCD, the manual also mentions that VMS can be used to display other messages, such as "safety messages, transportation-related messages, emergency homeland security messages, and America's Missing: Broadcast Emergency Response (AMBER) alert messages" (FHWA, 2009). An example template for colored dynamic message signs is shown in Figure 2.1.

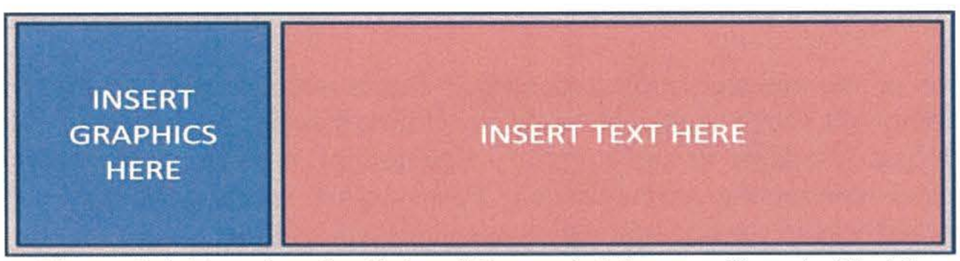



**Figure 2.1.** Template for Colored Dynamic Message Signs in Florida (Heller et al., 2012; Figure 1)

While there are many different message types for VMS, the main information that motorists, in particular commuters, want to receive is travel times to specific destinations (Lerner et al., 2009; Robinson et al., 2017), especially in areas where recurring congestion is an issue (Paniati and Lindley, 2004). Studies have shown that a successful way of disseminating travel time information is via VMS (Martin, 2007). Displaying travel information with the units of time has been found to be the most useful way of disseminating congestion information, while distance to destination, travel speeds, or congestion descriptions were found to be less beneficial (Lerner et al., 2009).

Additionally, street names or towns are recommended for the destinations listed on VMS, as opposed to exit numbers, which are not recommended (Lerner et al., 2009).

The Strategic Highway Research Program (SHRP 2) Reliability Program conducted a study consisting of surveys and focus groups to determine the effectiveness of disseminating travel information and identifying the best messaging and wording to communicate travel time (Kuhn et al., 2014a; Kuhn et al., 2014b). The travel time types considered were average travel time, buffer time, arrival time, departure time, recommended departure time, recommended route, and 95th percentile travel time. Buffer time refers to "the extra time, or time cushion, that travelers add to their average travel time" (Kuhn et al., 2014a) to account for possible delays. Including departure time and buffer time on dynamic message signs was deemed not appropriate, and the majority of people did not understand what the 95th percentile travel time meant (Kuhn et al., 2014a; Kuhn et al., 2014b). The preferred messaging to portray average travel time was estimated travel time (Kuhn et al., 2014a; Kuhn et al., 2014b). Furthermore, graphics (e.g., the so-called GRIP or graphic route information panels) can also be used on VMS to portray information to motorists (Ma et al., 2014; Roca et al., 2018). In a study that utilized a survey questionnaire, respondents preferred messages with graphics as compared to messages with only text, with the graphic placed on the left side (Wang et al., 2007).

In addition to providing real-time traffic information to motorists, such as travel time to a specific destination, VMS can be used by agencies to divert traffic in an effort to reduce congestion on a specific route. Route diversion can include messages stating a particular alternative route for motorists or can be used to simply display an advisory that motorists should use another route without specifying a particular alternative route. While it can be difficult to divert motorists to different routes by displaying travel time on VMS (Lerner et al., 2009), using certain terms in the messaging can aid in maximizing route diversion (Lerner et al., 2009; Robinson et al., 2017). Examples of messaging that can be used to maximize route diversion are shown in Table 2.1.

While the goal of messaging, such as that displayed in Table 2.1, is to encourage the use of alternative routes by motorists, the exact impact of the VMS messaging is difficult to quantify and there is a significant lack of data regarding potential impacts (Lerner et al., 2009). Another method to increase the use of alternative routes could be displaying traffic information to motorists prior to their entering the freeway on freeway approaches (Lerner et al., 2009).

Several states have published best practices related to their use of dynamic message signs, including deployment information, system planning and development, data collection and processing, travel time messaging, public outreach and impacts, issues and how they were resolved, and lessons learned. These states include: Oregon, Tennessee, Texas, and New York (New York State Thruway Authority, 2011; Oregon Department of Transportation, 2005; Tennessee Department of Transportation, 2005; Texas Department of Transportation, 2005).
The Oregon Department of Transportation (ODOT) uses dynamic message signs in Portland for road closures, emergency situations, incidents, construction and maintenance operations, adverse weather conditions, special events information, travel time information, and public service announcements (Oregon Department of Transportation, 2005). An example of the traffic information posted on a dynamic message sign targeting local commuters in Portland is shown in Figure 2.2. A survey conducted by the ODOT showed that while motorists found the information

useful in congested conditions, in free-flow travel conditions, motorists preferred that traffic information was not shown on dynamic message signs (Oregon Department of Transportation, 2005).

**Table 2.1.** Messaging to maximize route diversion (Robinson et al., 2017; Table 16).

| Messaging Description | Display Messaging | Display Example |
|---|---|---|
| Recommended alternate route | USE ALT RTE | TRAVEL TIME TO<br>FALLS RD 16 MIN<br>USE ALT RTE |
| Specific route | VIA RTE 355 | TRAVEL TIME TO<br>FALLS RD 16 MIN<br>USE ALT RTE<br>VIA RTE 355 12 MIN<br>or<br>TRAVEL TIME TO<br>DEMOCRACY 24 MIN<br>HOV SAVES 5 MIN |
| Major delay or incident information | MAJOR DELAY | MAJOR DELAYS AHEAD<br>DETOUR SHADY GROVE |
| Open-ended travel time estimate | 30+ MIN | TRAVEL TIME TO<br>SHADY GROVE 10 MIN<br>GW PKWY 30+MIN |
| Travel times for both current and alternative route | - | TRAVEL TIME TO<br>PEACHTREE 18 MIN<br>USE ALT RTE<br>VIA RTE 33 7 MIN |

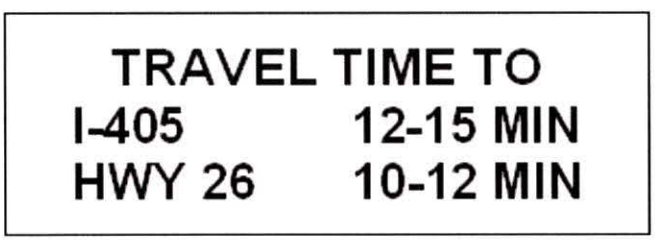



**Figure 2.2.** Example dynamic message sign with travel time information in Portland, Oregon (Oregon Department of Transportation, 2005; Figure 1).

While the Oregon Department of Transportation provided travel time information to motorists, the Tennessee Department of Transportation (TnDOT) provided both travel time (in two to three minute ranges) and distance to a specific destination in Nashville (Tennessee Department of Transportation, 2005). These dynamic message signs always display travel time information unless there is an incident that is reported on the signs instead, as the TnDOT prefers to have information appear on the signs instead of leaving them blank (Tennessee Department of Transportation, 2005). An example dynamic message sign is shown in Figure 2.3.


**Figure 2.3.** Example dynamic message sign in Nashville, Tennessee (Tennessee Department of Transportation, 2005; Figure 2b).

Similar to the method used by the Oregon Department of Transportation, the Texas Department of Transportation (TxDOT) also displays travel times to motorists on dynamic message signs in Houston (Texas Department of Transportation, 2005). Through a survey, TxDOT determined that motorists preferred to see travel time information and also incident information. TxDOT created a hierarchy of displaying information on dynamic message signs, which is (1) incidents, (2) construction or pre-construction, (3) amber alerts, (4) travel times, (5) special events, and (6) safety campaigns (Texas Department of Transportation, 2005). An example of the format and message of a dynamic message sign in Houston is shown in Figure 2.4.

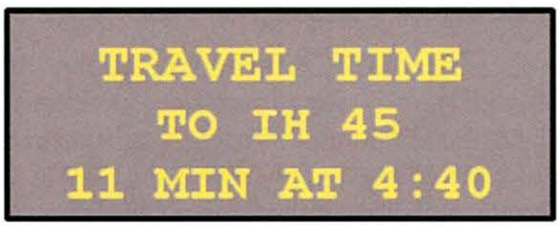



**Figure 2.4.** Example dynamic message sign in Houston, Texas (Texas Department of Transportation, 2005; Figure 3).

The New York (NY) State Thruway Authority (Thruway) also uses dynamic message signs to provide motorists with information. Message categories displayed on dynamic message signs are incident management, public safety, congestion management, motorist guidance, construction and maintenance activities, special events, environmental, law enforcement messages, and public service campaigns (New York State Thruway Authority, 2011). The Thruway offers general standards for messages on dynamic message signs. Some guidelines include leaving the sign blank if there is no message, not using the signs for advertising, and avoiding the use of exploding or moving messages (New York State Thruway Authority, 2011).

While there are many different types of messages that can be displayed on VMS, a common practice described in the literature and state practice guides is to include travel time to a specific destination on VMS. Travel times on VMS should reflect the actual roadway conditions and change accordingly. However, it should be noted that "travel time messages are not appropriate for every DMS or for every hour of the day (Paniati and Lindley, 2004)."

## 2.2 Legibility and Visibility of VMSs

While the sign visibility can be considered "an imprecise term in that it encompasses both sign detectability and sign legibility" (Garvey and Kuhn, 2004), the legibility distance of a VMS is "the maximum distance at which a driver can first correctly identify letters and words" (FHWA, 2009). The MUTCD offers guidance for the legibility and visibility of VMS, which differs in daytime and nighttime conditions. VMS should be visible from one-half mile away on roadways with speed limits of 55 mph or above for both daytime and nighttime conditions (FHWA, 2009). Under normal conditions, the legibility distance at night should be a minimum of 600 ft and in the day should be 800 ft. However, when these conditions cannot be met, for example when environmental conditions reduce legibility and visibility, messages should be shortened and, if possible, limited to one phase (FHWA, 2009). Further, VMS should be displayed in a positive contrast format (i.e., light text on a darker background) (FHWA, 2009).

A different perspective states that regulatory, warning, or guidance messages on VMS should be legible from at least 200 meters (approximately 565 feet) (Bezuidenhout, 2015). However, messages that are considered essential, such as speed limits, should be visible from 150 meters (approximately 492 feet) (Bezuidenhout, 2015). VMS should also be visible up close, as close as 35 meters (approximately 115 feet) (Bezuidenhout, 2015).

## 2.3 Design Characteristics of VMS

VMSs can vary in design; however, the MUTCD mentions that they "shall not include advertising, animation, rapid flashing, dissolving, exploding, scrolling, or other dynamic elements (FHWA, 2009)." VMS should also display a maximum of three lines of text (FHWA, 2009; Robinson et al., 2017) and not include more than 20 characters on each line (FHWA, 2009). When VMS contain more than three lines, undesirable demands on the drivers' attention may occur due to the need of drivers to read and process more information, which is why messages should be limited to two or three lines and not exceed three lines (Lerner et al., 2009). Robinson et al. (2017) also noted that four destinations (or three destinations) on a VMS took longer for motorists to process as compared to a VMS with three destinations (or two destinations).

The spacing on VMS differs between characters (i.e., kerning), words, and lines. The kerning on VMS is recommended to be 25 percent to 40 percent of the letter height (FHWA, 2009; Garvey, 2002). The spacing between words should be 75 percent to 100 percent of the letter height, and the inter-line spacing should be 50 percent to 75 percent of the letter height (FHWA, 2009; Garvey, 2002).

In addition to the number of lines and spacing, guidance is available on the capitalization and height of letters on VMS. Words should consist of all uppercase letters (FHWA, 2009; New York State Thruway Authority, 2011; Robinson et al., 2017). Abbreviations should also be in all uppercase letters (Robinson et al., 2017). While Garvey (2002) recommends using uppercase or mixed case for single words and using lowercase for longer textual messages, this is not supported by the MUTCD.

When roadways have a speed limit of 45 mph or higher, the minimum height for letters on VMS should be 18 inches (FHWA, 2009; New York State Thruway Authority, 2011). The New York State Thruway Authority allows using letters with a smaller height, but this must be approved by the Authority (New York State Thruway Authority, 2011). When roadways have speed limits less than 45 mph, the minimum height for letters on VMS should be 12 inches (FHWA, 2009). There is also guidance relating to the width of letters on VMS (generally thought of as the width-to-height ratio). It is recommended that letters on VMS have a width-to-height ratio between 0.7 and 1.0, and the width-to-height ratio of the stroke is recommended to be 0.2 (FHWA, 2009; Garvey, 2002).

It should be noted that there are several other VMS characteristics that impact the message display that are not fully covered in the MUTCD. These characteristics include the VMS display type (e.g., full matrix versus line matrix) and pixel pitch (i.e., the space between pixels). PennDOT typically determines the requirements for these characteristics on a project-by-project basis. This allows PennDOT to procure a VMS that fits the specific needs intended for the use within the particular region.

While there is guidance in the MUTCD regarding legibility requirements for letters and words on VMS, a study was performed for TxDOT to test different letter heights and widths to determine the optimal letter design characteristics (Carlson, 2016). The experiment tested (1) letters with a height of 16 inches (height of 20 pixels and width of 12 pixels), (2) 18 inches (height of 23 pixels and width of 14 pixels), and (3) 18 inches with a wider footprint (height of 23 pixels and width of 15 pixels). Each VMS had a blue background with white text. The signs were designed so that one type had the text covering the whole sign and the other had about one third of the VMS blank (i.e., one third being negative space). The various VMS designs are shown in Table 2.2. Through testing of the various VMS font and sign type combinations, it was determined that 18-inch letters were seen farther away than 16-inch letters, and the legibility of all the fonts was around 40 ft per inch, which is the minimum recommended legibility index in the Texas MUTCD (Carlson, 2016). Additionally, leaving one third of the sign blank did not have an effect on the sign legibility. This could allow for the placement of a sponsor logo on the sign in the open area (Carlson, 2016).

There is some guidance on the justification of words and lines on VMS. Many sources recommend justifying the destinations on the left and justifying the travel times on the right (Lerner et al., 2009; Robinson et al., 2017). The heading is also recommended to be center justified on the top of the sign (Lerner et al., 2009; Robinson et al., 2017). An example of this formatting on a VMS is shown in Figure 2.5. However, the New York State Thruway Authority mentions that the text on its VMS must be center justified as stated in their general standards for these types of signs (New York State Thruway Authority, 2011).

**Table 2.2.** VMS sign designs tested by the Texas Department of Transportation (Carlson, 2016; Table 2, Table 3, Table 4).

<table>
<tr><th>VMS Image</th><th>VMS Image</th></tr>
<tr><td><br><br>Full board, 16-inch letters (20 x 12 pixels)</td><td><br><br>Full board, 18-inch letters (23 x 15 pixels)</td></tr>
<tr><td><br><br>Two-thirds board, 18-inch letters (23 x 14 pixels)</td><td><br><br>Two-thirds board, 18-inch letters (23 x 15 pixels)</td></tr>
<tr><td><br><br>16-inch letters (20 x 12 pixels)</td><td><br><br>18-inch letters (23 x 14 pixels)</td></tr>
<tr><td colspan="2"><br><br>18-inch letters (23 x 15 pixels)</td></tr>
</table>


**Figure 2.5.** Example VMS with recommended word justification (Robinson et al., 2017; Figure 49).

The luminance contrast of VMS is recommended to be between 8 and 10 for daytime and nighttime conditions (FHWA, 2009; Garvey, 2002). A luminance of 30 candela per square meter (cd/m$^2$) for nighttime conditions and a luminance of greater than 1,000 cd/m$^2$ for daytime conditions are recommended (Garvey, 2002). In addition to the luminance, the text color on VMS is recommended to be either green or yellow with a positive contrast orientation. The NY State

Thruway Authority recommends displaying numbers and characters in the color amber (New York State Thruway Authority, 2011). However, the MUTCD does offer guidance stating that when a black VMS background is used, the legend color should coincide with standard sign color for that sign type (FHWA, 2009). For example, yellow should be used for warning signs, red should be used for stop or yield signs, and white should be used for regulatory signs (FHWA, 2009). Additionally, one study, employing a survey questionnaire, reported that respondents preferred amber messaged over green and red messaged (Wang et al., 2007).

PennDOT currently utilizes its *Dynamic Message Sign Operating Standards* guideline, published in 2013, to provide its Regional Transportation Management Centers (RTMCs) with design guidance for travel time message formats (Figure 2.6) (Pennsylvania Department of Transportation, 2013).

These templates serve as a starting point for the RTMCs to develop travel time messages; however, the message formats are usually different than the templates based on the location of the sign and the relevant destinations and/or routes that are within the vicinity of the VMS location.

**Travel Times**

| Sign | Phase 1 | Phase 2 | Examples | |
|---|---|---|---|---|
| TRAVEL<br>TIME<br>AHEAD | TRAVEL TIME AHEAD<br>I-XX TO I-XX<br>XX MI XX MIN | | TRAVEL TIME AHEAD<br>I-83 TO I-81<br>4 MI 12 MIN | |
| TRAVEL<br>TIME<br>TO | AVG TRAVEL TIME TO<br>US X (X MI) X MIN<br>I-XX (XX MI) XX MIN | | AVG TRAVEL TIME TO<br>US 30 (5 MI) 8 MIN<br>I-83 (12 MI) 18 MIN | |
| TRAVEL<br>TIME<br>2ND PHASE | | (ROUTE) - XX MIN<br>(ROUTE) - XX MIN<br>(ROUTE) - XX MIN | | I-95 - 8 MIN<br>US 1 - 10 MIN<br>I-76 - 12 MIN |

**Figure 2.6.** Pennsylvania Guideline for Travel Time Message Formats (PennDOT, 2013)

It should be noted that PennDOT is currently in the process of revising these guidelines, and a new version is expected to be published during the 2018 fiscal year.

The Florida Department of Transportation has provided guidelines for the use of dynamic message signs, which includes permitted and prohibited message types along with travel time templates. These guidelines state that dynamic message signs displaying travel time messages should have a black background and amber colored text (Figure 2.7) (Heller et al., 2012). Dynamic message signs displaying event management messages, such as warning messages or incident management alerts, should have a black background with yellow text (Figure 2.8) (Heller et al., 2012).

**Figure 2.7.** Florida Template for Travel Time Messages (Heller et al., 2012; Figure 2)

**Figure 2.8.** Florida Template for Event Management Messages (Heller et al., 2012; Figure 3)

Additionally, in dynamic message sign guidelines, the Florida Department of Tranportation prescribes legend and background colors for each type of sign message, as shown in Table 2.3 (Heller et al., 2012).

As previously mentioned, many cities and states have used and currently use VMS to provide information to drivers. Figure 2.9 through Figure 2.15 show some of these signs.

**Table 2.3.** Colors of Different Type of Sign Messages (Heller et al., 2012; Table A-1)

| | Legend | | | | | | Background | | |
|---|---|---|---|---|---|---|---|---|---|
| **Type of Sign Message** | Red | White | Yellow | Orange | Fluorescent Yellow-Green | Fluorescent Pink | Black | Blue | Green |
| Regulatory | X | X | | | | | X | | |
| Warning | | | X | | | | X | | |
| Temporary Traffic Control | | | X | X | | | X | | |
| Guide | | X | | | | | X | | X |
| Motorist Services | | X | | | | | X | X | |
| Incident Management | | | X | | | X | X | | |
| School, Pedestrian, Bicycle | | | X | | X | | X | | |


**Figure 2.9.** Highway 217 and Barnes Road (Image Source: Randy McCourt)


**Figure 2.10.** Interstate 5 (Image Source: Randy McCourt)


**Figure 2.11.** California Department of Transportation Bulb Signs (Image Source: Randy McCourt)


**Figure 2.12.** Washington State Department of Transportation Travel Time Signs (Image Source: Randy McCourt)


**Figure 2.13.** Arizona Department of Transportation Signs (Image Source: Randy McCourt)

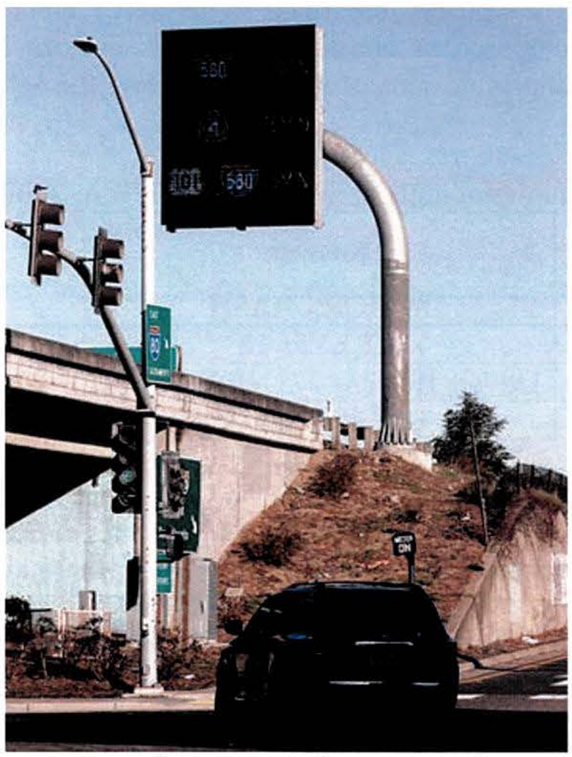


**Figure 2.14.** California Department of Transportation I-80 Project near Berkeley (Image Source: Randy McCourt)


**Figure 2.15.** Florida Department of Transportation Dynamic Message Sign (Image Source: Randy McCourt)

## 2.4 Message Length, Units of Information, and Display Time

Message length on VMS is typically described in terms of units of information. Units of information are phrases composed of one to three words but can include up to four words (Bezuidenhout, 2015). Examples of units of information from the MUTCD are shown in Table 2.4.

**Table 2.4.** Examples of units of information (FHWA, 2009; Table 2L-1).

| Question | Answer | Number of Information Units |
|---|---|---|
| What happened? | MAJOR CRASH | 1 |
| Where? | AT EXIT 12 | 1 |
| Who is the advisory for? | Drivers Heading TO NEW YORK | 1 |
| What is advised? | USE ROUTE 46 | 1 |

The MUTCD mentions that, as a standard, no more than two phrases can be used for each message, each phrase should have three or fewer lines of text, and the lines of text should be center justified (FHWA, 2009). When operating speeds are 35 mph or more, the maximum number of units of information that should be in a message is four ( FHWA, 2009; Paniati and Lindley, 2004). When operating speeds are less than 35 mph, the maximum number of units of information that should be in a message is five ( FHWA, 2009; Paniati and Lindley, 2004). One line should contain only one unit of information (FHWA, 2009).

However, Robinson et al. (2017) state that one line should contain no more than two units of information. When VMS signs contain more than six units of information, undesirable demands are placed on drivers (Lerner et al., 2009). Therefore, VMS text should be limited to a total of five or six units on information (Robinson et al., 2017). According to Paniati and Lindley (2004), there should be no more than three units of information for the length of a VMS message phase, and there should be no more than two units of information for the length of a VMS message line. Table 2.5 shows the maximum units of information and legibility distance requirements by speed based on MUTCD standards and guidance.

**Table 2.5.** Maximum units of information and legibility distances by speed according to the MUTCD (Robinson et al., 2017; Table 17).

| Speed (mph) | Maximum Number of Information Units | Legibility Distance (mi) |
|---|---|---|
| 25 | 5 | 0.5 |
| 35 | 5 | 0.5 |
| 45 | 4 | 0.5 |
| 55 | 4 | 0.5 |

In addition to the number of units per line and per VMS, the MUTCD offers guidance regarding the time that phases are displayed and the allowable cycle length. The minimum amount of time that phases should be displayed on a VMS is the lesser of the following two conditions: (1) 1 second per word or (2) 2 seconds per unit of information (FHWA, 2009). When a VMS has two phases, the cycle time should be a maximum of 8 seconds (FHWA, 2009). The time between when the two phases are displayed should not be greater than 0.3 seconds (FHWA, 2009). The New York State Thruway Authority states that the display time for messages on VMS should be 1.5 to 2.5 seconds per panel (New York State Thruway Authority, 2011). Garvey (2002) advises that the static display time for messages on VMS should be 10 seconds.

## 2.5 Analysis Method

Different methods have been cited in the literature regarding the use of methods to analyze experiments pertaining to VMS and testing using human participants. A common method employed is an analysis of variance (ANOVA). Studies by Lerner et al. (2009), Paxion et al. (2014), Roca et al. (2018), Bugdol et al. (2014), and Chrysler et al. (2017) have all used an ANOVA to evaluate data collected from VMS studies or studies using human participants.

## 2.6 Summary of Literature Review

VMS can be installed on roadways to disseminate different types of information to drivers. Information displayed on VMS can include real-time traffic information, such as travel time to a specific destination, safety messages, weather warnings, and incident or work zone management. While multiple messages can be displayed on VMSs, drivers, especially commuters, have indicated that they prefer to see travel times to specific destinations on the signs. The MUTCD, individual state manuals and support documents, and research experiments offer guidance and advice for the design of messages on VMS. This guidance principally relates to the legibility and visibility, font characteristics, and wording requirements.

While there is literature and studies have been performed pertaining to VMS, testing still needs to occur to determine the most effective messages and design of VMS. In a dynamic message sign survey conducted to obtain the opinions of industry professionals and National Committee on Uniform Traffic Control Devices members, it was determined there are still research needs regarding such signs (McCourt and Conrad, 2017). The top research needs identified by the respondents included research pertaining to messages, colors and symbols, font, glare, brightness, intensity, and dimming, and dynamic message sign use for public service announcements and advertising (McCourt and Conrad, 2017). However, given this stated need for research in these areas, there was no research directly relevant to the subject of this study, using color VMS boards to display travel time messages.

# 3. Expert Interviews

Informal interviews with transportation professionals were conducted by a member of the research team to gain a deeper insight into the use of variable message signs. The transportation professionals interviewed held expertise related to VMS through working on VMS projects or studies with either government agencies or private companies. The interviews provided best practices related to VMS design and use. Some of the affiliations and related expertise of the professionals are shown below.

- Pennsylvania Department of Transportation (PennDOT),
- Federal Highway Administration (FHWA),
- Texas A&M Transportation Institute (TTI),
- Florida Department of Transportation, and
- VMS manufacturers.

Each of these experts was provided a set of preliminary color-coded travel time message formats that were proposed for testing. The experts were asked to give their input on any potential concerns they had with the preliminary set. Message formats that were excluded from further study based on this feedback can be found in Appendix A.

The following subsections summarize information gathered as part of the interviews with these industry experts. This section also discusses details on current PennDOT practices with dynamic message signs, including what messages should be displayed, what letters and/or graphics should be used, colors and color coding that should be considered, and other issues to think about when testing and implementing colored VMS.

## 3.1 Types of Messages on VMS

The interviews with transportation professionals offered insight into what travel time message formats are currently being displayed on signs, which messages work well, and which do not work well. It was also noted that the Manual on Uniform Traffic Control Devices (MUTCD) guidelines are followed in most states for VMS implementation. Professionals noted that they are interested in exploring what constitutes the best travel time display for travelers with the greatest simplicity and least amount of text.

Currently in Pennsylvania, the messages displayed on existing dynamic message signs differ depending on the RTMC area in which the sign is located. For example, messages differ in terms of how the destination is described (e.g., exit number versus city) and in the type of information provided (e.g., only the travel information versus the travel time and distance information; n.b., as previously noted, PennDOT uses its *Dynamic Message Sign Operating Standards* as the starting point for travel time message formats). Practices in Florida are also area-dependent. Currently in

Florida, both miles and minutes, only miles, or only minutes are used on existing VMS. Similarly, Texas uses portable VMS in work zones to display travel information in miles and minutes based on travel speed data. However, it was noted that these travel times are often underestimated since they are based on posted speed limits rather than actual travel speeds on the roadway.

An important consideration for the messages displayed on VMS is choosing destinations to present the information such that a large proportion of the travelers can understand the messages. Messages should consider both commuters and visitors to the area. Providing too much information to travelers becomes confusing to them; therefore, offering simple yet useful information is important. The messages proposed to be tested for this project were thought to be appropriate in providing an adequate amount of information without confusing the drivers.

The experts' consensus was that testing travel time in minutes and travel distance in miles will be beneficial to see what drivers need or prefer, including the pairing of signs such as a DMS with real-time travel time with prior static signs such as interchange sequence signs (MUTCD 2E.40) or post-interchange distance signs (MUTCD 2E.39). Many professionals thought providing a combination of miles and minutes with color would work best to relay the necessary information to drivers. Most currently used dynamic messages signs state travel times in minutes. It could appeal to commuters and visitors. It is also important to plan for three-digit travel times because this could be a possibility. It should be noted that the current PennDOT standards do not allow for posting of three-digit travel times.

Additionally, the destinations associated with the miles and minutes need to be named appropriately, with options including exit number, milepost, or city name. When providing the traffic information, issues could arise about how to convey the information of whether the travel time presented was a fast or slow travel time. One way to avoid this potential problem and help clarify this issue would be by providing both mileage and travel time information, but this configuration might not be easily understood by the general public. Ultimately, the message format will be dictated by the number of characters per line the sign is capable of displaying along with the number of characters it takes to provide sufficient information to identify the travel time destination and/or route.

While many VMS aim to provide sufficient information for drivers to make a route choice decision, Caltrans is expanding on that idea. Caltrans is aiming to provide information to help beyond the route choice decision, for example, by including train travel times on their signs so that travelers can use this information to make a mode choice decision. Additionally, several transportation professionals noted that there were no dynamic message signs that tried to represent congestion level. One respondent recommended trying a message that states heavy congestion on a specific route without providing travel time information.

One issue or concern raised that needs to be considered was how to deal with express lanes. Express lanes could be an issue when portraying travel times because there might be multiple travel times along the same route when express lanes exist. It should be noted that PennDOT currently does not own or operate any express lanes.

## 3.2 Design Characteristics of VMS (Letters and Graphics)

Through the interviews, insight was also obtained in relation to the lettering and graphics on VMS. It was suggested by many of the experts that it would be beneficial to test route symbols as well as text descriptions of interchanges as indicators of destinations. However, it was stated by some of the hardware experts that the clarity of graphic route symbols would depend on the VMS display type (the displays would need to be full matrix displays) along with the pixel pitch. It was noted that using abbreviations for route name could lead to different conclusions in the study. Including route shields on VMS could potentially rectify this issue if four- or five-letter abbreviations for the route names were not possible, and complete route names could be more effective in conveying the information and could provide better comprehension of the message. Some states, such as Florida, use shields on VMS to display travel time messages instead of using text or words. This is similar to what was going to be tested in this study. It should be noted that PennDOT's Advanced Traffic Management System (ATMS) software, OpenTMS developed by Q-Free, is capable of displaying graphics on VMS; however, the graphics need to be generated separately.

Concerns were raised with some of the preliminary message formats that were distributed to the experts for review. One of the concerns was that the outlines around the words (i.e., colored backgrounds, hereinafter referred to as color bands) would make the sign difficult to read. Additionally, the use of the message format that employed color-coded asterisks was criticized since it might be difficult to interpret their meaning. For example, some experts thought they could be interpreted as snow. Due to the large number of concerns, asterisks were not tested as a part of this project. In regards to letter size, an 18-inch letter height was found to crowd the line spacing and could affect legibility. One last concern was in relation to the phases. If a dual phase is used, information might be difficult to process in the 3-second time discussed earlier in this report.

While shields can help drivers identify destinations, there were concerns that some of the shields on the signs to be tested were not on the correct side. For example, when reading from left to right, the information is in the wrong spot. The alignment of the shield was also thought, by some, to be incorrect. It was mentioned that any image on the signs should typically be on the left side not the right side. It should be noted that PennDOT's OpenTMS software can post graphics as either left or right justified on the VMS display.

## 3.3 Colors and Color Coding of VMS

Different colors for the letters and background and color coding of the messages were to be tested in the experiment. Several experts thought that to help drivers determine if the travel times provided are fast or slow, traditional red, yellow, and green colors can be used to reflect the travel time. Given current practice with traffic signals, several experts thought that the colors tested would work well for drivers with color blindness, but there are always concerns whether or not they will be suitable for people with color blindness when used in new situations. Therefore, the experts thought that it was important to include color-blind subjects. Some of the transportation professionals consulted preferred colored text, while others preferred the squares (not the circles as they might be confused for traffic signal lenses) next to the text. However, neither was included in the final set of signs tested. Several experts noted that any color that would be posted on a VMS should use an MUTCD-compliant shade of that particular color.

While some professionals liked the idea of color coding the VMS travel time information messages, others were concerned that the color would be superfluous along with the travel time information. Some were nervous about the use of the red, yellow, and green colors. It was thought that if one of the travel times is shorter than the other, the users would probably pick this route regardless of whether it was red or green. It could also be confusing that if there are two routes that have naturally different travel times, the VMS would indicate the one with the shorter travel time as green and the one with the longer travel time red, regardless of the congestion. It was thought that this should be clarified before any tests were run.

As mentioned above, issues and concerns were raised regarding some of the preliminary message formats, one of which was the use of red and green balls/circles. Some experts thought that the red and green balls might confuse drivers since they are similar to traffic signals and stop signs. However, others thought a round symbol, asterisk, or rectangle would not make too much of a difference due to size-related issues trying to recognize these elements from a distance. While some interviewees thought that the green balls would work better than the squares, several also commented that the asterisks were too small in size to be visually effective. Others thought that separating the color from the message text would help cater to color-blind drivers or drivers with poor eyesight. Based on this feedback, none of the preliminary message formats that utilized color-coded circles, squares, or asterisks were tested as a part of this study.

One of the experts noted that Cobb County, Georgia was in the process of deploying color-coded travel time messages on its VMS boards (Figure 3.1). The interviewee recommended adding the message format that Cobb County was deploying as a potential format to be included as part of the testing for this project. (It should be noted that message formats 6 and 7 shown provided in Table 4.1 were added to the testing based on this suggestion.)

Florida has considered changing the color of the text on VMS to represent normal travel time in white, some congestion in yellow, and heavy congestion in red but this scheme was not implemented. Florida also considered putting a picture of a sign or a license plate on VMS during amber or silver alerts.

Concerns were raised about the color contrast of red against black and if the on-screen signs would look like those presented in the print mockups. Some experts thought that a red sign against a black background might be hard to see on the actual VMS itself, but this might depend on the brightness of the red color. Another issue raised was would drivers understand what the red text meant, especially if distance information was also presented. It was thought that drivers might confuse this with the route being longer rather than being congested, or drivers might think the red is just the color of the text.


**Figure 3.1.** Cobb County color-coded travel time message format.

There was some discussion that a VMS with a color band around the travel time (rather than colored text itself) might work better. However, it was also thought that this might be confusing if the band around the text were color coded only for the red travel times. While there are potential issues with color-coded text, it would be good for drivers who might not be able to see the travel time information but will still get partial information from the color. There was some feeling that there would be a need to also test white versus amber text to determine the relative effectiveness of each color. However, testing the white versus amber text would be better in the field due to concerns with fog. Some of the experts also noted that some of the depicted green text and red bands did not appear to comply with the allowable colors to be posted on VMS according to MUTCD Table 2A-5.

During the interview process, transportation professionals thought some of the signs were too colorful. It was advised to not use more than three or four colors on the entire panel.
It was believed that it might be beneficial to provide a simple map with color-coding on the map and travel time information. Additionally, it might be useful to consider developing separate

standards for the type of message displayed, the information provided in the message, etc., for both color signs and amber signs. The colors should also be tested in the field on real color VMS to see how well the images match what will be on the roadway to ensure the colors are correct.

### 3.4 Other Considerations for VMS

There are other considerations when implementing and using VMS for different situations. One consideration is regarding work zones, because sometimes signs that display too much information might lead to dangerous driving behavior. Specifically for work zones, signs should not capture the attention of drivers for too long.

When performing the experiments, several experts thought that information should be given to the participants about what road drivers are traversing and where they are trying to go. However, this would set up expectations for the participants.

Certain states have already been using VMS that range from basic to more complicated. It was recommended to test some of the basic VMS that are already in place and test some of the more complicated VMS. California would be an example of basic VMS usage, while Florida, Oregon, and Washington are examples of complicated VMS usage.

# 4. Laboratory Experiments

A laboratory experiment to evaluate the visibility and comprehensibility of a set of VMS color-coded travel time messages was conducted. As it is prohibitively expensive and time consuming to conduct a full-scale field experiment on the large number of potential VMS messages envisioned for the proposed research, the study was conducted in a laboratory setting where many messages could be evaluated in a short period of time using high-resolution, computer-generated graphics. The remainder of this section describes the test protocol and analysis methods and provides some summary results.

## 4.1 Test Protocol

This subsection describes the procedures used for conducting the variable message sign test procedure.

### 4.1.1 Location

The study took place at the Thomas D. Larson Pennsylvania Transportation Institute at Penn State in University Park, Pennsylvania. The experiments were conducted in the driver vision laboratory located within the building.

### 4.1.2 Research Participants

Subjects were recruited to take part in the study. All participants were required to speak English, hold a valid United States driver's license, be 18 years of age or older, and have a visual acuity of 20/40 or better. A total of 75 people participated in the study. Of those 75 participants, 22 were 18-29 years old (13 males and 9 females), 27 were 30-65 years old (13 males and 14 females), and 26 were 66 years old or older (13 males and 13 females). There were five participants who were colorblind. Of those, two participants were blue-gray colorblind and three participants were red-green colorblind.

### 4.1.3 Test Message Parameters

To develop realistic VMS message formats, the research team utilized a current VMS vendor's software. All of the test messages created for the purposes of this test were based on a VMS with the following characteristics:

- Display type – full matrix with full color capability,
- Pixel matrix (H x W) – 96 pixels x 288 pixels,
- Pixel pitch – 20 mm,

- Character height – 18-inch[1],
- Font size (H x W) – 23 pixels x 15 pixels,
- Lines of text/Characters per line – 3 lines of text with 15 characters per line,
- Interline spacing – 12 pixels,
- Character spacing – 4 pixels, and
- Color Shades – Any color that was used within a test message format was developed using a MUTCD-compliant shade for the particular color. The shades of red and green were created based on the information provided in Appendix B.

These VMS parameters were derived from current full-matrix color VMS that are already deployed by PennDOT.

### 4.1.4 Equipment

The equipment used included a LogMAR (logarithm of the minimum angle of resolution) visual acuity chart, a computer with two keyboards, and a television screen. One keyboard was used by the participants, while the other keyboard was used by experimenter. Additionally, the computer software MATLAB was used to execute the experiment and display the sign images to the participants.

### 4.1.5 Variables

There were 22 different test signs used in the experiment that included different combinations of text message and text colors. Each sign image is shown in Table 4.1. Signs 1 through 15 and 21 through 22 had a message format displaying one destination via two routes. Two variations of signs 1 through 15 and 21 through 22 were used where the order, top to bottom of the sign, of the alternative routes were reversed. Signs 16 through 20 had messages for two separate destinations along the same route. Signs 16 through 20 had three variations with small differences in the numerical value of the travel times.

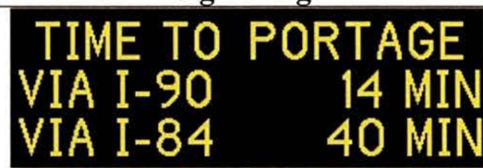
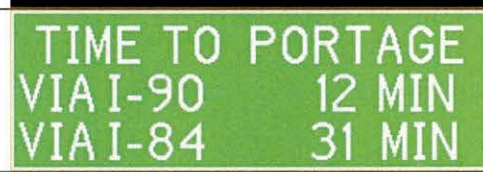
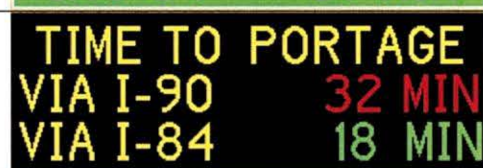
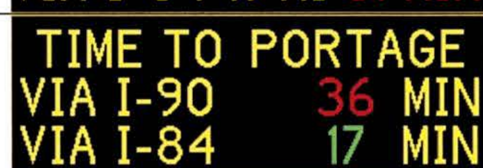
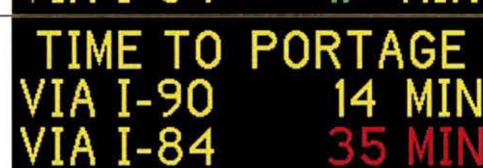
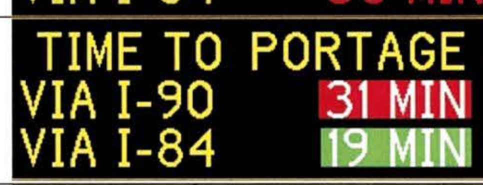
These two sign groups were set up because the types of test scenarios/questions that could be used to elicit "correct" or "incorrect" subject responses were different given the nature of the information on the two different sign categories (i.e., one destination via two routes versus two destinations on one route).

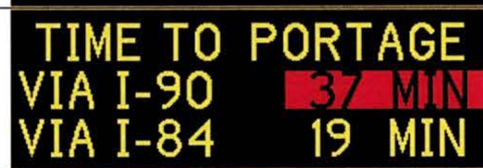
The presentation order of the signs was randomized to address any potential ordering effects.

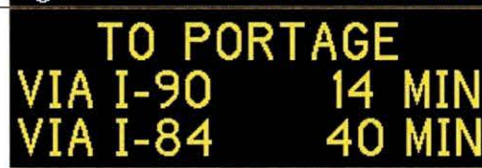
---

[1] 18-inch characters were used for the test message even though some of the expert feedback suggested this character height could crowd messages. Font size was selected based on MUTCD requirements and current PennDOT travel time message display example location.

**Table 4.1.** Test panels.

| Number | Sign Image |
|---|---|
| 1 |   |
| 2 |   |
| 3 |   |
| 4 |   |
| 5 |   |
| 6 |   |
| 7 |   |
| 8 |   |
| 9 |   |

| Number | Sign Image |
|---|---|
| 10 |   |
| 11 |   |
| 12 |   |
| 13 |   |
| 14 |   |
| 15 |   |
| 16 |   |
| 17 |   |
| 18 |   |
| 19 |   |

| Number | Sign Image |
| --- | --- |
| 20 |  |
| 21 |  |
| 22 |  |

### 4.1.6 Procedure

When the participants arrived at the study location, they were greeted at the entrance to the building. The participant was then escorted to the visual performance laboratory where the experiment took place. The participant and experimenter were seated around a conference table. Consent to participate in the study was obtained from the test subject. After the consent process, the participant was then given a visual acuity test. Each participant was required to have a visual acuity of 20/40 or better to be a test subject in the study. All participants met the visual acuity requirement.

After the vision test was completed, the experiment began. Participants were told that there would be two separate parts of the study. They were told that the first part would test how well they can see and understand different signs and that each sign would be displayed on the screen in front of them at a very small size and it would gradually get larger. The participants were told that before each sign was displayed that they would be given two questions to answer and the questions would be the same for each sign. They were then informed that the questions would be what route has the shorter travel time and what is that travel time. The participants were instructed that when they were able to read the sign and answer the question correctly, they were to push the spacebar on the keyboard. After they pushed the spacebar, they were then required to tell the experimenter the answers to the questions. The participants were also told that they would perform one practice trial before the experiment began.

The first part of the experiment would then commence. The experimenter would initiate the process to display the sign. The participant would then hit the spacebar on a computer keyboard in front of them when they were able to determine what route had the shorter travel time. They would then tell the experimenter what route that was and what the travel time for that route was. This participant's reaction time was recorded by the MATLAB software, and the experimenter would then record if their answers were correct or incorrect. The next sign would be displayed on the screen once the participant was ready. These steps were repeated for each sign.

After the first part of the experiment was completed, the second part of the experiment began. Participants were told that they were going to see a series of signs and that each sign would be shown on the screen for a certain amount of time. They were told that once the image disappears, they would be asked a question. The question would be what is the travel time to a specific route ("What is the travel time to route x?"). Participants were also told that there would be one practice trial first.

The second test procedure then began. The experimenter pushed a button starting the experiment. The sign image would then be displayed on the screen. Once the image disappeared, the experimenter would ask what the travel time was to a specific route. The experimenter would then log if the answer was correct or incorrect. That process was repeated for each sign.

Once Part 2 of the experiment was over, the experimenter told the participant that the experimental session was complete. The participant was then compensated for participating and was free to leave the building.

# 5. Analysis

In Part 1 of the experiment, participants saw all 22 signs presented in random order, and one of the alternative versions of each sign was also chosen at random to be part of the sign set viewed by an individual subject. The data recorded included the reaction time, reaction distance, whether or not the route was identified correctly, and whether or not the travel time was identified. In Part 2 of the experiment, participants saw the remaining two variants of sign numbers 16 through 20. Whether or not the participants identified the travel time correctly was recorded after the participant saw each sign for 2 seconds.

The analysis seeks to identify differences in how human subjects interpret travel time message formats that utilize color compared to the standard amber format travel time messages currently used today. To do so, subject performance measures for multiple signs were compared against one another. Table 5.1 displays a list of the comparisons by sign number and what feature of the signs is being compared.

**Table 5.1.** Sign comparisons used for the analysis.

| Signs Number Comparisons | Sign Aspect to Be Compared |
|---|---|
| 16, 17, 18 | Banner: "Travel Time to" vs. "Time to" vs. Nothing |
| 4, 5, 8, 9 | Message: Time and distance vs. Time only |
| 18, 20 | Distance text format: "MI" vs. "MILES" |
| 18, 19 | Shields: Left vs. Right |
| 5, 15, 21, 14 | Use of shield vs. Use of text |
| 1, 4, 6, 7, 10, 12, 13, 2, 8, 11 | Color: Use of color vs. No color |
| 4, 6 | Color text for time only vs. Color text for time & min |
| 1, 2 | Text: Yellow vs. White |
| 2, 3 | Backgrounds: Black vs. Green |
| 4, 7, 8, 11, 10, 12 | Color text for all travel times vs. Color text only for "Bad" travel times |
| 12, 13 | Color Band Format: Red vs. Amber |
| 5, 22 | Minutes listed before miles vs. Minutes listed after miles |

# 6. Results

In Part 1 of the experiment, there were a total number of 1,650 observations. When identifying the route with the shorter travel time, participants identified the correct route 93.2 percent of the time. When identifying what that shorter travel time was, participants identified the correct travel time 88.0 percent of time. When combining both the route and travel time question to determine if at least one answer was correct or incorrect, participants identified both questions correctly 84.5 percent of the time. The means and standard deviations for the different signs are shown in Table 6.1 along with the percent correct for each message.

**Table 6.1.** Part 1 descriptive statistics.

| Message # | Mean Reaction Time (sec) | Standard Dev. Reaction Time (sec) | Mean Reaction Distance (ft) | Standard Dev. Reaction Distance (ft) | % of Combined Correct Responses |
|---|---|---|---|---|---|
| 1 | 5.691 | 1.681 | 699.163 | 147.923 | 93.3 |
| 2 | 5.691 | 1.858 | 699.231 | 163.476 | 96.0 |
| 3 | 8.751 | 8.751 | 429.921 | 140.687 | 98.7 |
| 4 | 6.182 | 1.665 | 655.961 | 146.506 | 80.0 |
| 5 | 6.806 | 1.859 | 601.081 | 163.584 | 84.0 |
| 6 | 6.179 | 1.770 | 656.266 | 155.731 | 98.7 |
| 7 | 6.234 | 1.784 | 651.448 | 157.016 | 96.0 |
| 8 | 9.793 | 1.247 | 338.182 | 109.744 | 84.0 |
| 9 | 9.029 | 1.755 | 405.433 | 154.458 | 73.3 |
| 10 | 7.061 | 2.061 | 578.598 | 181.391 | 86.7 |
| 11 | 6.181 | 1.545 | 656.047 | 135.985 | 93.3 |
| 12 | 7.098 | 1.930 | 575.391 | 169.797 | 86.7 |
| 13 | 6.742 | 1.960 | 606.710 | 172.489 | 94.7 |
| 14 | 8.051 | 1.468 | 491.473 | 129.169 | 81.3 |
| 15 | 8.440 | 1.359 | 457.317 | 119.565 | 80.0 |
| 16 | 8.134 | 1.530 | 484.240 | 134.632 | 76.0 |
| 17 | 8.281 | 1.675 | 471.297 | 147.401 | 62.7 |
| 18 | 7.903 | 1.704 | 504.524 | 149.963 | 76.0 |
| 19 | 7.757 | 1.570 | 517.413 | 138.197 | 69.3 |
| 20 | 7.884 | 1.538 | 506.251 | 135.365 | 73.3 |
| 21 | 5.308 | 1.929 | 732.895 | 169.753 | 93.3 |
| 22 | 6.910 | 1.959 | 591.937 | 172.398 | 82.7 |

In Part 2 of the experiment, there were a total of 750 observations. When identifying the correct travel time for the specific route questioned, the percent correct for each sign is shown in Table 6.2.

**Table 6.2.** Part 2 descriptive statistics.

| Message # | % Correct |
|---|---|
| 16 | 65.3 |
| 17 | 53.3 |
| 18 | 58.0 |
| 19 | 32.0 |
| 20 | 62.0 |

## 6.1 Results of ANOVA Tests for Part 1

An analysis of variance (ANOVA) is a statistical model used to analyze differences among means in a sample. ANOVA examines variability within groups being compared and variability among the groups being compared to determine whether there are any statistically significant differences between the means. This allows analysts to see what result the independent variables have on the dependent variable or establish which factors (or variables) influence the outcome of the experiment.

For Part 1, ANOVA tests were conducted to identify any statistically significant differences in the reaction times, or the percentage of responses that were correct. The ANOVA tests were based on the list of sign comparisons shown in Table 5.1. A multivariate ANOVA was conducted to determine any statistically significant differences in the average percentage of correct responses or average reaction time for the list of comparison signs. The results of the multivariate ANOVA tests are shown in Table 6.3. This table shows if there was a statistically significant change (with 95 percent confidence) in percentage of correct responses or average reaction time for each considered aspect. The values in parenthesis represent the p-values of the ANOVA tests. Additionally, if statistically significant changes were observed, this table describes which aspect resulted in a higher percentage of correct answers or lower reaction times.

**Table 6.3.** Results of ANOVA tests for Part 1

| Sign Aspect to Be Compared | Statistically Significant Change in: | | Larger % of Correct Answers for: | Lower Reaction Time for: |
|---|---|---|---|---|
| | % Correct | Reaction Time | | |
| Banner: "Travel Time to" vs. "Time to" vs. Nothing | No (0.11) | No (0.36) | | |
| Message: Time and distance vs. Time only | No (0.31) | Yes (0.00) | | Time only |
| Distance text format: "MI" vs. "MILES" | No (0.71) | No (0.94) | | |
| Shields: Left vs. Right | No (0.36) | No (0.59) | | |
| Use of shield vs. Use of text | No (0.10) | Yes (0.00) | | Use of text |
| Color: Use of color vs. No color | Yes (0.00) | Yes (0.00) | No color | No color |
| Color text for time only vs. Color text for time & min | Yes (0.00) | No (0.99) | Color text number only | |
| Text: Yellow vs. White | No (0.47) | No (0.99) | | |
| Backgrounds: Black vs. Green | No (0.31) | Yes (0.00) | | Black background |
| Color text for all travel times vs. Color text only for "Bad" travel times | Yes (0.03) | Yes (0.00) | Color text only for bad travel times | Color text only for bad travel times |
| Color Band Format: Red vs. Amber | No (0.09) | No (0.26) | | |
| Minutes listed before miles vs. Minutes listed after miles | No (0.83) | No (0.74) | | |

Looking at Table 6.3, it can be seen that a sign that would result in the smallest reaction time would have the following properties, the:

1) Message would display time only,
2) Route numbers would be displayed in text, not shields,
3) Color would not be used, but if color were used it would only be used to show the congested travel times, and
4) A black background would be used.

To look further into the aspects for which the ANOVA tests revealed significant differences among the average reaction time or average percentage of correct responses, additional pairwise tests were conducted. The results of these pairwise ANOVA tests can be seen in Table 6.4. Looking at Table 6.4 it can be seen that all of the pairwise ANOVA tests confirm the multivariate ANOVA tests, except for the comparison between displaying both time and distance versus displaying time only. The two pairwise comparisons contradict each other – the comparison of signs 4 and 5 indicate that time-only displays would result in smaller reaction times, whereas the comparison of signs 8 and 9 indicate that time and distance displays would result in smaller reaction time. Looking at the signs themselves, it can be seen that 4 and 5 have colored text while 8 and 9 have a colored band around the travel time. This result could indicate that the colored band around the travel time makes it difficult to see the actual travel time, and the distance information helps aid in identifying the shorter travel route. Hence, one would expect the time-only displays to perform better when there are no visibility issues with the travel time display. Additionally, the pairwise tests confirm that monochromatic signs have superior performance in terms of both percentage of correct responses and reaction time. Notice that the pairwise tests show that there is no statistical difference in reaction time for signs 4, 6, and 7 compared to 1 or sign 11 compared to 2. Signs 4, 6, and 7 have only the colored text instead of the color band, while sign 11 only has a colored indicator for a congested travel time. This again indicates that the color band might make it difficult to comprehend the signs, while the colored text does not aid in or make it more difficult to comprehend the signs. Once again, these findings support the conclusion that if color is used, it should be used for the text and only to indicate congested travel times. However, it should be noted that when comparing signs 6 and 7 to monochromatic sign 1, and sign 11 to monochromatic sign 2, the results show no statistically significant difference. This implies that while color might not improve visibility or comprehensibility, it can perform as well as its monochromatic counterparts. The colored VMS signs would need to follow the general conclusions reached about sign format performance, as noted above, to be able to perform as well as monochromatic signs in terms of visibility and comprehensibility (i.e., only time would be displayed with route numbers shown in text on a black background).

**Table 6.4.** Results of pairwise ANOVA tests.

| Sign Aspect to Be Compared | Signs to Be Compared | Statistically Significant Change in: | | Larger % of Correct Answers for: | Lower Reaction Time for: |
|---|---|---|---|---|---|
| | | % Correct | Reaction Time | | |
| Message: Time and distance vs. Time only | 4 and 5 | No (0.53) | Yes (0.03) | | Sign 4 – time only |
| | 8 and 9 | No (0.11) | Yes (0.00) | | Sign 9 – time and distance |
| Use of shield vs. Use of text | 5 and 15 | No (0.53) | Yes (0.00) | | Sign 5 - no shield |
| | 14 and 21 | Yes (0.03) | Yes (0.00) | Sign 21 – no shield | Sign 21 – no shield |
| Color: Use of color vs. No color | 1 and 4 | Yes (0.02) | No (0.07) | Sign 1 – no color | |
| | 1 and 6 | No (0.10) | No (0.09) | | |
| | 1 and 7 | No (0.47) | No (0.06) | | |
| | 1 and 10 | No (0.18) | Yes (0.00) | | Sign 1 – no color |
| | 1 and 12 | No (0.18) | Yes (0.00) | | Sign 1 – no color |
| | 1 and 13 | No (0.73) | Yes (0.00) | | Sign 1 – no color |
| | 2 and 8 | Yes (0.01) | Yes (0.00) | Sign 2 – no color | Sign 2 – no color |
| | 2 and 11 | No (0.47) | No (0.08) | | |
| Color text for all travel times vs. Color text only for "Bad" travel times | 4 and 7 | Yes (0.00) | No (0.86) | Sign 7 - color text only for bad travel times | |
| | 8 and 11 | No (0.07) | Yes (0.00) | | Sign 11- color text only for bad travel times |
| | 10 and 12 | No (0.91) | No (1.00) | | |

Additionally, ANOVA tests were conducted to identify any differences between male and female participants, different age groups, or color blindness. The results of the ANOVA tests can be seen in Table 6.5 for reaction times and Table 6.6 for percentage of correct responses. These tables provide the average reaction time or percentage of correct responses for each message signs for participants grouped into males or females, into the three age groups, and colorblind or not colorblind. Additionally, in the last three columns any statistically significant difference in the average reaction time or percentage of correct responses is shown, along with the p-value in parenthesis.

Looking at Table 6.5 it can be seen that no statistically significant differences in average reaction time are observed between males and females except for sign 14, where males have a faster reaction time. Comparing age groups, for older participants a significantly longer reaction time is observed for all signs, except for sign 18, as expected. No statistically significant differences in reaction time were observed between colorblind or normally sighted participants.

Looking at Table 6.6 it can be seen that no statistically significant differences between males and females were observed for average percentage of correct responses. For signs 4 and 14, it was observed that older participants had a lower percentage of correct responses compared to younger participants with 95 percent confidence. Statistically significant differences in percentage of correct responses were observed for signs 2, 3, 4, and 20 where colorblind participants had a lower correct response rate.

**Table 6.5.** Results of ANOVA tests for comparing Male/Female, Age and Colorblindness for reaction times

| Sign # | Average Reaction Time (s) | | | | | | | Statistically Significant Difference in Averages | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Male | Female | Age 1 | Age 2 | Age 3 | Not Color Blind | Color Blind | Male vs. Female | Age | Color Blind |
| 1 | 5.69 | 5.69 | 4.87 | 5.25 | 6.85 | 5.63 | 6.56 | No (0.98) | Yes (0.00) | No (0.30) |
| 2 | 5.43 | 5.97 | 4.52 | 5.26 | 7.13 | 5.67 | 6.00 | No (0.21) | Yes (0.00) | No (0.71) |
| 3 | 8.67 | 8.84 | 7.77 | 8.68 | 9.66 | 8.70 | 9.52 | No (0.65) | Yes (0.00) | No (0.27) |
| 4 | 5.91 | 6.48 | 5.38 | 5.88 | 7.18 | 6.17 | 6.40 | No (0.14) | Yes (0.00) | No (0.76) |
| 5 | 6.72 | 6.90 | 5.43 | 6.54 | 8.25 | 6.75 | 7.64 | No (0.67) | Yes (0.00) | No (0.30) |
| 6 | 6.00 | 6.37 | 4.98 | 6.07 | 7.30 | 6.11 | 7.19 | No (0.37) | Yes (0.00) | No (0.19) |
| 7 | 6.07 | 6.41 | 5.11 | 6.01 | 7.42 | 6.19 | 6.87 | No (0.40) | Yes (0.00) | No (0.41) |
| 8 | 9.70 | 9.90 | 9.13 | 9.78 | 10.37 | 9.73 | 10.63 | No (0.50) | Yes (0.00) | No (0.12) |
| 9 | 9.20 | 8.84 | 8.31 | 8.99 | 9.68 | 8.97 | 9.84 | No (0.37) | Yes (0.00) | No (0.29) |
| 10 | 6.92 | 7.22 | 5.79 | 6.81 | 8.39 | 7.05 | 7.27 | No (0.54) | Yes (0.00) | No (0.70) |
| 11 | 6.15 | 6.22 | 5.16 | 5.72 | 7.52 | 6.13 | 6.92 | No (0.85) | Yes (0.00) | No (0.27) |
| 12 | 6.85 | 7.37 | 6.02 | 7.02 | 8.09 | 7.12 | 6.81 | No (0.25) | Yes (0.00) | No (0.73) |
| 13 | 6.54 | 6.97 | 5.72 | 6.36 | 8.01 | 6.72 | 7.08 | No (0.35) | Yes (0.00) | No (0.69) |
| 14 | 7.73 | 8.39 | 7.43 | 7.70 | 8.94 | 8.01 | 8.57 | Yes (0.05) | Yes (0.00) | No (0.41) |
| 15 | 8.30 | 8.59 | 7.93 | 8.15 | 9.17 | 8.40 | 9.04 | No (0.35) | Yes (0.00) | No (0.31) |
| 16 | 7.99 | 8.29 | 7.60 | 7.93 | 8.80 | 8.12 | 8.34 | No (0.40) | Yes (0.01) | No (0.75) |
| 17 | 8.03 | 8.56 | 7.69 | 8.02 | 9.05 | 8.29 | 8.18 | No (0.17) | Yes (0.01) | No (0.89) |
| 18 | 7.83 | 7.98 | 7.45 | 7.71 | 8.49 | 7.88 | 8.26 | No (0.72) | No (0.08) | No (0.63) |
| 19 | 7.65 | 7.87 | 6.96 | 7.70 | 8.49 | 7.76 | 7.74 | No (0.56) | Yes (0.00) | No (0.98) |
| 20 | 7.61 | 8.18 | 7.45 | 7.61 | 8.54 | 7.92 | 7.37 | No (0.11) | Yes (0.02) | No (0.44) |
| 21 | 5.21 | 5.41 | 4.17 | 4.89 | 6.71 | 5.26 | 5.92 | No (0.66) | Yes (0.00) | No (0.46) |

**Table 6.6.** Results of ANOVA tests for Male/Female, Age and Colorblindness for percentage of correct responses

| Sign # | Percentage of Correct Responses | | | | | | | Statistically Significant Difference in Averages | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Male** | **Female** | **Age 1** | **Age 2** | **Age 3** | **Not Color Blind** | **Color Blind** | **Male vs. Female** | **Age** | **Color Blind** |
| 1 | 95% | 92% | 91% | 96% | 92% | 93% | 100% | No (0.58) | No (0.73) | No (0.54) |
| 2 | 92% | 100% | 100% | 96% | 92% | 97% | 80% | No (0.09) | No (0.40) | Yes (0.06) |
| 3 | 97% | 100% | 100% | 100% | 96% | 100% | 80% | No (0.34) | No (0.40) | Yes (0.00) |
| 4 | 74% | 86% | 95% | 89% | 58% | 83% | 40% | No (0.20) | Yes (0.00) | Yes (0.02) |
| 5 | 82% | 86% | 91% | 74% | 88% | 83% | 100% | No (0.63) | No (0.21) | No (0.31) |
| 6 | 100% | 97% | 100% | 100% | 96% | 99% | 100% | No (0.30) | No (0.40) | No (0.79) |
| 7 | 97% | 94% | 91% | 96% | 100% | 96% | 100% | No (0.52) | No (0.28) | No (0.64) |
| 8 | 77% | 92% | 82% | 96% | 73% | 84% | 80% | No (0.08) | No (0.07) | No (0.80) |
| 9 | 74% | 72% | 86% | 70% | 65% | 74% | 60% | No (0.83) | No (0.25) | No (0.49) |
| 10 | 87% | 86% | 86% | 96% | 77% | 86% | 100% | No (0.89) | No (0.12) | No (0.37) |
| 11 | 87% | 100% | 100% | 96% | 85% | 93% | 100% | Yes (0.03) | No (0.08) | No (0.54) |
| 12 | 85% | 89% | 95% | 81% | 85% | 87% | 80% | No (0.59) | No (0.34) | No (0.65) |
| 13 | 97% | 92% | 95% | 100% | 88% | 96% | 80% | No (0.27) | No (0.18) | No (0.13) |
| 14 | 74% | 89% | 95% | 85% | 65% | 83% | 60% | No (0.11) | Yes (0.02) | No (0.21) |
| 15 | 87% | 72% | 95% | 81% | 65% | 80% | 80% | No (0.11) | Yes (0.03) | No (1.00) |
| 16 | 74% | 78% | 82% | 74% | 73% | 76% | 80% | No (0.73) | No (0.75) | No (0.83) |
| 17 | 69% | 56% | 82% | 56% | 54% | 61% | 80% | No (0.23) | No (0.08) | No (0.41) |
| 18 | 72% | 81% | 82% | 85% | 62% | 77% | 60% | No (0.38) | No (0.10) | No (0.93) |
| 19 | 69% | 69% | 77% | 67% | 65% | 69% | 80% | No (0.98) | No (0.64) | No (0.60) |
| 20 | 67% | 81% | 77% | 85% | 58% | 77% | 20% | No (0.17) | No (0.07) | Yes (0.00) |
| 21 | 97% | 89% | 91% | 93% | 96% | 93% | 100% | No (0.14) | No (0.76) | No (0.54) |

## 6.2 Results of ANOVA Tests for Part 2

In Part 2 of the experiment, participants were shown two variants of signs 16-20 for 2 seconds and were asked for the travel time on a particular route. The results of whether or not the responses were correct were recorded. Looking at the results, it can be seen that using MI instead of MILES can increase the percentage of correct responses when participants only briefly see the message sign.

**Table 6.7.** Results of ANOVA tests for Part 2

| Sign Aspect to Be Compared | Signs to Be Compared | Statistically Significant Change | Higher Percentage of Correct Responses for: |
|---|---|---|---|
| Banner: "Travel Time to" vs. "Time to" vs. Nothing | 16, 17, 18 | No (0.11) | |
| Distance text format: "MI" vs. "MILES" | 18 and 20 | No (0.48) | |
| Distance text format: "MI" vs. "MILES" | 18 and 19 | Yes (0.00) | Sign 18 – MI |

Again, the average percent correct responses were compared for males versus females, the different age groups, and colorblind and normally sighted participants. The results are shown in Table 6.8. As can be seen, only sign 20 resulted in a statistically significant difference in the percentage of correct responses between males and females, where females had a lower percentage of correct responses. The percentage of correct responses was smaller for older participants for all age groups. No significant changes were observed for colorblind participants.

**Table 6.8.** Results of ANOVA tests for Male/Female, Age and Colorblindness for percentage of correct responses in Part 2

| Sign # | Percentage of Correct Responses | | | | | | | Statistically Significant Difference in Averages | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Male | Female | Age 1 | Age 2 | Age 3 | Not Color Blind | Color Blind | Male vs. Female | Age | Color Blind |
| 16 | 72% | 58% | 86% | 65% | 48% | 66% | 60% | No (0.08) | Yes (0.00) | No (0.72) |
| 17 | 51% | 56% | 73% | 65% | 31% | 55% | 30% | No (0.60) | Yes (0.00) | No (0.13) |
| 18 | 59% | 57% | 73% | 56% | 50% | 60% | 40% | No (0.80) | No (0.07) | No (0.22) |
| 19 | 36% | 28% | 48% | 26% | 25% | 31% | 40% | No (0.29) | Yes (0.03) | No (0.58) |
| 20 | 71% | 53% | 80% | 63% | 46% | 61% | 80% | Yes (0.03) | Yes (0.00) | No (0.23) |

# 7. Conclusions

The goal of this project was to evaluate the visibility and comprehensibility of alternative VMS travel time message formats using an experimental setup. The experiments were conducted in a lab with 75 participants and each participant was shown 22 different sign designs. These designs included potential colored VMS signs along with monochromatic VMS (amber in color) signs representing the current signs used by PennDOT.

The results of the study show that the best design for comprehensibility and visibility of VMS travel time messages would entail the following:

1) Messages would display only time information, not travel distance information;
2) Route numbers would be displayed by numbers rather than shields;
3) Monochromatic signs would be used, but if colored VMS are used, the best use of color would be to display a congested travel time in red; and
4) The background would be black.

While it was found that colored VMS signs did not perform statistically better than monochromatic signs, some did perform as well in terms of comprehensibility and visibility as their monochromatic counterparts. These include sign numbers 6, 7, and 11. Of those three signs, sign number 6, which using "time to" employs color only for the travel time and displays routes as text, has the lowest reaction time and highest percentage of correct responses. Compared to all other signs, sign number 6 has the highest percentage of correct responses (tied with sign number 1), indicating that it performs very well in terms of visibility. Additionally, the reaction time for sign number 6 was not statistically significantly higher than the monochromatic signs, indicating good performance in terms of comprehensibility.

However, following the numbered guidelines above would generally result in the best comprehensibility of signs with no significant difference in the gender, age, or colorblindness of travelers. If colored signs are used, guidelines 1, 2, and 4 should still be followed.

# References


Bezuidenhout, U., 2015. Urban VMS conspicuity and message comprehension, in: *Insitution of Professional Engineers New Zealand (IPENZ) Transportation Conference*. Christchurch, New Zealand.

Bugdol, M.N., Wijata, A.M., Wacławska, K., Piwowarski, S., Skotnicka, M., Dyrda, A., 2014. Effective Communication of Information via Variable Message Signing from the Point of View of Driver's Basic Skills. *Roads Bridg.* 13, pp. 309-320.

Carlson, P., 2016. Traffic Control Device Evaluation, Technical Memorandum 9-1001-14-3, TXDOT Project 9-1001. College Station, TX.

Chrysler, S.T., Carlson, P.J., Brimley, B., Park, E.S., 2017. Effects of full matrix color changeable message signs on legibility and roadway hazard visibility. *Transp. Res. Rec.* 2617, 9–18.

Dudek, C.L., 2004. *Changeable Message Sign Operation and Messaging Handbook*. Federal Highway Administration Report No. FHWA-OP-03-070, Washington, D.C.

Federal Highway Administration (FHWA), 2015. Travel Times on Dynamic Message Signs (DMS) Status [WWW Document]. United States Dep. Transp. URL https://ops.fhwa.dot.gov/travelinfo/dms/ (accessed 1.1.18).

Federal Highway Administration (FHWA), 2009. *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD). Washington, D.C.

Garvey, P.M., 2002. *Synthesis on the Legibility of Variable Message Signing (VMS) for Readers with Vision Loss*, United States Access Board. University Park, PA.

Garvey, P.M., Kuhn, B.T., 2004. Highway Sign Visibility, in: McGraw-Hill (Ed.), *Handbook of Transportation Engineering*. New York.

Heller, R., Gordon, E., Krishnamurthy, A., 2012. SunGuide Software Color Dynamic Message Sign Support Concept of Operations, Technical Memorandum. Tallahassee, Florida.

Kuhn, B., Higgins, L., Nelson, A., Finley, M., Ullman, G., Chrysler, S., Wunderlich, K., Shah, V., Dudek, C., 2014a. *Effectiveness of Different Approaches to Disseminating Traveler Information on Travel Time Reliability*, SHRP 2 Report No. S2-L14-RW-1, Transportation Research Board, Washington, D.C.

Kuhn, B., Higgins, L., Nelson, A., Finley, M., Ullman, G., Chrysler, S., Wunderlich, K., Shah, V., Dudek, C., 2014b. *Lexicon for Conveying Travel Time Reliability Information*, SHRP 2 Report No. S2-L14-RW-2, Transportation Research Board, Washington, D.C.

Lerner, N., Singer, J., Robinson, E., Huey, R., Jenness, J., 2009. *Driver Use of En Route Real-Time Travel Time Information*, Federal Highway Administration White Paper, Washington, D.C.

Ma, Z., Shao, C., Song, Y., Chen, J., 2014. Driver response to information provided by variable message signs in Beijing. *Transp. Res. Part F Traffic Psychol. Behav.* 26, 199–209.

Martin, G., 2007. Travel Times Best Practices Manual.

McCourt, R.D., Conrad, J., 2017. *Electronic Display Traffic Control Task Force*, National Committee on Uniform Traffic Control Devices, Sun City West, AZ.

New York State Thruway Authority, 2011. *Guidelines for Use of Variable Message Signs*

*(VMS)*.
Oregon Department of Transportation, 2005. *Travel Time Messaging on Dynamic Message Signs - Portland, OR*, Washington, D.C.
Paniati, J.F., Lindley, J.A., 2004. *Dynamic Message Sign (DMS) Recommended Practice and Guidance Memorandum*, Federal Highway Administration White Paper, Washington, D.C.
Paxion, J., Galy, E., Berthelon, C., 2014. Effects of situation complexity and driving experience on performance through subjective and objective tension, in: ACM (Ed.), *Proceedings of the 2014 European Conference on Cognitive Ergonomics - ECCE '14*. Vienna.
Pennsylvania Department of Transportation. (2013). *Dynamic Message Sign Operating Standards*. Harrisburg: Pennsylvania Department of Transportation.
Robinson, E., Lerner, N., Singer, J., Baragan, D., Kulbicki, K., Kline, J., Kellman, D., 2017. *Travel Time Displays at Freeway Entrance Approaches*, Federal Highway Administration Report No. FHWA-HRT-16-059, McLean, VA.
Roca, J., Tejero, P., Insa, B., 2018. Accident ahead? Difficulties of drivers with and without reading impairment recognising words and pictograms in variable message signs. *Appl. Ergon.* 67, 83–90.
Tennessee Department of Transportation, 2005. *Travel Time Messaging on Dynamic Message Signs - Nashville, TN*, Washington, D.C.
Texas Department of Transportation, 2005. *Travel Time Messaging on Dynamic Message Signs - Houston, TX*, Washington, D.C.
Wang, J.-H., Hesar, S., Collyer, C., 2007. Adding Graphics to Dynamic Message Sign Messages. *Transp. Res. Rec.* 2018, 63–71.

# Appendix A: Formats Not Recommended for Further Study

1


2


3


4

5


TIME TO MEQUON
VIA I-90 10 MIN
VIA I-39 45 MIN

6


TIME TO MEQUON
VIA I-90 10 MIN
VIA I-39 45 MIN

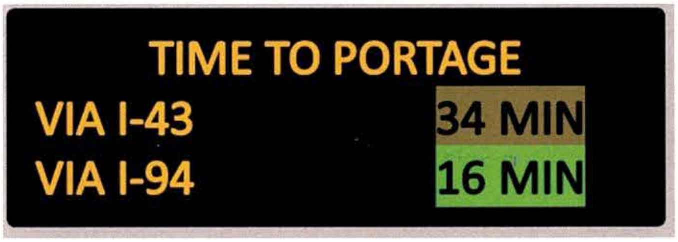
7


TIME TO PORTAGE
VIA I-43
10 MI 51 MIN

8


TIME TO PORTAGE
VIA I-43 34 MIN
VIA I-94 16 MIN

9


TIME TO PORTAGE
VIA I-43
34 MIN
VIA I-94
16 MIN

10


TIME TO
VIA I-155
10 MI 15 MIN
INTERSTATE
94

11


INTERSTATE
94
VIA
10 MI
15 MIN
INTERSTATE
155

12


GRAFTON VIA
INTERSTATE
94
10 MI 18 MIN

# Appendix B: PennDOT MUTCD-compliant VMS Color Recommendations

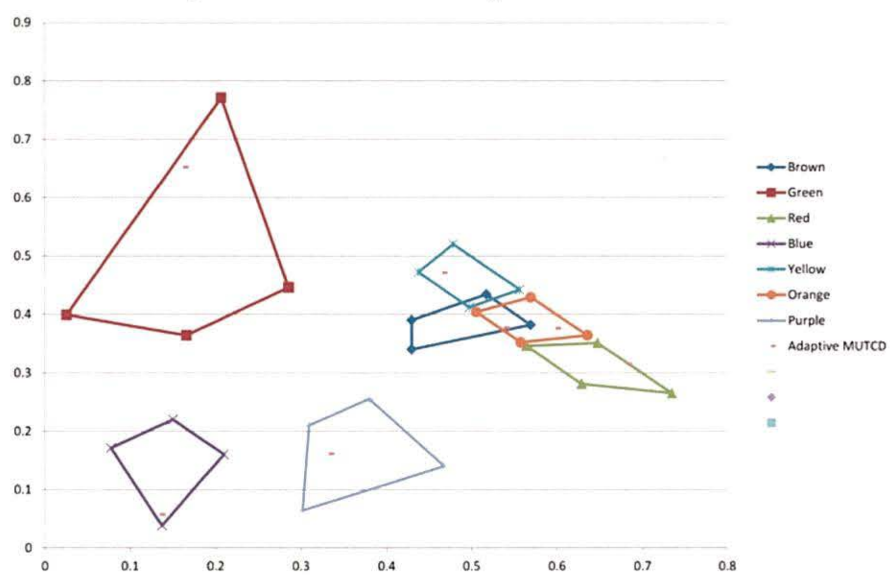
## Adaptive MUTCD Compliant Colors

| Color | RED | GREEN | BLUE |
|---|---|---|---|
| BROWN | 86 | 51 | 17 |
| GREEN | 55 | 255 | 45 |
| RED | 255 | 0 | 0 |
| BLUE | 0 | 0 | 255 |
| YELLOW | 255 | 241 | 0 |
| ORANGE | 221 | 117 | 0 |
| PURPLE | 114 | 22 | 126 |
| AMBER | 240 | 159 | 0 |

NOTE: Amber color is not listed in the MUTCD color specification, but is included in this chart for reference.

Adaptive

## Adaptive MUTCD Compliant Colors




Adaptive