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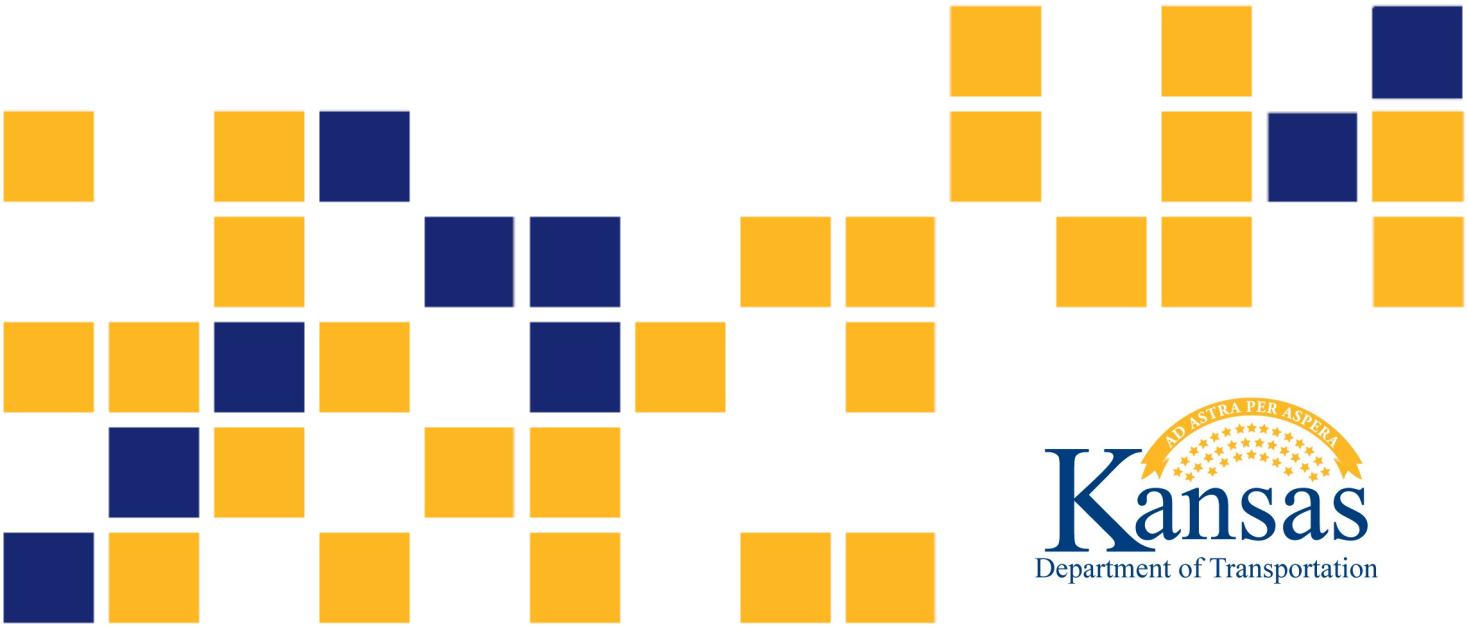
Creating Effective Graphic Changeable Dynamic Message Sign (DMS) Messaging

Alexandra Kondyli, Ph.D.
Steven D. Schrock, Ph.D., P.E.
Kirti Mahajan, Ph.D.
Saumik Sakib Bin Masud, Ph.D.
Aayush Maan Karki,
Saurav Shrestha,
Mahgam Tabatabaei

The University of Kansas



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16 Abstract

Successful transportation safety messages are only effective if travelers can comprehend the notices. However, one method of safety messaging, text-only messages, can be challenging for non-native English speakers and slow-reading populations, such as older adults. The addition of graphics can potentially improve message comprehension, but their effectiveness compared to text-only messaging campaigns is uncertain. This study evaluated the role of graphics, both with and without text, in enhancing comprehension and the effectiveness of dynamic message signs (DMS), with attention to demographic factors.

Results showed that signs with graphics and text consistently outperformed graphics-only signs across all measures, including conspicuity, comprehension, ease of use, intention to comply, and memorability. The lowest-scoring signs lacked text, leading to poor interpretation accuracy and compliance. Statistical analyses confirmed that text significantly improved message effectiveness by reducing comprehension gaps between native and non-native English speakers. Age also influenced performance, with drivers older than 41 years old demonstrating higher effectiveness scores, likely due to driving experience. Logistic regression showed that age, literacy rate, and text presence positively predicted accurate sign interpretation.

The findings indicate that graphics alone are insufficient for effective DMS communication, although pairing graphics with text enhances comprehension and compliance for all populations, especially for non-native speakers and young drivers. Awareness initiatives are recommended to improve familiarity with graphic signs.

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Prepared by

Alexandra Kondyli, Ph.D.
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Mahgam Tabatabaei

University of Kansas

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PREFACE

The Kansas Department of Transportation's (KDOT) Kansas Transportation Research and New-Developments (K-TRAN) Research Program funded this research project. It is an ongoing, cooperative and comprehensive research program addressing transportation needs of the state of Kansas utilizing academic and research resources from KDOT, Kansas State University and the University of Kansas. Transportation professionals in KDOT and the universities jointly develop the projects included in the research program.

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Abstract

Successful transportation safety messages are only effective if travelers can comprehend the notices. However, one method of safety messaging, text-only messages, can be challenging for non-native English speakers and slow-reading populations, such as older adults. The addition of graphics can potentially improve message comprehension, but their effectiveness compared to text-only messaging campaigns is uncertain. This study evaluated the role of graphics, both with and without text, in enhancing comprehension and the effectiveness of dynamic message signs (DMS), with attention to demographic factors.

Results showed that signs with graphics and text consistently outperformed graphics-only signs across all measures, including conspicuity, comprehension, ease of use, intention to comply, and memorability. The lowest-scoring signs lacked text, leading to poor interpretation accuracy and compliance. Statistical analyses confirmed that text significantly improved message effectiveness by reducing comprehension gaps between native and non-native English speakers. Age also influenced performance, with drivers older than 41 years old demonstrating higher effectiveness scores, likely due to driving experience. Logistic regression showed that age, literacy rate, and text presence positively predicted accurate sign interpretation.

The findings indicate that graphics alone are insufficient for effective DMS communication, although pairing graphics with text enhances comprehension and compliance for all populations, especially for non-native speakers and young drivers. Awareness initiatives are recommended to improve familiarity with graphic signs.

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Chapter 1: Introduction

1.1 Background

Successful transportation messages are only effective if travelers can read and comprehend the message. However, text-based messages can be challenging for non-native English speakers or slow-reading populations, such as the elderly. The addition of graphics messages as a potential aid to improve message comprehension is uncertain, as is their effectiveness compared to text-only messaging campaigns. Current literature reviews have focused on the use of graphical shields and highway signs for messaging, but research is needed to analyze the effectiveness of graphics for conveying safety messages without explanatory text and evaluate whether this approach could be beneficial for specific populations.

1.2 Objectives

The objectives of this project were to determine whether graphics can be used to enhance comprehension and effectiveness of messaging, and to help guide development of guidelines to determine when and how the graphics, either stand-alone or supplemental to text, can be used to enhance the comprehension and effectiveness of key safety messages.

Chapter 2: Review of Current Practice

This study conducted a thorough literature review to identify existing research related to dynamic message signs (DMS). Several publications, theses, and books were obtained from the University of Kansas (KU) Library and online library databases such as Google Scholar, Transportation Research International Documentation (TRID), ScienceDirect, DBPIA, JSTOR, and IEEE Xplore Digital Library.

2.1 Common Uses of Dynamic Message Signs

A DMS can be used to display various emergency messages to inform and guide drivers during critical situations. The specific messages displayed on DMS may vary depending on the region, situation, and messaging purpose. Many countries, including the United States, have adopted graphical DMS on highways and major roads to convey real-time en-route information including traffic/congestion situations, weather, incidents/emergencies, diversion needs and road conditions (Aitken et al., 2010). China and European countries such as the United Kingdom, Germany, France, Italy, and Spain employ graphical DMS as a part of their advanced traffic management systems (ATMSs) in urban areas and highways (Smyth, 2010). Australia uses graphical DMS to provide real-time traffic information, roadwork updates, and emergency alerts to drivers, and Canadian provinces and territories use graphical DMS to communicate information related to traffic management, weather conditions, and road safety (Saha et al., 2013). Similarly, Japan uses graphical DMS on highways and roads to provide information about traffic congestion, weather conditions, and accidents; South Korea employs graphical DMS to convey real-time traffic information, advisories, and emergency alerts (Tay & Choi, 2009), and the United Arab Emirates (UAE) and Brazil use graphical DMS to communicate traffic information and road conditions to drivers, especially in urban areas (Ahmed et al., 2016; Ratrout & Issa, 2014). Singapore uses graphical DMS to provide real-time traffic updates, advisories, and information to drivers. Given the improved comprehension and readability that graphics and symbols offer on DMS, recent research is investigating their application in communication between autonomous vehicles and pedestrians (Chng et al., 2022).

2.2 MUTCD Guidelines

Based on Chapter 2A in the Manual of Uniform Traffic Control Devices (MUTCD) (Federal Highway Administration (FHWA), 2023, Table 2A-2), Table 2.1 suggests distinct colors for backgrounds and legends for various types of changeable message signs. For example, with a black background, the color for the legend on a changeable message sign should match the background color that would be used on a standard sign for that type of legend, such as red/black/white for regulatory, black legend on yellow background for warning, orange for temporary traffic control, red for stop or yield, fluorescent pink for incident management, and fluorescent yellow-green for bicycle, pedestrian, and school warnings. If the DMS technology can duplicate static message sign graphics and colors, then such signs are recommended for enhanced legibility and easy recognition. The guidelines also recommend deviating from the suggested guidelines as appropriate based on engineering investigations or judgments.

Table 2.1: DMS Guidelines Based on Table 2A-2 MUTCD 2023

DMS Sign Type	Background	Legend/Border	Shape
Regulatory	Black	Red (circle or diamond as used in fixed signs), white	
Warning signs	Black	Yellow	
Temporary traffic control (TTC)	Black	Orange, yellow-W10-1 sign	
Guide signs	Black/green (pixels would be lit in the entire DMS, not just the legend)	White	
Motorist services	Black/Blue (entire DMS)	White	
Crash or incident management	Black	Yellow/fluorescent pink	
School, pedestrian, bicycle	Black	Yellow/fluorescent yellow-green	
Other Fixed Signs			
TTC	Orange, yellow: W10-1 sign or if orange is unavailable	Black	Diamond-shaped except few
TTC incident management warnings	Fluorescent pink	Black	
Guide signs			
Interstate route	Blue, red	White	
State and U.S. routes	White	Black	
County	Blue	Yellow	
Information	Blue	White	
Evacuation route, road-user service	Blue	White	
Recreational	Brown, green	White	

According to the MUTCD (FHWA, 2023, Section 6H.01), TTC zone warning signs shall additionally comply with the Standards for warning signs presented in FHWA's 'Standard Highway Signs' publication. The related publication includes standard alphabets, symbols and arrows for signs and pavement markings. Additionally, TTC warning signs shall be diamond-shaped with a black legend and border on an orange background, except for the W10-1 sign which shall have a black legend and border on a yellow background, and except for few other signs such as incident management warnings or construction/road works en-route that are required or recommended to have fluorescent yellow-green backgrounds. The use of fluorescent colors and

distinguishing shapes are therefore emphasized in these design principles. Chapter 2L of the MUTCD guidelines (FHWA, 2023) is dedicated to the design principles of changeable/DMS.

2.2.1 Legibility Characteristics

Section 2L.03 of the MUTCD guidelines (FHWA, 2023), recommends that letter heights for DMS be 18 in. on highways with a posted speed limit (PSL) of 45 mph or higher and 12 in. on roadways with a PSL less than 45 mph. In addition, a less illuminous or darker background should be used to enhance the legibility of display messages instead of increased letter height. The DMS should adapt to daytime and nighttime lighting conditions, and the message should be legible from a minimum distance of 600 ft for nighttime conditions and 800 ft for daylight conditions. The legibility distance is a vital parameter for rapid message comprehension, especially for unfamiliar or non-English speaking drivers (Ullman et al., 2009). To enhance legibility, messages are segmented into manageable units of information called phases that are displayed sequentially to be read by the drivers (Hoekstra-Atwood et al., 2022). Furthermore, to account for low legibility conditions due to environmental disturbances such as fog, rain, snow, or glare on extremely sunny days, either shorter message lengths should be utilized, or information should be restricted to a single phase.

2.2.2 Principles of Message Design and Display

According to Section 2L.05 of MUTCD (FHWA, 2023), the messaging on DMS should not exceed four words per unit of information to guide drivers. For example, the word “crash” could be used to describe the event, “drivers headed to X” could identify who the information is for, and “alternate route to X” could state what is advised (refer to Table 2L-2 of MUTCD, FHWA, 2023). Maximum allowable units depend on roadway speed, legibility of DMS (i.e., illumination, contrast, etc.), and lighting conditions. Each message should not exceed more than two phases, with a maximum of three lines of text and one unit of information per line. Each phase should be independent information, regardless of the sequence in which it is read. The MUTCD guidelines (FHWA, 2009, 2023; Hoekstra-Atwood et al., 2022) regarding the display of information on DMS are summarized in Table 2.2.

Table 2.2: Foundational Guidelines on Display of Information on DMS

Aspect	2009 MUTCD Standard	2022 & 2023 Practices & Research
Units per phase	≤ 3 units per phase	Same — still governed by 2009 MUTCD
Total units per message	≤ 4 units (≥ 35 mph), ≤ 5 units (< 35 mph)	Same — no change
Number of phases	≤ 2 phases	Same — no change
Phase display time	≥ 2 seconds per phase	Same — still applies
Cycle time (two phases)	≤ 8 seconds	Same — still applies
Inter-phase gap	≤ 0.3 seconds	Same — still applies
Use of color/symbols	Not generally addressed — amber-only assumed	Research available, but standards still per MUTCD 2009 guidelines

According to Ullman et al. (2009), in addition to legibility distance, the time required to comprehend the message is a significant parameter when determining the adequacy of a sign or symbol on a DMS. On highways with operating speeds of 35 mph or higher, a two-phase DMS message should be readable within a maximum cycle of 8 seconds, with a 0.3 s separation between each phase (i.e., each phase ≥ 2 s; inter-phase gap ≤ 0.3 s; ≤ 3 units per phase). The time to comprehend a message may further decrease with complex driving environments such as road incidents, roadwork, mandatory lane changing, and merging-diverging actions.

Previous studies have utilized a variety of methods to design and display pictographic messages for DMS. The focus groups and interview/video-based surveys help determine driver preferences for a pictogram among given alternatives; whereas, a driving simulator or field experiments can evaluate DMS effectiveness in altering driving behavior and measure reaction accuracy and speed. Previous studies have suggested that the use of adequate graphics in messages reduces comprehension time and improves legibility for unfamiliar or non-English speaking drivers (Wang & Clark, 2010; Dewar & Pronin, 2023; Dudek et al., 2000; Shinar & Vogelzang, 2013).

One way to ensure selected graphics can be easily understood by drivers is to use the same symbols and signs from the existing static sign symbols. Luoma and Rämä (2001) investigated the

comprehension of pictograms (graphics) for DMS via interviews with 795 drivers in six European countries. Results showed that, although interpretation of the graphics improved if presented in context, drivers more clearly understood text messaging. Additionally, most drivers interpreted the red triangle as a warning sign, but contrary to European signs and symbols, MUTCD (FHWA, 2009) recommends the use of a diamond shape instead of a triangle and an orange or pink fluorescent (incident management) background instead of white for warning or cautionary signs. Knoblauch et al. (1995) found that U.S. drivers correctly interpreted European symbols for congestion and crash only at close distances of 400 ft or less in daytime conditions. In both studies, the pictograms tested for crashes restricted lanes for buses or high-occupancy vehicles (HOVs), oncoming vehicles, skidding danger due to ice or snow, and reduced visibility due to rain or snow were less acceptable (Knoblauch et al., 1995; Luoma & Rämä, 2001). The pictograms for fog and hydroplaning were also termed 'highly inadequate' by the participating drivers emphasizing the inefficiency of pictograms used in the study. Er-hui et al. (2013) presented a questionnaire to 445 drivers to investigate driver's ability to accurately comprehend the alternative pictograms designed/used for rain, fog, snow, crosswind, and road closure. The study findings established which graphic designs facilitated the quickest and most accurate comprehension by drivers among the given alternatives for displaying weather and road condition messages on the DMS.

2.3 Graphical DMS in the United States

In addition to the DMS guidelines in MUTCD (FHWA, 2009), Minnesota, Missouri, New Mexico, California, and Virginia have developed unique practices to meet their state-specific transportation needs. Roelofs and Schroeder (2016) provided a list of guidelines and manuals for various states, highlighting significant variations of graphic-aided DMS guidelines by state. One common guideline is to allow graphics only if they duplicate the standard symbols and signs from MUTCD (FHWA, 2009). All state departments of transportation (DOTs) have found evidence to support the use of graphic-aided DMS to improve drivers' comprehension of DMS information, especially for non-native speakers (Kwigizile et al., 2022). The guidelines prioritize displayed messages based on their impact. This means events such as work-zone disruptions (planned) and crash incidents (unplanned) leading to lane closures and travel time delays are given the highest

priority due to their immediate impact; followed by medium-impact messages such as congestion/ramp backups, short-term work zones, and weather conditions. Public announcements or generic safety campaign messages are given the lowest priority.

Kwigizile et al. (2022) reported survey findings from 898 drivers in Michigan, in which more than 80% of drivers expressed their inability to read two-phase messages on the DMS display, especially at high speeds. Drivers also expressed their preference for color-coded formats for different types of messages, such as red for road closure signs, yellow for construction, blue to represent icy or snow conditions, and green to indicate travel time. Many drivers noted poor visibility of the yellow color and a preference for green, especially when driving in sunny conditions or with sun glare.

Charlton (2006) examined driver reactions to 16 road hazard warning signs of various formats by projecting life-sized videos of road scenes to 33 drivers in a driving simulator. The messages were examined for conspicuity, memorability, comprehension, and priming in road hazard warning signs. In roadworks, flashing messages were more conspicuous but were rated lowest for memorability, but the flashing feature conveyed a potential hazard more effectively in school zones. Similarly, Ullman et al. (2009) conducted a focus group discussion and a laptop-based questionnaire to investigate the ability of drivers to comprehend DMS messages that incorporated colors and symbols. Results showed that drivers preferred closed lanes to be displayed in red, open lanes to be indicated with yellow or green, and a road closure symbol to be a circle instead of a cross. Table 2.3 summarizes previous studies that have examined the effectiveness of design elements such as colors, symbols, and placement of graphic-aided DMS.

Table 2.3: Summary of Previous Studies on the Effectiveness of Graphic-Aided DMS

Author/Year	Factors	Method	Findings
(Wang & Clark, 2010) Aim: Graphical DMS for elderly drivers	• Sign type: Weather (slippery, snow); Construction (road works, lane shift); Information (congestion, accident); Regulatory (speed limit, seat belt, no trucks) • Age, gender • Native language – English, Spanish, Other • Display scenarios: red vs. amber on black; alternate graphics; text alignment-right, left, center; text vs. graphics; alternate static vs. dynamic graphics; flashing text; text abbreviations; text outline • 52 slides with 50 questions • Measurements: response speed, time, and accuracy	• Stated preference survey (480) • 60 subjects for laptop survey using PowerPoint slides • Videos extracted from driving simulator scenarios with graphics edited into the installed DMS were prepared and shown to the drivers.	• Survey results indicated that drivers preferred graphics messages. • Red was preferred in the survey, but amber improved reaction time. • Driving experiments showed driver reaction time was faster in dynamic graphics, amber-colored messages, red-colored graphics, animated, flashing text, center-text alignment, amber-only text outline, and initial information about the event in the DMS, including older and non-native English speakers. • Older drivers responded more slowly and less accurately than younger drivers; graphics improved reaction time and accuracy.
(Huang & Bai, 2019) Aim: Graphical DMS in work zones	• Elderly drivers • Portable changeable message signs (PCMS)	• Survey (1000) • Naturalistic (2,700 vehicles) • Speed	• Graphic-aided PCMS reduced mean vehicle speed by 13%–17%. • All drivers correctly interpreted the flagger graphic and two work-zone graphics. • 52%–71% of drivers preferred to see graphics in PCMS messages. • Age was not a significant factor.

Author/Year	Factors	Method	Findings
(Bai et al., 2011) Graphic PCMS in work zones Kansas (Report)	• Non-English-speaking drivers, with a short range of legibility • One-lane, two-way rural highway • Comparison between text PCMS, graphic-aided PCMS, and graphic PCMS	• Field experiments • Surveys to identify preferences and comprehensibility • Vehicle speed using speed sensors • Acceptance of PCMS	• Graphic-aided and graphic PCMS were preferred and easily understood by drivers. • In the field study, graphic PCMS led to the highest speed reduction in work zones (17% compared to 10% in graphic-aided and 13% due to text-only messages).
(Kwigizile et al., 2022) Western Michigan (Review)	• Route choice, work-zone PCMS, weather-related • Compliance of existing DMS: lane closure, incident management, and weather	• Field data sensors • Survey 901 • VR driving simulator (26 drivers)	• Negative factors included display of inaccurate, irrelevant, obvious, repetitive, trivial, erroneous, and poorly designed messages. • Differences were found among the states for prioritizing messages.
(Almallah et al., 2021) Animated VMS for work zones Qatar	• Measurements: lane-change time post DMS, speed reduction • Bilingual (Arabic & English) signs with graphics • Two-phase graphic messages: lane closed, merge right • Message format: black background, amber message, white text, red prohibition element or border • Doha expressway	• Driving simulator • ANOVA of speed, acceleration, deceleration, lane position, space headways • T-test for speed comparison at pre-post signs • Multiple testing combinations	• The mean deceleration was higher with graphic VMS. • VMS-induced earlier speed reduction and higher space headway occurred in work zones.

Author/Year	Factors	Method	Findings
(Dewar & Pronin, 2023) Design of signs and symbols			• Symbols must be meaningful, legible, learnable, memorable, and universal/consistent in design with the sign system. • **Common visual vocabulary** for road users and designers • Diamond and triangular warning signs • A supplementary plaque can maintain good legibility.
(Dudek et al., 2000) Frames, units, and flashing of DMS • Texas, U.S. participants from multiple regions	• Recall & comprehension of DMS • Response time • Format/sign preferences • Interpretability of timing: days, hours, dates, etc. • Accuracy of delays/travel time information • Accurate comprehension of technical vocabulary • Reading time and recalling information	• Laptop-simulated DMS • Questionnaire • 42 messages • Data descriptives	Display recommendations: • Limit to maximum eight words for high-speed facilities such as freeways • Message **familiarity** and correct order reduce reading time. • Divide the message into frames and display maximum 3 units per frame to improve driver recollection of information. Issues with DMS: • Brief alternatives for date/time/day of roadworks • Understanding of technical words (e.g., ramp vs. exit, congestion vs. heavy/major/normal, high-profile vehicles, etc.) • Flashing increased reading times but was preferred by some motorists because it catches drivers' attention. • Redundant information in two-frame messages may increase reading times, but it could be clearer. • One-frame messages are preferable to multi-frame messages.

Author/Year	Factors	Method	Findings
(Er-hui et al., 2013) Weather graphics	• Five graphic signs for weather information and road closure • Rain, fog, snow, cross-wind, and road closure	• Questionnaire • Sample 445 • Preference for graphics	• Highest proportion of graphics chosen by the subjects • The cross symbol was preferred for lane closure.
(Huang & Bai, 2019) Work-zone graphics PCMSs • Kansas US Highway 75	Measurements collected: • Subjective: Noticing DMS, accurate comprehension of information, found graphics more grasping than text, preference over text • Objective: vehicle speed change	• Field experiment (6 days, 6:00 a.m.–8:00 p.m.) • 536 questionnaire responses	• Work-zone and flagger graphics used in PCMS • Graphics-only and text-graphics led to effective speed reduction compared to text-only PCMS. • **Text-graphic with flagger** was correctly interpreted by 100% of drivers compared to text with work-zone graphics correctly interpreted by 88%. • Drivers paid more attention to traffic after PCMSs. • 52% preferred flagger graphics compared to 26% preferring work-zone graphics. • The effectiveness of graphic alternatives varied between truck drivers and car drivers.
(Shinar & Vogelzang, 2013) Symbolic traffic signs	• Speed and accuracy of comprehension		• Accuracy improved when symbol text was shown. • Display (symbol only, text only, symbol-text) and familiarity affect reaction time and accuracy.

Author/Year	Factors	Method	Findings
(Ullman et al., 2009) Aim: Use of graphics & symbols on DMS • Texas (Brownsville, Dallas, El Paso, Houston, and San Antonio)	• Representation of unusual scenarios: available lane information, incident information, work-zone, HOV lanes, toll lanes, etc. • Situations for implementation: near interchanges, toll lanes, incident information • Measurements: accuracy of comprehension and suggestions to improve graphics	• 38 subjects and 11 Spanish-speaking truck drivers • Focus group discussion: 7–10 subjects per group • Laptop survey with 160 subjects (32/location)	• Review of effective pictogram messages and legibility distances • Color and animation are not well investigated and adopted in the United States. • Drivers suggested including information about alternate routes or action information for any event on DMS. • Drivers suggested displaying closed lanes in red and open lanes in yellow or green, as well as displaying the closed symbol as a circle instead of a cross. • Drivers suggested text-graphics to convey the number of lanes closed.
(Xu et al.,2020) Adequate volume of info on VMS China	• Legibility speed, legibility distance, legibility time, comprehension accuracy, and driver subjective scoring • Road network information: Structure in either green, amber or red • vehicle locations, surrounding roads, directions, key nodes, distance & time to approaching nodes • Scenarios were created using a combination of 3 to 7 road intersection configurations.	• 32 subjects • Statistical analysis • Driving simulator • TOPSIS method of comprehension score evaluation	• Information about more than five roads significantly decreased comprehension accuracy, legibility speed, time, and distance.

Author/Year	Factors	Method	Findings
(Ilkhani et al., 2023) Tunnel evacuation messages Iran	• Four pictograms: no entry, warning, green emergency exit, and white emergency exit • Two text modes: one line, two lines and picture • Two image location modes: image in middle with text at bottom; image on the left side of text • Flashing lights at the VMS corner: on/off • 25 scenarios and 50 signs	• 374 (field) and 35 (online) • Questionnaire (binary preference) • Stated choice • Binary logit model	• Drivers preferred the green emergency exit image with the text message over the amber-colored triangular caution sign with text at the bottom. • Only the amber color was used in text, but small, medium, and large fonts were used.

Chapter 3: Methodology

This research used surveys and short videos displayed in the KU driving simulator to evaluate the effectiveness of various safety-related DMS graphics with and without text. The DMS graphics under investigation were selected following focus group discussions and consultations with the Kansas Department of Transportation (KDOT) and DMS operators in WICHway, the Intelligent Transportation System (ITS) in Wichita, Kansas. Participants recruited for the driving simulator at KU were given a screening questionnaire that gathered information regarding their demographics and driving behavior. Short (10 s) video clips were created in the driving simulator, where a DMS with varying graphics and texts was displayed in each video clip.

Simulator scenarios were created, including selecting and setting up DMS messages, and, following completion of the draft scenario, pilot testing was carried out to detect any discrepancies missed by the designer. Figure 3.1 highlights the main tasks performed in this study.

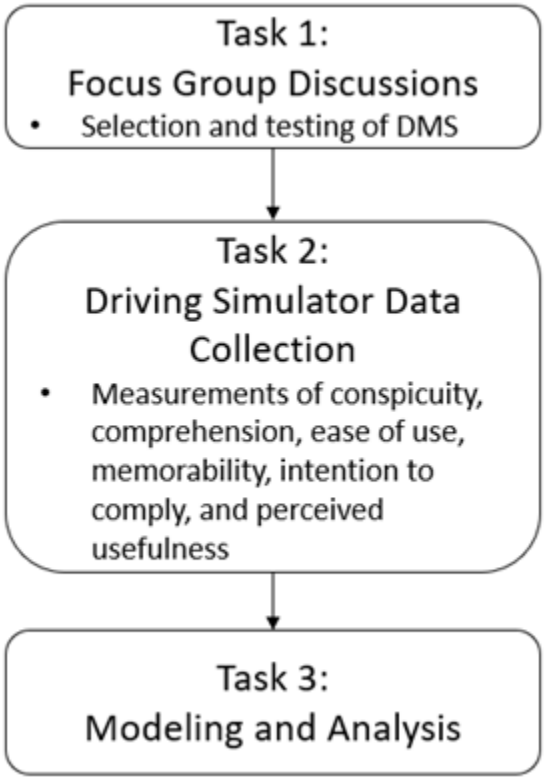


Figure 3.1: Research Framework

3.1 Focus Group Discussions

In the initial phase of the study, KDOT shared an exhaustive list of messages to be converted into graphic-aided messages for non-English speaking and slow-reading populations. The messages were categorized into the following themes:

- Crash or incident information
- Alternative route guidance
- Inclement weather warnings
- Work-zone and road closures
- Safety messages – DUI/impaired driving, speeding, etc.

Work-zone-related messages were adopted from MUTCD signs, and alternative graphics were developed for the remaining messages based on previous studies and symbols/signs used worldwide. A focus group discussion was conducted with three experts from KDOT and WICHway regarding DMS deployment and operation to determine effective graphic options corresponding to each type of message. Based on the inferences and preferences gathered through these discussions, the research team developed a list of messages to be included in the next round of testing. The selected graphics were then converted to portable network graphic (PNG) files and sent to WICHway, where they were uploaded to a test DMS to examine their appearance in a full-size DMS. Figure 3.2 shows examples of the mockup and live versions of the graphics.

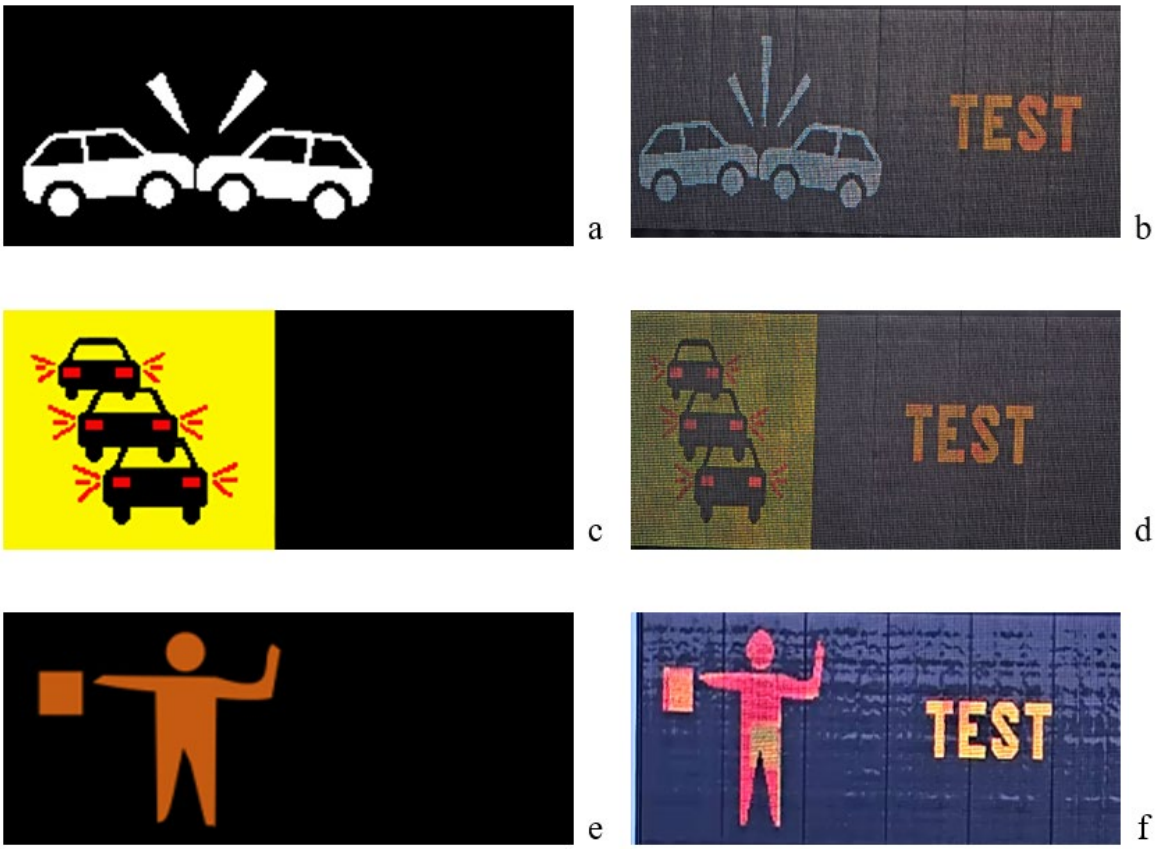


Figure 3.2: Graphical Images and Corresponding DMS Implementation: (a) Crash Graphic, (b) Crash DMS, (c) Congestion Graphic, (d) Congestion DMS, (e) Flagger Graphic, and (f) Flagger DMS

Because the pictures obtained from the physical DMS which rely on individual pixels (Figures 3.2b, 3.2d, and 3.2f) were of lower quality, Figures 3.2a, 3.2c, and 3.2e were displayed in the driving simulator data collection study.

3.2 Driving Simulator Data Collection

3.2.1 Overview of Data Collection

To investigate the effectiveness of the selected graphics, a survey study was conducted at the driving simulator lab at KU. The effectiveness measures of the graphics were conspicuity, comprehension, ease of use, intention to comply, memorability, and perceived usefulness. All metrics were measured using a questionnaire survey in which drivers rated their preferred graphics based on these criteria.

Each selected graphic was displayed on a simulated DMS board, as shown in Figure 3.3. Each message was displayed at 800 ft, allowing 8–9.8 s of visibility at 55 mph, during daytime conditions according to MUTCD (FHWA, 2009) recommendations for desired legibility of DMS. Shinar and Vogelzang (2013) and Ullman et al. (2009) found that a combination of symbols and text was preferable to DMS with only text or graphics. Therefore, a message with text and graphics was chosen as the baseline. Each alternative graphic was presented without text and with text to evaluate specific performance measures compared to a baseline condition of a text-only message. Video footage was collected via simulated DMS boards on a controlled segment of road that was displayed on projected screens in the driving simulator. A total of 36 graphics were displayed in the DMS boards (18 with text and 18 without text), and 10-s video recordings were generated for each graphic. The complete list of all graphics tested in this study is provided in Appendix A.

Figure 3.3: DMS Sign Shown in the Simulator

Participants sat inside the driving simulator cab as the researchers showed randomized videos with the displayed DMS. Each footage was separated by an interval of 5–10 s, and driver responses were recorded by the research team. After each displayed sign, participants were asked a set of questions to determine their understanding and collect the measures of interest.

3.2.2 Measures of Interest

As mentioned, the research team employed a series of questionnaires to collect specific measures that capture DMS effectiveness: conspicuity, comprehension, ease of use, memorability, and intention to comply. Most of the questions were either binary or employed a 5-point Likert scale. The research team recorded all responses into a spreadsheet. The following sections present these five measures and describe how they were collected.

3.2.2.1 Conspicuity

Conspicuity refers to the ability of a DMS to stand out and quickly attract drivers' attention. This measure was collected using two questions designed on a 5-point Likert scale:

1. *On a scale from 1 to 5, how easy was it to notice the message on the sign? 1 means very difficult to notice and 5 means very easy to notice.*
2. *On a scale from 1 to 5, how quickly did you notice the message on the sign? 1 means very slowly and 5 means very quickly.*

The scores for the two questions were averaged to obtain the final conspicuity score and perform the analysis. Participants were also asked to press a buzzer as soon as the sign became visible to them. The researchers used a stopwatch to record the time between the start of the video and the buzzer presses, and then they calculated the time between the buzzer presses and when the DMS first appeared on the screen.

3.2.2.2 Comprehension

Comprehension refers to how well drivers understand the message displayed on the DMS. Study participants had to verbally state the meaning of the message or the desired action, and their comprehension of the displayed graphics was based on their answer to the question — *What does the DMS message mean to you?* Although the responses to this question were descriptive and subjective, if participants provided an answer close or exact to the meaning of the sign, then this was considered as "correct." If the participants did not provide one or their answer was wrong, then this was entered as "incorrect." As such, this question was treated as a binary question. The researchers also used a stopwatch to measure the time immediately following the question's

presentation to when each participant began their response. In the analysis, only the *time to comprehend the correct answer* responses were considered.

3.2.2.3 Ease of Use

Ease of use quantifies whether the information displayed in the DMS is simple and easy to understand, as measured using the following question designed on a 5-point Likert scale: *Please rate the following statement on a scale from 1 to 5, where 1 means not at all agree and 5 means fully agree: Overall, I find DMS information convenient and easy to use.*

3.2.2.4 Intention to Comply

Intention to comply quantifies the likelihood that a participant will follow the recommendations displayed in the DMS. This measure was quantified using the following question designed on a 5-point Likert scale: *How likely are you to follow the recommendation displayed on the message sign? 1 means not at all likely and 5 means very likely.*

3.2.2.5 Memorability

Memorability is a binary measure that refers to whether the participants remember the sign or not. At the end of the experiment, participants were shown a PowerPoint deck, and they were asked if they remembered seeing each sign during the experiment. A 5-point Likert scale (1 = *do not remember at all*; 5 = *remember very well*) was considered, and the participants' responses were recorded.

3.2.3 Participant Recruitment

This study initially received approval from the Human Research Protection Program (HRPP) at KU, and then the experiment was advertised on platforms such as Facebook, WhatsApp, Nextdoor, the local newspaper (*The Lawrence Times*), and KU bulletin boards. Interested participants completed a pre-screening questionnaire regarding their demographics and driving experience. Participants 18–75 years old were required to have at least 3 years of driving experience and a driving exposure of at least 5,000 miles annually. Additional questions related to literacy level and familiarity with DMS were also included in the pre-screening questionnaire,

which is provided in Appendix B. A complete list of questionnaire responses is shown in Appendix C. A total of 46 participants were recruited for this study, with demographics similar to the population of Lawrence, Kansas (Table 3.1).

Table 3.1: Demographics of Study Participants

Age Group	Sample Size and Gender	Mean (st. dev) Driving Experience (years)	Mean (st. dev) English Reading Speed (1: very slow – 5: very fast)	Number (%) of Native English Speakers
18–30	22 (9 females, 13 males)	4.0 (3.7)	3.8 (0.6)	13/22 (59%)
31–40	8 (3 females, 5 males)	4.6 (3.9)	3.5 (1.1)	0/8 (0%)
40–75	16 (12 females, 4 males)	42.7 (11.8)	4.1 (0.8)	15/16 (94%)

3.3 Modeling and Analysis

All collected data were recorded in an Excel spreadsheet, where the results were tabulated for the five measures (conspicuity, comprehension, ease of use, intention to comply, and memorability) for each sign. The measure values were averaged to get the mean scores for each sign. Figure 3.4 depicts the data reduction process to obtain the average values for three signs, in which each measure was normalized to ensure a common range of 0–1 and comparability among the measures, and then the transformed scores were averaged to determine the composite score. For measures in which higher values denoted increased effectiveness (e.g., conspicuity, accuracy of interpretation, ease of use, intention to comply, and memorability), a min-max normalization was performed using the following equation:

$$Normalized\ value = \frac{Actual\ value\ of\ score - minimum\ value}{maximum\ value - minimum\ value}$$

Equation 3.1

Measures indicating time, such as conspicuity time and time to comprehend the correct answer, indicated more effective sign performance when they demonstrated lower values, so these measures were first transformed using min-max normalization and then subtracted from 1 so that higher values of the final measure denoted increased effectiveness. Normalization was conducted

to obtain a composite score in which a value close to 1 denoted increased sign efficiency. The composite score for each sign was used to compare the effectiveness of signs with text (baseline) and signs without text (graphics-only). This analysis also revealed which specific measure was most effective (i.e., highest score) for the two types of signs.

Signs	Average Conspicuity score		Conspicuity Time		Accuracy of interpretation		Time to comprehend correct answer		Ease of use		Intention to comply		Memorability		Composite Score
	Collected	Normalized	Collected	Normalized	Collected	Normalized	Collected	Normalized	Collected	Normalized	Collected	Normalized	Collected	Normalized	
4bWtext	4.87	0.99	0.54	0.66	1.00	1.00	0.89	1.00	4.72	0.95	4.91	1.00	5.00	1.00	0.94
4aWtext	4.85	0.97	0.60	0.45	1.00	1.00	1.14	0.84	4.78	0.99	4.91	1.00	5.00	1.00	0.89
9Wtext	4.86	0.98	0.60	0.44	1.00	1.00	0.96	0.96	4.78	0.99	4.80	0.93	4.98	0.94	0.89

Figure 3.4: Data Reduction Process

This study also utilized t-tests to conduct comparative analyses for different categories based on the presence of text, age group, and whether the participant was a native English speaker. The tests were performed on data collected at a 5% significance level. A classification model (Figure 3.5) was developed using logistic regression, where the independent variables included the age, literacy rate, presence of text, and a bias, and the dependent variable consisted of the accuracy of interpretation.

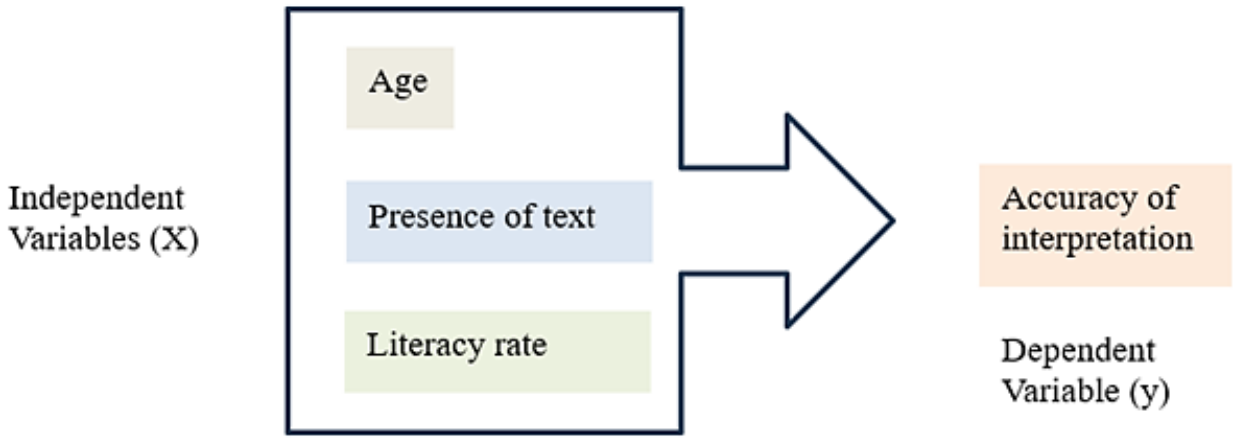


Figure 3.5: Overview of Classification Model

The classification model can be formulated using the following equation:

$$p(Y) = \frac{1}{1 + e^{-(\text{alpha} + \text{A} * X_{Age} + \text{B} * X_{Presence\_of\_text} + \text{C} * X_{Literacy\_Rate})}}$$

Equation 3.2

Where:

p(Y) = probability of accurate interpretation of the signs,

alpha = bias,

A, B, and C = coefficients of measures,

X_{Age} = age of participants,

$X_{Presence\_of\_text}$ = binary variable indicating presence of text (1 if yes, 0 if no), and

$X_{Literacy\_rate}$ = reading speed range of 1–5.

Chapter 4: Analysis Results

In this study, the recorded measures were evaluated to determine the effectiveness of DMS. A composite score was generated for each sign using the aggregate of the normalized values of each measure. Using the composite score, the signs were compared based on all the recorded measures and then ranked based on the composite score. Table 4.1 ranks the top five signs that received the highest scores overall. Table 4.2 presents the most effective signs that did not use text. Followed by Table 4.3, which provides pictorial representations of the findings. As shown in Table 4.3, the most effective signs overall had text and graphics. The effect of text on various metrics was further explored using statistical tests in the subsequent section. For example, the sign "Merge Left" (with text) had the highest composite score of 0.94 (Table 4.1); while the same sign without text had the highest composite score of 0.81 for signs without text (Table 4.2). Thus, indicating these signs were effective when used as DMS. Furthermore, the "Don't Drive Drunk" sign was one of the five most effective signs with and without text. In general, most of the signs that were effective with text were also effective without text. The recorded scores for each sign are provided in Table D.1 (Appendix D); whereas, the normalized and composite scores of the signs are shown in Table D.2.

Table 4.1: Results of Most Effective Signs (overall)

Rank	Description	Average Conspicuity Score	Conspicuity Time	Accuracy of Interpretation	Time to Comprehend Correct Answer	Ease of Use	Intention to Comply	Memorability	Composite Score
1	Merge Left (with text)	4.87	0.54	1.00	0.89	4.72	4.91	5.00	0.94
2	Merge Right (with text)	4.85	0.60	1.00	1.14	4.78	4.91	5.00	0.89
3	Road Closed Ahead (with text)	4.86	0.60	1.00	0.96	4.78	4.80	4.98	0.89
4	Flash Flood Warning (with text)	4.79	0.53	1.00	1.13	4.67	4.65	4.96	0.87
5	Don't Drive Drunk (with text)	4.87	0.64	1.00	1.09	4.72	4.87	5.00	0.87

Table 4.2: Results of Most Effective Signs (without text)

Rank	Description	Average Conspicuity Score	Conspicuity Time	Accuracy of Interpretation	Time to Comprehend Correct Answer	Ease of Use	Intention to Comply	Memorability	Composite Score
11	Merge Left	4.58	0.58	1.00	1.07	4.52	4.70	4.96	0.81
12	Don't Text Just Drive	4.76	0.51	1.00	1.22	4.39	4.09	5.00	0.81
18	Don't Drive Drunk	4.53	0.57	1.00	1.22	4.30	4.63	5.00	0.78
19	Merge Right	4.60	0.60	1.00	1.43	4.63	4.74	4.96	0.78
20	Obey Speed Limit	4.88	0.62	1.00	1.24	4.80	4.04	4.87	0.75

Table 4.3: Most Effective Signs (overall and without text)

Overall		No Text	
Rank	Sign	Rank	Sign
1		11	
2		12	
3		18	
4		19	
5		20	

Tables 4.4 and 4.5 rank the least effective signs based on composite score and with pictorial representations, respectively. None of the signs included text. The major factors contributing to the low scores were accuracy of interpretation, ease of use, and intention to comply. The accuracy of interpretation was remarkably low at 54% for the "Congestion Ahead" sign, which was the sign with the lowest score. Interestingly, the same sign had the lowest intention to comply and ease of use. Similar trends were observed for other signs with low composite scores. These findings indicate that the signs shown in Table 4.5 may not be effective options for DMS because these signs are likely to be interpreted inaccurately, and drivers are less likely to comply with them.

Table 4.4: Results of Five Least Effective Signs (overall)

Rank	Description	Average Conspicuity Score	Conspicuity Time	Accuracy of Interpretation	Time to Comprehend Correct Answer	Ease of Use	Intention to Comply	Memorability	Composite Score
36	Congestion Ahead	4.26	0.59	0.54	1.39	3.28	3.28	4.61	0.22
35	Roadwork Ahead	3.95	0.58	0.74	1.64	3.17	3.33	4.72	0.25
34	Severe Weather in Area	4.23	0.59	0.74	1.76	3.24	3.33	4.78	0.31
33	Reduced Visibility from Smoke	4.40	0.60	0.80	1.47	3.39	3.35	4.65	0.34
32	High Wind Warning	4.25	0.56	0.61	2.07	3.48	3.57	4.91	0.34

Table 4.5: Five Least Effective Signs (overall)

Rank	Overall	Description
36		Congestion Ahead
35		Roadwork Ahead
34		Severe Weather in Area
33		Reduced Visibility from Smoke
32		High Wind Warning

Table 4.6 shows the five least effective signs with text, along with the individual measures scores, and composite score. Despite having a lower composite score than the other signs with text, these signs were still more effective than most of the graphics-only signs, with a minimum composite score of 0.62. Table 4.7 illustrates these signs and their rankings.

Table 4.6: Results of Five Least Effective Signs (with text)

Rank	Description	Average Conspicuity Score	Conspicuity Time	Accuracy of Interpretation	Time to Comprehend Correct Answer	Ease of Use	Intention to Comply	Memorability	Composite Score
25	(6Wtext) Flagging Operation Ahead	0.802	0.366	0.762	0.236	0.640	0.707	0.833	0.62
21	(16Wtext_2) Obey Speed Limit	0.907	0.518	1.000	0.725	0.787	0.507	0.944	0.77
20	(3Wtext) Reduced Visibility from Smoke	0.849	0.566	1.000	0.673	0.861	0.800	0.667	0.77
17	(8bWtext) Width Limit	0.930	0.237	0.952	0.820	0.893	0.720	1.000	0.79
16	(15Wtext_1) Don't Text Just Drive	0.942	0.247	1.000	0.738	0.960	0.667	1.000	0.79

Table 4.7: Five Least Effective Signs (with text)

Rank	Overall	Description
25		Flagging Operation Ahead
21		Obey Speed Limit
20		Reduced Visibility from Smoke
17		Width Limit
16		Don't Text Just Drive

4.1 Statistical Comparison of Sign Categories

This study utilized t-tests to compare sign categories and determine the impact of demographics on sign effectiveness. The findings are presented in the following sections.

4.1.1 Text versus No-Text

To verify the findings that signs with text had higher scores than signs without text, a two-tailed t-test was performed on each of the collected measures at a confidence level of 95%. As shown in Table 4.8, all measures except conspicuity time were significantly different between the two categories. Overall, signs with text had higher measure values, indicating significantly

improved sign performance with text. Therefore, state DOTs are recommended to supplement DMS with appropriate texts.

Table 4.8: Statistical Comparison of Sign Effectiveness with and without Text

	Text		No Text			
Measure	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**	**t-statistic**	**p-value**
Average Conspicuity	4.804	0.049	4.433	0.210	7.313	**<0.001***
Conspicuity Time	0.581	0.039	0.587	0.052	-0.402	0.690
Accuracy of Interpretation	0.990	0.027	0.838	0.161	3.954	**0.001***
Time to Comprehend Correct Answer	1.229	0.240	1.531	0.343	-3.062	**0.005***
Ease of Use	4.611	0.162	3.888	0.514	5.693	**<0.001***
Intention to Comply	4.563	0.245	3.959	0.506	4.557	**<0.001***
Memorability	4.959	0.044	4.855	0.113	3.624	**0.001***
* Statistically significant at 95% confidence level						

4.1.2 Native versus Non-Native English Speakers

DMS must be easily interpretable for both native and non-native English speakers. Therefore, this study compared the collected measures using a two-tailed t-test between native and non-native English speakers for signs with and without texts. Table 4.9 presents the results for both categories. Several measures had different (higher) values for the native English-speaking group compared to the non-native English-speaking group for signs with and without text. For signs with no text, average conspicuity, accuracy of interpretation, ease of use, and intention to comply were measures that differed significantly between the groups. The presence of text eliminated the difference between accuracy of interpretation and intention to comply, indicating that the text makes signs easier to interpret for both native and non-native speakers. Moreover, both groups had a higher propensity to follow the message on the sign when text was present, and when text was not present, non-native speakers had significantly lower intention to comply compared to native English speakers. These findings indicate that the presence of text is crucial

for sign effectiveness for all speaking groups; thus, providing another strong reason for state DOTs to implement texts with signs.

Table 4.9: Statistical Comparison of Sign Effectiveness with Language Impact

	Native		Non-Native			
Measure	**Mean**	**Standard Deviation**	**Mean**	**Standard Deviation**	**t-statistic**	**p-value**
Average Conspicuity	4.488	0.783	4.340	0.818	2.547	**0.011***
Conspicuity Time	0.570	0.281	0.616	0.347	-1.960	0.051
Accuracy of Interpretation	0.889	0.315	0.752	0.433	4.848	**<0.001***
Time to Comprehend Correct Answer	1.447	1.029	1.595	1.446	-1.384	0.167
Ease of Use	4.056	1.123	3.601	1.357	4.947	**<0.001***
Intention to Comply	4.159	1.172	3.618	1.417	5.646	**<0.001***
Memorability	4.864	0.583	4.840	0.593	0.568	0.570
With Text						
Average Conspicuity	4.837	0.366	4.747	0.464	2.920	**0.004***
Conspicuity Time	0.558	0.263	0.620	0.347	-2.697	**0.007***
Accuracy of Interpretation	0.992	0.087	0.987	0.114	0.717	0.474
Time to Comprehend Correct Answer	1.251	0.764	1.176	1.092	1.054	0.292
Ease of Use	4.716	0.585	4.431	0.918	4.872	**<0.001***
Intention to Comply	4.586	0.806	4.523	0.873	1.036	0.300
Memorability	4.990	0.131	4.905	0.493	2.960	**0.003***
* Statistically significant at 95% confidence level						

4.1.3 Younger versus Older Drivers

Two age groups (18–40 and over 41 years old) were compared according to their responses to the signs. As shown in Table 4.10, the analysis results revealed that all measures except memorability differed significantly between the age groups for DMS without texts. Interestingly, the measure values were higher for the older-age group (41 and older), potentially due to driving experience. Because older drivers had previously encountered most of these signs, their attitudes towards the signs were primarily positive and they could more accurately interpret the signs, resulting in greater achievement in the selected performance measures. The difference in the accuracy of interpretation and the time to comprehend was eliminated when text descriptions were present in the signs, indicating that text improved sign efficiency.

Table 4.10: Statistical Comparison of Sign Effectiveness with Impact of Age

Without Text						
	18–40		**41+**			
Measure	**Mean**	**Standard Deviation**	**Mean**	**Standard Deviation**	**t-statistic**	**p-value**
Average Conspicuity	4.296	0.841	4.689	0.640	-7.520	**<0.001***
Conspicuity Time	0.607	0.334	0.549	0.246	2.837	**0.005***
Accuracy of Interpretation	0.802	0.399	0.906	0.292	-4.295	**<0.001***
Time to Comprehend Correct Answer	1.580	1.371	1.358	0.764	2.735	**0.006***
Ease of Use	3.672	1.267	4.292	1.058	-7.478	**<0.001***
Intention to Comply	3.726	1.360	4.396	1.027	-7.955	**<0.001***
Memorability	4.861	0.572	4.844	0.613	0.397	0.692
With Text						
Average Conspicuity	4.742	0.453	4.920	0.265	-7.143	**<0.001***
Conspicuity Time	0.609	0.325	0.528	0.232	4.163	**<0.001***
Accuracy of Interpretation	0.989	0.105	0.993	0.083	-0.625	0.532
Time to Comprehend Correct Answer	1.232	1.048	1.208	0.518	0.455	0.649
Ease of Use	4.480	0.823	4.857	0.455	-8.497	**<0.001***
Intention to Comply	4.431	0.928	4.809	0.530	-7.448	**<0.001***
Memorability	4.943	0.383	4.990	0.132	-2.578	**0.010***
* Statistically significant at 95% confidence level						

4.2 Logistic Regression

Accurate delivery of the message in the DMS was tested in this study using the accuracy of interpretation, which was evaluated via logistic regression, where it was fitted against the easily obtainable independent variables, presence of text, age, and literacy rate. The presence of text had a binary value of either "yes" (1) or "no" (0); whereas, participants' reported reading speeds of 1–5 represented the literacy rate. Logistic regression results in Table 4.11 show that all the independent variables were statistically significant at 5%. Although the pseudo-R-squared value remained low at 16.7%, indicating a moderate relation, the coefficients revealed a significant positive impact of the variables on the accuracy of interpretation. The findings reveal that the increase in age, the presence of text, and the increase in literacy rate contribute to improved interpretation of the DMS.

Table 4.11: Logistic Regression Model of Accuracy of Interpretation

Variable	Coefficient	Std Error	z-value	p-value
Intercept	-0.094	0.476	-0.198	0.843
Presence of Text	3.006	0.368	8.165	**<0.001***
Age	0.015	0.006	2.409	**0.016***
Literacy Rate	0.305	0.119	2.561	**0.010***
* Statistically significant at 5%				
Log-Likelihood	-403.721			
Null Log-Likelihood	-484.440			
Pseudo R-squared (McFadden)	0.167			
AIC	815.442			
BIC	837.089			

Chapter 5: Conclusions and Recommendations

5.1 Conclusions

The results of this study showed that signs with text descriptions had higher scores for conspicuity, comprehension, ease of use, intention to comply, and memorability than signs without text. The signs with the top five scores all had text and graphics, while the signs with the lowest scores did not have any supplemental text. In addition, signs with low scores were due to low accuracy of interpretation, ease of use, and intention to comply. The results of t-tests showed that the presence of text significantly improved the effectiveness of DMS.

T-tests were also performed to determine whether age and being a native English speaker affected sign effectiveness. Most of the evaluated measures (average conspicuity, accuracy of interpretation, ease of use, and intention to comply) differed significantly between native and non-native English speakers in the absence of text descriptions. However, these differences were mitigated for accuracy of interpretation and intention to comply when text was present, highlighting the importance of text for the non-native English-speaking group. In general, the presence of text made the DMS suitable for all types of speakers.

A comparison of sign effectiveness for various age groups indicated increased effectiveness for the older age group (41 years and older) as measured by average conspicuity, conspicuity time, accuracy of interpretation, time to comprehend, ease of use, and intention to comply. This result could potentially be due to the drivers' prolonged exposure to traffic signs and increased driving experience. Therefore, general awareness of the sign among the younger drivers may be a necessary step for effective implementation of DMS.

Logistic regression analysis was also used to investigate the accuracy of interpretation, where age, presence of text, and literacy rate were independent variables. All the independent variables were found to have a statistically significant and positive impact on the accuracy of interpretation, indicating the increased potential of accurate interpretation as the variables increased.

In summary, this study evaluated the effectiveness of various graphics signs with and without text when used as DMS. The most and least effective signs were determined based on composite scores derived from measuring the DMS's conspicuity, comprehension, ease of use,

intention to comply, and memorability. Moreover, the study examined demographic factors to capture variations in sign effectiveness.

5.2 Recommendations

Based on the results, text should be used with graphics to increase the effectiveness of DMS. For the less effective signs shown in Table 4.5, text descriptions are recommended in addition to the graphics. A proper awareness of the various graphics used in DMS is also suggested, especially for young drivers. This research investigated a limited set of graphics and text options for specific themes such as congestion, crash occurrence, adverse weather, etc. It is recommended that future work explore additional combinations for these themes and develop a comprehensive list of effective graphics and text options.

References

Ahmed, K., Al-Zoubi, K., Siddiqui, M. A., & Anas, M. (2016). Evaluation of the effectiveness of portable variable message signs in work zones in United Arab Emirates. *IET Intelligent Transport Systems*, *10*(2), 114-121. https://doi.org/10.1049/iet-its.2015.0007

Aitken, R. J., Zhang, G., Walton, C. M., & Conway, A. J. (2010). Enhanced traveler information dissemination through innovative Graphic Route Information Panels (GRIPS) (Paper No. 10-3481). In *TRB 89th Annual Meeting compendium of papers DVD*. Transportation Research Board.

Almallah, M., Hussain, Q., Alhajyaseen, W. K. M., Pirdavani, A., Brijs, K., Dias, C., & Brijs, T. (2021). Improved traffic safety at work zones through animation-based variable message signs. *Accident Analysis and Prevention*, *159,* Article 106284. https://doi.org/10.1016/j.aap.2021.106284

Bai, Y., Huang, Y., Schrock, S. D., & Li, Y. (2011). *Determining the effectiveness of graphic-aided dynamic message signs in work zones* (Report No. TPF-5(081)). Smart Work Zone Deployment Initiative. https://rosap.ntl.bts.gov/view/dot/88145

Charlton, S. G. (2006). Conspicuity, memorability, comprehension, and priming in road hazard warning signs. *Accident Analysis and Prevention*, *38*(3), 496–506. https://doi.org/10.1016/j.aap.2005.11.007

Chng, S., Kawasumi, M., Al-Ahda, M., Mangla, C., & Cheah, L. (2022). Evaluating the use of graphic symbols in autonomous vehicle-to-pedestrian communication. In *2022 IEEE 25th International Conference on Intelligent Transportation Systems (ITSC)* (pp. 389–394). IEEE. https://doi.org/10.1109/ITSC55140.2022.9922243

Dewar, R., & Pronin, M. (2023). Designing road sign symbols. *Transportation Research Part F: Traffic Psychology and Behaviour*, *94*, 466–491. https://doi.org/10.1016/j.trf.2022.12.008

Dudek, C., Trout, N., Booth, S., & Ullman, G. (2000). *Improved dynamic message sign messages and operations* (Report No. FHWA/TX-01/1882-2). Texas Transportation Institute. https://tti.tamu.edu/documents/1882-2.pdf

Er-hui, C., Jing, L., Yun-ling, W., & Juan, X. (2013). A study on variable message signs graphical comparation. *Procedia - Social and Behavioral Sciences*, *96*, 2523–2528. https://doi.org/10.1016/j.sbspro.2013.08.282

Federal Highway Administration (FHWA). (2009). Temporary traffic control zone devices. In *Manual on uniform traffic control devices for streets and highways (MUTCD)* (2009 ed.). Retrieved September 4, 2025, from https://mutcd.fhwa.dot.gov/htm/2009/part6/part6f.htm

Federal Highway Administration (FHWA). (2023). *Manual on uniform traffic control devices for streets and highways (MUTCD)* (11th ed.). Retrieved October 1, 2025, from https://mutcd.fhwa.dot.gov/pdfs/11th_Edition/mutcd11theditionhl.pdf

Hoekstra-Atwood, L., Campbell, J. L., Hoover, C., Katz, B., & Kehoe, N. (2022). *Use of color changeable message signs – Current practices and research* (Publication No. FHWA-HOP-18-067). Federal Highway Administration. https://ops.fhwa.dot.gov/publications/fhwahop18067/fhwahop18067.pdf

Huang, Y., & Bai, Y. (2019). Driver responses to graphic-aided portable changeable message signs in highway work zones. *Journal of Transportation Safety & Security*, *11*(6), 661–682. https://doi.org/10.1080/19439962.2018.1463336

Ilkhani, I., Yazdanpanah, M., & Dehghanbanadaki, A. (2023). Analysis of drivers' preferences toward content and message format of variable message signs during tunnel emergency evacuation: A case study of Niayesh tunnel in Tehran. *International Journal of Disaster Risk Reduction*, *93,* Article 103744. https://doi.org/10.1016/j.ijdrr.2023.103744

Knoblauch, R. L., Nitzburg, M., Seifert, R., McGee, H. & Daily, K. (1995). *Uniform traffic control warning messages for portable changeable message signs* (Report No. FHWA-RD-95-171). Federal Highway Administration. https://hdl.handle.net/2027/ien.35556023516727

Kwigizile, V., Oh, J.-S., Van Houten, R., Lee, K., Kwayu, K., Abushattal, M., Mwende, S., & Lyimo, S. (2022). *Quantifying effectiveness and impacts of digital message signs on traffic flow* (Report No. SPR–1709). Michigan Department of Transportation. https://rosap.ntl.bts.gov/view/dot/62965

Luoma, J., & Rämä, P. (2001). Comprehension of pictograms for variable message signs. *Traffic Engineering and Control*, *42*(2), 53-58. https://trid.trb.org/View/676068

Ratrout, N. T., & Issa, Y. F. (2014). Effectiveness of newly introduced variable message signs in Al-Khobar, Saudi Arabia. *Promet - Traffic & Transportation*, *26*(2), 169-177. https://hrcak.srce.hr/124157

Roelofs, T., & Schroeder, J. (2016). *The future of DMS messaging: Final report* (Report No. ENT-2016-2). ENTERPRISE Transportation Pooled Fund Study TPF-5(231). https://enterprise.prog.org/wp-content/uploads/ENT_The_Future_of_DMS_Messaging_FINAL_December2016.pdf

Saha, D., Gan, A., Haleem, K., Alluri, P., & Delgado, F. H. (2013). Applications of hybrid static-dynamic signs for active traffic management: A worldwide state-of-the-practice review (Paper No. 13-4307). In *TRB 92nd Annual Meeting compendium of papers DVD*. Transportation Research Board.

Shinar, D., & Vogelzang, M. (2013). Comprehension of traffic signs with symbolic versus text displays. *Transportation Research Part F: Traffic Psychology and Behaviour*, *18*, 72–82. https://doi.org/10.1016/j.trf.2012.12.012

Smyth, L. (2010, January). Lead the way. *Traffic Technology International*, 28-31. https://s44873.pcdn.co/wp-content/uploads/archive/2010-1-Jan.pdf

Tay, R., & Choi, J. (2009). Evaluation of pictograms in dynamic lane control systems in the Republic of Korea. *Journal of Transportation Systems Engineering and Information Technology*, *9*(2), 56-61. https://doi.org/10.1016/S1570-6672(08)60054-9

Ullman, B. R., Trout, N. D., & Dudek, C. L. (2009). *Use of graphics and symbols on dynamic message signs: Technical report* (Report No. FHWA/TX-08/0-5256-1). Texas Transportation Institute. https://rosap.ntl.bts.gov/view/dot/16835

Wang, J.-H., & Clark, A. (2010). *Employing graphic-aided DMS to assist elder drivers' message comprehension* (Report No. NETCR82). New England Transportation Consortium. https://www.newenglandtransportationconsortium.org/files/netcr82_05-6.pdf

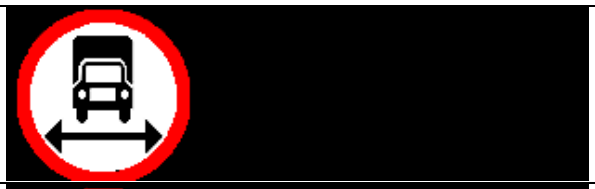
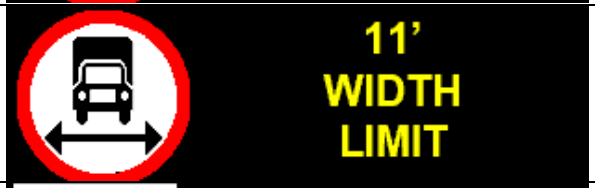
Xu, C., Wu, Y., Rong, J., & Peng, Z. (2020). A driving simulation study to investigate the information threshold of graphical variable message signs based on visual perception characteristics of drivers. *Transportation Research Part F: Traffic Psychology and Behaviour*, *74*, 198–211. https://doi.org/10.1016/j.trf.2020.08.023

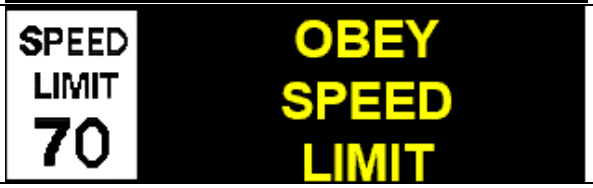
Appendix A: List of Tested Graphics

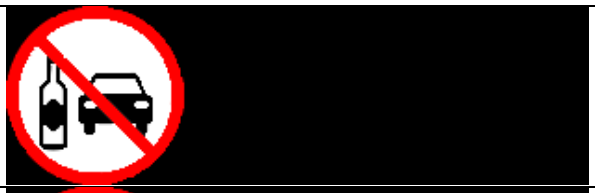
Table A.1: List of Tested Graphics

Name used in data collection	Description	Sign
1g	Crash Ahead	
1Wtext	Crash Ahead (with text)	
2ag	Congestion Ahead	
2aWtext	Congestion Ahead (with text)	
3g	Reduced Visibility from Smoke	
3Wtext	Reduced Visibility from Smoke (with text)	
4ag	Merge Right	

4aWtext	Merge Right (with text)	
4bg	Merge Left	
4bWtext	Merge Left (with text)	
5g	Roadwork Ahead	
5Wtext_1	Roadwork Ahead (with text)	
6g	Flagging Operation Ahead	
6Wtext	Flagging Operation Ahead (with text)	
8ag	Height Limit	
8aWtext	Height Limit (with text)	

8bg	Width Limit	
8bWtext	Width Limit (with text)	
9g	Road Closed Ahead	
9Wtext	Road Closed Ahead (with text)	
10ag	Flash Flood Warning	
10aWtext	Flash Flood Warning (with text)	
11g	Severe Weather in Area	
11Wtext_1	Severe Weather in Area (with text)	
12g	High Wind Warning	

12Wtext	High Wind Warning (with text)	
13g	Winter Weather Expected	
13Wtext_2	Winter Weather Expected (with text)	
14g	Click It or Ticket	
14Wtext_1	Click It or Ticket (with text)	
15g	Don’t Text Just Drive	
15Wtext_1	Don’t Text Just Drive (with text)	
16g	Obey Speed Limit	
16Wtext_2	Obey Speed Limit (with text)	

17g	Don’t Drive Drunk		
17Wtext_2	Don’t Drive Drunk (with text)		

Appendix B: Pre-screening Questionnaire

Participant Information Form

To be completed by the Experimenter

Experimenter: Testing Date:

IRB Protocol: ☐ tDCS

☐ Behavioral

☐ Online

To be completed by the Participant

The following information is for record-keeping only. Completion of this form is voluntary, and any information that you provide will be kept strictly confidential.

Name:_____ Date of Birth:_____

E-Mail Address:_____

Age:_____

Highest Level of Education:_____

Are you taking any prescription medications? ☐ YES ☐ NO

If yes, please list and describe:

_____

_____

Gender: Male ☐ Female ☐ Do Not Wish to Say

Ethnic Category:

☐ Hispanic or Latino

☐ Not Hispanic or Latino

☐ Do Not Wish to Say

Racial Category:

☐ American Indian/Alaskan Native

☐ Asian

☐ Native Hawaiian/Other Pacific Islander

☐ Black/African American

☐ White

☐ More Than One Race

☐ Unknown/Do Not Wish to Say

☐ Other:_____

Definitions:

- **-Hispanic/Latino:** A person of Cuban, Mexican, Puerto Rican, South or Central American, or other Spanish culture or origin, regardless of race. The term "Spanish origin" can also be used in addition to "Hispanic or Latino."
- **-American Indian/Alaskan Native:** A person having origins in any of the original peoples of North, Central, or South America, and who maintains tribal affiliations or community attachment.
- **-Asian:** A person having origins in any of the original peoples of the Far East, Southeast Asia, or the Indian subcontinent including, for example, Cambodia, China, India, Japan, Korea, Malaysia, Pakistan, the Philippine Islands, Thailand, and Vietnam. (Note: Individuals from the Philippine Islands have been recorded as Pacific Islanders in previous data collection strategies.)
- **-Black/African American:** person having origins in any of the black racial groups of Africa. Terms such as "Haitian" or "Negro" can be used in addition to "Black or African American."

- **-White:** A person having origins in any of the original peoples of Europe, the Middle East, or North Africa

Pre-experimental Questionnaires:

Q1) Are you a native English speaker?

☐ Yes

☐ No

Q2) An average adult can read 3-5 words per second or 200-320 words per minute. How would you rate your English reading speed compared to an average English-speaking adult on a scale of 1 (very slow) to 5 (very fast)?

Q3) Do you possess a valid U.S. Driver's license?

Q4) Date the driver's license was first obtained?

Q5) What is your annual vehicle mileage?

Q6) Which type of vehicle do you typically drive?

Q7) Following are a few examples of dynamic message signs (DMS).

Have you noticed any DMS on roadways while driving in Kansas?

☐ Yes

☐ No

Q8) How frequently have you noticed the following information on a DMS while driving? Rank from 1 = never to 5 = always

1	Traffic congestion alerts (travel time, rerouting, traffic pattern)	1	2	3	4	5
2	Accident/incident information					
3	Real-time travel time messages					
4	Weather-related advisories for traffic/routes					
5	Roadwork information (lane closures, detours, etc.)					
6	Amber alerts or special events					
7	Safety-related messages (public announcements, drunk driving, phone use, etc.)					

Appendix C: Participants Demographic Information

Table C.1: Demographics Information

ID	Age	Gender	Race	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8_1	Q8_2	Q8_3	Q8_4	Q8_5	Q8_6	Q8_7
P1	29	Male	Asian	No	4	Yes	1	8000	Passenger car	Yes	Sometimes	Sometimes	Sometimes	Most of the time	Most of the time	Most of the time	Sometimes
P18	30	Male	Asian	No	3	Yes	2	4000	Passenger car	Yes	Never	Most of the time	Never	Sometimes	Always	Never	Never
P14	23	Female	Asian	Yes	4	No	4	NA	Passenger car	Yes	Sometimes	Sometimes	About half the time	About half the time	Most of the time	Sometimes	Sometimes
P8	34	Male	Other	No	5	Yes	5	11000	Passenger car	Yes	Most of the time	Most of the time	Sometimes	Sometimes	Most of the time	Sometimes	Most of the time
P11	39	Female	White	No	4	Yes	2	10000	Passenger car	Yes	Most of the time	Sometimes	Never	Sometimes	Always	Never	Sometimes
P29	35	Male	Black/ African American	No	3	Yes	4	10000	Passenger car	Yes	Sometimes	Never	Sometimes	Most of the time	Always	Most of the time	Sometimes
P25	25	Male	White	Yes	3	Yes	9	20000	Passenger car	Yes	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes	Always
P4	38	Male	Asian	No	4	Yes	1	6000	Passenger car	Yes	Sometimes	Sometimes	Never	Sometimes	Sometimes	Never	Most of the time
P15	29	Male	White	Yes	4	No	13	5500	Passenger car	Yes	Most of the time	Sometimes	Most of the time	Sometimes	Most of the time	Sometimes	Sometimes
P7	32	Female	White	No	4	Yes	2	12000	Passenger car	Yes	About half the time	Sometimes	Most of the time	Always	Always	Never	About half the time
P2	60	Female	White	Yes	4	Yes	46	12500	Passenger car	Yes	About half the time	About half the time	Sometimes	Sometimes	About half the time	About half the time	About half the time

ID	Age	Gender	Race	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8_1	Q8_2	Q8_3	Q8_4	Q8_5	Q8_6	Q8_7
P17	32	Male	White	No	2	Yes	13	15000	Passenger car	Yes	Sometimes	Sometimes	Most of the time	About half the time	Most of the time	Sometimes	About half the time
P3	30	Female	White	No	4	No	0	10000	Passenger car	Yes	Most of the time	Most of the time	Most of the time	Most of the time	About half the time	Sometimes	Most of the time
P24	23	Male	White	Yes	4	Yes	2	3,000-4,000	Passenger car	Yes	Most of the time	Most of the time	Sometimes	Never	Most of the time	Never	Sometimes
P5	26	Female	Asian	No	4	Yes	3	10k-12k	Passenger car	Yes	Sometimes	Most of the time	Sometimes	Sometimes	Always	Sometimes	Sometimes
P19	29	Male	Asian	No	3	Yes	0	15000	Passenger car	Yes	Most of the time	Sometimes	Most of the time	About half the time	Always	Most of the time	Sometimes
P6	33	Female	Asian	No	2	Yes	7	1500	Passenger car	Yes	Sometimes	Never	Never	Never	Always	Never	Never
P28	24	Female	White	Yes	4	Yes	8	~5000	Passenger car	Yes	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes	Never	Most of the time
P21	22	Female	White	Yes	3	Yes	5	10000	Passenger car	Yes	Sometimes	Never	About half the time	Sometimes	Always	About half the time	About half the time
P10	30	Male	Asian	No	4	Yes	1	8000	Passenger car	Yes	Sometimes	Sometimes	Sometimes	Most of the time	Always	About half the time	Always
P12	28	Male	Asian	No	4	Yes	7	12-14000	Passenger car	Yes	Sometimes	Most of the time	Most of the time	About half the time	Always	Always	About half the time
P20	56	Female	White	Yes	3	Yes	42	10000	Passenger car	Yes	Sometimes	Never	Sometimes	Sometimes	Most of the time	Never	Sometimes
P27	22	Male	White	Yes	3	Yes	6	10000	Passenger car	Yes	Most of the time	Sometimes	Most of the time	Most of the time	Most of the time	Never	Sometimes
P9	22	Female	White	Yes	5	Yes	4	6000	Passenger car	Yes	Sometimes	Sometimes	Sometimes	Sometimes	Most of the time	Never	Most of the time

ID	Age	Gender	Race	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8_1	Q8_2	Q8_3	Q8_4	Q8_5	Q8_6	Q8_7
P23	29	Male	Asian	No	4	Yes	1	8000	Passenger car	Yes	Most of the time	Always	Most of the time	Always	Always	Sometimes	Most of the time
P22	61	Female	Asian	Yes	5	Yes	43	5000	Passenger car	Yes	Always	Always	About half the time	Always	Always	Always	Always
P31	64	Female	White	Yes	3	Yes	49	7500	Passenger car	Yes	Sometimes	Sometimes	Sometimes	Sometimes	Most of the time	Never	Sometimes
P13	29	Male	Asian	Yes	3	Yes	4	10000	Passenger car	Yes	About half the time	About half the time	About half the time	About half the time	About half the time	Sometimes	About half the time
P16	21	Male	White	Yes	5	Yes	0	10000	Passenger car	Yes	Sometimes	Sometimes	About half the time	Sometimes	About half the time	Most of the time	Sometimes
P34	34	Male	Asian	No	4	Yes	3	12000	Passenger car	Yes	Sometimes	Most of the time	Most of the time	Most of the time	Sometimes	Sometimes	Most of the time
P30	30	Female	Black/ African American	Yes	4	Yes	1	Over 5000	Passenger car	Yes	Most of the time	Most of the time	Most of the time	Sometimes	Most of the time	Sometimes	Sometimes
P35	29	Female	White	Yes	3	Yes	11	13500	Passenger car	Yes	Most of the time	Most of the time	Sometimes	Sometimes	Most of the time	Sometimes	Sometimes
P32	29	Female	Black/ African American	No	4	Yes	5	6000	Passenger car	Yes	Sometimes	Most of the time	Most of the time	Most of the time	Most of the time	Most of the time	About half the time
P33	61	Male	White	Yes	5	Yes	45	18000	Passenger car	Yes	Always	Always	Always	Always	Always	Always	Always
P37	51	Female	Black/ African American	Yes	4	No	37	15000	Passenger car	Yes	About half the time	Most of the time	Sometimes	Sometimes	Most of the time	Sometimes	Sometimes
P36	55	Male	White	Yes	5	Yes	39	10000	Passenger car	Yes	Always	Always	Always	Always	Always	About half the time	Sometimes

ID	Age	Gender	Race	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8_1	Q8_2	Q8_3	Q8_4	Q8_5	Q8_6	Q8_7
P26	19	Male	Black/ African American	Yes	4	Yes	2	N/A	Passenger car	Yes	About half the time	About half the time	Most of the time	About half the time	About half the time	About half the time	About half the time
P45	60	Male	White	Yes	5	Yes	44	5000	Commercial motor vehicle	Yes	Always	Always	Always	Always	Always	Always	Always
P38	70	Female	White	Yes	4	Yes	53	5000 per year	Passenger car	Yes	Most of the time	Most of the time	Most of the time	Most of the time	Sometimes	Never	Sometimes
P43	64	Female	White	Yes	4	Yes	47	10000	Passenger car	Yes	Sometimes	Always	Always	Always	Always	Sometimes	Sometimes
P40	55	Female	White	Yes	4	Yes	40	7000	Passenger car	Yes	Most of the time	Sometimes	Sometimes	Sometimes	Most of the time	Sometimes	Sometimes
P39	62	Male	White	Yes	3	Yes	46	6000+	Passenger car	Yes	Most of the time	Most of the time	Sometimes	Sometimes	Most of the time	Sometimes	Sometimes
P44	59	Female	White	Yes	5	Yes	42	6000?	Passenger car	Yes	Never	Never	Sometimes	Never	Sometimes	Never	Never
P41	63	Female	White	Yes	5	Yes	5	15000	Passenger car	Yes	Most of the time	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes	Sometimes
P42	58	Female	White	Yes	3	Yes	40	36000	Passenger car	Yes	Sometimes	About half the time	Sometimes	Sometimes	About half the time	Sometimes	Sometimes
P46	63	Female	White	Yes	4	Yes	63	12000	Passenger car	Yes	About half the time	Sometimes	Sometimes	About half the time	Sometimes	Most of the time	Never

Appendix D: Sign Scores

Table D.1: Average Scores of Signs

Signs	Average Conspicuity Score	Conspicuity Time	Accuracy of Interpretation	Time to Comprehend the Correct Answer	Ease of Use	Intention to Comply	Memorability
4bWtext	4.870	0.541	1.000	0.895	4.717	4.913	5.000
10ag	4.348	0.450	0.630	1.716	3.457	3.674	4.804
11Wtext_1	4.750	0.530	1.000	1.209	4.413	4.174	5.000
2ag	4.261	0.586	0.543	1.388	3.283	3.283	4.609
12Wtext	4.804	0.563	1.000	1.296	4.587	4.370	4.978
5g	3.946	0.585	0.739	1.638	3.174	3.326	4.717
13Wtext_2	4.783	0.561	1.000	1.357	4.565	4.370	4.957
13g	4.489	0.570	1.000	1.310	4.174	4.348	4.913
14Wtext_1	4.761	0.564	0.957	1.266	4.348	4.696	4.957
14g	4.543	0.587	0.957	1.153	4.304	4.739	4.783
15Wtext_1	4.826	0.650	1.000	1.286	4.739	4.370	5.000
4bg	4.576	0.575	1.000	1.067	4.522	4.696	4.957
16Wtext_2	4.793	0.578	1.000	1.305	4.457	4.109	4.978
15g	4.761	0.513	1.000	1.223	4.391	4.087	5.000
4aWtext	4.848	0.595	1.000	1.136	4.783	4.913	5.000
17g	4.533	0.567	1.000	1.218	4.304	4.630	5.000
1Wtext	4.772	0.574	1.000	1.032	4.783	4.717	4.957
1g	4.467	0.621	0.935	1.360	3.913	3.978	4.891
2aWtext	4.826	0.580	1.000	1.218	4.630	4.478	4.935
11g	4.228	0.591	0.739	1.756	3.239	3.326	4.783
3Wtext	4.739	0.565	1.000	1.383	4.578	4.587	4.870
3g	4.402	0.600	0.804	1.466	3.391	3.348	4.652
9Wtext	4.859	0.600	1.000	0.959	4.783	4.804	4.978
4ag	4.598	0.600	1.000	1.433	4.630	4.739	4.957

Signs	Average Conspicuity Score	Conspicuity Time	Accuracy of Interpretation	Time to Comprehend the Correct Answer	Ease of Use	Intention to Comply	Memorability
10aWtext	4.793	0.533	1.000	1.133	4.674	4.652	4.957
16g	4.880	0.615	1.000	1.245	4.804	4.043	4.870
5Wtext_1	4.859	0.588	1.000	1.183	4.609	4.783	4.891
12g	4.250	0.562	0.609J	2.066	3.478	3.565	4.913
6Wtext	4.696	0.619	0.891	2.036	4.217	4.435	4.935
6g	4.359	0.624	0.609	1.872	3.696	3.978	4.848
8aWtext	4.804	0.527	1.000	1.166	4.761	4.435	4.870
8ag	4.413	0.612	0.891	2.389	3.717	3.717	4.935
8bWtext	4.815	0.653	0.978	1.164	4.630	4.457	5.000
8bg	4.370	0.716	0.804	1.611	3.826	3.761	4.935
17Wtext_2	4.870	0.635	1.000	1.092	4.717	4.870	5.000
9g	4.370	0.597	0.826	1.642	3.674	4.022	4.826

Table D.2: Normalized and Composite Scores of Signs

Signs	Average Conspicuity Score	Conspicuity Time	Accuracy of Interpretation	Time to Comprehend the Correct Answer	Ease of Use	Intention to Comply	Memorability	Composite Score
4bWtext	0.988	0.657	1.000	1.000	0.947	1.000	1.000	0.942
4aWtext	0.965	0.453	1.000	0.838	0.987	1.000	1.000	0.892
9Wtext	0.977	0.435	1.000	0.957	0.987	0.933	0.944	0.891
10aWtext	0.907	0.688	1.000	0.840	0.920	0.840	0.889	0.869
17Wtext_2	0.988	0.305	1.000	0.868	0.947	0.973	1.000	0.869
1Wtext	0.884	0.533	1.000	0.908	0.987	0.880	0.889	0.869
8aWtext	0.919	0.711	1.000	0.818	0.973	0.707	0.667	0.828
5Wtext_1	0.977	0.483	1.000	0.807	0.880	0.920	0.722	0.827
12Wtext	0.919	0.575	1.000	0.731	0.867	0.667	0.944	0.815
2aWtext	0.942	0.510	1.000	0.784	0.893	0.733	0.833	0.814
4bg	0.674	0.529	1.000	0.885	0.827	0.867	0.889	0.810
15g	0.872	0.762	1.000	0.780	0.747	0.493	1.000	0.808
11Wtext_1	0.860	0.698	1.000	0.790	0.760	0.547	1.000	0.808
13Wtext_2	0.895	0.583	1.000	0.691	0.853	0.667	0.889	0.797
14Wtext_1	0.872	0.573	0.905	0.751	0.720	0.867	0.889	0.797
15Wtext_1	0.942	0.247	1.000	0.738	0.960	0.667	1.000	0.793
8bWtext	0.930	0.237	0.952	0.820	0.893	0.720	1.000	0.793
17g	0.628	0.560	1.000	0.784	0.693	0.827	1.000	0.785
4ag	0.698	0.437	1.000	0.640	0.893	0.893	0.889	0.779
3Wtext	0.849	0.566	1.000	0.673	0.861	0.800	0.667	0.774
16Wtext_2	0.907	0.518	1.000	0.725	0.787	0.507	0.944	0.770
16g	1.000	0.380	1.000	0.766	1.000	0.467	0.667	0.754
13g	0.581	0.547	1.000	0.722	0.613	0.653	0.778	0.699
14g	0.640	0.486	0.905	0.827	0.693	0.893	0.444	0.698

Signs	Average Conspicuity Score	Conspicuity Time	Accuracy of Interpretation	Time to Comprehend the Correct Answer	Ease of Use	Intention to Comply	Memorability	Composite Score
6Wtext	0.802	0.366	0.762	0.236	0.640	0.707	0.833	0.621
1g	0.558	0.358	0.857	0.688	0.453	0.427	0.722	0.581
9g	0.453	0.449	0.619	0.500	0.307	0.453	0.556	0.477
8ag	0.500	0.392	0.762	0.000	0.333	0.267	0.833	0.441
8bg	0.453	0.000	0.571	0.521	0.400	0.293	0.833	0.439
10ag	0.430	1.000	0.190	0.450	0.173	0.240	0.500	0.426
6g	0.442	0.345	0.143	0.346	0.320	0.427	0.611	0.376
12g	0.326	0.579	0.143	0.216	0.187	0.173	0.778	0.343
3g	0.488	0.437	0.571	0.618	0.133	0.040	0.111	0.343
11g	0.302	0.471	0.429	0.423	0.040	0.027	0.444	0.305
5g	0.000	0.494	0.429	0.503	0.000	0.027	0.278	0.247
2ag	0.337	0.490	0.000	0.670	0.067	0.000	0.000	0.223

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