Evaluation of Alternative Work Zone Signing

Final Report
August 2017

SWZDI
Smart Work Zone Deployment Initiative

Sponsored by

Smart Work Zone Deployment Initiative
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Midwest Transportation Center

U.S. DOT Office of the Assistant Secretary
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Iowa, Kansas, Missouri, and Nebraska created the Midwest States Smart Work Zone Deployment Initiative (SWZDI) in 1999 and Wisconsin joined in 2001. Through this pooled-fund study, researchers investigate better ways of controlling traffic through work zones. Their goal is to improve the safety and efficiency of traffic operations and highway work.

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16. Abstract

Many work zones require lane closures, and road users need to be notified of these closures through appropriate upstream signage. A literature review prepared for this study found several previous investigations indicating insufficient comprehension of the U.S. standard lane closure sign (designated in the *Manual on Uniform Traffic Control Devices for Streets and Highways* [MUTCD] as W4-2) and similar signs used internationally. The W4-2 sign is also unsuitable for signing interior lane closures on roadways with three or more lanes.

Driver comprehension of several alternative sign faces was tested through a survey using the ANSI Z535.3 process and was followed by a driving simulator study. The driver comprehension survey suggests that an Upward Drop Arrow design is a promising alternative to the existing W4-2 sign for sites where two upstream lanes are reduced to one lane in the work zone. In addition, one-arrow-per-lane signs developed as Americanized versions of the Vienna Convention G12a sign template are a promising option for interior lane closures on multi-lane roadway segments.

A driving simulator study compared the W4-2, a MERGE text sign with a horizontal arrow, and an Americanized version of the Vienna Convention G12a sign. In terms of sign comprehension, the W4-2 was the least understood of the three signs. The W4-2 resulted in more late merge maneuvers than the other two signs. Field evaluation of the Upward Drop Arrow and Americanized G12a signs is recommended as a follow-up to this study.

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EVALUATION OF ALTERNATIVE WORK ZONE SIGNING

Final Report
August 2017

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1. INTRODUCTION

Lane closures are frequently required for road construction and maintenance operations. The *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) designates various signs that can be used to warn road users as they approach such closures (FHWA 2009). The W4-2 LANE ENDS symbol sign is widely used and appears extensively in the MUTCD's work zone Typical Application drawings. The W4-2 design is also used for permanent lane reductions (black on yellow) and incident management (black on fluorescent pink) (Figure 1).

Figure 1. Variants of the W4-2 sign in the 2009 MUCTD

While most pictographic signs in the MUTCD are straightforward representations of potential hazards, the W4-2 is a relatively abstract symbol. In discussions with the research team, work zone traffic control practitioners expressed concern about driver comprehension of the W4-2 sign. As discussed subsequently, there is considerable research evidence to support this concern.

The W4-2 sign is not designed for identifying interior-lane closures on roadways with three or more lanes. A pictorial center lane closure sign for three-lane roadways (W9-3a) was introduced in the 2003 MUTCD (Figure 6b). The W9-3a design was withdrawn in 2009, leaving only a text-based center lane closure sign (W9-3). Text signs require knowledge of written English and are usually less visible than pictograms (Dewar et al. 1997, ANSI 2007). No signage is currently provided in the MUTCD to identify interior lane closures on roadways with 4 or more lanes.

The objectives of this study are to:

1. Identify potential alternatives to the existing MUTCD lane closure signage.
2. Evaluate driver comprehension of alternative work zone lane drop signing through a driver comprehension survey.
3. Compare driver behavior in work zones with MUTCD signing and alternative signing using a driving simulator study.
4. Present conclusions and recommendations including sign designs meriting field evaluation.

Chapter 2 presents a review of literature on driver comprehension of W4-2 sign and related signs used in the U.S. and internationally. The methodology and results of driver comprehension survey and driving simulator study are presented in Chapters 3 and 4 respectively. Finally, conclusions and recommendations are presented in Chapter 5.

2. LITERATURE REVIEW

As a first step toward evaluating possible alternatives to the W4-2, this study conducted a literature review to address two research questions:

- How well is the W4-2 understood by road users?
- What alternative graphic designs are used in the U.S. and abroad?

An abundance of published research addressing the first question was found. To answer the second, it was necessary to consult national standards, official agency guidelines, and other "grey literature" from the United States and abroad.

2.1. Evolution of Lane Reduction Signage

As shown in Figure 2, MUTCD lane reduction signage has changed over time. In the 1948 MUTCD, the only provision for a reduction in the number of lanes was a text sign with the words PAVEMENT NARROWS "to give advance notice of a reduction in the number of lanes of pavement, as from three lanes to two lanes, or from four lanes to two lanes" (Public Roads Administration 1948).

a. 1961 b. 1971–2000 c. 2003–2009

Figure 2. Evolution of the MUTCD W4-2 sign

The 1961 MUTCD appears to have been the first to introduce the W4-2 pictogram, originally called the PAVEMENT WIDTH TRANSITION sign (Bureau of Public Roads 1961). As shown in Figure 2a, the 1961 version of the W4-2 sign included lane lines, which were required to be an exact pictorial representation of site, with passing lanes designated by interior dashed lines and no-passing lanes designated by interior solid lines. Consequently, the 1961 MUTCD noted that "careful supervision is necessary to insure the proper use of this sign." Use of the sign in work zones was restricted: "It should not ordinarily be used in advance of a point where a lane is closed by construction operations, except where the condition will be stable for an appreciable duration." (The term "appreciable duration" was not defined.)

Important changes occurred in the 1971 MUTCD, which made a clearer distinction between lane *width* narrowing and reduction in the *number* of lanes. As shown in Figure 2c, lane lines were removed from the W4-2 sign. The 1971 MUTCD also introduced the use of orange backgrounds for temporary signage in work zones, and the black-on-orange W4-2 was included in four of the nine work zone Typical Application drawings presented in the manual.

In the mid-1990s concerns about driver comprehension of the W4-2 sign began to emerge. Perhaps as a result, the status of the W4-2 sign in the MUTCD Millennium Edition was somewhat ambiguous. The black-on-yellow version was removed from the permanent warning signs shown in Section 2 of the MUTCD, but the black-on-orange W4-2 was retained in Section 6 with its 1971 graphic design (FHWA 2000). The current W4-2 graphic design with three short dashes (Figure 2c) debuted in the 2003 MUTCD (FHWA 2003).

Figure 3. W9-1 and W9-2 text signs from the 2009 MUTCD

The MUTCD augments the W4-2 pictorial sign with a set of text-based signs, which include the W9-1 and W9-2 signs (Figure 3). In practice, the textual and graphical signs are often used in combination, for example Typical Application 23 advises using a LEFT (or RIGHT) LANE CLOSED AHEAD text sign in advance of a W4-2 symbol sign (Figure 4).

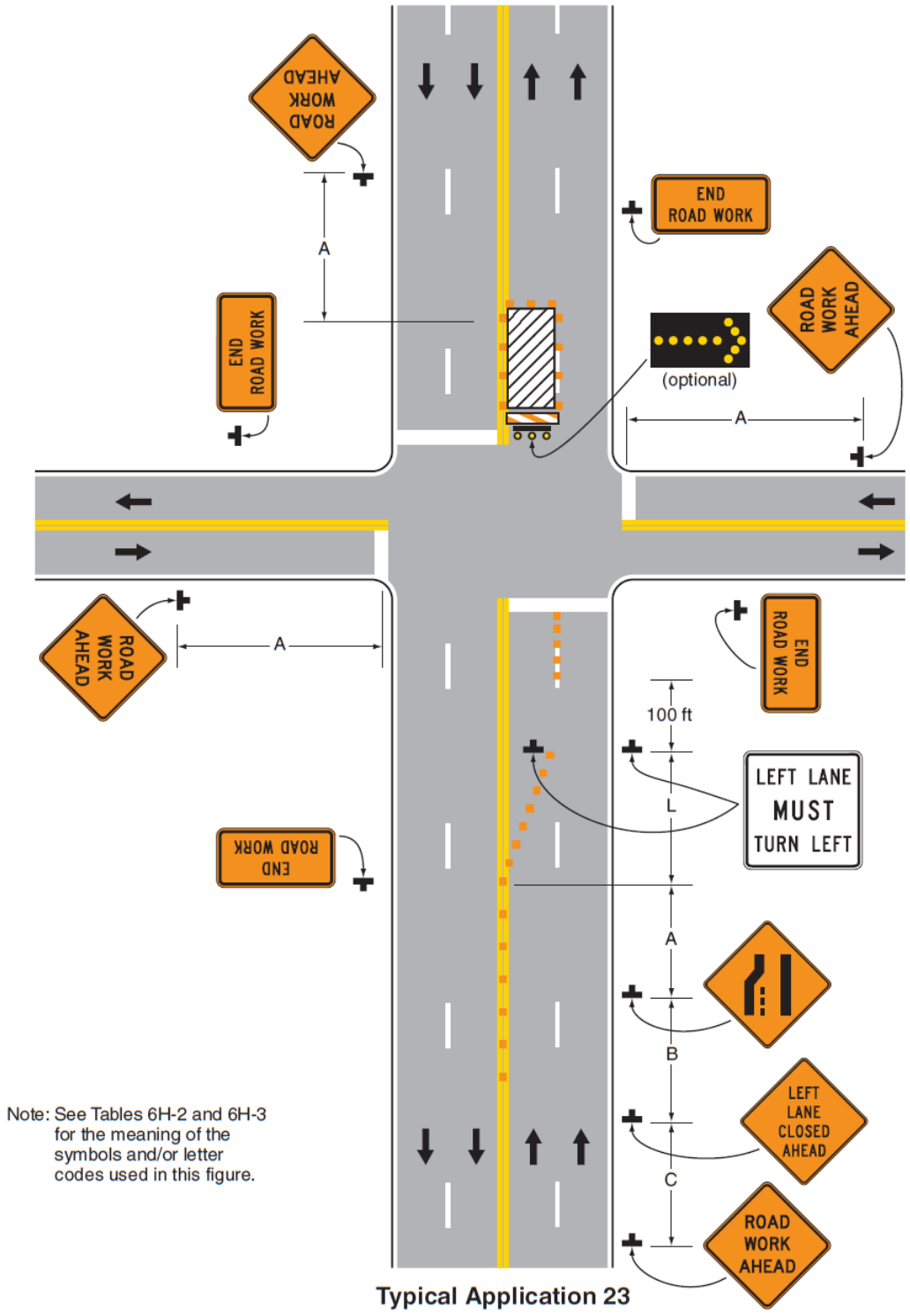
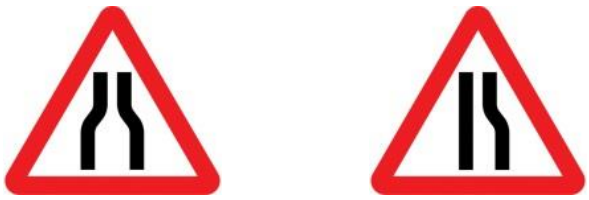


Figure 4. Typical Application 23 from the 2009 US MUTCD illustrates the use of the W4-2 and related signs for lane closures on multi-lane streets

The Vienna Convention on Road Signs and Signals (VC) is an international agreement on the general format of road signs (UNECE 2006). The Convention standardizes major graphic elements, but provides flexibility for individual countries to set their own standards for colors, fonts, line widths, and arrow shapes. Originally developed as an effort to standardize traffic signs in Europe, the system is now in use in 85 countries worldwide. Although the US and Canada do not follow the VC, Mexico has used the system since 1968.



a. Vienna Convention A4a sign b. Vienna Convention A4b sign

Figure 5. Vienna Convention ROAD NARROWS and LANE ENDS signage (United Kingdom version)

VC template A4a serves the same purpose as the MUTCD W5-1 ROAD NARROWS text sign, while template A4b is analogous to the MUTCD W4-2 symbol sign (Figure 5).

2.2. Signage for Interior Lane Closures

At times, it is necessary to close an interior lane on a multi-lane roadway. This situation occurs most frequently on urban streets, and is often associated with repair or replacement of underground utilities, subways, pedestrian tunnels, and other subterranean passageways.

The MUTCD currently provides only limited guidance for interior lane closures. As shown in Figure 6a, a text-based sign designated as W9-3 is provided for center lane closures; with four lines of text, its visibility distance is limited. A graphical center lane closure sign designated as W9-3a (Figure 6b) appeared in the 2003 MUTCD but was withdrawn in the 2009 edition. No documentation of the reasons for withdrawal of the W9-3a was found, but the W9-3a can potentially be misinterpreted as a lane shift around an obstacle (rather than a lane closure): the W9-3a graphic was visually similar to the frequently-used W6-1 DIVIDED HIGHWAY BEGINS sign (Figure 6c).

a. MUTCD W9-3

b. W9-3a from the 2003 MUTCD (withdrawn in 2009)

c. W6-1 DIVIDED HIGHWAY BEGINS sign

Figure 6. Current and former MUTCD signage for center lane closures and comparison to DIVIDED HIGHWAY BEGINS signage

As shown in Figure 7, interior lane closures are sometimes incorrectly marked using W4-2 signs.

Figure 7. Incorrectly signed center lane closure in Madison, Wisconsin (May 2016)

One-arrow-per-lane signage designs are used for interior lane closures in several Vienna Convention countries, and a diagrammatic interior lane closure sign is used in Taiwan, as discussed in more detail in a subsequent section of this report.

2.3.Road User Comprehension of Lane Reduction Signs

2.3.1. General Considerations

Symbols are used on a wide range of safety-related graphics that extend far beyond the domain of highway engineering. American National Standards Institute (ANSI) standard Z535.3

establishes guidelines for evaluating candidate safety symbols (ANSI 2007). The document recommends administering a comprehension test to at least 50 respondents drawn from the target population. A minimum of 85% should provide a correct response and no more than 5% should show critical confusion, which is defined as occurring when a safety symbol elicits the opposite, or prohibited action (for instance when a symbol meaning "No Fires Allowed" is misunderstood to mean "Fires Allowed Here"). In the context of this study, a critical confusion would occur if drivers are drawn toward the work activity area by a sign intended to inform them to merge into a lane that avoids the closure.

A variety of methods have been used to assess traffic sign comprehension. For example, a large-scale 1989 British study used in-home interviews (Cooper 1989). Participants in geographically diverse locations were selected randomly from voter registration records, shown paper copies of various traffic signs, and asked to describe each sign's meaning verbally. A large-scale 1990s study performed for FHWA used photographic projectors to show a total of 86 signs to groups of up to 40 subjects (Dewar et al. 1997). The participants wrote down the meaning of each sign (in their own words) and indicated their familiarity with the sign using a five-point scale. Other comprehension studies have used a multiple-choice survey similar to a driver licensing test (Ford and Picha 2000). In recent years, computerized surveys have increasingly been used to automate the process of displaying signs and recording responses (Shinar et al. 2003, Ben-Bassat and Shinar 2006, Shinar and Vogelzang 2013).

In the mid-1990s a Kansas study explored the effect of survey methodology on apparent comprehension rates for several MUTCD signs (Stokes et al. 1996). Self-paced survey forms with pre-printed color images of the signs were administered to 500 licensed drivers in seven counties considered demographically representative of the state as a whole. Some participants were asked to identify the meaning of each sign by responding to an open-ended question: "What is the meaning of this sign?" Others were asked to identify the same signs using a multiple-choice format, which offered five options: one correct answer, two incorrect answers, "not sure", and a space where participants could provide their own explanation. Correct response rates were much higher when the questions were offered in the multiple-choice format. Overall, nearly 86% of responses to the multiple-choice questions were correct, while only about 52% of the answers were correct in the open-ended format. The study's authors expressed concern that multiple-choice surveys may overstate comprehension rates because some respondents simply guess the answer by reading the possible responses.

2.3.2. MUTCD W4-2 Comprehension Studies

Several signage comprehension studies have included the MUTCD W4-2. These studies generally find unacceptably low comprehension rates for the W4-2 sign (Table 1).

Table 1. Summary of W4-2 comprehension study findings

Study	Year	Location	Sample Population	Method	Sample Size	Correct	Incorrect/ Don't Know
Hawkins et al. 1995	1995	Texas	Licensed Drivers	Multiple Choice	1,745	<66%	>33%
Stokes et al. 1996	1996	Kansas	Licensed Drivers	Multiple Choice	500	74%	26%
Dewar et al. 1997	1997	Alberta, Idaho, Texas	Drivers age 18+	Open-Ended	480	38%	62%
Ford and Picha 2000	2000	Texas	Teens Starting Driver Education Course	Multiple Choice	260	50%	50%

For example, research conducted for FHWA from 1991-1994 evaluated the legibility and comprehension of 85 MUTCD signs and identified the W4-2 as one of 10 signs with comprehension rates below 40% (Dewar et al. 1997). Only 38.1% of drivers correctly understood the W4-2 sign's meaning, compared to 75 to 100% for most of the other MUTCD pictograms that were evaluated.

A series of sign comprehension studies was conducted in Texas in the 1990s (Hawkins et al. 1995). A study using a multiple-choice format found that less than two-thirds of drivers correctly identified the W4-2 as meaning "fewer lanes ahead". Earlier work by the same author had found that two alternate sign designs were as effective as the standard MUTCD sign. When shown all three signs together in a focus group, participants generally preferred the standard symbol sign over the alternative symbol signs, despite the fact that many lacked understanding of the meaning of the standard sign.

Another mid-1990s sign comprehension study was conducted in Kansas, primarily using multiple-choice questions (Stokes et al. 1996). A total of 500 licensed drivers were surveyed (respondents in the 35-44 and 45–54 age groups were somewhat overrepresented and 16-24 year olds were somewhat underrepresented). The study found that the W4-2 sign was correctly understood by 74.3% of respondents, 20.3% gave incorrect responses and the remaining 5.4% said they were unsure of the sign's meaning.

A Texas study published in 2000 evaluated sign comprehension by 260 teens who were surveyed during the first day or two of their driver education courses (Ford and Picha 2000). Using a multiple-choice format, the study found that approximately one-half of respondents correctly identified the meaning of the W4-2 sign. Frequently-given incorrect responses included "the median between opposing traffic will end" and "the lane will become narrower."

2.3.3. Vienna Convention A4 Comprehension Studies

Although the Vienna Convention A4b LANE ENDS sign (Figure 5b) has received relatively little research attention, several multiple-sign studies have evaluated driver comprehension rates for the similar Vienna Convention A4a ROAD NARROWS sign (Figure 5a). The results of these investigations are summarized in Table 2. Taken together, they suggest that the A4 graphics are not very intuitive and comprehension is at least partially dependent on driver familiarity and/or driver education.

Table 2. Driver comprehension rates for Vienna Convention A4a ROAD NARROWS sign

Study	Year	Country	Sample Population	Sample Size	Correct	Partially-Correct	Incorrect/ Don't Know
Mackie 1967	1967	United Kingdom	Registered drivers in six geographically diverse areas	337	62%	4%	34%
Cooper 1989	1989	United Kingdom	Drivers who were registered voters in 100 selected geographical areas	1,181	88%		12%
Shinar et al. 2003	2003	Poland, Canada, Israel & Finland	Licensed Drivers (250 per country)	1,000	82%	4%	14%
Ward et al. 2004	2004	United States	78 undergraduate students and 22 community members from North Carolina	100	42%	36%	32%
Ben-Bassat and Shinar 2006	2006	Israel	Industrial engineering students	40	88%	7%	5%
Razzak and Hasan 2010	2010	Bangladesh	Professional and non-professional drivers	202	56%		44%
Shinar and Vogelzang 2013	2013	Israel	Industrial engineering students	16	75%	16%	6%

The A4a ROAD NARROWS graphic is used in numerous countries, but not in the United States (its MUTCD counterparts are text-based). To test comprehension of the sign on a group of subjects who were unfamiliar with VC signs, a study comprised primarily of North Carolina undergraduate students was conducted (Ward et al. 2004). In spite of the A4a sign's similarity to

the MUTCD W4-2, only 42% correctly understood it, while 32% showed "critical confusion" (i.e., interpreted it to have the opposite of its intended meaning). Participants in the North Carolina study were then given a brief training session and immediately re-tested; their comprehension rose to 88%. This is similar to the rate found in a 1989 study of drivers in the United Kingdom, where the A4a sign has been used since the mid-1960s (Cooper 1989). Nevertheless, it appears that even in countries where the sign is widely used and driver education is rigorous, perhaps 10 to 15% of drivers do not understand it. Various studies have indicated that young, well-educated people are the most likely to understand symbol signs, but even among two groups of Israeli industrial engineering students with several years of driving experience, about 5% did not understand the A4a sign (Ben-Bassat and Shinar 2006, Shinar and Vogelzang 2013).

2.4. Alternatives to the W4-2

2.4.1. United States

Some US states have developed their own lane reduction signage designs. Delaware's W9-2-DE sign (Figure 8a) combines LANE ENDS text with two diagonal downward arrows (DelDOT 2010). In Maryland, the same design is designated as W9-2(2). Both states use the sign in combination with the W4-2 and others as part of a sequence of signs and markings for the approach to a lane reduction (Figure 9).

a. Delaware and Maryland

b. Iowa, Minnesota, and Missouri

Figure 8. Lane reduction signage identified in state supplements to the MUTCD

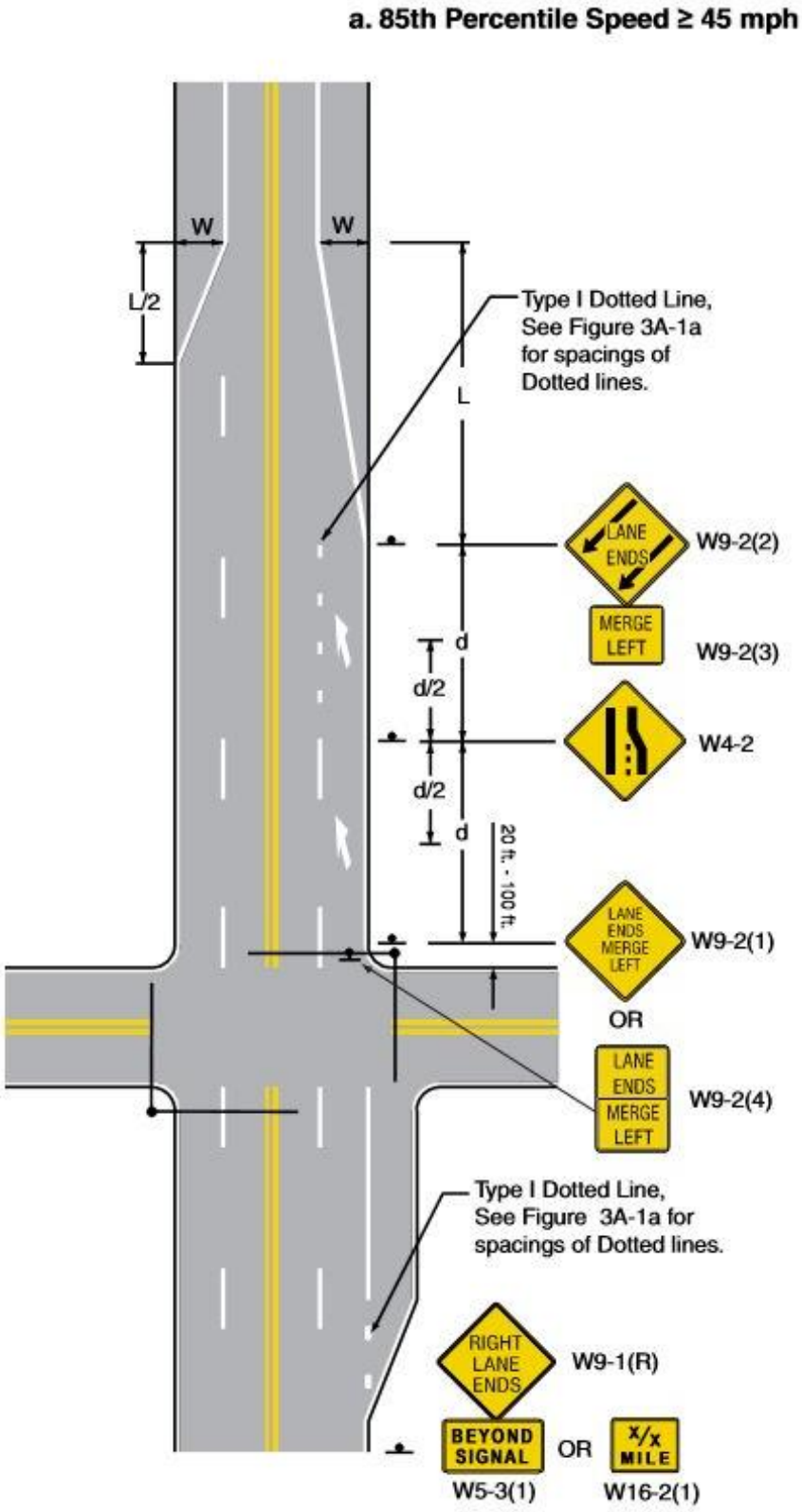


Figure 9. Maryland MUTCD lane-reduction detail for arterials with speeds over 45 mph

Another text + graphic combination sign is used in Iowa, Minnesota, and Missouri: it has the word MERGE and a horizontal left or right arrow (Figure 8b) (MnDOT 2014). It is used for work zones on multi-lane highways, with the standard W4-2 on the continuous side of the travel lanes and the MERGE + arrow on the lane-drop side, as illustrated in Figure 10.

MnDOT

Figure 10. MERGE + arrow sign and W4-2 in a Minnesota work zone

A recent study compared the effectiveness of the MERGE + arrow sign with an experimental control that used W4-2 signs (Edara et al. 2013). In the test configuration, a MERGE + arrow sign was placed on one side of the freeway lanes and a RIGHT LANE CLOSED sign on the other side of the same lanes. In the control configuration, W4-2 signs were used on both sides of the lanes. The study measured driver behavior characteristics including speeds and open lane occupancies at a work zone on Interstate 70 in Missouri. The study found that the open lane occupancy upstream of the merge sign was higher for the test sign in comparison to the MUTCD sign. The occupancy values at different distances between the merge sign and the taper were similar for both signs. The test sign had 11% more traffic in the open lane upstream of the merge sign. The analysis of speed characteristics did not reveal substantial differences between the two sign configurations. The 85th percentile speeds with the MUTCD sign were only 1 mph and 2 mph lower than the test sign at the merge sign and taper locations, respectively. Based on the study findings the authors concluded that the alternative sign configuration was not superior but performed equal to the MUTCD sign configuration.

2.4.2. Canada

The fifth edition of the Manual of Uniform Traffic Control Devices for Canada was published by the Transportation Association of Canada in 2014. Several Canadian provinces develop their own manuals or augment the national manual content, particularly for work zones. For example, Book 7 of the Ontario Traffic Manual identifies three sets of lane closure signs (MTO 2014). A symbol sign similar to the US MUTCD W4-2 is used to provide advance warning of a closed lane. Square text signs (LEFT LANE CLOSED, CENTRE LANE CLOSED, or RIGHT LANE CLOSED) are also authorized. In some provinces, upward diagonal arrows (without text) are part of the sign

sequence, placed at or just beyond the beginning of a lane closure taper (Figure 11 and Figure 12).

Luminosys Signalisation

Figure 11. Application of diagonal arrows in Quebec

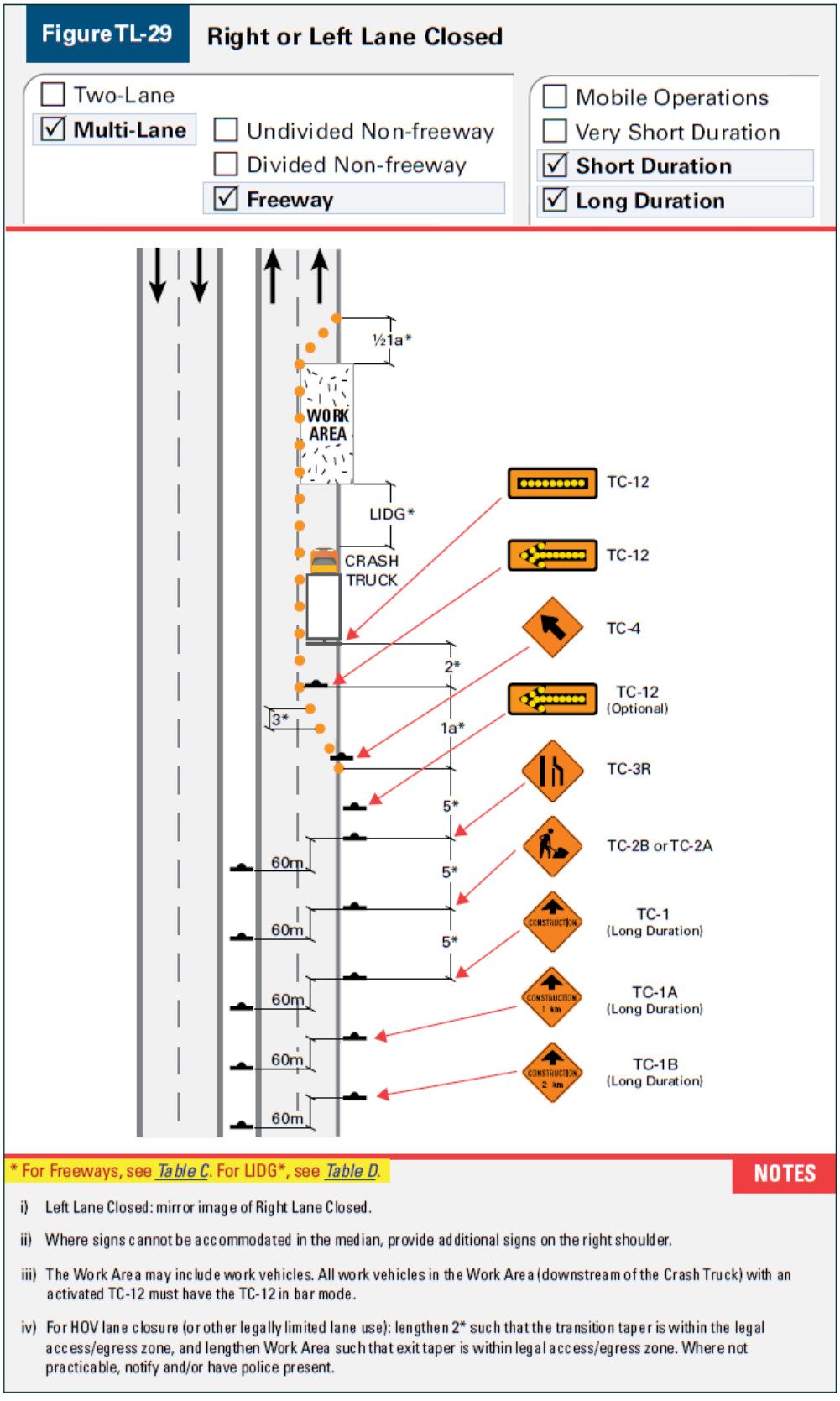


Figure 12. Typical application drawing from Book 7 of the Ontario Traffic Manual

A distinctive set of eight lane merge (FUSION DE VOIES) signs is used in Quebec (Figure 13) (MTQ 2013).

Figure 13. T-100 series signs used by the Ministry of Transport of Quebec (MTQ)

Although these signs appear to be patterned after the Vienna Convention G12a signage discussed in the next section, their graphic design is similar to other complex arrows used on North American signs. No information about the origin of these signs was found, but they are similar to signs that were explored experimentally in a mid-1990s Texas study (Hawkins et al. 1995).

2.4.3. Vienna Convention (VC)

In addition to the A4b sign discussed previously, the current Vienna Convention provides two templates, designated G12a and G12b, which identify lane closures using a one-arrow-per-lane style (Figure 14). The G12 signs provide greater detail about the downstream road configuration than the A4 series and are used in both permanent and temporary situations.

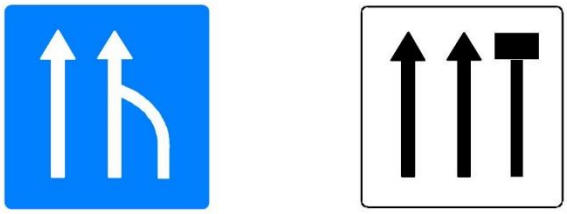
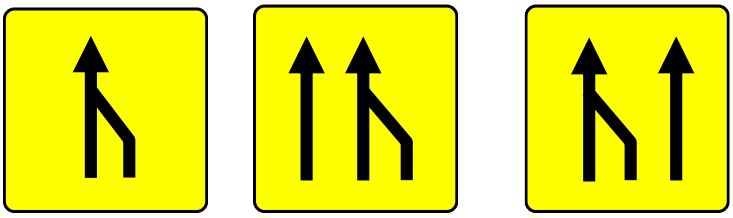
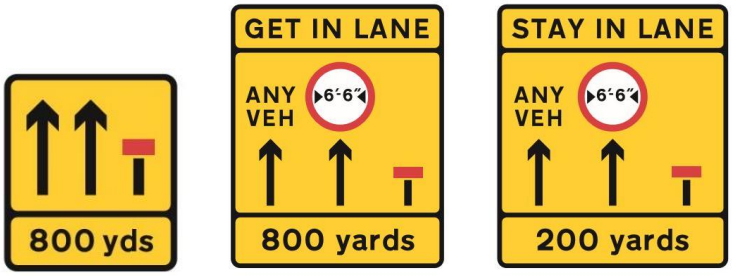


Figure 14. Vienna Convention G12a and G12b signs

In France and several other European countries, black-on-yellow signage is used to designate temporary conditions in work zones (similar to the use of black-on-orange in the United States). French work zone versions of the G12a sign are illustrated in Figure 15a. Notably, the G12a designs can be used for interior lane closures on multi-lane roadways; drivers in the lane that is closing are redirected to a specific lane. In the United Kingdom, basic G12b signs are sometimes combined with other graphic and text elements to provide detailed information about the distance to a closure and lane use restrictions (Figure 15b).



a. France

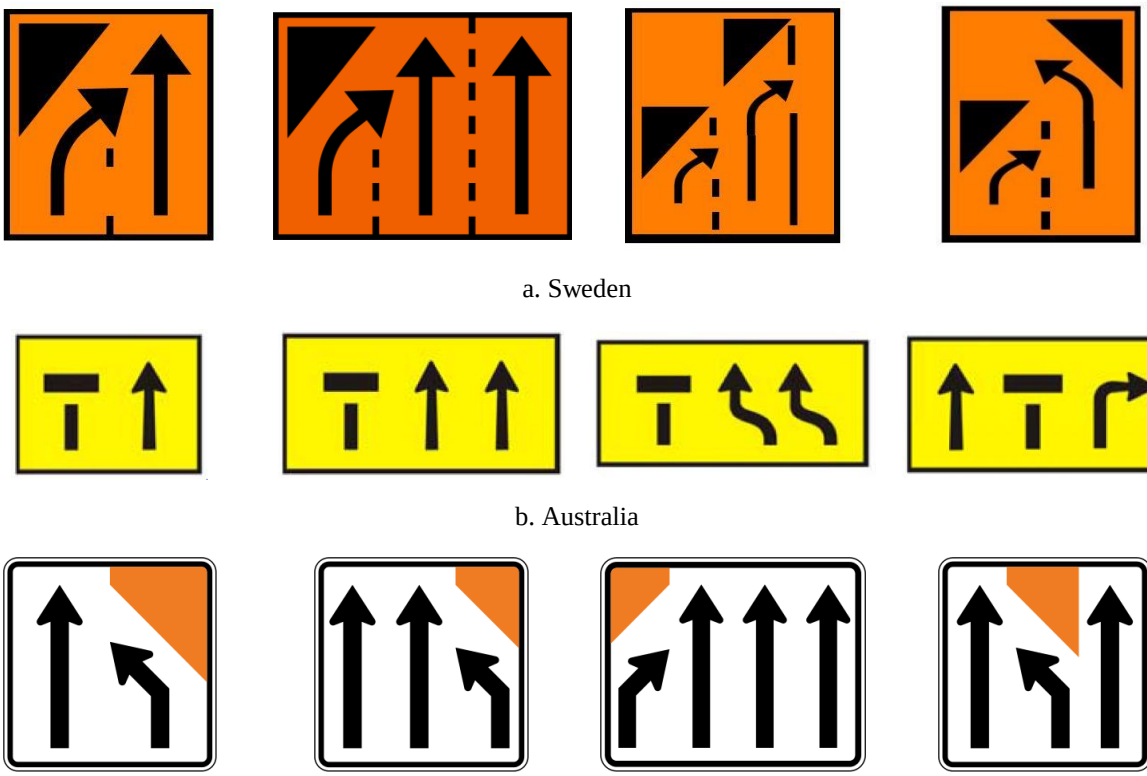


b. United Kingdom

Figure 15. Country-specific implementations of Vienna Convention G12a and G12b signage

2.4.4. Sweden, Australia, and New Zealand.

Sweden uses a version of the G12a sign that includes lane lines, a small curved arrow for the lane that is ending, and a black triangle suggesting a taper or blockage (Figure 16a); complex versions of the sign identify multiple lane shifts and chicanes (Swedish Road Administration 2008).



a. Sweden

b. Australia

c. New Zealand

Figure 16. Work zone lane closure signage for Sweden, Australia, and New Zealand

Although Australia is not a Vienna Convention country, a version of the G12b sign is used there (Figure 16b) (Roads and Traffic Authority 2010). In addition, a triangular sign with the word MERGE and a left or right arrow (conceptually similar to the Iowa/Minnesota/Missouri design) is authorized in the state of New South Wales (it is not a national standard).

New Zealand's approach is similar to Sweden's, but with more colors (black and orange on white) and without lane lines (Figure 16c) (NZTA 2015). Identifying interior lane closures is relatively straightforward with this design. Although the New Zealand *Code of Practice for Temporary Traffic Management* includes a sign similar to the pre-2003 MUTCD W4-2, it is allowed only on two-lane two-way roads that have been reduced to a single lane and have traffic volumes less than 1000 vehicles per day.

The typical application of G12 signage is illustrated in Figure 17 from a draft Swiss national standard.

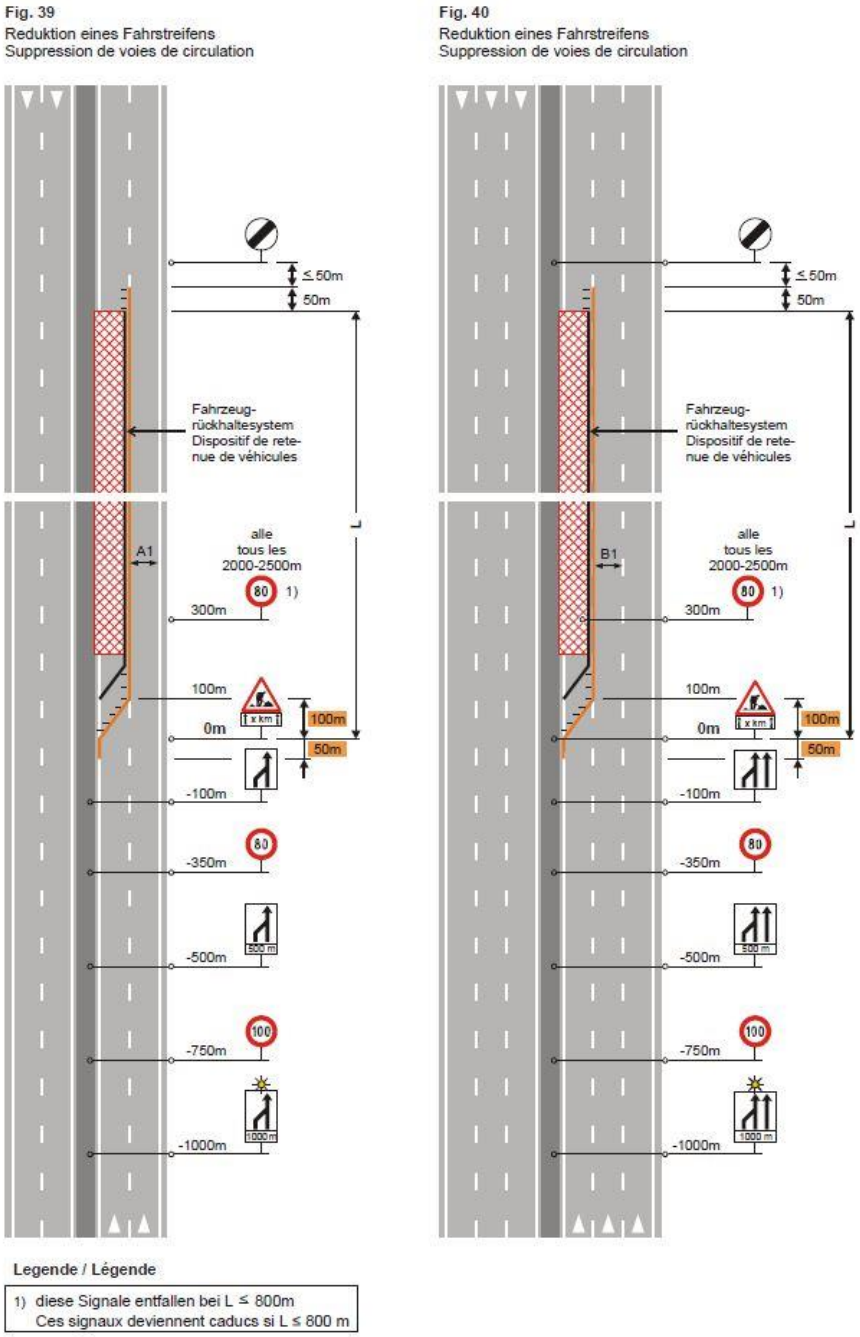
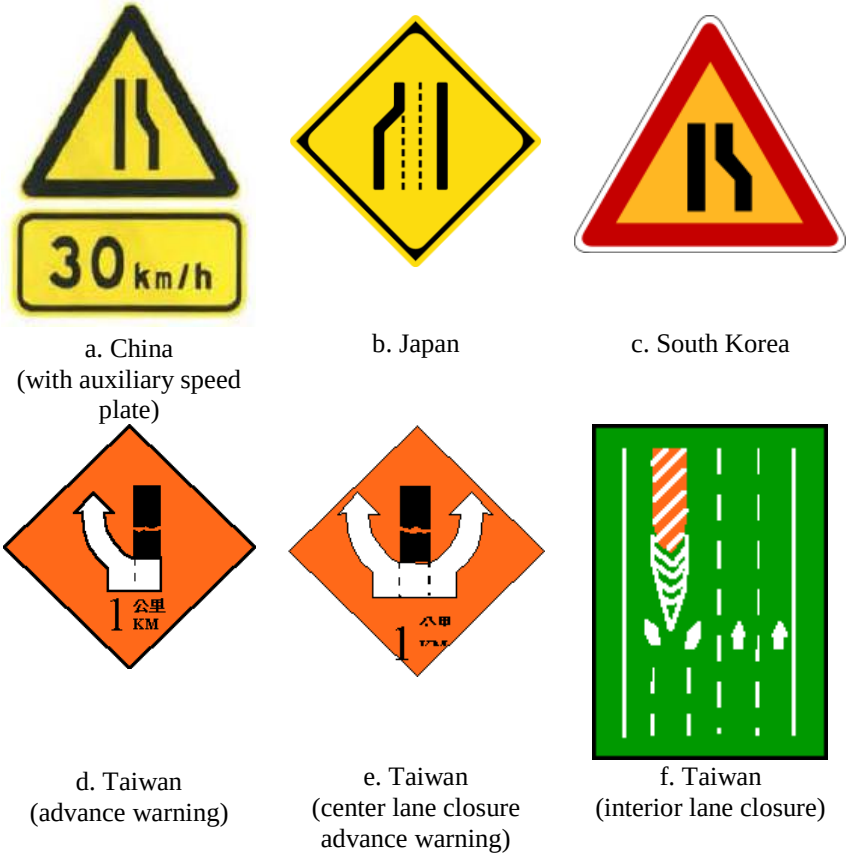


Figure 17. Swiss typical application drawing illustrating the use of G4a signs (speeds in km/h)

2.4.5. Asia

Although Mainland China is not a Vienna Convention country, A4b type signs are used to identify lane reductions (Figure 18a) (Standards Press of China 2009).



a. China (with auxiliary speed plate)

b. Japan

c. South Korea

d. Taiwan (advance warning)

e. Taiwan (center lane closure advance warning)

f. Taiwan (interior lane closure)

Figure 18. Lane reduction signage for mainland China, Japan, South Korea, and Taiwan

Optional auxiliary plaques can be used to identify the distance to the hazard or the recommended speed. In addition, auxiliary plaques with Chinese character text are often added to reinforce the meaning of the sign (Li 2016). Historically, black-on-yellow signs were used in work zones (the same as the non-construction signage), but as of 2016 at least one province (Jiangxi) was using black-on-orange signage for tollway work zones.

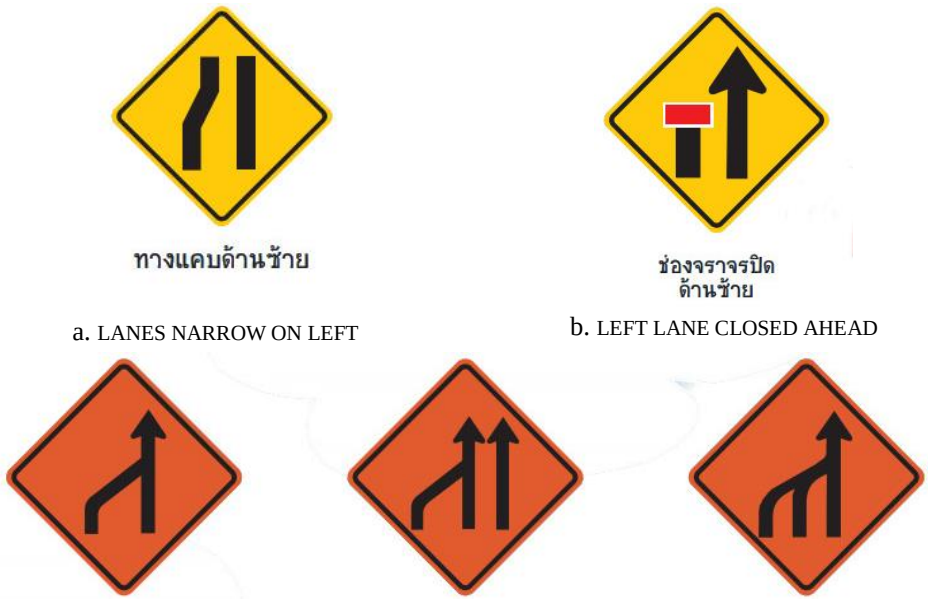
Although most of Japan's road signs are based on Vienna Convention designs, several warning signs apparently inspired by American designs are also used; these include a lane reduction sign similar to the 1961 version of the W4-2 (Figure 18b) (Ministry of Land, Infrastructure, Transport, and Tourism circa 2015).

India has not ratified the Vienna Convention, but the format and colors used for lane reduction signage are the same as in the United Kingdom (Figure 5) (Chandigarh Traffic Police circa

2015). South Korea is a Vienna Convention country and uses the A4 designs (Figure 18c) (KoROAD circa 2015).

Taiwan uses Vienna Convention type A4b signage at the closure point, but has unique designs to provide advance warning of lane closures. These include left, right, and center lane closure graphics (Figure 18d and Figure 18e). Diagrammatic signs are used to identify interior lane closures (Figure 18f).

Thailand's road signs combine practices from many countries (including elements derived from the MUTCD, Vienna Convention, and other sources), along with elements that are uniquely Thai (Figure 19) (Bureau of Highways Safety and Bureau of Standards and Evaluation 2002, Bureau of Highway Safety 2003, Department of Disaster Prevention and Mitigation circa 2015).



a. LANES NARROW ON LEFT

b. LEFT LANE CLOSED AHEAD

c. Lane reduction signs for work zones

Figure 19. Thai lane reduction signs

Thai Typical Application drawings use a sequence of several different lane closure symbols, perhaps on the premise that if a driver does not comprehend one sign, a subsequent sign will get the message across. For example, as shown in Figure 20, a driver approaching a lane closure on a four-lane undivided rural highway will first see the G12b symbol sign symbol sign, followed by an A4b (or pre-2003 style W4-2) sign, a message in Thai text, and barricades with horizontal arrows (DRR circa 2012). Work zone lane reduction signs similar to the ones adopted in Quebec are also shown in official Thai traffic management publications (Figure 19c).

8.3.9 การก่อสร้างบริเวณเกาะกลางถนน 4 ช่องจราจร (ลดจำนวนช่องจราจร) จะมีการติดตั้งระบบป้ายตามรูปที่ 9 แสดง

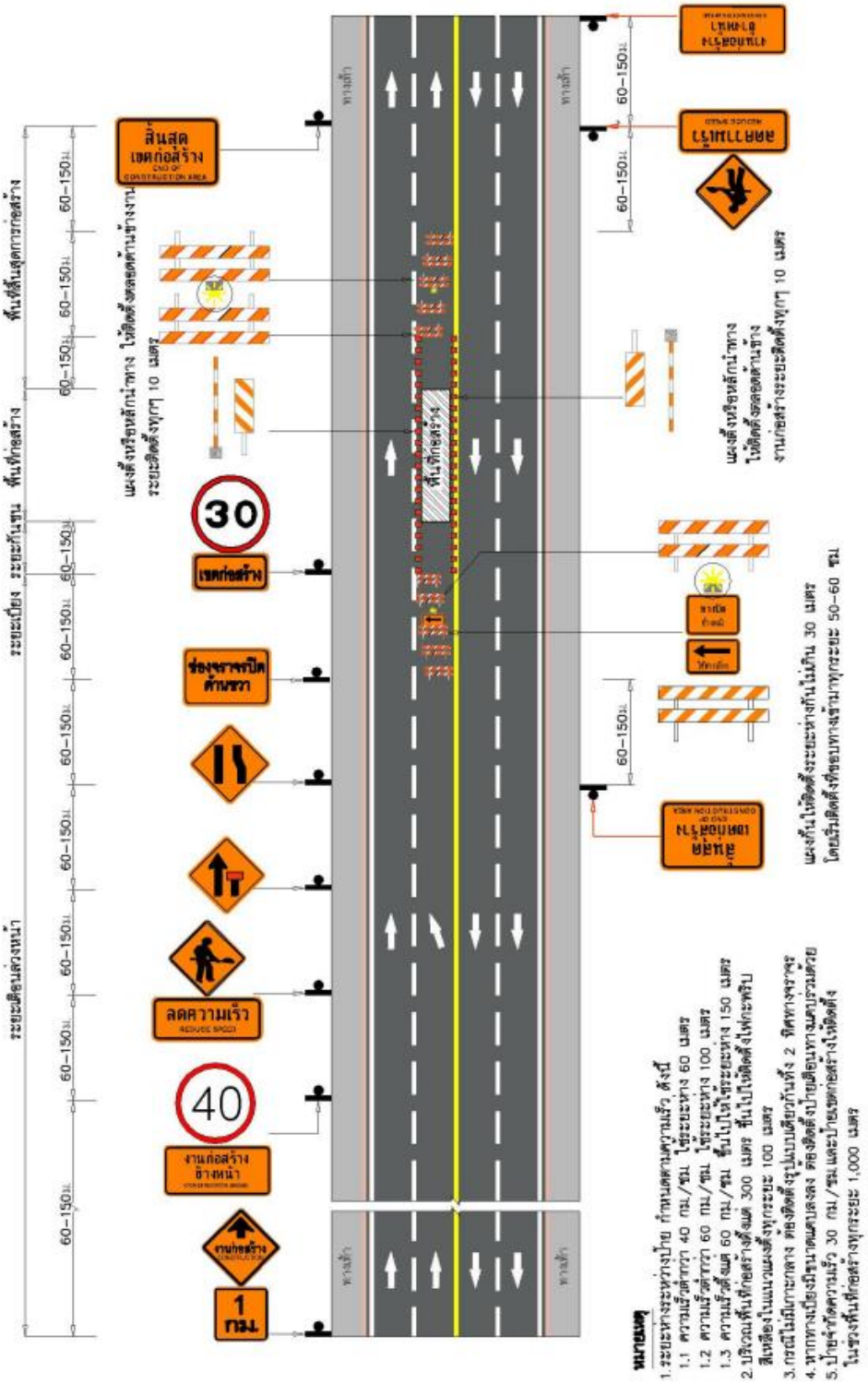


Figure 20. Thai typical application drawing for a two-to-one lane closure on a rural highway (driving on the left, speeds, and dimensions in metric units)

2.5.Literature Review Summary

Misinterpreted or ignored signs can contribute to safety problems, and hard-to-understand signs potentially require longer mental processing time that distracts from other driving tasks (Shinar and Vogelzang 2013). The U.S. population is multi-ethnic, highly mobile, and derived from a multiplicity of social and educational backgrounds, with varying reading and word comprehension skills (ANSI 2007). In general, symbol signs can be understood more quickly than text signs, and the relatively large size of most symbols makes the sign visible at a greater distance (Dewar et al. 1997).

Work zones are challenging driving environments whose conditions can change rapidly as work progresses. Comprehension of LANE ENDS signs is important for all roadways, but is especially important in work zones because the lane reductions are often new or unexpected. The need for sign comprehension is further increased when a merge point or taper is obscured by visual obstructions.

Several studies have explored comprehension rates for symbolic traffic signs (Mackie 1967, Cooper 1989, Hawkins et al. 1995, Dewar et al. 1997, Shinar et al. 2003, Ben-Bassat and Shinar 2006, Shinar and Vogelzang 2013). In general, these studies indicate that representational symbols (such as a stylized sketch of an animal) have higher comprehension rates than abstract symbols (such as a colored shape whose meaning has been defined by law or regulation) (Figure 21).

a. Representational symbol (riverbank or wharf)

b. Abstract symbol (beginning of through route)

Figure 21. Comparison of representational and abstract symbols used on Vienna Convention signs

Comprehension and legibility distance decline as driver age increases. Building on a line of earlier research, a recent Israeli study affirmed that adding text to the symbol improved comprehension and reduced the probability of misinterpreting the sign to mean the opposite of its intended message (Shinar and Vogelzang 2013). The Israeli study also found that although comprehension was higher for more familiar signs, familiarity alone was not a guarantee of good comprehension. Focus groups indicate that drivers generally prefer symbol signs to text (Dewar et al. 1997). Symbols are more salient when they depict dramatic action, but a cartoonish look is undesirable (ANSI 2007). The symbol should have enough detail to convey its intended

message, but superfluous details should be avoided (*2*). In general, signs are best understood by those driving high mileages, by those in lower age groups, and by those in higher socioeconomic groups (Cooper 1989). Low comprehension rates are reported for young, inexperienced drivers (Ford and Picha 2000).

Although the W4-2 was modified in 2003 by adding three small lane marker dashes (Figure 2), no studies comparing the effectiveness of the old and new graphics were found. Ongoing state-level use of alternative sign arrangements including text signs and text-graphic combinations suggests that practitioners continue to have concerns about the effectiveness of the current signs.

Concerns about comprehension of the A4a and A4b signs (the Vienna Convention counterparts of the W4-2) is reflected in a recent informal working document from the UNECE, which administers the Vienna Convention (Pronin 2014-15). The document includes several sketches suggesting a more pictorial representation of the roadway (Figure 22).

Figure 22. Potential new graphic designs for the A4a and A4b signs from a 2015 UNECE informal working document

Traffic safety experts and graphic designers from the United States, Canada, Europe, and Asia have developed a number of newer concepts to convey the LANE ENDS MERGE LEFT/RIGHT concept. Some of remain experimental, but many have been adopted as regional, national, or international standards. Notably, the Vienna Convention G12a design is used in North America (Quebec) and is extensible to address multi-lane roadways and center-lane closures.

There is interaction between the shape of a sign backplate and the legibility distance of the sign. For example, when a diamond-shaped backplate is used for a G12 type sign, the size of the graphics declines as the number of depicted lanes increases. This can affect legibility since the legend is not only smaller, but also at an increased lateral distance from the vehicles that need to merge. While the majority of MUTCD warning signs are diamond-shaped, several are square or rectangular. Therefore, this study examined Americanized versions of G12 signs in both diamond and rectangular formats.

A recent Vienna Convention informal working document raised the issue that some countries consider LANE ENDS signage to be a warning while others treat it as a regulation (Pronin 2014-15). This issue seems relevant to the United States as well. It is conceivable that in a Typical Application, the first instance of a sign derived from the G12 template would be treated as a warning upstream of the hazard, while the second (near the merge point) could be considered regulatory.

In summary, many alternatives to the W4-2 sign can be envisioned. A road user survey was conducted to evaluate some potential designs, including Americanized versions of signs used in other countries.

3. DRIVER COMPREHENSION SURVEY

Following the review of U.S and international literature and in consultation with the project's Technical Advisory Committee (TAC), the research team identified potential signs to be included in the driver comprehension survey. The American National Standards Institute (ANSI) standard Z535.3 methodology was used to administer the survey in three stages. The details of the methodology and results are presented in this chapter.

3.1.Survey Methodology

Annex B of American National Standards Institute (ANSI) standard Z535.3 lays out a three-stage methodology for evaluating the comprehension of symbols intended to convey safety-related messages. Study participants in all stages should be drawn from the population who will use the product or service associated with the warning graphic (in this case, licensed drivers). The process begins with review of any existing symbols and development of candidate graphic designs. Once a pool of candidate symbols has been established, the process proceeds as follows:

- Stage 1 serves as a screening tool to eliminate weak candidate graphics, such as symbols that are confusing or have poor legibility. Stage 1 participants are told the context and intended meaning of the symbol and asked to rate or rank how well each candidate conveys this message. Highly-rated symbols are then carried forward to the second stage.

- In Stage 2, a new set of participants is told the context of the symbol (i.e., "these are some signs you might see in a highway work zone") and asked to answer a multiple-choice test that evaluates whether they understand its meaning. The symbol(s) with the highest comprehension rates are carried forward to the third stage.

- In Stage 3, a new set of participants is told the context of the symbol and asked to explain its meaning in their own words. At this stage, at least 85% of participants should answer correctly, and no more than 5% should show critical confusion, which is defined as misinterpreting the symbol to have the opposite of its intended meaning (or an endorsement of the action which the symbol was intended to prevent).

3.2. Survey Results

All stages of survey were conducted at Department of Motor Vehicles offices in Wisconsin and Iowa. The locations and number of responses obtained at each location are presented in Table 3. In all, 397 members of the driving public participated in the ANSI Z535.3 process.

Table 3. Survey locations and number of responses

Survey Stage	DMV Location	Area Type	Number of Responses
Stage 1	Milwaukee-Greendale, Wisconsin	Suburban	143
Stage 2	Madison-West, Wisconsin	Urban	103
	Madison-East, Wisconsin	Urban	55
	Dubuque, Iowa	Small City	18
	Milwaukee-Northeast, Wisconsin	Urban	21
Stage 3	Madison-West, Wisconsin	Urban	57

3.2.1. Stage 1 Results

During Stage 1 of the survey, two questionnaires were administered. Questionnaire 1 (Appendix A) focused on a two-to-one lane reduction (left lane closure) and Questionnaire 2 (Appendix B) focused on a three-to-two lane reduction (center lane closure). Ninety-two responses were obtained for Questionnaire 1 and 51 responses for Questionnaire 2. The results for each questionnaire are presented in the following sections.

3.2.1.1. Stage 1 Questionnaire 1

The objective of this questionnaire was to identify promising signs for marking the approach to a two-to-one lane reduction. The review of international practices identified a number of candidate graphic designs, which were re-drawn using colors, arrow shapes, and lettering consistent with the U.S. MUTCD. Each sign was also assigned a description to facilitate communication amongst members of the study team; the description did not appear on any materials presented to the public. All signs depicted left lane closures.

Some of the signs used internationally are closely related or differ only in secondary details. For example, the signs used in Quebec, Canada (Figure 13) and France (Figure 15) are derived from the Vienna Convention G12a sign template (Figure 14), but use different graphic conventions to represent converging lanes. Similarly, in some countries work zone signs are produced using two colors (e.g., black and orange) while in other countries an additional color is introduced to emphasize or clarify specific graphic elements. Since adding a third color could affect sign production costs or service life, a corresponding improvement in comprehension is desirable. Therefore, apart from questions related to demographics, two research objectives were addressed in the questionnaire. The first objective was to identify graphics that drivers said would be the most easily understood. The second focused on identifying whether any of the secondary graphic design details increase or decrease respondents' perception of the signs' understandability.

Demographic Results. The demographics of the survey respondents are shown in Table 4 through Table 8.

Table 4. Driver license status of respondents for Stage 1 – Questionnaire 1

Driver License/Permit	Percentage of Responses (%)
Yes	89%
Came to DMV to apply for license/permit	9%
No	2%

Table 5. Primary language of respondents for Stage 1 – Questionnaire 1

Primary Language	Percentage of Responses (%)
English	92%
Spanish	3%
Hmong	0%
Other	4% (Arabic, Laotian, Tamil, Urdu one each)

Table 6. Gender of respondents for Stage 1 – Questionnaire 1

Gender	Percentage of Responses (%)*
Man	49%
Woman	51%

*Three respondents did not indicate gender

Table 7. Age of respondents for Stage 1 – Questionnaire 1

Age Group	Percentage of Responses (%)
13 or younger	0%
14-16	4%
17-18	6%
19-24	16%
25-34	18%
35-44	19%
45-54	15%
55-64	17%
65-74	6%
75-84	0%
85 or older	0%

Table 8. Number of hours driven each week by respondents for Stage 1 – Questionnaire 1

Approximate Number of Hours Driven Each Week	Percentage of Responses (%)
Less than 5	17%
6–10	27%
11–15	17%
16–20	12%
21–25	7%
26–30	10%
31–35	2%
36–40	0%
More than 40	8%

The sample was well distributed for gender, age, and number of hours driven each week:

- Table 4 shows the license status of the respondents. About 89% of the respondents had a driver's license or permit, 9% (mainly teens) came to the DMV to apply for one and 2% did not have a license or permit.

- The vast majority of the respondents (93%) had English as their primary language, with 3% Spanish and 4% for other languages as shown in Table 5. A higher number of non-native speakers of English would have been desirable.

- The survey respondents were about equally distributed between men (49%) and women (51%) (Table 6).

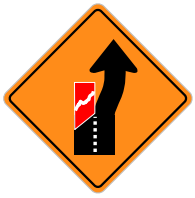
- The age distribution (shown in Table 7) was rather uniform between ages of 19 and 64. Young drivers (18 or under) were about 10% of the sample and older drivers (65 or over) were about 6%. Table 8 shows the distribution of the number of hours driven by the respondents each week. About 44% of the respondents drove 10 hours or less each week. Eight percent of the respondents drove 40 hours or more each week, probably representing commercial/professional drivers.

Rating Results. Respondents were asked to rate each sign candidate using the following scale:

1 = Excellent
2 = Good
3 = Fair
4 = Poor
5 = Unacceptable

In this rating system, *a low score indicates that survey participants thought a sign would be relatively easy to understand, while a high score indicates that participants thought the sign would be difficult to understand.* Importantly, all ratings are based on respondents' *perception* of each sign's understandability (this stage of the ANSI process does not objectively assess comprehension). Table 9 shows the results of question 1, where the focus was on different styles of signs.

Table 9. Results of comparing different styles of signs in Stage 1 – Questionnaire 1

MUTCD W4-2 (2003)  Overall 1.98 ± 1.05 Women: 2.02 ± 1.02 Men: 1.88 ± 1.07 Age ≤16: 2.50 ± 0.87 Age ≥65: 2.60 ± 0.80 NNS: 2.20 ± 1.14	**Vienna Convention G12b with Red Bar**  Overall: 3.58 ± 1.26 Women: 3.69 ± 1.26 Men: 3.53 ± 1.25 Age ≤16: 3.67 ± 0.94 Age ≥65: 3.60 ± 1.02 NNS: 3.40 ± 0.70	**Upward Drop Arrow with White Border**  Overall: 2.99 ± 1.11 Women: 3.14 ± 1.27 Men: 2.85 ± 0.84 Age ≤16: 3.50 ± 1.50 Age ≥65: 3.20 ± 0.40 NNS: 2.78 ± 1.48	**Vienna Convention G12a Quebec Style Arrows**  Overall: 2.65 ± 1.18 Women: 2.73 ± 1.21 Men: 2.56 ± 1.17 Age ≤16: 3.50 ± 0.50 Age ≥65: 2.80 ± 0.98 NNS: 3.10 ± 1.10
VC G12a New Zealand Style Arrows (Plain)  Overall: 3.34 ± 1.24 Women: 3.51 ± 1.15 Men: 3.18 ± 1.29 Age ≤16: 4.25 ± 0.83 Age ≥65: 3.40 ± 1.12 NNS: 3.25 ± 1.58	**MUTCD W9-1**  Overall: 1.53 ± 0.64 Women: 1.36 ± 0.60 Men: 1.71 ± 0.92 Age ≤16: 1.25 ± 0.43 Age ≥65: 1.80 ± 0.75 NNS: 1.78 ± 1.09	**Two Parallel Arrows with Prohibition Symbol**  Overall: 3.49 ± 1.25 Women: 3.51 ± 1.31 Men: 3.45 ± 1.20 Age ≤16: 4.00 ± 0.71 Age ≥65: 3.20 ± 1.17 NNS: 3.89 ± 1.27	**MERGE with Diagonal Upward Arrow**  Overall: 2.38 ± 1.15 Women: 2.24 ± 1.16 Men: 2.59 ± 1.13 Age ≤16: 2.25 ± 1.64 Age ≥65: 2.80 ± 0.98 NNS: 2.44 ± 1.13
Two Parallel Arrows with Worker Symbol  Overall: 2.94 ± 1.31 Women: 3.05 ± 1.29 Men: 2.81 ± 1.30 Age ≤16: 3.33 ± 1.25 Age ≥65: 3.20 ± 0.98 NNS: 3.20 ± 1.55	**MERGE with Horizontal Arrow**  Overall: 2.30 ± 1.16 Women: 2.29 ± 1.17 Men: 2.37 ± 1.14 Age ≤16: 2.00 ± 1.22 Age ≥65: 2.00 ± 0.63 NNS: 2.30 ± 1.34	**Upward Arrow with Broken Pavement – Red**  Overall: 3.65 ± 1.21 Women: 3.93 ± 1.10 Men: 3.38 ± 1.25 Age ≤16: 3.50 ± 1.12 Age ≥65: 3.80 ± 0.75 NNS: 3.56 ± 1.33	**Color-Inverted W4-2 with Grey Border**  Overall: 2.98 ± 1.22 Women: 3.13 ± 1.20 Men: 2.86 ± 1.21 Age ≤16: 2.50 ± 1.66 Age ≥65: 3.20 ± 0.75 NNS: 2.50 ± 1.51

Four symbol designs received average ratings of Fair or better (3 or less) and are highlighted in yellow

The average and standard deviations of the rankings are shown for each of the 12 signs. These values are shown for the overall sample, as well as by gender, younger/older drivers and for non-native speakers of English. However, given the small sample size for age 16 and under

(4 respondents), age 65 and over (5 respondents), and non-native speakers of English (4 respondents), the results for these demographic groups should be taken with caution.

As one might expect, the text-based LEFT LANE ENDS sign was ranked the highest overall, as well as across different genders, ages and language. This ranking is understandable given that the vast majority of respondents were fluent English speakers and the text was highly legible on the printed survey form. Nevertheless, previous field research has shown that text-intensive signs have relatively low legibility distance compared to pictographic signs.

The incumbent design, the W4-2 with three dots (introduced in the 2003 MUTCD) was included in the survey as a control. It ranked second-highest overall. This was expected since variations of the W4-2 have been in use in the U.S. since the 1960s. In addition, the W4-2 is used in a sample question on the Wisconsin driver licensing practice exam, so it should have been familiar to survey participants who were at the DMV to take the driver licensing test.

The Iowa/Minnesota/Missouri style MERGE signs with arrows were the next-best-ranked signs. These signs are distinct from the other candidates because they include both text and a graphic. Since the arrow direction (horizontal or upward diagonal) had almost no effect on the rankings, it appeared that participants relied mainly on the text to interpret these signs. This was affirmed in Stage 2, where the horizontal arrow performed poorly when not accompanied by MERGE text.

Four symbol designs received average rating of Fair or better (3 or less) and were chosen for inclusion in the Stage 2 survey. These four signs are highlighted in yellow in Table 9 and include:

1. Vienna Convention G12a with Quebec-Style Arrows

2. Two Parallel Arrows with Worker Symbol

3. Color-Inverted W4-2 with Grey Border

4. Upward Drop Arrow with White Border

The second survey question focused on identifying secondary details that could increase or decrease respondents' perceptions of the understandability of certain styles of signs. The results of this evaluation are presented in Table 10, where the average and standard distribution of the ratings for each of the signs is shown.

Table 10. Results of comparing variations within styles in Stage 1 – Questionnaire 1

MUTCD W4-2 (1971)  Overall: 2.44 ± 1.17 Women: 2.73 ± 1.12 Men: 2.14 ± 1.11 Age ≤16: 3.50 ± 0.87 Age ≥65: 2.40 ± 0.80 NNS: 2.40 ± 1.17	**MUTCD W4-2 (2003)**  Overall: 2.30 ± 1.16 Women: 2.22 ± 1.03 Men: 2.35 ± 1.26 Age ≤16: 2.75 ± 0.83 Age ≥65: 2.00 ± 0.63 NNS: 2.67 ± 1.58	**VC G12a French Style Arrows on Diamond**  Overall: 3.03 ± 1.16 Women: 3.09 ± 1.19 Men: 3.02 ± 1.08 Age ≤16: 4.00 ± 0.71 Age ≥65: 3.40 ± 1.20 NNS: 3.11 ± 1.36	**VC G12a Quebec Style Arrows on Diamond**  Overall: 3.04 ± 1.14 Women: 3.11 ± 1.22 Men: 3.02 ± 1.00 Age ≤16: 4.00 ± 0.71 Age ≥65: 2.80 ± 0.98 NNS: 3.20 ± 1.32
Color-Inverted W4-2 with Gray Border  Overall: 3.02 ± 1.18 Women: 3.11 ± 1.15 Men: 2.93 ± 1.15 Age ≤16: 2.25 ± 0.43 Age ≥65: 3.40 ± 1.02 NNS: 2.50 ± 1.18	**Upward Drop Arrow with White Border**  Overall: 3.03 ± 1.19 Women: 3.18 ± 1.25 Men: 2.90 ± 1.03 Age ≤16: 3.75 ± 1.09 Age ≥65: 3.60 ± 1.02 NNS: 2.56 ± 1.13	**Upward Drop Arrow White Border Red Triangle**  Overall: 3.58 ± 1.11 Women: 3.82 ± 1.05 Men: 3.36 ± 1.07 Age ≤16: 4.00 ± 1.22 Age ≥65: 3.80 ± 0.98 NNS: 3.38 ± 1.30	**Upward Drop Arrow No Border with Red Triangle**  Overall: 3.73 ± 1.02 Women: 3.86 ± 1.06 Men: 3.64 ± 0.89 Age ≤16: 4.33 ± 0.94 Age ≥65: 3.80 ± 0.98 NNS: 3.33 ± 1.22
VC G12a New Zealand Style Arrows on Square Backplate (Plain)  Overall: 3.33 ± 1.20 Women: 3.44 ± 1.18 Men: 3.24 ± 1.17 Age ≤16: 4.00 ± 0.71 Age ≥65: 3.40 ± 1.20 NNS: 3.50 ± 1.51	**VC G12a New Zealand Style Arrows with Black Triangle**  Overall: 3.59 ± 1.00 Women: 3.58 ± 1.04 Men: 3.59 ± 0.96 Age ≤16: 4.00 ± 0.71 Age ≥65: 3.00 ± 0.89 NNS: 4.29 ± 0.76	**VC G12a New Zealand Style Arrows on British Style Tapering Backplate**  Overall: 3.66 ± 1.04 Women: 3.78 ± 1.05 Men: 3.50 ± 1.02 Age ≤16: 4.25 ± 0.83 Age ≥65: 3.40 ± 1.20 NNS: 4.29 ± 0.76	**VC G12a New Zealand Style Arrows with Red Triangle**  Overall: 3.66 ± 1.07 Women: 3.91 ± 0.96 Men: 3.37 ± 1.12 Age ≤16: 4.25 ± 0.83 Age ≥65: 3.00 ± 0.89 NNS: 4.29 ± 0.76
VC G12a Quebec Style Arrows on Square Backplate (Plain)  Overall: 2.90 ± 1.18 Women: 3.00 ± 1.25 Men: 2.79 ± 1.09 Age ≤16: 3.50 ± 1.12 Age ≥65: 3.00 ± 1.26 NNS: 3.11 ± 1.27	**VC G12a Quebec Arrows with Black Triangle on Square Backplate**  Overall: 3.26 ± 1.08 Women: 3.36 ± 1.16 Men: 3.19 ± 0.98 Age ≤16: 4.00 ± 1.22 Age ≥65: 3.20 ± 0.98 NNS: 3.56 ± 1.13	**VC G12a Quebec Style Arrows on British Style Tapering Backplate**  Overall: 3.38 ± 1.09 Women: 3.67 ± 1.03 Men: 3.07 ± 1.05 Age ≤16: 4.00 ± 1.22 Age ≥65: 3.20 ± 0.98 NNS: 3.22 ± 1.39	**VC G12a Quebec Arrows with Red Triangle on Square Backplate**  Overall: 3.41 ± 1.15 Women: 3.64 ± 1.11 Men: 3.21 ± 1.15 Age ≤16: 4.00 ± 1.22 Age ≥65: 3.60 ± 0.80 NNS: 3.22 ± 1.30

The following inferences can be drawn from the results:

- Three lane-line dots were added to the W4-2 sign in 2003 in an attempt to improve comprehension. No studies evaluating the effectiveness of this change were found during the literature review. Scores for the 1971 and 2003 versions of W4-2 sign were very similar, suggesting that respondents did not perceive a strong improvement in understandability as a result of the adding the dots.

- Among the three arrow styles presented in combination with variants of the Vienna Convention G12a sign, respondents rated the Quebec arrow style as more understandable than the New Zealand style. The understandability of the French arrow style was rated equal to the Quebec style. (The curving Quebec style is more consistent with other US MUTCD signs than the angular French style). In verbal comments to the survey distributors, some respondents stated that the New Zealand style was confusing because they thought it was intended to signify making a right turn from the left lane.

- Among several variations of the G12a sign, respondents generally indicated a preference for graphic simplicity over the inclusion of colors and shapes intended to enhance legibility.

- The shape of the sign backplate (diamond vs square) did not appear to affect perceptions of understandability. This is important because the G12 type one-arrow-per-lane graphics can be displayed at a larger size if they are on a square or rectangular backplate, which will increase legibility distance.

- The British-style tapering backplate did not appear to be perceived as more understandable than a triangle representing the lane drop. Thus, there does not appear to be a strong justification for producing an irregularly-shaped sign.

3.2.1.2. Stage 1 Questionnaire 2

The objective of this questionnaire was to identify promising signs for interior lane closures. The most common type of interior lane closure, a center lane closure on a three-lane segment, was selected for this survey.

The demographics of the survey respondents for Questionnaire 2 are shown in Table 11 through Table 15.

Table 11. Driver license status of respondents for Stage 1 – Questionnaire 2

Driver License/Permit	Percentage of Responses (%)
Yes	97%
Came to DMV to apply for license/permit	3%
No	0%

Table 12. Primary language of respondents for Stage 1 – Questionnaire 2

Primary Language	Percentage of Responses (%)
English	91%
Spanish	6%
Hmong	0%
Other	3% (Vietnamese)

Table 13. Gender of respondents for Stage 1 – Questionnaire 2

Gender	Percentage of Responses (%)*
Man	37%
Woman	63%

*Three respondents did not indicate a gender

Table 14. Age of respondents for Stage 1 – Questionnaire 2

Age group	Percentage of Responses (%)
13 or younger	0%
14–16	8%
17–18	6%
19–24	8%
25–34	19%
35-44	25%
45–54	14%
55–64	17%
65–74	3%
75–84	0%
85 or older	0%

Table 15. Number of hours driven each week by respondents for Stage 1 – Questionnaire 2

Approximate number of hours driven each week	Percentage of Responses (%)
Less than 5	23%
6–10	27%
11–15	27%
16–20	9%
21–25	5%
26–30	0%
31–35	0%
36–40	0%
More than 40	9%

The tables show the following:

- Table 11 shows the license status of the respondents. About 97% of the respondents had a driver's license or permit and 3% came to the DMV to apply for one.

- The vast majority of the respondents (91%) had English as their primary language, with 6% Spanish and 3% for other languages as shown in Table 12.

- The survey respondents were about 37% men and 63% women (shown in Table 13).

- The age distribution (shown in Table 14) was about uniform between ages of 19 and 64. Young drivers (18 or under) were about 14% of the sample and older drivers (65 or over) were about 3%.

- Table 15 shows the distribution of the number of hours driven by the respondents each week. The majority (77%) of respondents reported that they spend 0 to 15 hours per week driving, while 9% indicated that they drive 40 or more hours per week.

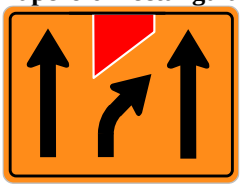
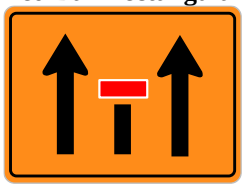
As with Questionnaire 1, respondents were asked to rate each sign as:

1 = Excellent
2 = Good
3 = Fair
4 = Poor
5 = Unacceptable

Therefore, signs with lower numeric value are perceived as “more understandable” than signs with higher numeric values.

Table 16 shows the average and standard deviations of the rankings for each of the 9 signs for center-lane closure. These values are shown for the overall sample.

Table 16. Results of comparing signs for center-lane closure in Stage 1 – Questionnaire 2

Former MUTCD W9-3a  2.94 ± 1.24	**VC G12a Quebec Style Arrows Diamond (Plain)**  3.35 ± 1.20	**MUTCD W9-3**  1.36 ± 0.78
VC G12a New Zealand Style Arrows Rectangular (Plain)  3.76 ± 1.08	**VC G12a Quebec-Style Arrows Rectangular (Plain)**  3.46 ± 1.16	**VC G12b Arrows and Black Bar Rectangular**  3.98 ± 1.17
VC G12a New Zealand Style Arrows with Red Trapezoid Rectangular  3.06 ± 1.22	**VC G12a Quebec Style Arrows with Red Trapezoid Rectangular**  2.98 ± 1.36	**VC G12b Arrows and Red Bar Rectangular**  3.43 ± 1.41

Three designs received average ratings of Fair or better (3 or less) and are highlighted in yellow

The W9-3 CENTER LANE CLOSED AHEAD text sign was included as a control and had the highest ranking (1.36 ± 0.78), but as noted earlier the legibility distance of text signs can be problematic. This is especially the case for the W9-3, which requires four lines of text. Another limitation of the W9-3 is that it does not provide any indication of whether vehicles in the center lane are expected to move to the right or to the left, nor is it applicable to roadways with more than three lanes.

The former MUTCD W9-3a pictographic sign was also included in this survey as a control. As noted in the literature review, the W9-3a was introduced in the 2003 MUTCD and withdrawn in 2009, apparently due to concerns about poor comprehension.

Other than the controls, the only sign with an average rating of Fair (less than 3) was the G12a sign with Quebec style arrows and a red trapezoid on a rectangular backplate. It is highlighted in yellow in Table 16 and was included in Stage 2 of the survey.

In contrast to the Questionnaire 1 results, inclusion of a red trapezoid representing the closure area appeared to enhance respondents' perception of the understandability of the interior lane closure signs. Although the existing W4-2 and W9-3 are used with diamond-shaped backplates, the use of rectangular backplates instead of diamonds did not appear to have an adverse impact on perceived understandability. This finding is important because a rectangular format can allow the width of signs for closures on multi-lane roadways to increase in proportion to the number of lanes. (As a close examination of Figure 13 reveals, the format of one-arrow-per-lane graphics is not well suited to a diamond-shaped backplate, so legibility distance suffers as the number of lanes increases).

3.2.2. Stage 2 Results

Based on results of the Stage 1 surveys, four experimental two-to-one lane reduction signs were selected for inclusion in Stage 2, with the existing (2003 and later) MUTCD W4-2 as a control. The Vienna Convention G12a sign with Quebec-style arrows and a red trapezoid on a rectangular backplate was selected as the most promising interior closure signage candidate. Thus, a total of six signs were evaluated in Stage 2. All candidates were tested without supplemental text.

Since the purpose of Stage 2 is to assess sign comprehension, the questionnaire was formatted as a multiple-choice test similar to the sign-related questions for a driver licensing examination. To avoid repetitive correct answers, the six work zone lane closure signs were intermingled with questions about non-work-zone signs from the MUTCD, which served as experimental controls. To keep the questionnaire short, two versions were created, each with three questions about lane closure signage and three questions about non-construction signs. The same control questions were used on both versions of the survey, so in the final tabulation (Table 22) the questions for work zone signage have about half as many responses as the control questions. The three MUTCD signs used as controls were as follows:

1. S1-1 school zone sign

2. W3-1 stop ahead sign

3. R4-7 keep right sign

The questions in Stage 2 were multiple-choice. Respondents were instructed to select one response from the four possible answers for each sign. The Stage 2 questionnaires were administered at Department of Motor Vehicles (DMV) offices in southern Wisconsin and northeast Iowa to customers (and their companions) who were waiting for DMV services. A total of 197 responses were collected.

Demographics of the survey respondents (for both questionnaires combined) are shown in Table 17 through Table 21.

Table 17. Driver license status of respondents for Stage 2

Driver License/Permit	Percentage of Responses (%)*
Yes	88%
Came to DMV to apply for license/permit	7%
No	5%

*Three respondents did not indicate a license status

Table 18. Primary language of respondents for Stage 2

Primary Language	Percentage of Responses (%)*
English	91%
Spanish	1%
Hmong	0%
Other	8%

*One respondent did not indicate a primary language

Table 19. Gender of respondents for Stage 2

Gender	Percentage of Responses (%)*
Man	56%
Woman	44%

*Four respondents did not indicate a gender

Table 20. Age of respondents for Stage 2

Age Group	Percentage of Responses (%)*
13 or younger	0%
14–16	5%
17–18	3%
19–24	9%
25–34	24%
35–44	20%
45–54	22%
55–64	6%
65–74	6%
75–84	4%
85 or older	0%

*Five respondents did not indicate an age group

The tables show the following:

- Table 17 shows the license status of the respondents. About 88% of the respondents had a driver's license or permit, 7% came to the DMV to apply for one and 5% did not have a license or permit.

- The vast majority of the respondents (91%) had English as their primary language, with 1% Spanish and 8% for other languages as shown in Table 18.

- The survey respondents were 56% men and 44% women (shown in Table 19).

- The age distribution (shown in Table 20) was rather uniform between ages of 25 and 54. Young drivers (18 or under) were about 8% of the sample and older drivers (65 or over) were about 10%.

- Table 21 shows the distribution of the number of hours driven by the respondents each week. About 52% of the respondents drove 10 hours or less each week. Eight percent of the respondents drove 40 hours or more each week, probably representing commercial/professional drivers.

Table 21. Number of hours driven each week by respondents for Stage 2

Approximate number of hours driven each week	Percentage of responses (%)*
Less than 5	26%
6–10	26%
11–15	22%
16–20	9%
21–25	4%
26–30	4%
31–35	2%
36–40	0%
More than 40	8%

*Twenty seven respondents did not indicate their driving intensity

The responses to the comprehension questions are presented in Table 22. The correct choice is indicated by a green arrow in each figure.

Table 22. Results of Stage 2 – work zone signs

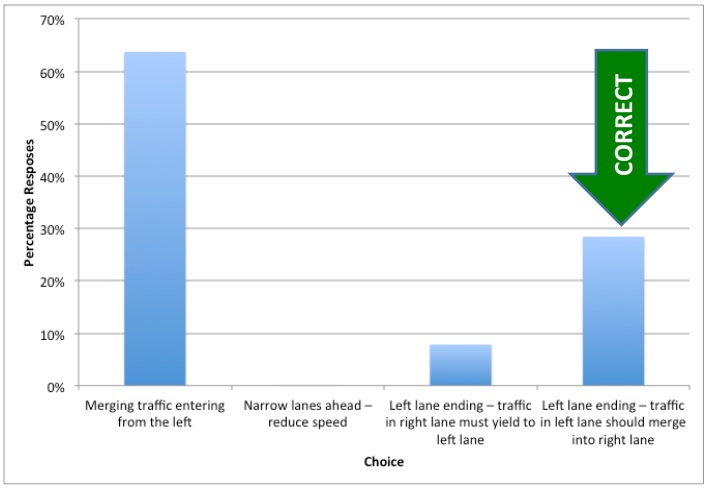
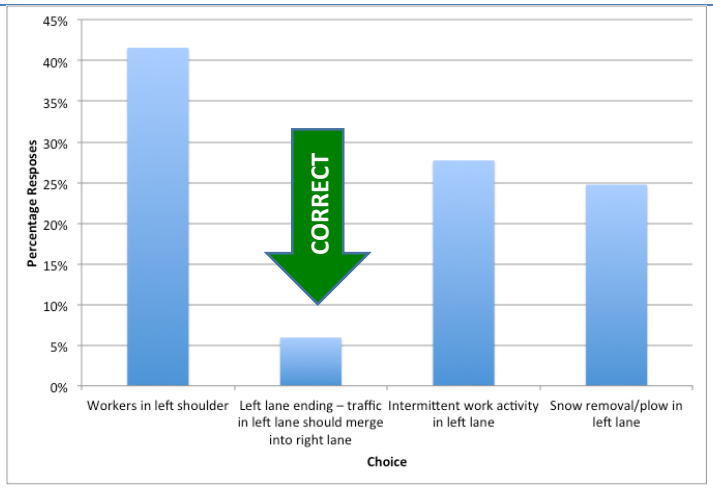
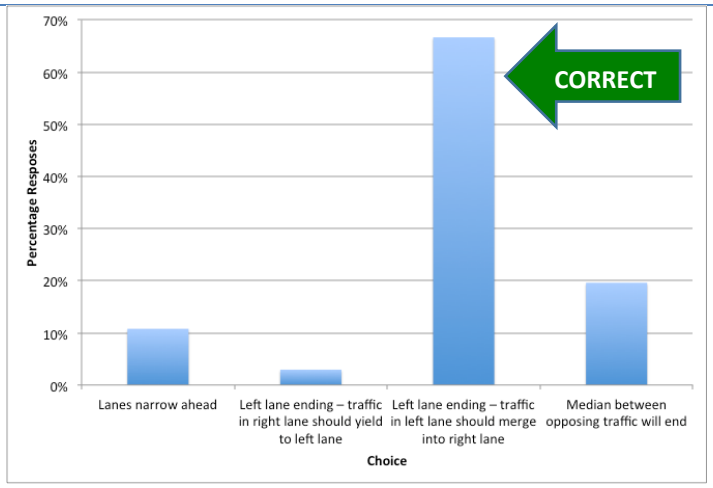
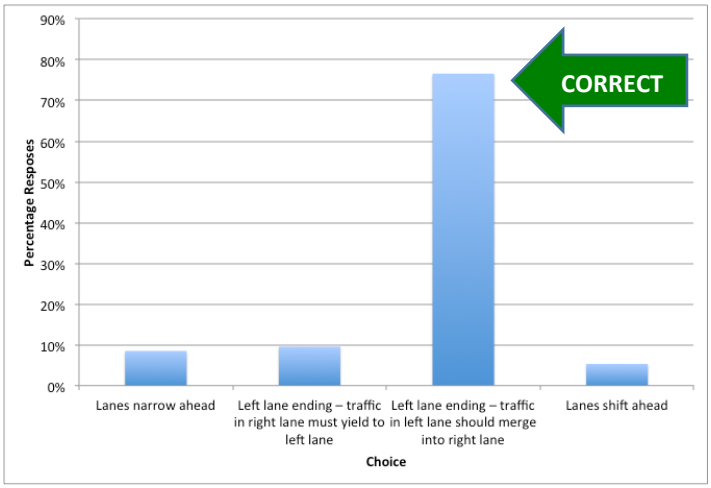
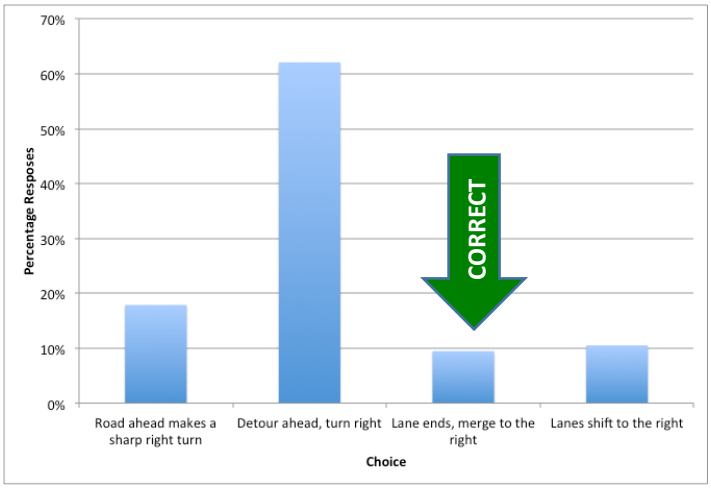
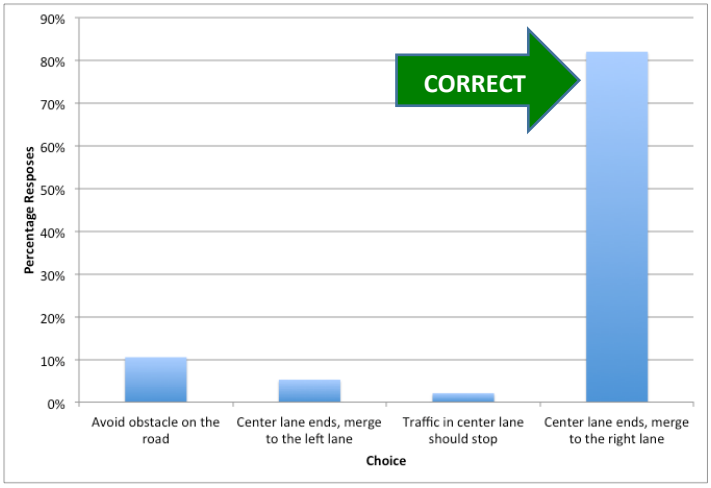
VC G12a with Quebec Style Arrows  # of responses: 102	
Two Parallel Arrows with Worker Symbol  # of responses: 101	
W4-2 (2003)  # of responses: 101	

Table 22. Results of Stage 2 – work zone signs (continued)

Upward Drop Arrow with White Border  # of responses: 94	
Horizontal Arrow  # of responses: 95	
G12a with Quebec Style Arrows and Red Trapezoid  # of responses: 95	

In the multiple-choice testing, the incumbent MUTCD W4-2 (2003) sign had 67% correct responses. About 20% chose "Median between opposing traffic will end" and another 11% chose "Lanes narrow ahead". These findings corroborate previous research, which noted these two misinterpretations as being frequently mentioned by drivers.

In the multiple-choice testing, 77% of respondents correctly identified the meaning of the Upward Drop Arrow (which is a heavily modified version of the W4-2). About 5% respondents chose "Lanes shift ahead" and 9% chose "Lanes narrow ahead". Thus, comprehension of the Upward Drop Arrow was substantially higher than comprehension of the incumbent W4-2 design.

The multiple-choice testing indicated excellent comprehension of the center lane closure version of the G12a sign with Quebec-style arrows and a red trapezoid representing the closure, with a correct response rate of 82%. Thus, this sign appears to be a very promising candidate for interior lane closures.

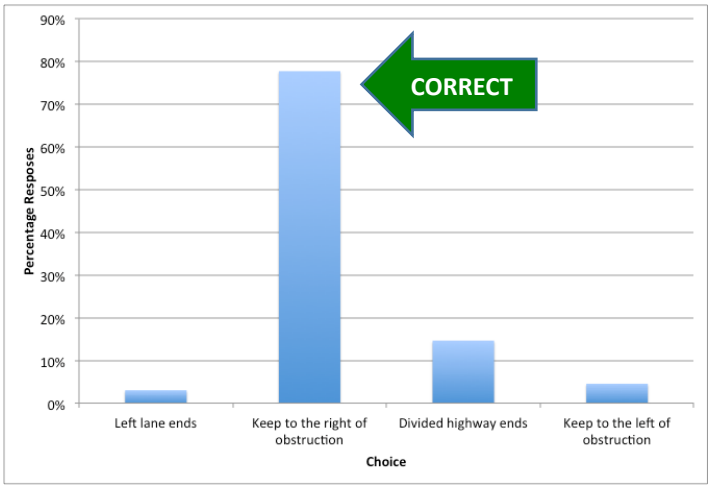
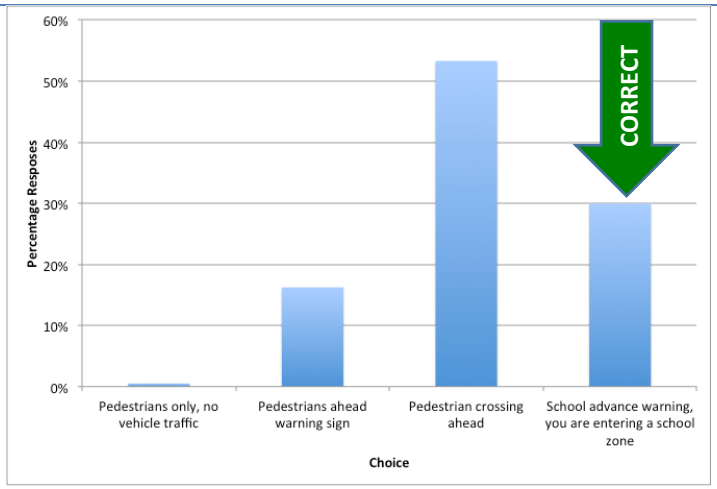
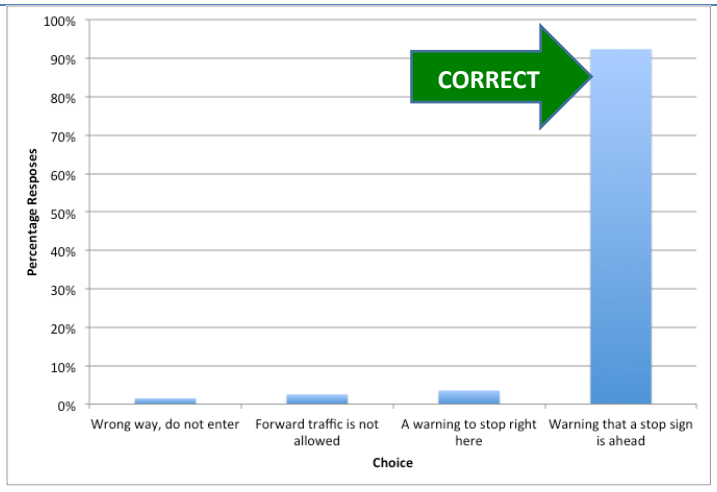
Stripped of the triangle representing the lane closure, comprehension of the two-to-one closure version of the G12a sign was less than satisfactory, with only 28% selecting the correct answer. About 64% chose "Merging traffic entering from left", a misinterpretation that could potentially have adverse safety impacts. This suggests that the graphic element representing the "blockage" could be more important to comprehension than the Stage 1 results indicated.

Stripped of the word MERGE, the Iowa/Minnesota/Missouri style horizontal arrow sign received only 9% correct responses. Most drivers interpreted the sign as indicating change of direction in the road. Thus, the inclusion of the word MERGE (as is the practice in the states where it is currently used) appears to be essential to the comprehension of the intended meaning of this sign.

In spite of its relatively good performance in the Stage 1 survey, the Two Parallel Arrows with Worker Symbol sign had a correct response rate of only 6%. About 42% interpreted the sign to mean that workers were present in the shoulder. While this level of miscomprehension is unacceptable for a symbol intended to signify a lane closure, it is a possible indication that with further adaptation and testing, some variant of this graphic might be useful for shoulder closure warnings.

Three non-work-zone signs were included in the questionnaires as experimental controls. The sample size and breakdown of responses for each question are shown in Table 23.

Table 23. Results of Stage 2 – control signs

Keep Right (R4-7)  # of responses: 198	
School Zone (S1-1)  # of responses: 197	
Stop Ahead (W3-1)  # of responses: 197	

The STOP AHEAD sign (W3-1) had a correct response rate of 92% and the KEEP RIGHT sign (R4-7) had a 78% correct response rate, while the SCHOOL ZONE (S1-1) had a surprisingly low correct

response rate of 30%. Over half of respondents misinterpreted the SCHOOL ZONE sign as an advance warning for a pedestrian crossing—a misinterpretation that could potentially have adverse safety impacts since a school zone typically covers a much larger geographical area than a pedestrian crossing.

In summary, among the two-to-one closure signs the Upward Drop Arrow had the highest correct response rate, with better driver comprehension than the exiting W4-2 sign. The G12a interior lane closure sign with Quebec-style arrows and a red trapezoid also had a high correct response rate. Therefore, both of these signs were selected for inclusion in Stage 3.

3.2.3. Stage 3 Results

The third stage of the ANSI Z535.3 safety symbol evaluation procedure consists of testing using an open-ended question format, where respondents explain the meaning of the symbol in their own words. Based on the Stage 2 results, two signs were selected for final comprehension testing in this stage:

- Upward Drop Arrow with White Border

- G12a with Quebec-style arrows and Red Trapezoid (as in the previous stages, this sign was tested for a center lane closure on a segment with three upstream lanes)

The Stage 3 questionnaire is reproduced in Appendix E. It consisted of a paper survey form with full-color depictions of the two signs, accompanied by the text "What does this sign mean to you?" and space for a hand-written response. Multiple-choice demographic questions identical to those used in previous stages of the project were also printed on the form. Deviating slightly from the ANSI Z535.3 procedure, no information about the context of the sign was provided on the survey form. The questionnaire was distributed at the Wisconsin DMV's Madison-West office, which is located on the ground floor of a multi-story building that also houses Wisconsin DOT's headquarters. A total of 57 responses were collected.

Demographics of the Stage 3 survey respondents are shown in Table 24 through Table 28.

Table 24. Driver license status of respondents for Stage 3

Driver License/Permit	Percentage of Responses (%)
Yes	93%
Came to DMV to apply for license/permit	7%
No	0%

Table 25. Primary language of respondents for Stage 3

Primary Language	Percentage of Responses (%)
English	91%
Spanish	2%
Hmong	0%
Other	7%

Table 26. Gender of respondents for Stage 3

Gender	Percentage of Responses (%)
Man	60%
Woman	40%

Table 27. Age of respondents for Stage 3

Age Group	Percentage of Responses (%)*
13 or younger	0%
14–16	5%
17–18	2%
19–24	13%
25–34	23%
35–44	20%
45–54	18%
55–64	11%
65–74	7%
75–84	2%
85 or older	0%

*One respondent did not indicate an age range

Table 28. Number of hours driven each week by respondents for Stage 3

Approximate Number of Hours Driven Each Week	Percentage of Responses (%)*
Less than 5	29%
6–10	24%
11–15	18%
16–20	12%
21–25	6%
26–30	4%
31–35	2%
36–40	0%
More than 40	6%

*Six respondents did not indicate number of hours driven each week

The tables show the following:

- Table 24 shows the license status of the respondents. About 93% of the respondents had a driver's license or permit and 7% came to the DMV to apply for one.

- The vast majority of the respondents (91%) had English as their primary language, with 2% Spanish and 7% for other languages as shown in Table 25.

- The survey respondents were 60% men and 40% women (shown in Table 26).

- The age distribution (shown in Table 27) indicates young drivers (18 or under) were about 7% of the sample and older drivers (65 or over) were about 9%.

- Table 28 shows the distribution of the number of hours driven by the respondents each week. About 53% of the respondents drove 10 hours or less each week. Six percent of the respondents drove 40 hours or more each week, probably representing commercial/professional drivers.

Given that the responses are open-ended, two raters evaluated each response and classified them as one of the following:

1. Correct: The respondent comprehended the intended message completely.

2. Partially correct: The respondent partially comprehended the intended message.

3. Incorrect: The respondent misunderstood the sign or indicated that its meaning was unknown or unclear.

4. Critical confusion: The respondent interpreted the sign to have the opposite of its intended meaning, or as authorizing a prohibited action. For example, if a respondent thought that a sign was guiding drivers into the work activity area, this would be a critical confusion.

The two classifications were compared for each of the 57 responses and reconciled between the two raters.

Results of the Stage 3 survey are tabulated in Table 29.

Table 29. Summary of responses to Stage 3 open-ended questions

Sign	Response	Response Example	Percent of Responses
Upward Drop Arrow with White Border 	Correct	"Two lane goes down to one lane w/ right lane continuing"	67%
	Partially Correct	"Lane ending"	28%
	Incorrect	"Road gets narrow"	5%
	Critical Confusion	None identified	0%
G12a with Quebec Style Arrows and Red Trapezoid 	Correct	"Three lanes narrow to two (same direction). Middle lane merges to the right lane; middle lane becomes closed."	37%
	Partially Correct	"A median or obstacle is in the middle lane"	28%
	Incorrect	"Keep straight/slight right"	35%
	Critical Confusion	None identified	0%

Overall, 95% of the responses to the Upward Drop Arrow were correct or partially correct, and the remaining 5% were generally relatively benign misinterpretations such as "road gets narrow"

and "…an acceleration [lane] on my left ends." For the G12a sign with Red Trapezoid, 65% of respondents gave a correct or partially correct response. Respondents who indicated that they did not understand the sign were scored as incorrect answers.

4. DRIVING SIMULATOR STUDY

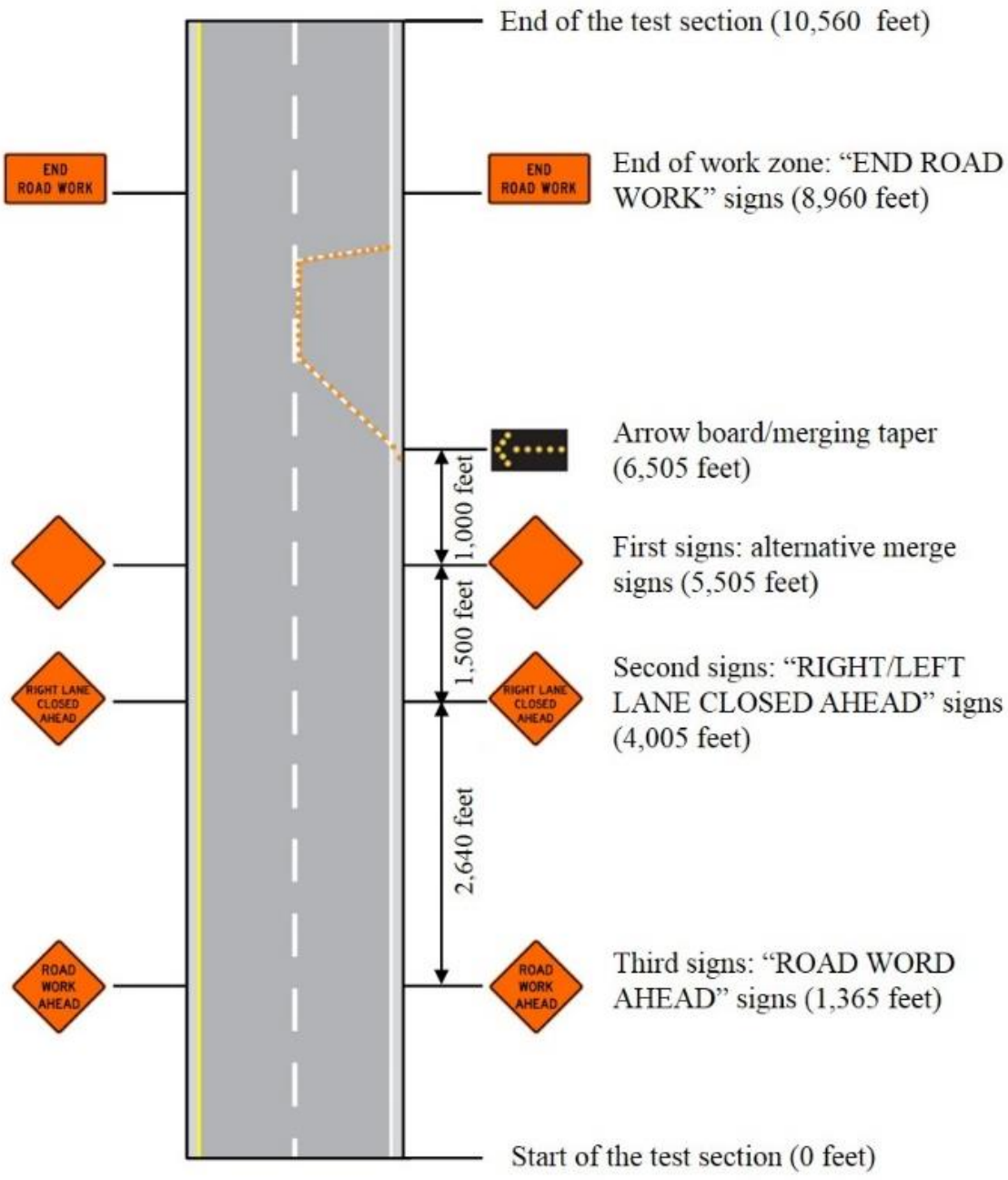
4.1. Design of Experiments

This task used the University of Missouri's ZouSim driving simulator to evaluate alternative work zone signing. ZouSim driving simulator is a fixed base driving simulator with a Toyota Corolla cabin (Figure 23).

Figure 23. ZouSim driving simulator

A triple LED monitor setup was used; this configuration provides a high level of clarity and brightness to reduce the probability of simulator sickness. The field of view for the driver was 184 degrees horizontal and 64 degrees vertical at a height of 5.5 feet. The active instrumentation in the vehicle includes a force-feedback steering wheel, brake and acceleration pedals, turn signals, and engine vibration generator.

The test section of the road simulated a long-term work zone on a divided two-lane highway, as shown in Figure 23. Each test section was 10,560 feet long, which included a 7,595-foot work zone. The work zone started at WORK ZONE AHEAD signs (1,365 feet from the beginning of the test section) and ended at WORK ZONE END signs (8,960 feet). All spacings followed the relevant MUTCD typical application drawing (Figure 24). The speed limit on the highway approaching the work zone was 65 mph and the reduced speed limit in the work zone was 55 mph.



*The "first sign" is the sign in a three-sign series that is closed to the temporary traffic control (TTC) zone; the "third sign" is the sign that is furthest upstream from the TTC zone

Figure 24. Test merge sign traffic control plan on a divided highway

As shown in Figure 25, alternative merge signs tested in this stage of the study were: (1) MUTCD W4-2 signs (the incumbent 2003 design, with three dots), (2) MERGE + arrow signs as used by the Iowa, Minnesota and Missouri DOTs (identified in the figures and tables as MoDOT signs) and (3) Quebec Ministry of Transportation type T-100-1 standard signs (Quebec's version of the G12a).

(1) MUTCD sign (W4-2)

(2) Iowa/Minnesota/Missouri (MoDOT) signs

(3) Quebec version of the G12a signs

Figure 25. Sign configurations tested in the simulator

For simplicity, all three designs were tested on diamond-shaped backplates. Each type of sign was tested twice: one was for a right-lane closure and the other was for a left-lane closure. While Figure 25 only shows the left-lane closures, similar set of signs were created for the right-lane closures. The only differences between the test sections were the alternative merge signs (labeled "first signs" in Figure 24). Each participant was asked to drive through six work zone segments: a combination of three signs and two closure configurations (left and right lane closed).

The test sequence for the six work zones followed a pre-established rule that a left lane closure was followed by a right lane closure and vice versa. The purpose of this rule was to force the participant to change lanes at least once at the approach to each successive work zone, so that the distance between the lane closure sign array and the lane change location could be observed for all six signage combinations (left and right closures for three sign face designs). Six different sign presentation sequences were generated as shown in Table 30. The participants were randomly assigned to a sequence.

Table 30. Sign presentation sequence for driving simulator experiments

Test Group	#1	#2	#3	#4	#5	#6
1	MUTCD-R	MoDOT-L	Quebec-R	MUTCD-L	MoDOT-R	Quebec-L
2	MUTCD-R	Quebec-L	MoDOT-R	MUTCD-L	Quebec-R	MoDOT-L
3	MoDOT-R	MUTCD-L	Quebec-R	MoDOT-L	MUTCD-R	Quebec-L
4	MoDOT-R	Quebec-L	MUTCD-R	MoDOT-L	Quebec-R	MUTCD-L
5	Quebec-R	MUTCD-L	MoDOT-R	Quebec-L	MUTCD-R	MoDOT-L
6	Quebec-R	MoDOT-L	MUTCD-R	Quebec-L	MoDOT-R	MUTCD-L

4.2. Study Participants

The pertinent IRB review and approval was received prior to beginning driving simulator experiments. Experiments began in September 2016 and concluded in October 2016. In order to be eligible to participate in this study, participants were required to have a United States driver's license. All participants were recruited through university email or word-of-mouth. As compensation for their time, participants who completed the trial runs and the surveys received a $10 gift certificate.

Overall, 27 participants completed the experiment. As shown in Table 31, of these 27 participants, 18 (70%) were male and nine (30%) female. A total of 22 (81%) participants were under 40, with 15 (56%) between the ages of 26 and 40. Of the participants older than 40, two (7%) were aged between 41-55, two (7%) were 56-70, and one (4%) was 71-95. All participants reported that they used a passenger car as their primary vehicle and a large proportion of the participants (85%) described themselves as primarily urban drivers.

Table 31. Participant demographic information

Gender		Age					Residency	
Female	Male	16-25	26-40	41-55	56-70	71-95	Urban	Rural
8 (30%)	19 (70%)	7 (26%)	15 (56%)	2 (7%)	2 (7%)	1 (4%)	23 (88%)	3 (12%)

4.3. Raw Measures from Simulator Experiments

The driving measures proposed to evaluate drivers' reaction to the signage were collected from dynamic data during the simulation and are listed below:

- Subjects' Vehicle Position – Position data were recorded every 1/4 second to track the lane changing behavior for each participant. Trajectories for each participant for all six scenarios were drawn to observe the driver's reactions to the lane reduction signage.

- Vehicle Decelerating Record – Deceleration magnitudes and locations were recorded every

1/4 second. The measure was used to report whether a late merge was conducted before the lane was fully closed.

- Lane Changing Position – The exact location of lane change from one lane to another.

- Vehicle Speed – The vehicle speed recorded every 1/4 second.

- Total Work Zone Travel Time – The travel time of each participant driving through a work zone.

All the driving measures were collected and exported using Python 2.7 programming language.

4.4. Driving Simulator Experiments

Participants were invited to the simulator room at the University of Missouri-Columbia campus to complete the simulator experiment. When they arrived, they were provided bottled water and offered an opportunity for a restroom break. After that, two copies of a consent form (one copy was for the participant) were signed by the participants and a brief introduction to the simulator experiment requirements was provided.

Once the requirements and possible concerns regarding simulator sickness were explained, participants entered the simulator and were asked to fasten their seat belt. Once ready, the participant started a warm-up run. This warm-up run used a segment identical to the four-lane freeway in the experiment except that the work zone was not present. The participant was instructed to adapt to the simulator controls by performing some lane changing maneuvers. After the participants became comfortable accelerating, decelerating and turning, they were instructed to make a full stop to wait for the real experiment to begin.

The experiment provided participants with a continuous 12 miles of driving to test their lane changing behavior when facing different merge signs on a four-lane freeway. They were instructed to start from a rest area, to drive normally as they pass through several work zones, and that the simulator would stop automatically after arriving at the destination. The entire performance for each participant was recorded by Loilo Recorder. The participants were also advised that they could pause the experiment at any time.

After completing the simulated driving task, participants were asked to complete a post-experiment survey and a motion sickness screening questionnaire. A $10 gift card was given to participants upon completion.

4.5. Findings

4.5.1. Travel Time Analysis

The total work zone travel time for each merge sign configuration was processed for all participants. Descriptive statistics for the travel times are shown in Table 32. Analysis of variance (ANOVA) test was conducted to compare travel times across the configurations. The ANOVA results are shown in Table 33.

Table 32. Total travel time in work zones with different signs

Sign Type	Number of Observations	Mean	95% CI (sec.)	Standard Deviation	Range (sec.)	Median (sec.)
MoDOT	52	126.37	122.0-130.8	14.2	88.5-173.5	124.6
MUTCD	52	128.25	123.9-132.6	15.8	103.5-173.5	124.5
Quebec	52	127.69	123.3-132.1	17.1	102.2-171.0	120.2

Table 33. ANOVA results of total travel time

Source of Variation	Sum of Squares	d.f.	Mean Squares	F statistic
Between	59.3	2	29.63	0.12
Error	36833.6	153	240.74	
Total	36892.8	155		

$p = 0.88$

Although the mean of total travel time in the work zone with MoDOT merge signs was the lowest (126.37 seconds), the ANOVA results showed that there was no significant difference ($p = 0.88$) between the total travel times across the merge sign configurations. Thus, the participants maintained comparable average speeds across work zones with different merge signs.

4.5.2. Safety Analysis

Two safety performance measures were analyzed using the dynamic driving measures data collected during the simulator experiment. These were: 1) the location of a vehicle merging into the open lane, and 2) the speed differential between the vehicle's merging speed and the speed entering the work zone.

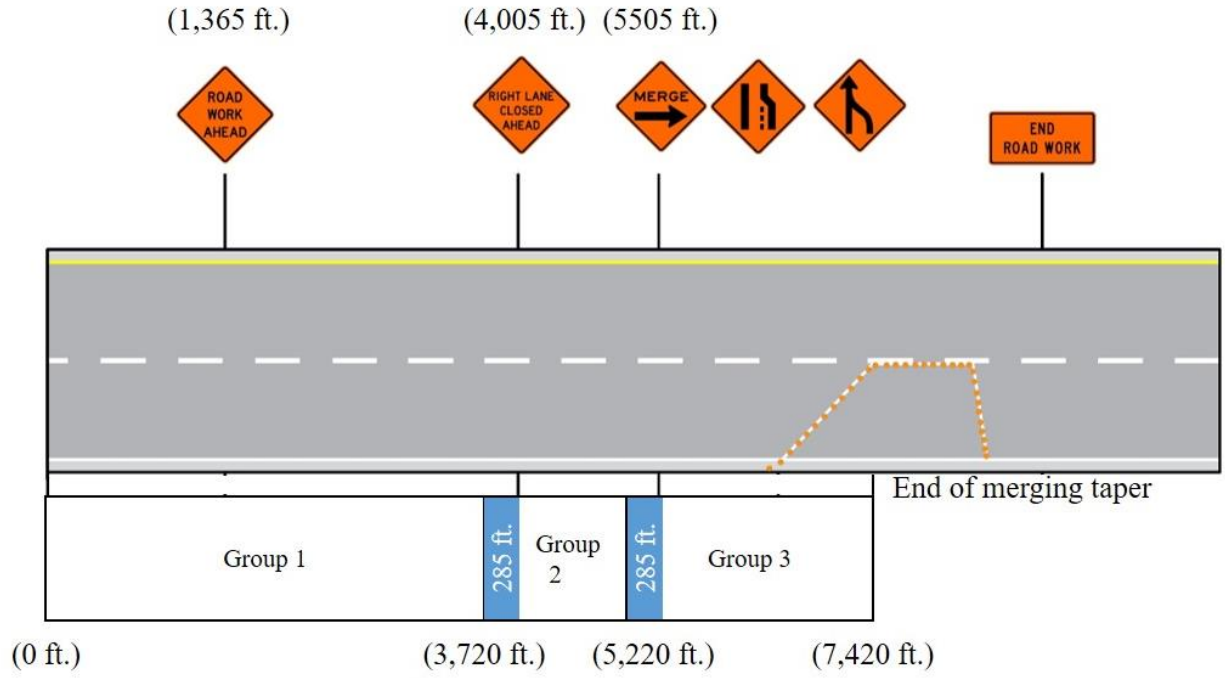
4.5.3. Merge Location Analysis

The results of merging locations were aggregated and classified by the merge sign configuration. Table 34 presents the results for the three merge sign configurations.

Table 34. Merge location in work zones

Sign Type	Number of Observations	Mean (ft)	95% CI (ft)	Standard Deviation	Range (ft)	Median (ft)
MoDOT	52	3059.1	2318-3800	2768	0-6612	4609
MUTCD	52	2852.7	2112-3593	2673	0-7242	4169
Quebec	52	2794.5	2054-3535	2669	0-7132	3018

The number of observations is reported as 52 as each merge sign configuration was driven two times by each participant (once with left lane closure and once with right lane closure) i.e. 26 times 2. The mean values of merge location varied from 2794.5 feet to 3059.1 feet measured from the start of the work zone segment. This indicates that some drivers merged into the open lane before seeing the sign of RIGHT/LEFT LANE CLOSED AHEAD placed at 4,005 feet from the start of work zone segment. Such samples needed to be excluded from analysis as the merge locations were not affected by the merge sign configuration (as the drivers did not encounter the merge sign). To exclude them, the merge locations were reclassified into three groups as illustrated in Figure 26.



*Blue area: 285-foot minimal recommended stopping sight distance to signs

Figure 26. Three locations for merge area analysis

The length of each group was determined by the location of signs and stopping sight distance. As a vehicle is travelling at the work zone reduced speed limit of 55 mph, a sight distance of 285 feet was determined *(1)*. Group 1 started from the beginning of the test section (0 feet) to 285 feet upstream of the second signs (3,720 feet); Group 2 began from 3,720 feet and ended 285 feet

upstream of the first signs (5,220 feet); and Group 3 began from 5,220 feet and ended at the end of taper (7,420 feet).

Table 35 shows the merge locations in the three groups.

Table 35. Merge locations in the three groups

	Group 1		Group 2		Group 3	
Sign Type	**No.**	**%**	**No.**	**%**	**No.**	**%**
MoDOT	24	46.2%	8	15.4%	20	38.5%
MUTCD	26	50.0%	12	23.1%	14	26.9%
Quebec	27	51.9%	12	23.1%	13	25.0%
Total	77	49.4%	32	20.5%	47	30.1%

Total samples 156 (26 participants×3 types×2 times)

For Group 1, there were 77 (49.4%) lane changes observed. These lane changes happened before drivers saw the second signs. Most of them were in the left-lane closed work zones. This was reasonable behavior as drivers tend to stay in the right lane during normal conditions. For Group 2, 20.5% of participants changed lanes after noticing the second signs of RIGHT/LEFT LANE CLOSED AHEAD signs in the work zone. For Group 3, 30.1 % of participants changed lanes after noticing the merge signs ("first signs"). The effectiveness of the merge sign configuration can be estimated by analyzing this portion of the samples.

Table 36 displays the descriptive statistics of the merge locations in Group 3.

Table 36. Descriptive statistics of merge location in Group 3

Sign Type	Number of Observations	Mean (ft)	95% CI (ft)	Standard Deviation	Range (ft)	Median (ft)
MoDOT	20	5,852.7	5,629–6,076	365	5,300–6,612	5,813
MUTCD	14	5,924.9	5,658–6,192	632	5,276–7,242	5,737
Quebec	13	6,013.5	5,737–6,290	505	5,332–7,132	5,843

The statistics include the mean and median of locations, standard deviation and 95% confidence interval. The mean merge location with MoDOT signs was the farthest from the work zone taper (or nearest to the start of work zone). In terms of safety, an early merge location is more desirable as it can reduce the likelihood of sudden or dangerous merging maneuvers approaching the lane closure area. An ANOVA analysis for the merge locations with the three different signs was conducted. As shown in Table 37, the ANOVA results revealed that the differences between the merge locations across the three sign configurations were not statistically significant at the 95% confidence level (p-value of 0.66).

Table 37. ANOVA results of merge locations in Group 3

Source of Variation	Sum of Squares	d.f.	Mean Squares	F
Between	2.0457E+05	2	1.0228E+05	0.4167
Error	1.0799E+07	44	2.4544E+05	
Total	1.1004E+07	46		

p = 0.66

The merge location data in Group 3 was also translated into open lane occupancy. "Open lane occupancy" is defined as the proportion of total traffic in the open lane at a given location (ANSI 2007). Figure 27 shows the open lane occupancies at different locations for three different merge sign configurations.

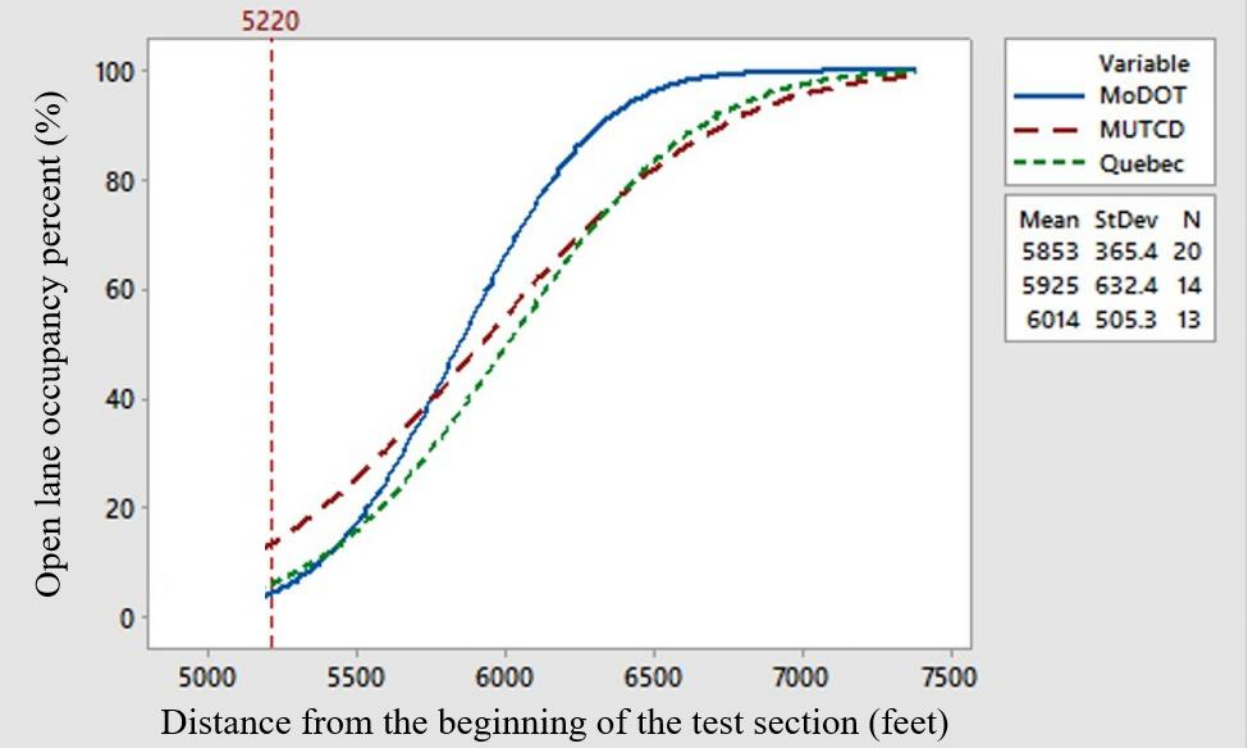


Figure 27. Open lane occupancies in Group 3

The MoDOT sign (in blue) has a steeper slope in the range of 5,750 feet to 6,250 feet and the smallest standard deviation compared to the other signs. This indicates that the driver response to MoDOT signs was more consistent than their response to the other two signs. In addition, the MUTCD (in dashed red) and Quebec (in dashed green) sign configurations showed a high number of subjects performing a late merge after 6,400 ft.

4.5.4. Speed Differentials

The speed differential values, merging speed minus the work zone entrance speed (i.e. at the Road Work Ahead sign), were compared for the three sign configurations. Table 38 shows the mean and standard deviation (S.D.) of the speeds at the work zone entrance, at merge location, and the speed differentials. Only those merges that were influenced by the merge sign (i.e., Group 3 data) were utilized in generating the statistics shown in Table 38.

Table 38. Descriptive statistics of vehicle speeds in Group 3

	At Work Zone Entrance (1,365 ft)		When Merging into the Open Lane		Speed Differential	
Sign Type	**Mean (mph)**	**S. D. (mph)**	**Mean (mph)**	**S. D. (mph)**	**Mean (mph)**	**S. D. (mph)**
MoDOT	60.65	5.74	50.40	8.03	-10.25	7.93
MUTCD	59.64	6.51	46.86	9.25	-12.79	9.07
Quebec	58.54	7.20	54.69	6.14	3.85	8.81

When the vehicles traveled through work zones with different merge signs, the average speeds were not significantly different (60.65 mph for MoDOT sign, 59.64 mph for MUTCD sign and 58.54 mph for Quebec sign, p-value of 0.65). However, the ANOVA test of speed differential revealed (Table 39) that the MUTCD sign produced a significantly higher speed reduction value compared with other two signs (-12.79 mph differential as reported in Table 38). As the means of merge location with MUTCD sign (5,924.9 ft) and Quebec sign (6,013.5 ft) were very close, the bigger speed reduction value indicated more late or hasty merging maneuvers in the work zones with the MUTCD sign.

Table 39. ANOVA results of speed differential in Group 3

Source of Variation	**Sum of Squares**	**d.f.**	**Mean Squares**	**F**
Between	574.6	2	287.3	3.956
Error	3196	44	72.63	
Total	3770	46		

$p = 0.026$

4.6.Post-Experiment Survey Results

A post-experiment survey and a motion sickness screening questionnaire were used to assess drivers' general impressions of the signage and comfort level with the simulator. These subjective measures complemented the previously discussed objective measures extracted from the simulator experiments.

4.6.1. Work Zone Signage Post-Experiment Survey

The survey was designed to assess participants' perspectives of the merge signs they encountered in the simulator after they finished driving. The survey comprised of three components: general aspects of signage, experience with the driving simulator, and a simulator sickness questionnaire. The entire survey as presented to the participant can be found in Appendix A.

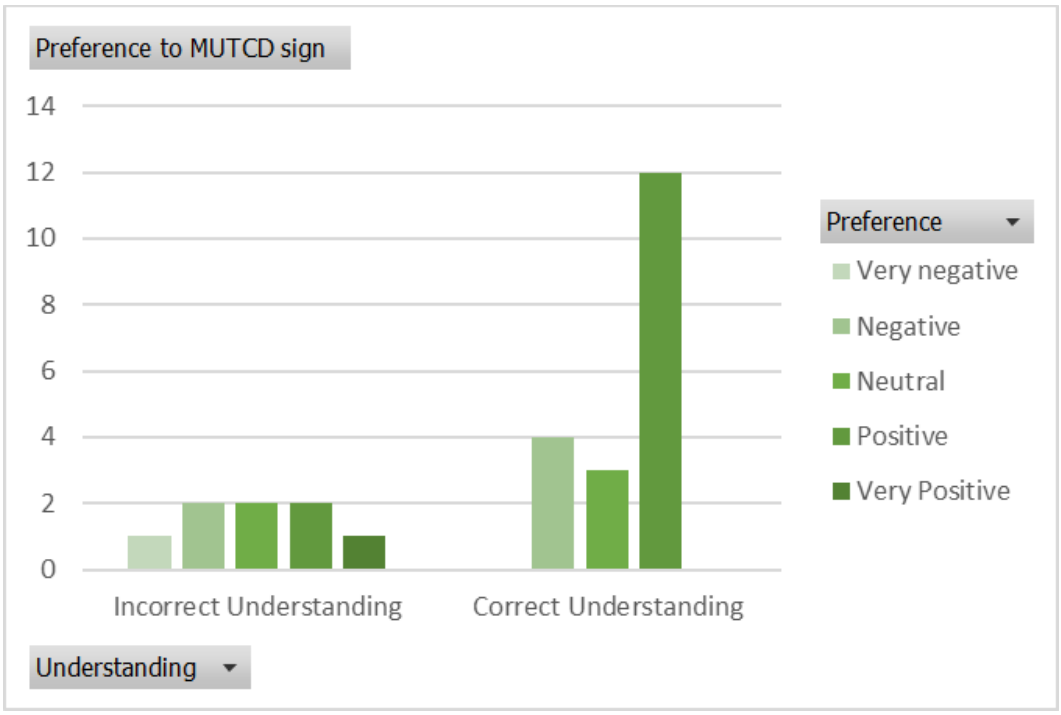
The general aspects of the signage were evaluated using four questions. The first question was intended to determine how participants perceived a sign. The second question asked if they were in favor of (or opposed to) the sign. Questions three and four offered the participant the opportunity to provide reasons for their preference. Table 40 provides a summary of the responses to the second question for the three signs.

Table 40. Positive preferences for each sign

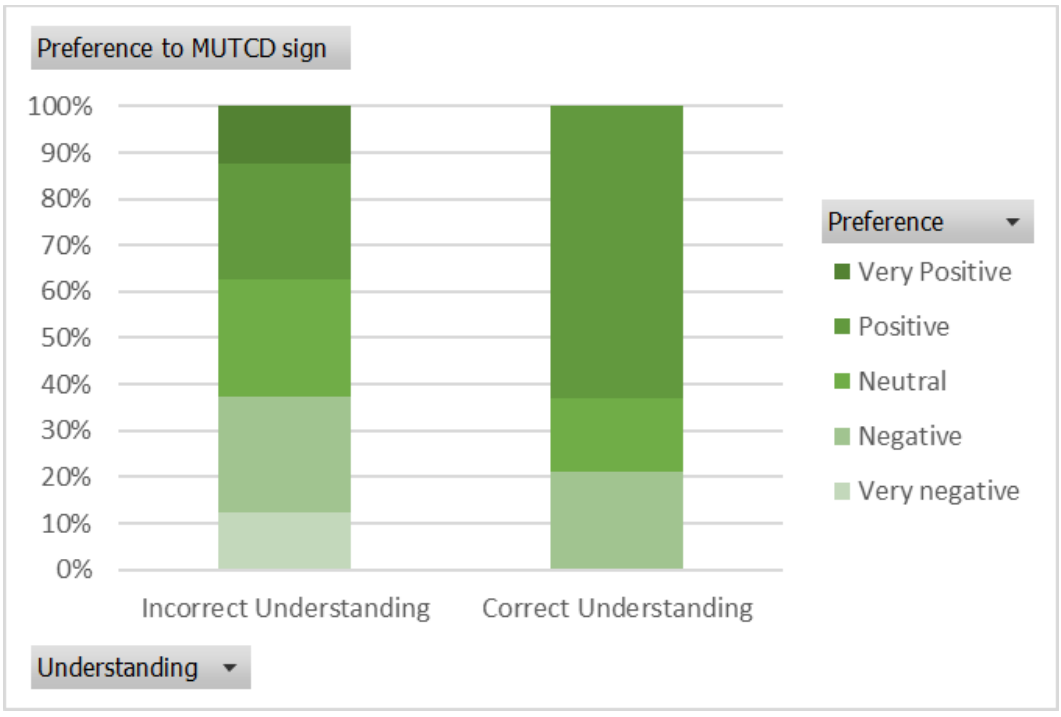
	Very Positive		Positive		Neutral		Negative		Very Negative	
Sign Type	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
MoDOT	7	25.93%	13	48.15%	4	14.81%	3	11.11%	0	0.00%
MUTCD	1	3.70%	14	51.85%	5	18.52%	6	22.22%	1	3.70%
Quebec	8	29.63%	12	44.44%	4	14.81%	2	7.41%	1	3.70%

From Table 40, it is clear that MUTCD was less popular than the MoDOT or Quebec signs. Whereas both MoDOT and Quebec signs had positive preferences totaling 74%, the MUTCD sign totaled 55% positive or very positive responses. Also in response to the first question, 8 of the 27 (30%) participants were either incorrect in identifying the MUTCD sign or said the sign was meaningless. The results were consistent with the results of previous MUTCD W4-2 comprehension tests (Table 1).

For both the MoDOT and Quebec signs, only one participant provided an incorrect or confused answer in response to the first question. However, as shown in Figure 28, if the participant understood the MUTCD sign correctly, he or she had a higher likelihood to have a positive preference ('Positive' and 'Very Positive') for it than if they were to not understand the sign.



(a)



(b)

Figure 28. Relationship between correct perception and sign preference

Figure 28a shows a frequency distribution of the preferences based on whether the participant accurately perceived the correct meaning of the MUTCD sign. Figure 28b shows the same

relationship but provides the preference responses as percentages. A darker green color means a more positive attitude to the MUTCD sign.

Table 41 tabulates the percentage responses for each sign only when it was correctly understood by a participant. The first two rows indicate that the MoDOT (73.08%) and Quebec signs (76.92%) had higher positive preferences than the MUTCD signs (63.16%).

Table 41. Preference for each sign when the sign was correctly understood by a participant

	MoDOT		Quebec		MUTCD	
Preference	**No.**	**%**	**No.**	**%**	**No.**	**%**
Very positive	6	23.08%	8	30.77%	0	0.00%
Positive	13	50.00%	12	46.15%	12	63.16%
Neutral	4	15.38%	4	15.38%	3	15.79%
Negative	3	11.54%	2	7.69%	4	21.05%
Very negative	0	0.00%	0	0.00%	0	0.00%
Total	26	100%	26	100%	19	100%

4.6.2. Experience with the Driving Simulator

Participants also provided feedback on their experience in the simulator. Four questions, Questions 10–13 in the survey, assessed the neutrality and fidelity while the fifth question provided the opportunity to respond with any issues that arose during the simulation. All four questions regarding neutrality and fidelity received over 50% positive responses. Table 42 shows the aggregated responses.

Table 42. Responses to the neutrality and fidelity of the simulator

	Q10 On the highway?		Q11 Drive freely?		Q12 Real to you?		Q13 Natural sense?	
Preference	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
Very Positive	6	22.22	5	18.52	1	3.846	4	14.81
Positive	17	62.96	15	55.56	13	50	10	37.04
Neutral	2	7.407	0	0	11	42.31	7	25.93
Negative	1	3.704	7	25.93	1	3.846	5	18.52
Very Negative	1	3.704	0	0	0	0	1	3.704

Question 14, the open-ended question, received 14 responses. Of these responses, 12 related negatively to the sensitivity of the steering wheel or accelerator.

4.6.3. Motion Sickness Screening Questionnaire

A motion sickness screening questionnaire from Kennedy et al. (1993) was administered to investigate if participants were comfortable after completing the simulator test.

As shown in Table 43, none of the symptoms experienced by the participants had a severe effect.

Table 43. Motion sickness screening results

	General discomfort		Fatigue		Headache		Eye strain	
	No.	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
None	17	65.38	21	80.77	23	88.46	20	76.92
Slight	9	34.62	4	15.38	2	7.69	5	19.23
Moderate	0	0.00	1	3.85	1	3.85	1	3.85
Severe	0	0.00	0	0.00	0	0.00	0	0.00
Sum	26	100	26	100	26	100	26	100
	Difficult focusing		**Salivation increasing**		**Sweating**		**Nausea**	
	No.	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
None	22	84.62	25	96.15	25	96.15	23	88.46
Slight	3	11.54	0	0.00	0	0.00	3	11.54
Moderate	1	3.85	1	3.85	1	3.85	0	0.00
Severe	0	0.00	0	0.00	0	0.00	0	0.00
Sum	26	100	26	100	26	100	26	100
	Difficulty concentrating		**Fullness of the head**		**Blurred vision**		**Dizziness with eyes open**	
	No.	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
None	22	84.62	21	80.77	21	80.77	23	88.46
Slight	4	15.38	5	19.23	5	19.23	3	11.54
Moderate	0	0.00	0	0.00	0	0.00	0	0.00
Severe	0	0.00	0	0.00	0	0.00	0	0.00
Sum	26	100	26	100	26	100	26	100
	Dizziness with eyes closed		**Vertigo**		**Stomach awareness**		**Burping**	
	No.	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
None	25	96.15	25	96.15	25	96.15	26	100.00
Slight	1	3.85	1	3.85	1	3.85	0	0.00
Moderate	0	0.00	0	0.00	0	0.00	0	0.00
Severe	0	0.00	0	0.00	0	0.00	0	0.00
Sum	26	100	26	100	26	100	26	100

	Totals	
	No.	**%**
None	364	87.50%
Slight	46	11.06%
Moderate	6	1.44%
Severe	0	0.00%
Sum	416	100.00%

There were only six (12% of total symptoms experienced) instances of moderate effect and 46 instances (88%) of slight effect. The six instances of moderate symptoms were experienced by four participants. Eleven participants (42%) did not experience any discomfort. The most common symptoms experienced were general discomfort with nine instances (34% of all participants); eye strain, six instances (23%); fatigue, fullness of the head and blurred vision all had five instances (19%); difficulty focusing and difficulty concentrating, four instances (15%); headache, nausea and dizziness, three instances each (12%). Each of the other symptoms experienced less than three instances overall.

4.7. Simulator Study Results

The following conclusions are drawn from the driving simulator experiments:

- The differences of work zone travel time across the three merge sign configurations were not statistically significant. Thus, the participants maintained comparable speeds across work zones with different merge signs.

- On average, participants merged earlier into the open lane when the MoDOT sign was used than the other two signs. However, there was no statistically significant difference among the three signs.

- The work zones with the MoDOT sign resulted in the smallest standard deviation of merge location, indicating that participant responses were consistent.

- The analysis of speed differential between vehicle speeds at merge location and work zone entrance revealed substantial differences among the signs. The high-speed reduction values for the work zones with the MUTCD sign indicated that there were more late or hasty merge maneuvers with this sign.

- The results of the post-simulator survey showed that 29.4% of participants incorrectly perceived the meaning of MUTCD signs, compared to 3.7% for either of the MoDOT or Quebec signs. Those participants that correctly understood the MUTCD sign rated the sign favorably.

5. CONCLUSIONS AND RECOMMENDATIONS

Practitioner experience and formal studies (Table 1) have identified significant concerns about driver comprehension of the MUTCD W4-2 LANE ENDS signage. Internationally, the use of signs similar to the W4-2 design appears to be declining, with many countries favoring one-arrow-per-lane designs based on the Vienna Convention G12a or G12b templates. An important example is New Zealand, which has replaced its version of the W4-2 with a G12a based design for all work zones except those on lower-volume (less than 1000 AADT) roads.

In an attempt to improve comprehension, the W4-2 sign face was slightly modified in 2003 by adding three dots representing lane lines (Figure 29a and Figure 29b).

a. W4-2 (1971) b. W4-2 (2003)

Figure 29. Incumbent MUTCD W4-2 LANE ENDS signage

No previous research on the effect of this change was found. The results of opinion research conducted during Stage 2 of this project suggest that drivers think the newer design was only a slight improvement over its predecessor. Therefore, it seems likely that the pre-2003 studies indicating low comprehension of the W4-2 remain relevant to the current situation.

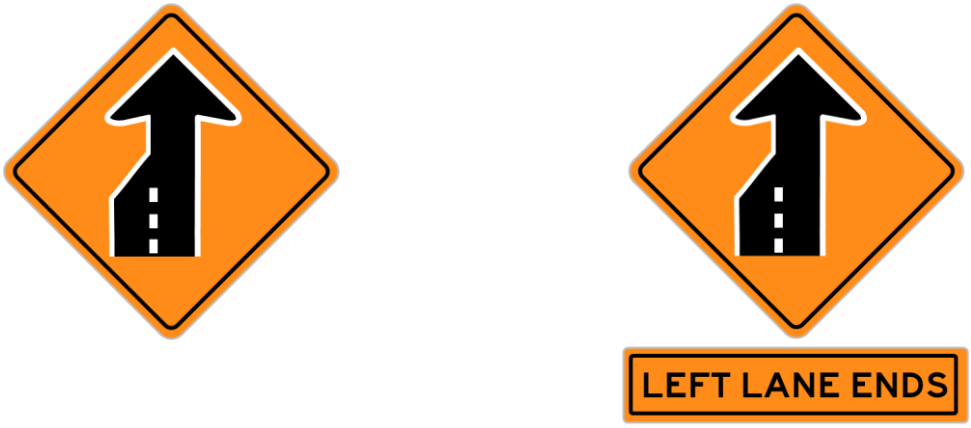
Following the review of U.S and international literature and in consultation with the project's Technical Advisory Committee (TAC), the research team identified potential signs to be included in the driver comprehension survey. The American National Standards Institute (ANSI) standard Z535.3 methodology was used to administer the survey in three stages.

Survey results demonstrate that the Upward Drop Arrow is a promising alternative to the existing W4-2 sign among the two-to-one closure signs. For interior lane closures, the G12a interior lane closure sign with Quebec-style arrows and a red trapezoid was found most promising.

A driving simulator study was conducted after the 3-stage survey to evaluate the W4-2, The Iowa/Minnesota/Missouri style MERGE sign and the G12a interior sign with Quebec-style arrows. In terms of sign comprehension, the W4-2 sign was the least understood of all three signs. The use of the W4-2 sign resulted in more late merge maneuvers than the other two signs.

Based on the survey and simulator results, Upward Drop Arrow with White Border and G12a Based Signs are found to be most promising and are recommended for field evaluations.

The Upward Drop Arrow with White Border (Figure 30a) is a heavily-modified version of the existing W4-2 sign.



a. Upward Drop Arrow as tested in this study

b. Upward Drop Arrow with supplemental text plaque

Figure 30. Upward Drop Arrow with White Border

Figure 31 illustrates the process that was used to derive the proposed sign from the existing W4-2.

Figure 31. Upward Drop Arrow derived from existing W4-2 sign

The existing graphic uses heavy black lines to depict the edges of the road, while the proposed sign face transforms this to a more conventional representation of the roadway with black driving lanes and white edge lines. A large arrow is added to indicate the direction of travel, resulting in a finished graphic that is similar to various MUTCD signs such as the W1 series horizontal alignment signs and the W4-1 and W4-5 entrance ramp merge signs.

Based on the results of the Stage 1 through Stage 3 research conducted as part of this project, the Upward Drop Arrow with White Border appears to be well understood by drivers. Overall, 77% to 95% of drivers appear to comprehend the sign, even without the use of supplemental text plaques or outreach/education efforts.

The Upward Drop Arrow signage graphic is best suited to sites where two upstream lanes merge into one lane at the work zone, which is the most common type of work zone lane closure. Although only the black-on-orange version of the sign was tested in this project, the graphic might also be applicable to other situations where the W4-2 sign is currently used, such as permanent lane reductions (black on yellow) and incident management (black on fluorescent pink), as shown in Figure 32.

a. Permanent Lane Reductions b. Incident Management

Figure 32. Potential extensions of the Upward Drop Arrow concept

Field testing of the Upward Drop Arrow with White Border is recommended. Typically, such testing would be conducted on public roads under an FHWA approved Request to Experiment process. Less commonly, testing could be conducted in a controlled environment such as a test track.

Comparison of the Stage 2 results with simulator testing of the MERGE + arrow sign affirms previous research indicating that comprehension is enhanced when a graphic is combined with explanatory text. Therefore, the use of a supplemental text plaque as illustrated in Figure 30a would be a conservative approach to testing and/or field deployment of the Upward Drop Arrow.

G12a Based Signs. Interior lane closures occur with some regularity on urban streets, predominantly as a result of repair/reconstruction of utilities, mass transit lines, and other underground facilities. Such closures often require extended work durations. Existing MUTCD signage provides only very limited options for communicating such closures to road users. Some agencies respond to this conundrum by closing an extra lane, but this can have severe capacity impacts--especially on signalized arterials where the simultaneous closure of two or more lanes can sometimes result in excessive queueing.

Vienna Convention template G12a establishes a one-arrow-per-lane design for lane reduction signage. G12a based designs performed fairly well in all stages of this project, and were preferred over the existing MUTCD signage by participants in the simulator study. Although the Quebec-style two-to-one lane version of the G12a sign did not perform as well as the Upward Drop Arrow in Stage 2 (and thus was not carried forward into Stage 3), the G12a design is a promising candidate for the difficult problem of communicating interior lane closures. Therefore, a G12a based center lane closure sign (Figure 33a) was evaluated in Stage 3.

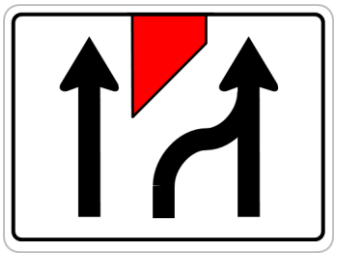
a. As Tested

b. With supplemental text plaque

c. Left Lane Closure

d. Third lane closure

e. Advance warning



f. Regulatory

Figure 33. Variations and extensions of the G12a sign

Without a supplemental text plaque (and with no information about the context of the sign on the survey instrument), the basic G12a center lane closure sign with a red "closure" trapezoid (Figure 33a) was understood by about 65% of respondents in the Stage 3 survey. It is likely that comprehension can be enhanced by adding a supplemental text plaque as illustrated in Figure 33b.

Importantly, the G12a design can be extended to cover a wide range of closures involving multilane roadways, such as those illustrated in Figure 33c and Figure 33d, and to provide advance warning of complex closures as illustrated in Figure 33e. The sign could also be adapted for use in a regulatory context as illustrated in Figure 33f (this example differs from the black-on-orange signs because it indicates that the lane that is ending *must* merge into a specific lane).

Field testing of Americanized versions of G12a signs with supplemental text plaques, as illustrated in Figure 33b, Figure 33c, and Figure 33d, is recommended as a follow-up to this study. Such testing would typically require FHWA approval through the Request to Experiment process. The use of these signs with supplemental text plaques is recommended for an extended time period while drivers become familiar with the design, and due to the relatively complex message they convey.

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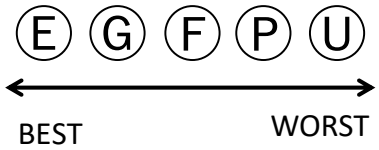
APPENDIX A: DRIVER COMPREHENSION SURVEY: STAGE 1 QUESTIONNAIRE 1

We are looking for better ways to warn drivers about lane closures during road work. On the next few pages you will see some traffic signs meant to show that "**you are approaching an area where a lane is closed and you might need to move over or merge with other traffic."** Some are signs you might have seen before, and some are new ideas.

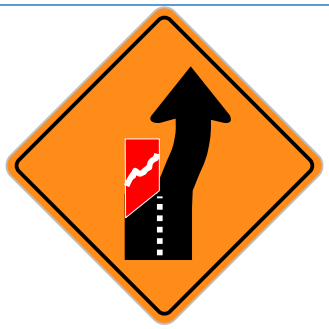
Please tell us how easy it is to understand each sign, using the following scale:

E: Excellent, G: Good, F: Fair, P: Poor, U: Unacceptable

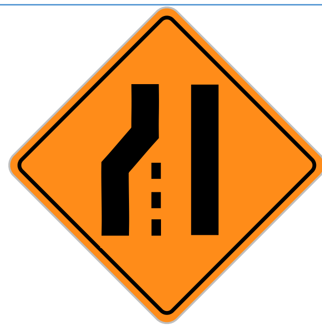
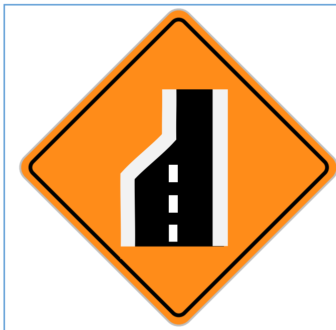
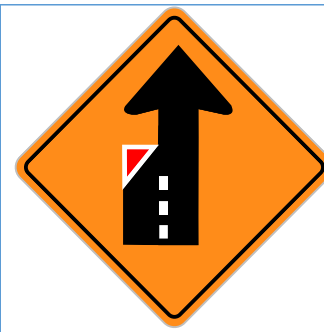


About this project:
This survey is being done by the Traffic Operations & Safety Laboratory at the University of Wisconsin–Madison. The research is sponsored by the Smart Work Zone Deployment Initiative. If you have questions about this project, contact Dr. Madhav Chitturi 608-890-2439.

If you are driving toward a lane closure, which signs best explain what to do?
Please grade each sign: E=Excellent, Good, G=Good, F=Fair, P=Poor, U=Unacceptable.

 E G F P U	 E G F P U	 E G F P U
 E G F P U	 E G F P U	 E G F P U
 E G F P U	 E G F P U	 E G F P U
 E G F P U	 E G F P U	 E G F P U

Sometimes small changes can make a sign easier or harder to understand.
Please grade each sign: E=Excellent, Good, G=Good, F=Fair, P=Poor, U=Unacceptable.

			
Ⓔ Ⓖ Ⓕ Ⓟ Ⓤ	Ⓔ Ⓖ Ⓕ Ⓟ Ⓤ	Ⓔ Ⓖ Ⓕ Ⓟ Ⓤ	Ⓔ Ⓖ Ⓕ Ⓟ Ⓤ
			
Ⓔ Ⓖ Ⓕ Ⓟ Ⓤ	Ⓔ Ⓖ Ⓕ Ⓟ Ⓤ	Ⓔ Ⓖ Ⓕ Ⓟ Ⓤ	Ⓔ Ⓖ Ⓕ Ⓟ Ⓤ
			
Ⓔ Ⓖ Ⓕ Ⓟ Ⓤ	Ⓔ Ⓖ Ⓕ Ⓟ Ⓤ	Ⓔ Ⓖ Ⓕ Ⓟ Ⓤ	Ⓔ Ⓖ Ⓕ Ⓟ Ⓤ
			
Ⓔ Ⓖ Ⓕ Ⓟ Ⓤ	Ⓔ Ⓖ Ⓕ Ⓟ Ⓤ	Ⓔ Ⓖ Ⓕ Ⓟ Ⓤ	Ⓔ Ⓖ Ⓕ Ⓟ Ⓤ

About You…

Do you have a driver license or permit?

- ○ Yes
- ○ Came to the DMV today to apply for license or permit
- ○ No

What is your primary language?

- ○ English
- ○ Spanish
- ○ Hmong
- ○ Other (please specify)

_____

Please indicate your gender in the box below or choose from the list:

- ○ Man
- ○ Woman

Age

- ○ 13 or Younger
- ○ 14-16
- ○ 17-18
- ○ 19-24
- ○ 25-34
- ○ 35-44
- ○ 45-54
- ○ 55-64
- ○ 65-74
- ○ 75-84
- ○ 85 or Older

Approximately how many hours do you drive each week?

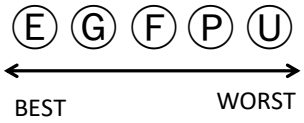
- ○ Less than 5
- ○ 6 to 10
- ○ 11 to 15
- ○ 16 to 20
- ○ 21 to 25
- ○ 26 to 30
- ○ 31 to 35
- ○ 40 or more

Thank you for your participation!

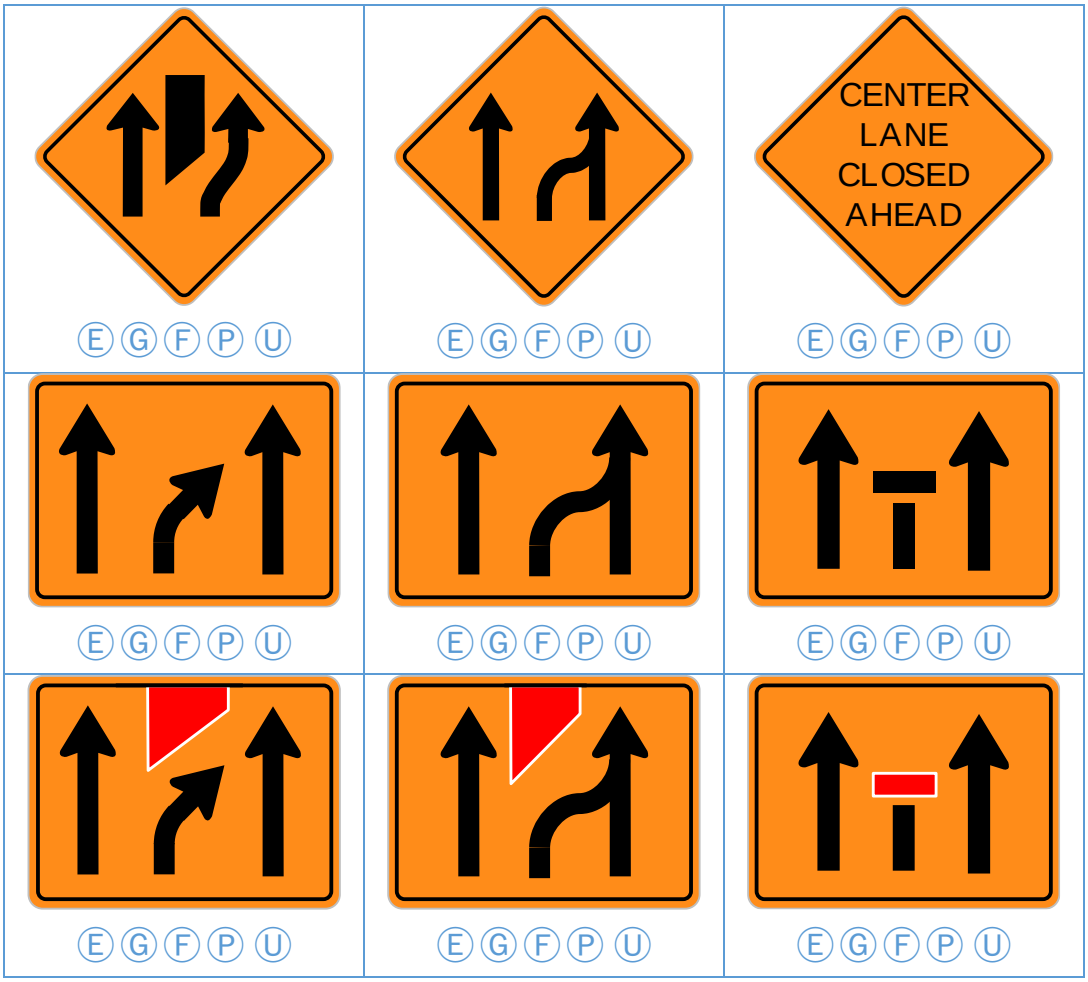
APPENDIX B: DRIVER COMPREHENSION SURVEY: STAGE 1 QUESTIONNAIRE 2

It is often necessary to close lanes to repair highways, streets, or underground utilities. Some roads have three lanes in each direction. When work the *middle* lane is required, some agencies close two lanes (left and center, or right and center), but that leaves only one lane open which can cause traffic congestion. As a result, we are looking for better traffic signs to identify middle lane closures. The drawings below show some signs meant to show that "**you are approaching an area where the center lane is closed and you might need to move over or merge with other traffic.**" *Please tell us how easy it is to understand each sign, using the following scale:*

E: Excellent, G: Good, F: Fair, P: Poor, U: Unacceptable



If you are driving toward a center lane closure, which signs best explain what to do?



About You…

Do you have a driver license or permit?

- ○ Yes
- ○ Came to the DMV today to apply for license or permit
- ○ No

What is your primary language?

- ○ English
- ○ Spanish
- ○ Hmong
- ○ Other (please specify)

_____

Age

- ○ 13 or Younger
- ○ 14-16
- ○ 17-18
- ○ 19-24
- ○ 25-34
- ○ 35-44
- ○ 45-54
- ○ 55-64
- ○ 65-74
- ○ 75-84
- ○ 85 or Older

Approximately how many hours do you drive each week?

- ○ Less than 5
- ○ 6 to 10
- ○ 11 to 15
- ○ 16 to 20
- ○ 21 to 25
- ○ 26 to 30
- ○ 31 to 35
- ○ 40 or more

Please indicate your gender in the box below or choose from the list:

- ○ Man
- ○ Woman

Thank you for your participation!

About this project:
This survey is being done by the Traffic Operations & Safety Laboratory at the University of Wisconsin–Madison. The research is sponsored by the Smart Work Zone Deployment Initiative. If you have questions about this project, contact Dr. Madhav Chitturi 608-890-2439.

APPENDIX C: DRIVER COMPREHENSION SURVEY: STAGE 2 QUESTIONNAIRE 1

This survey is being done by the Traffic Operations & Safety Laboratory at the University of Wisconsin–Madison. We are studying driver comprehension of different existing and proposed traffic signs. **For each sign, please PICK ONE OPTION to indicate what that sign means to you.** The research is sponsored by the Smart Work Zone Deployment Initiative. If you have questions about this project, contact Dr. Madhav Chitturi 608-890-2439.

What does this sign mean to you? (Please pick one) ❍ Left lane ends ❍ Keep to the right of obstruction ❍ Divided highway ends ❍ Keep to the left of obstruction	

What does this sign mean to you? (Please pick one) ❍ Merging traffic entering from the left ❍ Narrow lanes ahead – reduce speed ❍ Left lane ending – traffic in right lane must yield to left lane ❍ Left lane ending – traffic in left lane should merge into right lane	

Please Continue on Page 2…..

What does this sign mean to you? (Please pick one)

- ❍ Pedestrians only, no vehicle traffic
- ❍ Pedestrians ahead warning sign
- ❍ Pedestrian crossing ahead
- ❍ School advance warning, you are entering a school zone

What does this sign mean to you? (Please pick one)

- ❍ Workers in left shoulder
- ❍ Snow removal/plow in left lane
- ❍ Left lane ending – traffic in left lane should merge into right lane
- ❍ Intermittent work activity in left lane

What does this sign mean to you? (Please pick one)

- ❍ Wrong way, do not enter
- ❍ Forward traffic is not allowed
- ❍ A warning to stop right here
- ❍ Warning that a stop sign is ahead

Please Continue on Page 3…..

What does this sign mean to you? (Please Pick one) ❍ Lanes narrow ahead ❍ Left lane ending – traffic in right lane must yield to left lane ❍ Left lane ending – traffic in left lane should merge into right lane ❍ Median between opposing traffic will end	

About You…

Do you have a driver license or permit?
- ○ Yes
- ○ Came to the DMV today to apply for license or permit
- ○ No

What is your primary language?
- ○ English
- ○ Spanish
- ○ Hmong
- ○ Other (please specify)

_____

Age
- ○ 13 or Younger
- ○ 14-16
- ○ 17-18
- ○ 19-24
- ○ 25-34
- ○ 35-44
- ○ 45-54
- ○ 55-64
- ○ 65-74
- ○ 75-84
- ○ 85 or Older

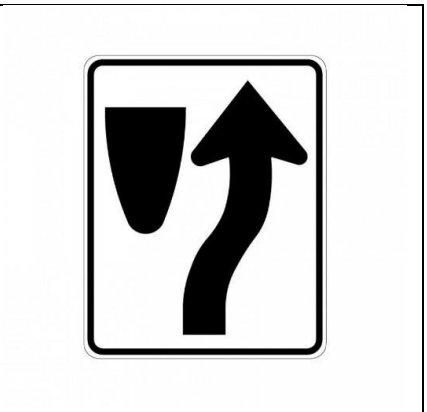
Approximately how many hours do you drive each week?
- ○ 5 or Less
- ○ 6 to 10
- ○ 11 to 15
- ○ 16 to 20
- ○ 21 to 25
- ○ 26 to 30
- ○ 31 to 35
- ○ 36 to 40
- ○ 40 or more

Which best describes your gender:
- ○ Man
- ○ Woman

Thank you for your participation!

APPENDIX D: DRIVER COMPREHENSION SURVEY: STAGE 2 QUESTIONNAIRE 2

This survey is being done by the Traffic Operations & Safety Laboratory at the University of Wisconsin–Madison. We are studying driver comprehension of different existing and proposed traffic signs. **For each sign, please PICK ONE OPTION to indicate what that sign means to you.** The research is sponsored by the Smart Work Zone Deployment Initiative. If you have questions about this project, contact Dr. Madhav Chitturi 608-890-2439.

What does this sign mean to you? (Please pick one) ❍ Left lane ends ❍ Keep to the right of obstruction ❍ Divided highway ends ❍ Keep to the left of obstruction	

What does this sign mean to you? (Please pick one) ❍ Lanes narrow ahead ❍ Left lane ending – traffic in right lane must yield to left lane ❍ Left lane ending – traffic in left lane should merge into right lane ❍ Lanes shift ahead	

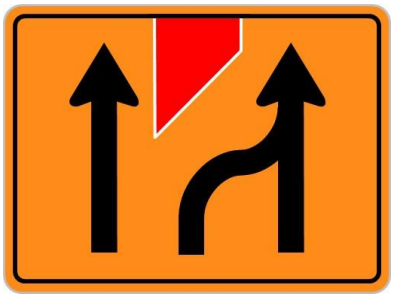
Please Continue on Page 2…..

What does this sign mean to you? (Please pick one) ❍ Pedestrians only, no vehicle traffic ❍ Pedestrians ahead warning sign ❍ Pedestrian crossing ahead ❍ School advance warning, you are entering a school zone	

What does this sign mean to you? (Please pick one) ❍ Road ahead makes a sharp right turn ❍ Detour ahead, turn right ❍ Lane ends, merge to the right ❍ Lanes shift to the right	

What does this sign mean to you? (Please pick one) ❍ Wrong way, do not enter ❍ Forward traffic is not allowed ❍ A warning to stop right here ❍ Warning that a stop sign is ahead	

Please Continue on Page 3…..

What does this sign mean to you? (Please pick one) ❍ Avoid obstacle on the road ❍ Center lane ends, merge to the left lane ❍ Traffic in center lane should stop ❍ Center lane ends, merge to the right lane	

About You…

Do you have a driver license or permit?
- ○ Yes
- ○ Came to the DMV today to apply for license or permit
- ○ No

What is your primary language?
- ○ English
- ○ Spanish
- ○ Hmong
- ○ Other (please specify)

_____

Age
- ○ 13 or Younger
- ○ 14-16
- ○ 17-18
- ○ 19-24
- ○ 25-34
- ○ 35-44
- ○ 45-54
- ○ 55-64
- ○ 65-74
- ○ 75-84
- ○ 85 or Older

Approximately how many hours do you drive each week?
- ○ 5 or Less
- ○ 6 to 10
- ○ 11 to 15
- ○ 16 to 20
- ○ 21 to 25
- ○ 26 to 30
- ○ 31 to 35
- ○ 36 to 40
- ○ 40 or more

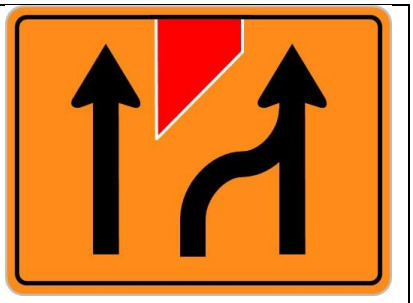
Which best describes your gender:
- ○ Man
- ○ Woman

Thank you for your participation!

APPENDIX E: DRIVER COMPREHENSION SURVEY: STAGE 3

This survey is being done by the Traffic Operations & Safety Laboratory at the University of Wisconsin–Madison. We are studying driver comprehension of proposed traffic signs. **For each sign, please describe in your own words what that sign means to you.** The research is sponsored by the Smart Work Zone Deployment Initiative. If you have questions about this project, contact Dr. Madhav Chitturi 608-890-2439.

What does this sign mean to you? _____ _____ _____	

What does this sign mean to you? _____ _____ _____	

About You…

Do you have a driver license or permit?
- ○ Yes
- ○ Came to the DMV today to apply for license or permit
- ○ No

What is your primary language?
- ○ English
- ○ Spanish
- ○ Hmong
- ○ Other (please specify)

_____

Which best describes your gender:
- ○ Man
- ○ Woman

Age
- ○ 13 or Younger
- ○ 14-16
- ○ 17-18
- ○ 19-24
- ○ 25-34
- ○ 35-44
- ○ 45-54
- ○ 55-64
- ○ 65-74
- ○ 75-84
- ○ 85 or Older

Approximately how many hours do you drive each week?
- ○ 5 or Less
- ○ 6 to 10
- ○ 11 to 15
- ○ 16 to 20
- ○ 21 to 25
- ○ 26 to 30
- ○ 31 to 35
- ○ 36 to 40
- ○ 40 or more

Thank you for your participation!

APPENDIX F: WORK ZONE SIGNAGE POST-TEST SURVEY

No _____ Date _____

Work Zone Signage Post-Test Survey

Proper signage is critical for the safe movement of traffic through work zones. Please provide us with your perspective on the following signage alternatives.

1. **What is the meaning of Sign 1?**

SIGN 1

a. Narrow lanes ahead – reduce speed.
b. Left lane ending – traffic in left lane should merge into right lane.
c. The sign makes no sense.

2. **How do you feel about Sign 1?**

[ ] Very positive [ ] Positive [ ] Neutral [ ] Negative [ ] Very negative

3. **Please check any reasons for your feeling on Sign 1.**

[] Clear/not confusing [] Message is effective [] Encourages safety [] Encourages efficient driving
[] Other _____

4. **What is the meaning of Sign 2?**

SIGN 2

a. Narrow lanes ahead – reduce speed.
b. Left lane ending – traffic in right lane should yield to left lane.
c. Left lane ending – traffic in left lane should merge into right lane.
d. The sign makes no sense.

5. **How do you feel about Sign 2?**

[ ] Very positive [ ] Positive [ ] Neutral [ ] Negative [ ] Very negative

6. **Please check any reasons for your feeling on Sign 2.**

[] Clear/not confusing [] Message is effective [] Encourages safety [] Encourages efficient driving
[] Other _____

7. **What is the meaning of Sign 3?**

SIGN 3

a. Narrow lanes ahead – reduce speed.
b. Left lane ending – traffic in right lane should yield to left lane.
c. Left lane ending – traffic in left lane should merge into right lane.
d. The sign makes no sense.

8. **How do you feel about Sign 3?**

[ ] Very positive [ ] Positive [ ] Neutral [ ] Negative [ ] Very negative

9. **Please check any reasons for your feeling on Sign 3.**

[] Clear/not confusing [] Message is effective [] Encourages safety [] Encourages efficient driving
[] Other _____

The next five questions are about your experience with driving the simulator.

10. I felt like I was actually there on the highway.

[ ] Strongly agree [ ] Agree [ ] Neutral [ ] Disagree [ ] Strongly disagree

11. I felt like I could drive around freely.

[ ] Strongly agree [ ] Agree [ ] Neutral [ ] Disagree [ ] Strongly disagree

12. To what extent did the driving experience seem real to you?

[ ] Highly realistic [ ] Realistic [ ] Neutral [ ] Unrealistic [ ] Highly unrealistic

13. My sense of movement on the highway seemed very natural.

[ ] Strongly agree [ ] Agree [ ] Neutral [ ] Disagree [ ] Strongly disagree

14. Did any issues arise while you were using the simulator?

[ ] Yes [ ] No

If yes, please explain the issue(s) that you experienced:

_____

_____

Please answer the demographic questions below.

15. Age range

[ ] 16-25 [ ] 26-40 [ ] 41-55 [ ] 56-70 [ ] 71-95

16. Gender

[ ] Male[ ] Female

17. My Residency

[ ] Urban [ ] Rural

18. My Regular Vehicle Type

[ ] Passenger Car [ ] Vehicle towing trailer [ ] Delivery/Moving Truck

[ ] Tractor trailer truck [ ] Bus

Please contact Dr. Praveen Edara (edarap@missouri.edu) for additional comments, concerns or information on this survey. Thank you for completing this survey! We greatly appreciate your time!

APPENDIX G: SIMULATOR DISCOMFORT QUESTIONNAIRE

No _____ Date _____

Simulator Discomfort Questionnaire

Instructions: Circle how much each symptom below is affecting you right now.

1. General discomfort	None	Slight	Moderate	Severe
2. Fatigue	None	Slight	Moderate	Severe
3. Headache	None	Slight	Moderate	Severe
4. Eye strain	None	Slight	Moderate	Severe
5. Difficult focusing	None	Slight	Moderate	Severe
6. Salivation increasing	None	Slight	Moderate	Severe
7. Sweating	None	Slight	Moderate	Severe
8. Nausea	None	Slight	Moderate	Severe
9. Difficulty concentrating	None	Slight	Moderate	Severe
10. Fullness of the Head	None	Slight	Moderate	Severe
11. Blurred vision	None	Slight	Moderate	Severe
12. Dizziness with eyes open	None	Slight	Moderate	Severe
13. Dizziness with eye closed	None	Slight	Moderate	Severe
14. *Vertigo	None	Slight	Moderate	Severe
15. **Stomach awareness	None	Slight	Moderate	Severe
16. Burping	None	Slight	Moderate	Severe

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

Source: Kennedy et al. 1993

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