TECHBRIEF

Evaluation of Additional Alternatives of, and Arrow Sizes for, Overhead Arrow-Per-Lane Guide Signs

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INTRODUCTION

Complex interchanges with multiple exit lanes, including an option lane, can be confusing to navigate. Roadway signs provide navigational, lane assignment, and roadway geometry information that explain complex interchanges to drivers. Well-designed roadway signs help drivers make timely and accurate decisions. Signs that are confusing or that violate driver expectations may lead to unnecessary lane changes, sudden lane changes, and mistakes that may compromise roadway system efficiency and driver safety.

The *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) (FHWA 2009) requires overhead arrow-per-lane (OAPL) guide signs or diagrammatic guide signs at multilane exit interchanges and splits with an option lane on freeways and expressways. Diagrammatic signs show a graphic view of the roadway with lane assignment for the through and exiting lanes (figure 1). OAPL guide signs use an upward pointing or curved arrow for each lane centered over the lane to indicate lane assignment for the through and exiting movements (figure 2). Both sign types also include text and route shields to indicate destinations accessible by each lane.

Figure 1. Illustration. Diagrammatic guide sign for a multilane exit with an option lane (MUTCD figure 2E-7) (FHWA 2009).

Source: FHWA.

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Figure 2. Illustration. OAPL guide sign for a multilane exit with an option lane (MUTCD figure 2E-3) (FHWA 2009).

Source: FHWA.

Previous research suggested that overhead signs with specific lane assignment information better support driver decisions and lane choice at interchanges than diagrammatic guide signs. The use of an individual arrow for each lane on guide signs is more effective in communicating lane assignment information than a graphic view of the entire roadway lane assignment displayed in one arrow (Brackett et al. 1992). Furthermore, drivers readily understand the relationship between specific lanes and corresponding destinations displayed by overhead signs with specific lane assignment information (Richard and Lichty 2013). Golembiewski and Katz (2008) found that drivers made significantly more correct lane choices and comprehended a sign configuration showing one arrow per lane compared to diagrammatic signs. Fitzpatrick et al. (2013) also found that OAPL signs were superior for helping drivers make correct lane choices compared with diagrammatic signs.

OAPL signs support quick and accurate lane choice decisions but are generally more expensive to construct than other advance guide signs. OAPL guide signs are larger than conventional diagrammatic signs and require costly support structures. The signs are wider to accommodate showing an arrow over each travel lane and taller to accommodate the required 66-inch through arrows. OAPL guide signs cannot make use of existing cantilevered mounting structures and require more substantial structures that span the entire roadway. Furthermore, even an existing support structure that spans the entire width of the roadway may need to be replaced to support an OAPL if it cannot support wind loads striking the larger sign.

Also, OAPL signs that comply with the current MUTCD provisions may be impractical in some applications. Minor and intermediate interchanges can be closely spaced in urban areas. OAPL signs occupy most of the space on a sign structure and may leave insufficient space for providing information about downstream interchanges (National Committee on Uniform Traffic Control Devices 2012a).

The provisions in the current version of the MUTCD (FHWA 2009) require that the OAPL sign include an arrow for each lane on the sign over the center of the lane, resulting in a large sign. Some agencies have proposed using a smaller, modified versions of OAPL guide signs as an alternative to OAPL guide signs. The smaller signs are less expensive and, in many cases, may be installed on existing cantilevered mounting structures. However, like their full-sized counterpart, these modified OAPLs, hereafter referred to as partial-width OAPL, use upward-pointing and curved arrows to communicate lane assignment and direction of travel. Though similar, partial-width OAPL signs display curved arrows only for the exit lanes. They show a bifurcated arrow for the option lane that serves both the through and exit movement, eliminating the straight arrows for only the through-route lanes.

As there is not a standard for a partial-width OAPL, the design characteristics (e.g., arrow size) and placement of signs are inconsistent. The MUTCD requires standardized arrows that are a height of 66 inches (FHWA 2009). However, some agencies have changed the arrow size and proportions on partial-width signs. Research has been limited on the effect smaller arrow sizes has on driver comprehension and effectiveness.

Fisher et al. (2004) used a driving simulator to evaluate six guide sign alternatives for two-lane freeway exits with an option lane in a simulated tunnel environment.

Results found that every driver correctly exited when shown an OAPL sign, and slightly more than one-third made an unnecessary lane change. A partial-width version of the sign with down arrows over each exit lane and a pull-through sign for the through lanes was effective at reducing the likelihood that drivers missed the exit. However, 50 percent of the drivers unnecessarily changed lanes from the option lane to the auxiliary lane when exiting, and 44 percent of drivers unnecessarily changed lanes from the option lane to the through lane when continuing the mainline. The authors acknowledged that the unnecessary lane changes may be attributed to the partial-width sign's arrows not explicitly indicating that the option lane continued into the mainline.

The Traffic Control Device Pooled Fund Study (TCD PFS) was formed to conduct research to provide traffic control device solutions to State department of transportations (DOTs). Under a previous study funded by the TCD PFS, Dagnall, Katz, and Bertola (2013) examined five different signing series that present information about an upcoming, multilane exit interchange with an option lane. This study included the following signs:

- Partial-width (referred to as *truncated* in the referenced study) OAPL guide sign with only option lane and exit-only lane information, i.e., no through movement information.
- MUTCD-compliant OAPL guide sign (MUTCD figure 2E-3).
- Partial-width OAPL guide sign with a pull-through sign (MUTCD figure E6-2a).
- MUTCD-compliant sign at intermediate and minor interchanges with multilane exits that include an option lane, when OAPL or diagrammatic guide signs are not warranted (MUTCD figure 2E-11).
- Conventional arrow guide sign that conveys the presence of option lanes.

Participants watched videos simulating freeway travel and were prompted to indicate the lanes they could and could not use to reach their destination (both the exiting destination and through destination). The full-sized OAPL guide sign and partial-width OAPL with a pull-through sign were the most effective at helping participants correctly indicate the lanes that would reach the destination. However, using partial-width OAPL may not be feasible in all cases. As with full-sized OAPL, partial-width OAPLs require overhead structures on which to install the signs.

Consistent sign design and practices are critical for supporting driver expectations and accurate, timely navigation decisions (Jackson et al. 2018). Additional research on partial-width OAPL guide sign design and arrow sizing must occur to inform practitioners and support consideration for future adoption in the MUTCD. This study, conducted under the TCD PFS, evaluated the effectiveness of various partial-width OAPL guide sign designs and arrow sizes for communicating the destination and direction that each lane serves for drivers approaching single and multiple closely spaced exits at minor and intermediate interchanges.

OBJECTIVES

This research explored alternative partial-width overhead signs and arrow sizing, including arrow height, proportionality, and form proportionate to the size of the sign to quantify driver comprehension and understanding on different roadway geometries. The objectives of this study were to understand driver's:

- Comprehension of partial-width OAPL guide sign configuration alternatives.
- Understanding of the roadway and exit lane geometry associated with partial-width OAPL guide sign alternatives, especially for too closely spaced exits.
- Comprehension and understanding of the sign alternatives and roadway geometry changes based on different locations of the sign legend and "EXIT ONLY" message.
- Lane changing behavior for each signing alternative.
- Comprehension of the arrow sizes.
- Understanding of time required for drivers to comprehend each arrow size and signing alternative.
- Preferences among the alternatives of arrow sizes and signs.

VARIABLES

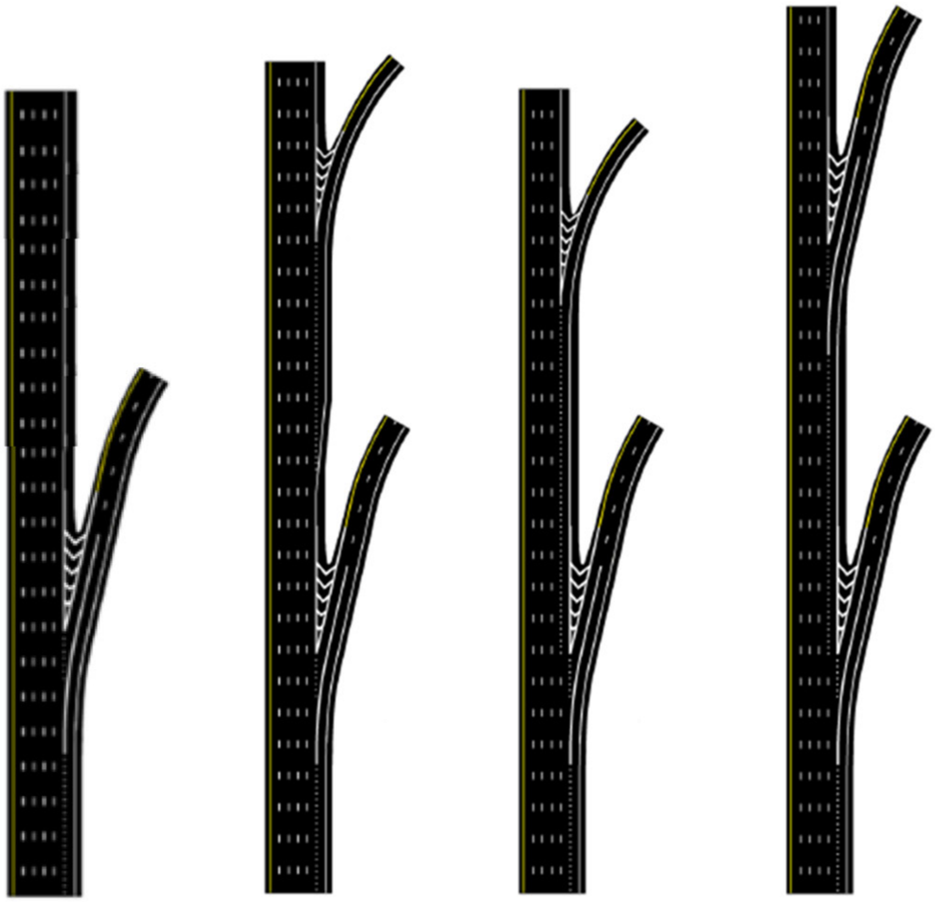
This research included three multilevel, independent variables.

Roadway Geometry

The research team evaluated the following four roadway geometries. Figure 3 shows schematic diagrams of the roadway geometries. The MUTCD has a provision for OAPL guide signs on single-exit roadway (roadway geometry 1). The other three roadway geometries have two, closely spaced (0.5 mi from the first exit) exits.

- Roadway geometry 1: Dual-lane exit with option lane and without a downstream exit.
- Roadway geometry 2: Dual-lane exit with option lane followed by downstream exit with auxiliary lane.
- Roadway geometry 3: Dual-lane exit with option lane followed by downstream exit with dropped lane.
- Roadway geometry 4: Dual-lane exit with option lane followed by downstream dual-lane exit with dropped and option lane.

Figure 3. Illustration. Roadway geometries 1, 2, 3, and 4 (from left to right).



Source: FHWA.

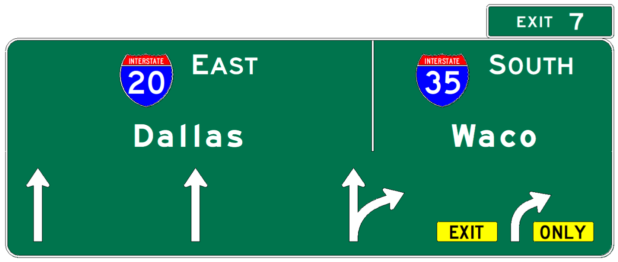
Sign Configurations

The study compared five sign configurations. The signs had a letter height of 20 inches, 20-inch uppercase and 15-inch lowercase loop height, and 48-inch route marker. The five sign configurations had slightly different exit information between single-exit and dual-exit roadway geometries.

Sign Configuration 1: OAPL Guide Sign for a Multilane Exit with an Option Lane

Sign configuration 1 is the compliant guide sign required for use at major interchanges and recommended for minor and intermediate interchanges that have multilane exits with an option lane (FHWA 2009). This sign does not address closely spaced interchanges. Figure 4 shows sign configuration 1 for the single-exit roadway geometry.

Figure 4. Illustration. Sign configuration 1: OAPL guide sign for a multilane exit with an option lane.



Source: FHWA.

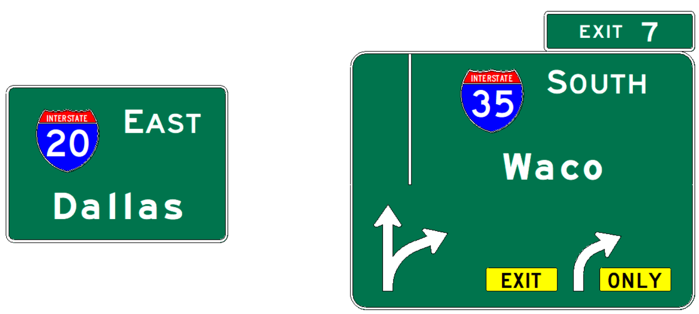
Sign Configuration 2: Partial-Width OAPL with Pull-Through

Sign configuration 2 is the partial-width OAPL guide sign with a separate pull-through sign (Dagnall, Katz, and Bertola 2013). Figure 5 shows sign configuration 2 for the single-exit roadway geometry.

Sign Configuration 3: Partial-Width OAPL without Vertical Separator or Pull Through Sign

Sign configuration 3 used the same partial-width OAPL guide sign design as sign configuration 2 minus the vertical separator for the through route. In addition, this configuration does not include the secondary pull-through sign. See figure 6 for sign configuration 3 for the single-exit roadway geometry.

Figure 5. Illustration. Sign configuration 2: Partial-width OAPL with pull-through.



Source: FHWA.

Figure 6. Illustration. Sign configuration 3: Partial-width OAPL without vertical separator or pull-through sign.

Source: FHWA.

Sign Configuration 4: Partial-Width OAPL with Vertical Separator and without Pull-Through Sign

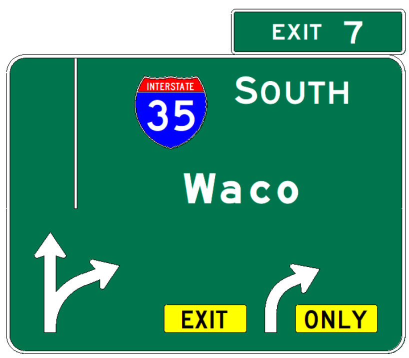
Sign configuration 4 used the same partial-width OAPL guide sign design as sign configuration 2. However, this configuration did not include the secondary pull-through sign. Figure 7 shows sign configuration 4 for the single-exit roadway geometry.

Sign Configuration 5: Partial-Width OAPL without Vertical Separator with Pull Through

Sign configuration 5 used the same partial-width OAPL guide sign design as configuration 2. However, this configuration did not include the vertical separator on the partial-width sign. Figure 8 shows sign configuration 5 for the single-exit roadway geometry.

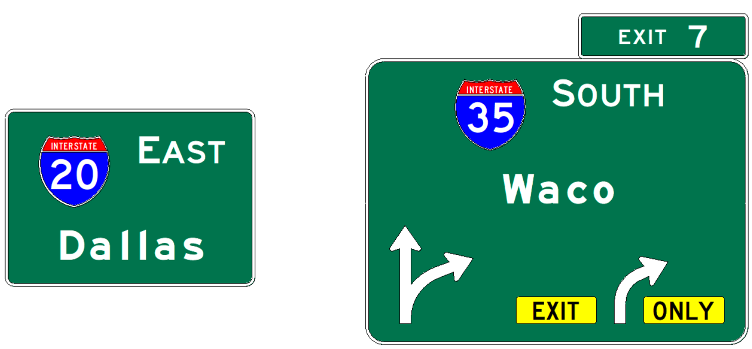
As noted previously in the Introduction section, sign configurations 1–5 were adjusted to provide information about multiple, closely spaced exits for roadway geometry 2–4 (dual exits). Figure 9 shows configurations 1–5 in this order as adapted for a roadway geometry with a closely spaced downstream exit. This set of signs presents the information about the downstream exit and the destination associated with it.

Figure 7. Illustration. Sign configuration 4: Partial-width OAPL with vertical separator and without pull through sign.



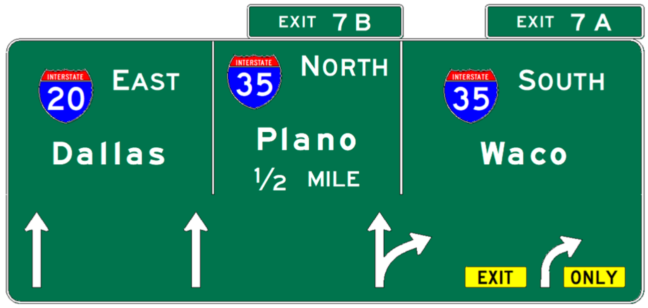
Source: FHWA.

Figure 8. Illustration. Sign configuration 5: Partial-width OAPL without vertical separator.



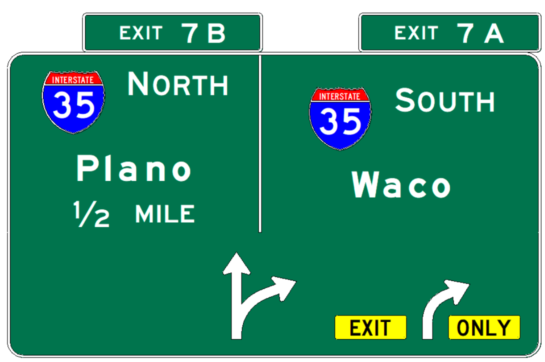
Source: FHWA.

Figure 9. Illustrations. Sign configurations 1–5 when applied to a closely spaced downstream exit (roadway geometries 2–4).

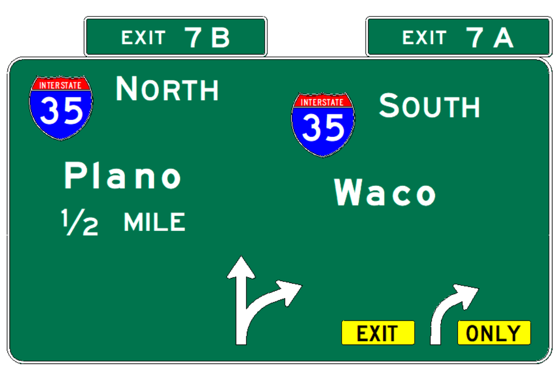


A. Sign Configuration 1.

B. Sign Configuration 2.



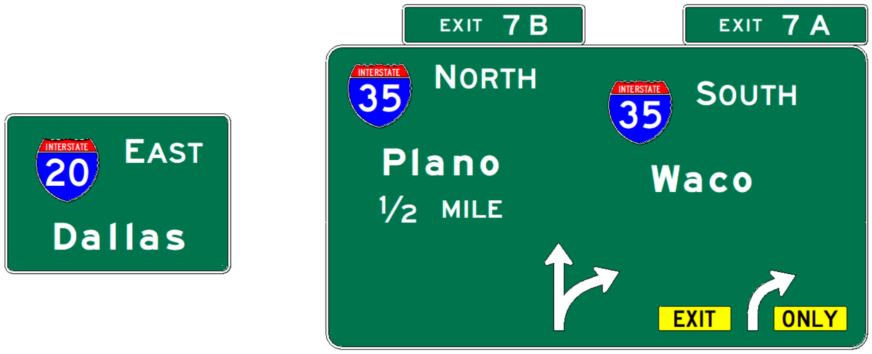
C. Sign Configuration 3



D. Sign Configuration 4.

Source: FHWA.

Figure 9. Illustrations. Sign configurations 1–5 when applied to a closely spaced downstream exit (roadway geometries 2–4). (Continued)



E. Sign Configuration 5.

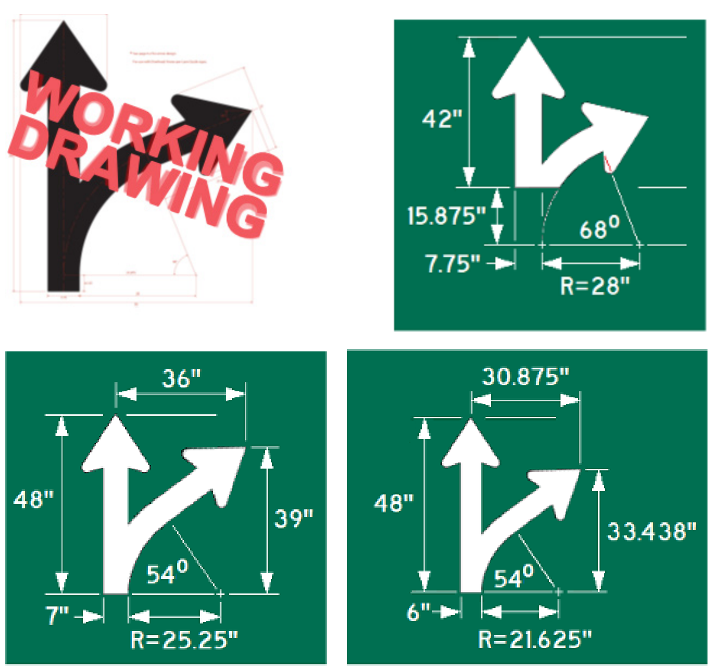
Source: FHWA.

Arrow Designs

The study evaluated several arrow designs (figure 10). The only arrow design and dimensions that comply with the 2009 MUTCD is arrow design 1. All others are not compliant with the MUTCD Researchers repeated sign configurations to include different arrow designs, and they manipulated arrow design as an independent variable between subjects.

- Arrow design 1: 21.625-inch type D directional arrowhead with an 8-inch-wide arrow shaft and height of 66 inches.
- Arrow design 2: 21.625-inch type D directional arrowhead with an 8-inch-wide arrow shaft and height of 42 inches.
- Arrow design 3: 21.625-inch type D directional arrowhead with a 7-inch-wide arrow shaft and height of 48 inches and turn arrow shaft extension rotated to 54 degrees from 68 degrees.
- Arrow design 4: 21.625-inch type D directional arrowhead with a 6-inch-wide arrow shaft and a height of 48 inches and turn arrow shaft extension rotated to 54 degrees from 68 degrees.

Figure 10. Illustration. Arrow designs 1, 2, 3, and 4.



Source: FHWA.

METHODS

The study experiment included two parts to address all research objectives.

Part 1—Arrow Design, Dynamic Visualizations

During the dynamic visualization portion of this experiment, participants watched a 15-s video containing a randomly assigned sign configuration and roadway geometry. The visualization simulated traveling at approximately 55 mph on an 8-lane, divided highway. In each visualization, the point of view was from the second lane from the right, which became the option lane and aligned with the bifurcated arrow on the sign. The study took place at the Turner-Fairbank Highway Research Center Sign Lab. The Sign Lab includes a 60-inch liquid crystal display monitor. The monitor is capable of telecasting from the visualization software. Participants used a keyboard to interact with the visualization displayed on the monitor. Figure 11 shows the experimental set up. Researchers instructed participants to use the space bar of the keyboard to stop the video as soon as they understood the destination information conveyed on the sign. The length of each video was approximately 20 s.

Figure 12 shows the picture that displayed when participants pressed the space bar on the keyboard, terminating the dynamic video. Using the number pad, participants selected a lane—1 to 4.

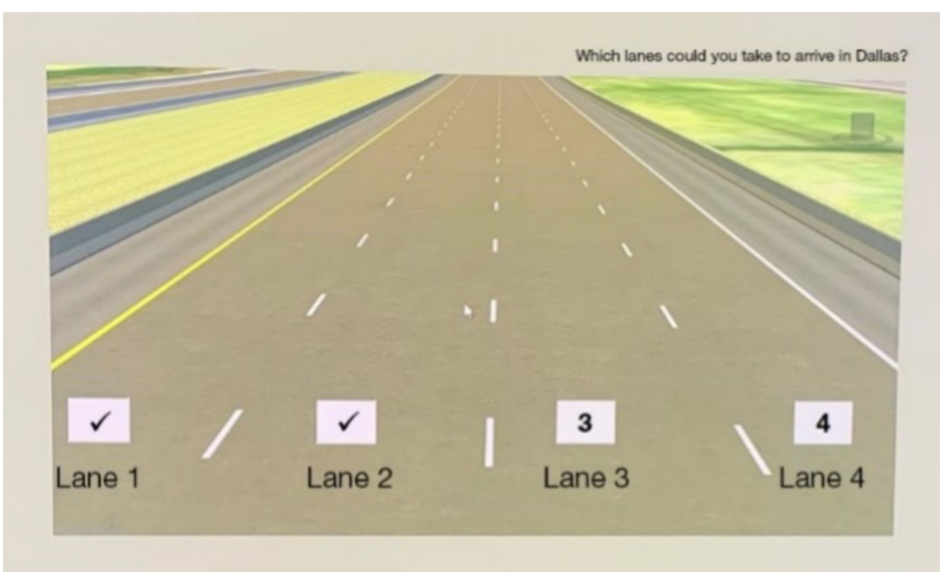
Figure 11. Photo. Experimental set up.

Source: FHWA.

Participants responded to the following questions:

1. If you were traveling to Dallas, what lane(s) could you take?
2. If you were traveling to Waco, what lane(s) could you take?
3. If you were traveling to Plano, what lane(s) could you take?

Figure 12. Screenshot. Lane choice options presented on screen.



Source: FHWA.

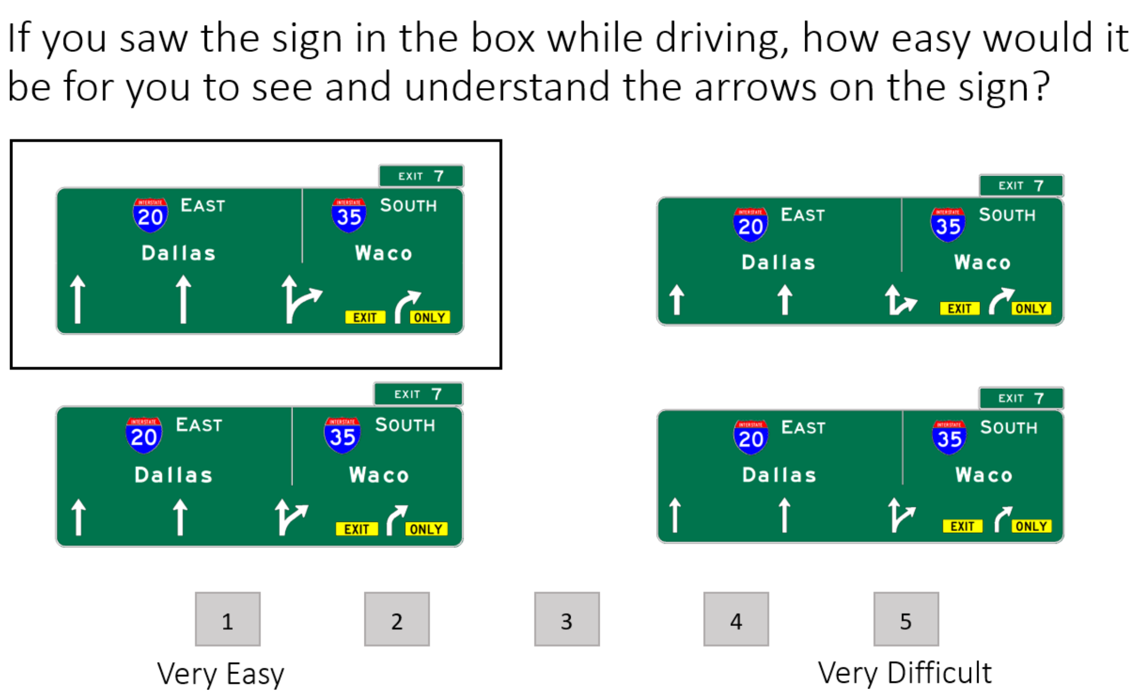
Across all trials, Dallas was the through destination, Waco was the exit destination, and Plano was the downstream exit destination. Therefore, in single-exit roadway geometry trials, question 3 was not asked. After answering the lane choice questions, participants were asked how confident they were in their answers on a scale of 1 to 5, where 1 is not at all confident and 5 is very confident.

For part 1 of the experiment, researchers randomly assigned participants to one of four arrow design groups. Within each arrow design, participants received exposure to all combinations of sign configurations and roadway geometries. The 80 trial configurations can be seen in the appendix of this document. Part 1 included videos showing signs placed 1 mi upstream of the exit gore, a 0.5 mi upstream of the exit gore, and at the exit location. Each participant viewed 60 videos.

Part 2—Questionnaire

As figure 13 shows, the questionnaire design focused on evaluating participant perceptions about the effectiveness of the 5 sign configurations and 4 arrow designs as part of a sign, resulting in 20 total questions. Figure 13 shows all arrow designs for one sign configuration. The question asked was, “If you saw the sign in the box while driving, how easy would it be for you to see and understand the arrows on the sign?” Participants answered the question by choosing an option from 1 to 5.

Figure 13. Screenshot. Arrow design preference.



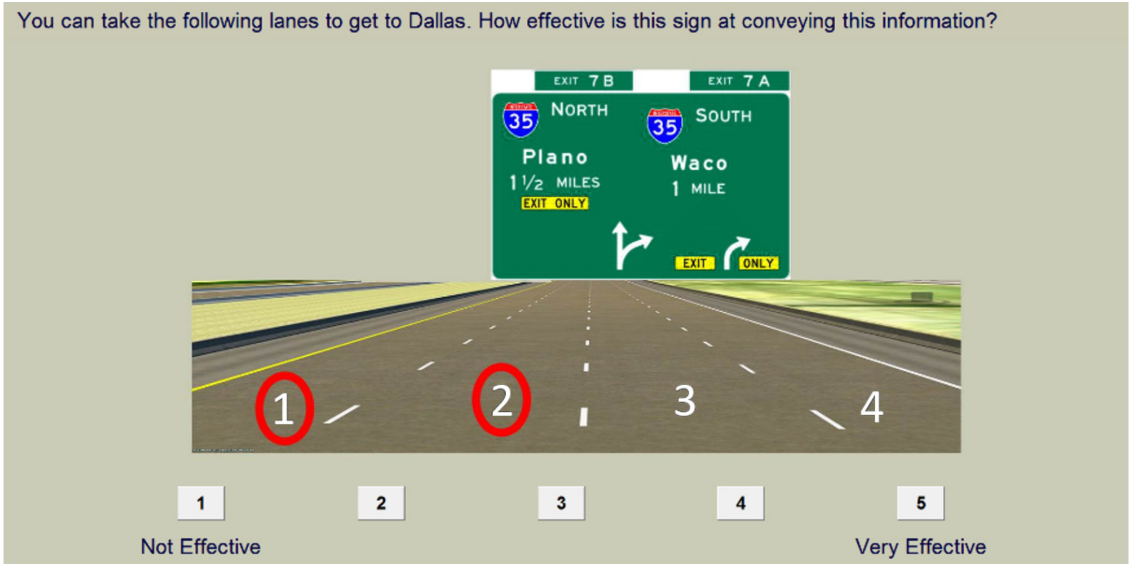
Source: FHWA.

To answer each question on the effectiveness of the sign configurations, participants saw a still image from the videos used in part 1 that displayed the sign of interest over a four-lane road superimposed with letters that labeled each lane of the highway. Red circles were used to identify the specific lane(s) that a driver could take to get to a specified destination. Figure 14 shows an example of a question. Participants selected a number defining how effective they thought each sign was at conveying the specific lane assignment information. Numbers ranged from 1 (not effective) to 5 (very effective). Questions appeared in random order. All the participants encountered the same set of questions for the same set of sign configurations.

Visualization Development

Researchers used several software suites to develop sign stimuli and dynamic visualizations for this study. They used drawing software to develop the signs to guarantee appropriate sign and arrow designs,

Figure 14. Screenshot. Visual aid to rate effectiveness of sign configurations.



Source: FHWA.

spacing, and proportionality. To create the roadway geometry and supplemental animations, the study used three-dimensional modeling and animating tools. Researchers developed 240 unique visualizations across the 4 arrow designs and roadway geometries.

Participants

Data collected for this research came from 112 participants, 56 male and 56 female. Researchers further split the male and female groups by age as young (< 46-yr-old) or older (≥ 46-yr-old) participants. There were 28 younger males and 28 older males in the study. In the female participant group, 28 participants were younger and 28 were older. Binning participants by gender and age was done this way to ensure representation from all age and gender to remove confounding effects of age and gender in the dataset. Most participants were unfamiliar with the locations used in the sign configuration. Similar level of familiarity among participants helps reduce biases. However, most participants were familiar with overhead arrow signs used in this research.

DATA ANALYSIS AND RESULTS

Data from 112 participants were used for the analysis. Response times associated with each sign configuration and confidence in selected answers, sign preference and arrow designs are different types of independent variables used in this study. Researchers manually scored accuracy of lane choices to produce the dataset. They also produced descriptive statistics and data visualizations to identify trends or patterns in the dataset. Applying generalized estimating equations (GEE) to the dataset detected statistically significant differences in participant groups based on dependent variables: response times, lane choice accuracy or response accuracy, confidence in lane choice, confidence in question answers, and preference of signs and arrow designs.

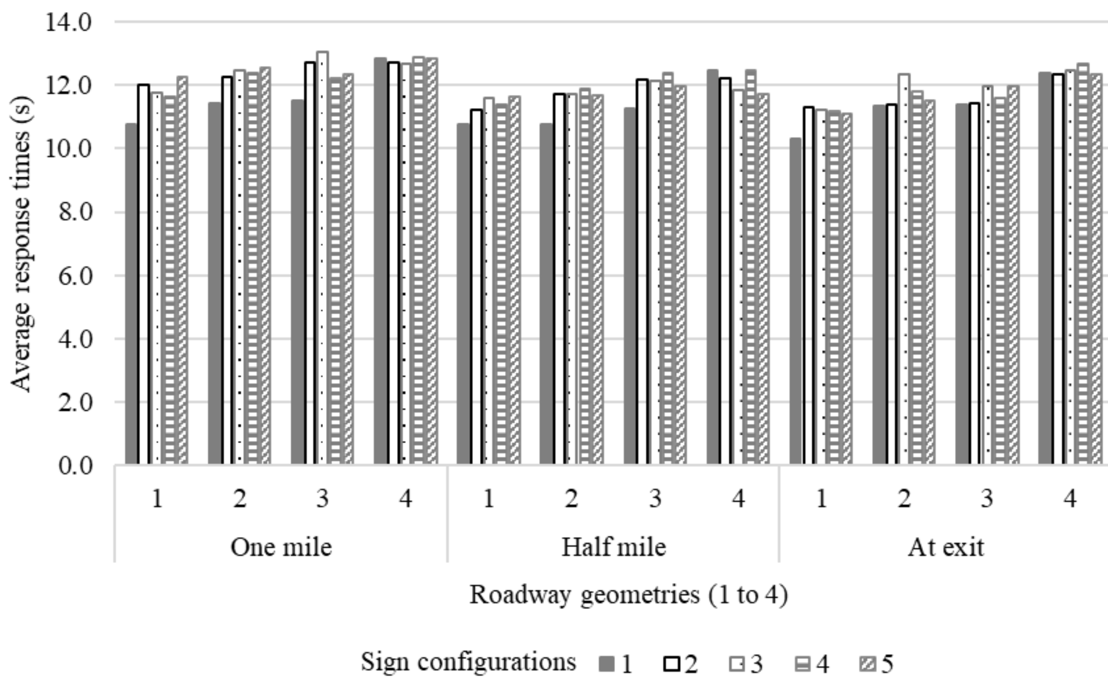
Response Time

Participants saw a video containing a road scenario in which they approached an overhead sign. The simulated approach speed was the equivalent of 55 mph. Researchers instructed participants to use the keyboard to stop the scenario once they comprehended the sign. Response time represented how quickly or slowly a participant comprehended a sign. Response time started at the beginning of the scenario and ended at the time the participant pressed the keyboard space bar to stop the video.

Average Response Time on Different Roadway Geometry

Figure 15 presents participant average response times for all sign configurations on all roadway geometries. For signs 1 mi from the exit location, sign configuration 1 had the shortest average response time of 10.8 s. Sign

Figure 15. Graph. Average response times for different sign configurations on different roadway geometries.



Source: FHWA.

configuration 3 had the longest average response time of 13.1 s on roadway geometry 3. The difference between the shortest and longest response time was 2.3 s among all sign configurations across the roadway geometries.

For the 0.5-mi location, sign configuration 1 had the shortest response times of 10.8 s for roadway geometries 1 and 2. Sign configuration 1 on roadway geometry 4 had the longest average response time of 12.5 s. Sign configuration 4 also had a 12.5-s average response time on roadway geometry 4. The difference between the shortest and longest response times was 1.7 s.

For the 1-mi location, sign configuration 1 relates to the shortest average response time of 10.8-s average response time on roadway geometry 1. The longest average response time of 12.7 s was captured for sign configuration 4 on roadway geometry 4. The difference between the maximum and minimum average response times among sign configurations across roadway geometries was 2.4 s.

Except for roadway geometry 4, figure 15 shows that average response times were shortest for roadway geometries 1 and 2. Roadway geometry 1 is the single-exit configuration. Roadway geometry 2 is a dual-exit configuration with an auxiliary lane. No consistent pattern was observed in average response times for the other four sign configurations.

Sign configuration 1 had shorter response times than other sign configurations on all roadway geometries except roadway geometry 4. There was no consistent pattern observed in average response times for other four sign configurations.

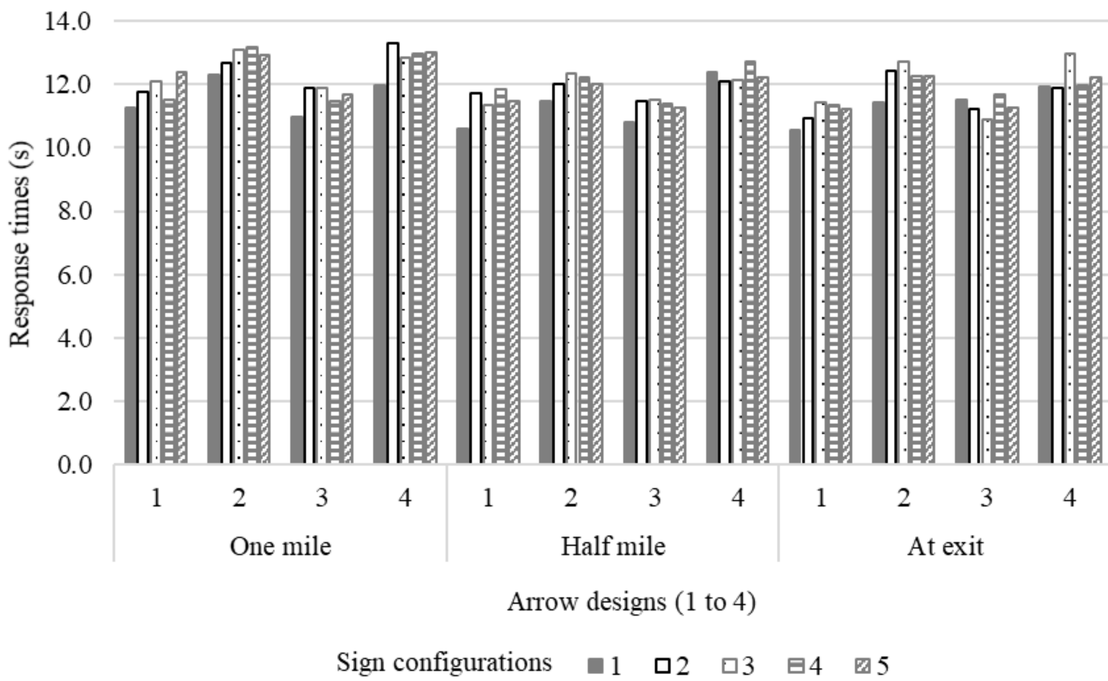
Response Times with Different Arrow Designs

Figure 16 presents average response times associated with different sign configurations and different arrow designs. For signs 1 mi from the exit location, participants had the shortest response time for configuration 1. Participants recorded the longest average response time for sign configuration 5 with arrow design 4. The minimum and maximum response times were 11 and 13.3 s, respectively. The difference was 2.3 s across all arrow designs.

On the 0.5-mi location, sign configuration 1, participant average response time was 10.6 s, the shortest response time with arrow design 1. For sign configuration 4, participant average response time was the longest at 12.7 s with arrow design 4. The difference was 2.1 s.

At the exit location, participants recorded the shortest average response time of 10.6 s for sign configuration 1 with arrow design 1. For sign configuration 4 with arrow design 4, participants had the longest average response time of 13 s. The difference was 2.4 s between the shortest and longest average response times.

Figure 16. Graph. Average response times of different sign configurations over different arrow designs.



Source: FHWA.

Participant average response time for sign configuration 1 with arrow design 1 and arrow design 3 was the shortest. The shortest participant response times was for arrow designs 1 and 3 at all locations across all signs (figure 16). Participants had the longest response time for arrow design 4 for all locations. No other pattern was observed for the other four sign configurations.

Average Response Times for Different Signs

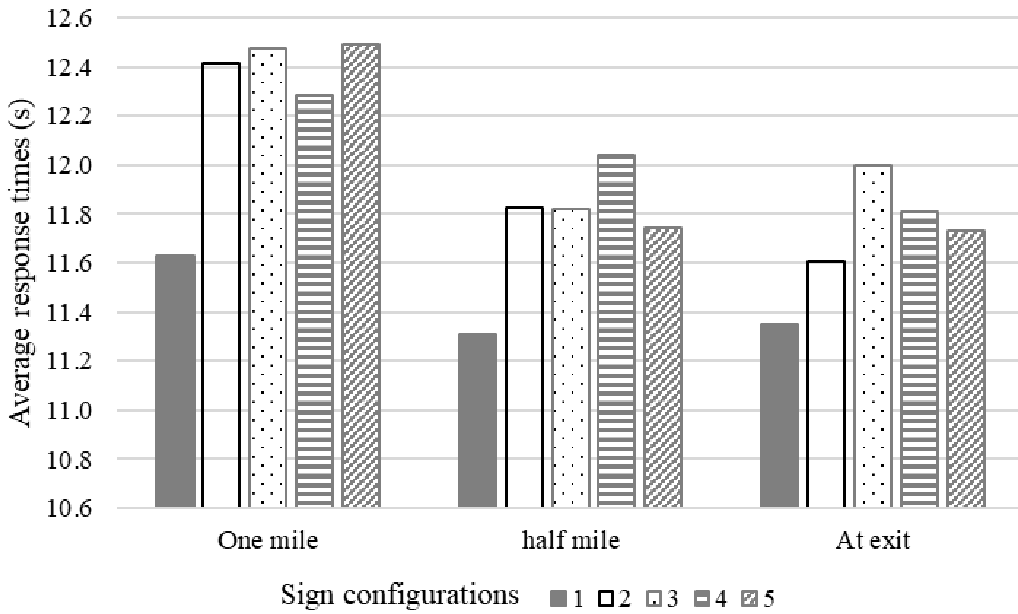
Figure 17 shows average response times corresponding to each sign configuration, composed of all arrow designs and roadway geometries. Associated with the shortest response time at 1-mi, 0.5-mi, and exit locations was sign configuration 1. For the 1-mi location, sign configuration 4 prompted shorter participant responses than the other three sign configurations. The other three configurations prompted similar average response times. Assessment of statistical analysis revealed that for the 1-mi location, arrow designs had no statistically significant impact on participant response times ($p = 0.196$). However, sign configurations ($p < 0.001$), roadway geometries ($p < 0.001$), gender degrees of freedom (df) 1, $p = 0.003$), and age ($p < 0.001$) had significant impacts on participant response times. Interactions between arrow design ($p = 0.039$) and sign configurations, and arrow designs, and roadway geometries ($p = 0.011$) were statistically significant. The three-way interaction between sign configuration, arrow designs, and roadway geometries was also statistically significant ($p = 0.001$).

For the 0.5-mi location, sign configuration 4 had the longest response time. Participant response times were similar for the other three signs. At this sign location, arrow design had no statistical significance ($p = 0.196$) on response times. The impacts of sign configurations ($p = 0.016$), roadway geometries ($p < 0.001$), gender ($p = 0.012$), and age ($p < 0.001$) were statistically significant. The three-way interaction was statistically significant ($p = 0.003$) as well.

Regarding exit location, participant response time was longer for sign configuration 3 than for other signs. Sign configuration 2 had a shorter response time than the other alternate sign configurations. Response times for alternate sign configurations did not show a consistent trend at all locations of the signs. Evaluation showed that the impact of arrow design on response time was not statistically significant. In contrast, the impacts of sign configurations ($p = 0.043$) and roadway geometries ($p < 0.001$) on response times were statistically significant. Interaction between arrow designs and sign configurations also were significant ($p = 0.003$).

Based on the estimates from the GEE model, the main effect (sole effect of an independent variable) of sign configurations and roadway geometry was significant

Figure 17. Graph. Average response times corresponding to each sign configuration.



Source: FHWA.

for all three locations. Table 1 shows the difference in response times relative to sign configuration 1 (full-sized OAPL). Sign configuration 1 relates to the shortest participant response time at all three sign locations. Participant response times for sign configurations 1, 2, and 3 at the 1-mi location were not statistically different. The response times for sign configurations 2 and 3 were 0.9 and 1.18 s, respectively, higher than for sign configuration 1. At the 0.5 mi location, participant response times for sign configurations 1, 3, and 5 were not statistically different from each other. Response times for signs 3 and 5 were 0.8 s higher than for sign configuration 1. Response times for all the signs were statistically different from each other at the exit location. Table 1 shows signs participant response times from lower to higher times.

This study found that the main effect of roadway geometries was statistically significant at a 95 percent confidence level ($p = 0.05$). Single-exit geometry had lower response times than dual-exit geometries for all sign locations. However, impact of interaction between sign configurations and roadway geometry on participant response time was statistically significant. At the 1-mi location, signs 2, 5, and 4 had lower response times than did sign configuration 1 for roadway geometry 4. Participant response times for those signs were, respectively, 1.7 s ($p = 0.021$ s), 2.4 s ($p < 0.001$), and 2.1 s ($p = 0.029$) shorter than for sign configuration 1. On roadway geometry 2, sign configuration 2 had a 0.9-s ($p = 0.047$) shorter participant response time than sign configuration 1 at the exit location. Participant response times for sign configuration 2 was better for roadway geometries 2 and 3 as well.

Table 1. Sign configurations' ranking based on response times from shortest to longest.

1 Mi	0.5 Mi	Exit
1, 2, 3*	1, 3, 5	1
4	4	5
5	2	3
—	—	2
—	—	4

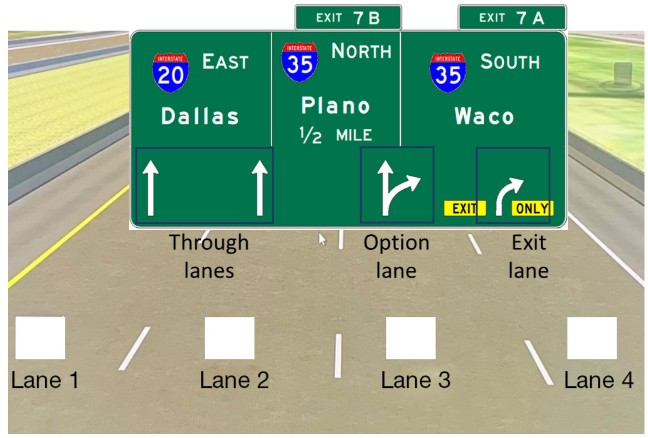
— = No entry.
*The differences between sign configurations placed on the same line were not statistically significant.

Response Accuracy

Participants received questions about the lanes to use to go to the destinations shown on the signs. This part of the study assessed the impact of sign location and sign configuration on the accuracy of participants' responses. Average accuracies corresponding to different destinations were calculated at different sign locations from the exit. Figure 18 shows the results of participants' average percent accuracy to signs placed at 1 mi from the exit, 0.5 mi from the exit, and at exit locations. For Dallas—the through destination—participants' responses to sign configuration 1 were approximately 20 percent higher than participants' responses to the other four sign configurations. For Plano and Waco, accuracies among the sign configurations showed mixed results, i.e., no distinct pattern of accuracy was noticed among sign configurations. Accuracies were higher for Plano than Dallas and Waco.

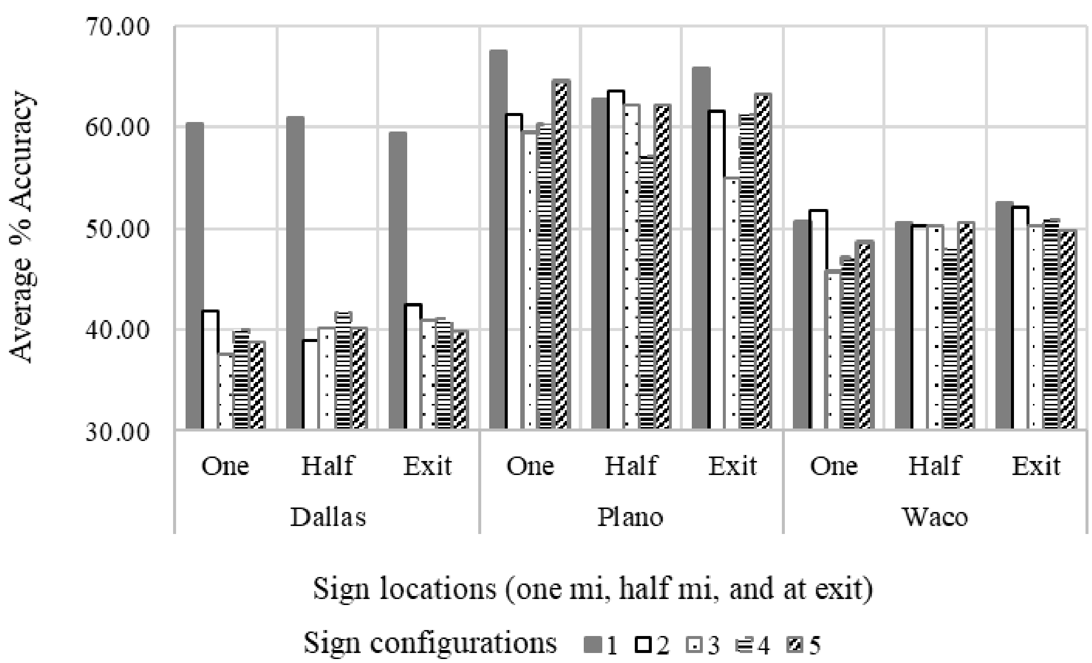
Accuracies for lane type were calculated based on the answers for destinations questions. Through lanes were defined as lanes that allow traffic moving only straight ahead. In this experimental setup, through lanes were the two far-left lanes. The option lane, the second lane from the right, was the lane that allowed bidirectional movement—straight ahead or right exit. The exit lane was the lane that took participants to only the exit destination, the far-right lane. Figure 19 shows the through option and exit lanes.

Figure 19. Illustration. Lane assignment categories in full-sized OAPL.



Source: FHWA.

Figure 18. Graph. Average percent accuracy of lane choice based on destinations.



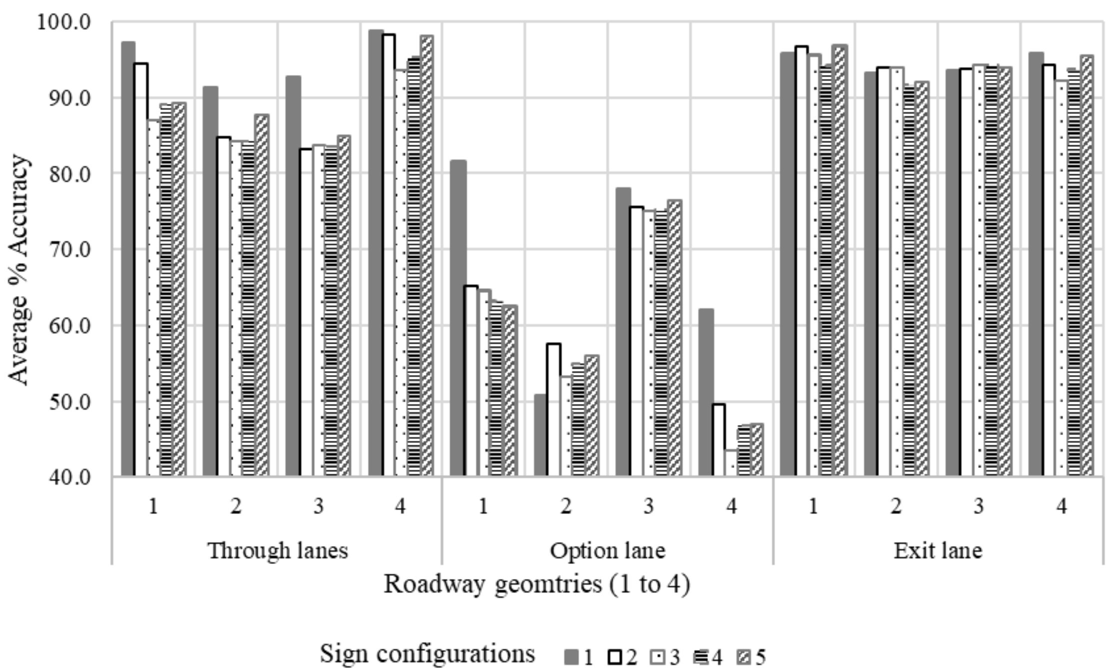
Source: FHWA.

Average Accuracy Time for Different Roadway Geometry

Figure 20 shows participants' average lane selection accuracy over different roadway geometries and arrow designs. Specifically, the graph presents sign-selection accuracy for a sign positioned 1 mi from the gore for the five sign configurations over four roadway geometries. In general, selection accuracy for through and exit lanes was higher than for the option lane. On most roadway geometries, participants responded to sign configuration 1 with greater accuracy than for through and option lanes.

For exit lanes, no discerning selection accuracy pattern could be observed. Similar comparisons were made among participant selection accuracies for different sign configurations at 0.5 mi and exit locations. Sign configuration 1 had higher selection accuracy than did the other sign configurations for most sign locations. Selection accuracies for through and exit lanes were higher for roadway geometries 1 and 4 than for roadway geometries 2 and 3. Accuracies associated with option lanes were low at all sign locations.

Figure 20. Graph. Response accuracy of sign configurations over roadway geometries.



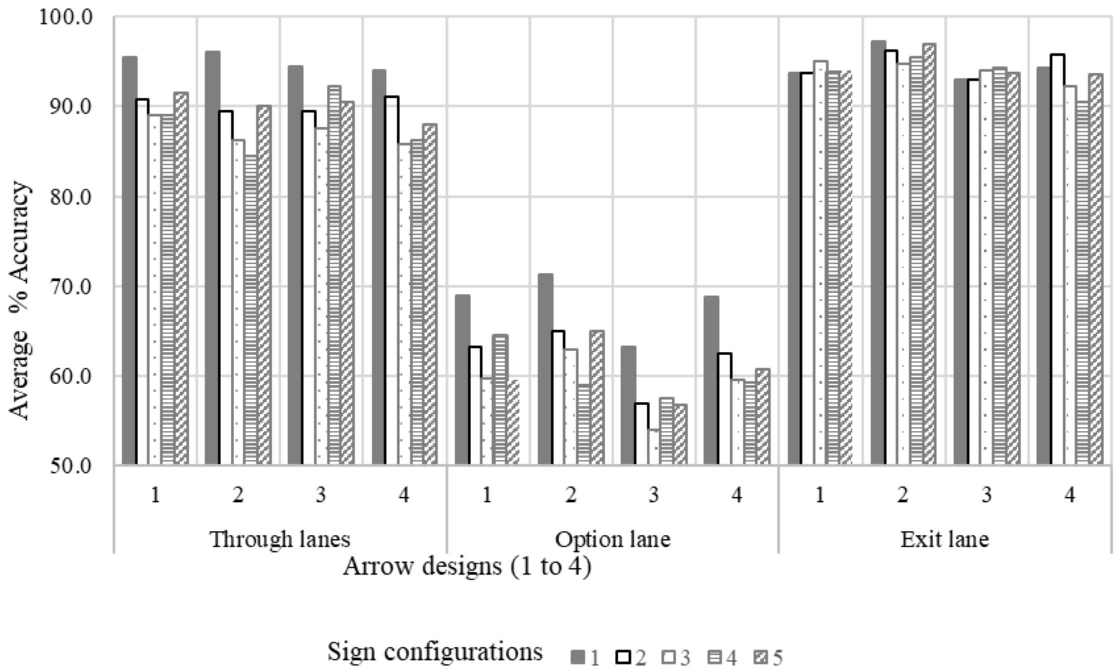
Source: FHWA.

Average Accuracy Time for Different Arrow Designs

Similarly, accuracies of response times to different sign configurations were compared over different arrow designs. Figure 21 presents lane selection accuracies for different arrow designs from gore. Selection accuracy for sign configuration 1 was higher for all the arrow designs. Option lane accuracy was consistently lower or through and exit lanes. Alternate sign configurations (2, 3, and 4) displayed inconsistent patterns for all sign locations. Lane selection accuracy for sign configuration 1 was higher for option lanes across all arrow designs.

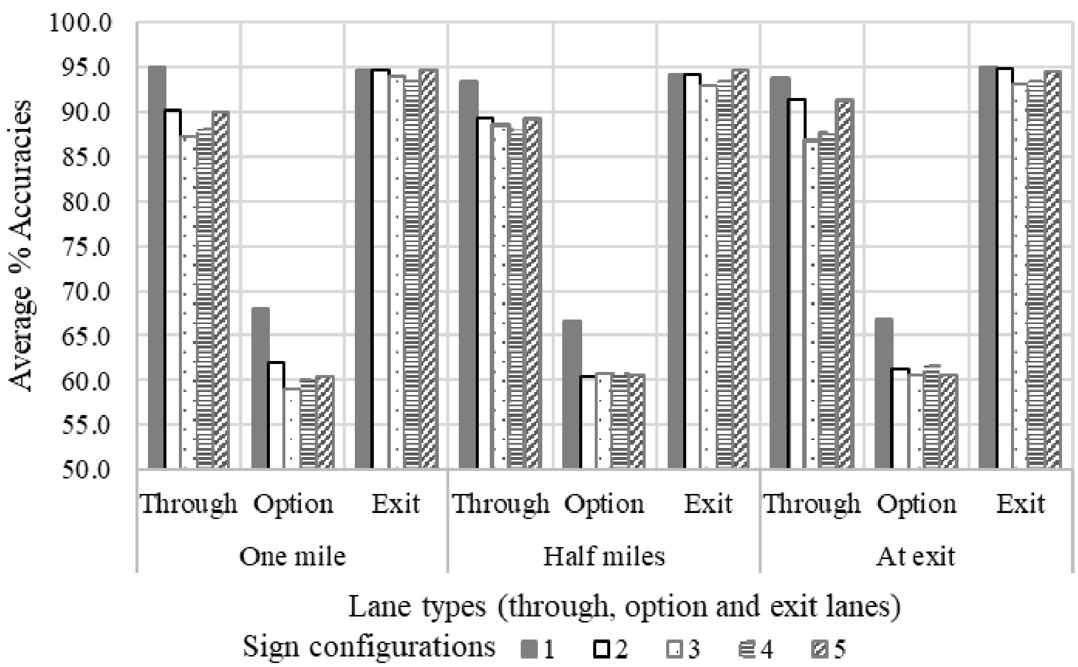
Sign configurations were compared by averaging accuracies across arrow designs and roadway geometries. Figure 22 shows lane selection accuracy for sign configuration 1 garnered slightly higher accuracy percentages for through and option lanes. Exit lane accuracies were similar for all the signs. Option lane accuracies were low for all three sign locations.

Figure 21. Graph. Response accuracy of sign configurations over arrow designs.



Source: FHWA.

Figure 22. Graph. Average percent accuracy based on sign configurations.



Source: FHWA.

The research team used GEE models to evaluate the statistical significance of the independent variables and found a 95 percent confidence level. Sign configurations and roadway geometries were statistically significant at 1- and 0.5-mi sign locations. Selection accuracy for the exit location was not statistically significant.

Table 2 summarizes the statistics regarding the significance of the independent variables (sign configurations, arrow designs, and roadway geometries).

In table 3, the order of sign configurations is from most to least likely to elicit an accurate lane selection response. Analysis of main effects of the sign configuration produced this order. Analysis of selection accuracies for different types of lanes occurred separately. More than one sign configuration on the same line indicates no statistical difference in lane selection accuracies between the configurations. For example, at the 1-mi sign location, sign configurations 1 and 2 were not found statistically different from each other regarding selection accuracy. The likelihood of sign configuration 5 eliciting accurate responses was lower than for sign configurations 1 and 2 for through lanes. For through lanes, sign configurations 1, 2 and 5 had higher likelihood than 3 and 4. For option and exit lane accuracies, no such pattern could be observed.

Table 2. Statistical significance of independent variables.

Sign Location	Statistical Features	Sign Configuration			Roadway Geometry		
		Through Lanes	Option Lane	Exit Lane	Through Lanes	Option Lane	Exit Lane
1 mi	df	4	4	4	3	3	3
	X^2	37	53	2.62	80.1	461	7.38
	p-Value	<0.001	<0.001	0.621	<0.001	<0.001	0.061
½ mi	df	4	4	4	3	3	3
	X^2	16	25.7	8.97	86	268.9	2.93
	p-Value	0.003	<0.001	0.062	<0.001	<0.001	0.403
At exit	df	4	4	4	3	3	3
	X^2	40	27	10.4	74.8	327	9.36
	p-Value	<0.001	0.034	<0.001	<0.001	<0.001	0.025

Table 3. Order of the sign configuration based on their accuracies and statistical significance.

Lane Types	1 Mi	0.5 Mi	Exit
Through lanes	1, 2	1	1
	5	2	5
	4	5	2
	3	3	3
	–	4	4
Option lanes	1	1,3	1, 4
	3, 4	2	5
	2	4	2
	5	5	3
Exit lanes	1, 2, 3, 4, 5	1, 2, 3, 4, 5	1, 2
			5
			4
			3

Note: The differences between sign configurations placed on same line were not found statistically significant.

Confidence of Answers

After responding to the questions about the appropriate lane choice for different destinations, participants rated confidence in their answers. The basis for calculating the average rate was their responses over roadway geometries and arrow designs. Using GEE models, researchers evaluated the sign configurations more likely to receive high confidence ratings. Table 4 shows average ratings of the sign configurations. Sign configuration 1 received the highest confidence ratings for all sign locations. Sign configurations 2 and 5 received higher confidence ratings than configurations 3 and 4. The statistical analysis, as well as the sign order in table 4, reflects this confidence level. Statistical analysis revealed that for the 0.5-mi sign location, sign configurations 2 and 5 were likely to have higher ratings than sign configurations 3 and 4. Sign configurations 2 and 5 did not have a statistically significant difference. Similarly, rating results for sign configurations at exit location were not statistically significant. Also, accuracy responses for sign configurations 3 and 4 were not statistically different.

Table 4. Confidence ratings of sign configurations.

1 Mi		0.5 Mi		Exit	
Sign Configurations	Ratings	Sign Configurations	Ratings	Sign Configurations	Ratings
1	4.5	1	4.5	1	4.5
2	4.3	2	4.3	2	4.4
3	4.1	3	4.2	3	4.2
4	4.2	4	4.1	4	4.2
5	4.3	5	4.3	5	4.3

The confidence ratings mirrored the accuracies for through lanes. Both accuracy and confidence ratings for sign configurations 2 and 5 were higher than for sign configurations 3 and 4. However, accuracies for option and exit lanes did not reflect this observation. It is worth noting that even though there are statistical differences between the confidence ratings of the signs, the ratings remained between 4.1 and 4.5.

Effectiveness of Sign Configurations

Participants also rated how effective each sign was at conveying the specific lane assignment information following the method demonstrated in figure 14. Sign configuration 1 received an effectiveness rating of 4.0 out of 5.0. Sign configurations 2 and 5 received ratings 3.9 and 3.7, respectively. Participants rated sign configurations 3 and 4 as 3.6 each out of 4.0.

Comparisons of Arrow Designs

Researchers used two methods to assess arrow designs: by actual differences in response times and accuracies and by participants' perceived effectiveness of the arrow designs used in a sign configuration. Arrow designs impacted response times significantly but did not impact response accuracy. Responses times for arrow designs 1 and 3 were statistically no different, and both were shorter that response times for arrow designs 2 and 4.

Participants also rated arrow designs for their effectiveness as part of a sign. Their design preferences did not match their response time results. Participants preferred arrow design 2, followed by designs 1, 4, and 3.

CONCLUSION AND RECOMMENDATION

This study evaluated the effectiveness of alternates to OAPL signs for different roadway geometries. It also evaluated the effectiveness of four different arrow designs and layouts used on the signs. The researchers used four dependent variables to study drivers' perception and comprehension of the signs: response time (how long it takes to understand the message of the sign), response accuracy (how accurately the participant interpreted the message about the lane choice of the sign), participants' confidence in their answers, and perceived effectiveness of the signs using ratings (how effective participants thought a sign was in indicating lane assignments). Independent variable (effectiveness of the arrow designs was also assessed).

Response times across the sign configurations were higher at the 1-mi sign location than at the ½-mi and exit sign locations. When the average response times were aggregated across different roadway geometries and arrow designs, the participants understood sign configuration 1 at the 1 mi location most quickly.

However, study findings indicate taking caution if considering the use of sign configuration 1 on roadway geometry 4 (dual-lane exit with option lane followed by downstream dual-lane exit with option lane). This is to note that sign configuration 1 is not MUTCD compliant for roadway geometries with multiple closely spaced exits. The reason is that roadway geometry 4 includes alternate sign configurations that had shorter response times than did sign configuration 1. Participant response times for sign configuration 2 differed from times for sign configuration 3; however, both times did not statistically differ from times for sign configuration 1.

Participants recorded the longest response times for sign configuration 5 (2.1 s longer than response time for sign configuration 1). The findings from response times indicated that the OAPL, partial-width OAPL with pull-through sign, and partial-width OAPL without pull through sign have some advantage over other sign configurations. For OAPL with pull through sign (sign configurations 2 and 5), a vertical separator was advantageous. However, for a partial-width OAPL (sign configurations 3 and 4), not having the vertical separator presented an advantage. An explanation for this difference may be that sign configurations 1, 2, and 5 present more information than information in sign configurations 3 and 4. The vertical separator may facilitate quick understanding of the information by providing a visual barrier between different segments of information. For sign configurations 3 and 4, a vertical separator may not have an importance.

In contrast, at the ½-mi sign location, sign configuration 5 was more effective than sign configuration 2. At that location, sign configurations 3 and 5 were found to be statistically insignificant from sign configuration 1 with the shortest response times. In this case, sign configuration 2 had the longest response time (1.3 s longer than sign configuration 1).

At the exit location of the sign, sign configuration 1 had the shortest response times followed by sign configuration 5 (1 s longer) and configuration 3 (1.1 s longer). Locations of the sign seemed to play an important role in variation in response times among sign configurations. Considering all the sign locations sign configuration 3 (partial-width arrow-per-lane without vertical separator or pull-through) was the most similar, meaning, prompted response times were very close to those recorded for sign configuration 1 (full-sized OAPL).

Descriptive statistics of response accuracy (lane choice accuracy) revealed that none of the signs conveyed option lane information as effectively as they conveyed information for through lanes and exit lanes. Sign configuration 1 had higher accuracy (95 percent at 1 mi, 93.3 percent at 0.5 mi, and 91.4 percent at the exit location of the sign) than the other sign configurations (figure 22). Overall, lane selection accuracies were higher when participants saw the sign 1 mi ahead of the exit than when sighted at a 0.5-mi and exit locations. It should be noted that at the 1 mi sign location, response times were longer than at other locations.

Sign configurations 2 and 5 (partial-width arrow-per-lane with and without vertical separator with pull-through sign) had higher accuracy than sign configurations 3 and 4 (partial-width arrow-per-lane with or without vertical separator or pull-through) for through lanes. An explanation for these differences could be that in the partial-width sign configurations without the pull-through sign (3 and 4), explicit information about the through destination was not provided. When participants were asked about the locations they have not seen in the sign (e.g., Dallas), the accuracy for through lanes was negatively impacted.

However, sign configurations 3 and 4 had higher lane choice accuracy than did sign configurations 2 and 5. Conveying option lane information is complicated. Partial-width sign configurations showing less information may contribute to the higher accuracy of option lane choice. If placing full-sized OAPL is not feasible, sign configurations 3 and 4 could be advantageous for agencies targeting a specific segment of the roadway where vehicle weaving movement in the option lane is a major concern. Although, this should be taken into consideration that sign configurations 3 and 4 are not MUTCD compliant and would need to go through the MUTCD Experimentation Process. Exit lane choice accuracy was similar between sign configurations 3 and 4, ranging from 94.8 to 93.3 percent among the sign configurations at three locations.

Confidence ratings regarding lane choice questions revealed that sign configuration 1 received the highest confidence, followed by sign configurations 2 and 5. A potential reason for sign configuration's high rating may be that these three sign configurations had information about all destinations. Sign configurations 3 and 4 ranked lower than sign configurations 1, 2, and 5; however, the rating scores remained between 4.1 and 4.5. Confidence in sign configurations 2 and 5 reflected the lane choice accuracies for those signs for through lanes. For option and exit lanes, there was no observable trend. Participants' preference for sign configurations 2 and 5, over 3 and 4, positively impacted effectiveness ratings for sign configurations 2 and 5.

Arrow design 1 was associated with lower preference and higher effectiveness ratings than alternate designs except for arrow design 3. Arrow design 3 is recommended as well as arrow design 1.

Although there is wide variation in the research findings, participants felt more confident in their lane selections and found it helpful to have information about all the destinations (sign configurations 1, 2, and 5). However, assessment of the time it took to comprehend the sign (response time) and lane choice accuracy (response accuracy) did not translate to participant preference in some cases. For example, participants did not find sign configurations 3 and 4 to be highly effective in conveying information about the lanes, but their lane choice accuracy was high for these sign configurations. There is the possibility that based on sign location and the goal the agency has for the sign may make sign configurations 2, 3, and 5 viable options, if using a full-sized OAPL is not feasible. Researchers of this study would like to reiterate that sign configurations 2, 3 and 5 are not compliant with current MUTCD guidelines and would need to go through the MUTCD Experimentation Process.

There is a clear tradeoff between cost and performance of sign configurations. Sign configuration 1 (full-sized OAPL) is the most effective in both response time and lane selection accuracy, but it is expensive. Findings of this study indicate the potential for using other sign configurations for specific locations and scenarios.

Further research could be conducted on simulated urban and rural roadways to test complexity of destination names (different length of the word can have different impact on sign comprehension), varying lettering and shield sizes, incorporation of various sign spacing between exits, volumes of traffic, number of lanes, etc. Additionally, testing could be expanded to test the effectiveness of signs in contrasting environments. Those tests would be helpful in producing recommendations for a wide variety of the agencies.

APPENDIX

The appendix displays different levels of the three independent variables that were used to produce different experimental scenarios. There were 5 sign configurations (1–5) those had separate versions for 4 different arrow sizes. These sign configurations with different arrow designs were, further, applied to different roadway geometries (1–4) to evaluate participants' comprehension and perception as shown in table 5.

Table 5. Experimental scenarios.

Roadway Geometries	Sign Configurations	Arrow Designs			
		1 (1,0,0)	2 (2,0,0)	3 (3,0,0)	4 (4,0,0)
1 (0,0,1)	1 (0,1,0)	(1,1,1)	(2,1,1)	(3,1,1)	(4,1,1)
	2 (0,2,0)	(1,2,1)	(2,2,1)	(3,2,1)	(4,2,1)
	3 (0,3,0)	(1,3,1)	(2,3,1)	(3,3,1)	(4,3,1)
	4 (0,4,0)	(1,4,1)	(2,4,1)	(3,4,1)	(4,4,1)
	5 (0,5,0)	(1,5,1)	(2,5,1)	(3,5,1)	(4,5,1)
2 (0,0,2)	1 (0,1,0)	(1,1,2)	(2,1,2)	(3,1,2)	(4,1,2)
	2 (0,2,0)	(1,2,2)	(2,2,2)	(3,2,2)	(4,2,2)
	3 (0,3,0)	(1,3,2)	(2,3,2)	(3,3,2)	(4,3,2)
	4 (0,4,0)	(1,4,2)	(2,4,2)	(3,4,2)	(4,4,2)
	5 (0,5,0)	(1,5,2)	(2,5,2)	(3,5,2)	(4,5,2)

Table 5. Experimental scenarios. (Continued)

Roadway Geometries	Sign Configurations	Arrow Designs			
		1 (1,0,0)	2 (2,0,0)	3 (3,0,0)	4 (4,0,0)
3 (0,0,3)	1 (0,1,0)	(1,1,3)	(2,1,3)	(3,1,3)	(4,1,3)
	2 (0,2,0)	(1,2,3)	(2,2,3)	(3,2,3)	(4,2,3)
	3 (0,3,0)	(1,3,3)	(2,3,3)	(3,3,3)	(4,3,3)
	4 (0,4,0)	(1,4,3)	(2,4,3)	(3,4,3)	(4,4,3)
	5 (0,5,0)	(1,5,3)	(2,5,3)	(3,5,3)	(4,5,3)
4 (0,0,4)	1 (0,1,0)	(1,1,4)	(2,1,4)	(3,1,4)	(4,1,4)
	2 (0,2,0)	(1,2,4)	(2,2,4)	(3,2,4)	(4,2,4)
	3 (0,3,0)	(1,3,4)	(2,3,4)	(3,3,4)	(4,3,4)
	4 (0,4,0)	(1,4,4)	(2,4,4)	(3,4,4)	(4,4,4)
	5 (0,5,0)	(1,5,4)	(2,5,4)	(3,5,4)	(4,5,4)
Total Trials Per Group	–	20	20	20	20

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