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16. Abstract

This report contains the results of a three-phase human factors study which tested driver comprehension of diagrammatic freeway guide signs and their text alternatives. Four different interchange types were tested: left optional exit, left lane drop, freeway to freeway split with optional center lane, and two lane right exits with optional lanes. Three phases of the project tested comprehension by using digitally edited photographs of advance guide signs in freeway scenes. Participants viewed a computer slideshow in which slides were shown for only three seconds to simulate a single driver eye glance at a sign. All signs were mounted overhead in the photographs. Participants were provided a route number and city name as a destination that could be reached either by the through route or the exit route. They indicated which lane or lanes they would choose to reach the given destination. The fourth phase of the study used a fixed-base driving simulator which presented full sign sequences consisting of two advance guides and one exit direction sign. Performance measures were distance from the gore at which required lane changes were made and number of unnecessary lane changes made. Results showed that for the left exits the standard text-only signs performed equal to or better than the diagrammatic signs. This performance was true for left lane drops also. For the right exit with optional lane, the standard text signs did well, as did the diagrammatic signs. For freeway-to-freeway splits, standard text signs with two arrows over the optional lane performed better than either style of diagrammatic sign. This report also contains an extensive literature review of previous work in the area, a discussion of testing methodology, and suggestions for future research.

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation. The United States government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

The engineer in charge of the project was Marcus A. Brewer, P.E. (TX-92997).

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CHAPTER 1:
BACKGROUND

A previous TxDOT project (Project Number 0-4170) on freeway guide signing included discussions of signing practice in focus groups with average drivers *(1)*. In speaking with drivers, it was clear that drivers have a preference for diagrammatic signs, or as one participant put it, "those ones with the little drawings on them." But diagrammatic signs are often larger than standard text-only advanced guide signs, and there are no good design standards in place to assure uniformity. With the freeway system becoming more varied and complex, it is becoming more difficult for drivers to anticipate the geometry of upcoming interchanges. Diagrammatic signs can be particularly useful to inform drivers of unexpected ramp configurations and lane drops. A better informed driver is a safer driver. Good advanced guidance may lead to reduced erratic maneuvers, slower speeds, and fewer conflicts at freeway interchanges.

EXISTING STANDARDS

United States Standards and Practices

Federal MUTCD

Chapter 2E-19 of the Manual for Uniform Traffic Control Devices (MUTCD) *(2)* defines diagrammatic guide signs as "signs that show a graphic view of the exit arrangement in relationship to the main highway." The chapter lists four design criteria for diagrammatic signs. The criteria are:

- the graphic will be a plan view showing the exit ramp arrangement,
- no symbols or route shields are to be substituted for arrowheads,
- diagrammatic signs are not to be used at the exit gore area (i.e. only as advance signs),
- and the EXIT ONLY panel is not to be used on a diagrammatic sign for a major split.

In addition, Table 2E-4 Section M of the MUTCD provides minimum standards for the design of the diagrammatic elements such as lane widths and spacing between design elements. The section is reproduced in Table 1.

Table 1. Lengths, Widths, and Spacing of Diagrammtic Sign Elements.

Element	Minimum Size	
	mm	in
Lane Widths	125	5
Lane Line Segments	25x150	1x6
Gap between Lane Lines	150	6
Stem Height (up to upper point of departure)	750	30
Arrowhead (standard “up” arrow)	200	8
Space between Arrowhead and Route Shield	300	12

The chapter also provides the following additional guidance for the design of diagrammatic guide signs:

- Graphic should not show deceleration lanes.
- Show only one destination per arrowhead.
- An EXIT ONLY panel should be used to supplement a lane drop graphic.
- Within the graphic, the exit ramp arrow shaft should be shorter than the through movement but not separated. Graphics for splits should have arrow shafts of the same length.
- Arrow shafts should contain lane lines where appropriate.
- All route shields, cardinal directions and destination names should be clearly related to an arrowhead and the arrowhead should point to the route shield for the exit movement.
- Cardinal directions should be positioned adjacent to the route shield with the destination name below the route shield and justified with the route shield.

The chapter also provides guidance for the application of diagrammatic guide sign and has figures depicting each application. The applications are:

- left exits,
- splits where the exit is to the left,
- optional lane splits for non-overlapping routes,
- two-lane exits with an optional lane that carries both the through traffic and the exiting traffic, and
- left exit with a lane drop.

The chapter concludes with the standard that diagrammatic signs are not to be used at cloverleaf interchanges. The standards and guidance provided in Chapter 2E-19 are referenced and repeated in other sections of Chapter 2.

Texas MUTCD

The 2006 TxMUTCD *(3)* follows the National MUTCD and includes identical text and graphics, with the substitution of the Clearview font. The TxMUTCD does reference specific guidelines for the design of diagrammatic signs. In practice, however, diagrammatic guide signs are used rarely on Texas roads.

Texas SHSD

The specific guidelines for the design of diagrammatic signs are found in the appendix of the Texas Standard Highway Sign Designs for Texas *(4)*. The guidelines provide general guidance for the design of guide signs such as letter heights, spacing, and borders. The diagrammatic sign guidance generally follows the language in the MUTCD with the following noted exceptions (in bold):

- The graphic legend shall be a plan view showing a **simplified** off-ramp arrangement.
- Only destination may be shown for each arrowhead, **with a maximum of two destinations per sign.**
- **Exit number panels should be located toward the top left edge of the sign for a left exit and toward the top right edge for right exits.**
- **Space between route shield and cardinal direction, should be equal to the largest letter/number height in that line.**

The guidance also specifies a 5-inch lane line width on the graphic but notes that wider lane widths appear to better meet the needs of older drivers.

International Standards and Practices

United Kingdom (UK)

Chapter 7 of the British Traffic Signs Manual *(5)* details the design of traffic signs in the UK. The design and layout of guide signs is based on "x-height" of the alphabet or font being

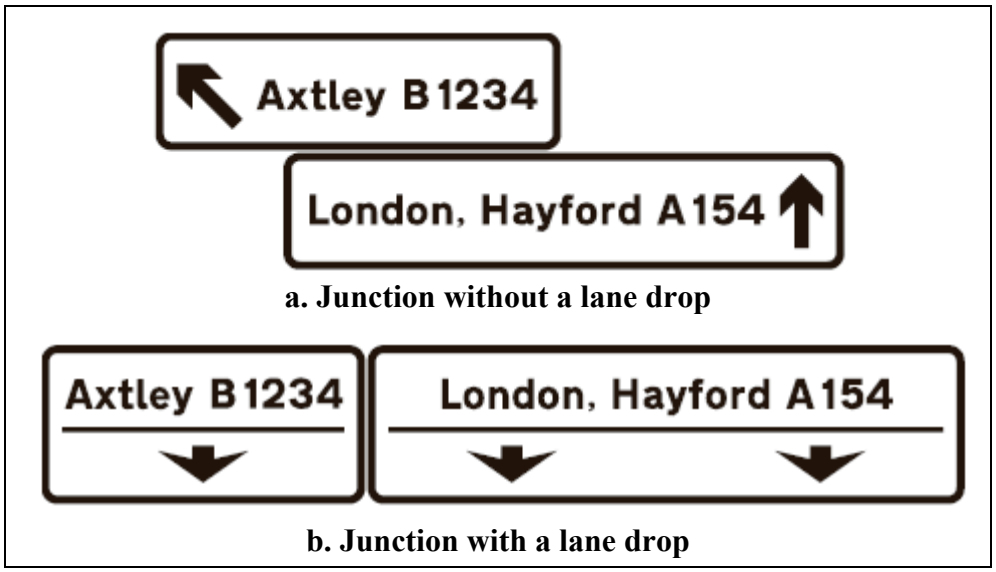
used (the UK only uses two sign fonts: Transport Medium for positive contrast signs and Transport Heavy for negative contrast signs). The "x-height" is the height of lower-case letter x for that particular sign. All symbol and legend spacing, border widths, and radii are given in number of stroke widths (sw). The stroke width is one-quarter of the x-height.

The UK uses four types of directional signing or guide signing. These are the stack type (Figure 1), the map type signs (Figure 2), dedicated lane signs (Figure 3), and gantry mounted (Figure 4). Stack type signs are similar to the destination and distance signing (D1, D2, D3 signs) used in the U.S. while map type signs are diagrammatic signs.

Figure 1. Stack Type Advance Guide Sign.

Figure 2. Map Type Advance Guide Sign.

Figure 3. Dedicated Lane Guide Sign.



a. Junction without a lane drop

b. Junction with a lane drop

Figure 4. Gantry-Mounted Advance Guide Sign.

Map type signs can be mounted on the roadway shoulder or on an overhead gantry. The design of the symbol on the map type sign is largely predicated on the junction. However, the lengths and widths of the route arms (i.e. directional arrows) are based on the route classification and the location of any legend or route shields. A width of 6sw is used for primary routes, 4sw for numbered non-primary routes, and 2.5sw for non-numbered local routes. A width of 5sw is reserved for routes indicated on a grade-separated junction and advance sign and for marking the approach arm of a roundabout at the end of an exit ramp on a grade-separated junction. The minimum length of a vertical route arm is 12.5sw. Horizontal route arms are two-thirds the length of the destination legend associated with that arm. Inclined or angled route arms have a minimum length of 12sw. When the advance sign is for a grade-separated junction, the width of all route arms is 5sw and the minimum length of the exit route arm is 24sw. Map type signs can also show stubs. Stubs are shortened route arms that indicate a road but do not give a direction. The length of a stub is equal to its width. Warning and Regulatory signs can also be placed within a map type sign. Theses signs are placed in-line with the route arrow and can include distance plaques. Symbol signs (airport, parking, etc.) are also placed within the map type sign and are associated with a route arm. Route shields (e.g., US highway shield) are not used on guide signs in the UK. Route numbers use a combination of color legend, a color background panel, and a letter code to indicate the roadway classification (motorway, primary route, etc.). In

addition, the background color of the map type sign indicates the classification of the traveled route.

The dedicated lane signs are used in advance of at-grade and grade-separated junctions. In the case of a grade-separated junction, the dedicated indicates the exit slip ramp. The directional arrows are 18sw in length with an 8sw head. If two or more lanes lead to the same direction, a horizontal bar is used (as shown in Figure 3). This is applicable for through lanes and exiting lanes. Lane widths on the sign should be equal for lanes with the same destination. The arrow indicating the widest lane should not be longer than two times the narrowest lane. Lane lines are always vertical, and the minimum length of a lane line is 3sw. If this minimum length cannot be met, the lane line should be omitted. Destination distances are not to be shown on dedicated lane signs. The distance to the junction can be shown and is located in the lower corner of the sign. Note that the dedicated lane arrow is vertical for the advance signing and is inclined only at the exit sign.

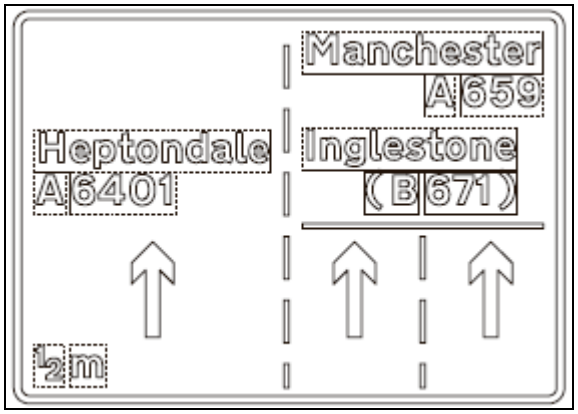


Figure 5. Dedicated Lane Sign Showing Distance to Junction.

The two signs shown in Figure 4 are for gantry-mounted signs. Gantry-mounted signs in the UK can include more than destination name for a given direction. The destination names are separated using a comma. When using a non-lane drop gantry sign, two signs are created. The first is the through movement. This panel is the lower of the two and is centered over the main carriageway or main lanes. The second sign is positioned above the first and offset to the left (in the US this offset would most likely be to the right) such that the inclined directional arrow is not positioned over the lower sign. If the main lanes curve to the right (exit to the left) the lower sign arrows can also be inclined to the right. The length of the arrows is typically 16sw. The

downward arrows of the lane drop sign are to be centered over the traffic lanes. The legend is centered and a horizontal bar is used. The sign should cover at least three-quarters of any lane to which it applies. In the case of a single lane, the sign panel may be wider than the lane but cannot cover more than one-quarter of a neighboring lane. The distance to the junction can be used and is added as third sign or as a panel within the sign. Warning signs, regulatory signs, tourist signs, and destination distance are not allowed on gantry-mounted signs.

The Motorway in the UK is the equivalent of the US Interstate. Signing rules for the motorway follow the guidelines outlined above. A motorway sign is indicated by its blue background. The signs also include the junction number. Motorway sign examples are shown in Figures 6 and 7. Figure 6 illustrates two exits in succession and two exits in quick succession. Figure 7 also shows two exits in quick succession but for a gantry-mounted sign.

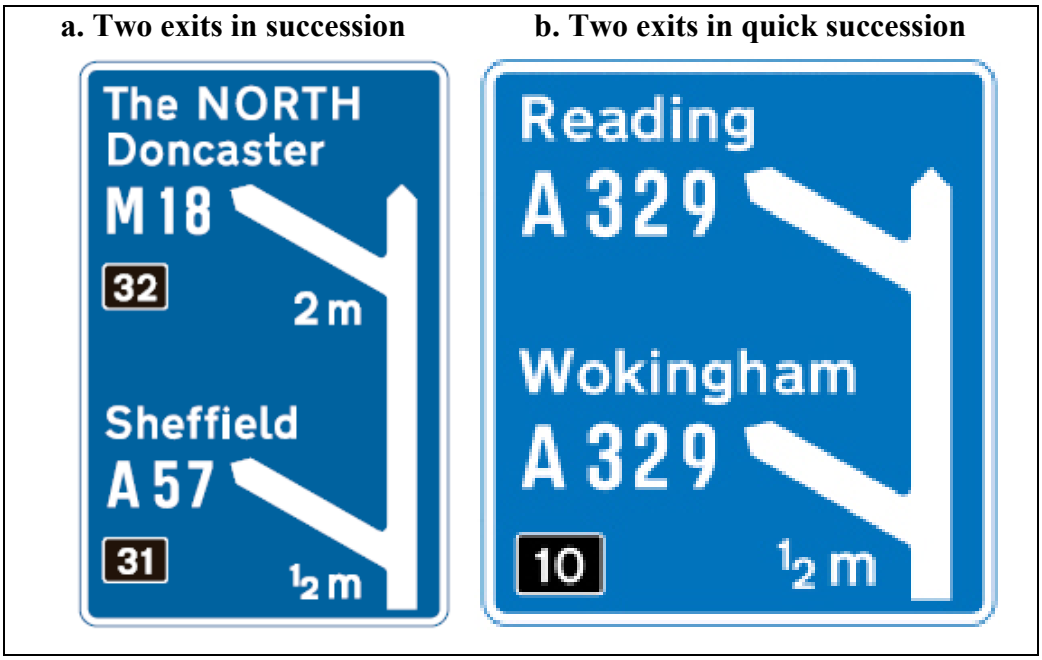


Figure 6. Motorway Shoulder Mounted Advance Signing.

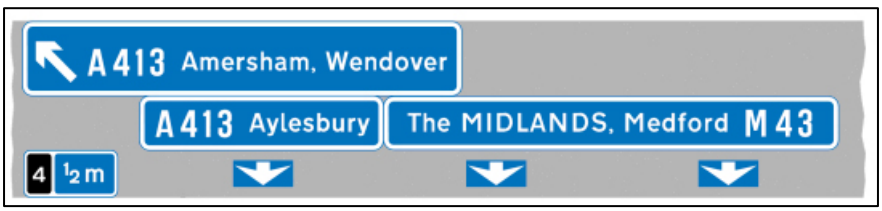


Figure 7. Motorway Gantry-Mounted Advance Sign.

Germany

The *Strassenverkehrs-Ordnung* or Road Traffic Regulations *(6)* is a summary of laws governing vehicles, traffic signs, and pedestrians published by the Federal Ministry of Transport, Building and Urban Affairs. Part II, Section 42, part 8 covers the use of guide signs and advance guide signs. The regulations give sign examples and descriptions for their use. Autobahn signing (equivalent to a US Interstate) uses a blue background. The signs can be shoulder-mounted or gantry mounted. An exit off the Autobahn is announced using the sign in Figure 8. This sign is placed 1000 m before the exit. Another form of the sign uses an interchange symbol (Figure 9). In this instance, the sign is placed 2000 m from the interchange. The next sign is an advance guide sign. This sign uses a diagrammatic arrow symbol as shown in Figure 10. This sign is typically placed 500 m before an exit and 1000 m before an interchange. The announcement sign also shows the exit number while the advance exit sign gives the through route number. Figure 11 shows examples of other forms of Autobahn advance exit signing. Note that in Figure 11c, the directional arrows for the exit have changed to straight, inclined arrows.

Figure 8. Autobahn Exit Announcement Sign.

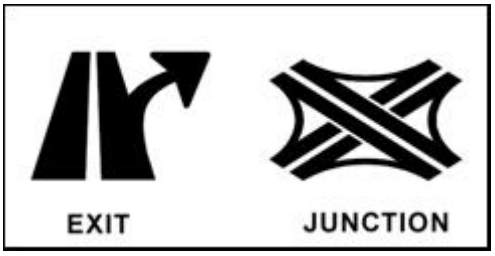


Figure 9. Autobahn Exit and Interchange Symbols.

Figure 10. Autobahn Diagramatic Advance Exit Sign.

a. Shoulder Mount Advance Sign

b. Gantry-Mounted Advance Sign

c. Exit Signing

Figure 11. Examples of German Signs *(7)*.

PAST RESEARCH

Several studies have attempted to identify situations where drivers do not understand the lane assignment message being conveyed by a guide sign. Study methods have included focus groups, surveys, laboratory testing, driving simulation, field observations, and eye tracking. This section summarizes the methods used and the results of this research.

Survey Studies

- Survey studies have presented hypothetical scenarios to the survey subject and then assessed whether the subject correctly understood the situation being presented. This section summarizes the results of these driver surveys. The Texas Transportation Institute (TTI) conducted a series of surveys in 1990 to determine driver understanding of lane assignment arrows *(8)*. Some of the findings of this extensive survey included:
- Conventional diagrammatic signs did not convey lane assignment information as well as a modified diagrammatic sign shown Figure 12.
- There was a great deal of driver misunderstanding of optional lane usage on exit signs. The provision of "Exit Only" signs over the lane with a required exit did not improve understanding.
- The number of arrows shown on a modified diagrammatic sign should equal the number of lanes at that particular location on the road. Trying to show added lanes downstream of the sign location resulted in increased driver confusion.

Researchers made several recommendations to alter diagrammatic signs in order to improve the understanding of older drivers in the FHWA publication *Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians (9)*. The authors recommend using a modified form of diagrammatic signing where a separate lane assignment arrow indicates the lane use on a freeway. The number of arrow shafts on the modified diagrammatic sign should be the same as the number of lanes on the freeway. The report notes that this configuration is not approved by the MUTCD and requires FHWA permission before it can be used. These recommendations were derived from the 1990 Texas Transportation Institute project described above.

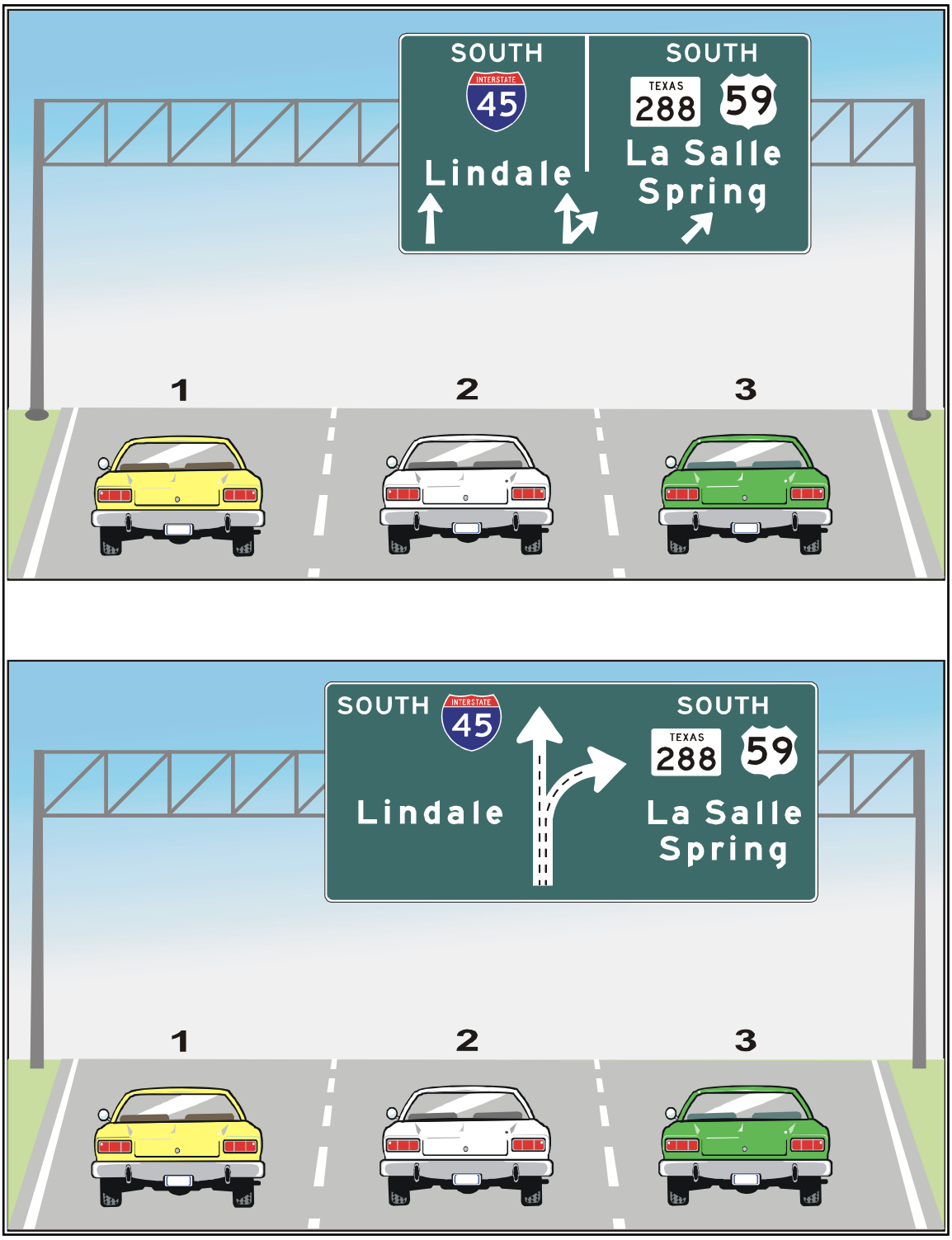


Figure 12. Modified (top) and Conventional (bottom) Diagrammatic Signs Studied in 1990 Survey *(8)*.

Skowronek examined the use of modified diagrammatic signs at freeway interchanges in Houston *(10)*. He conducted a driver survey where he tested conventional signing, diagrammatic

signing, and modified diagrammatic signing. The major findings of Skowronek's study included:

- The position of the sign had a major impact on the correctness of lane choice decisions for the conventional and modified diagrammatic signing. The signs should be positioned over the appropriate lanes in order to ensure the drivers understand the message correctly.
- The modified diagrammatic sign appeared to be effective in communicating lane assignment information. It appeared to provide superior performance to other sign types for signing optional exit lanes.

Based on these research results, modified diagrammatic signing appears to be worthy of more research. Past research on conventional diagrammatic signing has not provided conclusive results about its efficacy. The modified diagrammatic signs may provide a chance to improve driver understanding and also reduce sign fabrication costs.

Another study focused on lane choice at exit direction signs. These surveys produced several findings including *(11)*:

- Drivers had difficulty understanding guide signs when the number of lane assignment arrows did not equal the number of lanes on the road. When the number of lane assignment arrows was consistent with the number of lanes, this was not a problem.
- Diagrammatic signs were effective, but their effectiveness declined if too much information was presented. Information overload was particularly problematic with concurrent routing.

Signing at Interchange Lane Drops

Interchanges can represent very complex situations where the driver must make a series of decisions in a time-constrained environment. Situations where a lane is dropped at a freeway interchange have the potential to violate driver expectancy and can cause confusion among drivers. This confusion can result in high speed variability, erratic maneuvers, and driver frustration, all of which negatively impact safety. A variety of research has been performed to assess the effectiveness of different ways of signing lane drops at interchanges.

A study was conducted in the mid-1970s to assess the effectiveness of interchange lane drop signing standards *(12)*. This study examined left- and right-side exits for single lane drops. After reviewing the literature, surveying state agencies, and performing some limited driver surveys, the researchers developed several recommended treatments for signing interchange lane drops:

- **Right-side interchange lane drop:** "Exit Only" signs placed on the advance guide signs and exit direction signs significantly improved driver understanding of the lane drop. This research provided support for adding these plaques to the requirements for lane drops in the MUTCD.
- **Left-side interchange lane drop:** Based on previous research, diagrammatic signs were recommended for use on left-side exits. The researchers did not conduct any independent evaluation of the effectiveness of diagrammatic signs in this context.

In a 1996 TxDOT project, Somers et al. *(13)* evaluated alternative treatments for right-side multilane exits. First, the researchers evaluated innovative ways to sign an optional exit lane for a multilane exit. They tested the supplemental messages "EXIT OK" and "MAY EXIT" for use on the optional exit lane. They also examined the use of a divergent arrow over the optional lane to indicate lane usage. The divergent arrow was tested by itself, as well as in conjunction with the "EXIT OK" and "MAY EXIT" messages. The researchers hypothesized that this additional guidance would improve driver understanding of the use of the optional lane.

These alternatives were evaluated by surveying 548 subjects and evaluating their lane choices and comprehension of the messages. This survey produced several results:

- Only 50–65 percent of Texas drivers understood the current method for signing optional lanes on multilane exits.
- Adding the supplemental message "MAY EXIT" improved driver understanding of the optional lane use.
- The divergent arrow confused many survey participants who misinterpreted its navigational meaning.

The researchers then examined methods for signing a multilane exit with an optional lane exit followed by a secondary ramp split. This study evaluated treatments that utilized the "MAY EXIT" supplemental message and modified standards from Ohio and Texas. This study showed

that the differences between the "MAY EXIT" and modified Texas standard were not as large as the earlier survey results indicated. None of the methods provided a significant improvement over existing methods for signing a multilane exit followed by a secondary ramp split.

Laboratory Studies

Two landmark laboratory studies were conducted in the early 1970's which served to develop the guidance that is currently in the Federal MUTCD. The National Highway Traffic Safety Administration (NHTSA) conducted the first of these laboratory studies *(14)*. The researchers showed 102 subjects a series of signs with different guide signing concepts. The signs included conventional signing, diagrammatic signs showing a plan view of the interchange, and diagrammatic signs that attempted to provide a driver's eye with perspective of the upcoming interchange. Although the diagrammatic signs did not perform significantly better than conventional signing in most cases, they significantly improved lane choice selections when collector-distributor roads were present, when a secondary split occurred on a ramp, and when there was a major split in the highway. Driver preference studies showed that drivers preferred diagrammatic signs with plan views over all other types of signs. The details of the study merit review because of their influence on the current project and current standards.

The study focused on graphical characteristics that would most effectively communicate roadway-interchange and route-guidance information to the driver. The researchers designed a laboratory study using 35mm slide projectors and photographs of a roadway scene. The researchers identified several interchange characteristics associated with traffic flow and accident rate. The existence of two or more of these characteristics occurring at an interchange warranted the use of a graphic guide sign. These interchange characteristics were:

- heavy ramp volume,
- inability to see the gore,
- difficult and dangerous last minute lane changes,
- unexpected geometry, and
- interchanges where the wrong decision is difficult to correct.

The interchange types that typically had two or more of these characteristics were:

- collector-distributor with lane drop,
- multiple-lane split ramp,

- left ramp downstream from right ramp,
- exit ramps in quick succession,
- major fork, and
- cloverleaf.

The laboratory study was divided into four parts based on measures of effectiveness. Lane choice, subject confidence ratings, guide sign interpretation, and guide sign preference were the measures of effectiveness for the laboratory study. The researchers used a dual-projection tachistoscopic method consisting of two slide projectors with timer-controlled shutters to measure subject response. One projector displayed the roadway scene with images consisting of "through the windshield" images of a sign location. The second projector was fitted with a tachistoscopic shutter to project the image of a guide sign onto the roadway scene, overlaying the sign location. The shutter was timed for a 1 second exposure.

Prior to starting the test, subjects were given a destination and instructed on how to indicate lane choice and confidence level. 102 subjects participated in this portion of the study. Figure 13 shows the guide sign type concepts.

Figure 14 shows an example of the roadway scene shown to the participants. The researchers compared results of the graphic signs and found that a single sign type did not perform better than the other types across the interchange types. Testing the conventional signs against the graphic signs showed that graphic signs perform better with collector-distributor interchanges, close-choice points interchanges, and major fork interchanges.

In addition to the timed comprehension testing, a preference test was conducted with the lane choice and confidence test. The subjects were shown a line drawing of an interchange and a list of sign types (Figure 15). The subjects were asked to pick the sign type "liked best" and "liked least". Table 1 shows the results of the test. Note that the conventional signs were the least preferred ($p<0.05$).

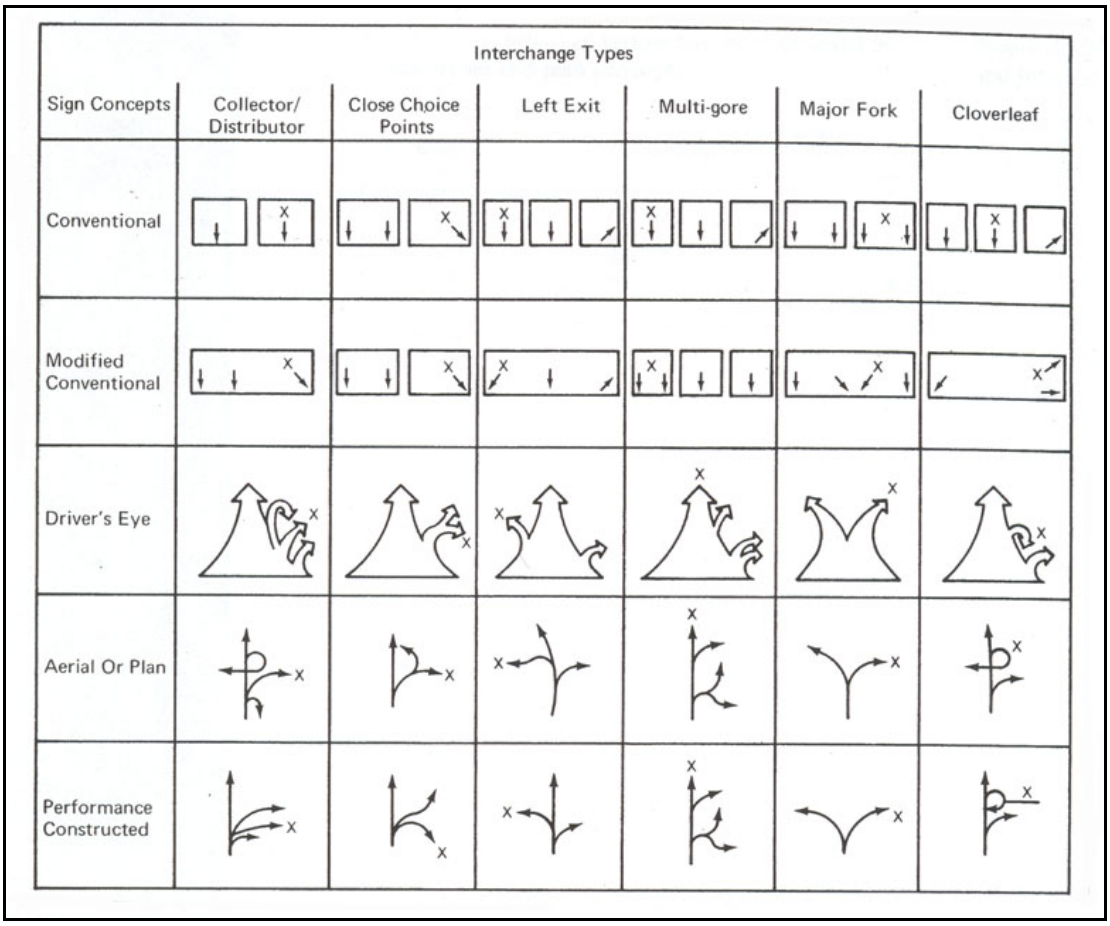


Figure 13. Sign Type Concepts Used for Lane Choice and Confidence Test.

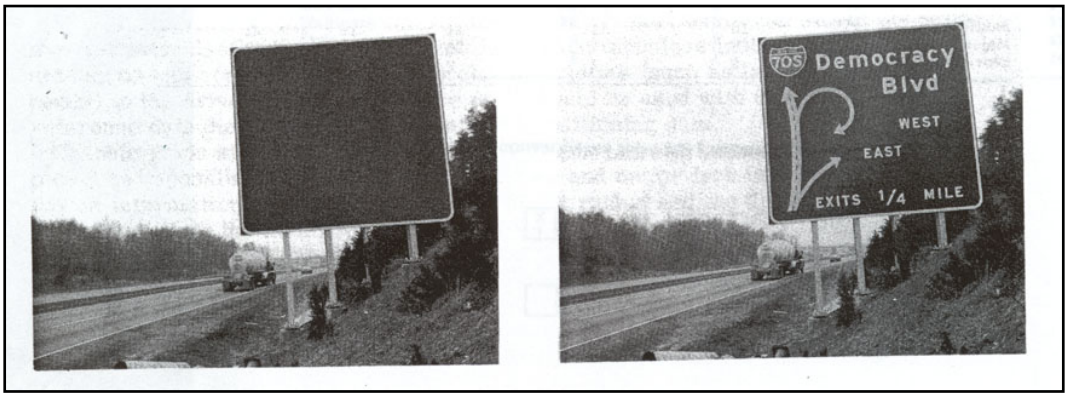


Figure 14. Roadway Scene Shown to Subjects with and without Guide Sign Information.

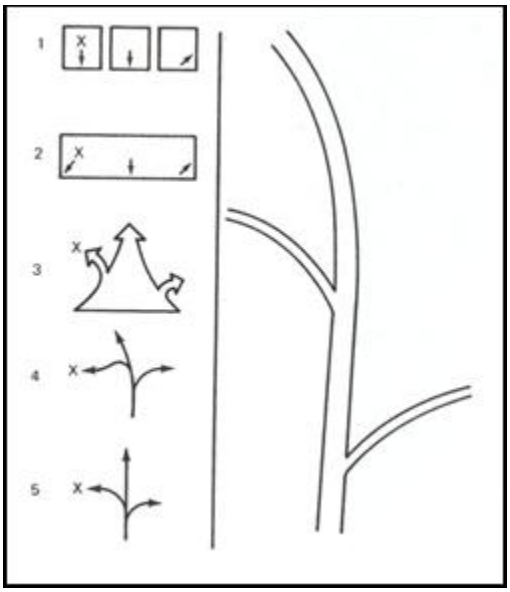


Figure 15. Display Used in Preference Test.

Table 2. Preference Test Results.

Interchange Type	Sign Concept Type Percent Subject Preference				
	Convent-ional	Modified Convent-ional	Driver's Eye	Aerial or Plan	Performance Constructed
Collector-Distributor	6	2	16	63	12
Close choice points	5	1	12	60	21
Left exit	12	8	13	43	25
Multigore	18	11	21	28	21
Major fork	8	8	25	18	42
Cloverleaf	8	1	3	74	14

Further experiments of this project tested additional design elements. This testing determined how well graphic signs convey information about roadway such as safe exit speed, distance between exits, and the location of the driver's exit. The researchers used the curvature of the arrow graphic and the distance between exits on the graphic as variables in this test. Subjects were asked to estimate the safe exit speed (miles per hour) and the distance (miles) between two exits. Two interchange designs were chosen and for each interchange four signs were tested: three graphic signs plus conventional signing. There were 48 test subjects. The tachistoscopic method was used in the test as well. Figure 16 illustrates the graphic and conventional signing used in the test. The researchers found that a curved exit arrow was

understood to mean a lower safe exit speed. The second graphic sign concept had twice the spacing than the other two. Drivers judged the distance between exits on the first graphic sign concept as being greater than the other two signs. The conventional signs had the highest estimate of exit speed. A significantly greater percentage of subjects correctly identified their exit with the graphic signs than the conventional signs.

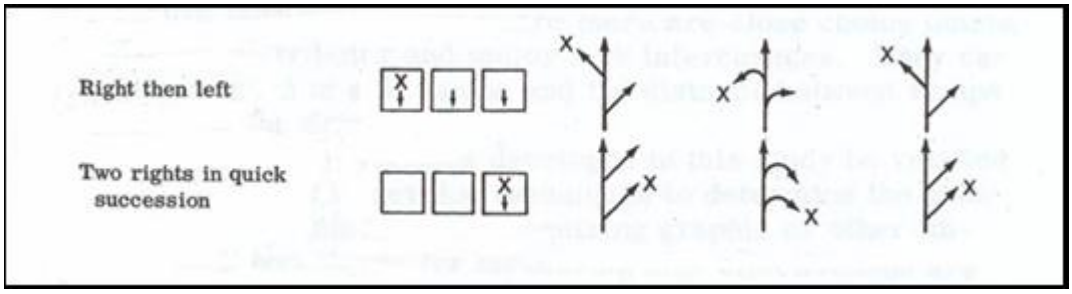


Figure 16. Example Graphic and Conventional Signs Used in Roadway Characteristics Test.

Based on the results of the three tests, the researchers determined that graphic guide signs can help improve lane position for closely spaced exits, collector-distributor, and major fork interchanges. The exit arrow can be used to provide information on exit speed and the distance between the exit ramps.

The FHWA conducted a follow-up laboratory study to the NHTSA diagrammatic sign study. This study modified the NHTSA study procedures by testing each subject individually and testing both destinations shown on the study signs *(15)*. Sixty test subjects viewed a series of slides with diagrammatic or conventional signs for six interchanges on Interstate 495 in Washington, D.C. The lane choice, reaction time, and driver preference for each type of sign was evaluated. The slide exposure time was controlled by the subjects, who pressed a button when they felt they understood the sign. This study found that drivers generally performed better at lane selection and had shorter reaction times with conventional signing. The conventional signs were also preferred by a larger number of test subjects than the diagrammatic signs. It is possible that greater driver familiarity with conventional signs than the then experimental diagrammatic signs may have influenced these results.

Another study examined the relative effectiveness of using diagrammatic signs rather than conventional guide signs *(16)*. One hundred and twenty participants viewed a series of slides. Subjects indicated which lane they would travel in to reach a predefined destination and

the correctness and latency of the response was recorded. This study found that there was no significant difference between the use of diagrammatic and conventional guide signs. The findings showed that subjects responded more quickly to conventional guide signs and generally seemed to prefer them to diagrammatic signs.

In general, these laboratory evaluations of diagrammatic signs did not show conclusive evidence that the diagrammatic signs outperformed conventional signs. The first large laboratory study showed strong preference for graphic signs and corresponding gains in performance, but the two subsequent studies showed that conventional signs performed better than graphic signs. These results may be biased, however, since the study was conducted at a time when diagrammatic signs were not familiar to many drivers. It is possible that results would be different if the study was conducted today. The research did identify specific geometric situations where the diagrammatic signs performed better than the conventional signs, but they did not show a widespread superiority over conventional guide signing across a range of conditions.

Often, a speed-accuracy tradeoff is observed in laboratory studies of sign comprehension. This tradeoff means that if subjects are allowed to control the amount of time they view the stimulus (speed) they will generally be highly accurate. In these cases, the measure of effectiveness is how long subjects needed to view the sign. The alternative is for the experimenter to control the time the subject is allowed to view the stimulus and examine how many errors are made. The idea here is that under time pressure, the poorly designed signs will show more errors. The difficulty for the experimenter is finding the best amount of time–too long and everyone will get everything correct, too short and all signs will do poorly. Accuracy is often the measure of effectiveness in many paper-based surveys. However, the amount of time each subject views each stimulus is not recorded, as these surveys are often administered in paper booklets where the subject is turning the pages. So, in these cases the time is neither controlled nor measured, which leaves the accuracy measure of effectiveness in question. Did they get that sign correct because it's a better sign or because they looked at it longer? In self-paced paper surveys, it is impossible to tell. The current study used a controlled exposure technique and used accuracy as the measure of effectiveness.

Driving Simulator Studies

A recent study sponsored by the National Cooperative Highway Research Program (NCHRP) specifically addressed two-lane freeway exits with one optional and one exit-only lane *(17)*. The signs tested included ones similar to those shown in Figure 17 but using a standard EXIT ONLY plaque for the far right lane. The researchers also tested conventional text-only signs with pull-through (down) arrows and conventional diagrammatic signs. These signs were compared to various arrangements of down arrows and exit plaque arrows slanted up and to the right. Ninety-six participants drove in a driving simulator and were asked to follow the signs to a particular destination. Measures of effectiveness of the various signs included path deviations (i.e. swerving) and lane changes. This flexibility is one advantage to using a dynamic driving simulator or on-road test. Rather than a discrete choice of lane as used in most surveys of sign comprehension, dynamic tests allow lane indecision to be assessed by examining the path of the driver. Overall, this study showed about 1/3 of drivers making unnecessary lane changes, demonstrating their poor understanding of optional lane exits. The study concluded by recommending the sign configuration shown in 2b.

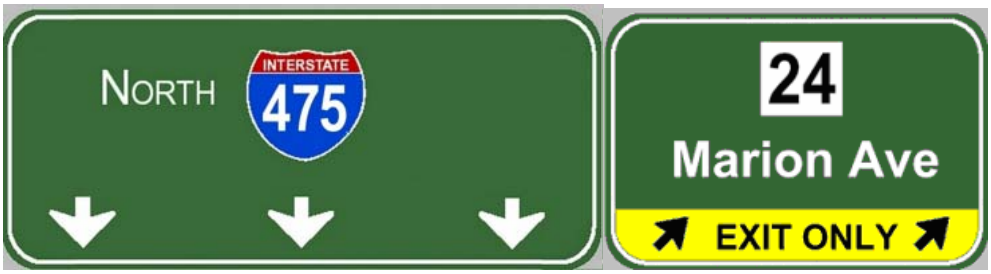


Figure 17a. Lane Designation Signs (Longitudinally located at the theoretical gore, i.e., at a point where the right edgeline for the mainline and the left edgeline for the ramp begin at a common point and then diverge. Laterally located so that arrows are centered above the lanes to which each applies.)

Figure 17b. Advance Guide Sign (Located approximately ½ mile in advance of exit and centered over the four approach lanes)

Figure 17c. Advance Guide Sign (Located 1 mile in advance of exit and centered over the four approach lanes)

Figure 17. Materials Used in a Recent Driving Simulator Study of Guide Sign Designs *(17)*.

Field Evaluations

Several studies also tested diagrammatic signs in the field. Roberts examined the use of diagrammatic freeway guide signs in New Jersey by implementing diagrammatic signs at an

interchange *(18)*. The researchers collected data on erratic maneuvers and traffic volumes at the interchange when conventional signing, diagrammatic signing, and diagrammatic signing with lane lines was used. In general, the diagrammatic signs performed better than the conventional signing. The number of erratic maneuvers dropped when diagrammatic signs were implemented and was reduced further when lane lines were added to the diagrammatic signs.

The research was performed at the request of the Federal Highway Administration. The location selected for evaluation was the interchange of I-287 and US 22. The study had three parts:

1. Modification of existing signs to conform with the Interstate sign manual (and at the same time conducive to diagrammatic signs use),
2. Replacement of conventional signing with diagrammatic signs, and
3. Addition of lane lines on the diagrammatic signs.

The researchers conducted "before and after" studies for each sign change and included after studies for the initial use of diagrammatic signs. The initial before study was performed in July and August 1969, and the final after study was completed in May 1970. The I-287 NB to US 22 WB exit was chosen as a study site. The eastbound exit to US 22 had a low volume of traffic and was not included in the study. Researchers recorded the number of unusual or erratic maneuvers at the exit gore. Researchers collected data using automatic traffic counters and video recorders, including through and left exit volumes. Traffic was video taped as it approached the exit gore at a point 400 feet upstream from the gore. All lanes were recorded and data collection was performed between 2 and 7 P.M. Figure 1 shows the study location layout.

The researchers found no significant differences (95% confidence level) in the rate of unusual maneuvers between the original signs and the modified signs. A significant reduction was found when the signs were changed to diagrammatic signs. This reduction may be attributable to the uniqueness of the diagrammatic signs (commanding greater attention) and that drivers may have felt that the change in sign type indicated a need for greater attention. A comparison of the after and long-term after studies for the diagrammatic signs showed an increase in the rate of unusual maneuvers. The researchers felt this could be attributed to changes in the traffic makeup and the six month span between data collection periods. After the addition of lane lines to the diagrammatic signs, researcher noted a significant decrease in the number of unusual lane changes.

The Virginia Highway Research Council conducted a diagrammatic sign field study in 1970 *(19)*. The council examined traffic volumes and the number of erratic maneuvers at the site. The number of erratic maneuvers actually increased after the diagrammatic signs were installed, but the researchers noted that data for diagrammatic signs were collected during later spring and early summer. During these months, the proportion of drivers not familiar with the area increases on the highways around Washington, D.C. The researchers hypothesized that these non-local drivers were responsible for the increase in erratic maneuvers.

The study evaluated erratic maneuvers using time-lapse photography. The variables were:

- occurrence of an erratic maneuver, type of maneuver,
- location,
- time of day,
- traffic volume, and
- type of signing.

Researchers choose the Exit 1 interchange on the Capital Beltway south of Alexandria, VA as the study site. This location exhibited sight distance restrictions and an unusual geometric layout.

The 85th percentile speed at the study location was determined to be 45 mph during the morning and afternoon peak times and 65 mph during the off-peak times. The main lanes at the exit had a volume of 81,000 vehicles per day An accident analysis showed that over a 26-month period prior to the study, there were 240 accidents including 4 fatalities and 136 injuries.

The researchers used the "comparative erratic maneuver" method for their analysis. They divided the study area into zones and recorded erratic vehicle movements in each zone. The erratic maneuvers identified were:

- weaves,
- weaves over gore areas,
- hesitations (slowing to 15 mph or less),
- stopping or backing, and
- partial weaves.

Traffic volumes and erratic maneuvers were recorded at random times during the day for 30-min intervals. The "before" data was collected during the fall of 1970 and early spring of 1971.

Diagrammatic signing replaced the standard guide signing. The diagrammatic signing used 20-inch route name letter heights and 36-inch route shields. The sign itself measured 14x19.5 ft.

The "before" period covered a period of 19 days. 56,326 vehicles were observed over 47 30-min intervals. The "after" period saw 91,423 vehicles over 73 30-min intervals. The research compared the before and after traffic volumes and found no evidence that tourist traffic had a significant effect. The researchers determined that after the installation of the diagrammatic signing, fewer motorists were weaving across the gore. The researchers also noted an increase in the amount of weaving traffic across the solid line pavement marking in advance of the gore area. This indicates that drivers were making lane decision earlier. The researchers also noted that the use of the diagrammatic signs, while reducing gore area weaving, increased the number of hesitations and partial weaves. The number of stopping and backing maneuvers also decreased.

A 1972 report by Mast and Kolsrud examined the use of diagrammatic signs on controlled access highways *(20)*. The objective of this research was to develop warrants and standards for the use of diagrammatic guide signs. The field studies used an instrumented vehicle, equipped with an in-vehicle sign display system. Subjects were required to navigate the test route using the information supplied by the in-vehicle signs for destination and direction. The routes used real highway facilities and interchanges open to normal traffic. The researchers measured the drivers' sign information interpretation time, vehicle speed control, incidence of hazardous maneuvers, and exiting errors.

As a result of the field studies, the researchers derived three general findings:

- More time is required to read, understand, and react to diagrammatic signs as compared to conventional guide signs with the same number of legends.
- Drivers have certain expectations as they drive along a highway. Situations that violate the expectation of both exiting and through traffic receive the most benefit from diagrammatic guide signs.
- Drivers make lane position decisions in advance of the gore area of an exit. Diagrammatic guide signing should only be erected at the advance and exit direction sign locations.

The researchers concluded that diagrammatic guide signs should be used in advance of left-exit interchanges. These interchanges include major forks where the through traffic uses the right fork and exiting traffic takes the left fork, interchanges where there is a single left exit in combination with a right exit, and for all single left exit interchanges. The researcher also recommended four cases where diagrammatic guide signs should not be used. The use of diagrammatic guide signs in these cases provides no benefit to the driver and in some instances may reduce driver performance:

- interchanges with a single right exit (i.e. diamond interchange),
- common cloverleaf interchanges without collector distributors,
- interchanges with collector distributors with a single right exit from the main roadway, and
- interchanges with double lane drops to the right followed by a fork, also known as a multiple split ramp interchange.

In addition to the application warrants listed above, Mast and Kolsrud developed design standards for diagrammatic signs as part of this study. These design standards still form the foundation of current designs in the MUTCD. The warrants and general design standards were developed from approximately 20 study sites in eight states: Arizona, Connecticut, Illinois, Michigan, New Jersey, Virginia, Wisconsin, and Wyoming.

The researchers identified 19 general design standards:

- The graphic component should portray only what is necessary for the driver to understand the required exit maneuver relative to the main roadway.
- The quantity of information on the diagrammatic sign must be limited.
- Graphics should basically adhere to the "plan" or "aerial" view but may be modified where necessary to ensure that the components of the graphic are clearly discernable.
- Deceleration lanes should not be depicted on the graphic components.
- Graphic components must not be separated.
- The through graphic component should be designed so that it is the visually dominant portion of the graphic (major fork is an exception).
- The length of the graphic must be adequate.

- Destination information must be clearly related to the appropriate arrow head.
- Lane lines should be present on graphic components.
- The route shield must not be substituted for the arrowhead.
- When two through route shields are required, the second should be positioned in line with the first.
- Route shields should be used as the reference points for formatting exiting information.
- Exiting information should not be placed so that it extends above the top of the route shield.
- Place names should be justified with the graphic side of the route shield.
- A left off-ramp tangential to the beginning of a curve in the through road should be shown as such.
- When the exit is accompanied by a single lane drop, the graphic on the diagrammatic sign should not be solely relied on to depict this condition.
- Addition of graphics cannot be accompanied by decreased letter sizes.
- The exit panel should be located above the destination information and be aligned with the right or left edge of the main sign as appropriate.
- Diagrammatic signs should not be positioned at the interchange gore location or at the beginning of the deceleration lane taper (if deceleration lanes present) but should be placed at all location in advance of these points.

Eye Tracking Research

One powerful research tool to study driver attention and sign reading is the use of eye tracking equipment. Older eye tracking equipment involved the use of headgear, often placed on motorcycle helmets, to monitor the location of eye fixations while driving or looking at a scene. Modern eye trackers are less intrusive and allow the use of dash-mounted cameras to monitor eye movements.

A recent study *(21)* used in-vehicle eye trackers to examine the effectiveness of ground-mounted diagrammatic guide signs placed before entrance ramps. The results indicate that the diagrammatic signs are not looked at excessively often or excessively long. The average look numbers and average look duration times indicated a normal and reasonable level of information

processing by the drivers. The values agreed with those found in earlier studies for regular traffic signs. The study recommends the use of diagrammatic signs on arterials approaching freeway interchanges.

Another recent study *(22)* used a laboratory eye tracker to examine eye scanning of day and nighttime roadway scenes. Subjects were seated in front of a computer monitor with their head in a chinrest. Photographs of roadway scenes were digitally manipulated to produce different levels of clutter and luminance. While this method allows for very exact eye tracking it is not practical to use a chinrest arrangement in a vehicle on the road. Another study using eye tracking examined lane change behavior *(23)*. This method, coupled with vehicle instrumentation, allows fine-grained analyses of driver attention and decision making while making lane change choices.

CHAPTER 2:
INTERCHANGE EXIT CONFIGURATIONS

After reviewing the literature, researchers compiled a "catalog" of interchanges, with emphasis on the configurations of various types of exits and approaches. In order to identify a wide variety of configurations that a Texas driver might encounter, researchers explored prevalent reference documents, including the TxDOT Roadway Design Manual and the American Association of State Highway and Transportation's (AASHTO) *A Policy on Geometric Design of Highways and Streets* (commonly known as the *Green Book*).

From these manuals, a total of 37 exit configurations, lane drops, and ramp alignments were identified and compiled for further review:

- 10 lane-drop exits,
- 9 ramp alignments,
- 4 two-lane exits,
- 3 split exits,
- 8 other exit lane configurations, and
- 3 arterial approaches to freeway ramps.

A number of these exit configurations were duplicates, in that they were left-hand exits that were mirror images of right-hand exits.

Researchers created diagrams of these configurations for presentation to the Project Monitoring Committee (PMC) for further review. Appendix A contains these diagrams. Discussions between researchers and the PMC centered on which of the configurations would benefit most from further study. The committee identified a number of situations where they felt diagrammatic signs would be especially beneficial:

- obstructed sight distance,
- closely spaced exits,
- lane splits,
- lane drops,
- multi-lane exits, and
- left-hand exits.

In general, these issues centered on one underlying question: what violates drivers' expectations? These issues may be manifested in geometry, sight distance, or crash history, but they are better identified in the design phase than after construction. Based on discussions with the PMC, researchers identified four exit configurations for further study:

- two-lane right-hand exit with optional lane,
- freeway to freeway split (major fork) with optional center lane,
- left lane drop, or left exit-only lane; and
- left optional exit.

CHAPTER 3:
PHASES 1 & 2 DRIVER COMPREHENSION TESTING USING POWERPOINT® SLIDES

MATERIAL PREPARATION

An advisory panel of state department of transportation district signing engineers collaborated to identify the sign designs to be tested. The sign layouts were drawn in SignCAD ™ software using standard conventions of text, route shield, and cardinal direction placement. These signs were then saved as bitmap files with further changes and refinements made in a more flexible drawing software package. Photographs of freeway scenes from the driver's perspective were taken on a variety of roadways. Researchers then removed the existing signs in these photographs and placed the test signs in the appropriate positions.

Left Exits (LE)

Figure 19 shows the signs selected for left optional exits from two lane freeways. The signs designs were from the following sources:

- LE-1 is the standard text sign recommended in the Freeway Signing Handbook (1) Figure 5-6 and was positioned over Lane 1 in the test photograph.
- LE-2 was developed by the researchers and is based on the modified diagrammatic signs recommended by an earlier TTI study (*8*) and incorporated in the Older Driver Handbook. It was positioned over the roadway centerline.
- LE-3 is the diagrammatic design recommended in the Federal MUTCD with the optional LEFT EXIT on the exit number plaque. It was positioned over the roadway centerline.
- LE-4 was added in Phase 2 and was an improved design of LE-3 with a wider through arrow allowing lane lines to be added. It is identical to Figure 2E-3 in the Texas MUTCD and includes the word LEFT in the exit number plaque.

Left Lane Drops (LLD)

Three-lane freeways with lane drop left exits were also tested and are shown in Figure 20. Six sign alternatives were designed as follows:

- LLD-1 is the standard text sign recommended in the Freeway Signing Handbook (1) Figure 5-7 and was positioned over Lane 1 in the test photograph.

- LLD-2 is the diagrammatic design recommended in the Federal MUTCD with the optional LEFT EXIT on the exit number plaque and the optional EXIT ONLY plaque on the sign face. It was positioned over the roadway centerline.
- LLD-3 is the diagrammatic design recommended in the Federal MUTCD with the optional yellow LEFT EXIT on the exit number plaque. It was positioned over the roadway centerline.
- LLD-4 is the diagrammatic design recommended in the Federal MUTCD without any of the optional plaques. This sign likely represents many diagrammatic signs installed prior to the addition of the optional plaques in the recent revision of the MUTCD. It was positioned over the roadway centerline.
- LLD-5 was developed by the researchers and is based on the modified diagrammatic signs recommended in the Older Driver Handbook. It was positioned over the roadway centerline.
- LLD-6 was developed by the researchers to incorporate several principals present in the previous signs. The through lane width was doubled, and lane lines were added to more accurately represent the lane geometry when compared to the MUTCD designs. The separate exit arrow element was derived from the modified diagrammatic sign which uses a single arrow to represent each lane. The EXIT ONLY plaque listed as an option in the MUTCD was also incorporated. It was positioned over the roadway centerline.
- LLD-7 was added in Phase 2. It was a version of the MUTCD diagrammatic without lane lines and can be compared to LLD-4.
- LLD-8 was added in Phase 2. It is based on lane assignment signs used in the Houston District for over 15 years which were derived from an earlier TTI study (*8*). These signs typically contain route markers only with no destination names. They are generally mounted on the side of the freeway on a large pedestal structure which brings them to the height of an overhead sign. Not that this sign does not contain cardinal directions or destination names. As such there are fewer units of information present on the sign compared to the others in this set.

Right Exits with Optional Lanes (REO)

This configuration has been the focus of much research and is becoming a common roadway geometry *(17)*. Figure 21 shows the signs tested for this lane configuration which were derived from the following sources:

- REO-2 is the standard Texas text alternative as shown in the Freeway Signing Handbook Figure 5-4. This sign was positioned over Lanes 2 and 3.
- REO-3 is a design found in Ontario where only the exit destination is listed and no through route information is provided. This sign was positioned over Lanes 2 and 3.
- REO-4 is a modified diagrammatic sign based on the Older Driver Handbook. It was positioned over the centerline of the roadway and includes an arrow for each lane of travel.
- REO-5 was added in Phase 2 and is a modified diagrammatic like REO-4 with the addition of an EXIT ONLY plaque.
- REO-6 was added in Phase 2 and is based on signs used in the Houston District, similar to LLD-8. Note that no destination name or cardinal directions are present, producing fewer units of information on the sign.
- REO-7 is the standard MUTCD advance sign, including the lane lines and exit number plaque. This sign was positioned over the centerline of the roadway.

Freeway to Freeway Splits (SPLT)

Researchers tested signs for freeway to freeway splits for three-lane freeways where the center lane has the option of taking either leg of the split (see Figure 22). All signs were positioned over the centerline of the roadway in the photographs. The signs were drawn from current practice and MUTCD recommendations as follows:

- SPLT-1 is the diagrammatic sign recommended in the MUTCD without lane lines. The presence of an exit number plaque on the left leg implies that leg is an exit and the right leg is the continuing route.
- SPLT-2 is a recommendation from the Texas Freeway Signing Handbook *(1)* Page 5-15. Note that this design favors the left leg as an exit and the right leg as a through route.

- SPLT-3 was designed after a sign currently in use in Minnesota. The three down arrows correspond directly to the three lanes, and the centering of the exit number plaque is intended to reinforce the message that both left lanes can access the left leg of the split.
- SPLT-4 is the current Texas practice. This design contains no exit number plaque and has four down arrows with the center two arrows both pointing to the center lane. Previous focus groups indicated good understanding of this design *(1)*.
- SPLT-5 was added in Phase 2 and is identical to SPLT-1 except for the addition of lane lines.

Table 3 lists all of the signs studied in Phases 1 and 2.

Table 3. Signs Studied for Phases 1 and 2.

Sign	Phase 1	Phase 2	Description
LE-1	√	√	Standard text sign recommended in Freeway Signing Handbook
LE-2	√	√	Modified diagrammatic based on TTI Study (*8*) and Older Driver Handbook
LE-3	√	√	Diagrammatic based on Federal MUTCD with narrow through lane leg
LE-4		√	Diagrammatic from Figure 2E-3 in the TX MUTCD
LLD-1	√	√	Standard text sign recommended in Freeway Signing Handbook
LLD-2	√	√	Diagrammatic based on Federal MUTCD
LLD-3	√	√	Diagrammatic based on Federal MUTCD
LLD-4	√	√	Diagrammatic based on Federal MUTCD
LLD-5	√	√	Modified Diagrammatic based on Older Driver Handbook
LLD-6	√	√	Combines several principles of other signs
LLD-7		√	Identical to LLD-4 without the lane lines
LLD-8		√	Modified Diagrammatic in use in Houston, no cardinal directions or destination names used
REO-2	√	√	Standard TX MUTCD text sign
REO-3	√	√	Ontario diagrammatic sign
REO-4	√	√	Modified Diagrammatic based on Older Driver Handbook
REO-5		√	Modified Diagrammatic with EXIT ONLY plaque
REO-6		√	Modified Diagrammatic in use in Houston, no cardinal directions or destination names used
REO-7	√	√	Combination of TX MUTCD, Federal MUTCD, and TX Freeway Signing Handbook
SPLT-1	√	√	Diagrammatic based on Federal MUTCD
SPLT-2	√	√	Based on the TX Freeway Signing Handbook
SPLT-3	√	√	Minnesota design with 3 down arrows
SPLT-4	√	√	Current TX practice with 4 down arrows
SPLT-5		√	Identical to SPLT-1 without lane lines

EXPERIMENTAL METHOD

Research Participants

Researchers tested a total of 210 participants in five Texas cities in small groups of 8 – 10 people. Testing was completed in Arlington, Waco, San Antonio, New Braunfels, and Houston. Participants ranged in age from 19 to 67, and all had a valid Texas driver's license. Participants were recruited through flyers and personal contacts and were each paid $40 for their attendance.

Data Collection

The PowerPoint slide show was displayed on a portable projection screen measuring six feet square. Each participant was given a response sheet that contained the question numbers and the options: Lane 1 Lane 2 Lane 3. They were instructed to circle the lane or lanes that were applicable to each given destination question. The experimenter controlled the onset of each question after assuring that all participants were ready.

As mentioned earlier, data was collected in two phases with slight changes in the procedure between phases. After reviewing the results from Phase 1 and speaking with participants, it was clear that they were prone to circling a single response even when more than one lane was correct and the instructions told them they could circle multiple items. The response forms were changed in Phase 2 to add explicit options "Lanes 1 & 2" and "Lanes 2 & 3" where appropriate, so respondents would only have to circle a single response. Another addition in Phase 2 testing was a confidence rating scale which asked participants to rate their confidence in the correctness of their response on a 1 to 10 scale with 1 labeled "Not at all confident" and 10 labeled "Very confident."

Researchers prepared two versions of a PowerPoint slide show that included the 17 test signs in random order. Half of the questions gave the exit direction as the destination and half gave the through direction. The questions were reversed across the two versions of the survey. At any one testing session all participants saw the same version. Across the entire study the two versions were administered an equal number of times. The experimental signs were mixed in with 12 filler questions that asked subjects to recall the text on warning and regulatory signs.

The stimulus presentation is shown in Figure 18 and was performed as follows:

- Cued the slide that announced the upcoming question number and stated the current position and destination represented in the photo – for example, "You are currently on Interstate 61 North, you want to go West on U.S. Highway 56 to Lindale."
- Presented test sign photograph for 3 seconds. The duration was determined during pilot testing.
- Re-stated the question superimposed on a photograph of the identical roadway scene without the signs present. Lane numbers were also superimposed in appropriate positions to assist subjects understanding of the question.

Appendix D contains the informed consent forms and sample answer sheets. Appendix B contains the PowerPoint slides used, which include instructions, for Phase 1 and 2.

Question 1.

You are driving North on Interstate 36 and want to exit on U.S. Highway 15 to Tudor.

SLIDE 1: Experimenter Controlled

SLIDE 2: Shown for 3 seconds

SLIDE 3: Experimenter Controlled

Figure 18. Experimental Procedure for One Test Sign.

RESULTS OF PHASES 1 & 2 POWERPOINT TESTING

As the testing was done with two slightly different methods, it follows that the results from these methods were different. With the exception of the Left Exit signs, each sign group had a significantly higher percentage of correct responses in Phase 2 when compared to Phase 1 (LLD's $z = -5.89$, $p<.001$; REO's $z=-3.44$, $p<.001$; SPLT's $z=-7.34$, $p<.001$). In the case of the Left Exit signs, participants actually responded with significantly more accuracy in Phase 1 (LE's $z = -1.69$, $p<.005$). The data comparing correct response percentages is displayed below in Table 4. Data presented in Table 4 only includes signs considered in both Phase 1 and Phase 2.

Table 4. Overall Sign Group Data, Phase 1 vs. Phase 2.

	Percentage of Correct Responses		
Sign Group	**Phase 1**	**Phase 2**	**Overall**
Left Exit	60.4%	53.6%	56.2%
Left Lane Drop	56.7%	72.9%	66.7%
Right Exit Optional	35.0%	48.7%	43.5%
Freeway-to-Freeway Split	41.3%	66.5%	56.9%

Despite these significant differences, the increase in correct response percentage from Phase 1 to Phase 2 was fairly uniform, so between-sign performance was very similar between phases. The exception is the obvious case of signs only considered in Phase 2: LE-4, LLD-7, LLD-8, REO-5, REO-6, and SPLT-5. In three of the four sign groups, the sign receiving the most accurate responses was one of these six designs. These designs clearly benefited by avoiding Phase 1 testing and thus receiving inflated response accuracy relative to the other signs. This is one reason further testing is necessary to validate the results presented in this section. In general, for the purpose of this report, overall response percentages will be used when combining data from both phases for signs tested in both phases.

Left Exit

The overall results for the Left Exit signs indicate that participants correctly interpreted LE-4, the modified MUTCD diagrammatic sign with dashed lane lines, more consistently than the other three options. For LE-4, participants correctly identified the left lane (Lane 1) as the target in 92% of the trials when asked to take the exit route. This was matched only by LE-1 (the current standard Texas sign), which also received correct responses in 92% of the trials under the

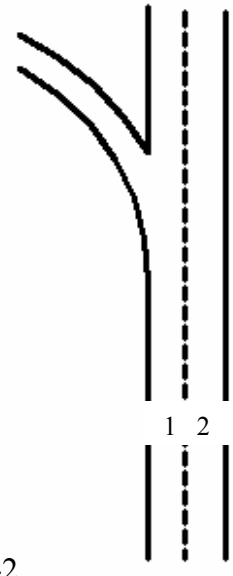
exit condition. While these two signs performed similarly under the exit condition, LE-4 significantly outperformed LE-1 in regard to the through condition ($z=3.57$, $p<.001$). This was also seen in the case of LE-3, which performed comparably well to LE-4 under the exit condition but received correct responses only 19% of the time under the through condition.

In the case of the Left Exit signs under the through condition, all three possible response choices ("Lane 1," "Lane 1 and 2," "Lane 2") would actually get the participants where they needed to go, but LE-4 showed the highest level of comprehension as participants correctly chose "Lanes 1 and 2" as their response in 53% of the trials. This constituted a significantly higher percentage of correct answers than the second best performing sign under this condition (LE-2, $z= 2.69$, $p<.004$). LE-2 did perform second best by this measure but with only 30% correctly choosing "Lanes 1 and 2." Despite the fact that in the case of all four signs participants had some trouble identifying "Lanes 1 and 2" as the correct choice in the through condition, an irregularly high percentage (22%) of participants in the case of LE-1 chose only "Lane 1" as their response. "Lane 1" was only chosen about 1% of the time in the case of the three other Left Exit signs (LE-2, LE-3, LE-4) under the through condition.

The confidence ratings for the Left Exit signs seemed to reflect the trends discussed above. Participants indicated that they were most confident using LE-2 to navigate the through route (average confidence (Avg. Conf). score = 9.2) and LE-1 to navigate the exit route (average conf. score = 9.1). The inverse of these paths through (LE-2 exit, LE-1 through) received the lowest scores within this section. The LE-1 through route scored especially poorly (average conf. score = 7.3), receiving the second lowest score throughout the entire study. As stated above, LE-4 proved to be the overall best Left Exit sign, as both its exit and through routes received the highest average confidence scores (9.1, 9.2 respectively) for this road geometry.

LE-4 had a smaller sample size than the other three Left Exit signs and was only tested in Phase 2, with the exit condition tested 83 times and the through condition tested 47 times. The other three signs each had over 100 trials for both the exit and through conditions. Figure 19 presents these results and sample sizes.

- Numbers represent percentage of responses for each category.
- Correct response percentages are shown in bold.



	# of trials	Lane 1	Lanes 1 & 2	Lane 2	Avg Conf
Exit	103	**92**	2	5	9.1
Through	107	22	**23**	54	7.3

LE-1

	# of trials	Lane 1	Lanes 1 & 2	Lane 2	Avg Conf
Exit	107	**86**	10	4	8.7
Through	103	1	**30**	68	9.2

LE-2

	# of trials	Lane 1	Lanes 1 & 2	Lane 2	Avg Conf
Exit	107	**85**	7	7	8.7
Through	103	0	**19**	80	9.0

LE-3

	# of trials	Lane 1	Lanes 1 & 2	Lane 2	Avg Conf
Exit	83	**92**	7	1	9.1
Through	47	0	**53**	47	9.2

LE-4

Figure 19. Left Exit Advanced Guide Sign Alternatives and Responses.

Left Lane Drop

The results for the Left Lane Drop sign alternatives produced one sign which clearly out performed the other seven but with an even smaller sample size than was seen with LE-4 (the best Left Exit sign). The first choice Left Lane Drop sign, LLD-8, received 100% correct

responses in both the exit and the through conditions although it was tested only in Phase 2. Under the exit route condition, LLD-1 (the current Texas standard) performed second best, producing correct responses 92% of the time. This performance level was significantly lower than the 100% produced by LLD-8 ($z= 2.95$, $p <.004$) and significantly higher than the third best sign, LLD-6 ($z=3.68$, $p<.001$).

An even larger gap existed between LLD-8 and the next best sign when participants were asked to take the through route. Participants responded correctly to this second best sign, LLD-6, only in 75% of the trials under the through condition. This response was significantly worse than LLD-8 ($z=5.90$, $p <.001$). It should be noted that LLD-8 was not tested in Phase 1 when scores for the Left Lane Drop signs were significantly lower than in Phase 2. When LLD-8 was compared to LLD data from Phase 2 only, it still performed significantly better than the next best sign under both exit and through conditions.

LLD-3 performed the worst of the Left Lane Drop signs, receiving the lowest percentage of correct responses for both the exit (57% correct) and the through (54% correct) condition.

LLD-7 received scores placing it near the middle of the group, but under the through condition 13% of participants incorrectly responded that all lanes would get them to their destination. Only one other sign received incorrect "All lanes" responses in more than 6% of trials.

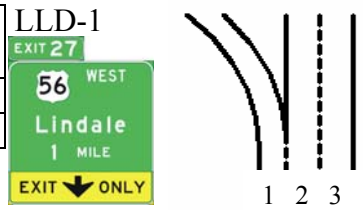
Like the Left Exit signs, the Left Lane Drop signs received confidence scores that basically agreed with their performance. LLD-8 received the highest average confidence scores of all the Left Lane Drop signs for both the exit and the through routes (9.4 and 9.1 respectively). LLD-4, LLD-5 and LLD-7 received the lowest average confidence scores. LLD-3, the sign that performed the worst, actually received confidence scores higher than 3 other signs (LLD-4, LLD-5, and LLD-7).

While the exit route for LLD-1 was easily understood (Avg Conf score = 9.3) under the through condition, it received a fairly low average confidence score of only 8.5 under the exit condition.

The exit route and through route results for LLD-8 were collected from sample sizes of 17 and 32 trials respectively. The comparable exit route results for LLD-1 and the through route results for LLD-6 were both collected from sample sizes of 103 subjects. These results and sample sizes are presented in Figure 20 below.

	# of trials	Lane 1	Lanes 1 & 2	Lane 2	Lanes 2 & 3	Lane 3	Avg Conf
Exit	103	**92**	4	0	2	0	9.3
Through	107	6	3	9	**61**	19	8.5

LLD-1



	# of trials	Lane 1	Lanes 1 & 2	Lane 2	Lanes 2 & 3	Lane 3	Avg Conf
Exit	107	**76**	14	7	0	2	8.9
Through	103	1	1	10	**74**	14	9.0

LLD-2

	# of trials	Lane 1	Lanes 1 & 2	Lane 2	Lanes 2 & 3	Lane 3	Avg Conf
Exit	103	**57**	34	4	3	0	8.6
Through	107	2	4	21	**54**	20	8.9

LLD-3

	# of trials	Lane 1	Lanes 1 & 2	Lane 2	Lanes 2 & 3	Lane 3	Avg Conf
Exit	107	**64**	15	16	3	2	8.6
Through	103	3	3	16	**56**	19	8.2

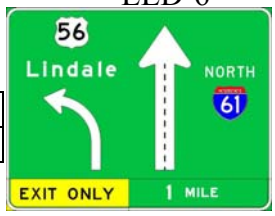
LLD-4

	# of trials	Lane 1	Lanes 1 & 2	Lane 2	Lanes 2 & 3	Lane 3	Avg Conf
Exit	103	**63**	27	9	3	0	7.4
Through	107	0	0	23	**55**	20	8.2

LLD-5

	# of trials	Lane 1	Lanes 1 & 2	Lane 2	Lanes 2 & 3	Lane 3	Avg Conf
Exit	107	**74**	8	6	0	3	9.1
Through	103	0	2	10	**75**	14	8.7

LLD-6



	# of trials	Lane 1	Lanes 1 & 2	Lane 2	Lanes 2 & 3	Lane 3	Avg Conf
Exit	83	**78**	17	2	2	0	8.4
Through	47	4	0	13	**66**	4	8.5

LLD-7

	# of trials	Lane 1	Lanes 1 & 2	Lane 2	Lanes 2 & 3	Lane 3	Avg Conf
Exit	17	**100**	0	0	0	0	9.4
Through	32	0	0	0	**100**	0	9.1

LLD-8

Figure 20. Left Lane Drop Sign Alternatives and Responses.

Right Exit Optional

For the Right Exit Optional signs, REO-6 produced much higher response accuracy under both conditions than any of the other five signs. Participants responded to correctly 94% of the time under the exit condition and 88% of the time under the through condition for this sign. Again though, REO-6 had a relatively small sample size with only 34 participants viewing the exit condition and 17 viewing the through condition. Also like LLD-8, REO-6 was not tested in Phase 1.

REO-4 also performed relatively well under both conditions, receiving correct responses 52% of the time under the exit condition and 62% of the time under the through condition. Both of these scores were significantly lower than those received by REO-6 (exit route, $z=4.89$, $p<.001$; through route, $z=4.30$, $p<.001$). When comparing data from Phase 2 only, REO-6 still performed significantly better under both conditions (exit route, $z=2.95$, $p<.002$; through route, $z=4.17$, $p<.001$) than REO-4, the second best performing sign.

REO-3 performed the worst among the Right Exit Optional signs, as 35% of participants indicated that they should be in the left lane to follow the exit route (leading to the right). No other sign had more than 5% of participants respond this way. REO-3 performed so poorly that it was not tested in Phase 2 of the study; therefore no confidence scores were collected.

REO-2 also performed fairly poorly. In the case of the exit route, only 18% of participants correctly indicated that they could be in either Lane 2 or Lane 3. Over all of the 23 signs tested, a score of 18% correct was the second lowest score received (SPLT-2, exit route, scoring 4% correct). Fifteen percent of participants incorrectly indicated that "All Lanes" was the correct response (and thus any lane would lead them to their destination) this contributed to the low score given to REO-2. Only one other question elicited "all lanes" response percentages over 6%.

Again, for the most part, the results of the trials agree with the participants' confidence scores. Of the Right Exit Optional signs, REO-4 produced the highest average confidence score (8.7) when both the scores for the exit and the through route were averaged together. One trend evident in each sign category was the tendency for a sign to do very well under one condition and very poorly under the other. This tendency was especially evident here. While the exit route for REO-2 received the highest score in this section (avg. conf. score= 9.3), its complement under the through condition received the lowest score (avg. conf. score = 6.5) over the entire

study. REO-6 showed a similar pattern, receiving the second highest average confidence score under the through condition (8.9) but the second lowest score under the exit condition (7.8).

These results and sample sizes are presented in Figure 21.

Freeway to Freeway Splits

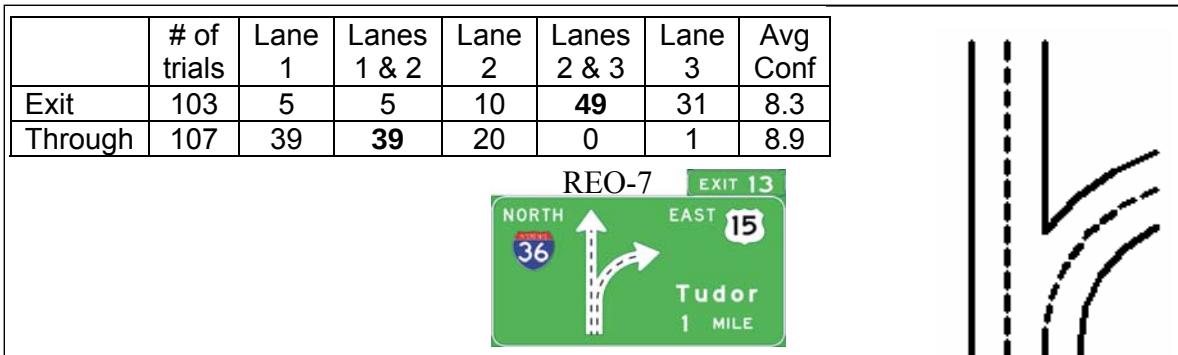
As with the other sign types, one sign clearly outperformed the others in the Freeway to Freeway Splits type. In this case though, the most accurately read sign also had a relatively large sample size (while the most accurately read signs for the Left Lane Drop and the Right Exit Optional patterns had disproportionately smaller sample sizes). SPLT-4 received correct scores 78% of the time under the exit condition and 84% of the time under the through condition. The 78% SPLT-4 received in the exit condition is significantly higher than the next closest sign, SPLT-3, which only received a score of 64% correct ($z=2.17$, $p<.015$).

SPLT-4 received a score of 84% in the through condition which was second only to SPLT-2 at 88%. In the exit condition, though, SPLT-2 received a score of only 4% correct, basically eliminating it from serious consideration. The lowest score received by any sign, for any road geometry was 4%. While the correct response under the exit route condition for SPLT-2 was "Lanes 1 and 2," 92% of participants indicated that only Lane 1 would get them to their correct destination.

The confidence scores for the Freeway-to-Freeway Split generally paralleled the accuracy of the participant responses with one major exception. For sign SPLT-2, under the exit condition, participants felt very confident in their responses, resulting in an average confidence score of 9.3 (second highest throughout the study), while responding correctly only 4% of the time. Conversely, in the case of SPLT-2 under the through condition, participants were even more confident in their responses (avg. conf. score = 94%), and were able to support this confidence by responding correctly to 88% of the trials. SPLT-4, the sign receiving the most accurate responses over the combination of both conditions in the Freeway-to-Freeway Split category, received the second highest confidence ratings (avg. conf. scores = 9.0, exit; 9.1, through).

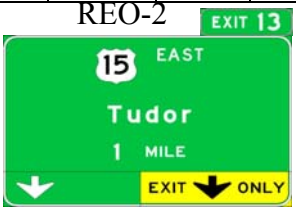
These results and sample sizes are presented in Figure 22.

	# of trials	Lane 1	Lanes 1 & 2	Lane 2	Lanes 2 & 3	Lane 3	Avg Conf
Exit	103	5	5	10	**49**	31	8.3
Through	107	39	**39**	20	0	1	8.9



	# of trials	Lane 1	Lanes 1 & 2	Lane 2	Lanes 2 & 3	Lane 3	Avg Conf
Exit	107	4	1	7	**18**	58	9.3
Through	103	17	**42**	9	3	11	6.5

REO-2

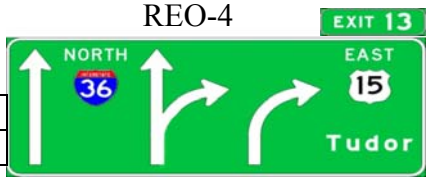


	# of trials	Lane 1	Lanes 1 & 2	Lane 2	Lanes 2 & 3	Lane 3	Avg Conf
Exit	20	35	5	15	**30**	15	-
Through	60	32	**25**	33	2	7	-

REO-3

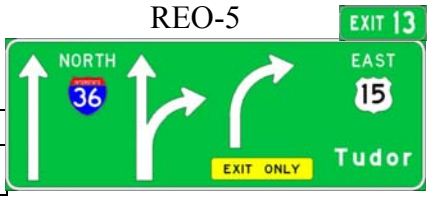
	# of trials	Lane 1	Lanes 1 & 2	Lane 2	Lanes 2 & 3	Lane 3	Avg Conf
Exit	107	2	0	1	**52**	45	8.7
Through	103	33	**62**	3	2	0	8.8

REO-4



	# of trials	Lane 1	Lanes 1 & 2	Lane 2	Lanes 2 & 3	Lane 3	Avg Conf
Exit	83	1	5	2	**20**	70	8.6
Through	47	21	**64**	2	9	0	8.0

REO-5

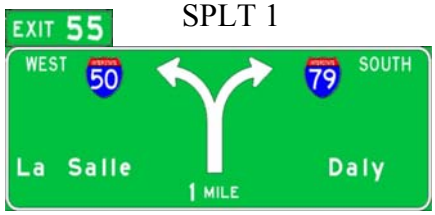


	# of trials	Lane 1	Lanes 1 & 2	Lane 2	Lanes 2 & 3	Lane 3	Avg Conf
Exit	34	0	3	0	**88**	6	7.8
Through	17	0	**94**	0	0	0	8.9

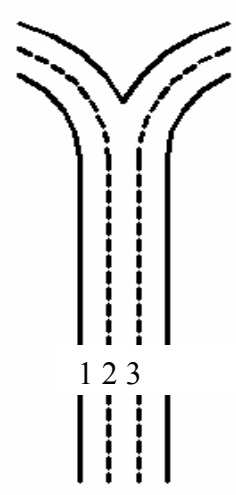
REO-6

Figure 21. Right Exit with Optional Lane Advance Guide Sign Alternatives and Responses.

	# of trials	Lane 1	Lanes 1 & 2	Lane 2	Lanes 2 & 3	Lane 3	Avg Conf
LaSalle	103	37	**58**	3	1	0	7.6
Daly	107	0	0	12	**36**	50	8.2



SPLT 1



SPLT-2

	# of trials	Lane 1	Lanes 1 & 2	Lane 2	Lanes 2 & 3	Lane 3	Avg Conf
LaSalle	107	92	**4**	3	0	2	9.3
Daly	103	1	2	6	**88**	2	9.4

SPLT-3

	# of trials	Lane 1	Lanes 1 & 2	Lane 2	Lanes 2 & 3	Lane 3	Avg Conf
LaSalle	103	31	**64**	2	3	0	8.0
Daly	107	2	2	6	**45**	42	8.5

SPLT-4

	# of trials	Lane 1	Lanes 1 & 2	Lane 2	Lanes 2 & 3	Lane 3	Avg Conf
LaSalle	107	17	**78**	4	1	1	9.0
Daly	103	0	3	4	**84**	8	9.1

SPLT-5

	# of trials	Lane 1	Lanes 1 & 2	Lane 2	Lanes 2 & 3	Lane 3	Avg Conf
LaSalle	47	28	**62**	6	2	2	8.6
Daly	73	0	0	4	**60**	24	8.7

Figure 22. Split Advance Guide Sign Alternatives and Responses.

DISCUSSION

Left Exit

While LE-1 did perform slightly better than LE-4 in the case of the exit route, the ambiguity apparent in LE-1's representation of the through route indicates it is not an ideal design. This is especially evident in the extremely low confidence score for the LE-1 under the through condition.

LE-3 also performed fairly well in terms of the exit route but again received a very low percentage of correct responses in terms of the through route. This is probably due to the lack of the dashed lane line being added, as LE-4 was almost identical to LE-3 (with the exception of this dashed lane line) yet received more than twice as many correct responses to the through condition.

Left Lane Drop

When comparing the performance of LLD-3 and LLD-4, the yellow "Left Exit" tab (on LLD-3) appears to be more effective than simply a green "Exit" tab (on LLD-4). While both signs performed poorly under the exit condition, in 16% of trials for LLD-4, participants responded that they could use only Lane 2 to follow the exit route (to the left). LLD-3 produced this error in only 4% of the trials. As these signs were identical other than the tabs, it is inferred that the addition of the word "left" on the tab of LLD-3 would effectively move drivers to the left lane from the center lane when trying to exit through a Left Lane Drop situation.

Regarding LLD-7, in 13% of trials participants somehow thought all lanes were appropriate for the through route. This impression could be attributed to the lack of dashed lane lines. When lane lines were added to LLD-7 (resulting in sign LLD-4), participants only indicated "all lanes" in 2% of trials. Although LLD-7 (no lane lines) produced a higher percentage of correct responses than LLD-4 (with lane lines) LLD-7 is not necessarily the better design. LLD-7 was not tested in Phase 1 where Left Lane Drop signs produced fewer correct responses than in Phase 2. Had LLD-7 been tested in both phases, it may have faired as bad as or worse than LLD-4 due to the lack of lane lines.

The perfect score received by LLD-8 is probably a result of using three discreet arrows to denote each of the three lanes. When comparing LLD-8 to LLD-5, one can see that using 2

arrows, especially of the same width, to represent 3 lanes confounded the participants. For the exit condition, participants could not be sure which of the arrows was representing 2 lanes, and in 27% of the trials, it is likely they assumed that the curved arrow stood for both Lanes 1 and 2, leading to them incorrectly selecting both "Lanes 1 and 2" as the exit route. For the through route, the same confusion likely led to the incorrect response of "Lane 3" in 20% of trials.

A different misunderstanding could have occurred if participants disregarded the road geometry on the slides and simply looked at the sign for their response. With only two arrows on the sign, if participants were not acutely aware that there were 3 lanes on the road, it would be apparent that the straight arrow on the right would represent the through route (and Lane 2), and the bent arrow on the left would represent the exit route (Lane 1). This confusion may have also led to sign LLD-5 receiving the lowest confidence scores in this section for both routes.

The high level of accuracy in responses to LLD-8 was definitely skewed somewhat as LLD-8 was not tested in Phase 1 where Left Lane Drop response accuracy was significantly lower.

Right Exit Optional

While signs REO-4 and REO-6 presented their information with a very similar diagram, REO-6 performed significantly better. This difference may be due to the simplified design of REO-6, presenting less extraneous information than REO-4. While the extra information presented by REO-4 was not needed to correctly respond in the context of this experiment, this information would likely be useful to a driver navigating unfamiliar roads. Also, as REO-6 was tested so few times, it is likely that this discrepancy between very similar signs may have been reduced had more trials been collected.

REO-2 under the exit condition seemed especially confusing for participants, receiving a very high confidence score yet receiving correct responses in only 18% of trials.

Freeway to Freeway Splits

Apparently the second downward facing arrow on sign SPLT-4 made it much clearer that the middle lane could be used for both the exit and the through routes. When the second arrow in the center of the sign was removed as in the case of sign SPLT-3, participants were much more likely to incorrectly select only one lane as their response.

Signs SPLT-1 and SPTL-5 are nearly identical, with the exception of the dashed lines added to SPLT-5 to indicate the different lanes. Thus, it can be inferred that the dashed lines were responsible for both the better accuracy and higher confidence elicited by SPLT-5.

Effects of EXIT ONLY Plaque

One interesting consistency found between sign REO-2 and sign SPLT-2 relates to the presence of a downward facing arrow and the words "EXIT ONLY." In both cases, it can be inferred that this demarcation led participants to believe the lane over which the arrow was pointing was their only option if they were asked to follow the exit route. This confusion is likely to have led participants in 58% of trials to incorrectly respond to REO-2 and in 92% of trials to incorrectly respond to SPLT-2. In the case of SPLT-2, the high average confidence score along with the extremely low response accuracy reinforces that this design is unacceptable for public use.

This method of indicating an exit lane was effective when used on the Left Lane Drop sign LLD-1; in this case, the only signage presented "EXIT ONLY" with a downward arrow over the sole exit lane. 93% of the trials produced correct responses for this sign. These results reinforce the conclusion stated in the previous paragraph that presenting "EXIT ONLY" with a downward arrow indicates to drivers (or at least to these participants) that the lane over which it is presented is the only lane option for exiting (as opposed to understanding that it actually indicates the only route available from that lane is the exit route). It just happens that in the case of the Left Lane Drop signs, the "EXIT ONLY" phrase would lead participants to the correct path regardless of whether they interpreted it in the correct manner or in the manner hypothesized above. If the phrase was interpreted as per the stated hypothesis (albeit incorrectly), it would serve to embolden participants to select only "Lane 1" as their response, leading to the high percentage of correct responses (and almost eliminating incorrect "Lanes 1 and 2" responses as were seen in LLD-3, -4, and -5). Also, the exit route for LLD-1 received an average confidence score of 9.3, the second highest throughout the study, indicating participants were sure that Lane 1 was their only option for exiting.

When "EXIT ONLY" was presented on other signs in different ways, it had a less predictable effect. Consistent with the paragraph above, for both LLD-6 and LLD-2, presenting "EXIT ONLY" over a lane that was truly the participants' only option for exiting proved

somewhat effective, as participants correctly responded to the exit conditions 74% and 76% of the time, respectively. Again though, it is impossible to tell in which way the participants were interpreting the sign, as either interpretation would lead them to respond correctly. The relatively high scores received by these two signs under the through condition would lead one to believe that participants interpreted EXIT ONLY as indicating that the left lane was for exiting only (the actual meaning), and thus Lane 2 and Lane 3 must be for following the through route.

This misinterpretation was again evident in sign REO-5. "EXIT ONLY" was presented on the right side of the sign, although either Lane 2 or Lane 3 could be used for the exit route. Predictably, in 70% of the trials, participants incorrectly responded that Lane 3 was their only option for exiting. This hypothesis was reinforced when comparing sign REO-4 and REO-5. REO-4 is almost identical to REO-5 with the exception that REO-5 contains the EXIT ONLY phrase and REO-4 does not. Confirming the hypothesis, participants responded incorrectly with the choice "Lane 3" in only 40% of the trials for REO-4. This difference indicates that the phrase EXIT ONLY would cause 25% of drivers to make an unnecessary lane change if they were trying to exit through a Right Exit Optional situation from the middle lane.

This hypothesis does not hold in the odd case of REO-3. In 35% of trials, participants incorrectly responded that they should be in the left lane to follow the exit route (to the right). This error is especially bad because being in the left lane may cause the driver to miss the exit or perhaps employ a dangerous, last minute driving maneuver to correct their course. It would seem that the presence of the EXIT ONLY phrase would cause more participants to choose only Lane 3 as their (incorrect) response, but for REO-3 that was not the case, as "Lane 3" was chosen in only 15% of the REO-3 exit route trials.

The misinterpretation of EXIT ONLY may occur in the signs recommended in the driving simulation research of Upchurch, et al. *(17)*. The recommended "Lane Designation Sign," presented at the gore, may mislead drivers trying to exit to change lanes from Lane 3 (third from left) to Lane 4 (right lane). Following the hypothesis presented above, drivers tend to incorrectly interpret the phrase "EXIT ONLY" to mean that the indicated lane is their only option to exit. Thus, drivers approaching the gore in Lane 3 would infer that the "exit (is) only" available exclusively from the right lane and make a sudden and potentially dangerous lane change.

A few differences are apparent when applying the previous hypothesis to the Upchurch recommendations. First, in the Upchurch sign, two arrows are presented pointing up and to the right; up arrows were not considered in this experiment. Also, as the sign in Upchurch is presented at or near the gore, drivers would likely have other visual clues to help them correctly visualize the road geometry.

Recommendations Based on Phases 1 and 2

Individual design elements were not tested in this study, but some assessment is possible by comparing across the sign groups. Whether or not to use lane lines in a large diagrammatic was tested for splits and left lane drops. In both cases the lane lines led to more correct responses. The modified diagrammatic style performed very well for the geometries with optional lanes but did quite poorly for the conventional left exit. The use of an EXIT ONLY panel on both the modified diagrammatic (REO-5) and a text sign (REO-2) seems to cause drivers to believe that they must use that lane if they want to exit. Phase 4 further investigated this trend.

This study demonstrates that digitally edited photographs can be used to assess sign comprehension. It also illustrates the iterative nature of freeway sign design. Future research could expand this type of testing to a national audience where local sign customs are more varied. The slide show presentation method makes a compact, inexpensive, and portable testing methodology. The methodology presented here is limited in that it is only testing comprehension well within the legibility zone. The advantage of diagrammatic signs may lie in their use of bold symbols which could be recognized much further away than similar text signs. The effect of sign sequencing was not tested in the current study. The advance guide sign works in concert with the exit direction sign to guide motorists. Future work should include both advance and exit direction sign designs.

Based on the results of the Phases 1 and 2 driver comprehension study, the following recommendations were made:

- **Left Exit -** The MUTCD diagrammatic sign (LE-4) is recommended for left exits, though the text sign over the exit lane (LE-1) performed adequately as well.
- **Left Lane Drop -** The modified diagrammatic (LLD-8) performed extremely well and the text sign over the exit lane (LLD-1) also is recommended. While LLD-8

produced perfect scores under both conditions, the sample size was so small that it is irresponsible to make conclusive statements about its effectiveness at this point.

- **Right Exit Optional-** The right exit with optional lane signs clearly showed an advantage for the modified diagrammatic design which shows an arrow for each lane (REO-6 and REO-4).
- **Freeway to Freeway Split-** The results show that the current Texas sign standards for freeway to freeway splits were well understood. These text signs are typically smaller than corresponding diagrammatic signs and thus could be fabricated and installed for less money.

The next phase of the research tested the best-performing sign designs from this study in an interactive driving simulator, similar to Upchurch et al. *(17)*. This method allowed the experimenters to control which lane a driver approaches an interchange from and allowed the full sign sequence (two advance signs and an exit direction sign) to be viewed. Lane selection in simulated driving may be a more realistic measure of effectiveness than stated behavior in response to static photographs.

CHAPTER 4:
PHASE 3 DRIVING SIMULATOR TESTING

For each of the four interchange types tested in Phases 1 and 2, the current Texas standard sign and the most promising diagrammatic alternatives were selected for testing in the driving simulator. The driving simulator was selected, as opposed to a field study, because it allowed multiple interchange types and several sign alternatives to be tested.

MATERIAL PREPARATION

Researchers developed full sign sequences for each interchange type. The sequences, following recommendations in the Freeway Signing Handbook *(1)*, included two advance guide signs and an exit direction sign. Some sign sequences contain pull-through signs for the continuation of the route, while some show only the exit signs. The presence or absence of pull-through signs in the experiment is in accordance with the Texas MUTCD. The conditions of when pull-through signs should be used, as stated in Section 2E.11 Pull-Through Signs of the Texas 2006 Edition MUTCD, are listed below.

> "Guidance: Pull-Through signs should be used where the geometrics of a given interchange are such that it is not clear to the road user as to which is the through roadway, or where additional route guidance is desired. Pull-Through signs with down arrows should be used where the alignment of the through lanes is curved and the exit direction is straight ahead, where the number of through lanes is not readily evident, and at multi-lane exits where there is a reduction in the number of through lanes."

The sign sequences tested are shown in Figure 23 through Figure 38. Each figure provides a short description of the source of the sign designs. Sign images were created using SignCAD ™ and Adobe Photoshop ™.

Signs Tested for Left Exits

LE-1
This sign sequence is based on the Texas Freeway Signing Handbook (Fig. 5-6).

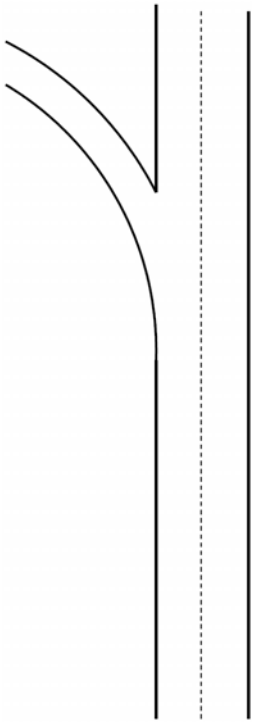


Figure 23. Simulator Sign Sequence LE-1.

LE-2
The exit direction sign is based on the Texas Freeway Signing Handbook (Fig. 5-6). The advance sign sequence is based on TTI Research Report 957-1 (*8*).

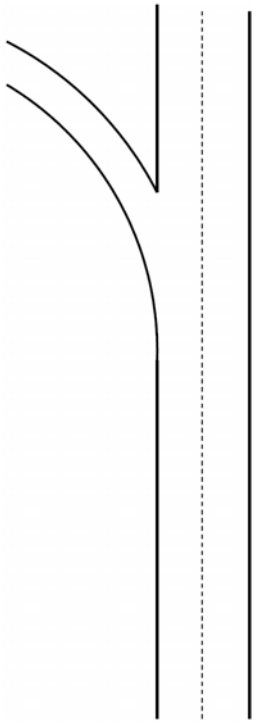


Figure 24. Simulator Sign Sequence LE-2.

LE-4
The exit direction sign is based on the Texas Freeway Signing Handbook (Fig. 5-6). The advance sign sequence is based the Texas 2006 Edition MUTCD (Fig. 2E-3). The exit number plaque does not contain the word LEFT, as shown in the MUTCD, in order to be consistent among test signs.

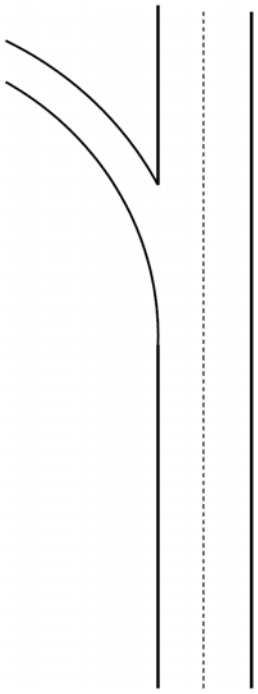


Figure 25. Simulator Sign Sequence LE-4.

Signs Tested for Left Lane Drop Exit

LLD-1
This sign sequence is based on the Texas Freeway Signing Handbook (Fig. 5-7) with the destination name and the route marker changed and the cardinal direction added.

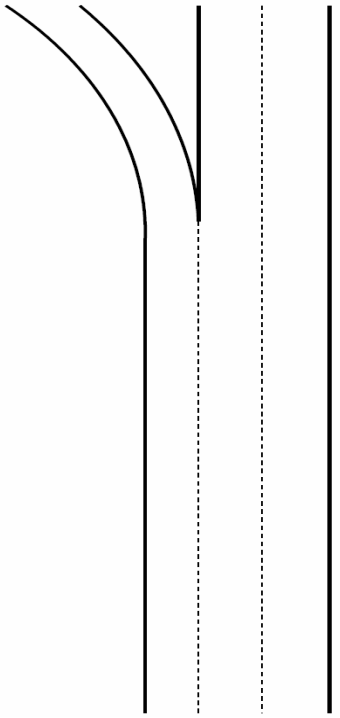


Figure 26. Simulator Sign Sequence LLD-1.

LLD-2

The sign sequence is based on the Texas 2006 Edition MUTCD (Fig. 2E-8) with the addition of a down arrow in the EXIT ONLY plaque. For Phase 1 & 2 testing, the exit number plaque contained the words LEFT EXIT. For Phase 3, the word LEFT was omitted to provide consistency among test signs.

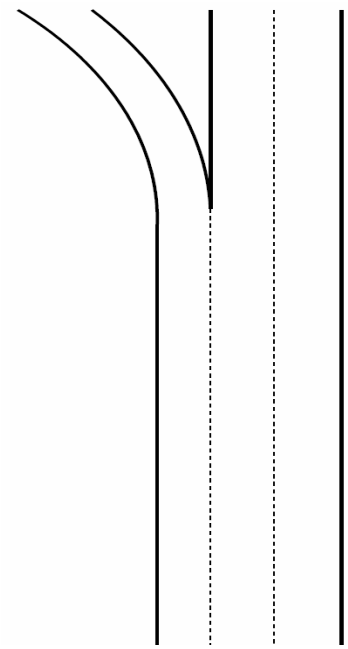


Figure 27. Simulator Sign Sequence LLD-2.

LLD-6
The exit direction sign is based on the Texas Freeway Signing Handbook (Fig. 5-7). The advance sign sequence was developed by the researchers.

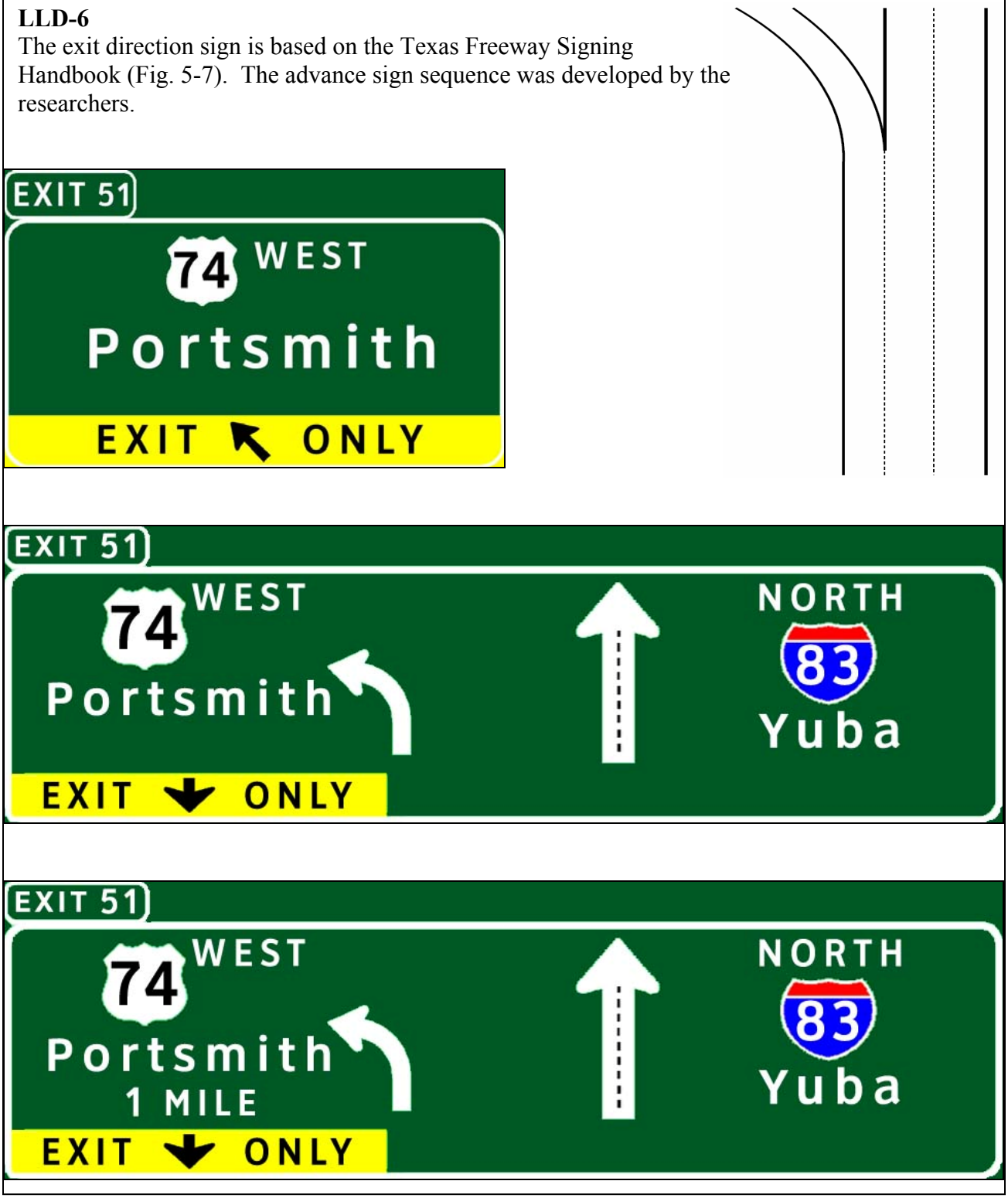
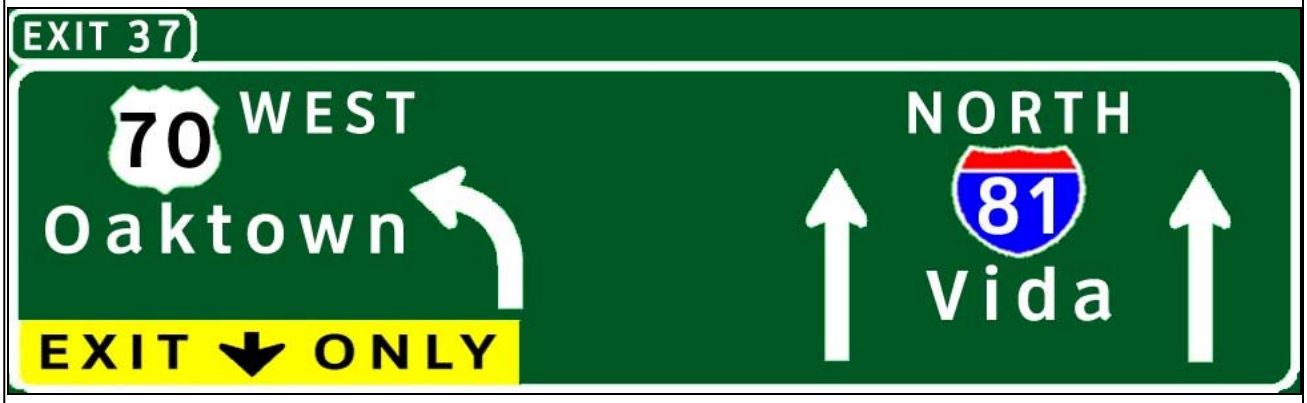


Figure 28. Simulator Sign Sequence LLD-6.

LLD-9
The exit direction sign is based on the Texas Freeway Signing Handbook (Fig. 5-7). The advance sign sequence is Modified Diagrammatic based on signs seen in Ontario and Houston.



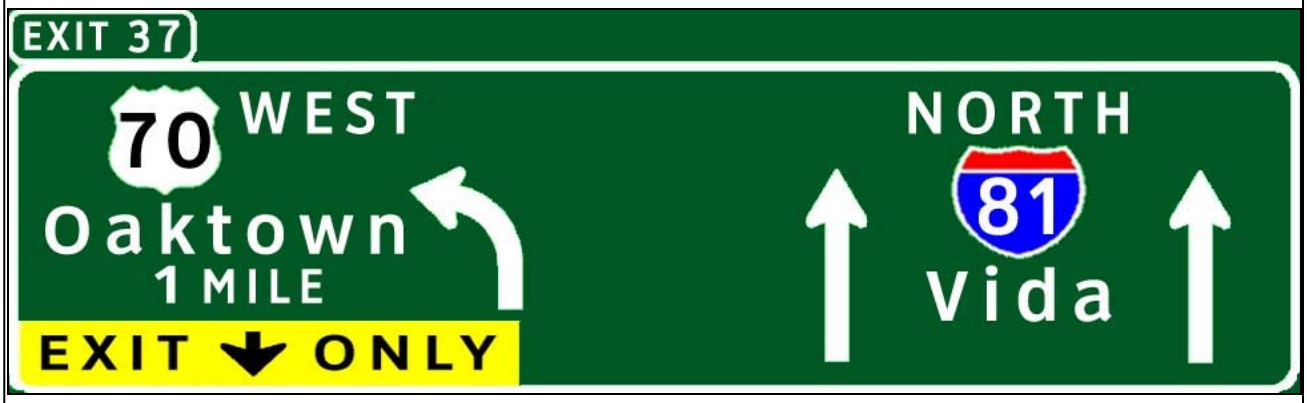


Figure 29. Simulator Sign Sequence LLD-9.

Signs Tested for Two Lane Right Exit with Optional Lane

REO-1

The left side of the exit direction sign is based on the Texas 2006 Edition MUTCD (Fig. 2E-7). The right side of the exit direction sign is based on the Texas Freeway Signing Handbook (Fig. 5-4). The diagrammatic advance sign is based on the Texas MUTCD (Fig. 2E-7).

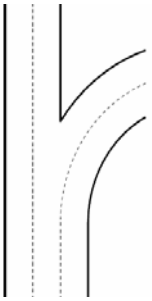


Figure 30. Simulator Sign Sequence REO-1.

REO-2
The sign sequence is based on Texas Freeway Signing Handbook (Fig. 5-4).

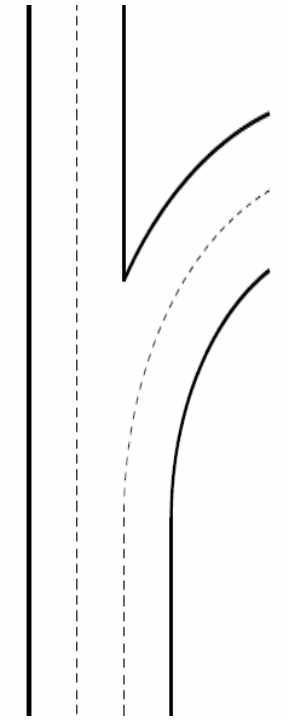


Figure 31. Simulator Sign Sequence REO-2.

REO-4

The left side of the exit direction sign is based on the Texas 2006 Edition MUTCD (Fig. 2E-7). The right side of the exit direction sign is based on the Texas Freeway Signing Handbook (Fig. 5-4). The advance sign sequence is a Modified Diagrammatic based on the Older Driver Handbook.

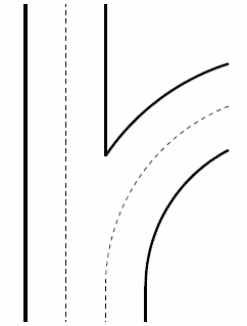
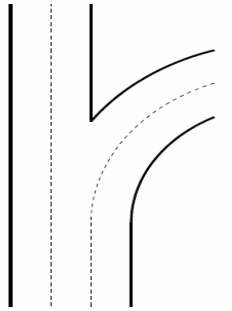
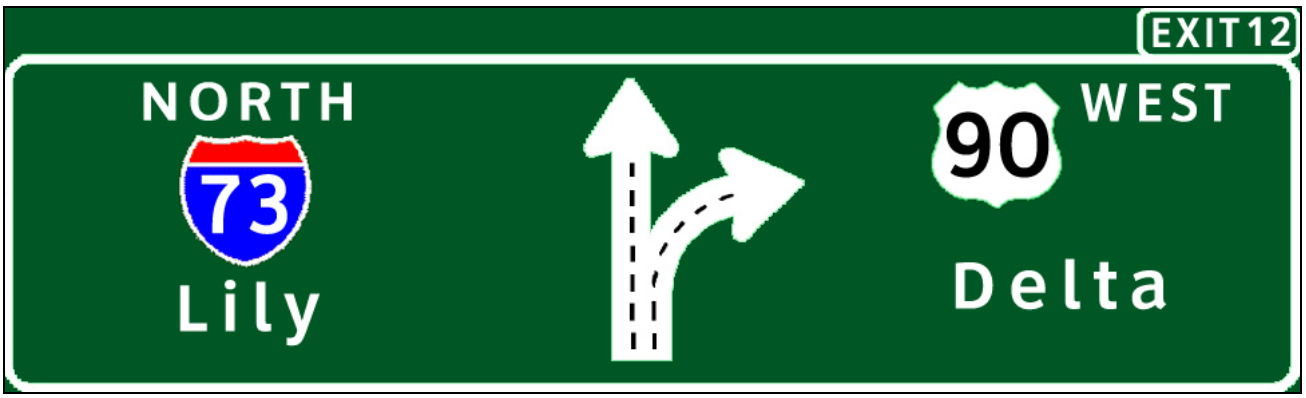


Figure 32. Simulator Sign Sequence REO-4.

REO-7

This sequence was the final recommendation from the NCHRP research by Upchurch, Fischer, and Waraich (17). The right side of exit direction sign shows two up arrows in the EXIT ONLY plaque.





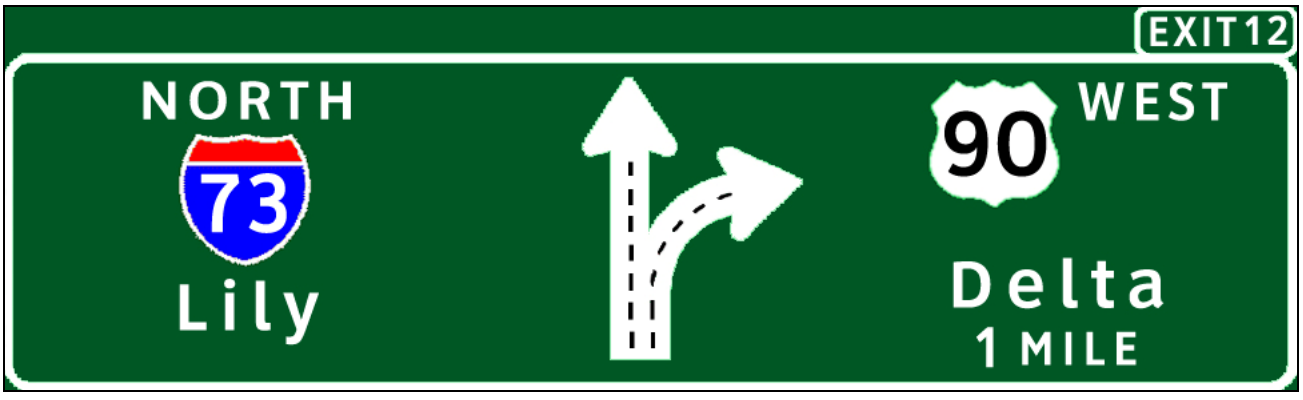
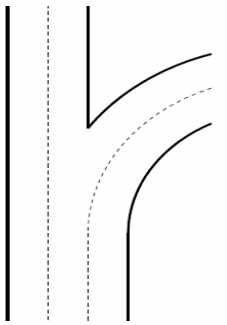


Figure 33. Simulator Sign Sequence REO-7.

REO-8
The sign sequence is based on the Texas 2006 Edition MUTCD (Fig. 2E-7).



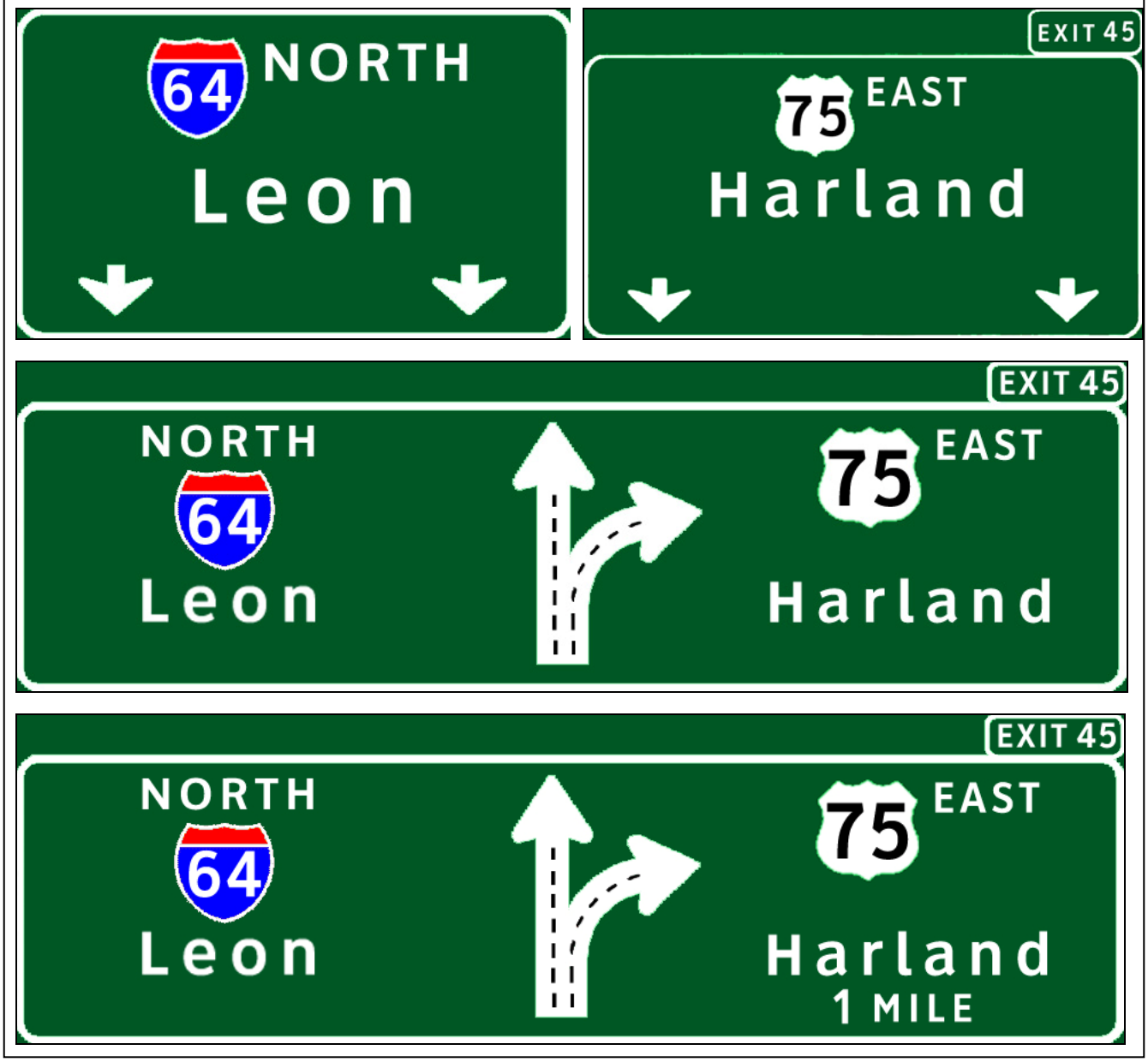
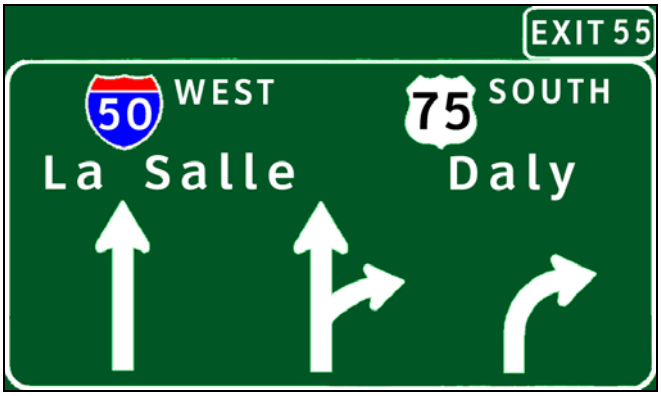
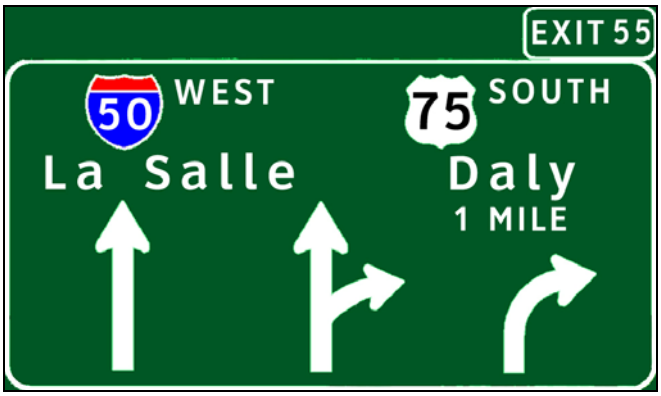


Figure 34. Simulator Sign Sequence REO-8.



REO-9
The left side of the exit direction sign is based on the Texas 2006 Edition MUTCD (Fig. 2E-7). The right side of the exit direction sign is based on the Texas Freeway Signing Handbook (Fig. 5-4). The Modified Diagrammatic advance sign sequence is based on Type II and signs tested by Upchurch, et al. (*17*). The first two signs of the sequence are ground-mounted on the right-hand side of the roadway, while the exit direction signs are mounted overhead.



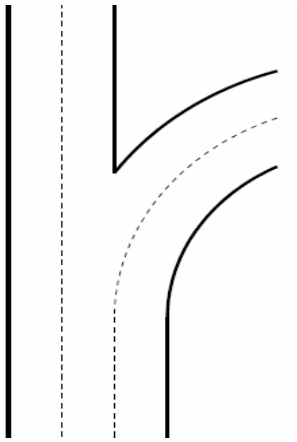
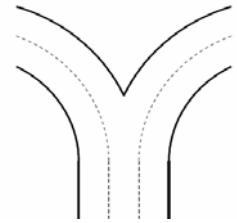
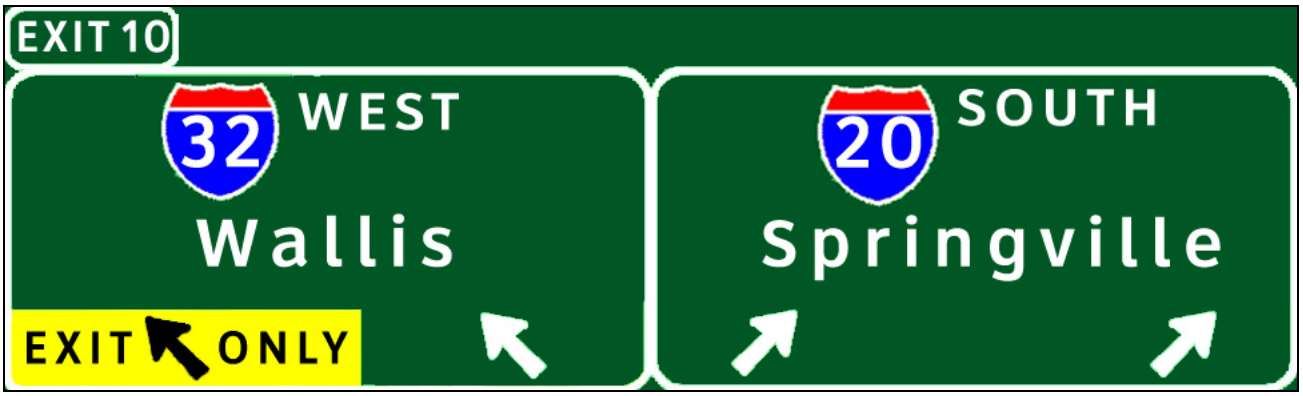


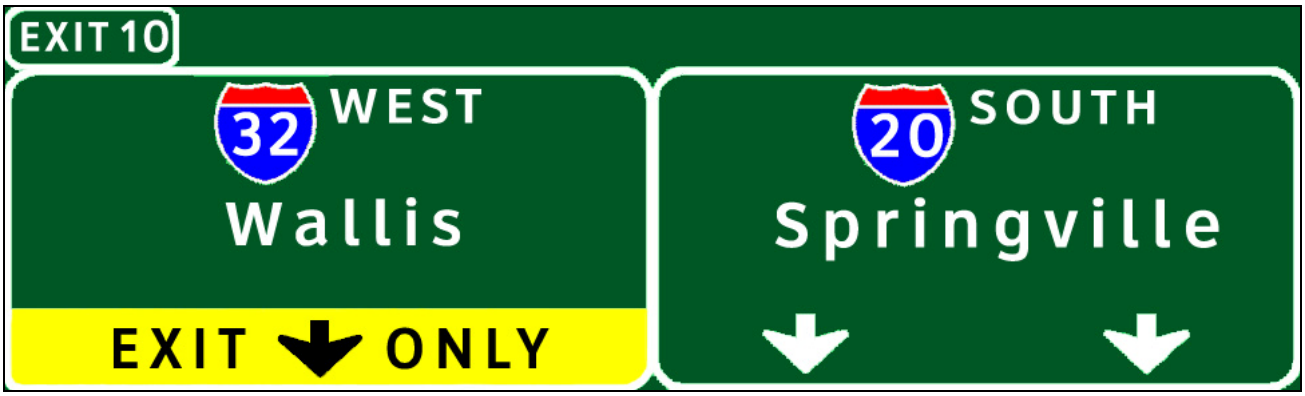
Figure 35. Simulator Sign Sequence REO-9.

Signs Tested for Freeway to Freeway Split with Optional Lane

SPLT-2
The sign sequence is based on the Texas Freeway Signing Handbook (Page 5-15).







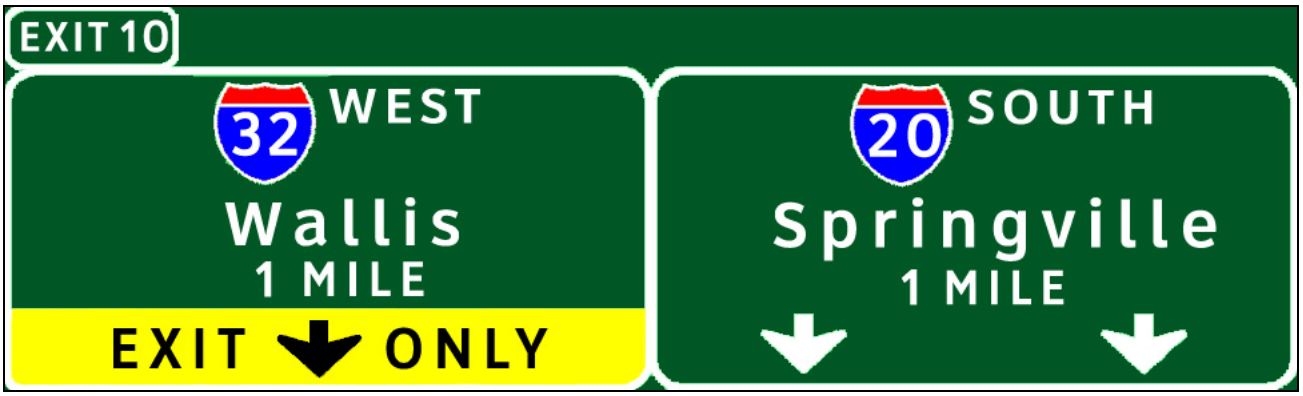
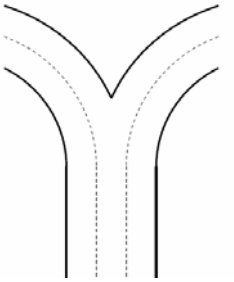


Figure 36. Simulator Sign Sequence SPLT-2.

SPLT-5
The exit direction sign is based on the Texas Freeway Signing Handbook (Page 5-15). The advance sign sequence is copied from the Texas 2006 Edition MUTCD (Fig. 2E-5).



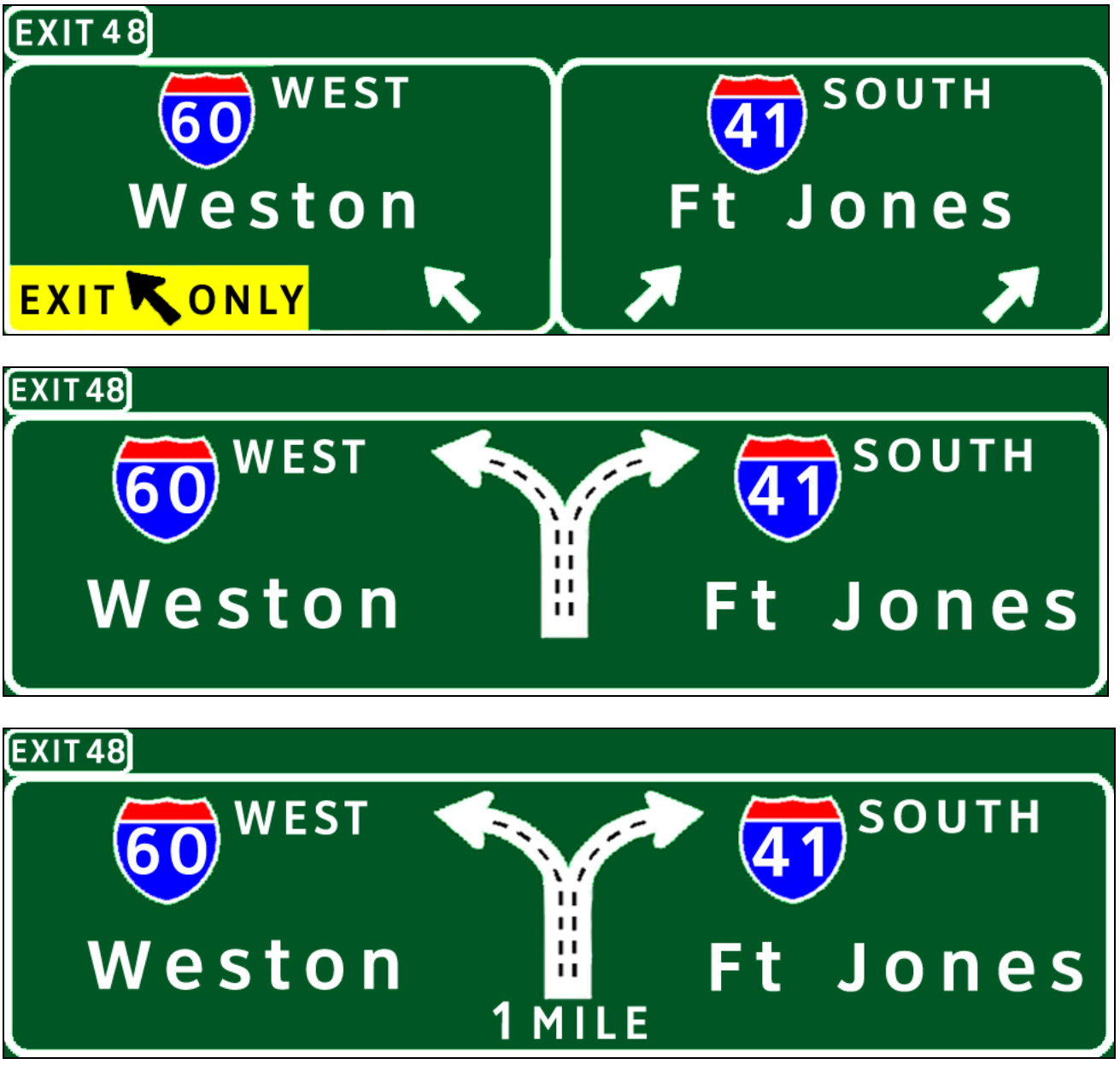
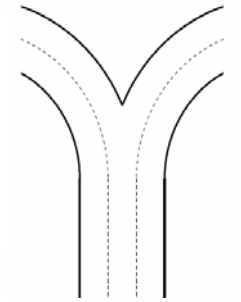
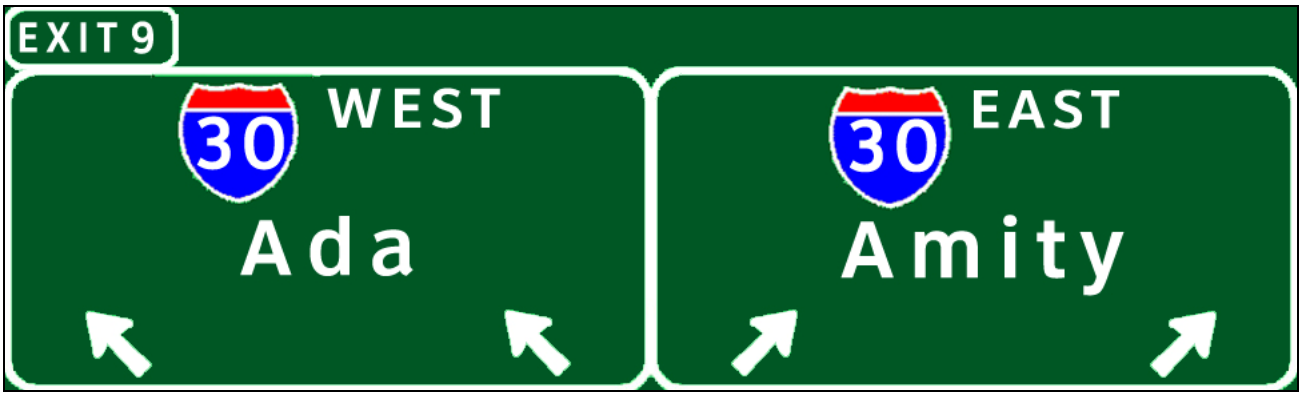
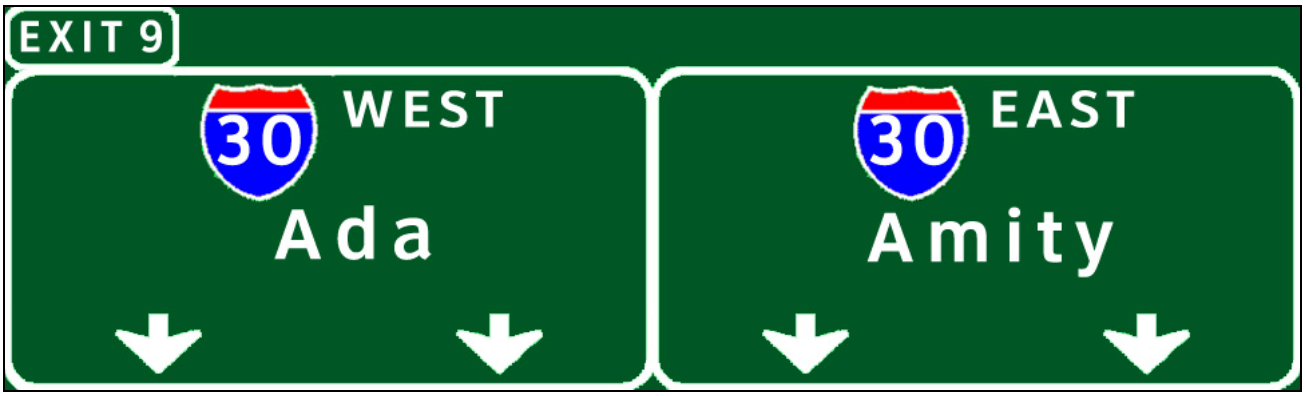


Figure 37. Simulator Sign Sequence SPLT-5.

SPLT-6
The sign sequence is based the Texas Freeway Signing Handbook (Fig. 5-22). The sign sequence was adapted from the four-lane approach shown in the Handbook, for the three-lane approach tested here.







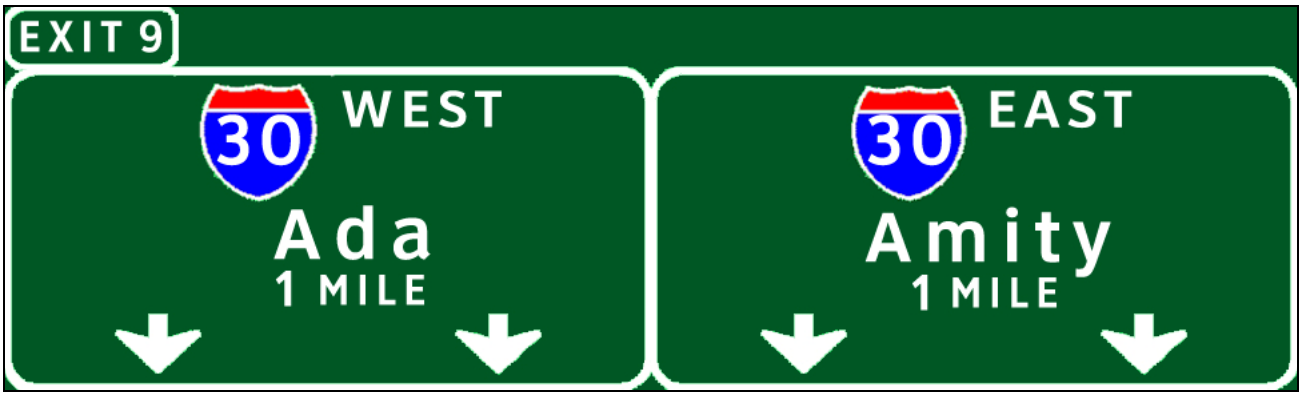


Figure 38. Simulator Sign Sequence SPLT-6.

Table 5 lists the signs studied in Phases 1-3.

Table 5. Signs Studied in Phases 1, 2, and 3.

Sign	Phase 1	Phase 2	Phase 3*	Description
LE-1	√	√	√	Standard text sign
LE-2	√	√	√	Based on TTI Study (8) and Older Driver Handbook
LE-3	√	√		Diagrammatic based on Federal MUTCD with narrow through lane leg
LE-4		√	√	Diagrammatic from Figure 2E-3 in the TX MUTCD
LLD-1	√	√	√	Standard text sign
LLD-2	√	√	√	Diagrammatic based on Federal MUTCD
LLD-3	√	√		Diagrammatic based on Federal MUTCD
LLD-4	√	√		Diagrammatic based on Federal MUTCD
LLD-5	√	√		Modified Diagrammatic based on Older Driver Handbook
LLD-6	√	√	√	Combines several principles of other signs
LLD-7		√		Identical to LLD-4 without the lane lines
LLD-8		√		Modified Diagrammatic in use in Houston
LLD-9			√	Based on the TX Freeway Signing Handbook
REO-1			√	Combination of TX MUTCD and Federal MUTCD
REO-2	√	√	√	Standard TX MUTCD text sign
REO-3	√	√		Ontario diagrammatic sign
REO-4	√	√	√	Modified Diagrammatic based on Older Driver Handbook
REO-5		√		Modified Diagrammatic with EXIT ONLY plaque
REO-6		√		Modified Diagrammatic in use in Houston
REO-7	√	√	√	Combination of TX MUTCD, Federal MUTCD, and TX Freeway Signing Handbook
REO-8	**	**	√	Combination of TX MUTCD, and Federal MUTCD
REO-9			√	Based on TX MUTCD, with ground-mounted advance
SPLT-1	√	√		Diagrammatic based on Federal MUTCD
SPLT-2	√	√	√	Based on the TX Freeway Signing Handbook
SPLT-3	√	√		Minnesota design with 3 down arrows
SPLT-4	√	√		Current TX practice with 4 down arrows
SPLT-5		√	√	Identical to SPLT-1 without lane lines
SPLT-6	***	***	√	Based on the TX Freeway Signing Handbook for four-lane approach

* City names and route numbers may have been changed from Phases 1 and 2 to make sure each sign type had unique destinations. Formatting of the cardinal directions and location of the city names and route shields may have been altered for consistency among signs.

** REO-8's data can be compared to the data for REO-7 in Phases 1 and 2, because they share the same advance sign format.

*** SPLT-6's data can be compared to the data for SPLT-4 in Phases 1 and 2, because they share the same advance sign format.

DESIGN

Driving Environment Development

Apparatus

Data collection was conducted in the Texas Transportation Institute's driving simulator. The driving simulator is comprised of four components: vehicle, computers, projectors, and screens. The vehicle, a complete, full-size 1995 Saturn SL automobile, is outfitted with computers, potentiometers, and torque motors connected to the accelerator, brakes, and steering. The Saturn also features full stereo audio, full instrumentation, and fully interactive vehicle components, all of which provide the realistic feel of driving. The Saturn is connected to a computer component that consists of one data-collection computer and three image-generation computers. Computer-generated driving scenes are sent to three high-resolution projectors and projected to three high-reflectance screens (see Figure 39).

Figure 39. TTI Driving Simulator.

Tile Development

TTI's Driving Simulator uses HyperDrive Authoring Suite™ to create the multiple test "worlds" through which the research participants drive. The roadways are created by piecing

together tiles, or small segments of pre-developed roads, which include the test intersections and filler tiles. The authoring suite also collects the data previously mentioned.

Before the start of this study the only freeway exit geometry available to use in the simulator was an optional right exit. In order to test the conditions evaluated in Phases 1 and 2, new tiles needed to be purchased and developed. Error! Reference source not found. shows the two tiles TTI researchers designed in order to achieve the various freeway geometries needed to test the LLD, REO, LE, and SPLT conditions. DriveSafety, Inc. developed the new software for the tiles. TTI researchers requested that the roadway curve configurations were designed so that a driver could take the curves at a speed of 60-65 mph without slowing down. Standard roadway markings were also requested.

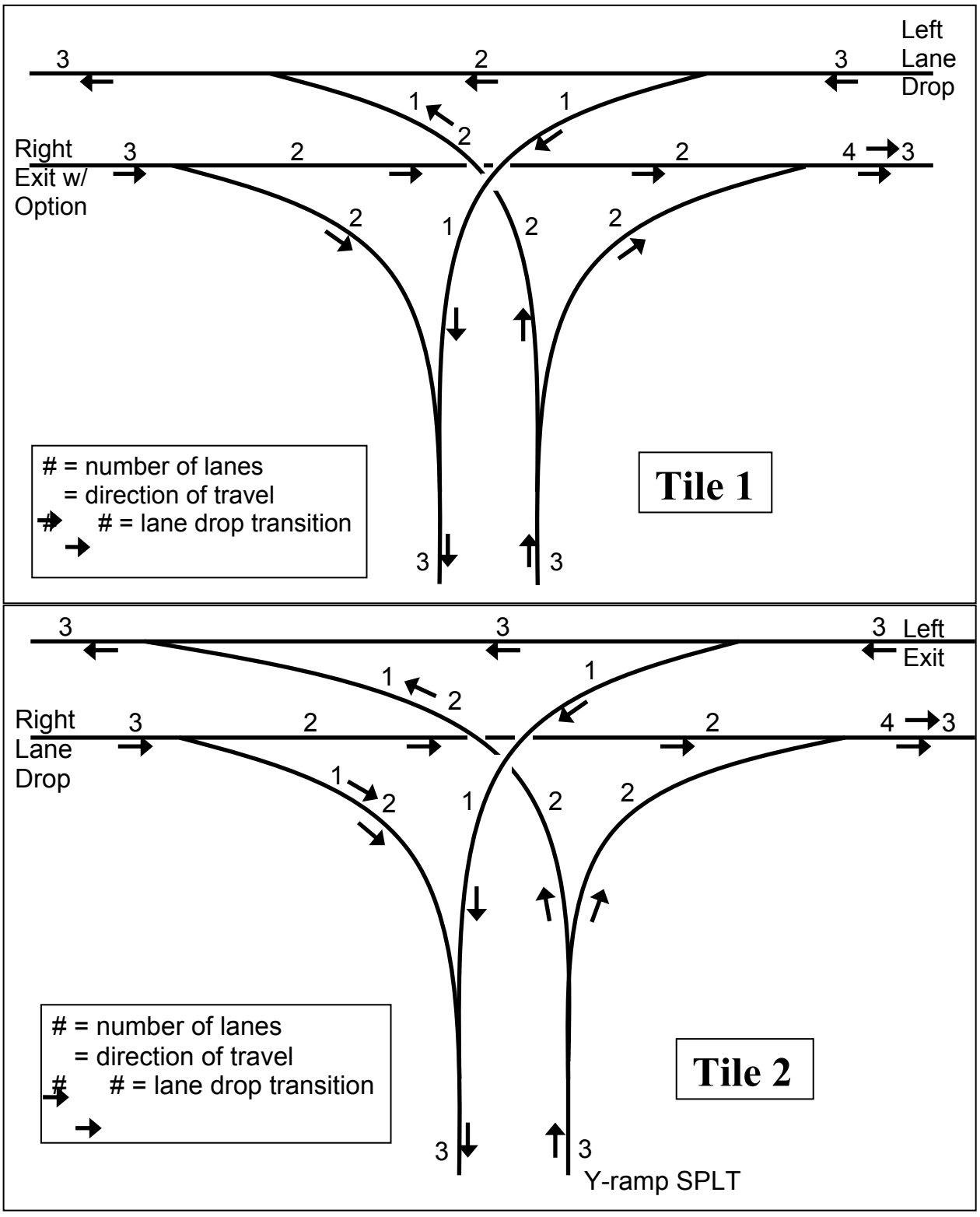


Figure 40. Tiles 1 and 2 Layouts Developed for the Simulator.

Driving Layouts

Because of time constraints and desired counterbalancing to be discussed later in this report, 10 simulator worlds or driving environments were developed. Each world was developed by piecing together the newly purchased tiles with stretches of straight roadway as filler between each stretch of testing location. The tiles would be strung together to create one long drive, chosen and oriented based on the desired counterbalancing. Figure 41 below is an example of one of these worlds (the B-β World).

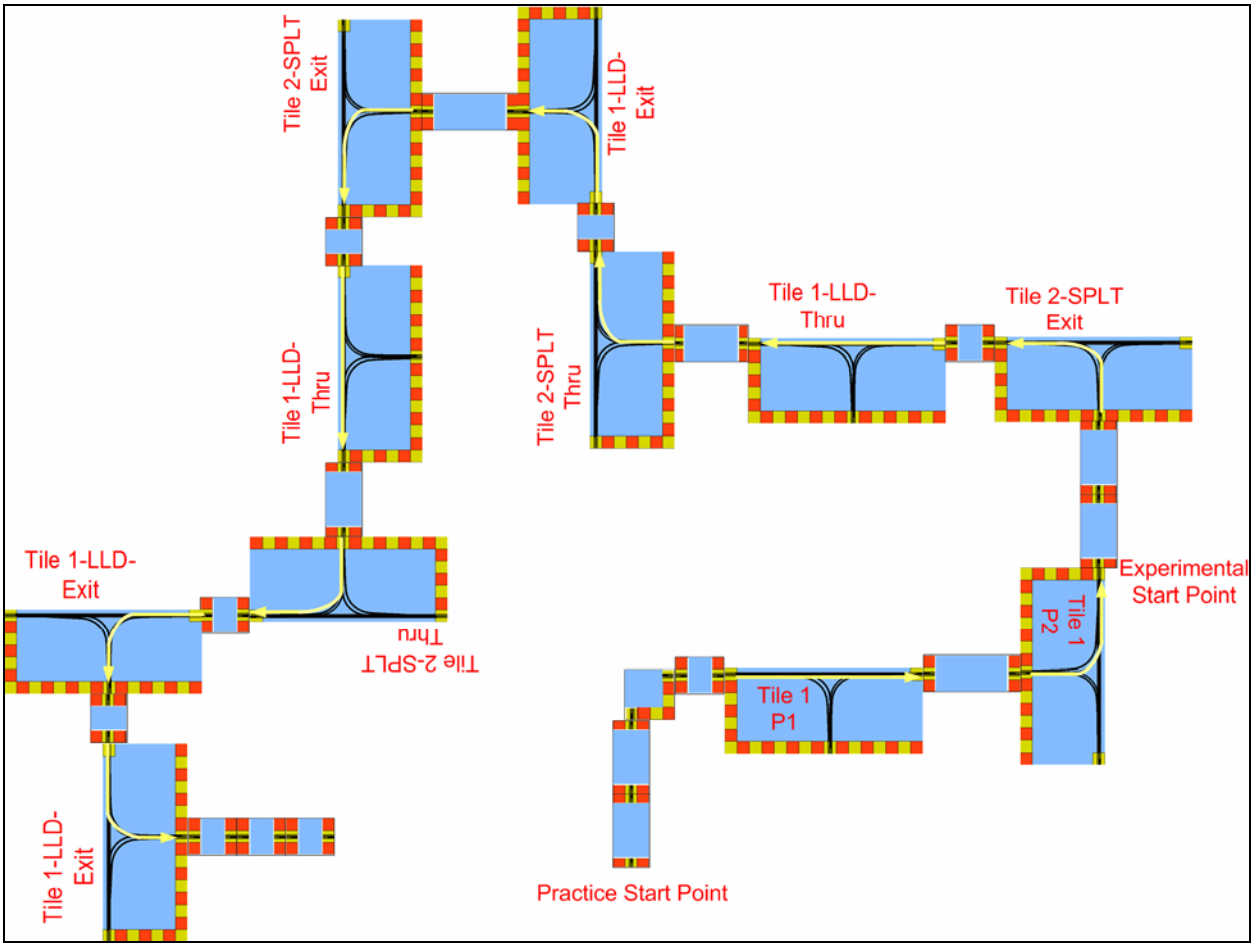


Figure 41. Map for the B-β Worlds.

The sign stimuli were first created using SignCAD and Photoshop before being uploaded as .sgi files and placed in their proper locations along the roadways. In order to minimize total driving time, and because driving speed and distance is somewhat distorted in the simulator, the 1 mile and ½ mile signs, were placed at distances of 2/3 and 1/3 miles from the gore.

The TTI simulator programmer placed a start point, or position and orientation that the vehicle can begin at in the simulator world, in the approach to every set of sign stimuli. This placement allowed for the study to be started at any location along the world in case participants made a wrong turn and needed to be placed back on track.

Roadway and signs for two practice conditions were added at the start of each world. Depending on whether it was the participant's first or second drive of the session, the simulation could start at the practice start point or the start point before the first sign stimuli.

Data Collection

The experimental worlds were programmed to collect data at 15 Hz in the test condition segments and not during the filler segments. The following variables were collected:

- sign number,
- time (sec),
- velocity (meters/sec^2),
- distance (meters),
- lane position (as an offset in meters of the center of the vehicle from the centerline),
- acceleration (on a scale from 0 to 1),
- steering (in degrees), and
- braking (on a scale from 0 to 1).

Research Participants

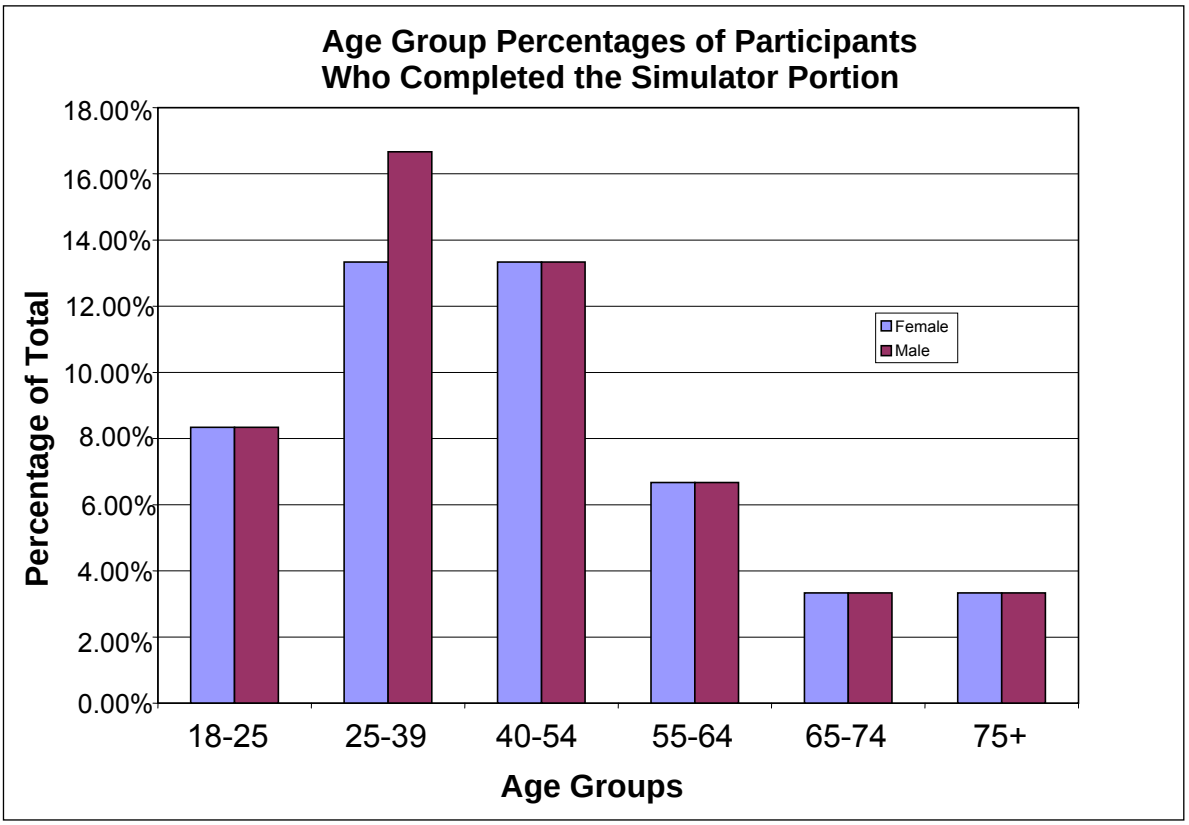


Figure 42. Percentage of Age Groups of Participants.

Sixty volunteer drivers, consisting of 29 women and 31 men completed the driving simulation experiment, with an average age of 44 (see Figure 42). The subjects represented a variety of education levels, driving experience, driving frequency, and geographical areas.

Counterbalancing

Due to time limitations, participants would not be able to view all of the sign stimuli mentioned earlier in the report, so half of the recruited participants would view the REO and LE signs, while the other half would view the LLDs and SPLTs. These divisions would be the A and B groups respectively.

In order to best evaluate the sign stimuli, researchers chose to have the participants begin in various lanes on the approach to each sign sequence. Sometimes the participants would already be positioned in the correct lane to get to the designated destination, and sometimes they would be required to make a lane change. Also, for the same sign sequence, some participants

would be directed to take the through route, while others would be directed to take the exit. Group A was divided into 3 subgroups and Group B into 2 subgroups in order to include all the necessary combinations of starting lane and ending choice, in counterbalanced order.

Due to limitations in the number of customizable signs hosted by the simulator authoring program, each subgroup was divided into two worlds, α and β. This division resulted in 10 total simulator worlds that were previously mentioned and can be seen below in Table 6 and Table 7.

Table 6. Sign, Route, and Start Lane Counterbalancing for the A Groups.

	A 1			A 2			A 3		
	Sign	**Route**	**Start Lane**	**Sign**	**Route**	**Start Lane**	**Sign**	**Route**	**Start Lane**
α	REO-9	T	R	REO-8	T	R	REO-7	T	R
	REO-7	T	L	REO-4	T	C	REO-9	T	R
	REO-1	E	L	REO-2	E	L	REO-1	E	L
	LE-4	T	R	LE-4	T	L	LE-2	T	R
	REO-2	T	R	REO-1	T	R	REO-4	T	L
	LE-1	E	L	LE-2	E	R	LE-4	E	R
	REO-9	E	R	REO-7	E	C	REO-7	E	R
	REO-7	T	R	REO-9	T	L	REO-2	T	L
	REO-4	E	R	REO-8	E	C	REO-8	E	R
	LE-2	T	L	LE-1	T	R	LE-1	T	L
β	REO-1	E	C	REO-2	E	R	REO-4	E	C
	REO-8	T	C	REO-4	T	R	REO-8	T	R
	LE-4	E	R	LE-4	E	R	LE-2	E	R
	REO-2	E	C	REO-7	E	L	REO-2	E	L
	REO-9	T	C	REO-8	T	L	REO-7	T	C
	LE-1	E	R	LE-2	E	L	LE-4	E	L
	LE-2	E	R	LE-1	E	R	LE-1	E	R
	REO-1	T	L	REO-2	T	C	REO-1	T	C
	REO-4	E	L	REO-1	E	R	REO-9	E	C
	REO-8	E	L	REO-9	E	L	REO-4	E	L

Table 7. Sign, Route, and Start Lane Counterbalancing for the B Groups.

	B1			B2		
	Route	Sequence	Start Lane	Route	Sequence	Start Lane
α	T	SPLT-2	C	T	SPLT-6	L
	T	LLD-2	L	T	LLD-9	C
	T	SPLT-5	R	T	SPLT-5	C
	E	SPLT-6	R	E	SPLT-2	C
	T	LLD-6	C	T	LLD-6	L
	E	LLD-9	L	E	LLD-2	C
	E	SPLT-2	R	E	SPLT-6	C
	E	SPLT-5	C	T	SPLT-2	L
β	E	SPLT-6	L	E	SPLT-5	R
	T	LLD-1	C	T	LLD-2	C
	T	SPLT-5	L	T	SPLT-2	R
	E	LLD-6	C	E	LLD-9	C
	E	SPLT-2	L	E	SPLT-5	L
	T	LLD-9	L	T	LLD-1	L
	T	SPLT-6	C	T	SPLT-6	R
	E	LLD-1	C	E	LLD-6	L
	E	LLD-2	L	E	LLD-1	L

Recruitment/Sickness Screening

Texas Transportation Institute employees recruited participants for the study through word of mouth and distributed fliers. Recruitment involved several prescreening questions to assess whether the recruits might experience simulator induced discomfort (SID). If the recruits appeared to be a candidate for the sickness, they were not scheduled for the study.

Along with the initial sickness screening, participants completed a quick widely-used questionnaire of possible symptoms they might obtain from their time in the simulator. Participants also completed an identical questionnaire at the end of their drive in the simulator. Appendix D contains the sickness symptoms questionnaire.

PROCEDURE

Before beginning the experiment, each participant was asked to read and sign a consent form acknowledging their rights as a research participant. The participants then completed the

sickness questionnaire previously mentioned and were asked to enter the vehicle and adjust the seat and air to their comfort.

Recorded Instructions

While the researcher began the first simulation world at the practice start point, the participants listened to the following recorded instructions:

"This experiment will consist of two driving portions, with a short practice segment at the beginning of the first driving portion and short computer-based segment at the end of the second portion. There will be a break between the two drives.

To begin our drive today, first get in the driver's seat, and get comfortable like you would in any unfamiliar car you are about to drive. Please wait until the end of the instructions to begin driving. In general, just drive as you normally would, following the standard "rules-of-the-road."

Please try to keep your speed around 70 miles per hour for the duration of the drive. If your speed drops below 65 or gets above 75, you will be given a reminder to speed up or slow down. Also, please try to make as few lane changes as possible in order to reach each destination you are directed to, and when you do change lanes, please use your turn signals.

You are now asked to complete an experimental driving scene. When the driving scene begins, the simulator vehicle will be stopped in the roadway. Place the vehicle in 'drive', and proceed through the driving environment. Again, please drive in a normal fashion and obey all traffic rules.

Several miles down the road, the experimenter will give you a destination to drive to. Use the guide signs you see along the roadway to navigate to this destination. Often this will require you to make lane changes and even exits. After each group of signs, the experimenter will ask you questions concerning your comprehension/opinion of the guide signs, then you will be given a new destination, and the procedure will start over again.

The simulator portion of today's experiment will be broken down into 2 drives of roughly 25 minutes. You will be given a short break between drives. At the end of the each drive the experimenter will ask you to bring the vehicle to a complete stop and place it in 'park'.

If you have any questions regarding your tasks in the experiment consult the experimenter. Otherwise, acknowledge that you are ready by telling the experimenter to begin

the driving scene. Again I'd like to remind you to maintain a speed of around 70 miles per hour, and to make as few lane changes as are necessary to reach each given destination."

Practice Session

After listening to the recorded instructions, the researcher gave the participants the following instructions and asked them to slowly drive the vehicle onto the freeway:

"Remember you are on 24 North heading to Johnston. Please drive 70 MPH and avoid any unnecessary lane changes. If you start feeling any simulator sickness symptoms please let me know, and you are free to stop at anytime."

During the practice drive, the participants experienced two different roadway geometries with two different sets of advance and exit direction guide signs. Unlike the test conditions, the practice sets of signs only consisted of one advance and one exit direction sign due to limitations in the number of custom signs the software could accommodate.

A couple of miles before the roadway split, the researcher gave the participants a lane to start in and a destination to drive to. Once the participants had driven though the decision point, they were asked to rate their confidence in their decision. An example of the researcher's script and data form looked like:

P1: *"Please maneuver to the **Right** lane, and continue driving on **24N to Johnstown**"*

After the driver maneuvers through the intersection:

"On a scale of 1 to 5, with 5 being the most confident, how confident are you that you are heading on 24N to Johnstown?"

1 2 3 4 5

Which lane was the subject in when they passed thru the intersection?

L C1 C2 R

Figure 43 and Figure 44 show two sets of practice signs each participant maneuvered through.

Practice Sign 1
The sign sequence is based on Upchurch Type III and the Texas Freeway Signing Handbook (Fig. 5-4).

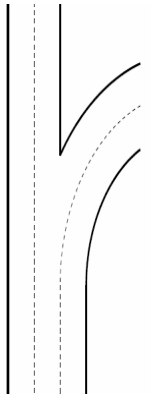


Figure 43. Simulator Sign Sequence P-1.

Practice Sign 2
This sign sequence is based on the Texas Freeway Signing Handbook (Fig. 5-6).

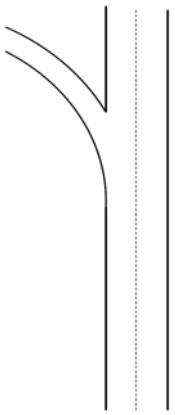


Figure 44. Simulator Sign Sequence P-2.

Experimental Session

After passing through the two practice conditions, if the researcher and participant agreed that the participant was ready, the experimental session began. Since the experimental worlds were designed with a practice session built onto the front of them, there was no need for the driver to stop, and the experimental session began immediately.

The procedure for this segment was the same as in the practice. Appendix D contains an example of the script/answer form. After completing the first session, the researcher offered the participant a break and loaded the next experimental world at the start point for the first sign. The participant also completed a demographic questionnaire that can be found in the Appendix D.

Once the program was loaded, the participant completed the drive in the second experimental world. The procedure was the same as before. After completing the experimental drive the participant was asked to complete another sickness symptom questionnaire before moving into a separate office to finish with a computer survey.

RESULTS

Introduction

In the simulator phase of this experiment, participants saw two types of trials: trials in which they began in a lane which would take them to their destination (a "correct" start lane) and trials in which they would have to change lanes to get to their destination (an "incorrect" start lane).

The experiment was designed using some concepts from Signal Detection Theory. An attempt to visually explain this model is presented in Figure 45. Participants were asked to detect when a lane change was necessary (signal stimuli) and when a lane change was not necessary (noise stimuli). Participants were essentially asked to respond to the signal (by changing lanes) and ignore the noise (by staying in their start lane). If a participant changed lanes when it was not necessary, this trial was scored a "False Alarm." If the participant did not change lanes in this situation, this trial was scored a "Correct Rejection."

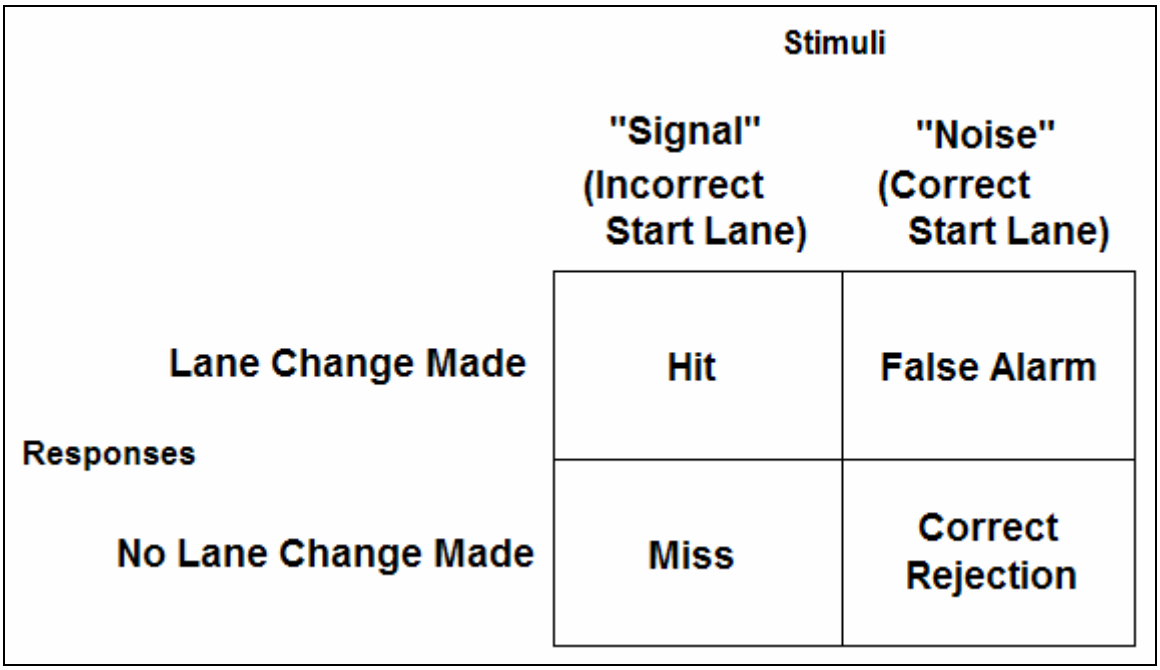


Figure 45. Signal Detection Concept Relating to Lane Changes.

If a participant began a trial in a lane that would not lead them to the requested destination, they had to change lanes at some point before the gore. Participants were asked to detect the "signal" and respond correctly by moving into an appropriate lane. A trial in which a participant moved from an incorrect lane into a correct lane was scored a "Hit." A trial in which the participant continued through the interchange in an incorrect lane was scored a "Miss." Trials scored as "Hits" were also scored on the distance from the gore at which the lane change occurred.

In some trials in which the participant began in an incorrect lane, it was possible to make a second lane change that would still lead the participant to the desired destination. In this case, while the first lane change was necessary, the second lane change was unnecessary as no trial required the participant to make 2 lane changes to reach their destination. This second lane change was scored as a "secondary false alarm" and regarded as an unnecessary lane change.

Figure 46 displays four possible paths for the REO interchange geometry. The scoring principles explained below were used for all 4 geometries. The labels below the paths in Figure 46 correspond to the following descriptions:

1. Participant begins in the center lane and is asked to proceed to the through destination. Under the signal detection model, this trial is considered a "Noise Trial." The participant moves one lane to the left even though this move is not necessary to

reach the through destination. This lane change is a "primary false alarm" as the lane change was unnecessary, and it was the first lane change of the trial.

2. Participant begins in the center lane and is asked to proceed to the exit destination. The signal detection model considers this trial a "Noise Trial." The participant moves one lane to the right even though this move is not necessary to reach the exit destination. This lane change is a "primary false alarm" as the lane change was unnecessary, and it was the first lane change of the trial.
3. Participant begins in the left lane and is asked to proceed to the exit destination. Because the left lane does not lead to the exit destination, a lane change will be necessary. Under the signal detection model, this trial is considered a "Signal Trial." The participant initially moves one lane to the right. This lane change is scored a "Hit," and the distance to the gore is measured. Once in the middle lane, no further lane changing is necessary. At this point the participant (for whatever reason) makes another lane change to the right even though this lane change is not necessary to reach the exit destination. This second (unnecessary) lane change is a "secondary false alarm." The lane change was unnecessary, and it was the second lane change of the trial.
4. Participant begins in the right lane and is asked to proceed to the through destination. Because the right lane does not lead to the through destination, a lane change will be necessary. Under the signal detection model, this trial is considered a "Signal Trial." The participant initially moves one lane to the left. This lane change is scored a "Hit," and the distance to the gore is measured. Once in the middle lane, no further lane changing is necessary. At this point the participant (for whatever reason) makes another lane change to the left even though this lane change is not necessary to reach the through destination. This second (unnecessary) lane change is a "secondary false alarm." The lane change was unnecessary, and it was the second lane change of the trial.

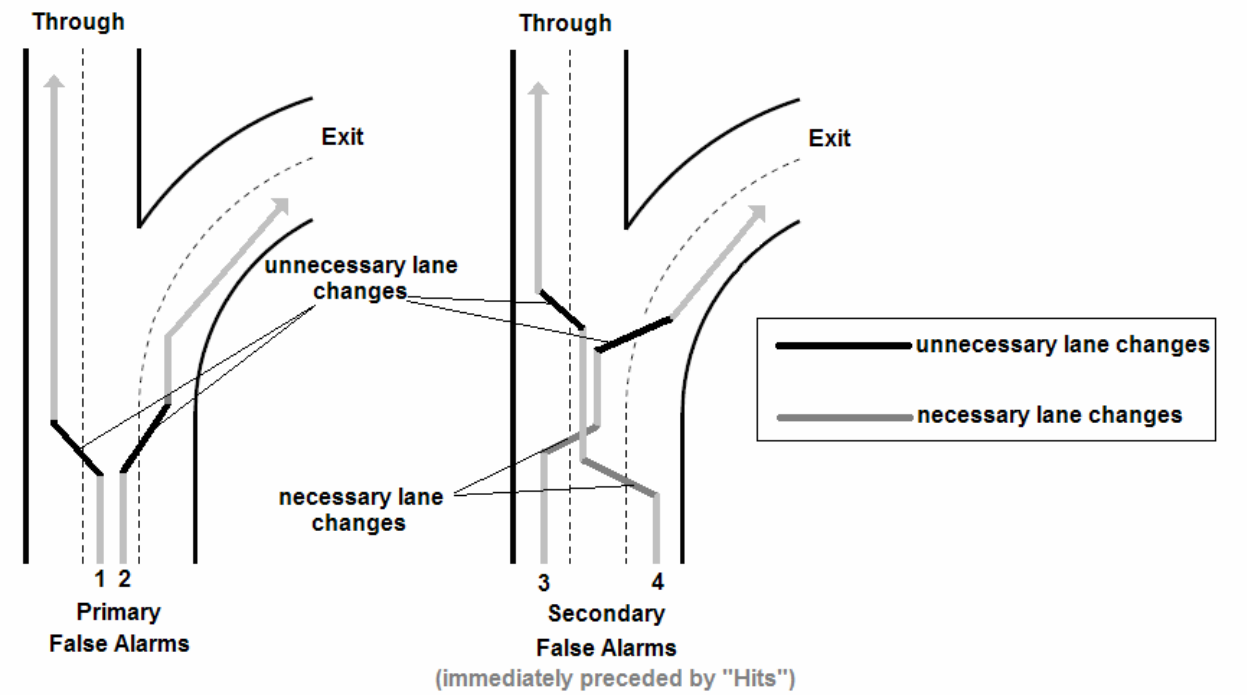


Figure 46. Primary and Secondary False Alarms Illustrated for REO Interchange Geometry.

Both primary and secondary false alarms are regarded as "unnecessary lane changes."

Four primary metrics were used to evaluate each sign sequence. First, researchers determined the number of misses for each sign. A large number of misses would give a clear indication that a sign sequence was being misinterpreted. Only 4 misses were recorded over the duration of this experiment, and they were all associated with a single test participant.

Second, researchers determined the number of unnecessary lane changes for each sign sequence. A high number of unnecessary lane changes could indicate that a sign sequence was ambiguous about which lanes would take a driver to each destination. This metric suffers from the fact that even despite specific instructions, some drivers would make an unnecessary lane change while possibly knowing that they were already in a correct lane, but wanting to "play it safe" and move over one more lane.

Third, for each sign sequence, for each correct lane change ("Hit") the lane change distance from the gore was measured to determine which sign sequence steered participants to the correct lane earliest. It is assumed that an easy-to-understand sign sequence compels drivers to move into their desired lane sooner than a hard-to-understand sign sequence. Early lane

changes are beneficial in the real world as they reduce pressure on drivers to make quick decisions about their lane choice as they approached the gore.

All necessary lane changes (Hits) were broken down into bins containing lane changes that occurred at different distances from the gore. The first bin contains lane changes that are attributed to information presented on the first (1 mile) advanced sign, as that was the only sign visible to the participant when these lane changes occurred. The second bin contains lane changes attributed to the second (½ mile) advanced sign for the same reason. The third bin contains lane changes that are attributed to the exit direction sign at the gore but does not include lane changes made at a very short distance (within 150m) from the gore. The fourth bin collected those changes.

While the driving simulator used "meters" to represent distances in the simulated "worlds," all distances should only be considered relative between sign sequences and do not necessarily correspond to actual absolute sight distances. Also, in order to include more trials in the limited time in which participants were driving in the simulator, the signs were actually moved closer to the gore than in a real-world situation. The "1 mile advanced sign" was actually positioned at 1070 "meters" from the gore (about 2/3 of a mile), and the "½ mile advanced sign" was actually positioned at 535 "meters" from the gore. This sign placement served to make each trial shorter in both distance and time duration, allowing more trials to be included in the 40-minute drive. The bin sizes used are also displayed in Table 8.

Table 8. Correct Lane Change Distances were Broken out into Bins, Defined Here.

Bin	Range of lane change distances from gore included in bin
Attributed to 1 mile sign	>900 meters
Attributed to ½ mile sign	900m>x>350m
Attributed to exit direction sign	350m>x>150m
Near gore	<150m

Most tables throughout this section list only the number of "valid" trials as some data was lost for various reasons. The two most common reasons for an invalid trial were either that a participant moved too slowly into the correct starting lane to start a trial and thus invalidated the trial, or that some data was lost due to equipment malfunction.

Left Exit

Figure 47 displays all paths for the LE geometry. Each path is numbered in the figure and explained below:

1. Participant begins in the left lane and is asked to proceed to the exit destination. Participant makes no lane change and correctly takes the left exit. This would be scored a correct rejection.
2. Participant begins in the left lane and is asked to proceed to the through destination. No lane change is made.
3. Participant begins in the right lane and is asked to proceed to the through destination. No lane change is made.
4. Participant begins in the right lane and is asked to proceed to the exit destination. The participant makes one necessary lane change to the left and correctly takes the left exit. This trial is scored a "hit," and the researchers measure the lane change distance from the gore.
5. Participant begins in the left lane and is asked to proceed to the through destination. The participant makes an unnecessary lane change to the right but correctly reaches the through destination. This trial is scored a "primary false alarm." The lane change was unnecessary, and it was the first lane change of the trial.
6. Participant begins in the right lane and is asked to proceed to the through destination. The participant makes an unnecessary lane change to the left but correctly reaches the through destination. This trial is scored a "primary false alarm." The lane change was unnecessary, and it was the first lane change of the trial.

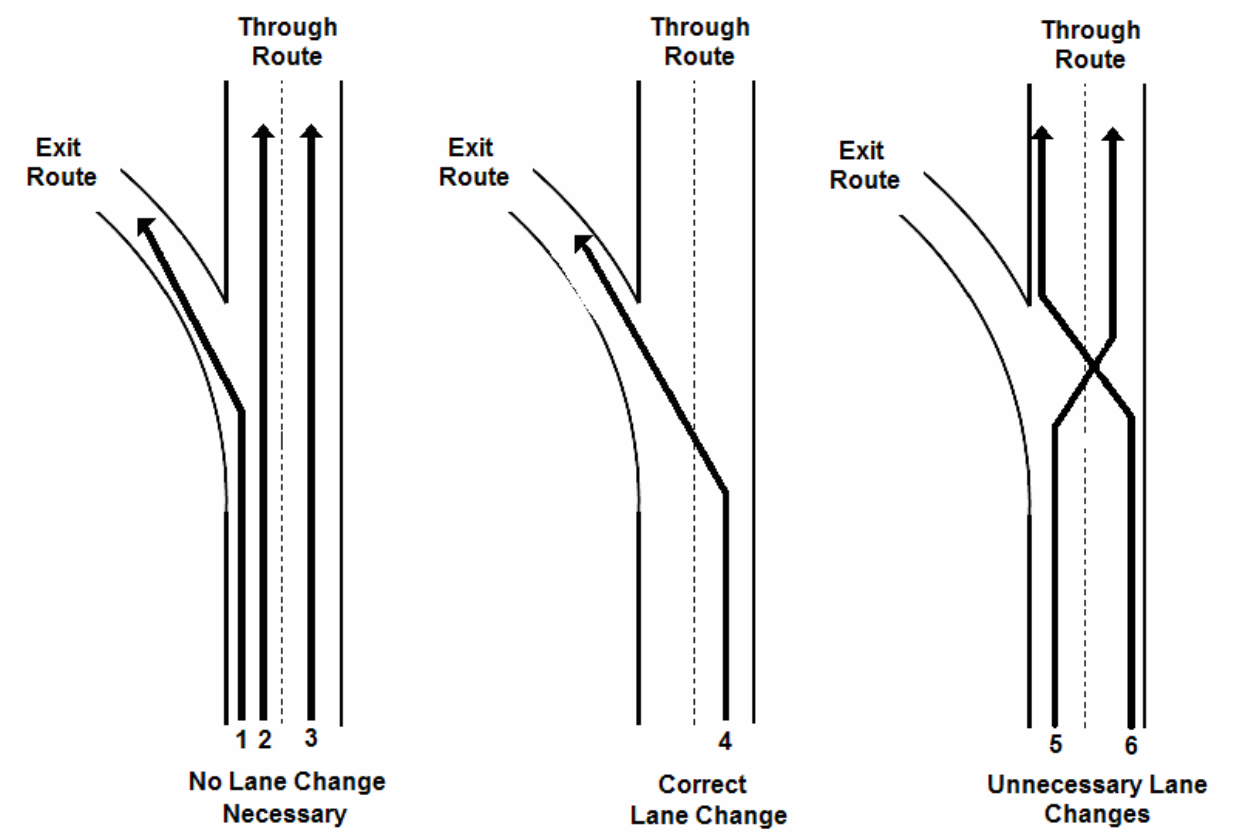


Figure 47. Left Exit Geometry Illustrating a Lane Change Was Only Necessary When the Trial Originated from the Right Lane and Continued to the Exit Route.

This experiment examined three signs sequences to guide drivers through a Left Exit (LE) interchange. Table 9 shows that the sample for the LE's was balanced between trials in which the participant was required to change lanes (signal trials) and trials in which the participant was not required to change lanes (noise trials).

Table 9. LE Sample Overview.

Left Exit Trials			# of valid trials starting in…	
Sign seq.	Total number of trials	Valid trials	an incorrect lane	a correct lane
LE-1	60	57	30	27
LE-2	60	55	28	27
LE-4	60	56	29	27

Table 10 presents data from trials in which participants began in a lane that would not lead them to their desired destination. Participants needed to change lanes for these trials. Based on the geometry of the left exit, these trials all began in the right lane with the desired destination being the exit route (route #4 in Figure 47). If participants started in the left lane, or if they were

asked to follow the through route, no lane change would have been necessary. Most notable in Table 10 is the fact that there was a miss recorded for both LE-2 and LE-4. These misses were 2 of the 4 total misses for all sign sequences throughout the experiment. A miss was scored when a participant failed to reach the desired destination. A single participant (#20) was responsible for both of these misses. This participant also recorded a second miss for sign sequence LE-2 in a trial that actually began in a correct lane (not included in Table 10).

Table 10. Left Exit Trials Starting in a Lane that Would NOT Lead to the Desired Destination (Noise Trials).

Sign seq.	Valid trials	Correct lane changes	% of trials with correct changes	Average correct lane change distance from gore (m)
LE-1	27	27	100%	786
LE-2	27	26	96%	663
LE-4	27	26	96%	796

As mentioned in the introduction to this section, the average lane change distance from the gore was recorded (and displayed above) for correct lane changes (only route #4 in Figure 47 for the Left Exit geometry). Table 10 above shows that while LE-1 and LE-4 had similar correct lane change distances, LE-2 produced later (closer to the gore) lane changes. None of these differences were significant due to the large standard deviations of the data sets. Table 11 displays the P-values generated though a single-factor ANOVA.

Table 11. P-Values for Left Exit Sign Sequence Average Lane Change Distance from the Gore Between-Sign Sequence Comparisons.

Sign sequence comparisons of average lane change distances from the gore	P-value
LE-1 vs. LE-2	0.14
LE-2 vs. LE-4	0.14
LE-1 vs. LE-4	0.91

Figure 48 shows the percentage of correct lane changes made within different segments of the roadway as the participant proceeded through the sign sequence towards the gore. Again, LE-2 stands out from the other sequences because a larger portion of participants waited to make their lane change when being guided by this sign sequence.

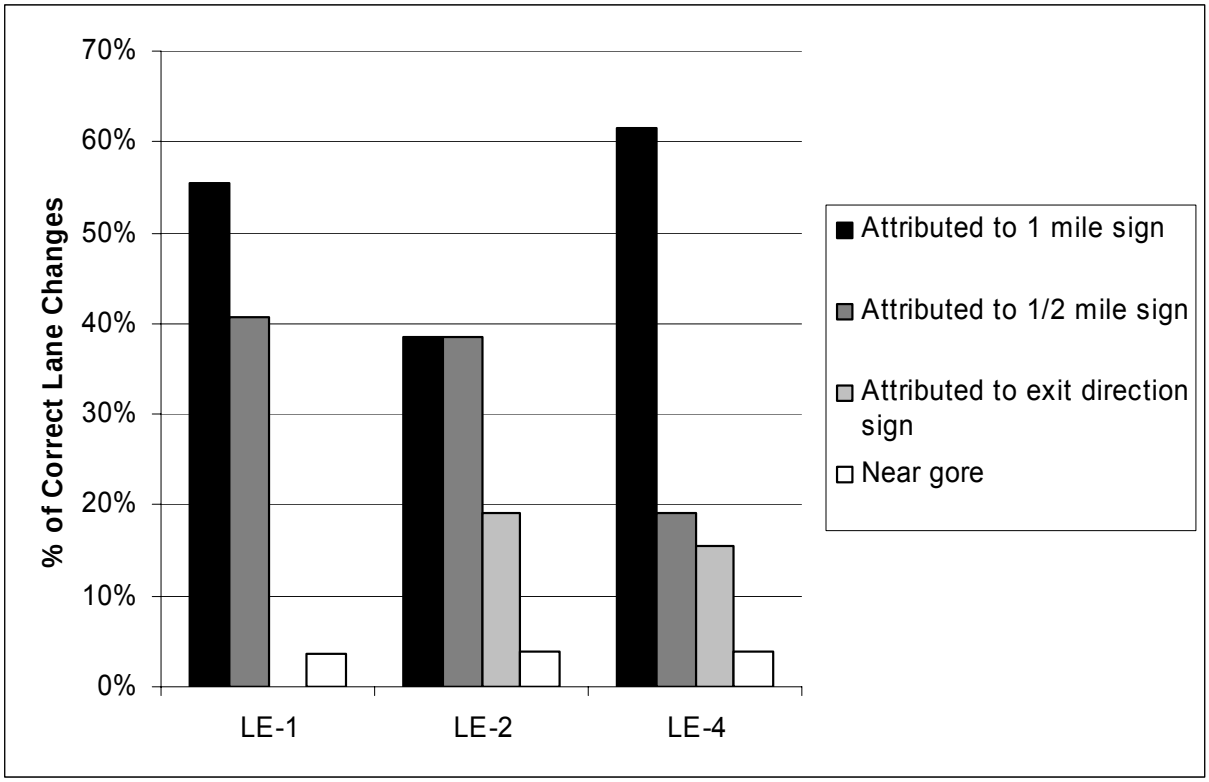


Figure 48. Correct Lane Change Distances, Measured from the Gore, Broken into Bins to Illustrate the Percentage of Correct Lane Changes Occurring as the Participants Approached the Gore.

Table 12 below displays data from trials that began in a correct lane. Any lane change in these trials was considered unnecessary. In Figure 47, routes #1, #2 and #3 represent the desired behaviors for these trials, while routes #5 and #6 represent unnecessary lane changes.

Table 12. Left Exit Trials Starting in a Lane That Would Lead to the Desired Destination (a Correct Lane).

Sign seq.	Valid trials	# of unnecessary lane changes	% of trials with unnecessary lane change
LE-1	30	7	23%
LE-2	28	6	21%
LE-4	29	5	17%

The trials in Table 12 originated in either the right lane with participants following the through route or in the left lane from which both routes could be followed with no lane change. As illustrated in the table above, the sign sequence LE-1 elicited the most unnecessary lane changes, and LE-4 elicited the fewest. Because this geometry consisted of a two-lane roadway, secondary false alarms were not examined for these sign sequences. Researchers recorded all

but one of the unnecessary lane changes during a trial in which the participant began in the left lane and was required to follow the through route (route #5 in Figure 47). LE-1 had one unnecessary lane change in a trial that started in the right lane and prompted the participant to follow the through route (route #5 in Figure 47).

In summary, while misses were recorded for both LE-2 and LE-4 (and not for LE-1), a single participant performed both. LE-4 produced a slightly longer average lane change distance from the gore than LE-1 (although not a significant difference). The average lane change distance from the gore was marginally shorter for LE-2. LE-1 produced the largest proportion of unnecessary lane changes but by only 2%. LE-4 produced the lowest proportion of unnecessary lane changes.

Left Lane Drop

The experiment tested four sign sequences to illustrate the Left Lane Drop geometry to the participating drivers. Figure 49 displays the different outcomes of the LLD trials

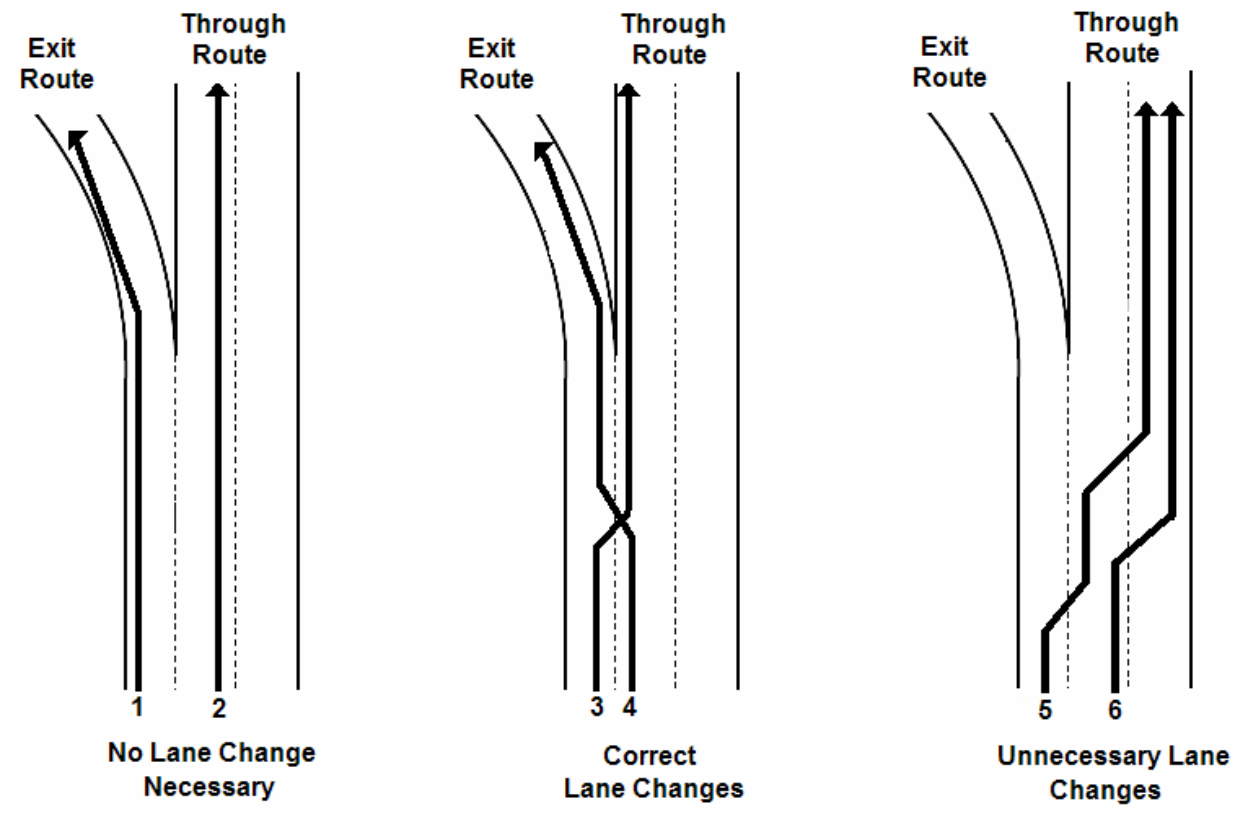


Figure 49. Left Lane Drop Trials and Potential Behaviors.

The trial descriptions are listed below (numbers corresponding to the behaviors illustrated in Figure 49):

1. Participant begins in the left lane and is asked to proceed to the exit destination. No lane change is necessary.
2. Participant begins in the center lane and is asked to proceed to the through destination. No lane change is necessary.
3. Participant begins in the left lane and is asked to proceed to the through destination. The participant correctly changes lanes once to the right and continues to the through destination. This trial is scored a hit, and the lane change distance from the gore is measured.
4. Participant begins in the center lane and is asked to proceed to the exit destination. The participant correctly changes lanes once to the left and continues to the exit destination. This trial is scored a hit, and the lane change distance from the gore is measured.
5. Participant begins in the left lane and is asked to proceed to the through destination. The participant makes a correct lane change to the right, and the distance to the gore from this lane change location is measured. The participant then makes a second, now unnecessary lane change to the right. This second (unnecessary) lane change is scored a secondary false alarm.
6. Participant begins in the center lane and is asked to proceed to the through destination. The participant makes an unnecessary lane change to the right but correctly reaches the through destination. This trial is scored a "primary false alarm" as the lane change was unnecessary, and it was the first lane change of the trial.

Participants did not start from the right lane in any trials for the Left Lane Drop geometry were as it would take two lane changes to reach the exit route. Table 13 shows that the trials for the left lane drop were equally split between trials in which the participant was required to make a lane change (routes #3, #4 and #5 in Figure 49) and trials in which the participant was not required to make a lane change (routes #1, #2, and #6 in Figure 49).

Table 13. Left Lane Drop Trial Breakdown.

			# of valid trials starting in…	
Sign seq.	Total number of trials	Valid trials	a correct lane	an incorrect lane
LLD-1	60	59	30	29
LLD-2	60	58	30	28
LLD-6	60	60	30	30
LLD-9	60	60	30	30

Table 14 presents data on the correct lane changes for the LLD sign sequences. Again, while LLD-1 on average produced lane changes later than the other three sign sequences due to the large standard deviations, none of the differences was significant. Table 15 presents the P-values for these average lane change distance from gore comparisons. Also, notice that there were no "misses" for any sign sequence in this geometry (trials in which the participant did not reach the desired destination).

Table 14. Correct Lane Changes for Left Lane Drop Geometry.

Sign seq.	Valid trials	Correct lane changes	% of trials with correct changes	Average correct lane change distance from gore
LLD-1	29	29	100%	839
LLD-2	28	28	100%	903
LLD-6	30	30	100%	932
LLD-9	30	30	100%	921

Table 15. P-Values for LLD Sign Sequences Average Lane Change Distance from the Gore Between-Sign Sequence Comparisons.

Sign sequence comparisons of average lane change distances from the gore	p-Value
LLD-1 vs. LLD-2	0.41
LLD-1 vs. LLD-6	0.22
LLD-1 vs. LLD-9	0.31
LLD-2 vs. LLD-6	0.68
LLD-2 vs. LLD-9	0.81
LLD-6 vs. LLD-9	0.89

When examining the average lane change distance from the gore more closely for the LLD sign sequences, it also becomes clear that participants were changing lanes earlier when asked to follow the through route. Table 16 displays this data. While differences were seen for all four sign sequences, significant differences were seen only for LLD-6 and LLD-9. This table

shows comparisons between trials in which the participant was required to follow the exit route and trials in which the participant was required to follow the through route.

Table 16. Average Lane Change Distance from the Gore.

	Average lane change distance from the gore (m)			
Sign	**Exit route**	**Through route**	**Difference (m)**	**P-value**
LLD-1	765	919	155	0.18
LLD-2	845	969	124	0.23
LLD-6	814	1049	236	0.01
LLD-9	772	1070	298	<0.01

In Figure 50, all correct lane changes for LLD sign sequences are grouped into bins based on the distance from the gore at which they occurred. While LLD-1 had the fewest lane changes attributed to the 1 mile advanced guide sign, it also was tied with LLD-6 for the fewest lane changes after the ½ mile sign (less than 350 meters).

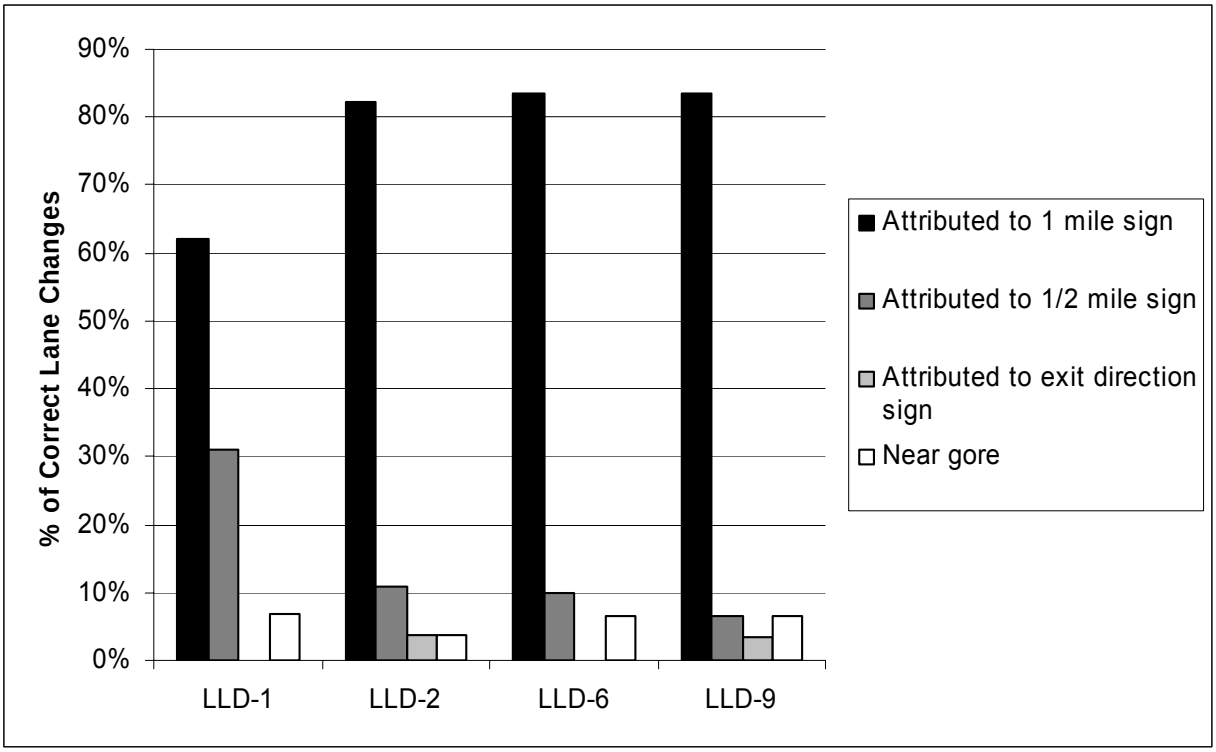


Figure 50. Correct Lane Change Distances for LLD Sign Sequences, Measured from the Gore, Broken into Bins to Illustrate the Percentage of Correct Lane Changes Occurring as the Participants Approached the Gore.

Figure 50 shows that only LLD-1 produced no unnecessary lane changes throughout this experiment. LLD-1 was the only sign sequence that performed this well under this metric for

any geometry. Very little difference is shown between the other sign sequences under this geometry. Table 18 shows that all of the unnecessary lane changes for this geometry were recorded in trials in which the participant was asked to follow the through route. Note the sum of each sign over both tables in Table 18 equals the total unnecessary lane changes in Table 17. All of these trials required participants to follow the through route. No unnecessary lane changes were recorded when participants were required to follow the exit route.

Table 17. Unnecessary Lane Changes in Left Lane Drop Trials.

Sign seq.	Valid trials	# of unnecessary lane changes	% of trials with unnecessary lane change
LLD-1	59	0	0
LLD-2	58	6	10%
LLD-6	60	6	10%
LLD-9	60	5	8%

Table 18. All Unnecessary Lane Changes for LD Sign Sequences.

	Start Lane			
Sign	Left	Valid data	# Secondary false alarms	% Secondary false alarms
LLD-1	15	14	0	0%
LLD-2	15	13	3	23%
LLD-6	15	15	3	20%
LLD-9	15	15	3	20%
	Start Lane			
Sign	Center	Valid data	# Primary false alarms	% Primary false alarms
LLD-1	15	15	0	0%
LLD-2	15	15	3	20%
LLD-6	15	15	3	20%
LLD-9	15	15	2	13%

In summary, while LE-1 received zero unnecessary lane changes, it also received the shortest (closest to gore) average lane change distance. For the other three sign sequences under this geometry, all unnecessary lane changes were recorded for trials in which participants were required to follow the through route. Overall, the lane changes made to follow the through route occurred earlier than lane changes made to follow the exit route for all sign sequences.

Right Exit Optional

Phase 3 tested six sign sequences to guide drivers through the Right Exit Optional geometry. Figure 51 displays possible outcomes of REO trials. Each path is then discussed below the figure.

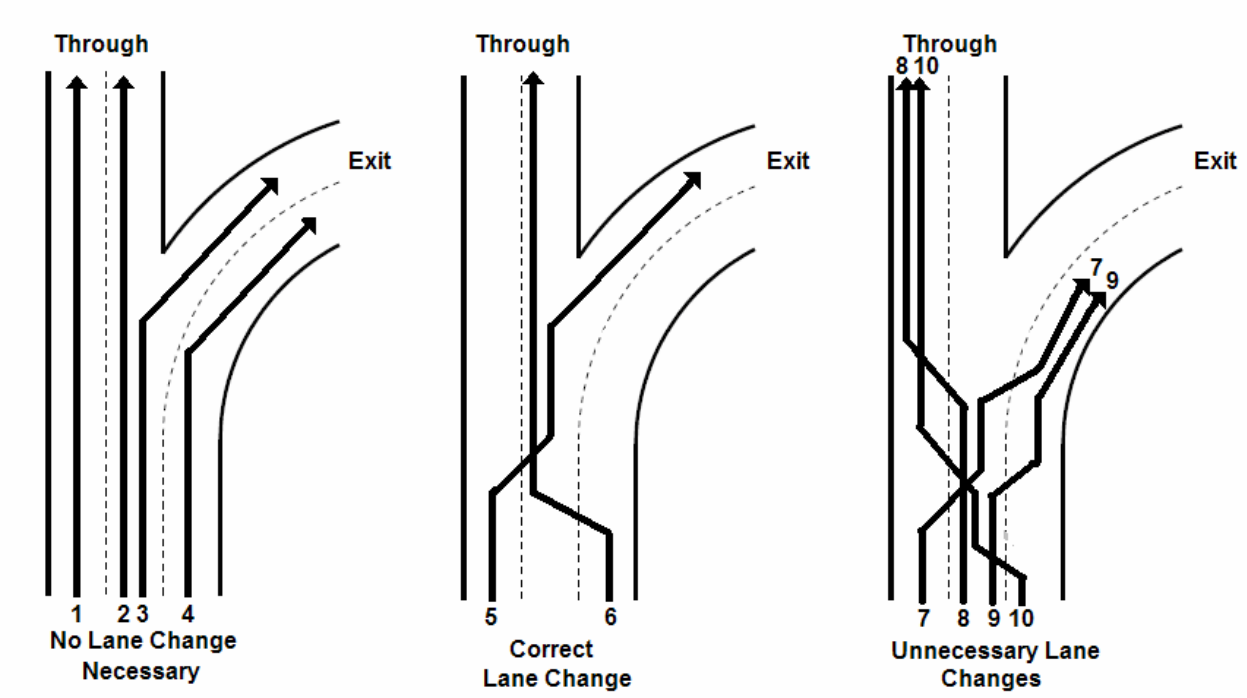


Figure 51. Possible Outcomes of the REO Trials.

1. Participant begins in the left lane and is asked to proceed to the through destination. Participant does not change lanes. This sequence is scored a correct rejection.
2. Participant begins in the center lane and is asked to proceed to the through destination. Participant does not change lanes. This sequence is scored a correct rejection.
3. Participant begins in the center lane and is asked to proceed to the exit destination. Participant does not change lanes. This sequence is scored a correct rejection.
4. Participant begins in the right lane and is asked to proceed to the exit destination. Participant does not change lanes. This sequence is scored a correct rejection.
5. Participant begins in the left lane and is asked to proceed to the exit destination. Participant changes lanes to the right. Participant proceeds in the center lane to the

exit destination. This sequence is scored a hit, and the lane change distance is measured from the gore.

6. Participant begins in the right lane and is asked to proceed to the through destination. Participant changes lanes to the right. Participant proceeds in the center lane to the through destination. This sequence is scored a hit, and the lane change distance is measured from the gore.
7. Participant begins in the left lane and is asked to proceed to the exit destination. Participant first changes lanes into the center lane. A hit is recorded for this lane change, and the distance from the gore is measured. The participant then makes a second lane change into the right lane and proceeds to the exit destination. This second lane change is unnecessary to reach the exit destination and is recorded as a secondary false alarm.
8. Participant begins in the center lane and is asked to proceed to the through destination. Participant changes lanes to the left. This change is not necessary to reach the through destination. The change is scored a primary false alarm.
9. Participant begins in the center lane and is asked to proceed to the exit destination. Participant changes lanes to the right. This change is not necessary to reach the exit destination. The change is scored a primary false alarm.
10. Participant begins in the right lane and is asked to proceed to the through destination. Participant first changes lanes into the center lane. A hit is recorded for this lane change, and the distance from the gore is measured. The participant then makes a second lane change into the left lane and proceeds to the through destination. This second lane change is unnecessary to reach the through destination and is recorded as a secondary false alarm.

Table 19 displays the trials for each REO sign sequence.

Table 19. REO Sign Sequence Sample Size.

			# of valid trials starting in…	
Sign seq.	Total number of trials	Valid trials	a correct lane	an incorrect lane
REO-1	70	67	38	29
REO-2	70	66	38	28
REO-4	70	65	39	26
REO-7	70	69	39	30
REO-8	70	69	40	29
REO-9	70	67	39	28

Table 20 shows that no misses were collected for any of the REO sign sequences. In the case of the correct lane change distance from the gore, REO-1 performed significantly better (p=.02) than the next best sign, REO-2. Again, an average lane change distance further from the gore likely indicates the participant understood the sign sequences earlier. Only one miss was recorded for any of the REO sign sequences. This miss was collected from the same participant that missed necessary lane changes on three other trials and was the only participant to record a miss in this study.

Table 20. Right Exit Optional Correct Lane Changes.

Sign seq.	Valid trials	Correct lane changes	% of trials with correct changes	Average correct lane change distance from gore
REO-1	29	29	100%	1068
REO-2	28	28	100%	942
REO-4	26	26	100%	931
REO-7	30	30	100%	934
REO-8	29	29	100%	933
REO-9	28	27	96%	874

While REO-1 elicited an average lane change distance significantly larger than the other signs, it also had a very small standard deviation of lane change distance in relation to the other signs. This deviation was the result of only one lane change taking place after the ½ mile sign. All other signs had at least on lane change within 350 m of the gore. This data is displayed in Figure 52.

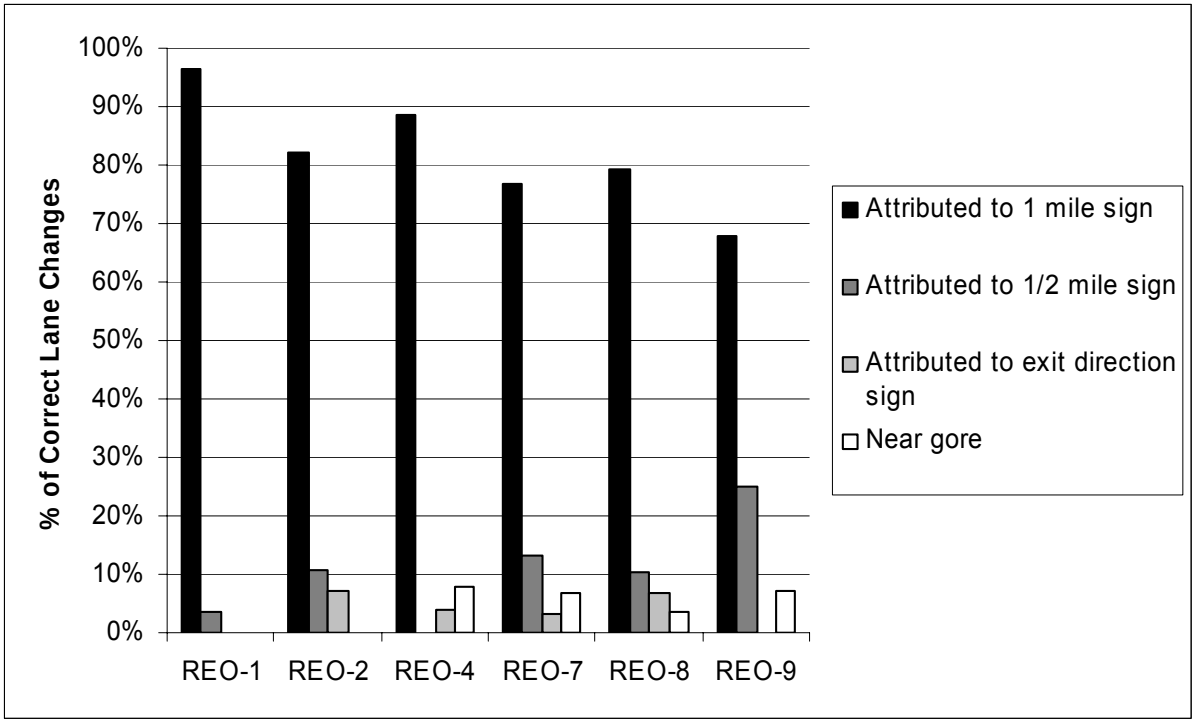


Figure 52. Correct Lane Change Distances for REO Sign Sequences, Measured from the Gore, Broken into Bins to Illustrate the Percentage of Correct Lane Changes Occurring as the Participants Approached the Gore.

Table 21 displays the proportion of unnecessary lane changes elicited by each REO sign sequence. REO-1, the sign performing the best under the lane change distance from gore metric (longest average distance from gore), produced the most unnecessary lane changes. Similarly, REO-9, the sign sequence producing the shortest average lane change distance from gore, produced the fewest unnecessary lane changes.

Table 21. Right Exit Optional Unnecessary Lane Changes.

Sign seq.	Valid trials	# of unnecessary lane changes	% of trials with unnecessary lane change
REO-1	67	27	40%
REO-2	66	20	30%
REO-4	65	24	37%
REO-7	69	19	28%
REO-8	69	18	26%
REO-9	67	17	25%

When the unnecessary lane changes are separated by their destination (through or exit), an interesting separation in the data can be seen. This relationship is presented in Figure 53.

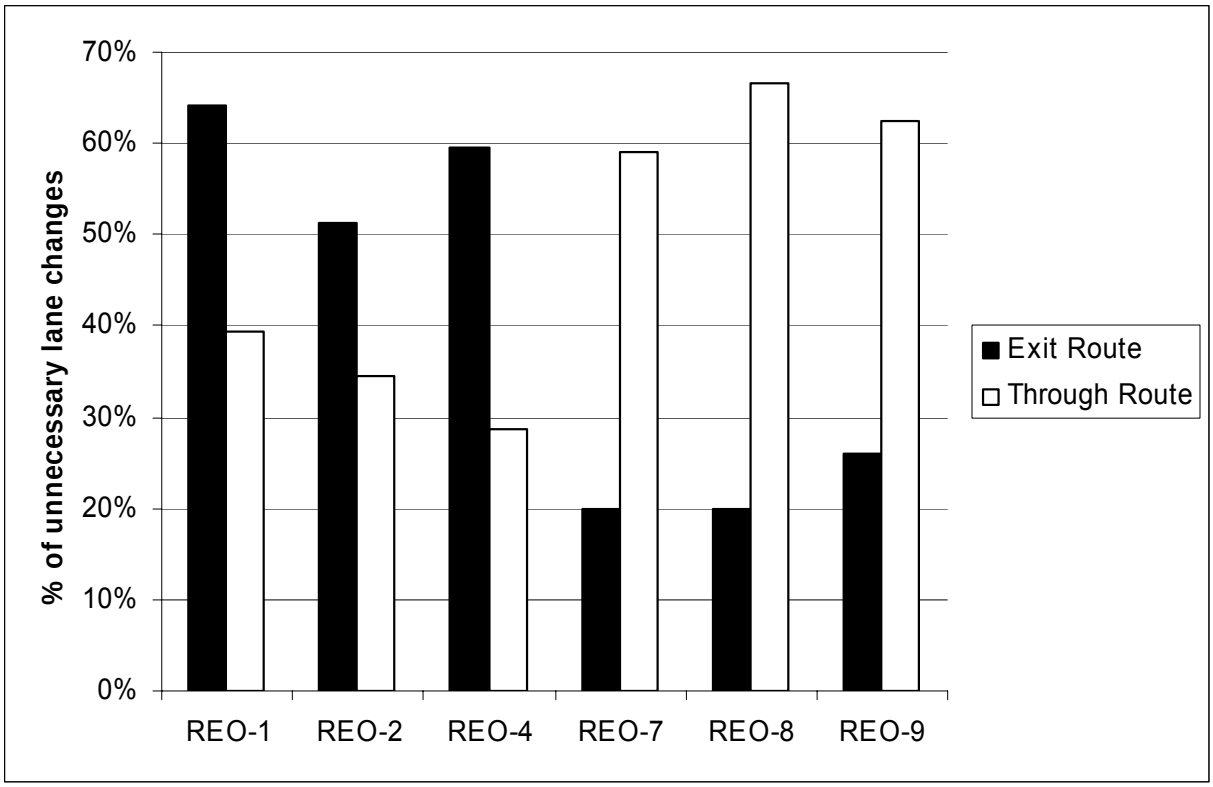


Figure 53. REO Unnecessary Lane Changes Separated by Desired Destination.

Figure 53 shows that REO-1, REO-2 and REO-4 performed much better for the through route, producing fewer unnecessary lane changes, and REO-7, REO-8 and REO-9 performed much better for the exit route.

In summary, REO-1 recorded lane change distances significantly greater than any other REO sign sequence. REO-9 received the shortest average lane change distance, although it was not significantly different from the sign sequence receiving the next shortest average lane change distance (REO-4). Sign sequences displaying the REO geometry elicited many unnecessary lane changes. These unnecessary lane changes occurred in 40% (the highest percentage) of trials for REO-1 and in 25% (the lowest percentage) of trials for REO-9. When unnecessary lane changes were divided between the two destinations, it was evident that some signs performed much better for the exit destination and some signs performed much better for the through destination.

Freeway to Freeway Splits

Three sign sequences were tested to guide drivers through the Freeway to Freeway Split geometry. Table 22 displays the sample sizes below. Researchers collected a larger sample (90 potential observations) because there were only 3 sign sequences tested for this geometry.

Table 22. Freeway to Freeway Split Sample Summary.

			# of valid trials starting in…	
Sign seq.	Total number of trials	Valid trials	a correct lane	an incorrect lane
SPLT-2	90	87	59	28
SPLT-5	90	88	59	29
SPLT-6	90	88	60	28

Figure 54 displays potential paths through the SPLT interchange. They are explained in detail below. Notice that the paths are nearly identical to those for the REO interchange, except that in the case of the REO interchanges, the exit route is to the right. Here, the exit is to the left.

1. Participant begins in the left lane is asked to proceed to the exit destination. Participant does not change lanes. This sequence is scored a correct rejection.
2. Participant begins in the center lane and is asked to proceed to the exit destination. Participant does not change lanes. This sequence is scored a correct rejection.
3. Participant begins in the center lane and is asked to proceed to the through destination. Participant does not change lanes. This sequence is scored a correct rejection.
4. Participant begins in the right lane and is asked to proceed to the through destination. Participant does not change lanes. This sequence is scored a correct rejection.
5. Participant begins in the left lane and is asked to proceed to the through destination. Participant changes lanes to the right. Participant proceeds in the center lane to the through destination. This sequence is scored a hit, and the lane change distance is measured from the gore.
6. Participant begins in the right lane and is asked to proceed to the exit destination. Participant changes lanes to the right. Participant proceeds in the center lane to the right exit destination. This sequence is scored a hit, and the lane change distance is measured from the gore.

7. Participant begins in the left lane and is asked to proceed to the through destination. Participant first changes lanes into the center lane. A hit is recorded for this lane change, and the distance from the gore is measured. The participant then makes a second lane change into the right lane and proceeds to the through destination. This second lane change is unnecessary to reach the through destination and is recorded as a secondary false alarm.
8. Participant begins in the center lane and is asked to proceed to the exit destination. Participant changes lanes to the left. This change is not necessary to reach the exit destination. The change is scored a primary false alarm.
9. Participant begins in the center lane and is asked to proceed to the through destination. Participant changes lanes to the right. This change is not necessary to reach the through destination. The change is scored a primary false alarm.
10. Participant begins in the right lane and is asked to proceed to the exit destination. Participant first changes lanes into the center lane. A hit is recorded for this lane change, and the distance from the gore is measured. The participant then makes a second lane change into the left lane and proceeds to the exit destination. This second lane change is unnecessary to reach the exit destination and is recorded as a secondary false alarm.

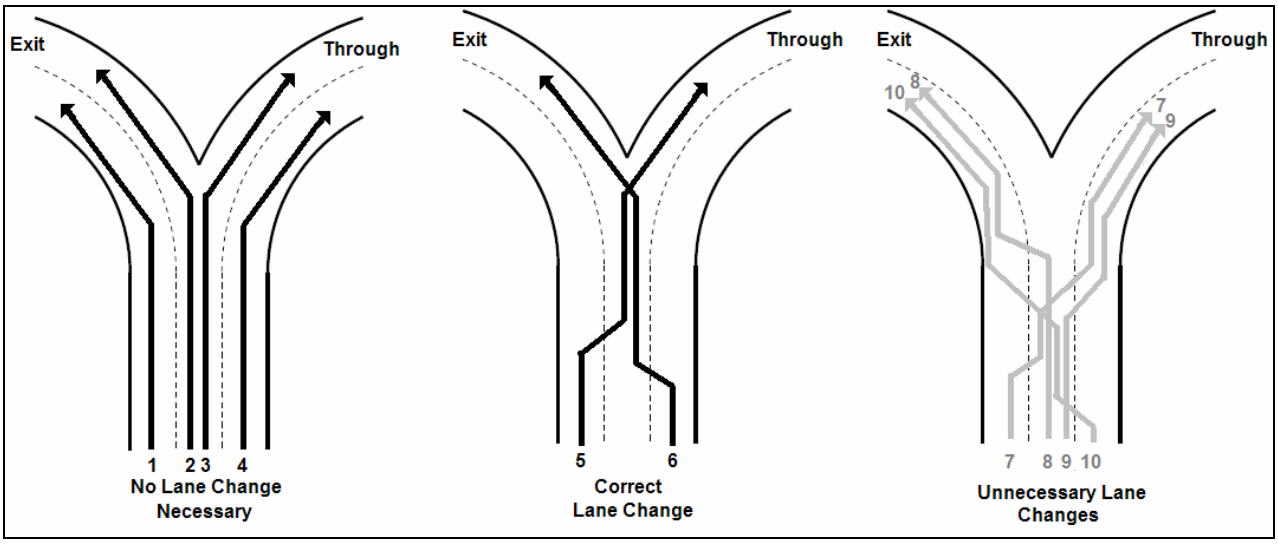


Figure 54. Potential Paths Through Freeway to Freeway Split Interchange.

Table 23 displays the average lane change distance from the gore for the SPLT sign sequences. On average, this geometry yielded lane changes earlier than the other three geometries considered in this experiment. SPLT-6 elicited lane changes at an average distance from the gore longer than any other sign in this experiment; while SPLT-2 and SPLT-5 received the third and fourth longest lane change distances (only SPLT-6 and REO-1 received longer average distances). Also, no misses were recorded for any of the SPLT sign sequences.

Table 23. SPLT Correct Lane Change Distances.

Sign seq.	Valid trials	Correct lane changes	% of correct changes	Average correct lane change distance from gore
SPLT-2	28	28	100%	1028
SPLT-5	29	29	100%	1022
SPLT-6	28	28	100%	1079

Consistent with the early average lane change distances presented above, very few lane changes were made based on the ½ mile advanced sign or the guide sign. This data is presented in Figure 55. SPLT-6 was the only sign sequence in the entire study to have all lane changes attributed to the 1 mile advanced sign.

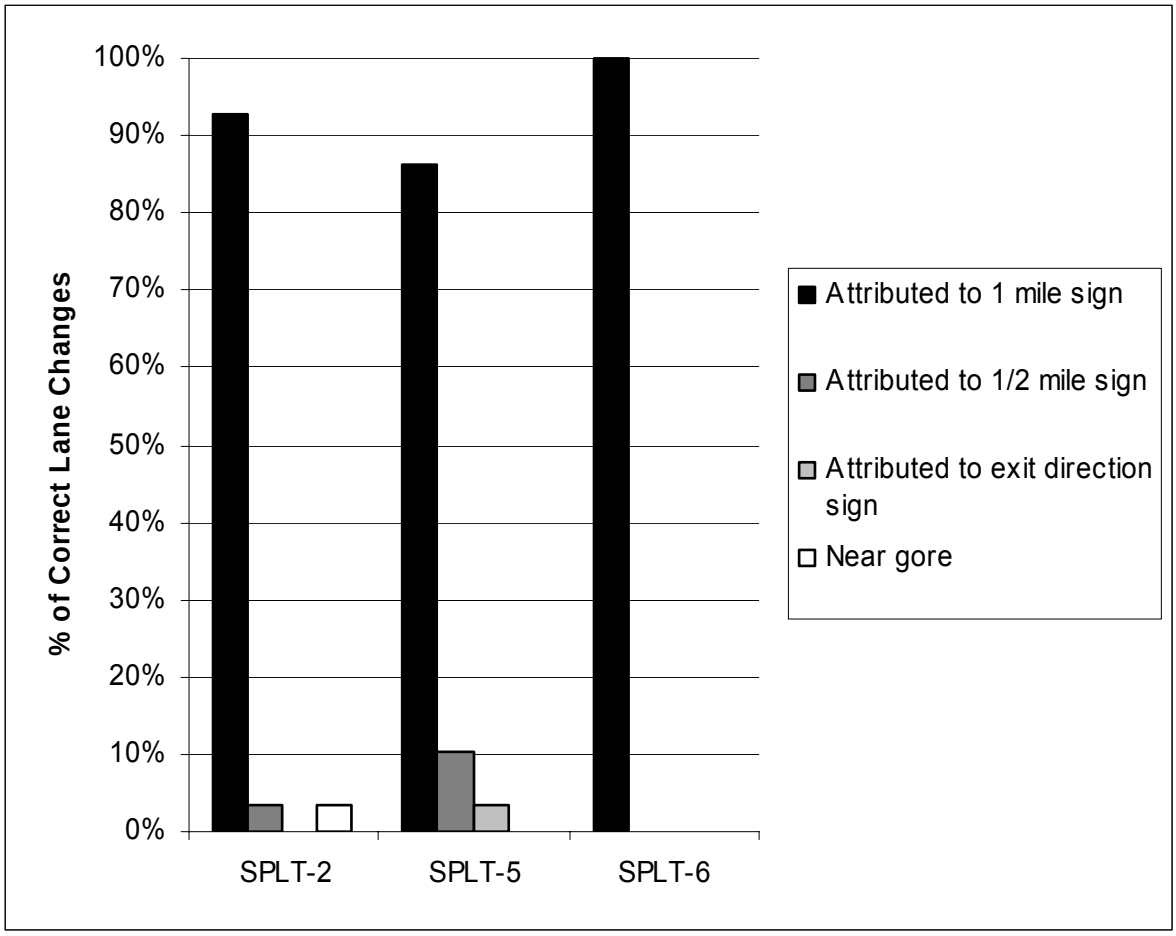


Figure 55. Correct Lane Change Distances for SPLT Sign Sequences, Measured from the Gore, Broken into Bins to Illustrate the Percentage of Correct Lane Changes Occurring as the Participants Approached the Gore.

The SPLT sign sequences showed a wide spread in the proportion of unnecessary lane changes elicited from sequence to sequence. Participants performed an unnecessary lane change in 37% of trials for SPLT-2, the second highest proportion throughout the entire experiment. In contrast, SPLT-5 only elicited unnecessary lane changes in 10% of trials.

SPLT-2 produced significantly more unnecessary lane changes than either of the other two SPLT sign sequences (SPLT-2 vs. SPLT-5, $p<.01$, SPLT-2 vs. SPLT-6, $p<.01$). The data are presented in Table 24.

Table 24. SPLT Unnecessary Lane Changes.

Sign sequence	Valid trials	# of unnecessary lane changes	% of trials with unnecessary lane change
SPLT-2	87	32	37%
SPLT-5	88	9	10%
SPLT-6	88	16	18%

In Table 25 and Table 26, unnecessary lane changes for the SPLT sign sequences are broken down into primary and secondary false alarms. While SPLT-2 performed slightly worse than SPLT-6 in terms of secondary false alarms, SPLT-5 performed significantly better than SPLT-6 in terms of primary false alarms (3% vs. 17%, $p < .01$).

Table 25. Primary False Alarms for SPLT Sign Sequences.

Sign sequence	Valid data	# Primary false alarms	% of trials with primary false alarm
SPLT-2	59	17	29%
SPLT-5	59	2	3%
SPLT-6	60	10	17%

Table 26. Secondary False Alarms for SPLT Sign Sequences.

Sign sequence	Valid data	# Secondary false alarms	% of trials with secondary false alarm
SPLT-2	28	15	54%
SPLT-5	29	7	24%
SPLT-6	28	6	21%

In summary, SPLT sign sequences together received the longest lane change distances in this experiment. Within the SPLT sign sequences, SPLT-6 received the longest average lane change distance. SPLT-2 elicited a large percentage of unnecessary lane changes, significantly more than either of the other two signs.

DISCUSSION

Left Exit

For the LE sign sequences, the simulator data showed only small differences between the TxDOT standard text-based sign sequence (LE-1), and the MUTCD diagrammatic sign sequence (LE-4). LE-4 produced lane changes with an average distance slightly further from the gore than LE-1. LE-2 produced lane changes significantly closer to the gore than either of the other two

sign sequences indicating that participants had a hard time both recognizing the correct route at a far distance and comprehending the sign on their first attempt at deciphering it (near the 1 mile advance sign).

LE-4 had more correct lane changes attributed to the first advanced sign than LE-1, possibly indicating that the diagram may be usable to some drivers earlier than the word on the text-based sign. However, LE-4 also caused more people to wait until the second or third sign to make their lane change. The text sign (LE-1) caused the majority of drivers to move to the left lane after the first or second sign. It yielded only one lane change occur inside of 350 meters from the gore. This pattern of results suggests that LE-1 is clear to nearly all drivers and prompts an immediate response, while LE-4 seems to produce a wider variety of responses across drivers. Many drivers did immediately move, but several waited until the last sign in the sequence to change lanes.

One possible interpretation is that while some drivers are confident in their ability to read diagrammatic signs, some are not. The confident drivers can interpret the diagram at a further distance than the text-based sign's words, accounting for the longer lane change distance. The drivers that are not comfortable utilizing the diagrammatic signs choose to wait for at least two viewings of the diagrammatic sign to make their lane choices, potentially even waiting to view the (text-based) exit direction sign. This exit direction sign also had the yellow EXIT ONLY plaque, which could have provided further confirmation of the appropriate route. The familiarity of the text-based sign causes less trepidation in the participants, and although it may not be clear at long distances, after two viewings of the text-based sign, all but one participant made their lane change choices.

In terms of unnecessary lane changes made, the results were far from conclusive. While the diagrammatic LE-4 produced fewer unnecessary lane changes than the other two sign sequences, the margin was so small that it is difficult to draw conclusions. Interestingly, LE-1 did have one trial in which a driver actually committed a primary false alarm by changing from the right lane to the left lane when told to follow the through route (route #6 in Figure 47). This lane change is an indication that the driver either seriously misunderstood the text-based sign or at least was unsure of its meaning enough to want to wait to move to the left lane. This type of primary false alarm is unique to the text-based LE sign sequence.

Overall, the results indicate that the diagrammatic sign, by some metrics, performed slightly better than the current standard text-based sign sequence. This sign, however, seemed to produce more variability in responses. The differences between the MUTCD diagrammatic (LE-4) and the current standard (LE-1) were not statistically significant nor practically large enough to warrant a change in TxDOT practice for Left Exits.

Left Lane Drop

For the Left Lane Drop sign sequences, the measures of effectiveness conflict somewhat with which sign sequence design is best used to illustrate the LLD interchange geometry. When only looking at unnecessary lane changes, the current TxDOT standard text sign (LLD-1) emerges as a clear front-runner as it received zero primary or secondary false alarms. All three other sign sequences for this geometry received at least five false alarms.

This sign is not the clear winner when lane change distance is examined. LLD-1 produced the shortest average lane change distance of the four sign sequences. Although none of the differences were statistically significant due to the large variances, LLD-1's average lane change distance (840 m) was well short of the other three signs, all of which had distances over 900 m.

The two modified diagrammatic signs (LLD-6 and LLD-9) seemed to have required multiple viewings to be understood. Drivers who started in the center lane waited to move to the exit lane much more for exit destinations than for through destinations. This may be due to the visual complexity of the left side of these modified diagrammatic signs. With the route marker, exit number, distance, and directional arrows all crowded on one side of the sign, drivers may have required seeing the sign a second time before being able to extract the lane drop message.

Overall, even though the average lane change distance was much shorter for LLD-1 than for the other three sign sequences, the fact that participants never committed an error when directed by LLD-1 strongly indicates that the text-based Left Lane Drop sign sequence is effective at getting drivers where they want to go.

Right Exit Optional

Six sign sequences were tested for the REO interchange geometry. REO-1, a diagrammatic sign with EXIT ONLY plaques on all three signs, yielded an average lane change

distance significantly farther than any other REO sign sequence. REO-9, a shoulder-mounted modified diagrammatic, received the shortest average lane change distance, with the other four signs performing very similarly in terms of this measure of effectiveness.

REO-1 also received no short distance lane changes and in fact had only one change not attributed to the 1 mile advanced sign. Consistent with the results from the other sign sequence geometries, REO-1 also had the largest proportion of unnecessary lane changes.

Participants navigating the REO interchange geometry committed many of the unnecessary lane changes. For the exit route, participants navigating using REO-1 committed primary and secondary false alarms in over 65% of trials. As the unnecessary lane change data for the REO geometry is examined more carefully, an interesting trend emerges (this data is presented in Figure 53 in the results section). For sign sequences REO-1, REO-2, and REO-4, participants navigating the exit route committed a much larger proportion of the unnecessary lane changes than ones committed by participants navigating the through route. The opposite is true for sign sequences REO-7, REO-8 and REO-9. The researchers hypothesized that this trend is due to the presence of the EXIT ONLY plaque on the 1 mile advanced sign for sequences REO-1, REO-2, and REO-4. The EXIT ONLY plaque helps the participant following the through route but will result in a large number of unnecessary lane changes when the driver attempts to follow the exit route. The absence of the plaque has the opposite effect. Sign sequences without the EXIT ONLY plaque received many unnecessary lane changes for participants following the through route.

Looking at the two principle measures of effectiveness shows that the combination of the diagrammatic illustration and the EXIT ONLY plaque results in participants making early lane changes that are not necessarily correct. The next chapter further discusses this trend.

Overall, REO-8 performed slightly better than the other five signs sequences. No sign performed extraordinarily better than the others, but with the second lowest proportion of unnecessary lane changes and a credible average lane change distance from the gore, REO-8 is probably the best sign out of these six at safely guiding drivers through a REO interchange.

REO-7 was the sign recommended by Upchurch et al. (17) and proposed as a new standard to the National Committee on Uniform Traffic Control Devices. REO-8 represents the current MUTCD standard sequence. The difference between the two sequences is the exit direction sign: REO-7 has an EXIT ONLY plaque with two diagonal up arrows, while the

current standard has two white down arrows. The simulator portion of the study showed no difference between these two sequences. The current study does not support a change to the Texas MUTCD Figure 2E-7.

If a diagrammatic sign is selected, the research supports the use of REO-8. This is the standard MUTCD diagrammatic. If a text sign is desired, REO-2, the current standard, is recommended. Overall, the differences among the signs in the simulator portion of the project were not large enough to warrant a change to the current text sign standard (REO-8).

Freeway to Freeway Splits

The SPLT sign sequences produced the largest average lane change distances among all four geometries explored in this experiment. SPLT-6 received a longer average lane change distance than SPLT-2 and SPLT-5, although none of the differences are significant.

The presence of the EXIT ONLY plaque on the advance signs for SPLT-2 produced a large number of unnecessary lane changes for the exit direction. The study shows that signs that do not convey the optional nature of the center lane could result in reduced capacity at the interchange.

Another recurring trend is seen here. The diagrammatic sign (SPLT-5) received the fewest unnecessary lane changes but also the shortest average lane change distance. Again, this may reveal that participants tend to guess when a sign is visible at a long distance.

The current TxDOT standard (SPLT-6) had a fair number of unnecessary lane changes, but its overall performance was buoyed by the outstanding performance on lane change distance. The MUTCD diagrammatic (SPLT-5) performed well with very few unnecessary lane changes. Both signs performed better than the SPLT-2 sequence recommended by the Freeway Signing Handbook *(1)*. One concern about SPLT-5 is the use of an EXIT ONLY panel over just one leg of the split. Phase 4 of the project examined variations on the exit direction sign array.

CHAPTER 5:
PHASE 4 DRIVER COMPREHENSION TESTING WITH POWERPOINT SLIDES

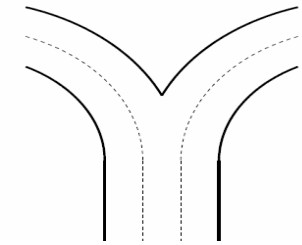
After the simulator drive, participants completed a computer portion similar to the laptop studies of Phases 1 and 2. The purpose of this additional session was to focus on sign variations that time would not allow in the simulator, to allow the participants to give their personal preferences on the signs, and also to grasp the participants' driving styles when it came to making lane choice decisions.

MATERIAL PREPARATION

The signs SPLT-2, SPLT-5, SPLT-6, REO-1, REO-7, and REO-8 are repeated from the simulator study. In addition, several variations on these signs were also tested, particularly with regard to exit direction, or gore, signs. The researchers were particularly interested in examining more closely how drivers understand EXIT ONLY panels.

Freeway to freeway splits pose a unique challenge because it is not always clear which leg should be treated as the exit leg. This phase included several additional variations on split signing. The Freeway Signing Handbook provides guidance for situations where the through route continues on the left and the right legs, as well as locations where the through route terminates at the split. The guidance recommends placing an EXIT ONLY plaque over the outside lane of the exit leg as shown in Figure 56. This sequence does not use the EXIT ONLY plaque on the advance sign which was tested in SPLT-2 (see Figure 36). It makes logical sense to include an EXIT ONLY plaque over both outside lanes, since they each only serve a single leg. This idea was tested in SPLT-7 (Figure 57). The SPLT-8 sequence (Figure 58) included a modified diagrammatic version of the split sign.

SPLT-4 (Phase 4 computer portion)
The exit direction sign is based on the Texas Freeway Signing Handbook (Page 5-15). The advance sign sequence is copied from the Texas Freeway Signing Handbook (Fig. 5-22).



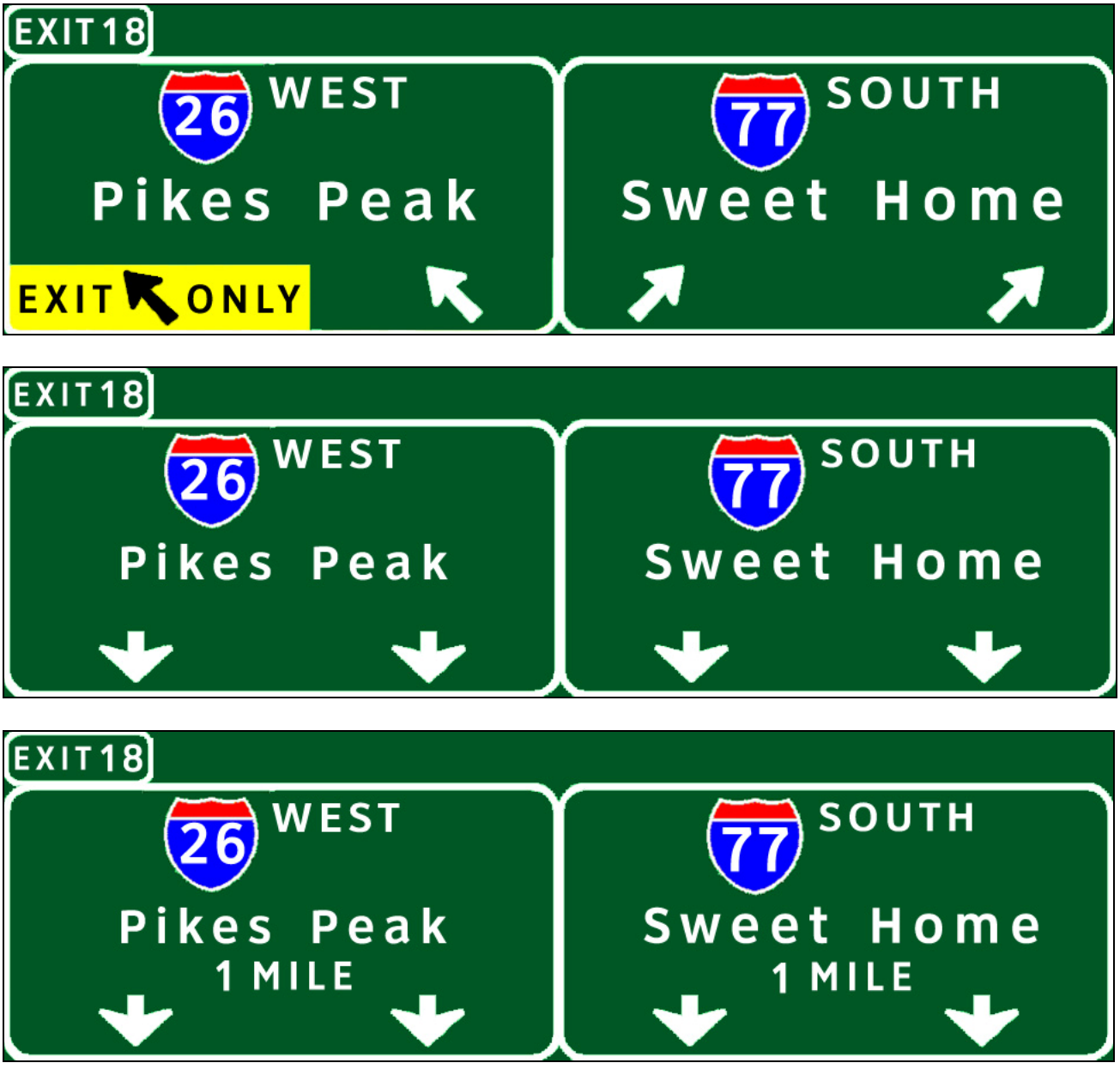
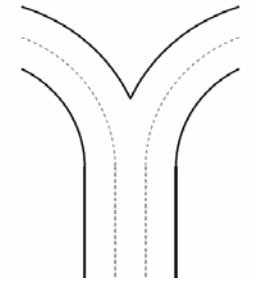


Figure 56. Computer Sign Sequence SPLT-4.

SPLT-7 (Phase 4 computer portion only)
The exit direction sign is based on the Texas Freeway Signing Handbook (Page 5-15) with the addition of an EXIT ONLY plaque on both legs of the split and with the destination name, the route marker, and the cardinal direction added. The advance sign sequence is copied from the Texas Freeway Signing Handbook (Fig. 5-22).



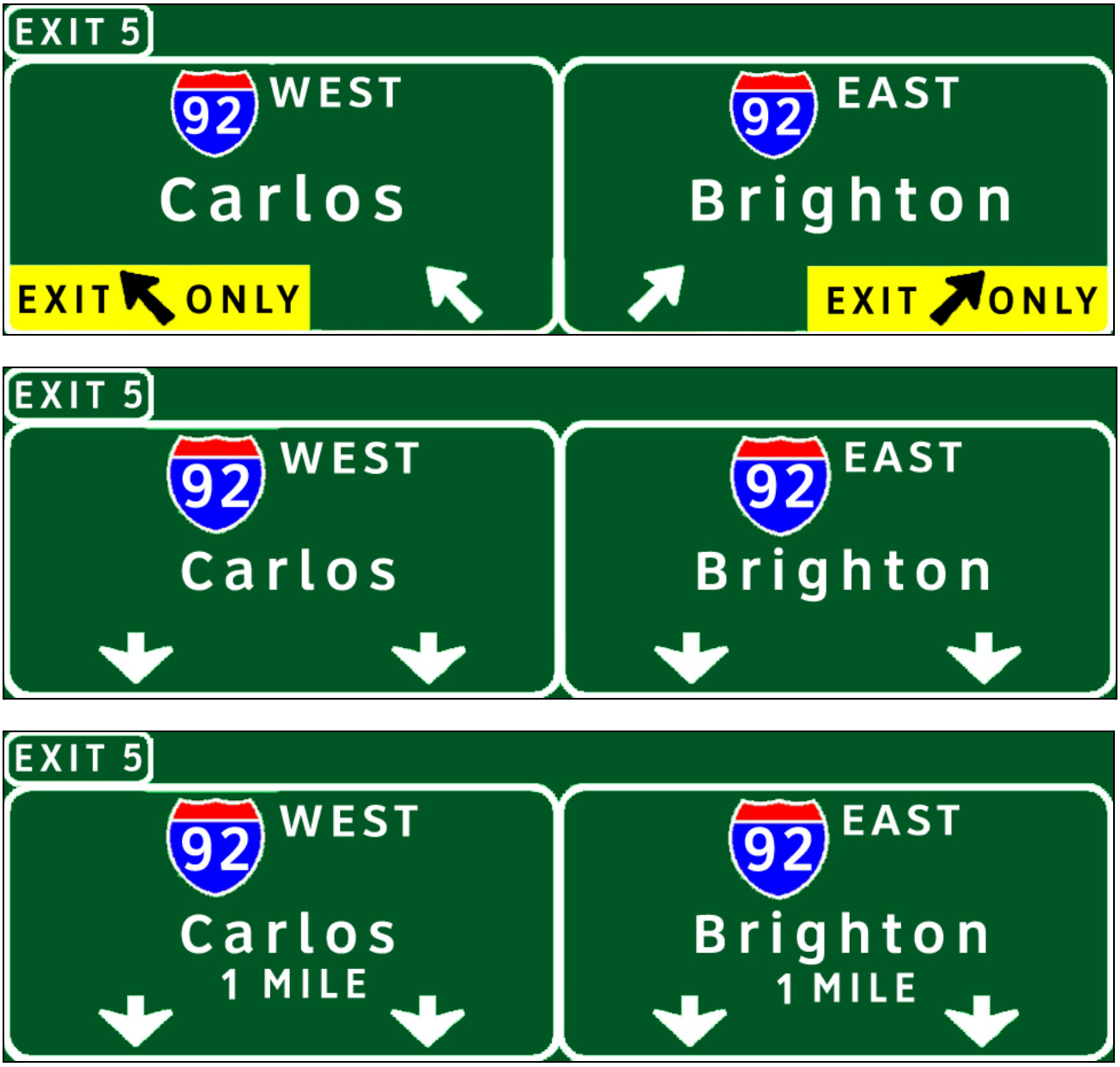
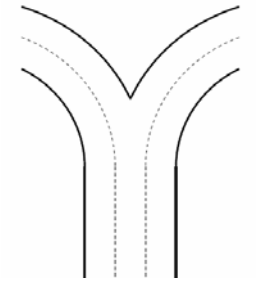
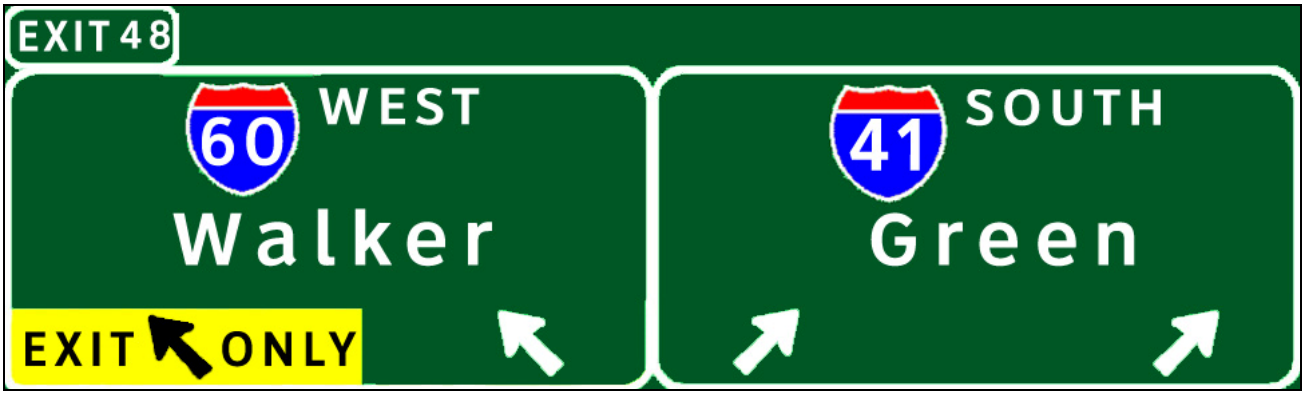


Figure 57. Computer Sign Sequence SPLT-7.

SPLT-8 (Phase 4 computer portion only)
The exit direction sign is based on the Texas Freeway Signing Handbook (Page 5-15). The advance sign sequence is developed by the researchers.





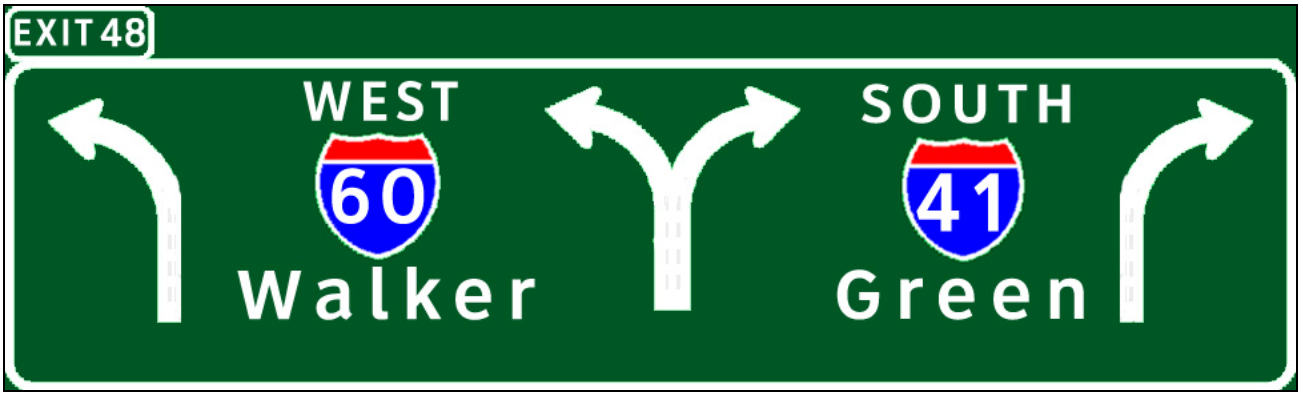
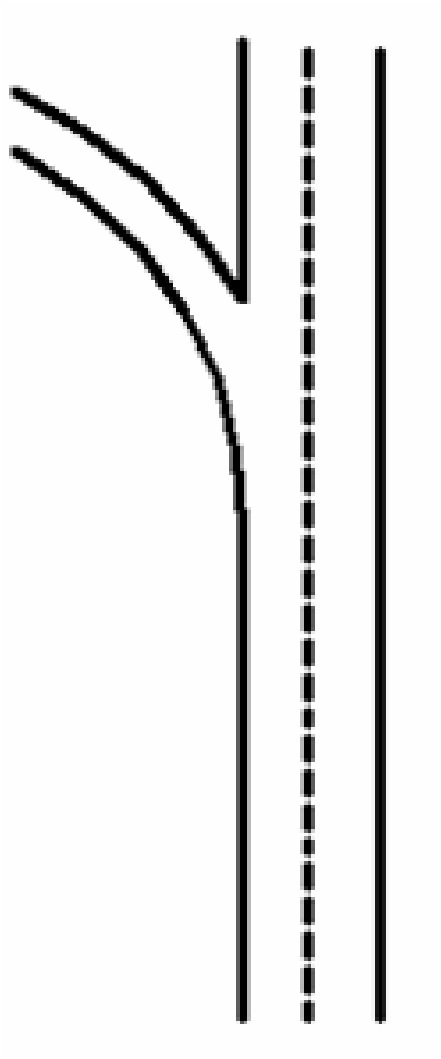


Figure 58. Computer Sign Sequence SPLT-8 .

Participants were also asked to indicate their preference among the various advance guide sign designs. Figure 59 shows an example of this type of question for the LE signs. The signs used for the preference questions for the LLD, REO and SPLT layouts follow in Figures 60 through 62.

"Imagine that one of these signs will be installed one mile before an exit ramp. Which sign would best explain the layout of the roadway pictured below?"

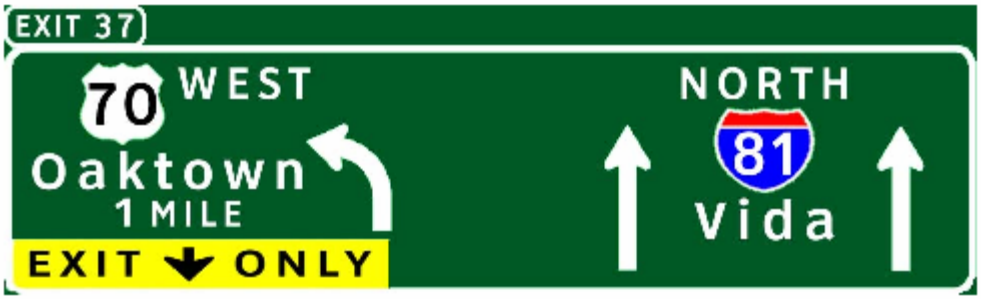


LE-1

LE-2

LE-4

Figure 59. Computer LE Preference Question Signs.



LLD-9

LLD-1

LLD-2

Figure 60. Computer LLD Preference Question Signs.

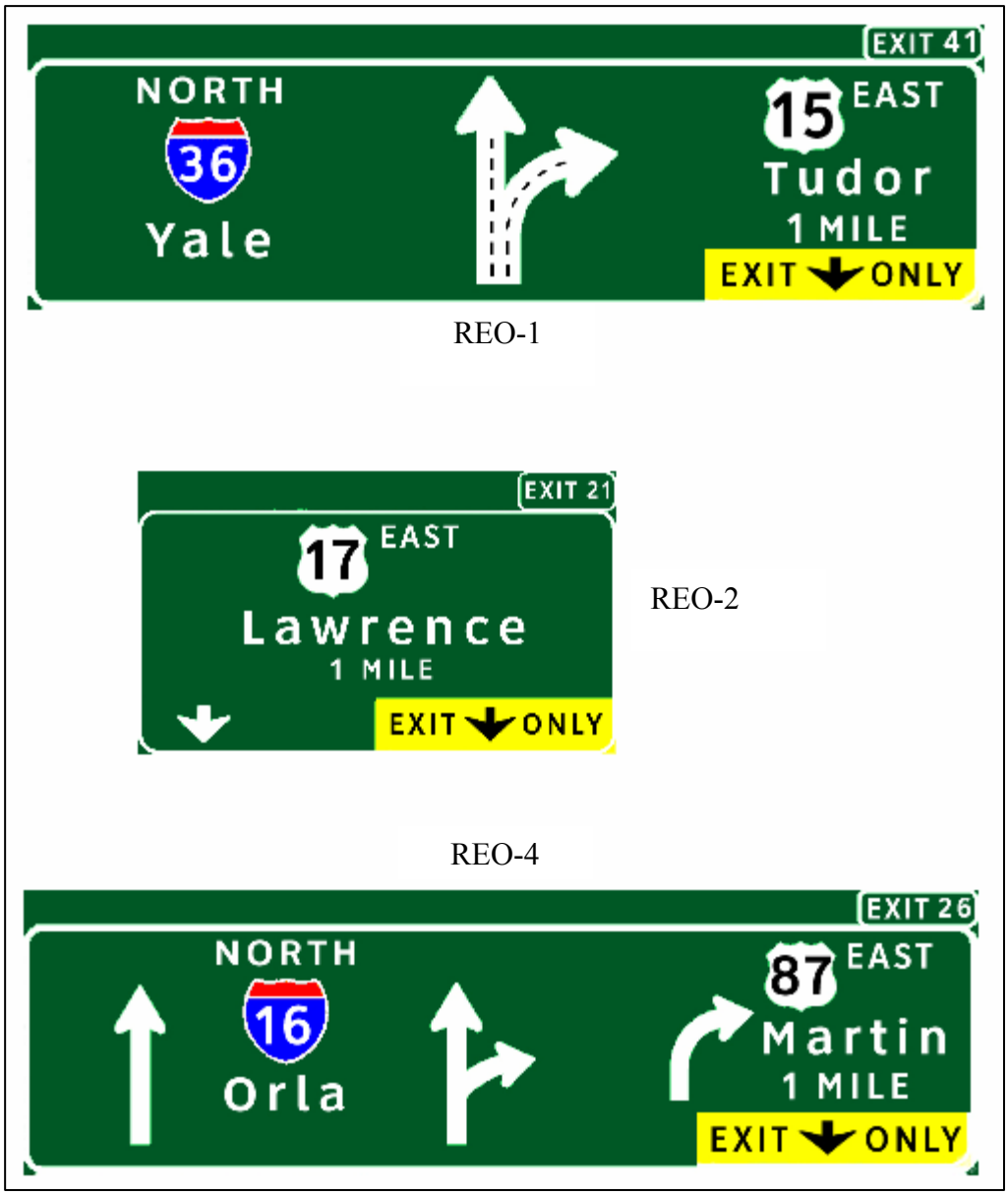


Figure 61. Computer REO Preference Question Signs.

SPLT-8

SPLT-5

SPLT-4

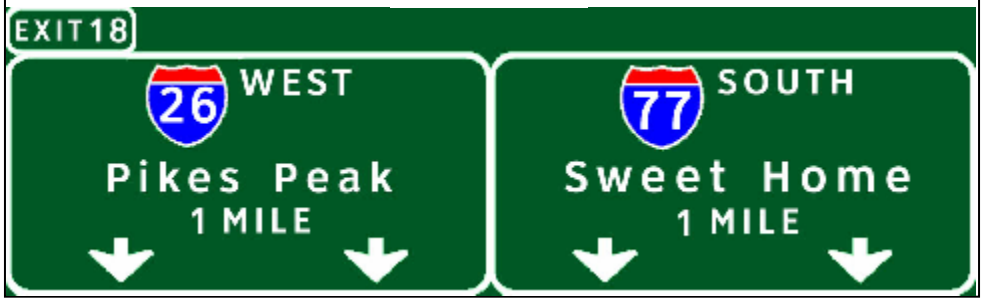


Figure 62. Computer SPLT Preference Question Signs.

Figure 63 shows the sign used to access the participants' understanding of the "Exit Only" plaque. The question asked was as follows:

"The yellow Exit Only plaque means: (select True of False for each statement)

A. If I am in the right lane, I will be forced to take the exit to Lawrence.

B. If I want to go to Lawrence, I must be in the right lane; no other lane will allow me to exit."

Figure 63. Computer Exit Only Comprehension Question Sign (REO-2).

The final type of question for the Phase 4 portion determined the participants' lane changing tendencies. This question could be used to help assess whether the subjects were making unnecessary lane changes because they were misunderstanding the sign or because it was their usual driving style (see Figure 64).

"Assume you are traveling in the center lane of the road section shown below. If you want to take the exit route, are you more likely to:

A. Stay in the center lane

B. Change lanes"

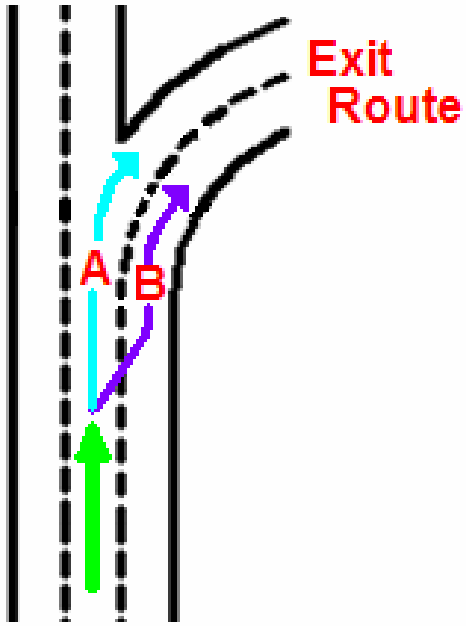


Figure 64. Computer Lane Change Tendency Question.

DESIGN/PROCEDURE

As with the simulator study, signs were counterbalanced and the exit/through for the same sign sequences were studied by forming two different groups, X and Y, with half the participants completing one and the remaining half the other. Table 27 shows the order of the questions for the two groups, and Appendix D contains an example of group X's questions.

Table 27. Computer Phase 3 Survey for Groups X and Y.

Question	Group X	Group Y
1	SPLT-7 Exit	SPLT-2 Exit
2	SPLT-6 Through	REO-8 Exit
3	REO-1 Exit	SPLT-4 Through
4	SPLT-5 Exit	REO-7 Exit
5	SPLT-8 Through	SPLT-5 Through
6	REO-7 Exit	REO-1 Exit
7	SPLT-4 Exit	SPLT-8 Exit
8	REO-8 Exit	SPLT-6 Exit
9	SPLT-2 Through	SPLT-7 Through
10	LLD Preference	LE Preference
11	Exit Only Comprehension	Exit Only Comprehension
12	SPLT Preference	REO Preference
13	Lane Change Tendency	Lane Change Tendency
14	REO Preference	SPLT Preference
15	LE Preference	LLD Preference

Researchers developed the surveys using a PowerPoint presentation. For the lane choice decision questions, the participants viewed all three signs in each sign sequence before making their decisions. Each advance sign was displayed for three seconds, and the exit direction sign was shown for five seconds. Additional questions showed various signs that could be used for the same roadway geometry and asked the participants which sign they preferred. The final types of questions focused on how the participants interpret signs, specifically the term "Exit Only," and what their personal driving styles are when choosing a lane to drive in.

After completion of the computer portion, the participants were compensated, thanked for their time and offered a debriefing handout explaining the purpose of the study.

Table 28 lists all of the signs studied in Phases 1-4.

Table 28. All Signs Studied in Phases 1, 2, 3 and 4.

Sign	Phase 1	Phase 2	Phase 3*	Phase 4*	Description
LE-1	√	√	√		Standard text sign
LE-2	√	√	√		Based on TTI Study (*8*) and Older Driver Handbook
LE-3	√	√			Diagrammatic based on Federal MUTCD with narrow through lane leg
LE-4		√	√		Diagrammatic from Figure 2E-3 in the TX MUTCD
LLD-1	√	√	√		Standard text sign
LLD-2	√	√	√		Diagrammatic based on Federal MUTCD
LLD-3	√	√			Diagrammatic based on Federal MUTCD
LLD-4	√	√			Diagrammatic based on Federal MUTCD
LLD-5	√	√			Modified Diagrammatic based on Older Driver Handbook
LLD-6	√	√	√		Combines several principles of other signs
LLD-7		√			Identical to LLD-4 without the lane lines
LLD-8		√			Modified Diagrammatic in use in Houston
LLD-9			√		Based on the TX Freeway Signing Handbook
REO-1			√	√	Combination of TX MUTCD and Federal MUTCD
REO-2	√	√	√		Standard TX MUTCD text sign
REO-3	√	√			Ontario diagrammatic sign
REO-4	√	√	√		Modified Diagrammatic based on Older Driver Handbook
REO-5		√			Modified Diagrammatic with EXIT ONLY plaque
REO-6		√			Modified Diagrammatic in use in Houston
REO-7	√	√	√	√	Combination of TX MUTCD, Federal MUTCD, and TX Freeway Signing Handbook
REO-8	**	**	√	√	Combination of TX MUTCD, and Federal MUTCD
REO-9			√		Based on TX MUTCD, with ground-mounted advance
SPLT-1	√	√			Diagrammatic based on Federal MUTCD
SPLT-2	√	√	√	√	Based on the TX Freeway Signing Handbook
SPLT-3	√	√			Minnesota design with 3 down arrows
SPLT-4	√	√		√	Current TX practice with 4 down arrows
SPLT-5		√	√	√	Identical to SPLT-1 without lane lines
SPLT-6	***	***	√	√	Based on the TX Freeway Signing Handbook for four-lane approach
SPLT-7				√	Identical to SPLT-4 with EXIT ONLY plaque on both outside lanes
SPLT-8				√	Modified Diagrammatic developed by researchers

RESULTS

This phase asked four different types of questions. Primarily, participants were asked questions similar to the task performed in the simulator in regard to six SPLT sign sequences and

three REO sign sequences. Also, a subjective preference question was asked for each of the four geometries. Each participant was also asked two other questions: one regarding general driving tendencies and the other in relation to understanding of an EXIT ONLY plaque on a guide sign.

Table 29 below displays the Phase 4 data for the SPLT sign sequences. In general, participants correctly responded significantly more often to questions dealing with the through condition compared to the exit condition (87% vs. 72%, $p<.001$).

Table 29. Phase 4 SPLT Data.

Sign Seq.	Total	Valid	Exit valid	Exit correct	Exit corr. %	Through valid	Through correct	Through corr. %	Overall corr.	Overall %
SPLT-2	60	60	30	20	67%	30	30	100%	50	83%
SPLT-4	60	59	30	22	73%	29	25	86%	47	80%
SPLT-5	60	60	30	19	63%	30	25	83%	44	73%
SPLT-6	60	60	30	26	87%	30	24	80%	50	83%
SPLT-7	60	60	30	22	73%	30	26	87%	48	80%
SPLT-8	60	55	26	18	69%	29	24	83%	42	76%
Overall			176	127	72%	178	154	87%		

Among the SPLT sign sequences, SPLT-2 and SPLT-6 both received correct responses in 83% of the trials, which tied them for the highest proportion for SPLT sign sequences. This average does obscure the fact that SPLT-2 did very poorly (63% correct) under the exit condition but then received a perfect score (100% correct) under the through condition. SPLT-6, in contrast, received a score of 87% correct under the exit condition and 80% correct under the through condition. SPLT-6 was the only sign which scored better under the exit condition than under the through condition. SPLT-5 received the lowest percentage of correct responses at 73%.

In Phase 4, the REO sign sequences were only evaluated for the exit condition. Table 30 displays these results.

Table 30. Phase 4 REO Data (Exit Route Only).

Sign Seq.	Total	exit valid	exit correct	exit correct %
REO-1	60	59	41	69%
REO-7	60	59	49	83%
REO-8	60	60	49	82%

As illustrated in Table 30, REO-1 received the lowest percentage of correct responses, while REO-7 received the highest percentage of correct responses. REO-1 received a proportion of correct responses significantly lower then REO-7 (69% vs. 83%, p=.04) but not significantly lower than REO-8 (69% vs. 82%, p=.06).

The Phase 4 computer-based portion of this experiment included four questions on the participants' subjective preference of one sign design format over another. The survey asked participants which type of sign design (text-based, diagrammatic, modified diagrammatic) they would prefer to see when they encountered each of the four interchange geometries. Table 31 displays the results of these preference questions.

Table 31. Subjective Preference Responses Regarding Advanced Sign Sequence Format for Each Type of Geometry.

	Roadway Geometry				
Design Format	LE	LLD	REO	SPLT	Overall
Text-based	12%	10%	18%	33%	18%
Diagrammatic	46%	67%	68%	52%	58%
Mod. Diagrammatic	42%	23%	13%	15%	23%

Overall, participants preferred the diagrammatic design over the other two formats. This was especially true in terms of the REO and the LLD sign sequences, with 68% preferring the diagrammatic in the case of the REO's and 67% preferring the diagrammatic in the case of the LLD's. For the LE sign sequences, participants still preferred the diagrammatic design but only by a small margin.

The survey also asked all participants a question regarding their understanding of the use of an EXIT ONLY plaque at the bottom of a guide sign. Participants were shown the sign in Figure 65 and asked to respond true or false to the statements following the sign.

Figure 65. Sign From "EXIT ONLY" Placard Comprehension Question in Phase 4.

Question 1:

"If I am in the right lane, I will be forced to take the exit to Lawrence" (true/false).

Question 2:

"If I want to go to Lawrence, I must be in the right lane; no other lane will allow me to exit" (true/false).

The first statement is true, the second statement is false. The results from these questions are displayed in Table 32.

Table 32. Responses to "EXIT ONLY" Placard Question.

Question	total	correct	% correct
1	60	56	93%
2	60	46	77%

While participants scored fairly high on Question 1, the results from Question 2 illustrate the fact that 23% of drivers do not fully grasp the meaning of the ubiquitous "EXIT ONLY" plaque found on many guide signs. Between both questions, 25% of participants missed either Question 1 or Question 2.

DISCUSSION

Clearly, people prefer diagrammatic signs over text-based versions. These preferences were elicited by giving raters an unlimited amount of time to compare sign designs side-by-side. These preferences do not always correspond to driving performance, as evidenced in the Phase 3

simulator portion which showed the text signs performing equal to or better than the diagrammatic signs.

The results from the various SPLT variations show that overall, drivers more accurately select lanes for the through destination than for the exit destination. The current text standard (SPLT-6) performed the best and was the only sign to produce more accurate lane choices for the exit leg than the through leg.

The REO signs tested in this Phase were identical to those tested in the simulator. The results from Phase 4 confirmed that the EXIT ONLY panel on the advance sign (REO-1) produced a large number of incorrect lane choices for the exit direction. As in the simulator portion, the Upchurch recommended sequence (REO-7) performed similarly to the current MUTCD diagrammatic (REO-8).

The EXIT ONLY questions revealed that a large portion of participants misunderstand the meaning of this auxiliary plaque. The results from Phase 4 confirm what was seen in previous Phases. The next chapter discusses the overall effect of EXIT ONLY plaques.

CHAPTER 6:
CONCLUSIONS AND RECOMMENDATIONS

SIGN DESIGN ELEMENTS

EXIT ONLY Panel

The strong effect of the addition of an EXIT ONLY plaque on an advanced guide sign was one of the most striking discoveries made throughout this research. Beginning with the Upchurch study mentioned in the literature review and through all phases of this study, it was observed that drivers do not fully grasp the meaning of the EXIT ONLY plaque, and thus consistently make incorrect decisions about the meaning of signs displaying this plaque.

In the Upchurch study, the MUTCD sign configuration was the only sign sequence not displaying the EXIT ONLY plaque on the advanced guide signs. While the other three signs sequences received unnecessary lane change on roughly 90% of trials leading to the exit route, the MUTCD sign received unnecessary lane changes in roughly 60% of these trials. Conversely, in trials that dealt with the through or mainline route, the MUTCD sign produced unnecessary lane changes in 40% of trials, while the other three signs yielded unnecessary lane changes in roughly 12% of trials.

The addition of the EXIT ONLY plaque tended to have the affect of increasing unnecessary lane changes for the exit route but reducing the unnecessary lane changes for the through (or mainline) route.

The exit plaque tends to pull drivers planning to exit all the way over to the lane marked with the EXIT ONLY plaque. Researchers inferred from this result that drivers tend to believe EXIT ONLY means that the lane over which the sign is displayed is their only option to exit the main roadway.

In Phases 1 and 2 of this study, the same trend is apparent. Comparison of the Phases 1 and 2 SPLT-2 and SPLT-3 signs shows the best example of this trend. While the signs are very similar, the addition of the EXIT ONLY plaque on SPLT-2 incited 92% of drivers to incorrectly assume they must be in the far left lane to exit. When the EXIT ONLY plaque was absent on SPLT-3, only 31% of drivers made the same mistake.

The misunderstanding of the plaque does not always result in negative outcomes. In Phases 1 and 2 when LLD-2 is compared to a very similar LLD-3, the misunderstanding of the

EXIT ONLY plaque on LLD-2 likely caused 20% more drivers to (correctly) assume that the left lane was their only option to exit, although this assumption may again illustrate the misunderstanding of the EXIT ONLY plaque. The plaque actually declares that the indicated lane will be forced to exit, not that the indicated lane is the only option by which one may exit. This case is unique because either the correct or incorrect understanding of the plaque will correctly lead participants to believe that the left lane is the only option to exit from the Left Lane Drop interchange geometry. Consistent with the statement made in regard to the Upchurch study, the addition of the EXIT ONLY plaque did increase correct responses when participants were attempting to follow the through route.

The final example from Phases 1 and 2 is REO-2, where 58% of participants believed they must be in the right lane to exit with the EXIT ONLY plaque present, when in fact either the center or the right lane would lead to the exit route.

In Phase 3, the trend was most apparent in the case of the Right Exit Optional sign sequences. Three of the REO sign sequences displayed an EXIT ONLY plaque on the advanced guide signs, while three did not. In the case of REO-1 vs. REO-8, the sign series were identical except for this detail. The addition of the EXIT ONLY plaque on REO-1 resulted in unnecessary lane changes in 64% of exit route trials but only 39% of through route trials. Conversely, an identical sign minus the EXIT ONLY plaque (REO-8) received unnecessary lane changes in only 20% of exit route trials and 67% of through route trials. This data is presented in Figure 53 in the results section of this report.

Finally, in Phase 4, participants were specifically asked if they understood the meaning of the EXIT ONLY plaque. The results indicated that 25% of drivers do not understand the correct meaning of the EXIT ONLY plaque.

As mentioned above, drivers tend to believe that they must be in the identified lane to exit, which contributed to the unnecessary lane changes when participants were asked to take the exit route. Conversely, when participants were asked to take the through route, the presence of the EXIT ONLY plaque over the right lane made them comfortable that the center lane would not be exiting, so they were less compelled to change out of that lane.

Future research should focus on the use of using EXIT ONLY plaques for optional lane situations, including multi-lane exits and splits. While the driving habit of going to the outside

lane "just to be sure" could promote safety by reducing lane changes at the gore, it would reduce the capacity of the interchange.

Text vs. Diagrammatic

In the simulator portion of the study, LLD-1 had no unnecessary lane changes but had the lowest average distance from the gore for lane changes. This result was consistent with the trend of the sign sequences resulting in the fewest unnecessary lane changes also receiving the shortest lane change distance (REO-9, SPLT-5).

Text-based signs may indeed be easier to understand across the entire driver population, but they are not necessarily visible from as long a distance as the diagrammatic or modified diagrammatic signs. The longer viewing distance may lead to more guessing, and thus more unnecessary lane changes; yet when these picture-based signs are "guessed" at correctly, the early changes result in longer lane change distances.

Diagrammatic vs. Modified Diagrammatic

The modified diagrammatic signs tested here were based on designs originally used with route shields only in the Houston metropolitan area. When used with route shields only (see REO-6 in Phases 1 & 2), the signs are relatively straightforward and uncluttered. This sign design performed very well in the early phases of the project. In Phase 3, additional elements were added to the modified diagrammatic signs to equate the amount of information present across sign types. Phases 3 & 4 presented modified diagrammatic signs with route shields, cardinal directions, and destination city names. When the additional elements are added, the signs become crowded and visually complex. This complexity may have led to their relatively poor performance in the simulator portion of the project. If applied to larger freeway interchanges with more lanes represented, the visual complexity will only increase. More research is needed to refine the design of these signs and test their application at large multi-lane interchanges.

In Phase 4, when participants were asked to decide which sign design type they preferred for each interchange type, the diagrammatic design received more support than the modified diagrammatic design for all four geometries. Only in the case of the LE geometry were the subjective preference numbers even close. Although participants overwhelmingly preferred the

diagrammatic sign design to the modified diagrammatic sign design, the results were not decisive enough to make a strong conclusion about which sign design methodology is more effective.

In the case of the LE and the REO sign sequences, the modified diagrammatic signs received shorter average lane change distances. In the case of the LLD sign sequences, the modified diagrammatic signs had longer average lane change distances overall. It is interesting to note that LLD-9 and REO-4 were very similar and mirror images of each other but performed quite differently. For the left lane drop condition, the modified diagrammatic (LLD-9) produced long lane changes and only 8% unnecessary lane changes. For the right exit only, the modified diagrammatic (REO-4) produced shorter lane change distances and 37% unnecessary lane changes. These results show that modified diagrammatic signs may be good for a single lane drop situation but may not be good for optional lane drop configurations. Using different styles of signs for different interchange types, however, may introduce an unacceptable lack of uniformity.

Left Exits

The results of the research do not support a change to the current TxDOT practice of using a text sign with a LEFT EXIT plaque with no pull-through sign (LE-1). The Phase 4 questions concerning overall preference of sign design indicated that drivers preferred the MUTCD diagrammatic style sign (LE-4). The objective performance in the other phases of the study, however, did not demonstrate that lane choice behavior agreed with drivers' stated sign style preference. The laptop surveys concerning advance guide signs conducted in Phases 1 & 2 showed that the current TxDOT standard text sign (LE-1) performed well, though not quite as well as the MUTCD diagrammatic sign. The full sign sequences of two advance signs and an exit direction sign were tested in Phase 3 in the driving simulator. These results again show LE-1 and LE-4 performing quite similarly. The modified diagrammatic sign (LE-2) did not do as well as the other signs in any phase of the study.

Left Lane Drops

The results of the research do not support a change to current TxDOT practice of using a text sign with an EXIT ONLY plaque with no pull-through sign (LLD-1). The simulator portion of the project showed that this text sign produced no unnecessary lane changes. While the

modified diagrammatic performed well in the early phases of the study, LLD-9 was a late addition to the simulator portion of the study and was only seen by a small number of subjects. The early version of the modified diagrammatic contained only route shields. When additional information elements were added, the sign did not clearly outperform the text sign, though it still did well. For that reason, if a non-text sign is desired, a modified diagrammatic style is recommended for left lane drops.

Right Exit Only

The results of the research do not support a change to the current TxDOT practice of using a text sign with an EXIT ONLY plaque with no pull-through sign (REO-2). In general, the MUTCD diagrammatic performed equally to the text-only version and would be an acceptable alternative. For freeways with more than three lanes, however, a diagrammatic sign may become too large and complex to comprehend. Further research is needed for multiple lane drops and multiple through lane situations. For more complex interchanges, pull-through signs may be a complement the text signs.

Splits

The results of the research do not support a change to the current TxDOT practice of using text signs with each leg showing two down arrows (SPLT-6). Earlier research called into question the advisability of showing four down arrows over just three lanes of traffic. The current study shows that drivers understand the four arrows fine, and that they convey the optional nature of the center lane. Note that the Freeway Signing Handbook (Figure 5-22) shows four down arrows applied for a four-lane approach. The current project used these same signs for a three-lane approach. Any consideration of policy change should consider any inconsistency caused by the application of the same sign sequence for four- and three-legged approaches.

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APPENDIX A

ROADWAY GEOMETRY TYPES CONSIDERED

SINGLE LANE DROP EXITS

Figures 1-9 illustrate examples of roadway geometry containing single lane drops to exits. Unless otherwise noted, lane drops lead to diagonal or directional ramps.

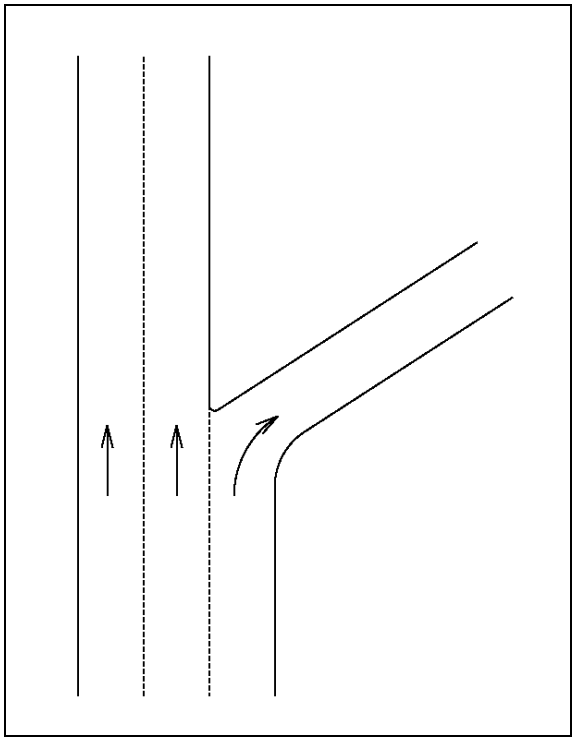


Figure 1. Right Lane Drop from 3 Lanes.

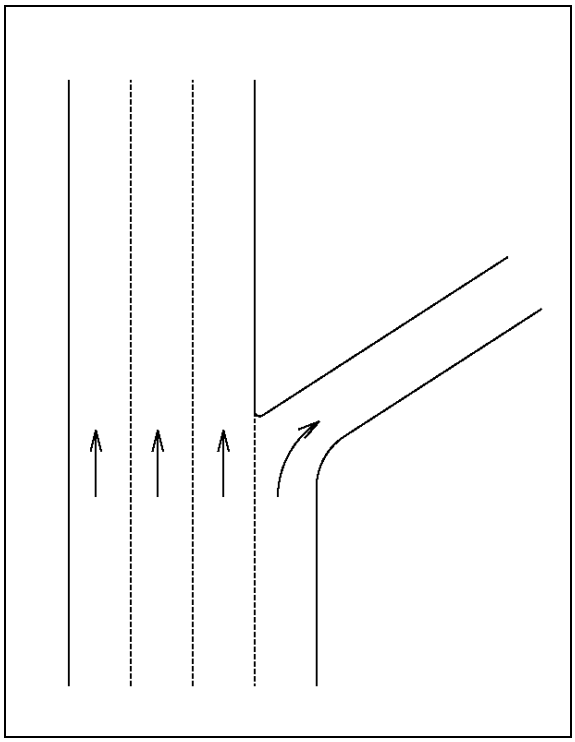


Figure 2. Right Lane Drop from 4 Lanes.

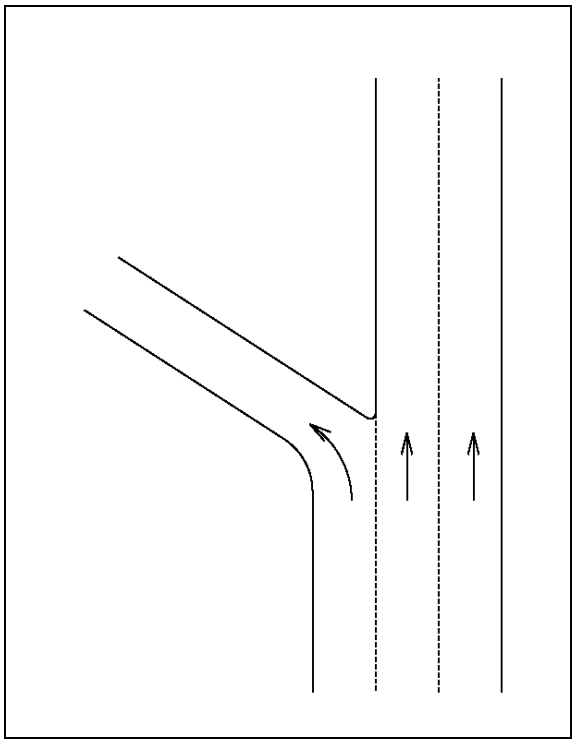


Figure 3. Left Lane Drop from 3 Lanes.

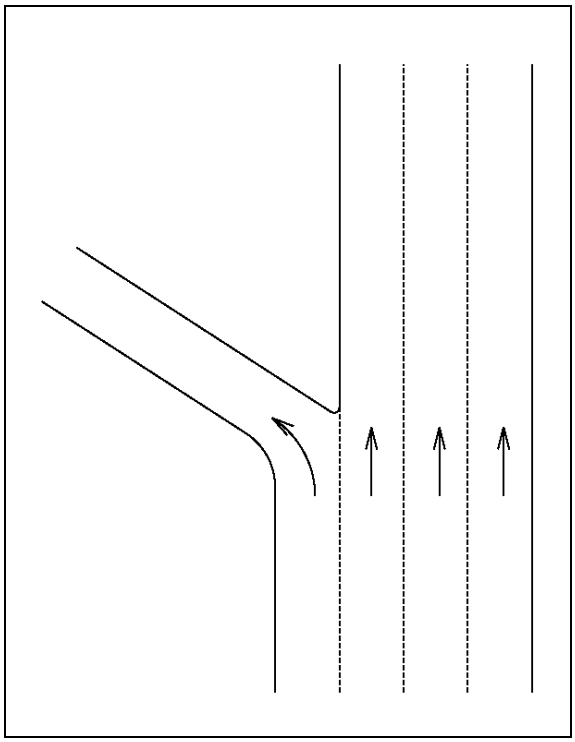


Figure 4. Left Lane Drop from 4 Lanes.

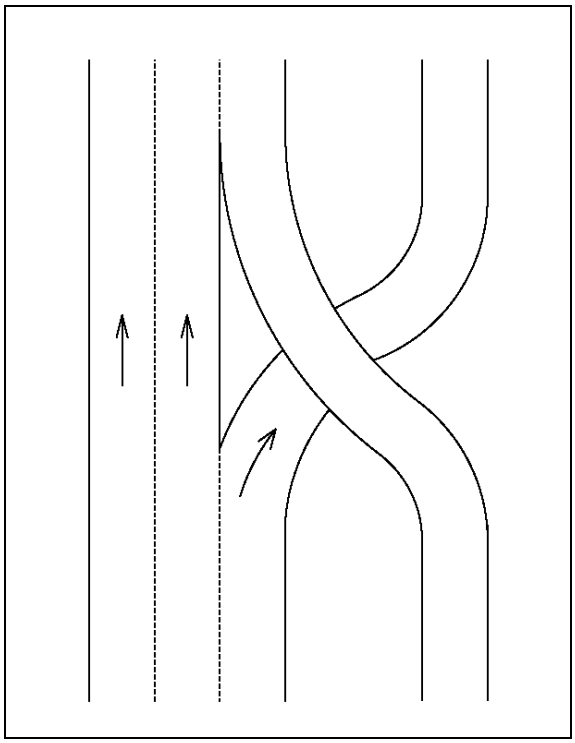


Figure 5. Braided Ramps to and from Frontage Roads.

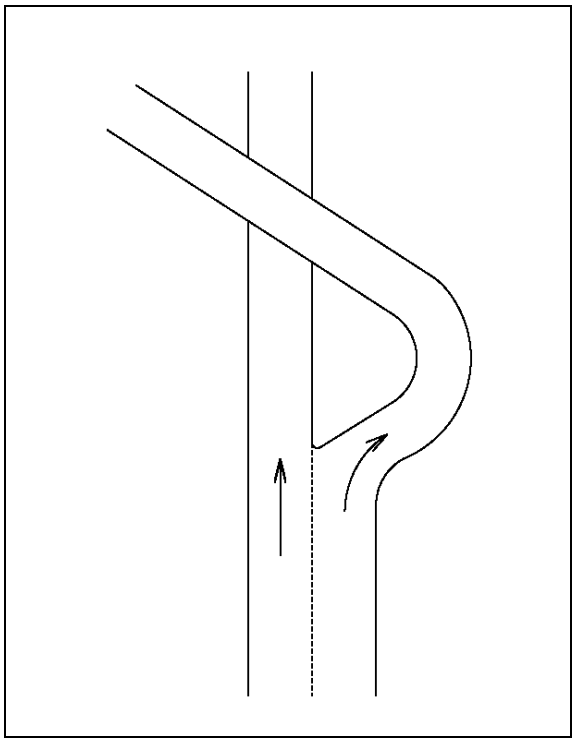


Figure 6. Right Lane Drop to Semidirectional Ramp.

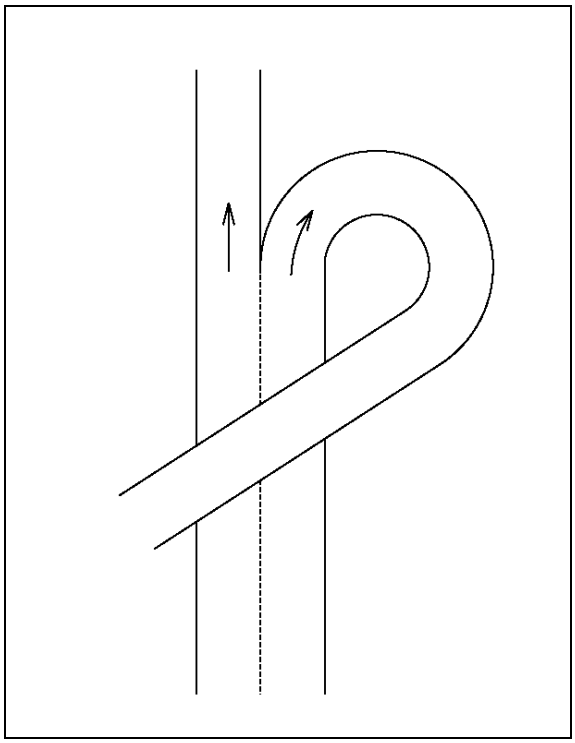


Figure 7. Right Lane Drop to Loop Ramp.

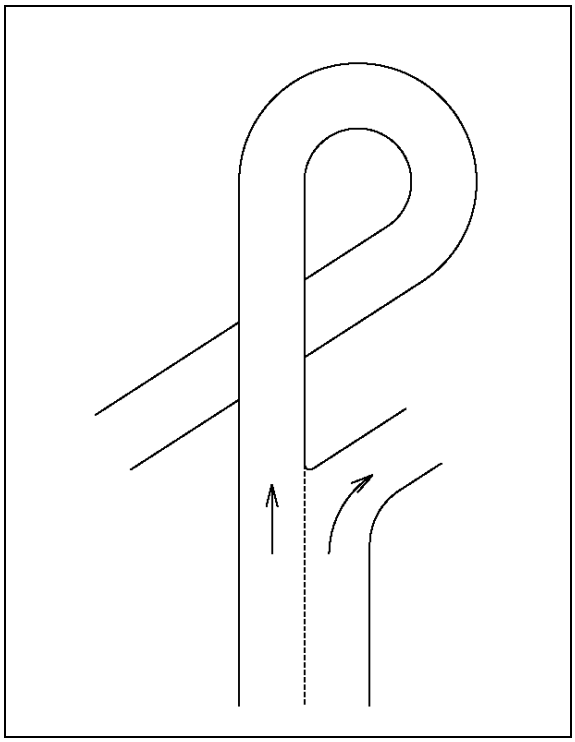


Figure 8. Right Lane Drop with Through Traffic Entering Loop Ramp.

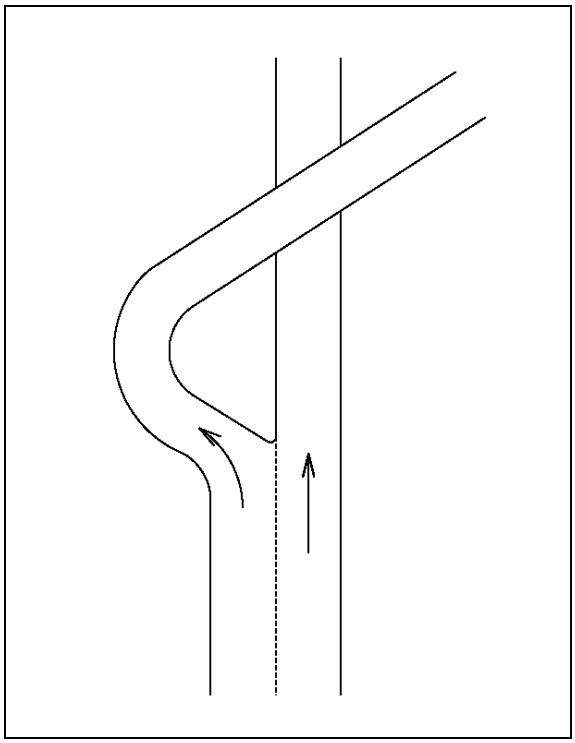


Figure 9. Left Lane Drop to Loop Ramp.

SPLIT GEOMETRIES

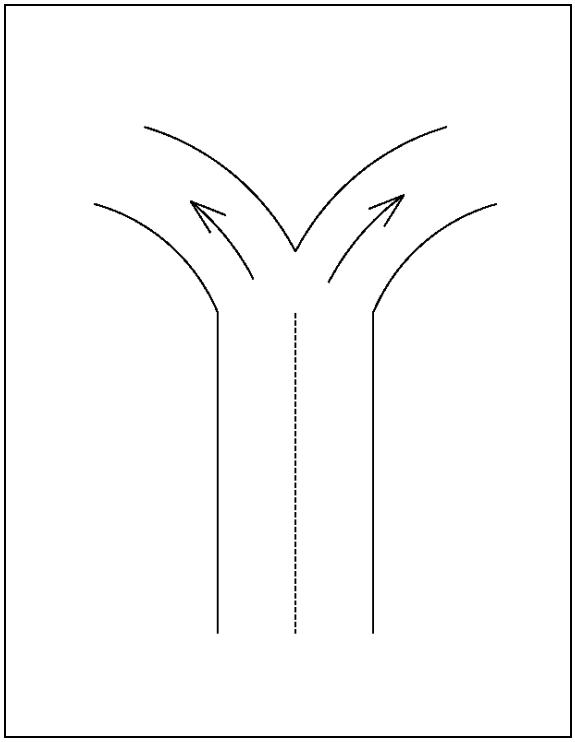


Figure 10. Two-Lane Split with Dedicated Lanes.

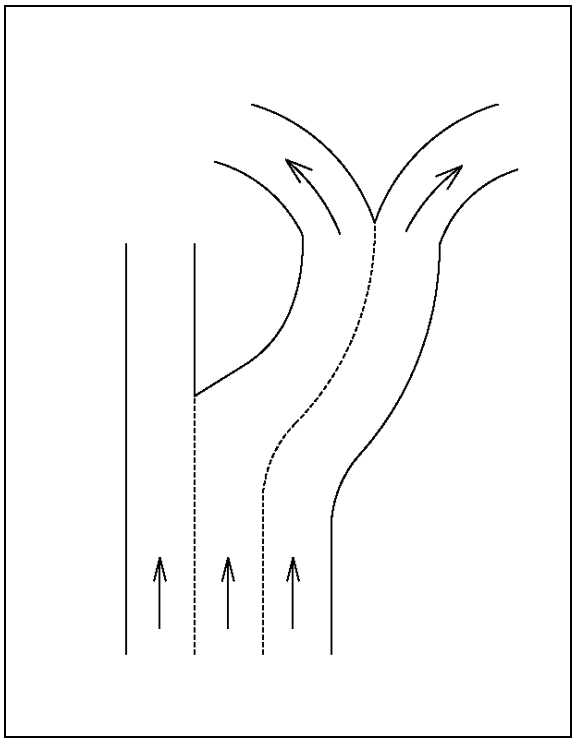


Figure 11. Right Hand Dual Lane Drop to Split with Dedicated Lanes.

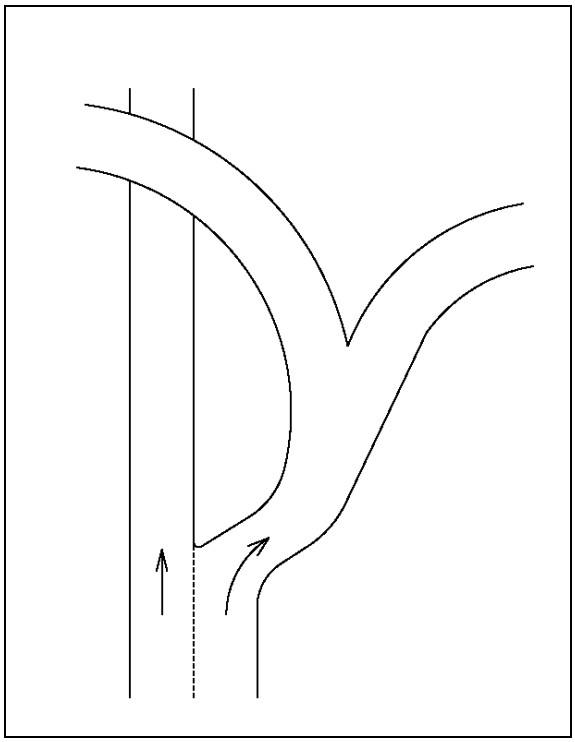


Figure 12. Right Lane Drop to Split Ramp with Single Optional Lane.

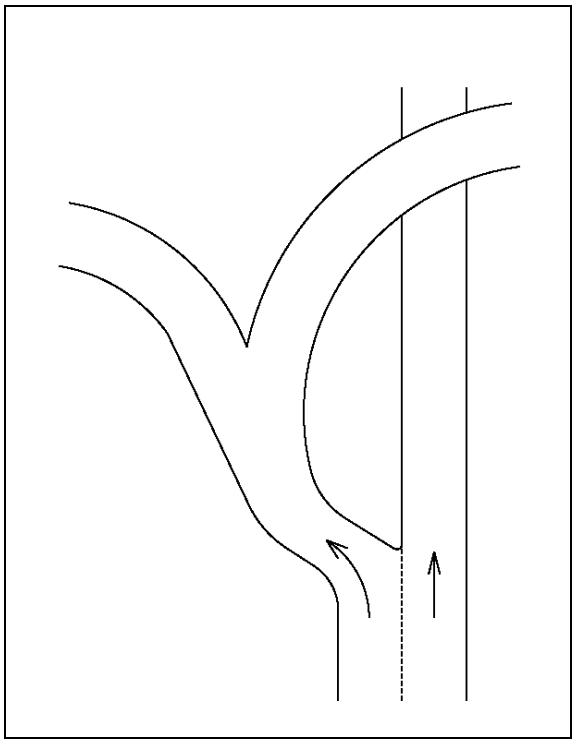


Figure 13. Left Lane Drop to Split Ramp with Single Optional Lane.

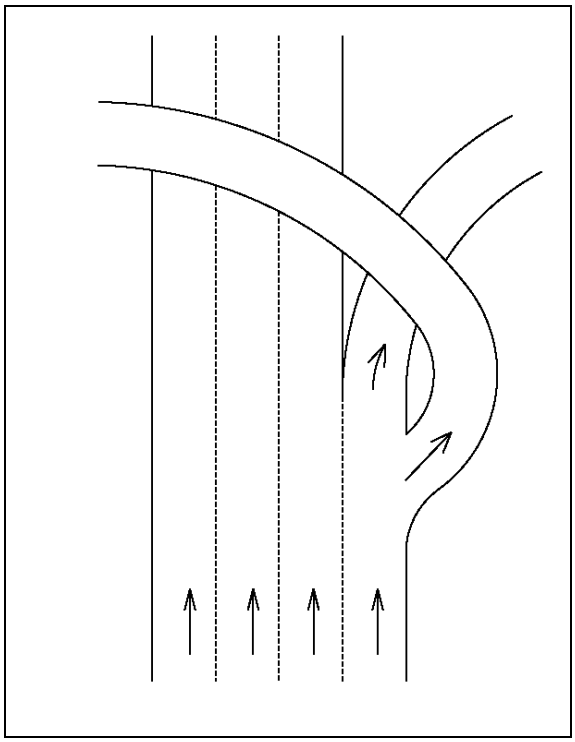


Figure 14. Right Lane Drop to Split Ramp with Single Optional Lane.

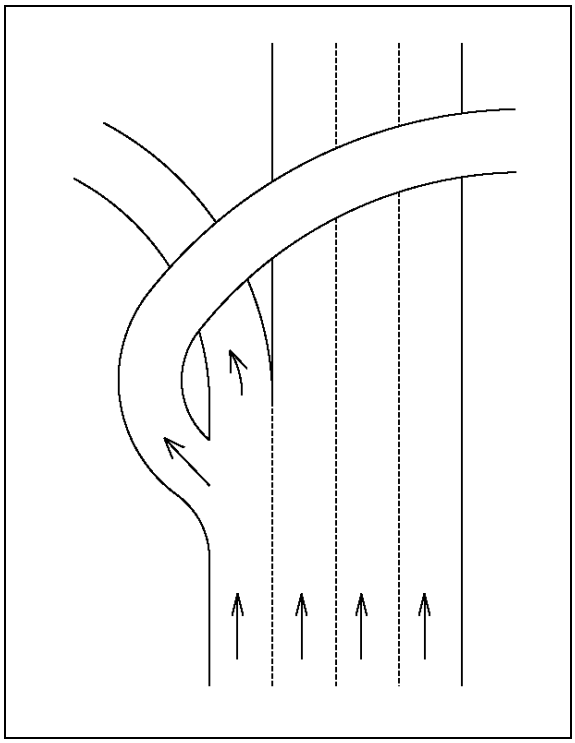


Figure 15. Left Lane Drop to Split Ramp with Single Optional Lane.

TWO-LANE EXITS WITH OPTIONAL LANES

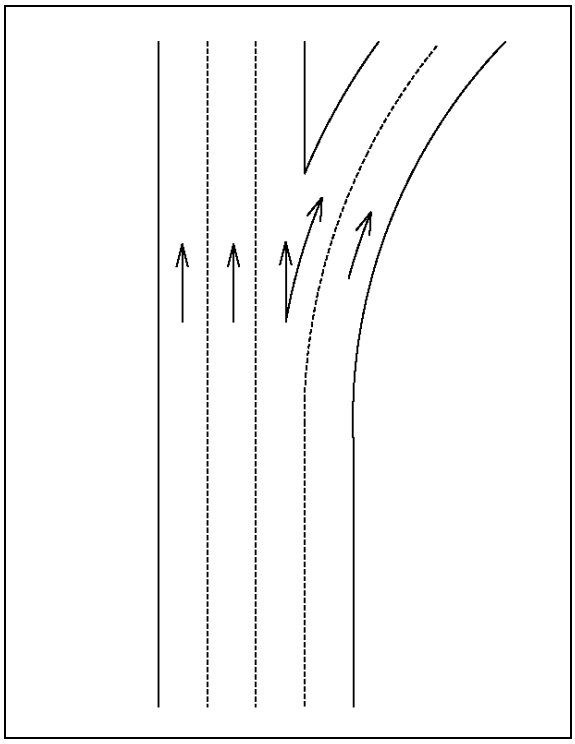


Figure 16. Right-Hand Two-Lane Exit with Optional Lane and Dedicated Lane.

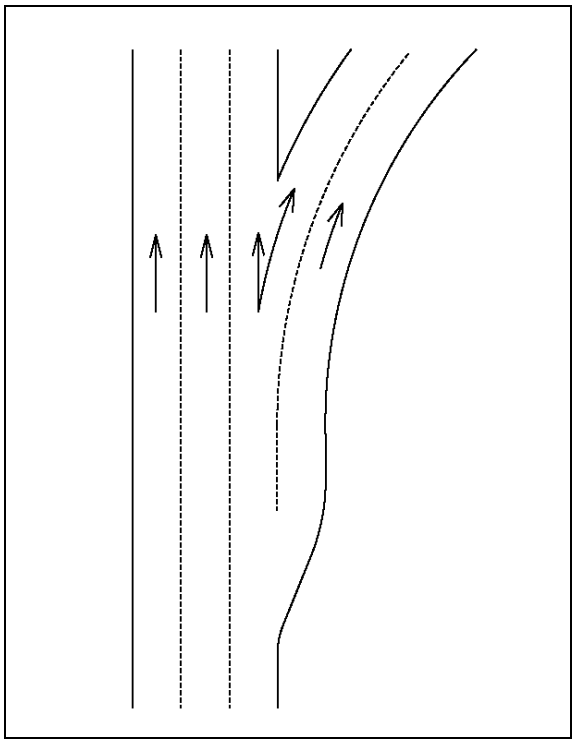


Figure 17. Right-Hand Two-Lane Exit with Optional Lane and Auxiliary Dedicated Lane.

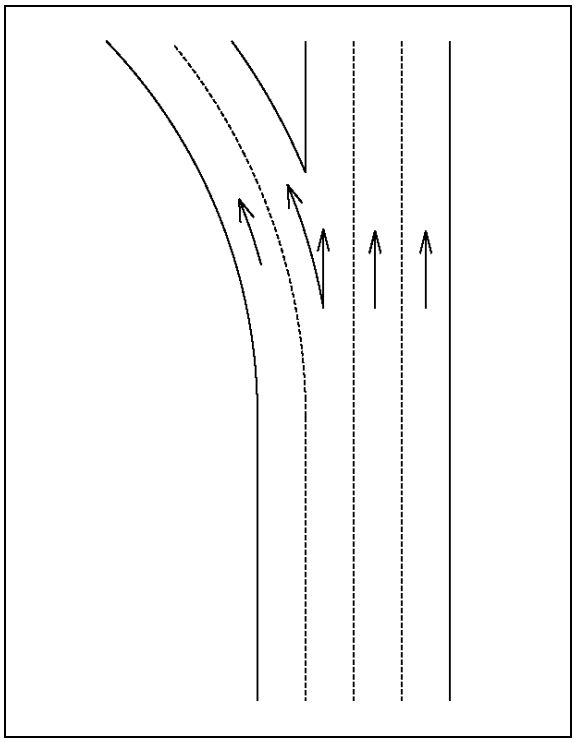


Figure 18. Left-Hand Two-Lane Exit with Optional Lane and Dedicated Lane.

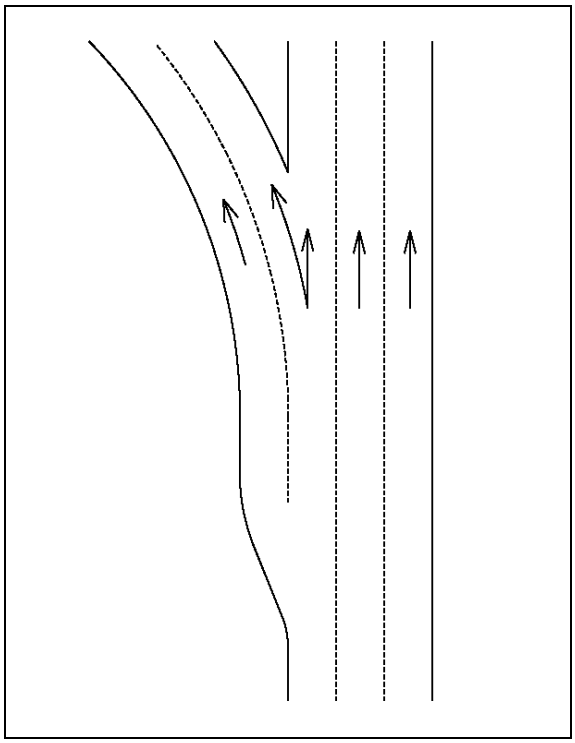


Figure 19. Left-Hand Two-Lane Exit with Optional Lane and Auxiliary Dedicated Lane.

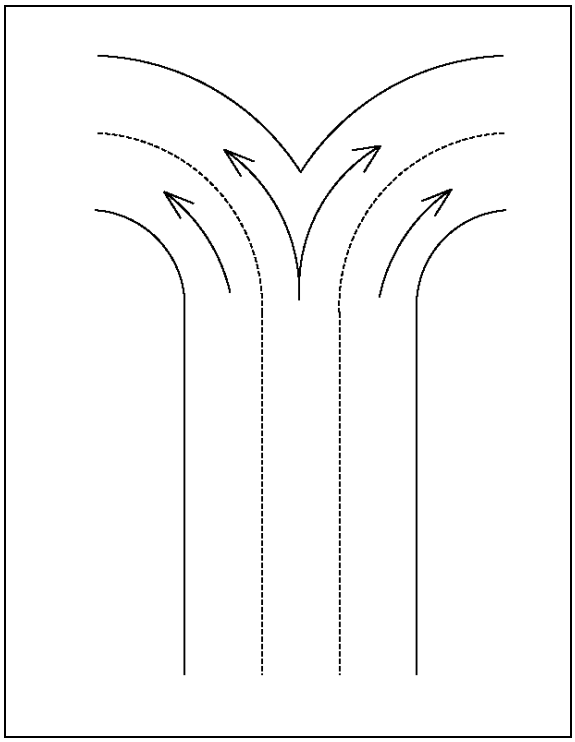


Figure 20. Major Fork with Shared Center Lane.

ARTERIALS AND FRONTAGE ROAD GEOMETRIES

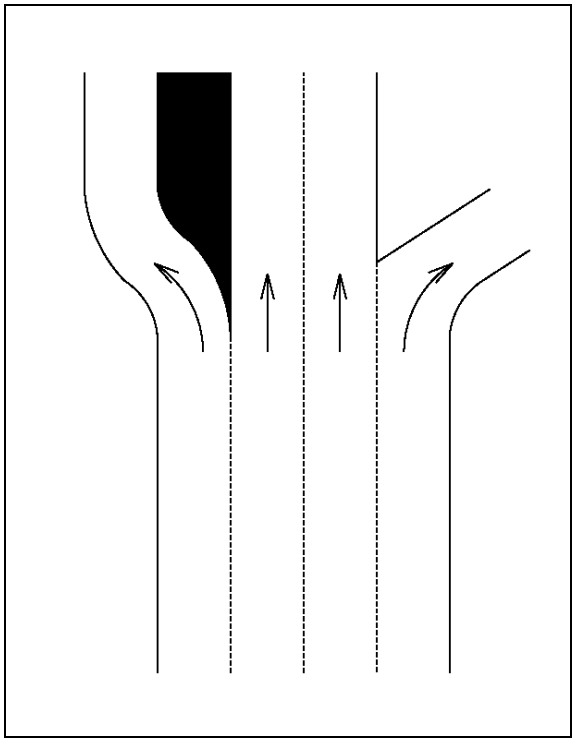


Figure 21. Arterial Approach to Interchange On-Ramps.

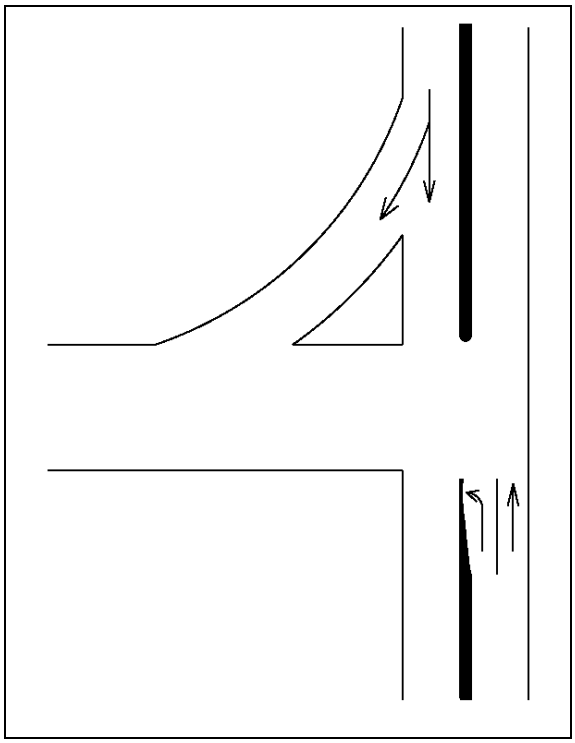


Figure 22. Intersection of Two-Lane Two-Way Roadway with Frontage Road or On-Ramp.

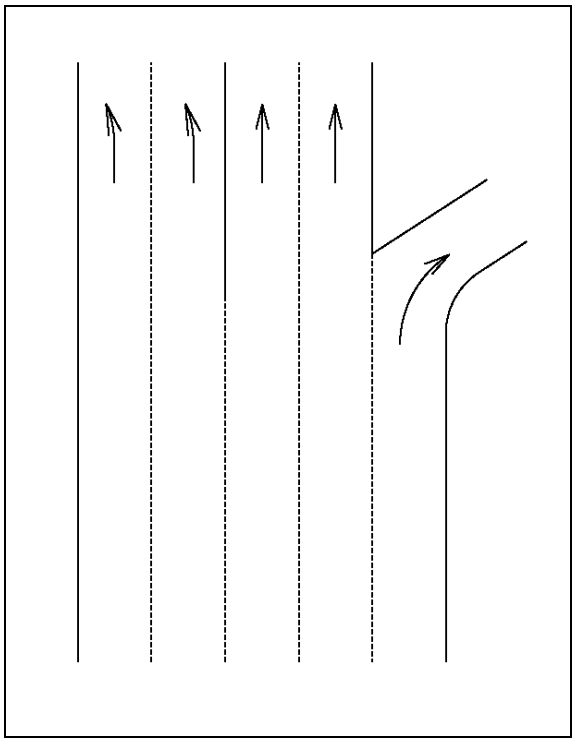


Figure 23. Off-Ramp or Frontage Road Approach to Single Point Urban Interchange.

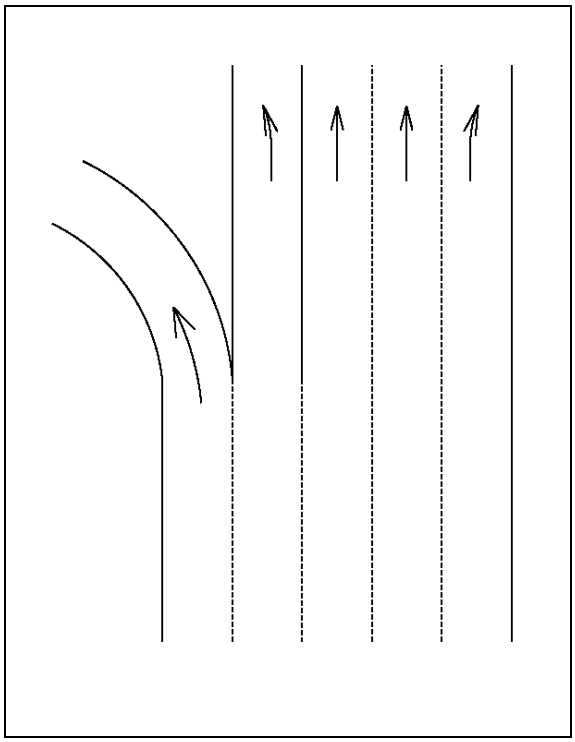


Figure 24. Frontage Road Approach to Diamond Intersection.

SIMPLE OPTIONAL EXIT GEOMETRIES

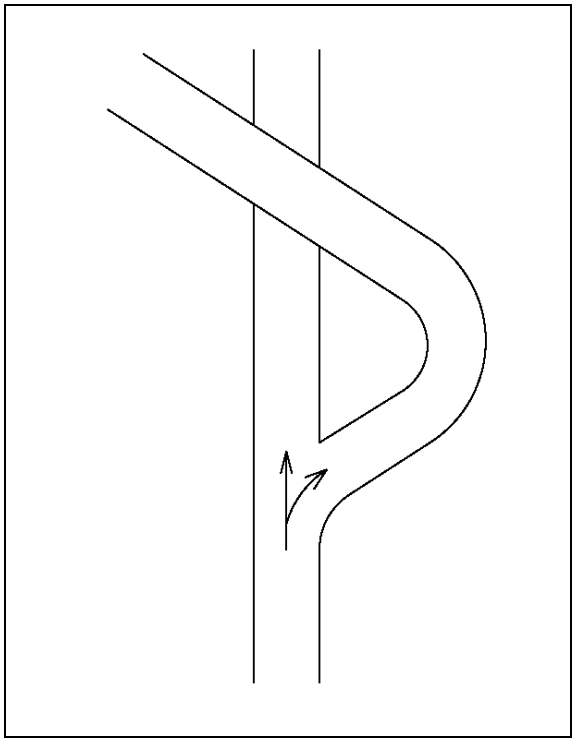


Figure 25. Right-Hand Optional Exit to Semi-Directional Ramp.

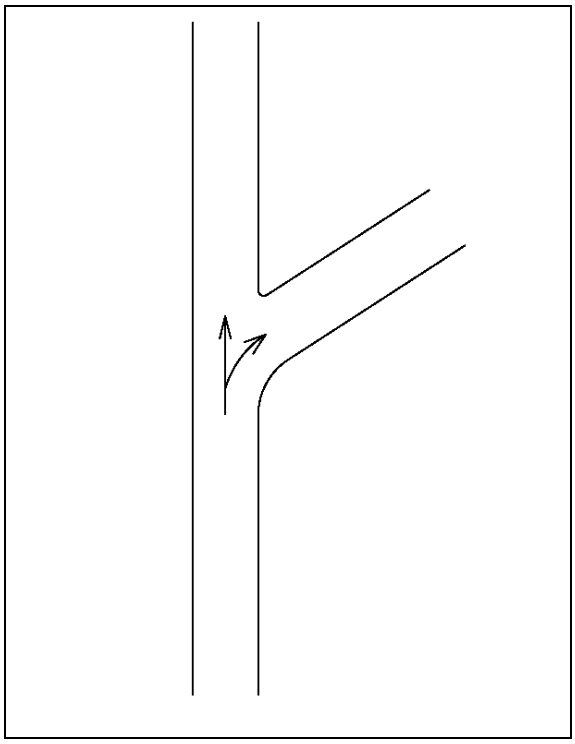


Figure 26. Right-Hand Optional Exit to Diagonal or Directional Ramp.

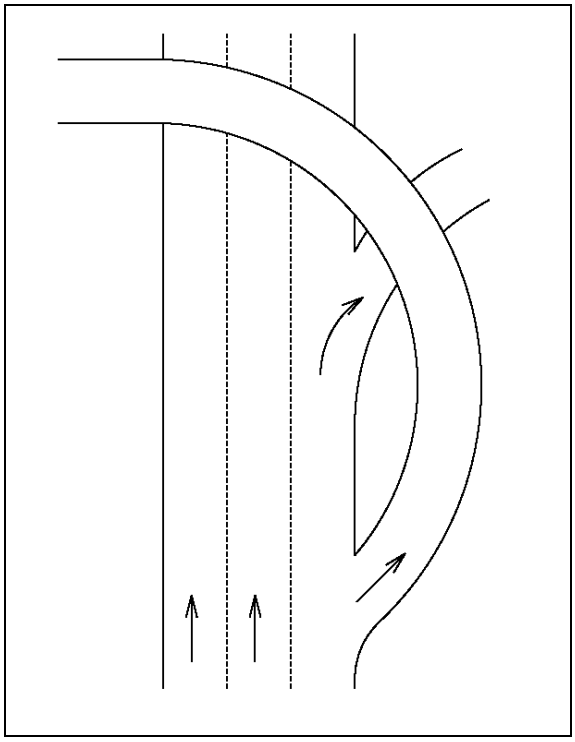


Figure 27. Right-Hand Optional Exit with Multiple Options.

OTHER RAMP AND EXIT CONFIGURATION GEOMETRIES

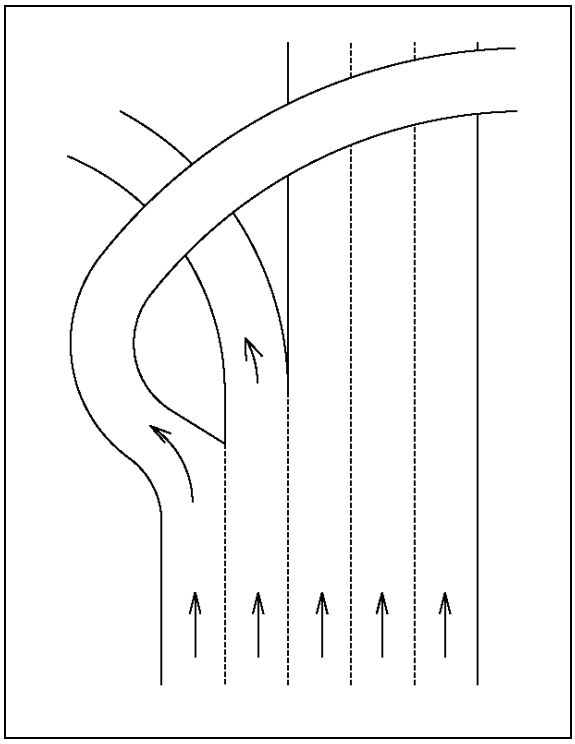


Figure 28. Left-Hand Dual Lane Drop to Dedicated Lanes.

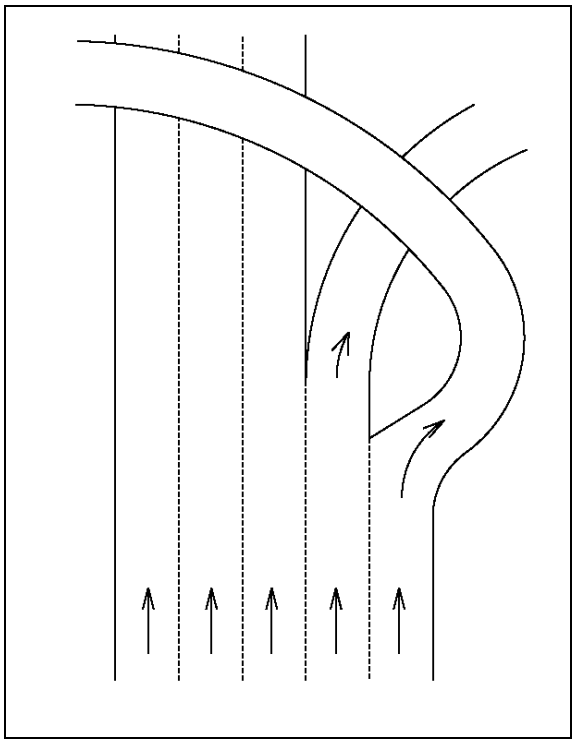


Figure 29. Right-Hand Dual Lane Drop to Dedicated Lanes.

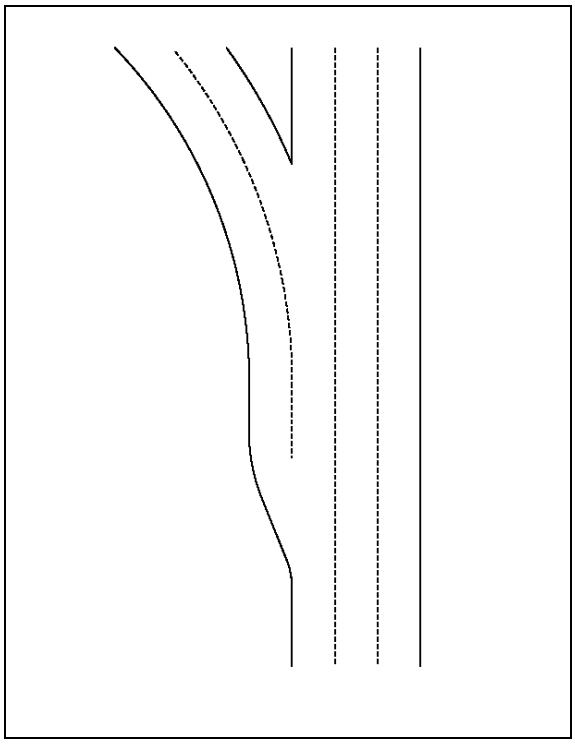


Figure 30. Left-Hand Two-Lane Exit.

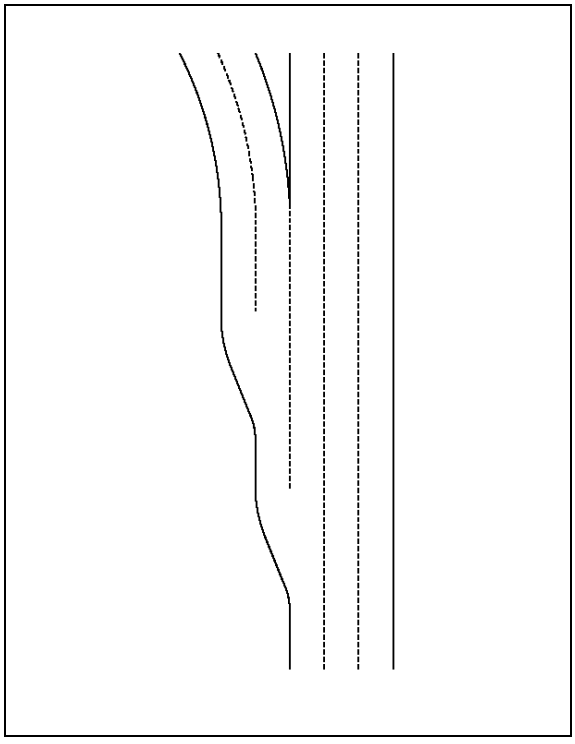


Figure 31. Left-Hand Two-Lane Exit with Auxiliary Dedicated Lanes.

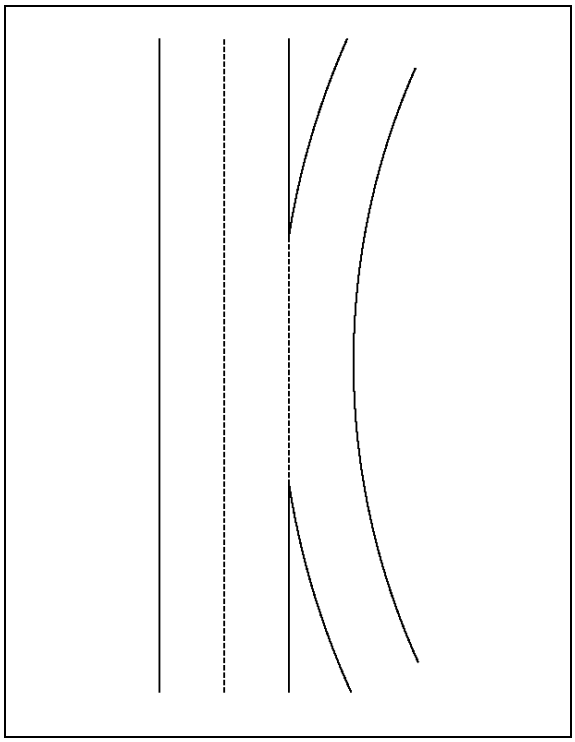


Figure 32. Right-Hand Auxiliary Weaving Lane Dropped at Physical Nose of Gore.

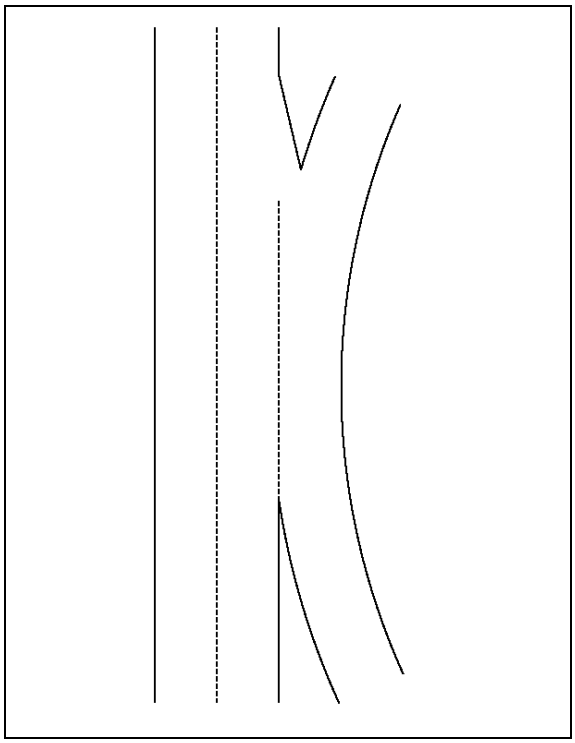


Figure 33. Right-Hand Auxiliary Weaving Lane Tapered into Through Roadway.

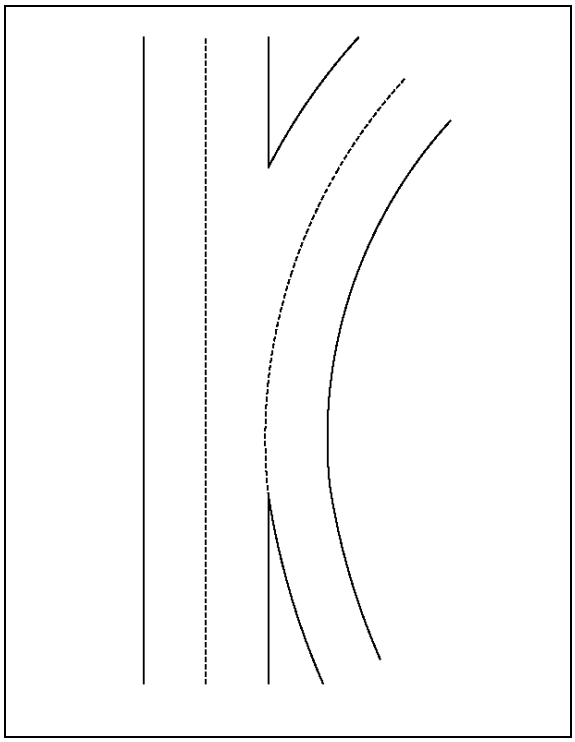


Figure 34. Right-Hand Auxiliary Weaving Lane Dropped on Exit Ramp.

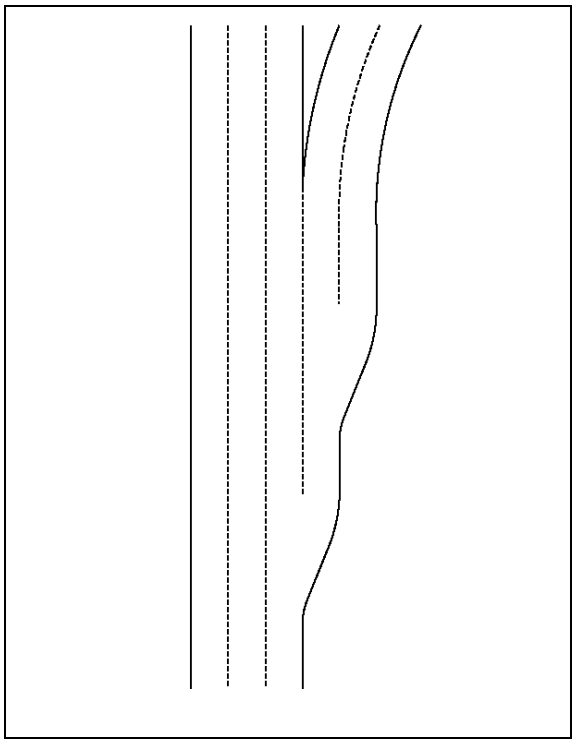


Figure 35. Right-Hand Two-Lane Exit with Auxiliary Dedicated Lanes.

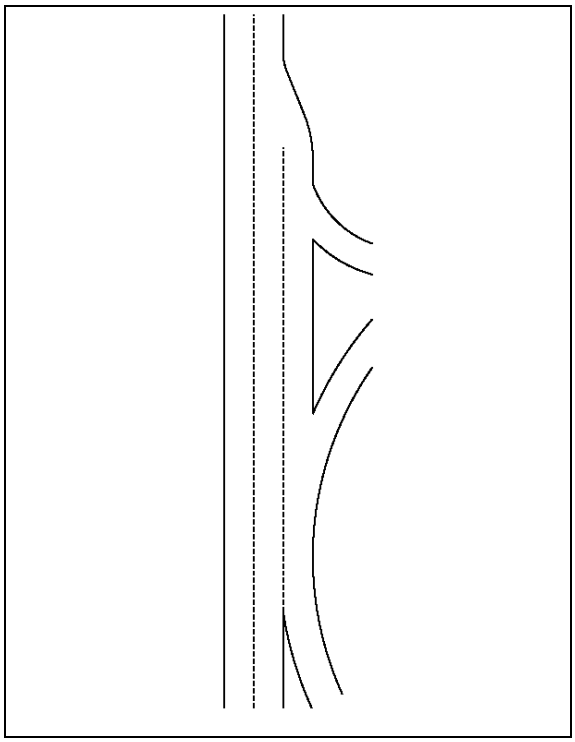


Figure 36. Right-Hand Auxiliary Lane Dropped Beyond an Interchange.

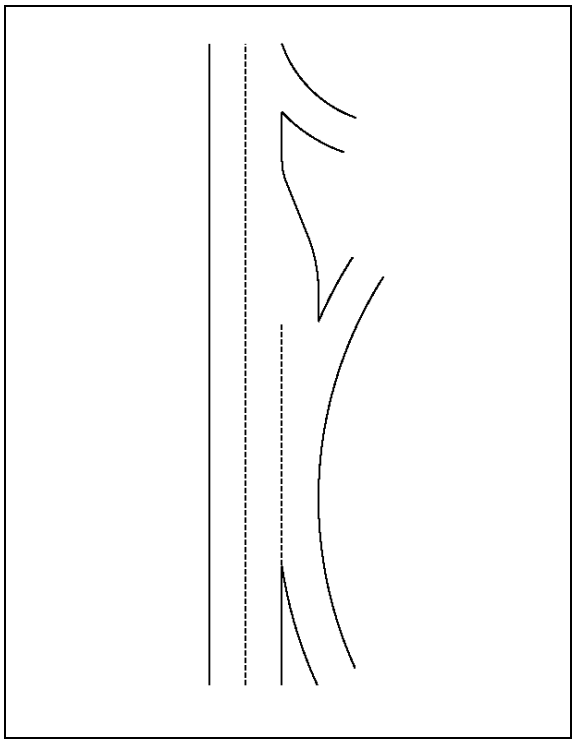


Figure 37. Right-Hand Auxiliary Lane Dropped Within an Interchange.

APPENDIX B

Thank you for coming today

Texas Transportation Institute

Practice Question 1

Question P1

- Please read the road sign displayed on the next slide.

(press space bar when you're ready to view the next scene)

Question P1

- Please write down the message displayed on the road sign in the blank provided on your answer sheet.

(press space bar when you're ready to view the next scene)

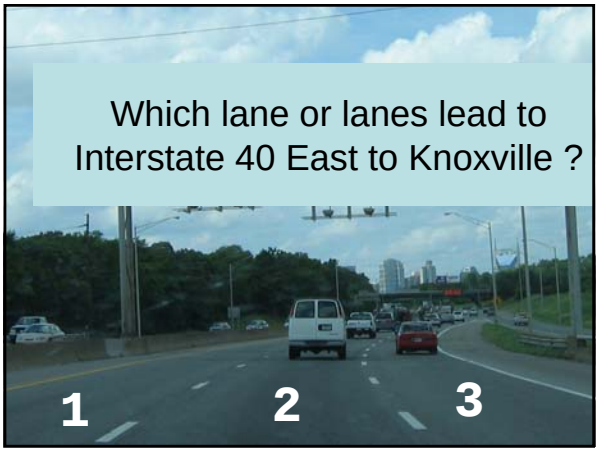
Practice Question 2

(press space bar when you're ready to view the next scene)

Question P2

You are driving Interstate 40 East and want to stay on that road to go to Knoxville.

(press space bar when you're ready to view the next scene)



Now you are ready to be tested!

(press space bar when you're ready to view the next scene)

Q1

(press space bar when you're ready to view the next scene)

Question 1

Please read the road sign displayed on the next slide.

(press space bar when you're ready to view the next scene)

Question 1

- Please write down the message displayed on the road sign in the blank provided on your answer sheet.

(press space bar when you're ready to view the next scene)

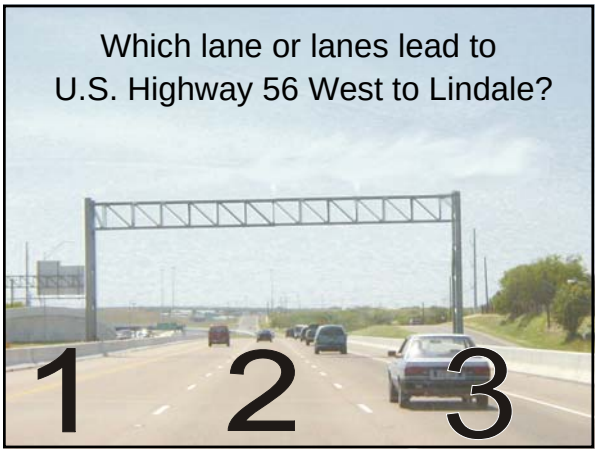
Q2

(press space bar when you're ready to view the next scene)

Question 2

You are driving on Interstate 61 North and you want to exit on US Highway 56 West to Lindale.

(press space bar when you're ready to view the next scene)



Q3

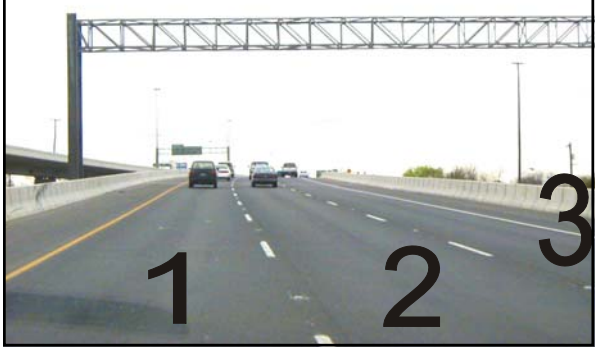
(press space bar when you're ready to view the next scene)

Question 3

You are driving on Interstate 36 North and you want to stay on that road.

(press space bar when you're ready to view the next scene)

Which lane or lanes lead to Interstate 36 North?



Q4

(press space bar when you're ready to view the next scene)

Question 4

Please read the road sign displayed on the next slide.

(press space bar when you're ready to view the next scene)

Question 4

- Please write down the message displayed on the road sign in the blank provided on your answer sheet.

(press space bar when you're ready to view the next scene)

Q5

(press space bar when you're ready to view the next scene)

Question 5

Please read the road sign displayed on the next slide.

(press space bar when you're ready to view the next scene)

Question 5

- Please write down the message displayed on the road sign in the blank provided on your answer sheet.

(press space bar when you're ready to view the next scene)

Q6

(press space bar when you're ready to view the next scene)

Question 6

You are driving on Interstate 49 North and you want to stay on that road.

(press space bar when you're ready to view the next scene)

Which lane or lanes lead to Interstate 49 North?

Q7

(press space bar when you're ready to view the next scene)

Question 7

You want to go on Interstate 50 West to LaSalle.

(press space bar when you're ready to view the next scene)

Q8

(press space bar when you're ready to view the next scene)

Question 8

You are driving Interstate 61 North and you want to stay on that road.

(press space bar when you're ready to view the next scene)

Q9

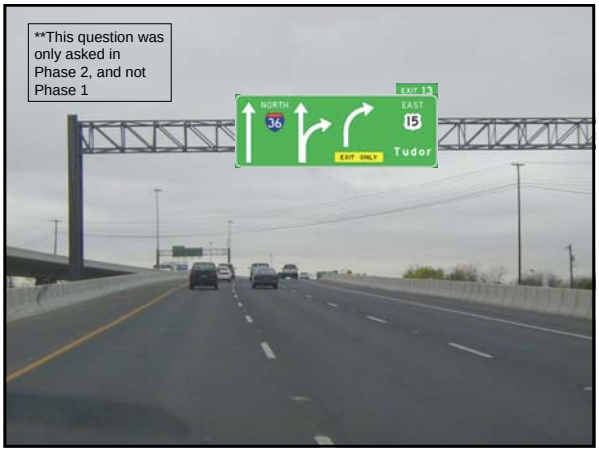
(press space bar when you're ready to view the next scene)

Question 9

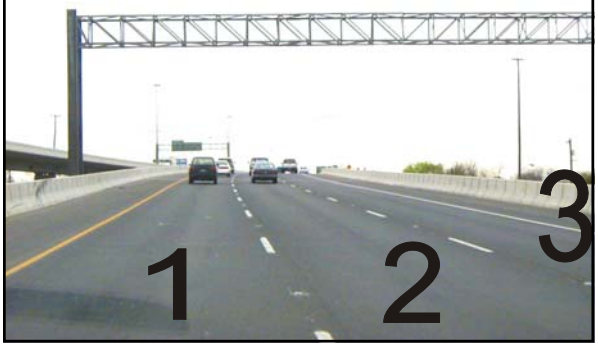
You are driving on Interstate 36 North and you want to stay on that road.

(press space bar when you're ready to view the next scene)

**This question was only asked in Phase 2, and not Phase 1



Which lane or lanes lead to Interstate 36 North?



Q10

(press space bar when you're ready to view the next scene)

Question 10

Please read the road sign displayed on the next slide.

(press space bar when you're ready to view the next scene)

Question 10

- Please write down the message displayed on the road sign in the blank provided on your answer sheet.

(press space bar when you're ready to view the next scene)

Q11

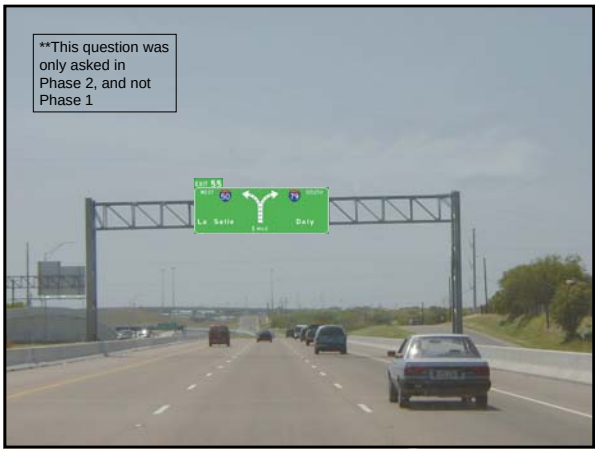
(press space bar when you're ready to view the next scene)

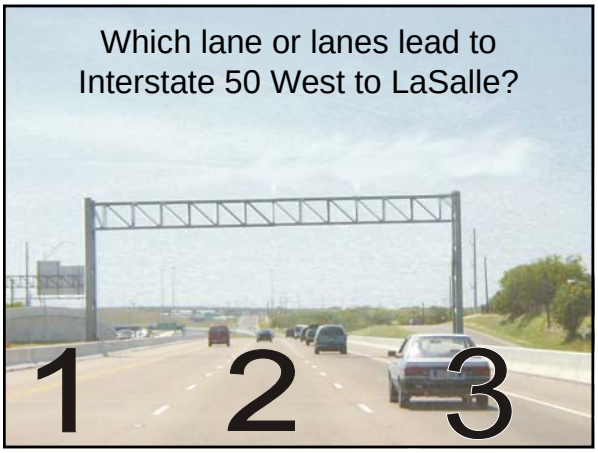
Question 11

You want to go on Interstate 50 West to LaSalle.

(press space bar when you're ready to view the next scene)

**This question was only asked in Phase 2, and not Phase 1





Q12

(press space bar when you're ready to view the next scene)

Question 12

Please read the road sign displayed on the next slide.

(press space bar when you're ready to view the next scene)

Question 12

- Please write down the message displayed on the road sign in the blank provided on your answer sheet.

(press space bar when you're ready to view the next scene)

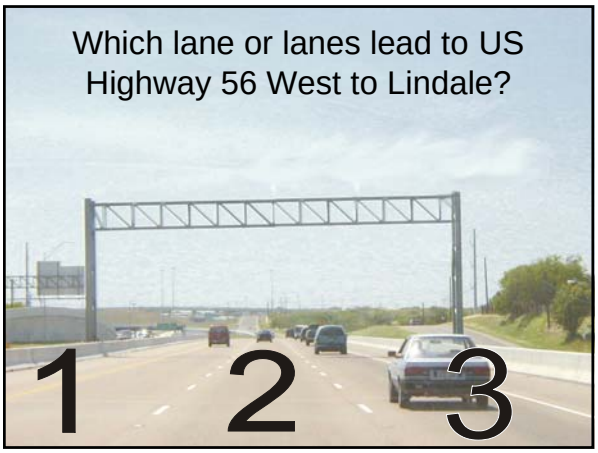
Q13

(press space bar when you're ready to view the next scene)

Question 13

You are driving on Interstate 61 North and you want to exit on US Highway 56 West to Lindale.

(press space bar when you're ready to view the next scene)



Q14

(press space bar when you're ready to view the next scene)

Question 14

Please read the road sign displayed on the next slide.

(press space bar when you're ready to view the next scene)

Question 14

- Please write down the message displayed on the road sign in the blank provided on your answer sheet.

(press space bar when you're ready to view the next scene)

Q15

(press space bar when you're ready to view the next scene)

Question 15

Please read the road sign displayed on the next slide.

(press space bar when you're ready to view the next scene)

Question 15

- Please write down the message displayed on the road sign in the blank provided on your answer sheet.

(press space bar when you're ready to view the next scene)

Q16

(press space bar when you're ready to view the next scene)

Question 16

You are driving on Interstate 36 North and you want to exit on US Highway 15 East to Tudor.

(press space bar when you're ready to view the next scene)

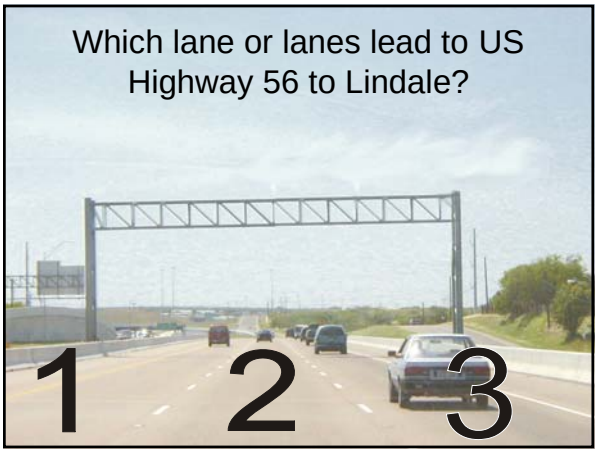
Q17

(press space bar when you're ready to view the next scene)

Question 17

You are driving on Interstate 61 North and you want to exit on US Highway 56 West to Lindale.

(press space bar when you're ready to view the next scene)



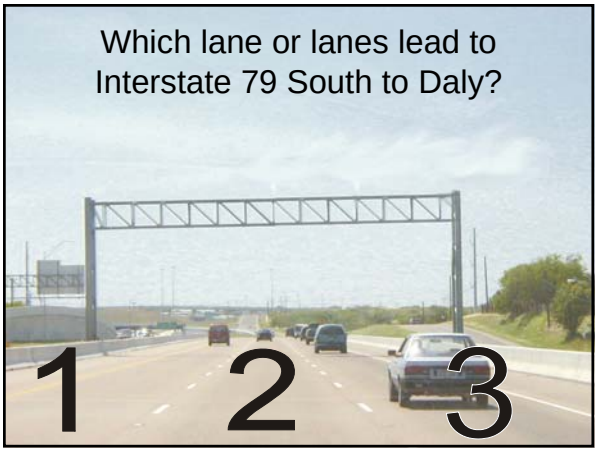
Q18

(press space bar when you're ready to view the next scene)

Question 18

You want to go on Interstate 79 South to Daly.

(press space bar when you're ready to view the next scene)



Q19

(press space bar when you're ready to view the next scene)

Question 19

Please read the road sign displayed on the next slide.

(press space bar when you're ready to view the next scene)

Question 18

- Please write down the message displayed on the road sign in the blank provided on your answer sheet.

(press space bar when you're ready to view the next scene)

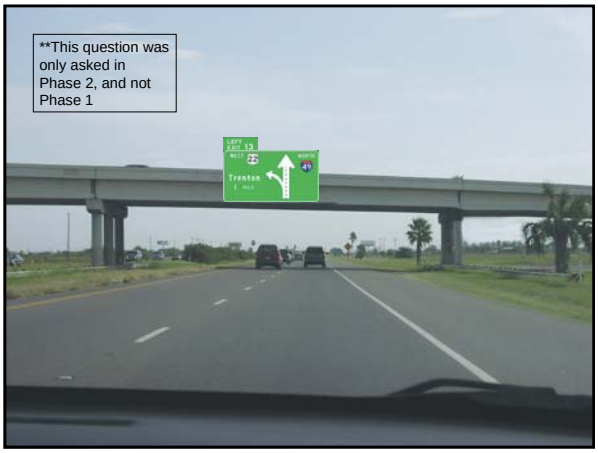
Q20

(press space bar when you're ready to view the next scene)

Question 20

You are driving on Interstate 49 North and you want to stay on that road.

(press space bar when you're ready to view the next scene)



Which lane or lanes lead to Interstate 49 North ?

Q21

(press space bar when you're ready to view the next scene)

Question 21

Please read the road sign displayed on the next slide.

(press space bar when you're ready to view the next scene)

Question 21

- Please write down the message displayed on the road sign in the blank provided on your answer sheet.

(press space bar when you're ready to view the next scene)

Q22

(press space bar when you're ready to view the next scene)

Question 22

You are driving on Interstate 61 North and you want to stay on that road.

(press space bar when you're ready to view the next scene)

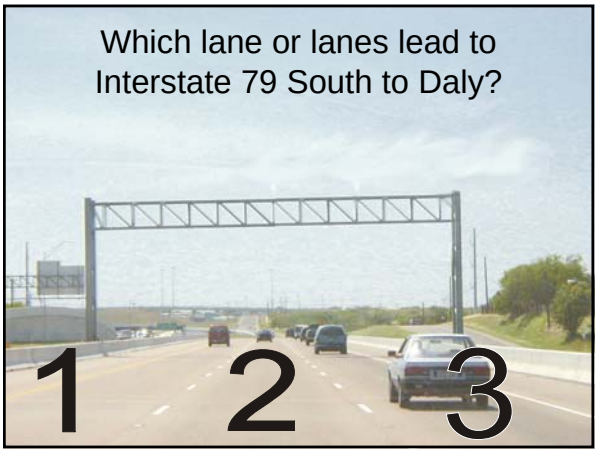
Q23

(press space bar when you're ready to view the next scene)

Question 23

You want to go on Interstate 79 South to Daly.

(press space bar when you're ready to view the next scene)



Q24

(press space bar when you're ready to view the next scene)

Question 24

Please read the road sign displayed on the next slide.

(press space bar when you're ready to view the next scene)

Question 24

- Please write down the message displayed on the road sign in the blank provided on your answer sheet.

(press space bar when you're ready to view the next scene)

Q25

(press space bar when you're ready to view the next scene)

Question 25

You are driving on Interstate 49 North and you want to exit on US Highway 22 West to Trenton.

(press space bar when you're ready to view the next scene)

Which lane or lanes lead to US Highway 22 West to Trenton?

Q26

(press space bar when you're ready to view the next scene)

Question 26

Please read the road sign displayed on the next slide.

(press space bar when you're ready to view the next scene)

Question 26

- Please write down the message displayed on the road sign in the blank provided on your answer sheet.

(press space bar when you're ready to view the next scene)

Q27

(press space bar when you're ready to view the next scene)

Question 27

You are driving on Interstate 61 North and you want to stay on that road.

(press space bar when you're ready to view the next scene)

**This question was only asked in Phase 2, and not Phase 1

Which lane or lanes lead to Interstate 61 North ?

Q28

(press space bar when you're ready to view the next scene)

Question 28

You are driving on Interstate 36 North and you want to exit on US Highway 15 East to Tudor.

(press space bar when you're ready to view the next scene)

Q29

(press space bar when you're ready to view the next scene)

Question 29

Please read the road sign displayed on the next slide.

(press space bar when you're ready to view the next scene)

Question 26

- Please write down the message displayed on the road sign in the blank provided on your answer sheet.

(press space bar when you're ready to view the next scene)

Q30

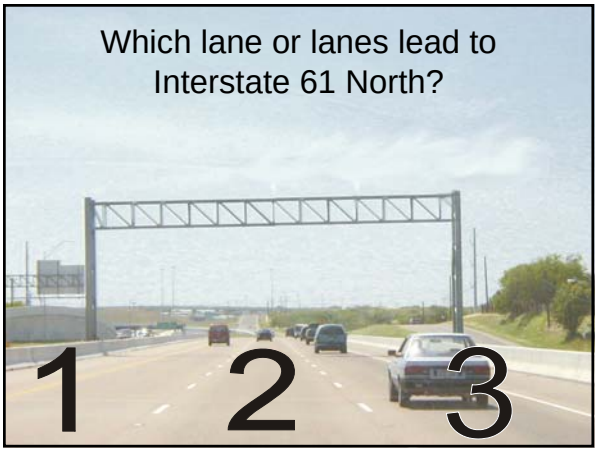
(press space bar when you're ready to view the next scene)

Question 30

You are driving on Interstate 61 North and you want to stay on that road.

(press space bar when you're ready to view the next scene)

Which lane or lanes lead to Interstate 61 North?



Q31

(press space bar when you're ready to view the next scene)

Question 31

You want to go on Interstate 50 West to LaSalle.

(press space bar when you're ready to view the next scene)

Q32

(press space bar when you're ready to view the next scene)

Question 32

Please read the road sign displayed on the next slide.

(press space bar when you're ready to view the next scene)

Question 32

- Please write down the message displayed on the road sign in the blank provided on your answer sheet.

(press space bar when you're ready to view the next scene)

Q33

(press space bar when you're ready to view the next scene)

Question 33

Please read the road sign displayed on the next slide.

(press space bar when you're ready to view the next scene)

Question 33

- Please write down the message displayed on the road sign in the blank provided on your answer sheet.

(press space bar when you're ready to view the next scene)

Q34

(press space bar when you're ready to view the next scene)

Question 34

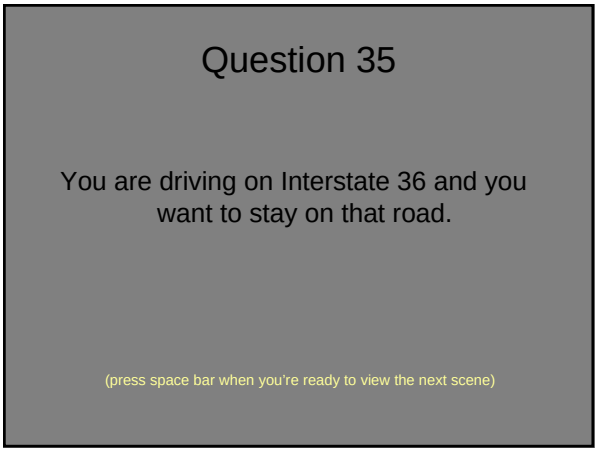
You are driving on Interstate 49 North and you want to exit on US Highway 22 West to Trenton.

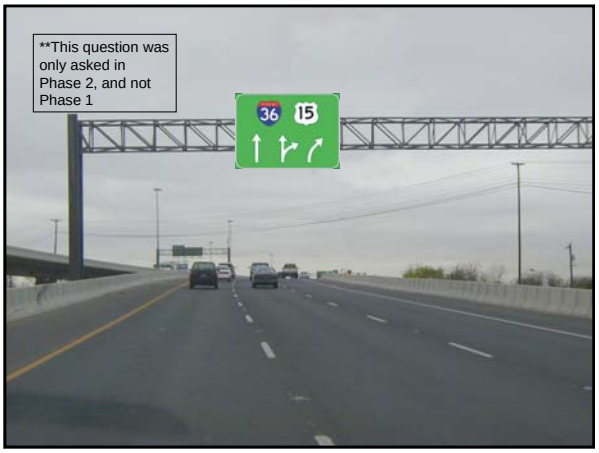
(press space bar when you're ready to view the next scene)


LEFT
EXIT 13
WEST
22
NORTH
49
Trenton
1 MILE


Which lane or lanes lead to US Highway 22 West to Trenton?
1
2


Q35
(press space bar when you're ready to view the next scene)


Question 35
You are driving on Interstate 36 and you want to stay on that road.
(press space bar when you're ready to view the next scene)


**This question was only asked in Phase 2, and not Phase 1
36
15


Which lane or lanes lead to Interstate 36 ?
1
2
3

Q36

(press space bar when you're ready to view the next scene)

Question 36

You are driving on Interstate 61 and you want to exit on US Highway 56.

(press space bar when you're ready to view the next scene)

**This question was only asked in Phase 2, and not Phase 1

Which lane or lanes lead to Highway 56?

Thank you for you time and participation.

Please tell the experimenter of any concerns or comments that you may have.

Thank you!

If you have any questions or comments please contact:

Susan T. Chrysler, Ph.D.
Research Scientist
Manager, Human Factors Program
Center for Transportation Safety
Texas Transportation Institute
3135 TAMU
College Station TX 77843-3135

979-862-3928
979-845-4872

s-chrysler@tamu.edu

APPENDIX C

Thank you for coming today.

Please write your answers on the sheet provided.
(X)

Texas Transportation Institute

Some of the questions will start by briefly showing you a picture of a roadway.

You can't control the timing of the photos on these questions.

You'll start by practicing one of these questions.

When you are given your target destination, you will have to remember it while viewing the guide signs

The following photographs will show you a sequence of three signs leading up to the exit.
(you do not have to hit the space bar after each picture)

You will then be asked which lane or lanes you would choose to reach the destination.
(press space bar when you're ready to start the sequence)

Practice Question 1

Question P1

You are driving Interstate 40 East and you want to take Highway 56 West to Lindale.

(press space bar when you're ready to view the next scene)

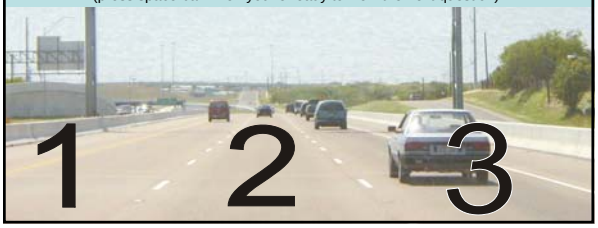
Now you are ready to be tested!

(press space bar when you're ready to view the next scene)

Practice Question

Which lane or lanes lead to Highway 56 West to Lindale?

(press space bar when you're ready to view the next question)



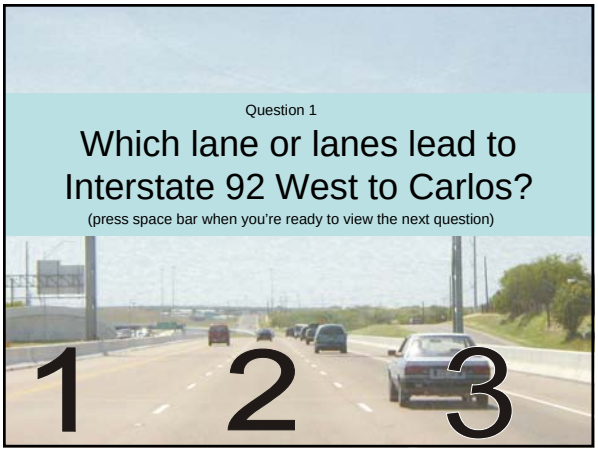
Q1

(press space bar when you're ready to view the next scene)

Question 1

You want to go on Interstate 92 West to Carlos

(press space bar when you're ready to view the next scene)



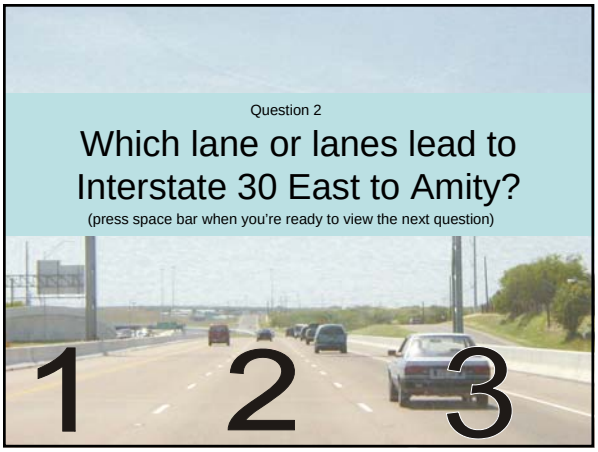
Q2

(press space bar when you're ready to view the next scene)

Question 2

You want to go on Interstate 30 East to Amity

(press space bar when you're ready to view the next scene)



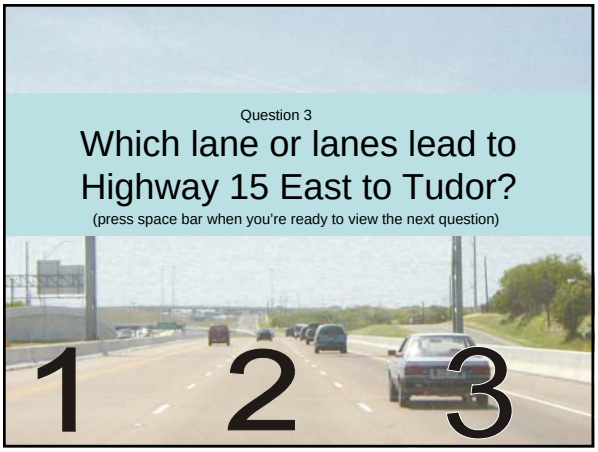
Q3

(press space bar when you're ready to view the next scene)

Question 3

You are driving on Interstate 36 North and you want to exit on Highway 15 East to Tudor.

(press space bar when you're ready to view the next scene)



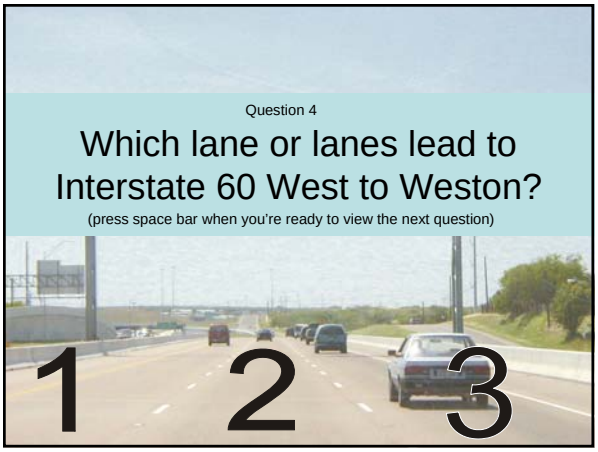
Q4

(press space bar when you're ready to view the next scene)

Question 4

You want to go on Interstate 60 West to Weston

(press space bar when you're ready to view the next scene)



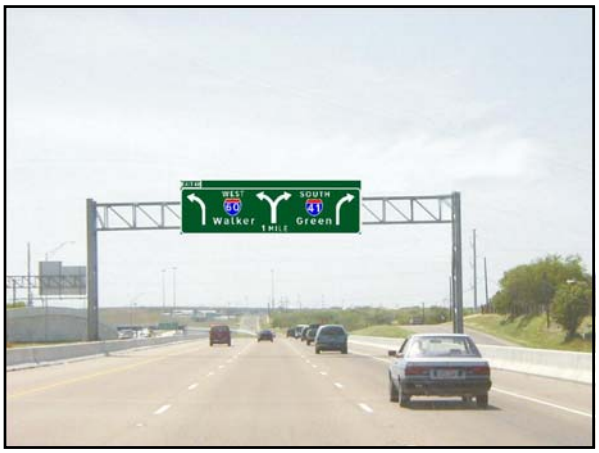
Q5

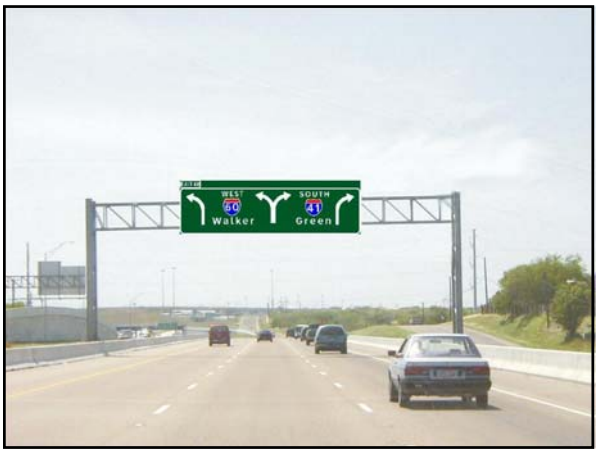
(press space bar when you're ready to view the next scene)

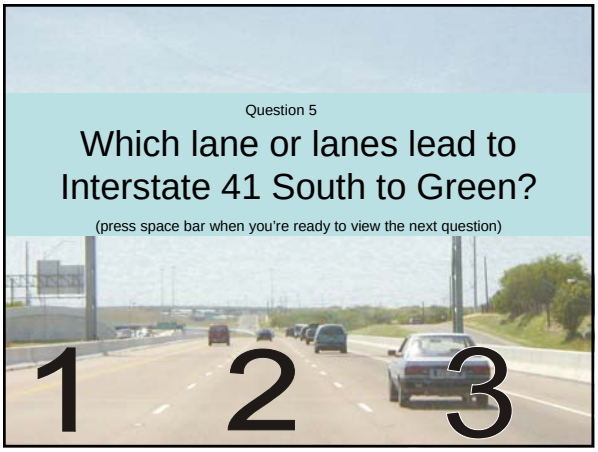
Question 5

You want to go on Interstate 41 South to Green

(press space bar when you're ready to view the next scene)







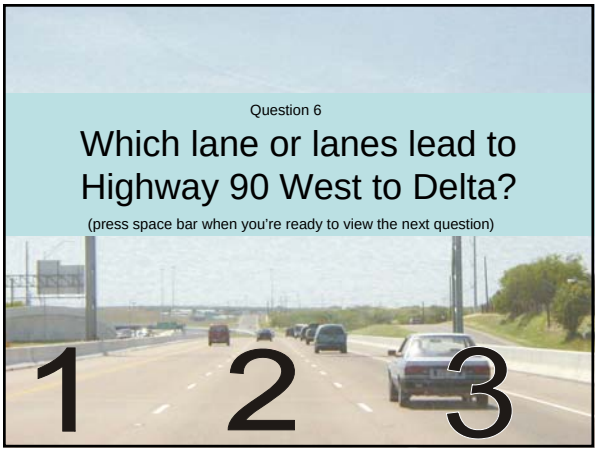
Q6

(press space bar when you're ready to view the next scene)

Question 6

You are driving on Interstate 73 North and you want to exit on Highway 90 West to Delta.

(press space bar when you're ready to view the next scene)



Q7

(press space bar when you're ready to view the next scene)

Question 7

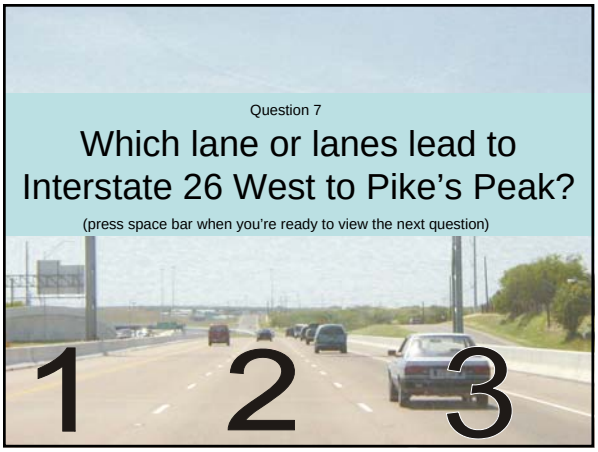
You want to go on Interstate 26 West to Pike's Peak

(press space bar when you're ready to view the next scene)

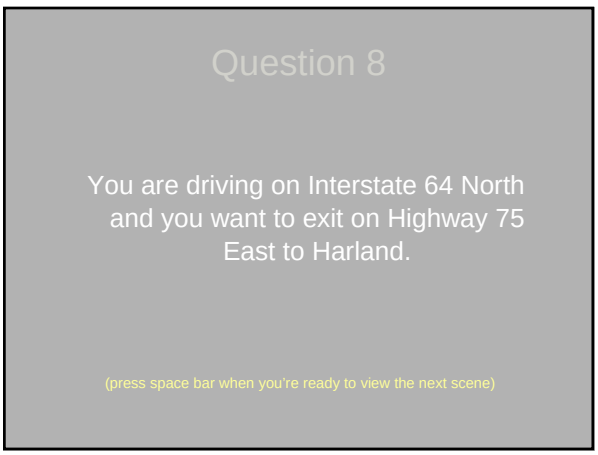

26 WEST
Pikes Peak
1 MILE
77 SOUTH
Sweet Home
1 MILE

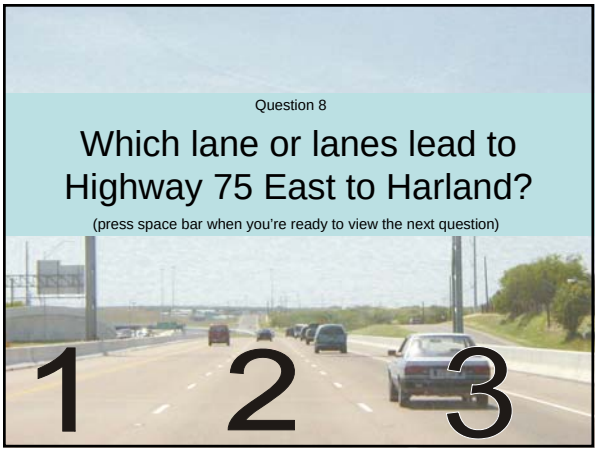

26 WEST
Pikes Peak
77 SOUTH
Sweet Home


26 WEST
Pikes Peak
EXIT ONLY
77 SOUTH
Sweet Home


Question 7
Which lane or lanes lead to Interstate 26 West to Pike's Peak?
(press space bar when you're ready to view the next question)
1 2 3


Q8
(press space bar when you're ready to view the next scene)


Question 8
You are driving on Interstate 64 North and you want to exit on Highway 75 East to Harland.
(press space bar when you're ready to view the next scene)



Q9

(press space bar when you're ready to view the next scene)

Question 9

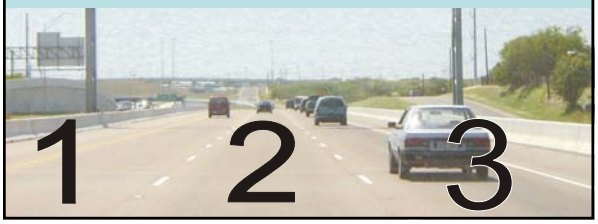
You want to go on Interstate 20 South to Springville

(press space bar when you're ready to view the next scene)

Question 9

Which lane or lanes lead to Interstate 20 South to Springville?

(press space bar when you're ready to view the next question)



Q10

(press space bar when you're ready to view the next scene)

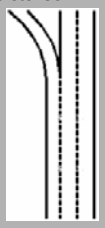
Question 10

A

B

C

Imagine that one of these signs will be installed one mile before an exit ramp. Which sign would best explain the layout of the roadway pictured below?



(press space bar when you're ready to view the next question)

Q11

(press space bar when you're ready to view the next scene)

Question 11

In terms of this sign:

The yellow "Exit Only" plaque means:

(select True or False for each statement)

A. If I am in the right lane, I will be forced to take the exit to Lawrence.

TRUE or FALSE

B. If I want to go to Lawrence, I must be in the right lane, no other lane will allow me to exit

TRUE or FALSE

(press space bar when you're ready to view the next question)

Q12

(press space bar when you're ready to view the next scene)

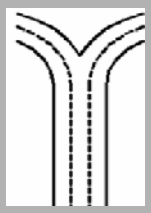
A

B

C

Question 12

Imagine that one of these signs will be installed one mile before an exit ramp. Which sign would best explain the layout of the roadway pictured below?



(press space bar when you're ready to view the next question)

Q13

(press space bar when you're ready to view the next scene)

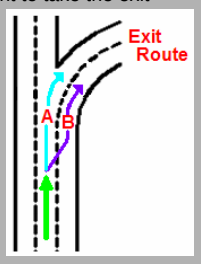
Question 13

Lane Change Tendencies

Assume your are traveling in the center lane of the road section shown below. If you want to take the exit route, are you more likely to:

A. Stay in the center lane

B. Change lanes



(press space bar when you're ready to view the next question)

Q14

(press space bar when you're ready to view the next scene)

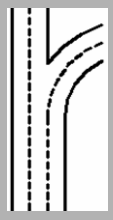
A

B

C

Question 14

Imagine that one of these signs will be installed one mile before an exit ramp. Which sign would best explain the layout of the roadway pictured below?



(press space bar when you're ready to view the next question)

Q15

(press space bar when you're ready to view the next scene)

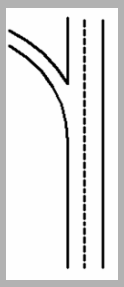
Question 15

Imagine that one of these signs will be installed one mile before an exit ramp. Which sign would best explain the layout of the roadway pictured below?

A

B

C



(press space bar when you're ready to view the next question)

APPENDIX D

APPENDIX D TABLE OF CONTENTS

Page

INFORMED CONSENT (PHASES 1 AND 2)

Purpose: I have been asked to participate in a research study to help determine how diagrammatic signs should be used. I was selected to be a possible participant because I am 18 years of age or older, and possess a current, valid drivers license.

Procedures: If I agree to be in this study, I will be asked to take a computer survey. In this survey, I will be shown a destination name followed by a photograph of a freeway with a guide sign. This image will be shown to me for a brief time. Following that image, I will be shown an image of the freeway without the guide sign and with the freeway lanes numbered. I will be asked to indicate on the supplied response form which lane I would choose to drive in, in order to reach the previously indicated destination. In addition, I may be asked to supply my reason for choosing the lane I have indicated. I will be responsible for marking my responses on a supplied response form. In addition to freeway guide signs I will also occasionally be asked to identify what other roadside signs say. I will be shown approximately 30 sign images. The survey will take no more than 45 minutes to complete.

Compensation: At the end of my participation in the survey, I will be compensated $40.00. If I am uncomfortable with any part of the procedure, I will not hesitate to make it known to the researcher. If I choose not to continue to participate in the research for any reason, I am free to quit at any time. If I do quit before the end of the study, I will receive compensation of $10.00. Unforeseen circumstances such as equipment breakdown may cause the researcher to excuse me from further participation on the project. In that event, I will be compensated at least $20.00. Other than the compensation, I understand that there are no special benefits to me for participating.

Confidentiality: This study is anonymous and the records of this study will be kept private. No identifiers linking me to the study will be included in any sort of report that might be published. Research records will be stored securely in Room 308 of the Gilchrist Building on the Texas A&M University campus and only TTI personnel working on the project will have access to the records. I will be asked to sign a form acknowledging payment for my participation. These forms are kept separate from this signed consent form and any other data that would identify me by name. I understand that if I accept payment for participating in this study, the fact that I participated in this study may be obtained under the Texas Open Records Act, even though any information that I gave to the investigator is confidential.

TTI Subject Pool: I understand that the Texas Transportation Institute conducts many research projects throughout the year and may contact me again to participate in another study. I am under no obligation to participate in future studies. My name, contact information, responses to demographic and driving habits questionnaires, and performance on any vision tests will be retained to assist in my potential selection for inclusion in future studies. If I do **not** wish to be contacted in the future I may indicate this by marking the box below.

Initials_____Date_____

____ "I do **not** wish to participate in any further studies. Do not retain my personal information nor contact me for participation in any future studies."

Voluntary Nature of the Study: My decision whether or not to participate will not affect my current or future relations with Texas A&M University, TTI, or FHWA. If I decide to participate, I am free to refuse to answer any of the questions that may make me uncomfortable. I can withdraw at any time without my relations with the University, TTI, FHWA, or SWUTC being affected.

Contacts and Questions: The researcher conducting this study is Susan Chrysler. If I have questions now or later, I may contact Susan Chrysler at the Texas Transportation Institute, Texas A&M University, College Station, Texas 77843-3135, (979) 845-3928, s-chrysler@tamu.edu.

I will be given a copy of this form for my records
A copy of this form will be given to me if I wish to keep one.

I understand that this research study has been reviewed and approved by the Institutional Review Board - Human Subjects in Research, Texas A&M University. For research-related problems or questions regarding subjects' rights, the Institutional Review Board may be contacted through Dr. Michael W. Buckley, Director of Research Compliance. Office of the Vice President for Research at (979) 845-8585 (e-mail: mwbuckley@tamu.edu).

Statement of Consent: *I have read and understand the explanation provided to me. I have had all my questions answered to my satisfaction, and I voluntarily agree to participate in this research project. I have been provided a copy of this consent form.*

_____
Research Participant Date

_____
Researcher Date

Principal Investigator:
Susan Chrysler
Research Scientist
Center for Transportation Safety
Texas Transportation Institute
(979) 845-3928

SAMPLE ANSWER SPACE FROM PHASE 1

Circle the correct response or write-in the correct answer in the space provided

Q.1 Lane 1 Lane2 Lane3

SAMPLE ANSWER SPACE FROM PHASE 2

Circle the correct response or write-in the correct answer in the space provided

Q.1	Lane 1	Lane 2	Lane 3
	Lanes 1 & 2	Lane 2 & 3	All Lanes

Please rate how confident you are that your answer is right (circle one number):

Not at all confident 1 2 3 4 5 6 7 8 9 10 Very confident

Please write any comments you have about what made that sign easy or hard to read, recognize, or remember :

INFORMED CONSENT (PHASE 3 AND 4):

I have been invited to participate in an experiment to evaluate various freeway guides signs in a driving simulator. The experiment is to take place in the Gibb Gilchrist Building. I am being selected as a possible participant because I have normal or corrected to normal vision, I hold a valid driver's license, I have no apparent limitations impeding my ability to drive, and meet the age requirements. I have been instructed to read this form and ask any questions I may have before agreeing to participate in the study. This experiment is being conducted by Dr. Susan T. Chrysler of the Texas Transportation Institute (TTI), part of the Texas A&M University System.

Background Information: The purpose of this study is to examine various green guide sign layouts for freeway exits in the driving simulator. 80 people like me will participate in the study.

Procedures: If I agree to be in this study, I will be asked to participate in a brief introductory session, a practice session, and the experimental session in the simulator. This study will take no longer than 2 hours.

Introductory Session: During the introductory session I will read the consent form, and will indicate my willingness to continue with the experiment by signing the form. Before proceeding, I will receive a copy of this form. I will also fill out a Simulator Sickness Questionnaire, indicating any from a list of symptoms I may feel before beginning the study.

Driving Simulator Practice Session: During the practice session I will be provided an information sheet about the simulator and instructions on performing the practice session. This practice session will provide the opportunity to become familiar with driving the simulator and will last approximately 10 minutes.

Driving Simulator Experimental Session: During the simulator portion of the experiment, I will be asked to drive through a simulated driving environment in the same manner as I normally would when driving my own vehicle on the freeway. I will be instructed to navigate to a particular destination, and will read and use the guide signs to direct me to this destination. I will also be asked to answer questions while driving. Periodically I will be given a new destination to drive too. This portion of the experiment will take approximately 1 hour.

Questionnaire: Following the experiment, I will be asked to complete a questionnaire to provide demographic information about myself, as well as some information about my driving habits. I will also complete a second Simulator Sickness Questionnaire, indicating any symptoms I may feel after exiting the simulator vehicle.

Debriefing: Before leaving, I will be provided a debriefing packet explaining the purpose of the study and how the results will be used. _____ *Initial* _____*Date*

Risks: I understand that the only risk associated with this study is a temporary condition named 'Simulator Induced Discomfort' (SID) which is characterized by feelings of dizziness and increased body temperature. The potential for this discomfort is minimal as it only mildly affects about 10 persons out of every 100 under the driving conditions, are rarely occurs with younger people. I understand that I am to indicate to the investigator if I experience any of these symptoms, and that the study will be stopped to prevent any further discomfort to me. I understand that it is my right to stop the study at any time for any reason without any repercussion.

Confidentiality: I understand the records of this study will be kept private. In any sort of report that might be published, no information will be included which may make it possible to identify me. I understand the research records will be kept in a locked file, accessible only to the investigator. My driving performance data, speed and lane position, is being recorded by the computer. These data files will be coded only with an ID number and not by my name.

Benefits: Upon the completion of the introductory session, the practice session, the experimental sessions, and the questionnaire, I will receive a payment of $40 for their participation.

If I experience Simulator Induced Discomfort or equipment malfunction during the practice session or the experiment, the experiment will be stopped. I will still receive full compensation if I experience SID. If an equipment malfunctions occurs within the first 30 minutes of the study, I will receive $20, after that full compensation will be received.

If I decide not to complete the experiment (except in the case of Simulator Induced Discomfort or equipment malfunction), compensation will be reduced to $20.

Voluntary Nature of the Study: My decision whether or not to participate will not affect my current or future relations with the Texas Transportation Institute, Texas A&M University, or the Texas A&M University System. If I decide to participate, I am free to withdraw at any time without affecting those relationships.

Contacts and Questions: The researcher conducting this study is Susan T. Chrysler, Ph.D. If I have questions now or later, I may contact Susan T. Chrysler at the Texas Transportation Institute, Texas A&M University, College Station, TX 77843-3135, (979) 862-3928, s-chrysler@tamu.edu.

I will be given a copy of this form for my records.
A copy of this form will be given to me prior to my proceeding with the experiment.

_____ *Initial* _____*Date*

This research has been reviewed and approved by the Institutional Review Board - Human Subjects in Research, Texas A&M University. For research-related problems or questions regarding subjects' rights, the Institutional Review Board may be contacted through Ms. Angelia Raines, Director of Research Compliance, Office of the Vice President for Research, at (979) 458-4067 (araines@vprmail.tamu.edu).

I understand that the Texas Transportation Institute conducts many research projects throughout the year and may contact me again to participate in another study. I am under no obligation to participate in future studies. My name, contact information, responses to demographic and driving habits questionnaires, and performance on any vision tests will be retained to assist in my potential selection for inclusion in future studies. If I do not wish to be contacted in the future I may indicate this by marking the box below.

☐ I do not wish to participate in any further studies. Do not retain my personal information nor contact me for participation in any future studies.

Statement of Consent: *I have read and understand the explanation provided me. I have had all my questions answered to my satisfaction, and my signature indicates I voluntarily agree to participate in this study. I have been provided a copy of this consent form.*

_____ _____
Signature of Research Participant Date

_____ _____
Signature of Principal Investigator Date

SIMULATOR SICKNESS QUESTIONNAIRE (BEFORE DRIVE)

Study Name_____
Date_____ Participant #_____

Directions: Circle any symptoms below that apply to you right now

1	General discomfort	None	Slight	Moderate	Severe
2	Fatigue	None	Slight	Moderate	Severe
3	Boredom	None	Slight	Moderate	Severe
4	Drowsiness	None	Slight	Moderate	Severe
5	Headache	None	Slight	Moderate	Severe
6	Eye Strain	None	Slight	Moderate	Severe
7	Difficulty Focusing	None	Slight	Moderate	Severe
8	Salivation increased	None	Slight	Moderate	Severe
9	Salivation decreased	None	Slight	Moderate	Severe
10	Sweating	None	Slight	Moderate	Severe
11	Nausea	None	Slight	Moderate	Severe
12	Difficulty concentrating	None	Slight	Moderate	Severe
13	Mental depression	None	Slight	Moderate	Severe
14	"Fullness of the Head"	None	Slight	Moderate	Severe
15	Blurred Vision	None	Slight	Moderate	Severe
16	Dizziness w/ eyes open	None	Slight	Moderate	Severe
17	Dizziness w/ eyes closed	None	Slight	Moderate	Severe
18	Vertigo *	None	Slight	Moderate	Severe
19	Visual flashbacks **	None	Slight	Moderate	Severe
20	Faintness	None	Slight	Moderate	Severe
21	Awareness of breathing	None	Slight	Moderate	Severe
22	Stomach awareness ***	None	Slight	Moderate	Severe
23	Loss of appetite	None	Slight	Moderate	Severe
24	Increased appetite	None	Slight	Moderate	Severe
25	Desire to move bowels	None	Slight	Moderate	Severe
26	Confusion	None	Slight	Moderate	Severe
27	Burping	No	Yes	Number of times_____	
28	Vomiting	No	Yes	Number of times_____	
29	Other	_____			

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

** Visual illusion of movement or false sensations similar to automobile dynamics, when not in the simulator or the automobile.

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

DRIVING HABIT QUESTIONNAIRE Subject#_____

DEMOGRAPHICS

Sex: ☐ Male ☐ Female Birthdate: _____
Race/Ethnicity:

- ☐ White
- ☐ Black, non-Hispanic
- ☐ Asian or Pacific Islander
- ☐ Hispanic, non-Black
- ☐ Other or Mixed

DRIVING HISTORY

How long have you been driving?_____

How often do you drive a motor-vehicle?

- ☐ A few times a year
- ☐ A few times a month
- ☐ A few times a week
- ☐ Once a day
- ☐ Several times a day

Please estimate how many days a month you drive on each type of roadway: (circle your answer)

Urban Freeway (high speed, multiple lanes near large cities); ex: 1-45 in Houston

0 1-2 3-5 6-10 11-20 21 or more

Rural Freeway; ex: HW 21 to Austin

0 1-2 3-5 6-10 11-20 21 or more

For day to day driving, do you feel you have any visual limitations?
(Ex. Can't see very far past the hood of your car, or trouble seeing items over your shoulder)

_____

_____

_____

SIMULATOR DEBRIEFING SHEET

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If you would like a copy of the results of this study or have any questions concerning your participation please write or call the Human Factors Program of the Texas Transportation Institute at Texas A&M University.

The objective of this study is to assess driver comprehension of advanced guide signs and exit direction signs. Today you drove along multiple roadway geometries, and viewed different variations of the signing for the roadway. Diagrammatic signs are signs that use pictorial arrows to illustrate the roadway geometry and/or the appropriate exit configurations.

Results of this study will help the Texas Department of Transportation (TxDOT) improve freeway signing throughout the state. See the following website to view current TxDOT signing practices:

http://www.dot.state.tx.us/trf/mutcd/2006part1.pdf

To learn more about Texas Transportation Institute and its research, please visit the following website:

http://tti.tamu.edu/

SCRIPT/ANSWER FORM FOR SIMULATOR WORLD A1-A

S19: *"Please maneuver to the **Right** lane. Your first destination is **50W to La Salle**"* After the driver maneuvers through the intersection:

"On a scale of 1 to 5, with 5 being the most confident, how confident are you that you are heading on 50W to La Salle?"

1 2 3 4 5

Which lane was the subject in when they passed thru the intersection?

L C1 C2 R

Comments:

S20: *"Please maneuver to the **Left** lane. Your next destination is **73N to Lily**"* After the driver maneuvers through the intersection:

"On a scale of 1 to 5, with 5 being the most confident, how confident are you that you are heading on 73N to Lily?"

1 2 3 4 5

Which lane was the subject in when they passed thru the intersection?

L C1 C2 R

Comments:

S1: *"Please maneuver to the **Left** lane. Your next destination is **15E to Tudor**"* After the driver maneuvers through the intersection:

"On a scale of 1 to 5, with 5 being the most confident, how confident are you that you are heading on 15E to Tudor?"

1 2 3 4 5

Which lane was the subject in when they passed thru the intersection?

L C1 C2 R

Comments:

S2: *"Please maneuver to the **Right** lane. Your next destination is **47 N Mio**"*

After the driver maneuvers through the intersection:

"On a scale of 1 to 5, with 5 being the most confident, how confident are you that you are heading on 47 N to Mio?"

1 2 3 4 5

Which lane was the subject in when they passed thru the intersection?

L C R

Comments:

S3: *"Please maneuver to the **Right** lane. Your next destination is to continue on **47 N to Mio**"*

After the driver maneuvers through the intersection:

"On a scale of 1 to 5, with 5 being the most confident, how confident are you that you are heading on 47 N to Mio?"

1 2 3 4 5

Which lane was the subject in when they passed thru the intersection?

L C1 C2 R

Comments:

S4: *"Please maneuver to the **Left** lane. Your next destination is **22 West to Trenton**"*

After the driver maneuvers through the intersection:

"On a scale of 1 to 5, with 5 being the most confident, how confident are you that you are heading on 22 West to Trenton?"

1 2 3 4 5

Which lane was the subject in when they passed thru the intersection?

L C R

Comments:

S5: *"Please maneuver to the **Right** lane. Your next destination is **75 South to Daly**"*

After the driver maneuvers through the intersection:

"On a scale of 1 to 5, with 5 being the most confident, how confident are you that you are heading on 75 South to Daly?"

1 2 3 4 5

Which lane was the subject in when they passed thru the intersection?

L C1 C2 R

Comments:

S6: *"Please maneuver to the **Right** lane. Your next destination is **73 North to Lily**"*

After the driver maneuvers through the intersection:

"On a scale of 1 to 5, with 5 being the most confident, how confident are you that you are heading on 73 North to Lily?"

1 2 3 4 5

Which lane was the subject in when they passed thru the intersection?

L C1 C2 R

Comments:

S7: *"Please maneuver to the **Right** lane. Your next destination is **87 East to Martin**"*

After the driver maneuvers through the intersection:

"On a scale of 1 to 5, with 5 being the most confident, how confident are you that you are heading on 87 East to Martin?"

1 2 3 4 5

Which lane was the subject in when they passed thru the intersection?

L C1 C2 R

Comments:

S8: *"Please maneuver to the **Left** lane. Your next destination is **33 North to Enid**"*

After the driver maneuvers through the intersection:

"On a scale of 1 to 5, with 5 being the most confident, how confident are you that you are heading on 33 North to Enid?"

1 2 3 4 5

Which lane was the subject in when they passed thru the intersection?

L C R

Comments:

PHASE 3 COMPUTER SURVEY ANSWER FORM

Note: The same answer form was used for both X and Y groups. A similar form was also used for Phase 1 and 2 groups.

Circle the correct response

Practice	Lane 1	Lane 2	Lane 3
	Lanes 1 & 2	Lanes 2&3	All

Please rate how confident you are that your answer is right (circle one number):

Not at all confident 1 2 3 4 5 6 7 8 9 10 Very confident

Please write any comments you have about what made that sign easy or hard to read, recognize, or remember :

Q.1	Lane 1	Lane 2	Lane 3
	Lanes 1 & 2	Lanes 2&3	All

Please rate how confident you are that your answer is right (circle one number):

Not at all confident 1 2 3 4 5 6 7 8 9 10 Very confident

Please write any comments you have about what made that sign easy or hard to read, recognize, or remember :

Q.2	Lane 1	Lane 2	Lane 3
	Lanes 1 & 2	Lanes 2&3	All

Please rate how confident you are that your answer is right (circle one number):

Not at all confident 1 2 3 4 5 6 7 8 9 10 Very confident

Please write any comments you have about what made that sign easy or hard to read, recognize, or remember :

Q.3	Lane 1	Lane 2	Lane 3
	Lanes 1 & 2	Lanes 2&3	All

Please rate how confident you are that your answer is right (circle one number):

Not at all confident 1 2 3 4 5 6 7 8 9 10 Very confident

Please write any comments you have about what made that sign easy or hard to read, recognize, or remember :

Q.4	Lane 1	Lane 2	Lane 3
	Lanes 1&2	Lanes 2&3	All

Please rate how confident you are that your answer is right (circle one number):

Not at all confident 1 2 3 4 5 6 7 8 9 10 Very confident

Please write any comments you have about what made that sign easy or hard to read, recognize, or remember :

Q.5	Lane 1	Lane 2	Lane 3
	Lanes 1&2	Lanes 2&3	All

Please rate how confident you are that your answer is right (circle one number):

Not at all confident 1 2 3 4 5 6 7 8 9 10 Very confident

Please write any comments you have about what made that sign easy or hard to read, recognize, or remember :

Q.6	Lane 1	Lane 2	Lane 3
	Lanes 1&2	Lanes 2&3	All

Please rate how confident you are that your answer is right (circle one number):

Not at all confident 1 2 3 4 5 6 7 8 9 10 Very confident

Please write any comments you have about what made that sign easy or hard to read, recognize, or remember :

Q.7	Lane 1	Lane 2	Lane 3
	Lanes 1&2	Lanes 2&3	All

Please rate how confident you are that your answer is right (circle one number):

Not at all confident 1 2 3 4 5 6 7 8 9 10 Very confident

Please write any comments you have about what made that sign easy or hard to read, recognize, or remember :

Q.8	Lane 1	Lane 2	Lane 3
	Lanes 1&2	Lanes 2&3	All

Please rate how confident you are that your answer is right (circle one number):

Not at all confident 1 2 3 4 5 6 7 8 9 10 Very confident

Please write any comments you have about what made that sign easy or hard to read, recognize, or remember :

Q.9	Lane 1	Lane 2	Lane 3
	Lanes 1&2	Lanes 2&3	All

Please rate how confident you are that your answer is right (circle one number):

Not at all confident 1 2 3 4 5 6 7 8 9 10 Very confident

Please write any comments you have about what made that sign easy or hard to read, recognize, or remember :

Q.10	A	B	C	

Please write any comments you have about what made that sign easier to read, recognize, or remember :

Q.11	A TRUE or FALSE	B TRUE or FALSE	

Q.12	A	B	C	

Please write any comments you have about what made that sign easier to read, recognize, or remember :

Q.13	A	B	

Please write any comments you have about what made that sign easier to read, recognize, or remember :

Q.14	A	B	C	

Please write any comments you have about what made that sign easier to read, recognize, or remember :

Q.15	A	B	C	

Please write any comments you have about what made that sign easier to read, recognize, or remember :