Simulator Study of Signs for a Complex Interchange and Complex Interchange Spreadsheet Tool

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FOREWORD

The overall goals of this research on complex interchanges were to increase understanding of motorists' expectations when navigating complex interchanges, determine how those expectations affect their behavior, and discover how the safety of the interchanges can be effectively increased through the use of better signing and marking practices.

Based on the initial literature review task and other ongoing work, the project was divided into two studies: (1) conduct a driving simulator study and (2) develop a metric that can score, rate, or otherwise categorize interchange complexity. This report documents a Federal Highway Administration project that identified potential improvements to current signing practices for complex interchanges and developed a spreadsheet decision tool for defining and quantifying interchange complexity.

This report is of interest to engineers, planners, and other practitioners who are concerned about implementing signing treatments for freeways as well as city, State, and local authorities who have a shared responsibility for ensuring public safety.

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16. Abstract

This report documents a Federal Highway Administration (FHWA) project to identify potential improvements to current signing practices for complex interchanges. Based on the initial literature review task along with discussions on other ongoing work, FHWA and the research team divided the project into the following two studies: (1) conduct a driving simulator study and (2) develop a metric or tool that can score, rate, or otherwise categorize interchange complexity.

In the first study, test signs were introduced as six topics in a simulation along freeway roadways to evaluate drivers' real-time response to the signs. Topic 1 tested the understanding and use of different methods to sign for an option lane. Almost all participants made the correct decision to exit or stay on the freeway; however, many unnecessary lane changes were made with each of the three sign sets (SSs). Topic 2 studied sign methods when two interstate exits were within close proximity and a need existed to sign for three destinations (two interchanges/exits and the through lanes). For the SS that had an arrow-per-lane design, all participants made correct lane change decisions. Topic 3 evaluated signing for an upcoming exit that had a Y-split into two directions. While several incorrect lane changes were made for each SS, the SS that used split exit signs at all three sign bridge (SB) locations had the fewest incorrect lane changes and was judged superior in comparison to the other two arrangements. Topic 4 evaluated whether it was better to fill an advance single sign with supplemental way-finding information or to spread the information among multiple signs. An observation from this topic was that spreading information about the next exit across multiple signs on a single bridge may have unintended consequences if the SB also includes a sign for another exit that is located to the left of the preferred lane. Topic 5 evaluated the effectiveness of sign spreading when there were many pieces of information on one SB. Similar to topic 4, it was determined that the lateral position of a sign on the SB is important. Topic 6 evaluated driver understanding of left exit signs. The difference between the two SSs that were tested was minimal.

In study 2, the complexity rating tool focused on geometric design factors and related effects on driver expectancy and driver workload. After several revisions, researchers settled on a spreadsheet tool that considered the effects of 32 weighted factors that were based on site characteristics. To determine how well the spreadsheet tool would evaluate interchanges, the research team used the spreadsheet to review 28 existing sites in 11 States. The sites were submitted by State transportation departments based on their perceived complexity. For the characteristics included in the spreadsheet, the results provided a general sense of the relative complexity of the interchanges studied.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^{o}F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^{o}C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^{o}C	Celsius	1.8C+32	Fahrenheit	^{o}F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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LIST OF ABBREVIATIONS

AASHTO	American Association of State and Highway Transportation Officials
C	Correct lane change
C-D	Collector-distributor
FHWA	Federal Highway Administration
G	Pregore undetermined
H	Lane change to be in the lane as instructed as the starting lane
IC	Lane change to correct an incorrect lane change
IL	Incorrect lane change to the left
IR	Incorrect lane change to the right
IS	Incorrect lane change to go through
L	Last recording for the participant (to estimate/double check PE)
MUTCD	*Manual on Uniform Traffic Control Devices*
N	Number of participants driving a particular testing variation
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
PC	Lane change leading to the correct lane change
PE	Lane change to move into the end lane/pulling over to end simulation
PI	Lane change leading to the incorrect lane change
PS	Lane change to move into the start lane
PU	Lane change leading to the unnecessary lane change
S	Swerve (swerve from left lane to right and back to left is counted as two)
SB	Sign bridge
SCL	Speed change lane
SL	Start lane
SS	Sign set
sw	Stroke width
TRB	Transportation Research Board
TTI	Texas Transportation Institute
TxDOT	Texas Department of Transportation

U	Unnecessary lane change
UC	Lane change to correct an unnecessary lane change (other than swerve)
W	Representing indecision (i.e., S, IC, or UC)

EXECUTIVE SUMMARY

BACKGROUND

As transportation agencies struggle with adding freeway lane capacity in times of limited resources and shrinking right-of-way, new interchange designs are being built beyond the traditional diamond and cloverleaf configurations. Freeway interchanges with lane drops, double lane exits with optional lanes, and other unusual geometries confuse drivers and may result in late lane changes and erratic movements near the gore.

OBJECTIVES

This project was initiated to identify potential improvements to current signing and marking practices for complex interchanges. Two approaches were used to investigate complex interchanges—a driving simulator study and a decision tool. The driving simulator task identified driver lane changing behavior for six research questions related to freeway guide signing. The decision tool was developed to measure complexity. If traffic control device practice is to vary by complexity, a way to define complexity is needed.

PROJECT OVERVIEW AND FINDINGS

Driving Simulator Study of Signing for Complex Interchanges

In the driving simulator task, 42 drivers from rural and urban areas in Texas used a desktop driving simulator to navigate to fictional destinations by following test guide signs. Driver peformance measures included lane change proximity to (theoretical) gore as well as the number of unnecessary lane changes. In addition, subjective measures of comfort and confidence were obtained.

The research team created a list of potential topics or research questions for sign sequences used at complex interchanges. A driving simulator was considered for those topics where it was important to know how quickly a driver would make a lane choice. Other topics were investigated using focus groups conducted in a separate collaborative project. The simulator was also considered when it was important to view signs in a sequence and for drivers to see their spatial placement on the roadway. A priority order was determined for the list of topics, and the top six topics were selected. Table 1 lists the six topics investigated in this study along with the number of sign sets (SSs) considered within each topic. The table also provides the number of testing variations (e.g., start lane (SL) and destination combinations).

Table 1. Number of testing scenarios.

Topic Number	General Description	Number of SSs	Number of Testing Variations	Total Test Scenarios
1	Use of option lane	3	4	12
2	Close proximity of two interstate exits	3	6	18
3	Y-split	3	4	12
4	Information spreading (more signs per bridge)	3	4	12
5	Information spreading (multiple sign bridges)	2	3	6
6	Left exit	2	3	6
Total	Not applicable	16	24	66

Topic 1

Topic 1 tested the understanding and use of different sign methods for an option lane. The topic evaluated driver understanding of three different SSs: arrow per lane, a down arrow per lane, and a sign only for the exit and not the through movement. Almost all participants made the correct decision to exit or stay on the freeway; however, many unnecessary lane changes were made with each of the three SSs by people whose SL was either the on the far left or the far right. Interestingly, drivers who started in the center lanes and who were told to exit moved to the far right lane, which included an unnecessary lane change. However, drivers who started in the center lane and given the through destination did not move to the far left lane. This may be due to some reluctance on their part to move into the left lane, which is typically used for high-speed passing.

Topic 2

Topic 2 studied methods for creating signs when two interstate exits are within close proximity and there is a need for signs for three destinations (two interchanges/exits and the through lanes). For the SS that had an arrow per lane design, all participants (42) made correct lane change decisions. A sign adapted from the *Manual on Uniform Traffic Control Devices* (MUTCD)-style diagrammatic sign also had many correct lane change decisions with five or more of the seven participants in a group (with same SL and destination) making the correct decision.[(1)] Of the 42 participants who viewed this SS, only three made incorrect lane change decisions. The SS with multiple signs with exit only panels did not have as favorable results (e.g., 6 of the 42 participants made incorrect lane change decisions). This sign array also had more of the participants wanting additional information to make a lane change decision.

Topic 3

Topic 3 evaluated signing for an upcoming exit that then has a Y-split into two directions. Signing options included a split sign to explore if it helps to guide drivers into the appropriate lane for the Y-split in advance of the initial exit. The split sign shows the two destinations side-by-side with a vertical white line separation. One SS (3-B) had the split sign used for the two advance signs and at the gore. Another SS (3-C) only used the split sign at the gore with the two advance signs showing the destinations vertically stacked. The third SS tested (3-A) used the vertical stacked format for both the two advance signs and the gore sign. The lateral location of the destination on the sign was used by the participants in making a lane change decision. Several lane changes were made at the first appearance of the split exit sign. While several incorrect lane changes were made for each SS, SS 3-B, which used split exit signs at all three sign bridge (SB) locations, had the fewest and was deemed superior in comparison to the other two arrangements.

Topic 4

Topic 4 evaluated whether it is better to fill an advance single sign with supplemental way-finding information, such as exit information for a convention center, or to spread the information among multiple signs, including ground-mounted signs. Gore signs with advance signs at 1 mi were used to explore if sign spreading on a single bridge or on multiple bridges improved where the lane change was occurring. For most of the variations studied, a SS with the supplemental information on a separate sign located between the 1-mi advance and the exit gore had the most participants make the correct lane change decision. However, another SS presenting information for the next exit stacked on one sign also had many of the participants correctly making lane positioning decisions. When the destination information was spread across multiple signs on a single bridge, the supplemental sign ends up being located in the center of the SB. When this variation was tested, several participants made incorrect lane changes to the left when the instructions were to go to the second destination. These drivers may have been positioning their vehicles in the lane under the sign with their intended destination. This finding indicates that spreading information about the next exit across multiple signs on a single bridge may have unintended consequences if the SB also includes a sign for another exit that is located to the left of the preferred lane.

Topic 5

Topic 5 evaluated the effectiveness of sign spreading when there are many pieces of information on one SB. One SS did not have sign spreading (SS 5-A), and the other SS had sign spreading longitudinally across multiple SBs (SS 5-B). The lateral position of a pull-through sign on the SB is important. SS 5-A had more unnecessary lane changes as compared to SS 5-B. Half of the participants with SS 5-A had unnecessary lane changes, while SS 5-B had no unnecessary lane changes. Because SS 5-A had more signs on a single-SB, the sign for the through destination was farther to the left, which may have resulted in participants trying to position themselves below the destination name, resulting in an unnecessary (but not incorrect) lane change.

Topic 6

Topic 6 evaluated driver understanding of the 2009 MUTCD left exit standards.[1] Only 1-mi and 0.5-mi advance signs were used to test how quickly a driver identifies the left exit and changes lanes and whether there is confusion if it is an exit only or optional exit. SS 6-A had a yellow plaque at the top left, which is the new MUTCD standard, while SS 6-B had a yellow panel at the bottom of the sign, which is the old standard. Generally, for the two SSs tested under this topic, participants understood which side of the road the exit was located. It is unclear if this was because the participants were cued by the placement of the sign over the left lane, read the word "left" on the signs, or a combination of the two. The placement of the sign over the left lane resulted in the participants correctly avoiding moving across multiple lanes to make a right exit. However, when the participants did not need to make a left exit, they frequently moved out of the leftmost lane due to personal preference even though the lane was not an exit-only lane. A few more of the non-exiting participants who saw SS 6-B with the yellow panel at bottom of sign moved out of the leftmost lane (8 of 14) as compared to the participants who saw SS 6-A with a yellow plaque at the top left (5 of 14). For this study, the difference between these two SSs was minimal.

Decision Tool to Define and Quantify Interchange Complexity

Because complexity is typically a qualitative characteristic, the ability to objectively evaluate the complexity of an interchange is somewhat difficult. That difficulty is compounded when trying to compare the complex features of multiple interchanges. This task developed a spreadsheet-based decision tool as a method of quantifying and comparing the complexity of freeway interchanges in the United States. Efforts within the task included initially developing the tool by the research team, reviewing the preliminary tool by a set of experts, and modifying the spreadsheet tool based on a review of the characteristics of 28 existing interchanges in 11 States. These study sites ranged from relatively simple to very complex, and results indicate that the spreadsheet generated scores that were generally consistent with researchers' qualitative estimation of the sites' relative complexity.

During the initial stages of developing the spreadsheet, researchers discussed a variety of methods to apply a consistent set of criteria to measure complexity, and many potential variables were considered (e.g., geometric design variables, traffic control device variables, driver workload variables, etc.). Researchers also discussed the basis on which the following variables would be considered:

- Interchange-wide variables (e.g., number of vertical levels).
- Route-specific variables (e.g., number of decision points/ramps to travel from an origin to a destination).
- Ramp-specific variables (e.g., left-side or multilane exit).

Researchers also discussed how to determine the complexity of each variable. That is, what quantity of a particular variable is considered to add complexity, and how does that compare to the complexity contributed by other variables? Researchers assigned threshold values to each variable, such that if the variable exceeded that value at a given interchange, it was deemed to have greater complexity. For example, if an interchange had more than three left-hand exits, the complexity of that interchange would be greater than an interchange with three or fewer left-hand exits. Threshold values could also be compared to values in commonly used guidelines, such as the 2011 American Association of State and Highway Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets* (commonly known as the *Green Book*), and they can be weighted to reflect their contribution to the overall complexity relative to other variables.(2)

Given all of these considerations, researchers compiled a list of noteworthy variables, assigned proposed values and weights to them, and incorporated this list into the initial version of the spreadsheet tool. In January 2011, the researchers conducted an expert panel discussion to present the initial spreadsheet tool for feedback and enlist the experts' help in identifying factors that contribute to the driving complexity of an interchange. This discussion was limited to design and geometric variables and did not address existing signing or other traffic control devices. In addition to the four members of the research team, the panel was composed of six practitioners: three from State transportation departments, two from the Federal Highway Administration (FHWA), and one from a State turnpike authority.

Overall, the panel thought the three categories of variables were helpful for addressing interchange complexity, but they noted that the workload and expectancy categories were very interrelated and could be combined into a single category. The example provided was that if the decision points for several major destinations were within the interchange area, the workload would be significantly increased without violating any expectations regarding traffic movements. Panelists stated that workload can be reduced through interchange design by spreading the decision points along the corridor and that addressing variables within the design category could eliminate complexity from both workload and expectancy violations. This point emphasized the need for early coordination of geometric design and signing needs.

Based on the panel's feedback, researchers revised the spreadsheet into its current version. Some of the key features of the spreadsheet tool are as follows:

- The spreadsheet includes 37 unique variables—three interchange characteristics and 34 ramp-specific characteristics. The variables emphasize geometric design elements and related interchange features.

- All 37 of these variables can be obtained without an in-person site visit to the interchange in question. The variables were chosen so that a practitioner could identify the information needed to complete the spreadsheet through site plans, aerial photographs, and/or online mapping services.

The effect of each of these variables on the complexity of an interchange is calculated separately, but it is weighted to provide an indication of that variable's complexity compared to the others in the spreadsheet.

To determine how well the spreadsheet tool would evaluate interchanges, the research team issued a request to State transportation departments for locations of the most complex interchanges in their respective states. The research team received responses from 11 States, documenting 35 interchanges. After reviewing the information provided by the transportation departments, the research team used 28 of the interchanges for processing in the spreadsheet. Six of the remaining interchanges contained more than four approaches, which is the capacity of the spreadsheet, while the last site was not used because of poor aerial image quality. The 28 interchanges had a variety of characteristics, providing a unique opportunity to use the spreadsheet tool to compare interchange complexity. Researchers tested multiple combinations of weights to develop scores for the 28 sites based on the effects of characteristics from each site. The results generated by the final version of the spreadsheet produced a set of interchange complexity scores that were nearly identical to the research team's subjective ranking of the sites' complexity. This suggests that for the characteristics included in this spreadsheet, the spreadsheet tool provides a practical means of quantifying and comparing the relative complexity of interchanges in different locations with different characteristics.

CHAPTER 1. INTRODUCTION

BACKGROUND

As transportation agencies struggle with adding freeway lane capacity in times of limited resources and shrinking right-of-way, new interchange designs are being built beyond the traditional diamond and cloverleaf configurations. Designs such as the diverging diamond, flyover ramps with directional splits on the flyover, left merging entrance ramps, and others can be complex and run counter to driver expectations. The FHWA MUTCD offers limited advice for the use of diagrammatic signs for left exits, freeway-to-freeway splits, and two-lane exits with option lanes.[1] The inclusion of these diagrammatic signs has been under scrutiny by the FHWA MUTCD team and members of the Guide and Motorist Information Technical Committee of the National Committee on Uniform Traffic Control Devices. In the 2009 revision of the MUTCD, arrow-per-lane diagrammatic signs were added based on research conducted for the National Cooperative Highway Research Program (NCHRP) and as part of the traffic control device pooled fund study. (See references 1 and 3–5.)

Freeway interchanges with lane drops, double-lane exits with optional lanes, and other unusual geometries have been the subject of many studies concerning signs and markings. These geometries violate driver expectations and may result in late lane changes and erratic movements near the gore. (See references 3, 4, and 6–9.) A 1996 Texas Department of Transportation (TxDOT) project reinforced the idea that drivers have a weak understanding of optional lane interchange signing, with only 50–65 percent of drivers correctly interpreting the current (conventional) method of signing.[8]

In 1993, the Texas Transportation Institute (TTI) studied lane use arrow pavement markings along with longitudinal striping at freeway lane drops utilizing both surveys and field studies.[6] The study demonstrated that the installation of lane drop markings caused drivers to move into or out of the exiting lane farther upstream than before markings were installed. Before and after studies also revealed that the number of erratic maneuvers within the study segment decreased with the installation of lane use arrow markings.

Two different studies have been conducted to evaluate guide signing at freeway lane drops with an optional exit lane using driving simulations. First, a 2003 NCHRP project using a driving simulator showed that roughly one-third of drivers made unnecessary lane changes at these interchange locations.[3] Ultimately, the study recommended diagrammatic advanced guide signs and a conventional gore sign with pull-through arrows for the through route and an exit only plaque over the exit.[3] A 2006 TTI study determined that drivers are likely to make unnecessary lane changes when an exit only plaque is present regardless of the type of sign.[7] Drivers tended to interpret the plaque as marking the only exit lane available as opposed to a lane that is forced to exit where there may also be a second optional exit lane.[7]

TTI conducted a recent project on the use of pavement marking symbols, arrows, text, and route markers.[9] Two human factor surveys were conducted to evaluate driver comprehension and preference for different in-lane pavement marking applications. Data analysis consisted of comprehension and preference identification. The studies were conducted using a laptop computer. Both video clips and still images were used to display the interchange sign and pavement marking information as appropriate for the situation. The study made recommendations about arrows, regulatory text, route markers, and cardinal direction text.

PROJECT OBJECTIVE

This project was designed to identify potential improvements to current marking and signing practices for complex interchanges. Because of the initial literature review task along with discussions on other ongoing work, FHWA and the research team divided the project into two studies with the following objectives:

- Conduct a driving simulator study.
- Develop a metric that can score, rate, or otherwise categorize interchange complexity.

STUDY APPROACHES

Study 1: Conduct Driving Simulator Evaluation of Sign Treatments

As decided at the kickoff meeting, TTI was to perform a driving simulator study using its desktop simulator. The research team developed the signs to be tested by a combination of a review of the existing signs and complex interchanges submitted by the State transportation departments and by the guidance presented in the 2009 MUTCD.[1] Input from focus groups and a task analysis were also to be considered. The simulator studies were to be conducted in Texas with the pilot using drivers from the College Station area. Due to the rural nature of the city, this population represented drivers unfamiliar with more complicated interchange designs typically found in urban areas. The studies were to be conducted both in College Station and in Houston to test drivers with different levels of experience with freeway driving.

Study 2: Develop Decision Tool to Define and Quantify Interchange Complexity

The concept of complexity as it relates to an interchange and drivers' decision process to navigate the interchange can be applied in multiple ways; therefore, it was necessary to establish a definition of complexity and identify ways to quantify its effects on the driving public. Researchers believed that developing a tool that incorporated these elements would provide a list of factors that a reviewer could score based on a review of site plans, and the presence of those factors at the interchange could be translated into a numerical complexity score. Thus, study 2 was focused on developing such a tool.

TOPIC IDENTIFICATION

A list of potential topics was created as a guideline for the types of sign sequences needing evaluations. The initial list included the following:

- Driver understanding of gore sign down arrow or arrow per lane versus only signing the exit and not the through movement.
- Driver understanding of down arrow per lane versus shared arrow gore sign.

- Driver understanding of advance signs for multilane freeways.
- Driver lane change behavior when encountering lane ends.
- Driver understanding of exit number plaque placement and driver behavior in a sequence of splits and exits. For example, driver comprehension of signage for left lanes that becomes right exits because of a sequence of splits and exits.
- Driver understanding of 2009 MUTCD left-exit standards.[1]
- Driver understanding of exit only sign text to provide confirmation of earlier findings that drivers prefer to get out of an option lane.
- How to sign for distant downstream destinations and challenges with exits being out of order relative to destination proximity.
- Determination of whether it is better to fill an advance single sign with extra navigation information (i.e., more than two destinations) or to spread the information among multiple signs (possibly ground signs).
- Determination of which sign elements drivers read in multisign banks, what order they are read, and whether the lane is dependent.
- Driver interpretation of multiple separate exit-only panels in the same sign bank.
- Determination of whether there are limits on the number of lanes that can be effectively communicated by diagrammatic signs (i.e., more than four).
- Driver interpretation of sign information above one lane that pertains to a different lane. This could include driver assumptions about the pairing of signs with lanes rather than exit order.
- Driver interpretation of route ends signs (typically freeway spurs).
- Driver comprehension of signs with complex yellow panels (i.e., including exit distance and speed limit).
- Driver comprehension of what information goes together on signs with complex layouts.
- How different sign elements and sign layout options affect drivers' expectations of the upcoming interchange geometry.
- How different sign elements affect drivers' understanding of the interchange navigation and the destination groupings.
- How to sign for three destinations (legs).

This list was later altered, and topics were assigned using photographs, a TTI simulator study, or both. When deciding which topics should be addressed by the contractor survey and which by the TTI survey, researchers first considered the measures of effectiveness. For topics where it was important to determine how quickly a driver would make a lane choice, a simulator study was desired. If it was only important to know what lane drivers would choose, the contractor survey was a more appropriate and less expensive option. Also, if it was important to see signs in a sequence and for the driver to see their spatial placement on the roadway, the simulator study was more appropriate. While the simulator offered driver immersion and driving data, the laboratory study allowed for quick, inexpensive testing of many different SSs. It is important to note that finalizing the topic list was an iterative process with the division of topics between the TTI simulator study and the contractor survey, as well as the elimination and addition of particular topics.

REPORT ORGANIZATION

This report is organized into the following chapters:

- Chapter 1 presents the general background information and the project's objective and the approach used for the two studies conducted as part of this project.
- Chapter 2 presents the findings from the literature review. The findings provided direction regarding the topics to be studied in the simulation study.
- Chapter 3 discusses the procedure used to develop, test, reduce, and analyze the sequence test topics evaluated in the simulator study.
- Chapter 4 describes the characteristics of the spreadsheet tool developed to compare the complexity of multiple interchanges. It also discusses the process used to develop the tool and the results of an evaluation of 28 existing interchanges.
- Chapter 5 provides a summary of the two studies conducted as part of this project.
- Appendix A presents the details about the driver simulator study.
- Appendix B describes the spreadsheet tool developed as a method of evaluating and comparing the complexity of freeway interchanges in the United States.
- Appendix C contains descriptions of each of the 28 interchanges used in developing the complex interchange spreadsheet tool.

CHAPTER 2. IDENTIFY SIGNING PROBLEMS AND POTENTIAL SOLUTIONS

INTRODUCTION

A *complex interchange* is defined as a facility that contains many lanes (i.e., four or more in each direction) and carries high traffic volumes through a maze of tightly spaced ramps and connectors.[(10)] Additionally, drivers often have to make multiple lane changes requiring intense attention and rapid decisionmaking. As transportation agencies struggle with adding freeway lane capacity in times of limited resources and shrinking right-of-way, new interchange designs are being built beyond the traditional diamond or cloverleaf configurations that are increasing the frequency of drivers having to navigate through a complex interchange. The MUTCD offers limited advice for signing at non-traditional interchanges; however, there are still improvements that could be made to current signing and marking practices that could further affect driver decisionmaking, comfort, and safety.[(1)]

This chapter identifies the current state-of-the-practice regarding signing standards and summarizes research that has been conducted regarding signing at complex interchanges.

DRIVER NEEDS AND INFORMATION PROCESSING

To effectively design and place freeway guide signs at a complex interchange, a practitioner must be cognizant of the limitations of drivers while navigating through an interchange area. Information should be presented in a clear, concise, and consistent manner to help ensure that motorists unfamiliar with the route can easily interpret the information presented. Repetition of messages is also encouraged.

This section provides a brief review of issues related to driver information needs and processing as related to freeway guide signing. It also provides a brief description of the various components of the driving task. Research on legibility and information processing is also briefly discussed. Readers are advised to consult the relevant source material for a more detailed treatment of these topics. Finally, a methodology for evaluating the adequacy of guide signing is reviewed.

Positive Guidance and the Driving Task

The concept of positive guidance is often used as a guiding principle for providing information to drivers. Positive guidance consists of creating and maintaining a driving environment that has the following characteristics:[(11)]

- Motorists are provided with the maximum amount of useful visual information.
- Information is presented in such a way that it is prioritized by importance.
- Information is presented uniformly, allowing drivers to develop expectancies about the location of information.
- Information is visible under most, if not all, environmental conditions.

If the principles of positive guidance are applied consistently, drivers will subconsciously develop expectations about where to seek information. It is important to understand the demands that are placed on the driver during the driving task when the concepts of positive guidance are applied. The driving task is made up of a number of subtasks that require varying levels of time and cognitive activity. The three most basic subtasks are as follows:[12]

- Control.
- Guidance.
- Navigation.

Performance of these subtasks allows drivers to maintain control of their vehicles, maintain their positions in the lane, and navigate to their final destinations. Drivers perform these subtasks continuously at various cognitive levels, although the amount of attention and cognitive resources allocated to each task may vary depending on the specific conditions that are present at a given point and time. A detailed description of each of these subtasks is given in the following subsections. The features of the positive guidance concepts were summarized into tables and are reproduced.[13]

Control

The control subtask consists primarily of steering control and speed control.[12] Steering control involves maintaining the orientation of the vehicle with respect to the roadway, and it usually has the highest priority to the driver. Speed control involves using the brake and accelerator to select an appropriate speed for a given situation. Table 2 summarizes the basic characteristics of these two components of the control subtask.

Table 2. Characteristics of the control subtask.[13]

Characteristic	Steering Control	Speed Control
Priority	High	High
Driver level of effort	Varies depending on geometrics	Varies depending on geometrics and traffic
Information needs	Vehicle response characteristics relative position of vehicle	Vehicle braking and acceleration characteristics and road conditions ahead of driver
Demand on driver	Usually low because subtask is over learned	Greater than steering since driver must look farther down the road

Guidance

The guidance subtask involves maintaining a safe and efficient path relative to all factors in the roadway environment.[12] Some examples of actions included in the guidance subtask are car following, passing, and responding to traffic control devices. Table 3 summarizes the characteristics of the guidance subtask. The ability to perform the guidance subtask is a function of the driver's previous knowledge of similar conditions. Once a particular condition has been observed by drivers, they must process the information to determine an appropriate course of action. The level of cognitive demand that this places on drivers is dependent on their previous experiences in a given situation.

Table 3. Characteristics of the guidance subtask.[13]

Characteristic	Guidance
Priority	Varies depending on conditions but usually intermediate between control and navigation
Driver level of effort	Higher than control subtask with more conscious decisionmaking necessary
Information needs	Traffic conditions, road geometry, weather conditions, and other information that impacts the road environment
Demand on driver	Varies depending on the driver's previous experiences and prior knowledge

Navigation

The portion of the driving task that is most directly affected by freeway guide signing is the navigation subtask.[12] The navigation subtask consists of planning a trip from the beginning to the end and then executing the trip plan. The navigation subtask can be broken into two areas: (1) trip preparation and planning and (2) direction finding. Trip preparation and planning can consist of anything from drivers using their own mental map of an area to consulting maps or knowledgeable persons in order to plan a trip. If drivers are well prepared prior to beginning a trip, they will be more successful in the navigation subtask even if there is limited en route information. Direction finding occurs while drivers are en route and attempting to reach their destinations. This portion of the subtask involves interpreting direction guidance on signs to receive information about the appropriate path. The characteristics of the navigation subtask are summarized in table 4.

Table 4. Characteristics of the navigation subtask.[13]

Characteristic	Trip Preparation and Planning	Direction Finding
Priority	Performed pretrip, so no demands on driver while en route	Usually lowest of all subtasks, although demands may increase in complex or unfamiliar situations
Driver level of effort	Varies depending on driver familiarity with route	Usually low
Information needs	Location or origin and destination and physical or mental map of alternative routes	Guide signs, route markers, street name signs, landmarks, etc.
Demand on driver	Usually low	Usually low except in unusual circumstances

Additional Issues

Attention is an important component of the driving task.[12] When a subtask has a low demand, it can be performed with little conscious attention, allowing drivers to allocate attention to tasks that require more cognitive resources. When the demands of the driving task require that more attention be placed on a particular subtask, it comes at the expense of performing tasks requiring a higher level of attention. This process is known as load shedding. For example, a driver on an uncongested freeway can easily perform navigational subtasks. If traffic becomes extremely congested, the navigational subtasks become more difficult to perform because the driver must allocate more attention to the control and guidance subtasks.

Expectancy is also very important in the driving task.(12) Drivers need to have reasonable expectations about how their vehicles will perform, the geometry of the road downstream of their positions, and where to find navigational information. If the expectancy of the driver is violated, the performance of the driving task may suffer. This situation is particularly important in freeway guide signing where an unfamiliar driver relies on guide signs to provide information to perform the navigation subtask.

Reading Time

In a freeway environment, drivers must read, interpret, and react to freeway guide sign messages in a limited amount of time in order to obtain information for the navigation subtask. If a sign presents too much information, there is a possibility that a driver will not comprehend important navigational information. The following subsections present studies that have attempted to determine both the amount of time required to read a guide sign and the maximum amount of information that should be displayed on a guide sign.

Relationship Between Number of Words and Reading Time

Researchers have hypothesized that the amount of time required to read a guide sign is a function of the number of words on a sign. Mitchell and Forbes defined one of the first relationships between sign reading time and the number of words on a sign.(14) They developed the equation in figure 1 to determine reading time for signs with more than three words.

$$T = \frac{N}{3}$$

Figure 1. Equation. Relationship between sign reading time and number of words.

Where:

N = Number of familiar words on the sign.
T = Reading time (s).

This relationship yields an average reading time of 333 ms per word. Researchers then modified this formula to incorporate a safety factor in case the driver was distracted while attempting to read the sign. The researchers arbitrarily determined that a safety factor of 2 should be provided. This safety factor was not the result of any research. The revised formula is shown in figure 2.(14) The modified equation yields a reading time of 667 ms per word.

$$T = \frac{2N}{3}$$

Figure 2. Equation. Revised formula for relationship between sign reading time and number of words.

Issues related to sign placement, sign content, traffic conditions, and driver familiarity with the message can significantly alter the amount of time required to read a sign. One study examined drivers' eye fixations while driving on an interstate highway and found that drivers did not continually read signs.[15] Instead, drivers made a series of discrete fixations on signs that lasted between 100 and 600 ms. As drivers became more familiar with a sign, they spent less time reading the sign to obtain information.

A British study attempted to evaluate the impact of information overload on the time required for drivers to respond to guide signs.[16] The researchers evaluated guide signs on normal surface streets and found that the relationship between response time and the number of destinations was non-linear. Although the search times were greater when more destinations were present, there was no evidence that drivers' search abilities broke down when more destinations were present.

A 1989 study attempted to determine the time necessary to read signs while subjects were performing demanding driving tasks.[17] Non-freeway guide signs were used in this evaluation. The number of destinations on the signs ranged from four to nine, with a maximum of three destinations in each cardinal direction. They found that reading times varied from 0.88 s for signs with four names to 1.33 s for signs with nine names. When participants were asked to find destinations that were not on the sign, the reading times increased from 1.42 to 2.24 s. While reading times increased as the number of words increased, it was not always a substantial increase.

McNees and Messer conducted a study that examined the ability of drivers to successfully read and interpret freeway guide signs within limited time constraints.[18] Drivers were presented with two to five individual sign panels on a simulated overhead sign structure. Each sign panel contained 2 to 10 units of information per panel. Each place or street name, route number, cardinal direction, command, distance, or lane use arrow was counted as a separate unit of information. Subjects were asked to identify the proper travel lane that should be used to reach a predetermined destination. Time constraints were applied in order to simulate the impact of heavy driver task loads under freeway speeds. Signs were displayed for 2.5, 4.0, and 6.0 s in order to reflect unacceptable, acceptable, and desirable amounts of available reading time.

As expected, it took participants longer to read signs that had more information on them. When the exposure time was limited and a lot of information was presented, the participants had a lower accuracy for message interpretation.

Table 5 summarizes the accuracy results of the test subjects for different information loads and display times. The researchers recommended an optimum value of six units of information per sign. The average correct response rate varied as a function of the total number of units of information presented on each sign.

Table 5. Driver response accuracy to varying information loads and exposure times.[18]

Information per Panel (units)	Display Rate (s)	Percent of Drivers with Correct Response			
		2 Panels	3 Panels	4 Panels	5 Panels
2	6	93	83	94	80
	4	88	83	93	80
	2.5	83	82	80	84
4	6	96	82	63	46
	4	93	83	69	52
	2.5	91	94	92	76
6	6	100	92	33	95
	4	87	92	36	86
	2.5	99	92	52	92
8	6	81	55	76	58
	4	93	80	82	61
	2.5	75	45	91	36
10	6	77	60	65	70
	4	83	71	75	73
	2.5	57	80	78	79

Desirable and Maximum Reading Times and Information on Guide Signs

McNees and Messer used the reading time data collected in the study to generate a table of desirable and minimum reading times that should be provided to drivers for overhead guide signs.[18] The elapsed time between when a sign was initially displayed and when the subject made a correct lane choice was recorded. The researchers then developed a series of regression lines that they used to predict desirable reading times that should be provided for varying levels of information.

Table 6 summarizes these results. Desirable reading times represent a predicted reading time where at least 85 percent of the drivers would make the correct lane choice decision. The minimum reading time represents a time where 75 percent of the drivers would make the proper decision. Cells with a dash indicate situations that should not be used on the road. These situations represent cases where more than 20 units of information are presented on the sign structure.

Researchers also generated a table of desirable and maximum amounts of information that should be placed on overhead sign structures (see table 7). The table shows that placing five sign panels on a single structure is not a desirable design and should not be used if possible. The maximum amount of information on any sign structure should not exceed 20 units.

Table 6. Desirable reading times for overhead guide signs.[18]

Units of Information per Panel	Condition	Reading Time (seconds)			
		2 Panels	3 Panels	4 Panels	5 Panels
2	Desirable	3.1	3.5	3.9	4.4
	Minimum	2.7	2.7	3.0	3.3
4	Desirable	3.6	4.2	5.0	5.7
	Minimum	2.7	3.2	3.7	4.2
6	Desirable	3.8	4.5	—	—
	Minimum	2.8	3.4	—	—
8	Desirable	3.9	—	—	—
	Minimum	2.9	—	—	—
10	Desirable	4.0	—	—	—
	Minimum	3.0	—	—	—

— Indicates situations that should not be used on the road.

Table 7. Maximum amount of information per sign structure.[18]

Number of Panels	Condition	Maximum Units of Information per Structure
2	Desirable	12
	Maximum	16
3	Desirable	18
	Maximum	20
4	Desirable	16
	Maximum	20
5	Desirable	—
	Maximum	20

— Indicates an undesirable design.

Detection and Legibility

Before interpreting the message on a sign, drivers must be able to determine that a sign is present, and they must be able to read the message. The initial detection of a guide sign occurs when a driver can see the sign without being able to read it. The ability of a driver to detect a guide sign is usually a function of the size of the sign and the contrast between the sign and the surrounding background. At night, the luminance of the sign also impacts the ability of a driver to detect it. This section provides a brief overview of some of the factors that can influence the legibility of a sign.

Drivers must be able to read the sign before they can comprehend its message. The designer has the ability to alter a variety of factors that can influence sign legibility including font, letter height, and type of sign illumination or retroreflectivity.

Letter Height

Some of the earliest research on legibility was performed in the 1930s by Forbes and Holmes.[19] The researchers evaluated the day and night legibility of signs using highway series B and series D letters. Letter heights that were evaluated ranged between 6 and 24 inches. Approximately 400 young adult observers drawn from a college student population were used to view the signs. The observers approached the sign, and researchers made note of the distance at which the observers could read the message on the sign. All signs were ground mounted. Nighttime legibility studies were performed using reflectorized floodlighted letters for the series B signs and both floodlighted and reflectorized letters for the series D signs.

The researchers examined the 80th percentile legibility distances for the signs. The daytime legibility was consistently better than the nighttime legibility for both letter series; the nighttime legibility was between 8 and 20 percent lower than the daytime legibility. They found that a person with a visual acuity of 20/40 had a legibility of 33 ft per inch of letter height for B series letters and 50 ft per inch of letter height for D series letters. Since the subjects tended to be young, their eyesight was fairly acute, with a median value of 20/20.

In 1958, Allen evaluated the daytime and nighttime legibility of highway series E letters (typically used on freeway guide signs in the 1950s) using 48 participants.[20] The researchers tested four different levels of external illumination as well as button copy and retroreflective sheeting. Both ground-mounted and overhead guide signs were evaluated. Subjects approached the sign while traveling in a vehicle at 15 mi/h, and the distance at which the subjects could read the sign was noted. The average age of the subjects was 33. The average visual acuity of the subjects was 20/18, so they tended to have good vision.

Letter heights between 8 and 18 inches were evaluated. This study showed that the average daytime legibility of the message was about 88 ft per inch of letter height. When the sign was externally illuminated, the legibility declined by about 15 percent. There were several possible reasons for the differences between Allen's and Forbes and Holmes' studies. Allen's study used four-letter words that were familiar to drivers. Forbes and Holmes' study used six-letter words with deliberate misspellings in order to ensure that subjects read the entire word. By using familiar words, the legibility distances in Allen's study may have been increased. The visual acuity of the test subjects was also slightly better for Allen's study than for Forbes and Holmes' study.

Font

There is some concern that the E(modified) font used on freeway guide signs is not suitable for use with prismatic materials due to its wider stroke width compared to other fonts. The E(modified) font may be susceptible to irradiation, where the letter stroke is so bright that it may bleed into open spaces in the letter. This blurring can reduce the legibility of the letters. The Clearview font was developed to mitigate some of these concerns by creating wider open spaces with the letters.

A study performed at Texas A&M University compared the daytime legibility of the E(modified), Clearview, and British Transport fonts and found no significant differences between the daytime legibility of these fonts.[21] The author recommended that the type of font used on a guide sign be determined based on nighttime legibility concerns. A recent study by TTI evaluated the difference in nighttime legibility between Clearview and E(modified) when a prismatic sheeting was used.[22] This study found that nighttime legibility distance increased by approximately 70 ft (10 percent) over E(modified) when the Clearview font was used with the prismatic sheeting.

Another study examined the relative effectiveness of the Clearview font across several material types.[23] The study found that the Clearview font did not create significantly better recognition distances than the E(modified) font, although it did perform better than a series D font during the day. At night, the Clearview font did appear to improve recognition and legibility distances over the E(modified) font. When the Clearview font was increased to 112 percent of its normal size, the legibility distances were approximately 50 ft greater than the E(modified) font.

Letter Case

Gordon examined the legibility of cardinal direction words using all capitals and mixed-case lettering.[24] The mixed-case font used initial capital letters that were of the same size as the lowercase letters. The researchers hypothesized that emphasizing the initial letter of the cardinal direction would improve legibility. The results indicated that the cardinal directions could be identified from 10 percent farther away when the mixed-case font was used.

Guide Sign Level of Service

In the early 1980s, Messer and McNees developed a level of service indicator for analyzing freeway guide signs.[25] The purpose of this indicator was to provide an objective means to determine if a guide sign was adequate for a driver with 20/40 vision. Their rating scheme was based on an assessment of three factors: navigation, workload, and response. The assessment of these factors was then used as input into an overall comprehensive level of service for the sign. This section briefly discusses this level of service concept.

Navigation

The first component of the level of service concept was an assessment of the ability of a sign to guide motorists unfamiliar with an area to their destinations. Four factors were used to perform this assessment: sufficiency, consistency, expectancy, and relatability. Each one of these components was subjectively scored as good, fair, or poor, and the resulting rating was converted into a level of service. This portion of the assessment determined whether drivers received enough information to make an informed decision about their paths of travel.

Workload

Messer and McNees also assessed the workload that the sign placed on the driver.[25] They defined the *workload of the sign* as the ratio of the time required to process the information on a sign to the time available for this to occur. Workload ratings were then converted into a level of service for the sign. This level of service assessed whether a driver could read the information in the required amount of time.

Response

Driver ability to react to the information on the sign within the space permitted was also examined as part of the level of service assessment. The total travel distance needed to respond to a sign was calculated and then divided by the physical distance available at the site to perform these actions. This measure indicated whether enough time was provided for a driver to react to the message.

Assessment of Methodology

Messer and McNees developed a tool to objectively assess the workload and response criteria, but the navigation criteria remained relatively subjective.[(25)] Their method permits comparisons between signing alternatives, but it may be too cumbersome to use in practice. The user must perform a variety of calculations to determine the amount of time or space available to see and react to a sign, and the conditions used to determine these values often represent idealized situations. This methodology is a step in the right direction but may have limited value to the practitioner.

Although this tool cannot illustrate what sign sequence should be used for every possible interchange geometry, its guidance and standards provide a starting point for the design and placement of the appropriate sequences for complex interchanges.

Driver Information Overload Modeling

Lerner et al. developed a model and accompanying analysis software that predicted driver workload as a function of sign density, units of information per sign, and some limited roadway geometric data.[(26)] This work is promising, but only simple roadway geometries can be input into the modeling tool. The workload predictions for these simple geometries demonstrate the high impact of sign density on driver workload.

POTENTIAL SOLUTIONS: APPLICATION OF EXISTING MUTCD STANDARDS TO COMPLEX INTERCHANGES

The 2009 MUTCD contains the basic principles that govern the design and use of traffic control devices for all roadways open to the public.[(1)] The fundamentals of the MUTCD state that signing on freeways and expressways should serve the following purposes:

- Give direction to/at destinations, streets, highway routes, intersections, and interchanges.
- Furnish advance notice of the approach to intersections or interchanges.
- Direct road users into appropriate lanes in advance of diverging or merging movements.
- Identify routes and directions on those routes.
- Show distances to destinations.

- Indicate access to general motorist services, such as rest, scenic, and recreational areas.
- Provide other information of value to the road user.

However, complex interchanges occur where multiple roadways intersect and where there are an increased number of exits to surface streets, thereby creating an increased amount of information that must be provided to the driver. At this point, providing all of the necessary information to fulfill a driver's signing needs without overloading the driver's abilities becomes difficult.

Due to the variable nature of interchanges that can be encountered by a designer, the MUTCD provides an option to State and local agencies in developing word messages not provided in the manual in situations where roadway conditions make it necessary to provide drivers with additional guidance information. These new word messages may be used without experimentation and may be beneficial in the development of complex interchange signing.

The manual also provides basic guidance to the practitioner on where to locate signs. This is of particular importance at complex interchanges, as the distribution of information along the path can have a significant impact on driver understanding. Section 2A.17 of the MUTCD states, "Overhead signs should be used on freeways and expressways, at locations where some degree of lane use control is desirable, and at locations where space is not available at the roadside."(pg. 41)[(1)] The section then lists conditions where overhead signs may be beneficial, including complex interchange design, as well as other characteristics that this project has categorized to contribute to an interchange being complex. Later, the manual adds further direction, stating that if overhead signs are warranted, "The number of signs at these locations should be limited to only those essential in communicating pertinent destination information to the road user."(pg. 183)[(1)] However, these simple directions do not necessarily answer the question of how the information for a complex interchange should fit into this format.

Beyond this simple advice to use overhead signs, the manual further addresses sign locations in section 2A.16, stating that "Signs requiring separate decisions by the road user shall be spaced sufficiently far apart for the appropriate decisions to be made."(pg. 37)[(1)] Additionally, the manual suggests the concept of sign spreading when major overhead signs are spaced so that they are not all placed at a single location, possibly overloading the driver. Guidance states that "sign spreading should be used at all single exit interchanges and to the extent possible at multi-exit interchanges."(pg. 183)[(1)] Unfortunately, when addressing complex interchanges, this guidance can be hard to comply with, as the number of decisions points within a small travel space can be very high.

Other portions of the signing design that can be applied to complex interchanges include the following:

- Pull-through signs should be used for cases where geometrics are not clear or additional route guidance is desired.
- Arrow use should be positioned over the approximate center of each lane.
- Exit only panels should be used for lane drops.

Additionally, section 2E.07 of the MUTCD gives the following list of special sign treatments that may be desirable due to specific operating conditions or road geometrics on urban freeways and expressways, and therefore apply to the complex interchanges this project is studying:[1]

- Use of interchange sequence signs.
- Use of sign spreading to maximum extent possible.
- Elimination of general or specific service signing.
- Reduction to a minimum of post-interchange signs.
- Display of advance signs at distances closer to the interchange with appropriate adjustments in the legend.
- Use of overhead signs on roadway structures and independent sign supports.
- Use of overhead arrow-per-lane or diagrammatic guide signs in advance of intersections and interchanges.
- Frequent use of street names as the principal message in the guide signs.

For complex interchanges with multiple major and intermediate interchanges, it can become difficult to place two to three advanced signs without violating manual guidance previously mentioned about the amount of information on a sign as well as the number of signs at a single location.

There are two unique formats that can be applied to guide signs addressing complex interchanges that have optional lanes and multilane exits: arrow-per-lane signs or diagrammatic signs. Each of these signs is addressed within the MUTCD; however, there are no definitive correct applications as to what conditions would make one or the other of these designs appropriate. The following sections discuss the makeup of each of these types of sign formats.

Arrow-per-Lane Guide Signs

An arrow-per-lane guide sign uses upward-pointing arrows above each lane to convey the direction of travel of that lane at the split or exit (see figure 3). Research has shown that these types of signs can be beneficial for splits and multilane exits with an option lane because the option lane can otherwise be difficult to interpret by the driver.

Figure 3. Illustration. Arrow-per-lane guide sign for a multilane exit.[(1)]

Section 2E.21 of the MUTCD states the following:

> Where used, the Overhead Arrow-per-Lane guide sign at the exit or split shall be located at or in the immediate vicinity of the point where the existing lanes begin to diverge from the through lanes or, for a split, at the point where the approach lanes begin to diverge from one another, preserving the relation of the arrows displayed on the sign to their respective lanes. Overhead Arrow-per-Lane guide sign at the exit shall not be located at or near the theoretical gore.(pg. 193)[(1)]

The section goes on to provide the standard sign details, focusing on the look, orientation, and placement of the arrows.

> The arrow for an option exit lane that also carries the through route shall have a single shaft that bifurcates into a vertically upward-pointing arrow and a curving arrow corresponding to the configuration of the through and exit lanes. For splits with an option lane, the arrow for the lane from which either direction of the split can be accessed shall have a single shaft that bifurcates into two upward-pointing curving arrows showing the approximate degrees of curvature of the two roadways beyond the theoretical gore.(pg. 194)[(1)]

Figure 4 shows an example sequence of arrow-per-lane signs for a split with an option lane. Important guidance for the arrow-per-lane signs states "No more than one destination should be displayed for each movement, and no more than two destinations should be displayed per sign."(pg. 198)[(1)]

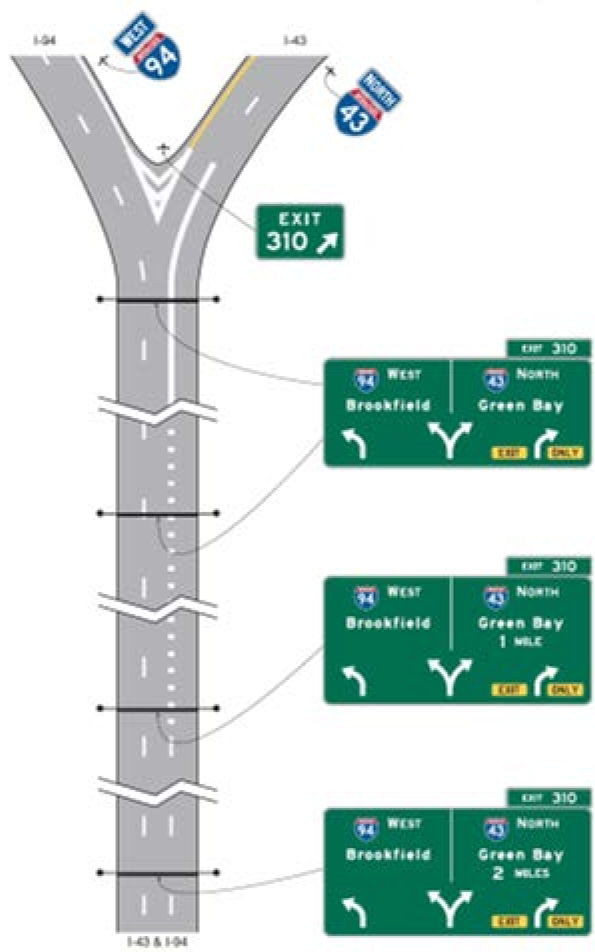

Figure 4. Illustration. Arrow-per-lane sequence for a split.[(1)]

Diagrammatic Guide Signs

Diagrammatic guide signs show a graphic view of the exit/split geometry in relation to the main highway. As with arrow-per-lane signs, they are used when there is an option lane present at a freeway or expressway exit or split. The MUTCD provides the standards and guidance in section 2E.22 for this type of sign.[(1)] An example diagrammatic guide sign is shown in figure 5.

The standards prohibit the use of diagrammatic signs at cloverleaf interchanges except for the following:

> Where the outer (non-loop) exit ramp of the cloverleaf is a multilane exit having an optional exit lane that also carries the through route; and at cloverleaf interchanges that include collector-distributor roadways, such as those that are accessed from the mainline by a multilane exit having an optional exit lane that also carries the through route. In this case, the Diagrammatic guide sign shall only show the configuration of the lanes at the exit point to the collector-distributor roadway and not the entire interchange configuration.(pg. 199)[(1)]

Figure 5. Illustration. Diagrammatic guide sign for a multilane exit.[1]

Collector-Distributor (C-D) Roadways

A C-D roadway is a one-way access road typically located next to freeway lanes that is used as the exit/entrance point for some or all of the ramps that would otherwise be merging with the freeway. Although the initial reaction to this type of geometry is to assume that it will simplify the interchange area by removing the exit/entrance points from the main lanes, this geometry leads to a new set of signing issues when advance and exit signing is needed to move traffic from the mainlines to the C-D road before the actual interchange or exit. Also, multiple exits may need to be signed as a single movement from the main lanes to the C-D. If this type of system is unfamiliar to a driver, it can violate driver expectations and create a need for greater signing information to ensure proper movements. The MUTCD contains limited guidance for signing for simple C-D roads, but solutions that extend these to modern C-D roads that may have access points for downstream exits miles before the actual intersection still need to be developed.

Managed Lanes

Preferential lanes are defined by the MUTCD as "Lanes designated for special traffic uses such as high-occupancy vehicles, light rail, buses, taxis, or bicycles."(pg. 253)[1] Managed lanes are a type of preferential lane that "Typically restricts access with the adjacent general-purpose lanes to designated locations only."(pg. 253)[1] Under varying operational strategies, the occupancy requirements of managed lanes can change, or it may even cost to use the lane based on time of day or congestion levels.

For a managed lane running adjacent to the mainlines of a freeway or expressway, the facility will require similar advanced guide and exit direction signs as the mainlines but will need sign sequences for both its entry and egress points to and from the lane. The MUTCD addresses these types of facilities and provides an example geometry and sign sequence.[1]

The combination of the signage for a managed lane facility and a complex interchange could quickly become overload for a road user, and special consideration would need to be taken to help the driver focus on the signs relevant to his or her travel.

In many ways, managed lanes are analogous to C-D roadways in that they provide limited access points that may serve multiple and distance downstream exit points. The principles developed for managed lane advance exit signing could be applied to C-D situations.

FREEWAY AND INTERCHANGE GEOMETRIC DESIGN HANDBOOK[27]

Concerning signage, the Institute of Transportation Engineers *Freeway and Interchange Geometric Design Handbook* stresses that signs should be placed where their message is integrated with other information that drivers use to make decisions, especially for departure from the freeway.[27] For example, the coordination of the sign, pavement markings, and the actual exit ramp itself, all in the same visual field, paint a picture for the driver for maximum clarity and comprehension.

POTENTIAL SOLUTIONS

International Standards

United Kingdom

Chapter 7 of the *Traffic Signs Manual* details the design of traffic signs in the United Kingdom (UK).[28] 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 lowercase letter "x" for that particular sign. All symbol and legend spacing, border widths, and radii are given in number of stroke widths (sw). The sw is one-quarter of the x-height.

The UK uses four types of directional signing or guide signing: stack type, map type, dedicated-lane type, and gantry-mounted type. Stack type signs are similar to the destination and distance signing used in the United States, while map type signs are diagrammatic signs.

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 6 sw is used for primary routes, 4 sw for numbered non-primary routes, and 2.5 sw for non-numbered local routes. A width of 5 sw 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 12.5 sw. 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 12 sw. When the advance sign is for a grade-separated junction, the width of all route arms is 5 sw, and the minimum length of the exit route arm is 24 sw. 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. These 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., U.S. highway shield) are not used on guide signs in the UK. Route numbers use a combination of a 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 lane sign indicates the exit slip ramp. The directional arrows are 18 sw in length with an 8 sw head. If two or more lanes lead to the same direction, a horizontal bar is used. 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 3 sw. 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. The dedicated lane arrow is vertical for the advance signing and is inclined only at the exit sign.

Gantry-mounted signs in the UK can include more than the 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 United States, 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 16 sw. 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 a third sign or as a panel within the sign. Warning, regulatory, tourist, and destination distance information is not allowed on gantry-mounted signs.

The motorway in the UK is the equivalent of the U.S. interstate. Signing rules for the motorway follow the guidelines outlined in this section. A motorway sign is indicated by its blue background. The signs also include the junction number.

Germany

The *Strassenverkehrs-Ordnung* (i.e., *Road Traffic Regulations*), provides a summary of laws governing Germany's vehicles, traffic signs, and pedestrians published by the Federal Ministry of Transport, Building and Urban Affairs.[29] 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 (equivalent to a U.S. interstate) signing uses a blue background. The signs can be shoulder-mounted or gantry-mounted.

PREVIOUS RESEARCH

Numerous studies have attempted to identify situations where drivers do not understand the lane assignment message being conveyed by a guide sign. This section summarizes some of the key points from these studies.

Guide Signing

National Highway Traffic Safety Administration (NHTSA) Laboratory Study

Two landmark laboratory studies conducted in 1970 served to develop guidance for the MUTCD.[1] NHTSA conducted the first of these laboratory studies.[30] The researchers showed subjects a series of signs with different guide signing concepts. The signs included conventional signs, diagrammatic signs that showed 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 C-D roads were present, a secondary split occurred on a ramp, and a major split occurred 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 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 included the following:[31]

- Heavy ramp volume.
- Inability to see the gore.
- Difficult and dangerous last-minute lane changes.
- Unexpected geometry.
- Interchanges where the wrong decision is difficult to correct.

The interchange types that typically had two or more of these characteristics included the following:[31]

- C-D with lane drop.
- Multilane split ramp.
- Left ramp downstream from right ramp.
- Exit ramps in quick succession.
- Major fork.
- Cloverleaf.

The laboratory study was divided into four parts based on measures of effectiveness: (1) lane choice, (2) subject confidence ratings, (3) guide sign interpretation, and (4) guide sign preference. 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 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-s exposure.

Prior to starting the test, subjects were given a destination and instructed on how to indicate lane choice and confidence level. A total of 102 people participated in this portion of the study. An example of the roadway scene shown to the participants is in figure 6 for the without guide sign information and in figure 7 for the with guide sign information. 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 performed better with C-D interchanges, close-choice point 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. The subjects were asked to pick the sign types that they liked best and least. The conventional signs were the least preferred ($p < 0.05$).

Figure 6. Photo. Roadway scene shown to subjects without guide sign information.[30]

Figure 7. Photo. Roadway scene shown to subjects with guide sign information.[(30)]

Further experiments of this project tested additional design elements to determine how well graphic signs convey information about roadways, such as safe exit speed, distance between exits, and 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 a conventional sign. There were 48 test subjects. The tachistoscopic method was used in the test as well. 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.

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

FHWA Laboratory Study

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.[(31)] A total of 60 test subjects viewed a series of slides with diagrammatic or conventional signs for six interchanges on I-495 in Washington, DC. 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.

Diagrammatic and Conventional Guide Sign Studies

Another study examined the relative effectiveness of using diagrammatic signs rather than conventional guide signs.[(32)] A total of 120 participants viewed a series of slides. They indicated which lane they would travel in to reach a predefined destination, and the correctness and latency of the responses were 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 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 studies were conducted at a time when diagrammatic signs were not familiar to many drivers. It is possible that results would be different if such a study were 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.

Recently, researchers made several recommendations to alter diagrammatic signs to improve the understanding of older drivers.[(33)] The authors recommend using a modified form of diagrammatic signing using a separate lane assignment arrow to indicate 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 a 1990 TTI project where Skowronek examined the use of different guide sign formats at freeway interchanges in Houston, TX.[(34)] He conducted a driver survey and tested conventional signing, diagrammatic signing, and modified diagrammatic signing. The major findings of Skowronek's study are as follows:[(34)]

- 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 to ensure that drivers correctly understand the message.

- 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.

Another study focused on lane choice at exit direction signs.[35] Driver surveys were used and produced the following findings:

- 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.[35]

NCHRP Study

A recent study sponsored by NCHRP addressed two-lane freeway exits with one optional and one exit only lane.[4] The signs that were tested are similar to those shown in figure 8 through figure 10 but used 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. A total of 96 participants drove in a driving simulator and were asked to follow 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 that about one-third of drivers made unnecessary lane changes, demonstrating their poor understanding of optional lane exits.

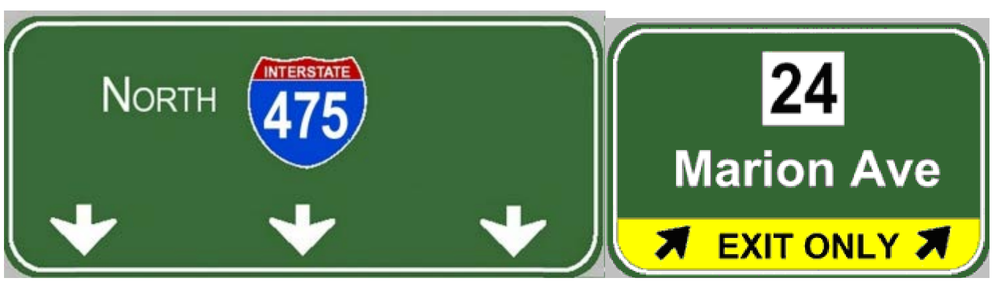

Figure 8. Illustration. Lane designation signs.[4]

Figure 9. Illustration. Advance guide sign located approximately 0.5 mi in advance of exit and centered over the four approach lanes.[4]

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Figure 10. Illustration. Advance guide sign located 1 mi in advance of exit and centered over four approach lanes.[(4)]

TTI Human Factors Study

Another study conducted at TTI evaluated driver comprehension of diagrammatic freeway guide signs and their text alternatives through a multiphase human factors study.[(7)] Signing for four different types of interchanges was tested: (1) left optional exit, (2) left lane drop, (3) freeway-to-freeway split with optional center lane, and (4) two-lane right exits with optional lanes.

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. Drivers did not fully grasp the meaning of the exit only plaque and thus consistently made incorrect decisions about the meaning of signs displaying this plaque.[(4)] The addition of the exit only plaque tended to have the effect of increasing unnecessary lane changes for the exit route but reducing the unnecessary lane changes for the through (or mainline) route. The exit plaque tended to pull drivers planning to exit all the way over to the lane marked with the exit only plaque. From this result, researchers inferred 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 the TTI research, the same trend was apparent, with the majority of drivers incorrectly assuming they must be in the exit only lane.[(7)]

However, the misunderstanding of the plaque did not always result in negative outcomes. In a lane drop scenario, more drivers correctly assumed that the left lane was their only option to exit. Although this assumption may again illustrate the misunderstanding of the plaque, it did increase correct responses when participants were attempting to follow the through route.

Based on these findings, future research should focus on using exit only plaques for optional lane situations, including multilane 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.

In the text versus diagrammatic portion of the study conducted using the driving simulator, the results were consistent with the trend of the sign sequences resulting in the fewest unnecessary lane changes also receiving the shortest lane change distance. Researchers attributed this phenomenon to the fact that text-based signs may 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 drivers to guess the lane configuration based on the large arrows before they can read the destination names. This can lead to more unnecessary lane changes due to chance; however, when these guesses are accurate, the early changes result in longer lane change distances.

The modified diagrammatic signs that were tested were originally based on those that contained only route shields because these signs are relatively straightforward and uncluttered. This sign design performed very well in the early phases of the project. However, in later phases, additional elements were added to the modified diagrammatic signs to equate the amount of information present on the other sign types. This information included route shields, cardinal directions, and destination city names. When the additional elements were added, the signs became crowded and visually complex, resulting in relatively poor performance in the final phases of the research. Additionally, if this sign format is applied to larger freeway interchanges with more lanes represented, the visual complexity will increase. More research is needed to refine the design of these signs and test their application at complex interchanges.

Field Evaluations

Roberts and Klipple Diagrammatic Study for FHWA

Several studies tested diagrammatic signs in the field. Roberts and Klipple examined the use of diagrammatic freeway guide signs in New Jersey by implementing diagrammatic signs at an interchange.[(36)] The researchers collected data on erratic maneuvers and traffic volumes at the interchange when conventional signing, diagrammatic signing, and diagrammatic signing with lane lines were used. In general, the diagrammatic signs performed better than the conventional signs. 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 FHWA. The location selected for evaluation was the interchange of I-287 and US-22 in Somerville, NJ. The study had the following three parts:

1. Modification of existing signs to conform with the interstate sign manual (and at the same time be conducive to diagrammatic sign use).

2. Replacement of conventional signs with diagrammatic signs.

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 northbound (NB) to US-22 westbound (WB) exit was chosen as a study site. The eastbound (EB) exit to US-22 had a low traffic volume 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 videotaped as it approached the exit gore 400 ft upstream from the gore. All lanes were recorded, and data were collected between 2 and 7 p.m.

The researchers found no significant differences (95 percent 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 the fact 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 6-month span between data collection periods. After the addition of lane lines to the diagrammatic signs, researchers noted a significant decrease in the number of unusual lane changes.

Virginia Highway Research Council Diagrammatic Study

The Virginia Highway Research Council conducted a diagrammatic sign field study in 1970 that examined traffic volumes and the number of erratic maneuvers at the site in Washington, DC.[37] The number of erratic maneuvers increased after the diagrammatic signs were installed, but the researchers noted that data for diagrammatic signs were collected during late spring and early summer. During these months, the proportion of drivers not familiar with the area increases on the highways around Washington, DC. 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 included the following:

- Occurrence of an erratic maneuver and type of maneuver.
- Location.
- Time of day.
- Traffic volume.
- Type of signing.

Researchers chose 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 mi/h during the morning and afternoon peak times and 65 mi/h 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 included the following:

- Weaves.
- Weaves over gore areas.
- Hesitations (slowing to 15 mi/h or less).
- Stopping or backing.
- Partial weaves.

Traffic volumes and erratic maneuvers were recorded at random times during the day for 30-min intervals. The before data were collected during fall 1970 and early spring 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 14 by 19.5 ft.

The before period covered 19 days, and 56,326 vehicles were observed over 47 30-minute intervals. The after period observed 91,423 vehicles over 73 30-minute intervals. The research compared the before and after traffic volumes and found no evidence that tourist traffic had a significant effect on traffic volume, suggesting a similar mix of familiar and unfamiliar drivers during the study periods. 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, which indicates that drivers were making lane decisions earlier. The researchers also noted that while the use of the diagrammatic signs reduced gore area weaving, it increased the number of hesitations and partial weaves. The number of stopping and backing maneuvers also decreased.

Mast and Kolsrud Diagrammatic Study

A 1972 report by Mast and Kolsrud examined the use of diagrammatic signs on controlled access highways.(38) 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 discovered the following three general findings:

- More time is required to read, understand, and react to diagrammatic signs 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.[38] 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 all single left exit interchanges. The researchers also recommended four cases where diagrammatic guide signs should not be used, as 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 C-Ds.
- Interchanges with C-Ds with a single right exit from the main roadway.
- 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, Mast and Kolsrud developed design standards for diagrammatic signs as part of this study.[38] 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 the following 19 general design standards:

- The graphic component should portray only what is necessary for drivers to understand the required exit maneuver relative to the main roadway.
- The quantity of information on the diagrammatic sign must be limited.
- Graphics should adhere to the plan or aerial view but may be modified where necessary to ensure that the components of the graphic are clearly discernible.
- 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 arrowhead.

- 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.
- The addition of graphics cannot be accompanied by decreased letter sizes.
- The exit panel should be located above the destination information and should 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 lane is present) but should be placed at all locations in advance of these points.

Eye Tracker Research

Another study used a laboratory eye tracker to examine eye scanning of day and nighttime roadway scenes.[39] Participants were seated in front of a computer monitor with their heads 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.[40] This method, coupled with vehicle instrumentation, allowed for fine-grained analyses of driver attention and decisionmaking while making lane change choices.

Signing at Interchange Lane Drops

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.[41] 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 the following 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 improve 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. evaluated alternative treatments for right-side multilane exits.[8] 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 examined by surveying 548 participants and evaluating their lane choices and comprehension of the messages. This survey produced the following results:

- Only 50 to 65 percent of Texas drivers understood the current method for signing optional lanes on multilane exits.

- Adding the supplemental "May Exit" message 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.

SUMMARY AND FUTURE PROJECT DIRECTION

The review of research literature and applicable signing standards helped the research team identify signing problems and potential solutions. The main problems identified in the literature review are as follows:

- Recommended advanced guide sign distances cannot be met while maintaining minimum longitudinal sign separation for closely spaced ramps.
- Unexpected ramp geometry when coupled with closely spaced exits is not well addressed in existing standards but clearly poses a challenge for drivers.
- The number of signs on a single structure may well exceed recommended maximums if all individual sign recommendations are followed.
- Signing for multiple destinations served by C-D exits is not well addressed and has a high likelihood of violating driver expectations.

CHAPTER 3. DRIVER SIMULATOR EVALUATION OF SIGN TREATMENTS

This chapter discusses the procedure used to develop, test, reduce, and analyze the sequence test topics evaluated in the simulator study. A list of potential sign sequences needing evaluations was created. This list was then refined to determine which were appropriate for a simulator study. For example, if it was important to determine how quickly a driver would make a lane choice or if it was important to see signs in a sequence and for the driver to see their spatial placement on the roadway, a simulator study was more appropriate., Table 1 provides an overview of the six topics selected for the simulator study and lists the number of SSs tested and the number of determined testing variations (SL and instructed destination).

PROCEDURE

TTI houses a Realtime Technologies, Inc. desktop simulator that can be operated with one or three screens depending on study requirements. During the study, test signs were introduced to the simulation along freeway roadways to evaluate drivers' real-time response to the signs. Drivers were verbally provided with a starting lane and a destination they were to drive toward. The starting lane and destination (exit, through, or a destination not mentioned on the signs) were varied between participants for each SS tested. The simulation environments were designed so that the driver had ample time to reach an instructed 60–70 mi/h speed before viewing the first SS in each sequence.

For each method, the recorded measures included lane choice with proximity to each set of signs, any unnecessary lane changes or indecisiveness, speed, and braking. Verbal follow-up questions (e.g., what other lanes could you have been in to reach your destination?) or questions about information on the set of signs pertaining to an alternate destination than assigned were also asked following each drive segment.

EXPERIMENTAL DESIGN

Figure 11 through figure 16 provide the geometry roadway and SB location for each of the six topics. Due to the high number of test scenarios, a between-participants experimental plan was designed that divided the participants and the test scenarios into 6 groups with each participant seeing 15 scenarios. For a few scenarios, a group would see a test variation from the same topic/SS combination. Once reordered, these particular scenarios were separated by many others so that researchers believed a new SS with new destinations would not be required for the second time the same topic was shown.

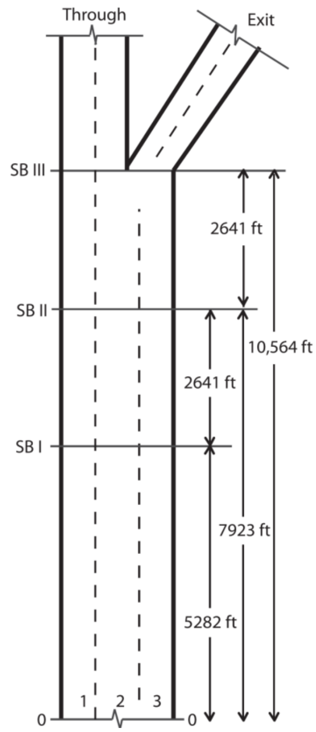


Figure 11. Illustration. Geometry for topic 1.

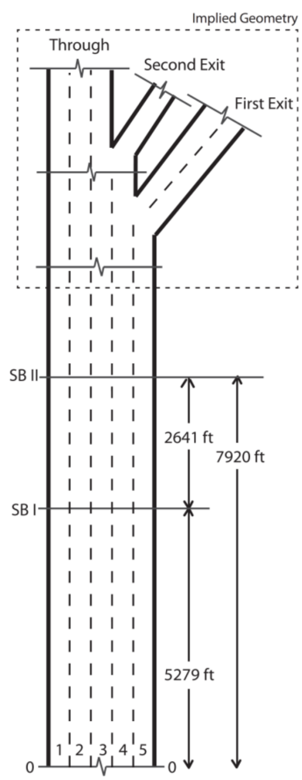


Figure 12. Illustration. Geometry for topic 2.

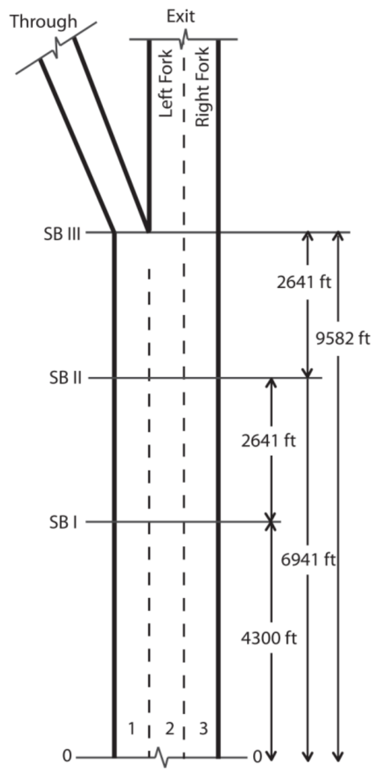


Figure 13. Illustration. Geometry for topic 3.

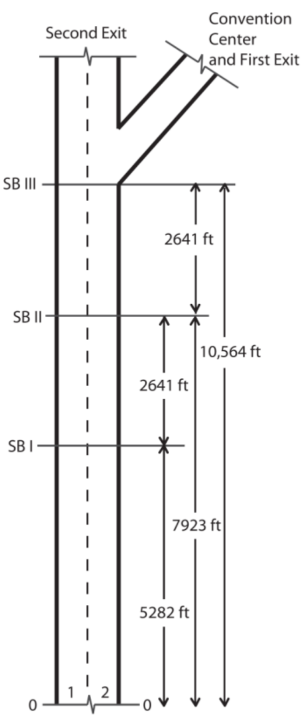


Figure 14. Illustration. Geometry for topic 4.

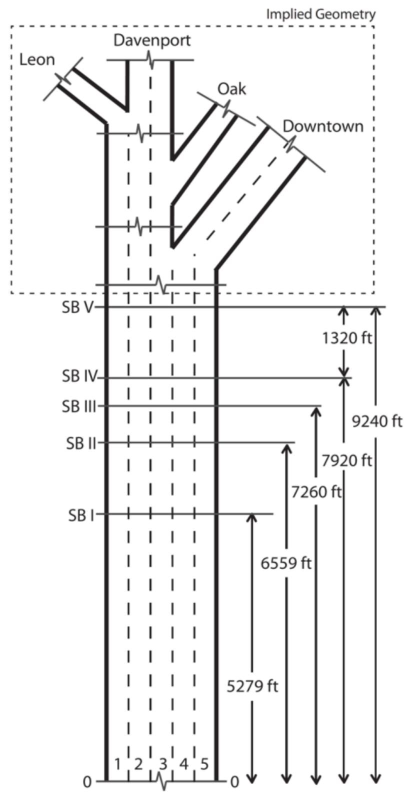


Figure 15. Illustration. Geometry for topic 5.

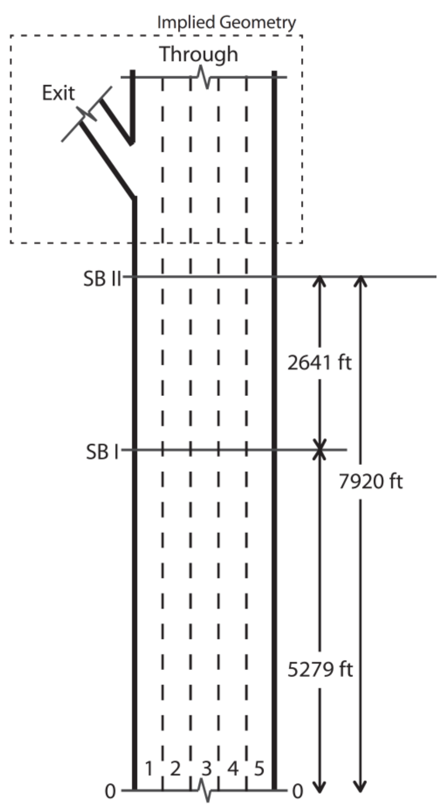


Figure 16. Illustration. Geometry for topic 6.

PARTICIPANT RECRUITMENT

A total of 42 participants were recruited—18 in College Station, TX, and 24 in Houston, TX. Researchers used Texas demographics as a guide for participant recruitment to obtain a more accurate sample of the driving population in the test cities. Gender and age of licensed drivers were obtained from 2009 FHWA statistics.(42) The education breakdown of Texans ages 18 and older was obtained from the U.S. Census Bureau.(43) These breakdowns were used as guides, with education taking priority followed by age and then gender. The number of participants by education was as follows:

- Some high school: Three participants (7 percent).
- High school graduate: 10 participants (24 percent).
- Some college/vocational: 15 participants (36 percent).
- College graduate: 10 participants (24 percent).
- Some graduate school: Zero participants (0 percent).
- Graduate degree: Four participants (10 percent).

The number of participants by age group was as follows:

- < 24 years old: Three participants (7 percent).
- 24–33 years old: 12 participants (29 percent).
- 34–43 years old: Nine participants (21 percent).
- 44–53 years old: Five participants (12 percent).
- 54–63 years old: 10 participants (24 percent).
- 64–73 years old: Three participants (7 percent).

DATA REDUCTION

The assembled data subsets of participant files, follow-up questions, and demographic information were used to build databases for analysis. The participant file containing the lane position and distant travel data was exported, and participant number and topic information were added to develop a database for further analysis.

Participant position within a lane was one of the variables collected in the simulation study. A lane was assumed to be 11.8 ft wide, and the lane position was measured from the center of the lane, with negative values when the car moved left of the centerline and positive values when it moved right. Lane change maneuvers and their direction in the participant data subsets were identified by reviewing the change in lane change position values. A change in lane position (greater than 1.7 in absolute value) from negative to positive indicated a lane change to the left, whereas a change from positive to negative indicated a lane change to the right. A lane change was recorded when the center of the vehicle crossed the lane line.

To determine the impacts of each SS for various combinations of SL and destination, each lane change maneuver was labeled. Apart from the correct, incorrect, and unnecessary lane change labels, different labels were used to account for the differences among the topics. Figure 17 shows an example of the lane change coding used. Table 8 explains all labels used in building the dataset. These lane changes were checked with the sketch on participant data sheet for accuracy and notes/comments.

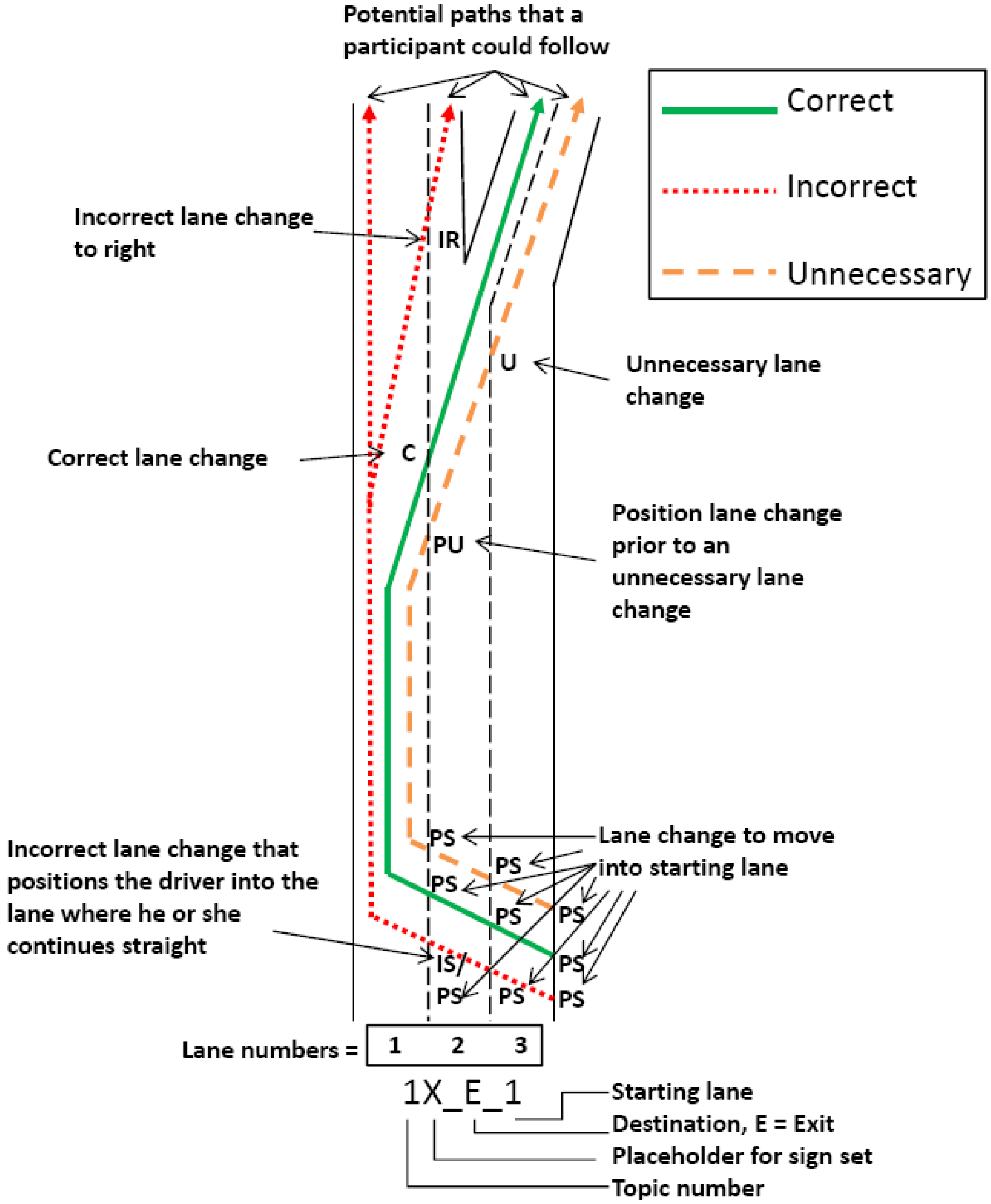


Figure 17. Illustration. Example of labels used to code lane changes.

Table 8. Labels used to code lane changes shown in plots.

Label ID	Description
N	Number of participants driving a particular testing variation.
C	Correct lane change.
H	Lane change to be in the lane instructed as the starting lane. This is also the correct lane for the requested through or exit maneuver (in other words, the participant did not need to make an additional lane change to satisfy instructions).
U	Unnecessary lane change.
✓	Sum of C, H, and U.
IL	Incorrect lane change to the left.
IR	Incorrect lane change to the right.
IS	Incorrect lane change to go through.
✗	Sum of IL, IR, and IS.
G	Pregore undetermined. For some scenarios, the simulation was stopped before the driver reached the interchange; therefore, it could not always be determined at that point whether the participant had made a correct or incorrect lane choice.
S	Swerve (swerve from left lane to right and back to left is counted as two).
IC	Lane change to correct an incorrect lane change (other than swerve, typically at a later time).
UC	Lane change to correct an unnecessary lane change (other than swerve, typically at a later time).
W	Representing indecision (i.e., S, IC, or UC).
PS	Lane change to move into the SL.
PE	Lane change to move into the end lane/pulling over to end simulation.
PC	Lane change leading to the correct lane change.
PI	Lane change leading to the incorrect lane change.
PU	Lane change leading to the unnecessary lane change.
L	Last recording for the participant (to estimate/double check PE).
SB I	Sign bridge 1 location.
SB II	Sign bridge 2 location.
SB III	Sign bridge 3 location.
SB IV	Sign bridge 4 location.
SB V	Sign bridge 5 location.

DATA ANALYSIS AND FINDINGS

Topic 1

Overview

Topic 1 involved testing driver understanding and use of the option lane. The topic evaluated driver understanding of arrow per lane, down arrow per lane, or signing only the exit and not the through movement. As shown in figure 18 through figure 20, SS 1-A has arrow-per-lane signs, SS 1-B has down arrow-per-lane through signs, and SS 1-C has no pull through signs. The geometry for the topic was three lanes at the start that then split, with two lanes exiting to the right and two lanes going straight (see figure 11).

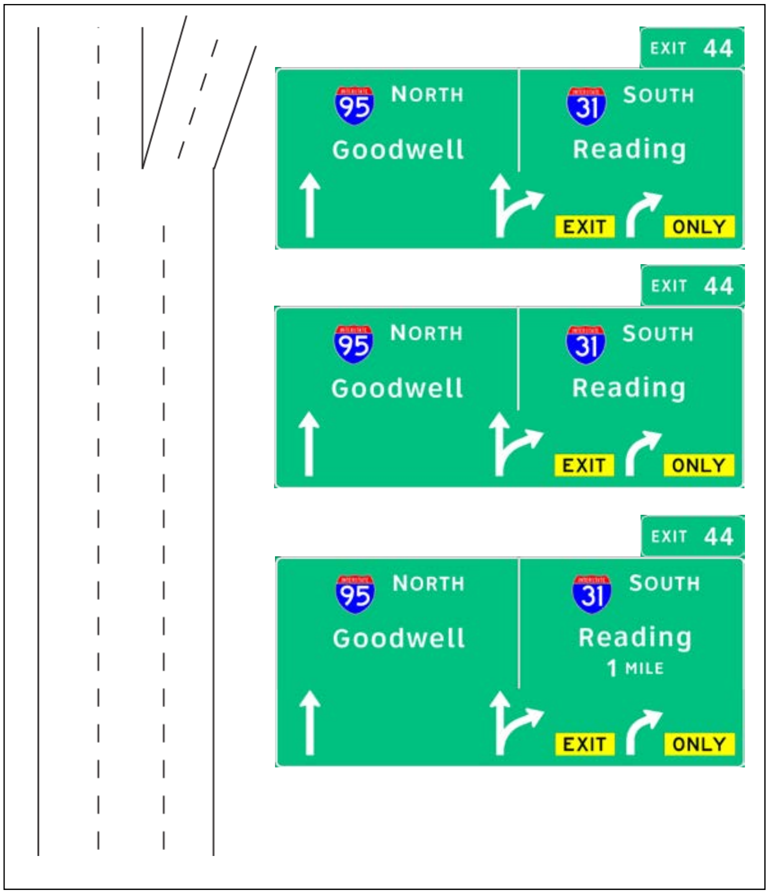


Figure 18. Illustration. SS 1-A: arrow-per-lane sign.[1]

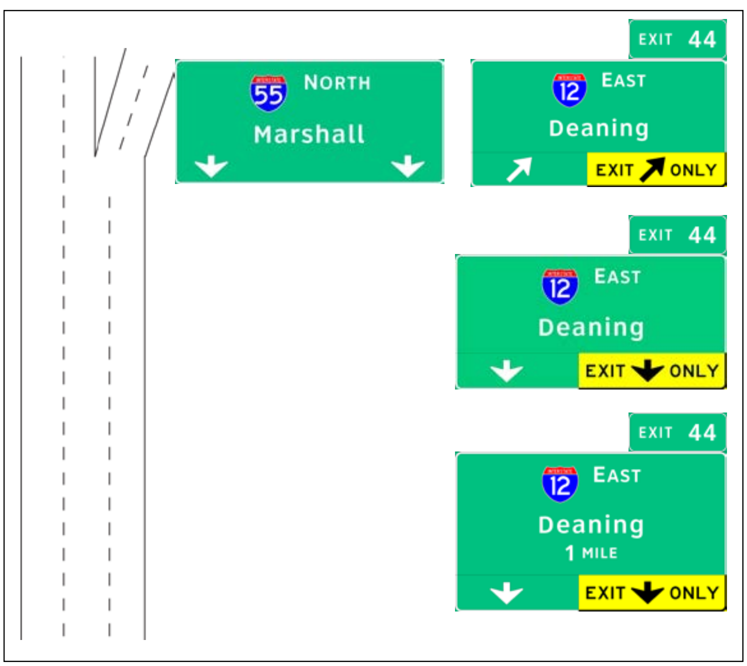


Figure 19. Illustration. SS 1-B: down arrow-per-lane through sign.[1]

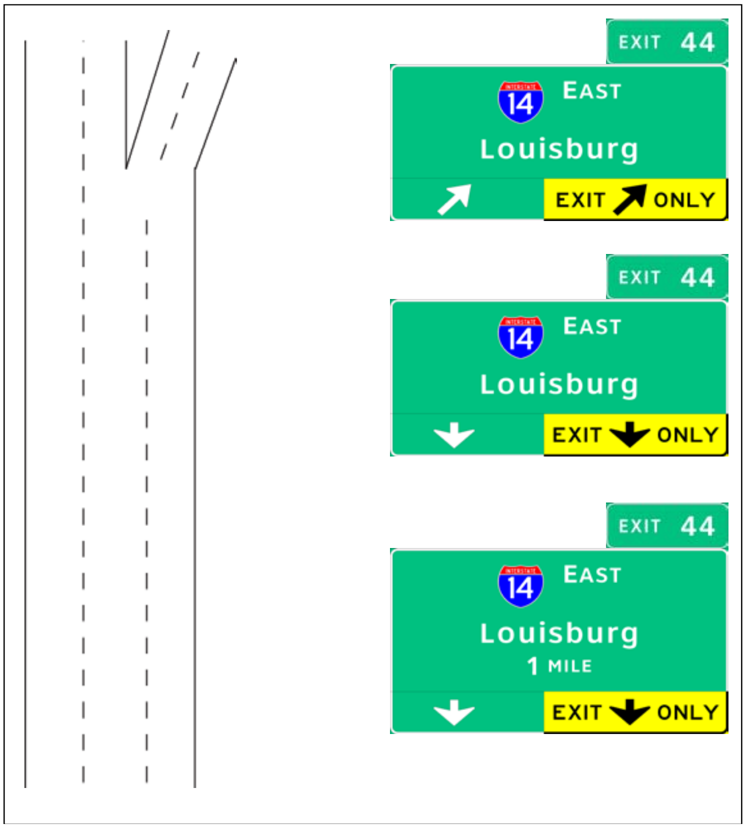


Figure 20. Illustration. SS 1-C: no pull through sign.[(1)]

Observations

Table 9 shows a summary of the number of participants with correct, incorrect, and unnecessary lane changes by test variation for topic 1. Note that each participant was assigned one of these codes: C, H, U, IL, IR, and IS. If the participant had more than one type of lane change (e.g., both an incorrect lane change to the right (IR) and an unnecessary lane change (U)), the code was assigned in the following priority order: IL, IR, IS, U, C, and H. Observations for topic 1 are as follows:

- When starting in lane 1 and being told to exit (variation 1X_E_1, see figure 17 for explanation of codes), all drivers correctly exited. Most drivers did make an unnecessary lane change. Within the follow-up questions, almost all drivers said they had enough time to make a decision and were confident of their choice (93 to 100 percent).

- When starting in lane 2 and being told to exit (variation 1X_E_2), all drivers correctly exited; however, most drivers made an unnecessary lane change to use the right-most lane (57 to 93 percent of the participants). Only a few drivers did not make any lane change (which is preferred). SS 1-B had the most unnecessary lane changes (93 percent), and SS 1-C had the fewest unnecessary lane changes (8 compared to 11 or 13 participants).

- When starting in lane 2 and being told to go through (variation 1X_T_2), most drivers stayed on the through lanes. Only one driver with SS 1-B made an incorrect lane change to exit. Most drivers did not make any lane changes (which is preferred), and a few drivers made an unnecessary lane change to use the left-most lane.

- When starting in lane 3 and being told to go through (variation 1X_T_3), most drivers made the needed lane changes to stay on the through lanes. Most drivers who made unnecessary lane changes saw SS 1-A. Two drivers with SS 1-C did not make a lane change (which was incorrect) and exited. Note that the name of the through destination for SS 1-C (Jackson) was not present on any of the signs. These drivers made the incorrect decision very early and never corrected. SS 1-A had the highest proportion (71 percent) of drivers who made an unnecessary lane change to use the left-most lane to stay on the freeway.

- Overall, participants who viewed SS 1-C were slightly less confident in their lane choice than those who viewed the other two SSs. Participants viewing SS 1-B had the highest confidence.

- Participants were slightly more likely to recall more of the information on the signs (the names of the through and exit destinations) when viewing SS 1-A, which included all information on a single sign which was repeated three times. Overall, participants frequently could not recall the destination for the through lanes when told to exit or the destination for the exit when told to stay on the freeway (percent correct was between 36 and 86 percent). Since they did not expect to need that information, the participants did not attempt to retain it.

Table 9. Topic 1: number of participants with lane change type by test variation.

SS	D	SL	N	C	H	U	✓	IL	IR	IS	✗	%✓	%✗	%U	Scenario
A	E	1	14	5	0	9	14	0	0	0	0	100	0	64	1A_E_1
B			14	5	0	9	14	0	0	0	0	100	0	64	1B_E_1
C			14	6	0	8	14	0	0	0	0	100	0	57	1C_E_1
A		2	14	0	3	11	14	0	0	0	0	100	0	79	1A_E_2
B			14	0	1	13	14	0	0	0	0	100	0	93	1B_E_2
C			14	0	6	8	14	0	0	0	0	100	0	57	1C_E_2
A	T	2	21	0	15	6	21	0	0	0	0	100	0	29	1A_T_2[1]
B			14	0	10	3	13	0	1	0	1	93	7	21	1B_T_2
C			14	0	11	3	14	0	0	0	0	100	0	21	1C_T_2
A		3	7	2	0	5	7	0	0	0	0	100	0	71	1A_T_3[1]
B			14	12	0	2	14	0	0	0	0	100	0	14	1B_T_3
C			14	11	0	1	12	0	0	2	2	86	14	7	1C_T_3

D = Destination (E = Exit and T = Through).
N = Number of participants driving a particular testing variation.
✓ = Sum of number of participants with correct lane changes.
✗ = Sum of number of participants with incorrect lane changes.
% ✓ = Percent of participants with correct lane changes.
% ✗ = Percent of participants with incorrect lane changes.
% U = Percent of participants with unnecessary lane changes.
[1] 1A_T_3 and 1A_T_2 were each to be tested twice; however, due to a researcher error, 1A_T_2 was tested three times and 1A_T_3 was only tested once.

Key Findings

Almost all participants made the correct decision to exit or stay on the freeway; however, many unnecessary lane changes were made with each of the three SSs for those people whose SL was either the far left or the far right. Those drivers who started in the center lane and were given a through route destination were less likely to make unnecessary lane changes compared to all other conditions. The interesting finding is that drivers who started in the center lanes and were told to exit moved to the far right lane, which included an unnecessary lane change. However, drivers who started in the center lane and were given the through destination did not move to the far left lane. This may have been due to some reluctance on their part to move into the left lane, which is typically used for high-speed passing.

Topic 2

Overview

Topic 2 studied signing methods when two interstate exits are within close proximity and there is a need to create signs for three destinations (two interchanges/exits and the through lanes). Figure 21 through figure 23 shows the SSs studied; only 1.5- and 1-mi advance signs were used. It was assumed that the far right lane would be an exit only lane with the second to the right lane being an optional exit for the first interstate exit and then becoming an exit only lane for the second exit. As shown in figure 21, due to the complexity, SS 2-A does not indicate the second exit as an exit only in any manner in the advance signs. SS 2-A has multiple signs with exit only panels, SS 2-B has arrow-per-lane signs, and SS 2-C has diagrammatic signs. Figure 12 presents a graphic of the geometrics for the portion of the road the participants drove along. The simulation ended prior to the participants reaching any of the exits.

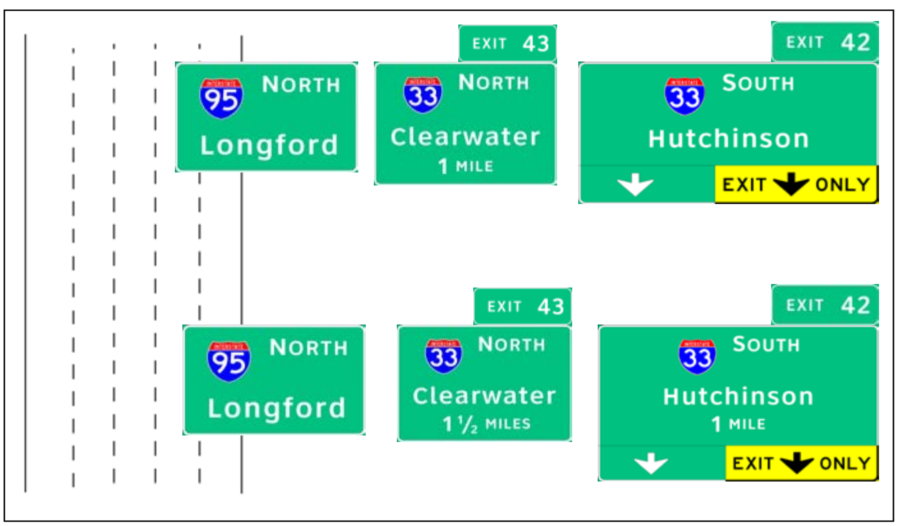


Figure 21. Illustration. SS 2-A: multiple signs with exit only panels.

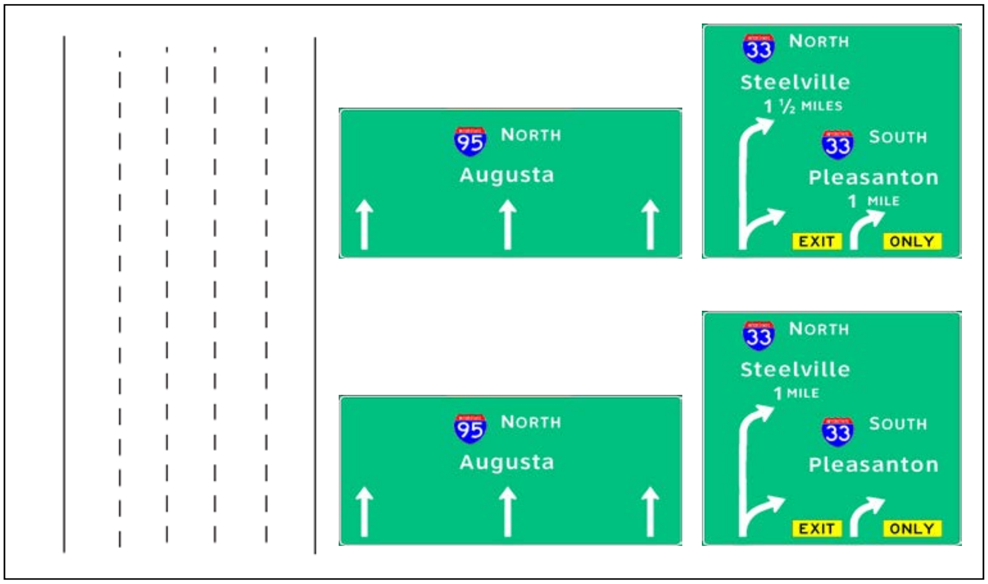


Figure 22. Illustration. SS 2-B: arrow-per-lane sign.

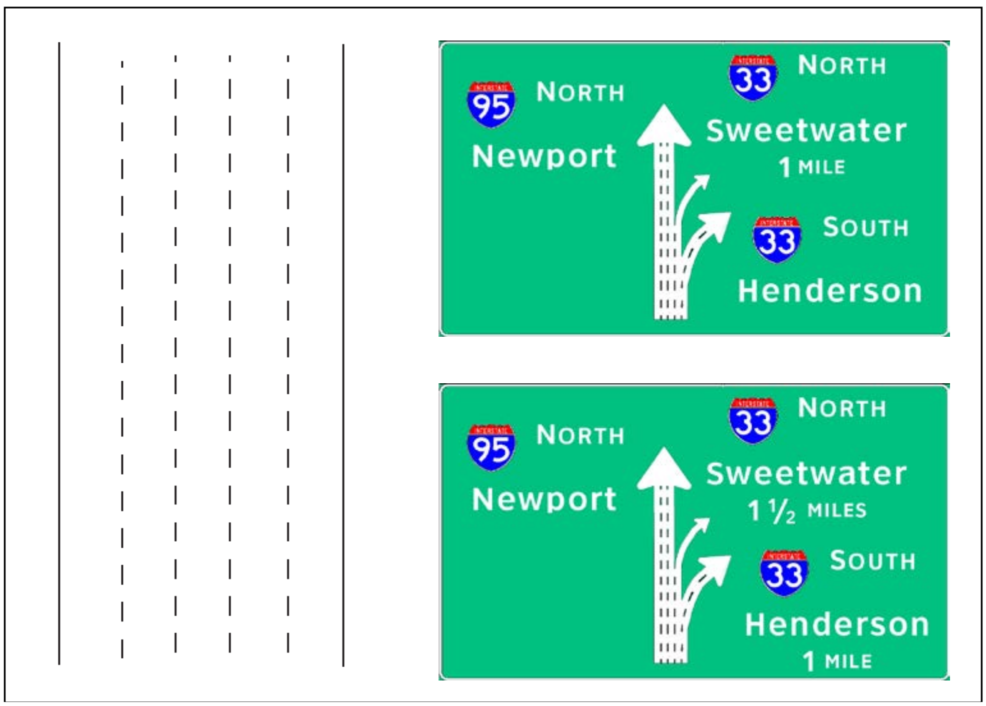


Figure 23. Illustration. SS 2-C: diagrammatic sign.

Observations

Table 10 shows a summary of the number of participants who made correct, incorrect, unnecessary, or pregore undetermined lane changes by test variation for topic 2. Questions asked following the driving portion of this topic included the following:

- How confident are you that you picked the correct lane (1–10)? (See table 10 for the weighted averages.)

- What about the signs influenced your decision to change lanes or not change lanes?
- Why did you change lanes (if they moved out of lane 3)?

Note that each participant was assigned one of these codes: C, H, U, IL, IR, IS, and G. If the participant had more than one type of lane change (e.g., both an incorrect lane change to the right (IR) and an unnecessary lane change (U)), the code was assigned in the following priority order: IL, IR, IS, U, C, H, and G.

Table 10. Topic 2: number of participants with lane change type by test variation.

SS	D	SL	N	C	H	U	✓	IL	IS	✗	G	%✓	%✗	%G	W	Scenario
A	T	3	7	0	4	3	7	0	0	0	0	100	0	0	9.6	2A_T_3
B			7	0	5	2	7	0	0	0	0	100	0	0	10.0	2B_T_3
C			7	0	4	3	7	0	0	0	0	100	0	0	9.6	2C_T_3
A	T	4	7	0	0	6	6	0	0	0	1	86	0	14	9.7	2A_T_4
B			7	7	0	0	7	0	0	0	0	100	0	0	10.0	2B_T_4
C			7	3	0	4	7	0	0	0	0	100	0	0	7.1	2C_T_4
A	1	2	7	4	0	3	7	0	0	0	0	100	0	0	9.7	2A_1st_2
B			7	2	0	5	7	0	0	0	0	100	0	0	9.6	2B_1st_2
C			7	4	0	3	7	0	0	0	0	100	0	0	8.0	2C_1st_2
A	2	2	7	1	0	0	1	0	0	0	6	14	0	86	7.3	2A_2nd_2
B			7	7	0	0	7	0	0	0	0	100	0	0	10.0	2B_2nd_2
C			7	5	0	0	5	0	0	0	2	71	0	29	6.6	2C_2nd_2
A	2	4	7	0	4	0	4	3	0	3	0	57	43	0	9.3	2A_2nd_4
B			7	0	7	0	7	0	0	0	0	100	0	0	8.9	2B_2nd_4
C			7	0	6	0	6	1	0	1	0	86	14	0	8.0	2C_2nd_4
A	2	5	7	4	0	0	4	3	0	3	0	57	43	0	10.0	2A_2nd_5
B			7	7	0	0	7	0	0	0	0	100	0	0	9.7	2B_2nd_5
C			7	5	0	0	5	1	1	2	0	71	29	0	7.0	2C_2nd_5

D = Destination (T = Through, 1 = First exit, and 2 = Second exit).
N = Number of participants driving a particular testing variation.
✓ = Sum of number of participants with correct lane changes.
✗ = Sum of number of participants with incorrect lane changes.
%✓ = Percent of participants with correct lane changes.
%✗ = Percent of participants with incorrect lane changes.
%G = Percent of participants with pregore undetermined lane changes.
W = Weighted average for responses to following question: "How confident are you that you picked the correct lane on a scale of 1 to 10 with 10 being the most confident?"

The observations for this topic are as follows:

- Some of the participants may not have made necessary lane changes because the simulation did not include the exits.
- When the participants were told the destination was Longford, Augusta, or Newport (i.e., they were to stay on the freeway, variations 2X_T_3 or 2X_T_4), they made correct

lane changes in all but one case. Several unnecessary lane changes were made by participants who started in the lane in which they should stay (lane 3, 2X_T_3). When the participants started in lane 4, they needed to make at least one lane change to the left. In all cases but one, the participants made that lane change. In that one case, it is unknown if the participant would have made the lane change because the simulation did not include the actual exit. Therefore, no difference in lane-change behavior was seen for the different SSs for this scenario.

- When participants were told to go to Hutchinson, Pleasanton, or Henderson (i.e., the first destination, variation 2X_1st_2), all of them were in the correct position to make the first exit. To make the first exit, participants needed to move from lane 2 to either lanes 4 or 5. If they changed the minimum number of lanes (i.e., to lane 4), then they were coded as "C." If participants made the extra unnecessary lane change to lane 5 (i.e., right-most lane), they were coded as being correct but with an unnecessary lane change (U). Many of the participants did make the additional unnecessary lane change to move into the far right lane of the freeway. A few more participants (five compared to three) made the unnecessary lane change for SS 2-B.

- When participants were told to go to Clearwater, Steelville, or Sweetwater (i.e., the second destination, variations 2X_2nd _2, 2X_2nd_4, or 2X_2nd_5), all participants were in the correct lane at the end of the simulation for SS 2-B (arrow-per-lane signs) regardless of the participants' starting lane. Participants seeing SS 2-C (diagrammatic signs) had more correct lane positions than those who saw the multiple signs with exit only panels (SS 2-A) but not as well as for the arrow-per-lane signs (SS 2-B). For those starting in lane 2 and seeing SS 2-A, six of the seven participants (86 percent) had not changed into the correct lane by the end of the simulation.

- The average confidence ratings for SSs A, B, and C were 9.3, 9.7, and 7.7, respectively. Drivers were most confident with their lane choice for the signs that provided an arrow per lane (SS 2-B). Drivers were least confident with the diagrammatic sign (SS 2-C).

Key Findings

For SS 2-B, which had an arrow-per-lane design, all participants (42) made correct lane change decisions. SS 2-C, which had a diagrammatic sign, also had many correct lane change decisions, with five or more of the seven participants in a group making the correct decision. Of the 42 participants who viewed SS 2-C, only 3 made incorrect lane change decisions. SS 2-A did not have as favorable results. For example, 6 of the 42 participants made incorrect lane change decisions. SS 2-A also had more of the participants needing additional information to make a lane change decision.

Topic 3

Overview

Topic 3 evaluated signs for an upcoming Y-split. Researchers looked at how quickly drivers made a lane choice and whether one SS better separated drivers into their proper lane for the upcoming Y-split. Signing options included a split sign to explore whether it helps to maneuver drivers into the appropriate lane for the Y-split in advance of the initial exit. The SSs are shown in figure 24 through figure 26. SS 3-A had shared exit signs, SS 3-B had split exit signs both in advance and at the gore, and SS 3-C had shared exit advance signs with a split exit sign at the gore. At the Y-split for SSs 3-A and 3-C, the city exit on top of the sign branched to the left, and the one on the bottom branched to the right.

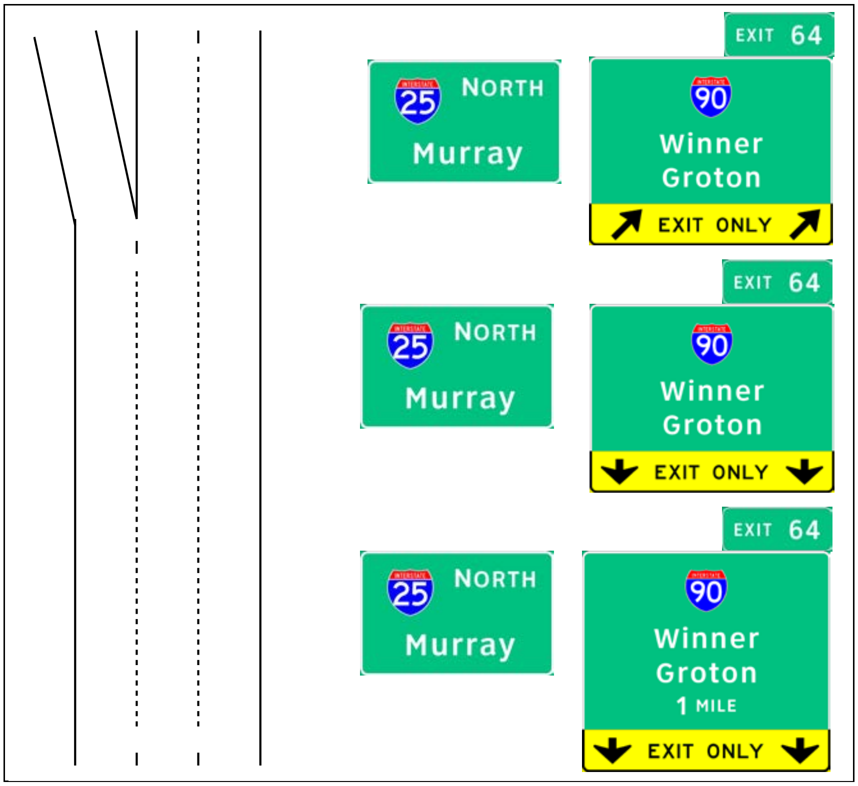


Figure 24. Illustration. SS 3-A: shared exit signs.

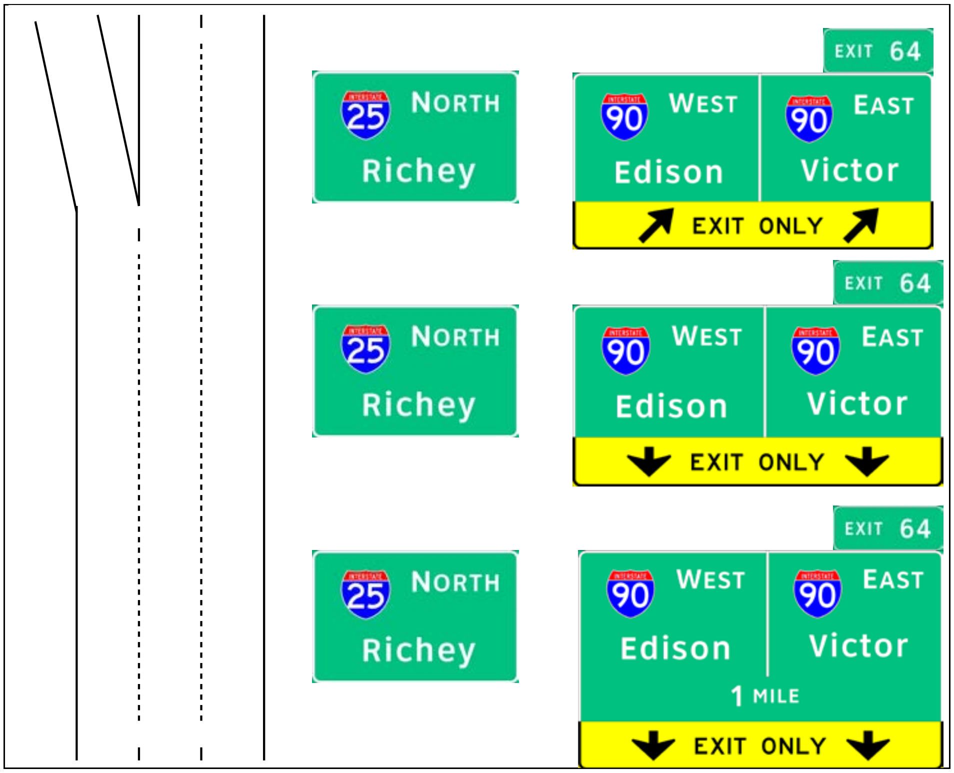


Figure 25. Illustration. SS 3-B: split exit signs.

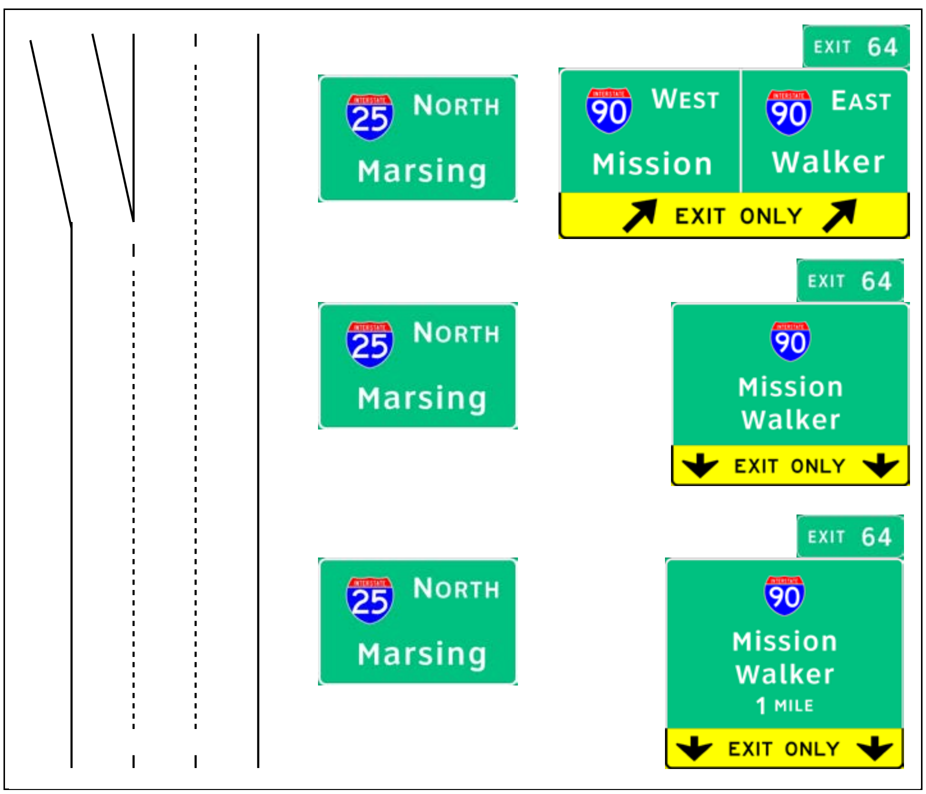


Figure 26. Illustration. SS 3-C: shared exit advance signs with split exit gore sign.

The geometry presented to the drivers was three lanes at the beginning with two lanes exiting to the right. The geometry in the simulator showed the exit lanes traveling straight and the through lane curving to the left, as shown in figure 13.

Observations

Table 11 shows a summary of the number of participants with correct, incorrect, unnecessary, and swerve lane changes by test variation for topic 3. Observations for this topic are as follows:

Table 11. Topic 3: number of participants with lane change type by test variation.

SS	D	SL	N	C	H	✓	IL	IR	IS	✗	%✓	%✗	S	IC	?	Scenario
A			7	0	3	3	0	4	0	4	43	57	2	1	3	3A_Left_2
B	L	2	7	0	5	5	1	1	0	2	71	29	0	1	1	3B_Left_2
C			7	0	6	6	0	1	0	1	86	14	0	0	0	3C_Left_2
A			7	0	0	0	0	0	7	7	0	100	0	0	0	3A_Left_3
B	L	3	7	6	0	6	0	0	1	1	86	14	0	0	0	3B_Left_3
C			7	4	0	4	0	0	3	3	57	43	0	0	0	3C_Left_3
A			7	1	0	1	0	0	6	6	14	86	0	0	0	3A_Right_2
B	R	2	7	7	0	7	0	0	0	0	100	0	0	0	0	3B_Right_2
C			7	6	0	6	0	0	1	1	86	14	0	0	0	3C_Right_2
A			7	0	7	7	0	0	0	0	100	0	0	0	0	3A_Right_3
B	R	3	7	0	7	7	0	0	0	0	100	0	0	0	0	3B_Right_3
C			7	0	7	7	0	0	0	0	100	0	0	0	0	3C_Right_3

D = Destination (L = Exit ramp lane was on the left for the assigned destination and R = Exit ramp lane was on the right for the assigned destination).
N = Number of participants driving a particular testing variation.
✓ = Sum of number of participants with correct lane changes.
✗ = Sum of number of participants with incorrect lane changes.
%✓ = Percent of participants with correct lane changes.
%✗ = Percent of participants with incorrect lane changes.
? = Number of participants making indecisive lane changes. Note the two swerves are associated with the same participant.

Note that each participant was assigned one of these codes: C, H, IL, IR, or IS. If a participant had more than one type of lane change, the code was assigned in the following priority order: IL, IR, IS, C, and H.

When the destination was the left fork (Winner, Edison, or Mission) and drivers started in lane 2 (variation 3X_Left_2), they should not have moved out of the starting lane. SS 3-C had the fewest participants making an incorrect lane change. SS 3-A with the destinations stacked had the most incorrect lane changes, with all incorrect lane changes occurring near the initial SB (see figure 27).

When the destination was the left fork (Winner, Edison, or Mission) and drivers started in lane 3 (variation 3X_Left_3), all of the participants failed to change lanes into the correct lane in advance of the Y-split with SS 3-A (i.e., participants did not recognize that the stacking of the cities was associated with lane position). Only half of the participants did so with SS 3-C, which had stacked city names for the first two signs and the divided sign on the final SB. For SS 3-C, four of the seven participants correctly changed lanes near the third SB (see figure 28). SS 3-B had the cities split on the initial SB, and five of the seven participants made the correct lane change near this SB, with another participant making the lane change near the second SB. The remaining participant did not make any lane change in response to the signs.

When the destination was the right fork (Groton, Victor, or Walker) and drivers started in lane 2 (variation 3X_Right_2), the patterns observed for the left fork situation were similar to the right fork situation. Participants made the correct lane change when they saw the sign with the exits side by side rather than stacked. For SS 3-B, this was the initial SB, while for SS 3-C, this was the final SB. Only one of the participants made a correct lane change for SS A (see figure 29).

When the destination was the right fork (Groton, Victor, or Walker) and drivers started in lane 3 (variation 3X_Right_3), the SS did not matter. All of the participants stayed in their lane (see figure 30).

When asked after the simulation had stopped which lane they needed to be in prior to the split, participants were least likely to answer the correct lane with SS 3-A and were most likely to pick the correct lane with SS 3-B.

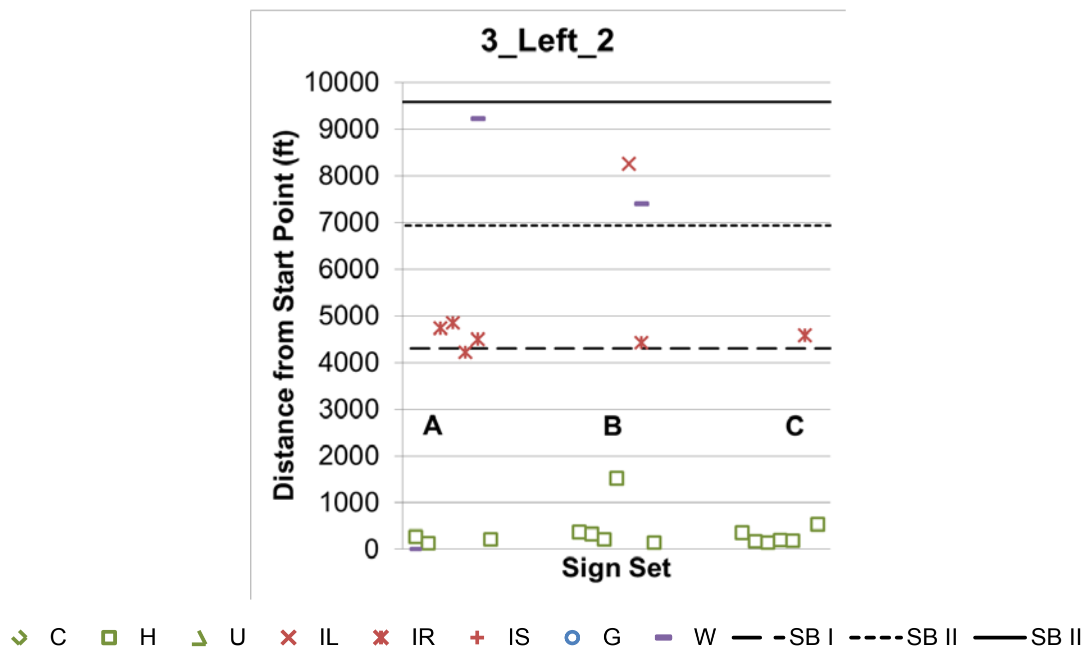


Figure 27. Graph. Topic 3 lane change location 3X_Left_2.

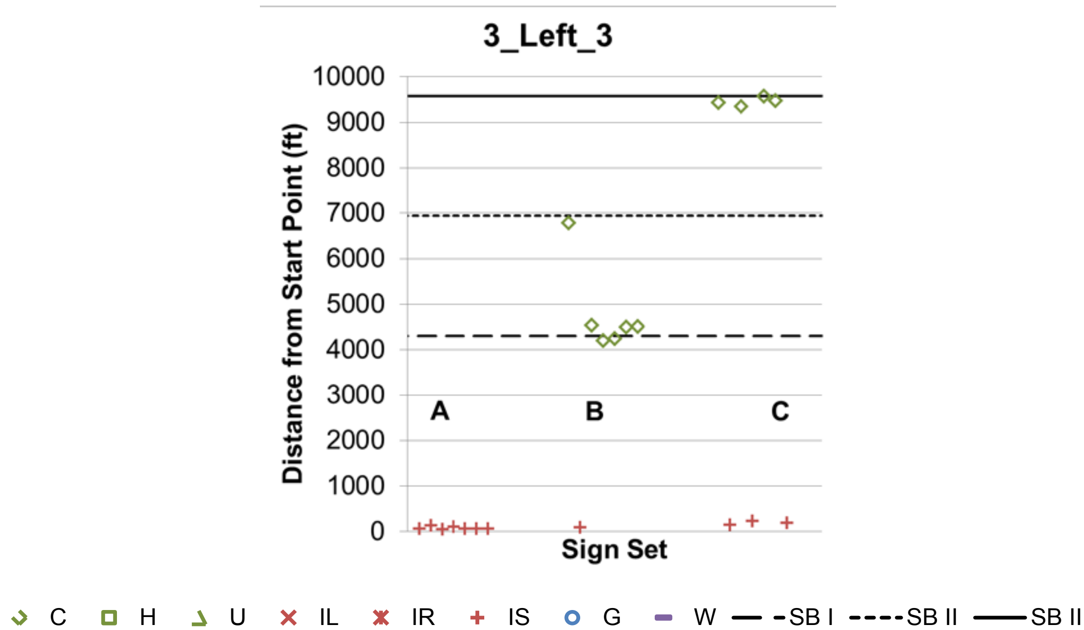


Figure 28. Graph. Topic 3 lane change location 3X_Left_3.

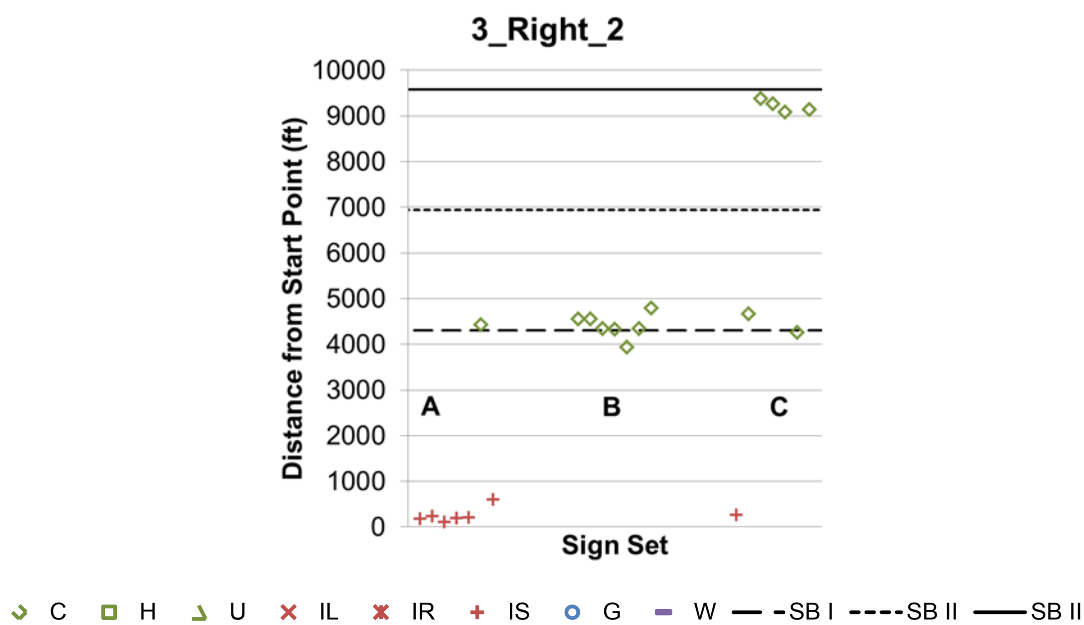


Figure 29. Graph. Topic 3 lane change location 3X_Right_2.

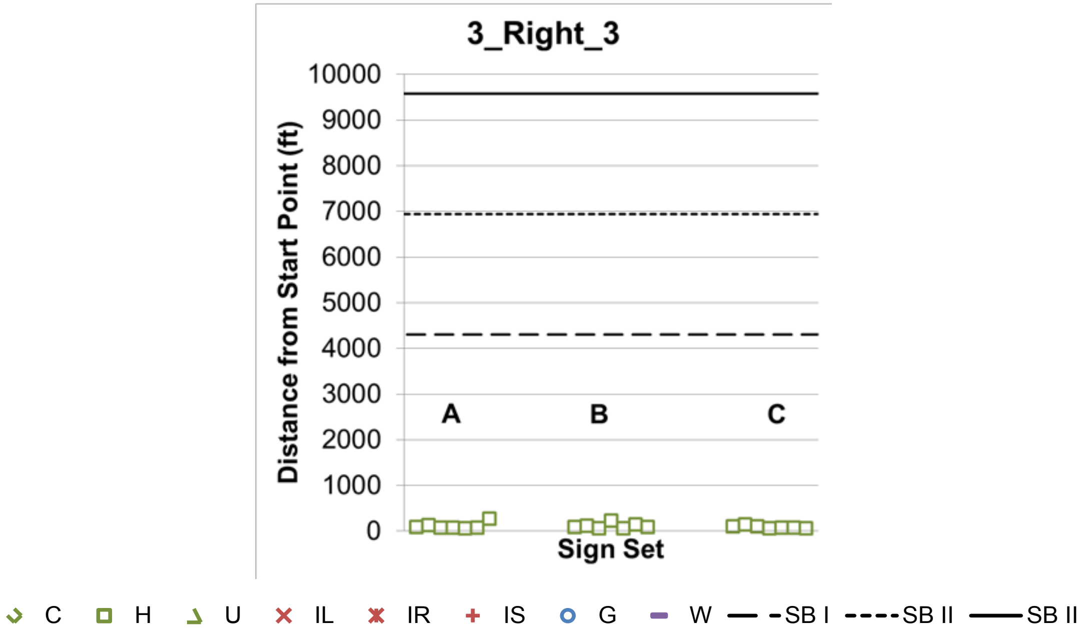


Figure 30. Graph. Topic 3 lane change location 3X_Right_3.

Key Findings

For SS 3-B, the split sign was used for the two advance signs and at the gore. SS 3-C only used the split sign at the gore, with the two advance signs showing the destinations vertically stacked. SS 3-A used the vertical stacked format for both the two advance signs and the gore sign. The lateral location of the destination on the sign was used by participants in making a lane change decision. As can be seen in figure 27 through figure 30, several lane changes were made at the first appearance of the split exit sign (at SB I location for SS 3-B and at SB III location for SS 3-C). While several incorrect lane changes were made for each SS, SS 3-B, which used split exit signs at all three SB locations, had the fewest and was judged superior in comparison to the other two arrangements.

Topic 4

Overview

Topic 4 evaluated whether it was better to fill an advance single sign with supplemental way-finding information or to spread the information among multiple signs, including ground-mounted signs. The AASHTO *Guidelines for the Selection of Supplemental Guide Signs for Traffic Generators Adjacent to Freeways* provides a basis for the development of State policies for selecting supplemental guide signs for traffic generators adjacent to freeways.(44) Gore signs with advance signs at 1 mi were used to explore if sign spreading on a single bridge or on multiple bridges improved where the lane change was occurring. As shown in figure 31 through figure 33, SS 4-A had a single sign with multiple destinations, SS 4-B had split signs on a single SB, and SS 4-C had sign spreading on multiple SBs. All of the SSs have the exit number panels positioned on the upper right.

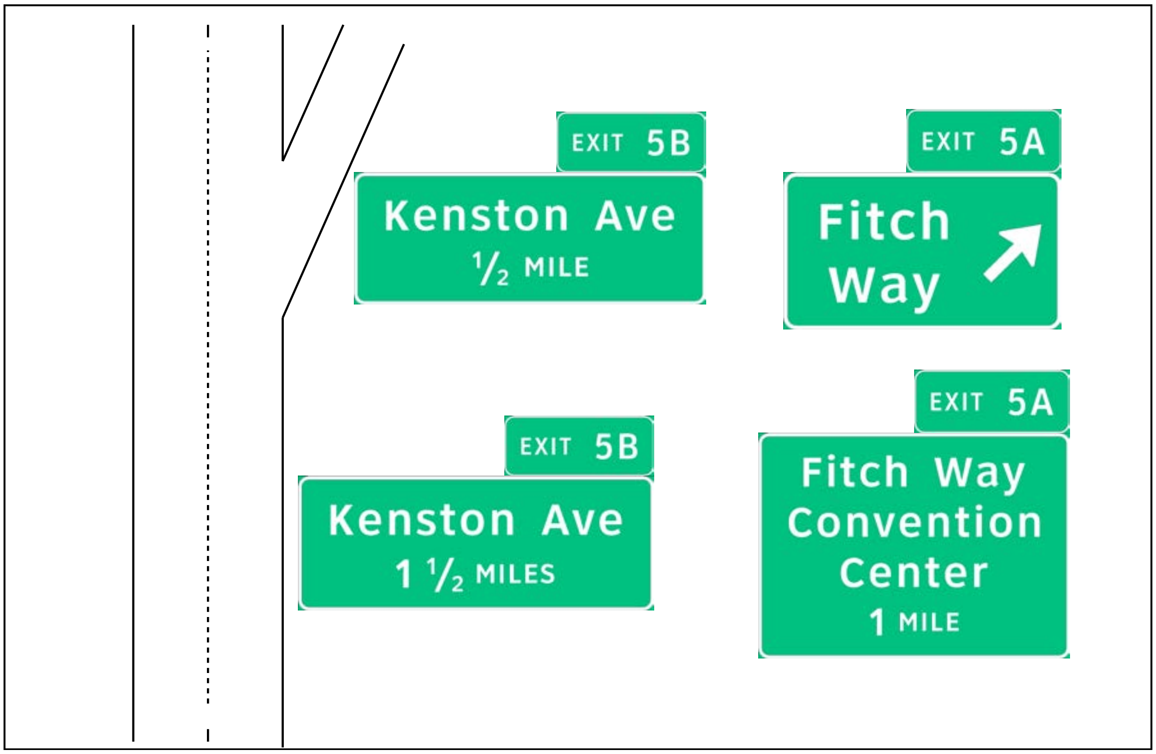


Figure 31. Illustration. SS 4-A: single sign with multiple destinations.

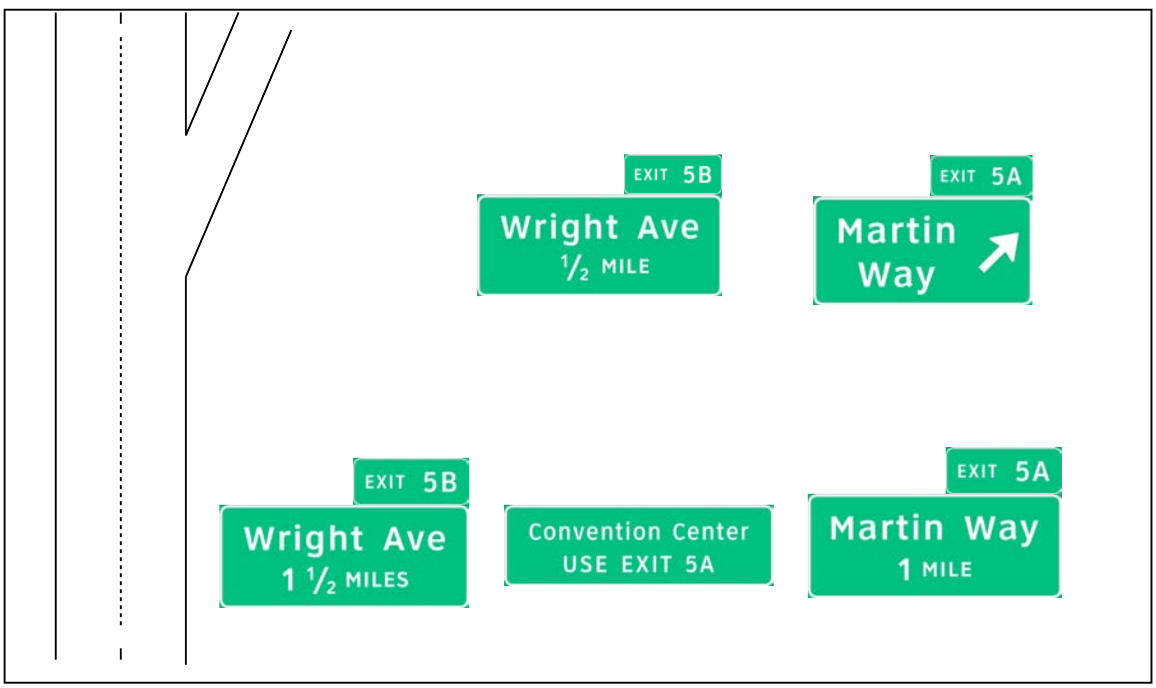


Figure 32. Illustration. SS 4-B: sign spreading across multiple signs on a single bridge.

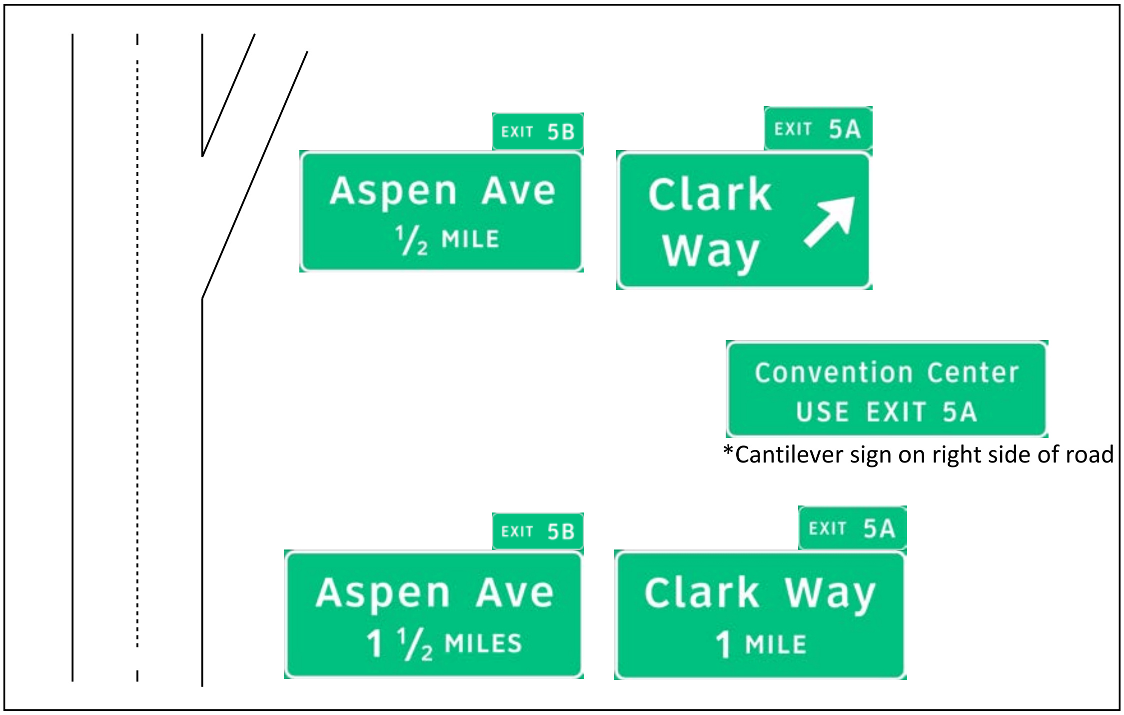


Figure 33. Illustration. SS 4-C: sign spreading across multiple SBs.

Observations

Table 12 shows a summary of the number of participants with correct, incorrect, unnecessary, and indecisive lane changes by test variation for topic 4. Questions asked following the driving segment included the following:

- What lane would you have gotten in to go to Kenston/Wright/Aspen—left or right?
- Should you have exited if you wanted to go to the convention center?
- How did you know to exit (if they took the exit)?
- How much longer do you drive until you will exit (if they did not take the exit)?

Note that each participant was assigned one of these codes: C, H, IL, IR, or IS. If the participant had more than one type of lane change, the code was assigned in the following priority order: IL, IR, IS, C, and H. Also, a participant could have both a code of IC along with a code of C, H, IL, IR, or IS.

Table 12. Topic 4: number of participants with lane change type by test variation.

SS	D	SL	N	C	H	✓	IL	IR	IS	✗	%✓	%✗	IC	?	Scenario
A			7	4	0	4	0	3	0	3	57	43	0	0	4A_CNV_1
B	C	1	7	6	0	6	0	0	1	1	86	14	0	0	4B_CNV_1
C			7	7	0	7	0	0	0	0	100	0	0	0	4C_CNV_1
A			7	0	6	6	0	0	1	1	86	14	0	0	4A_CNV_2
B	C	2	7	0	5	5	0	0	2	2	71	29	0	0	4B_CNV_2
C			7	0	7	7	0	0	0	0	100	0	0	0	4C_CNV_2
A			7	0	6	6	1	0	0	1	86	14	0	0	4A_2nd_2
B	2	2	7	0	2	2	5	0	0	5	29	71	1	1	4B_2nd_2
C			7	0	4	4	3	0	0	3	57	43	2	2	4C_2nd_2
A			7	0	6	6	1	0	0	1	86	14	0	0	4A_1st_2
B	1	2	7	0	7	7	0	0	0	0	100	0	0	0	4B_1st_2
C			7	0	7	7	0	0	0	0	100	0	0	0	4C_1st_2

D = Destination (C = Exit to convention center, 2 = Go to second exit (Kenston, Wright, or Aspen), and 1 = Go to first exit (Fitch, Martin, or Clark).
N = Number of participants driving a particular testing variation.
✓ = Sum of number of participants with correct lane changes.
✗ = Sum of number of participants with incorrect lane changes.
%✓ = Percent of participants with correct lane changes.
%✗ = Percent of participants with incorrect lane changes.
? = Number of participants making indecisive lane changes.

Observations for this topic are as follows:

- When participants were told the destination was the convention center (variation 4X_CNV_1 or 4X_CNV_2), SS 4-B and SS 4-A had similar poorer results, indicating these SSs were not as well understood as the sign spreading approach used with SS 4-C. When starting in lanes 1 or 2, participants viewing SS 4-C were always correct. About half of the participants who started in the far left lane missed the exit to the convention center with SS 4-A. Only one of the participants who started in lane 2 missed the convention center with SS 4-A. SS 4-B also was associated with participants who missed the exit to the convention center.

- When participants were told the destination was Kenston Avenue, Wright Avenue, or Aspen Avenue (i.e., second exit; variation 4X_2nd_2), SS 4-B had the most incorrect lane changes, with only two of the seven participants correctly staying in their original lane. The spreading of the information on the single SB caused the sign with the information about the second destination (i.e., to Wright Ave.) to be over lane 1, which is the lane that five of the seven participants entered. When the sign spreading was across multiple SBs or when the information was stacked on one sign, fewer drivers made the incorrect lane change to the left.

- When participants were told the destination was Fitch Way, Martin Way, or Clark Way (i.e., first exit; variation 4X_1st_2), almost all of the participants correctly drove these scenarios. Participants who took the exit said they knew to exit because the convention center was mentioned on a sign, regardless of the SS they viewed.

Key Findings

For most of the variations studied, SS 4-C (sign spreading across two SBs) had the most participants making the correct lane-change decision, although SS 4-A (information for next exit stacked on one sign) also had many of the participants correctly making lane positioning decisions. When the destination information was spread across multiple signs on a single bridge, several participants made incorrect lane changes to the left when the instructions were to go to the second destination. These drivers may have been positioning their vehicles into the lane under the sign with their intended destination. This finding indicates that spreading information about the next exit across multiple signs on a single bridge may have unintended consequences if the SB also includes a sign for another exit that is located to the left of the preferred lane.

Topic 5

Overview

Topic 5 evaluated the effectiveness of sign spreading when there were many pieces of information on one SB. The question being explored was the following: "Does sign spreading affect where lane changes occur?" As shown in figure 34 and figure 35, SS 5-A did not have sign spreading, while SS 5-B had sign spreading across many SBs. Because only 1.5- and 1-mi advance signs were used in the simulation, there could be some cases where the needed lane change would have occurred after the simulation was stopped. Therefore, the coding included a pregore undetermined option.

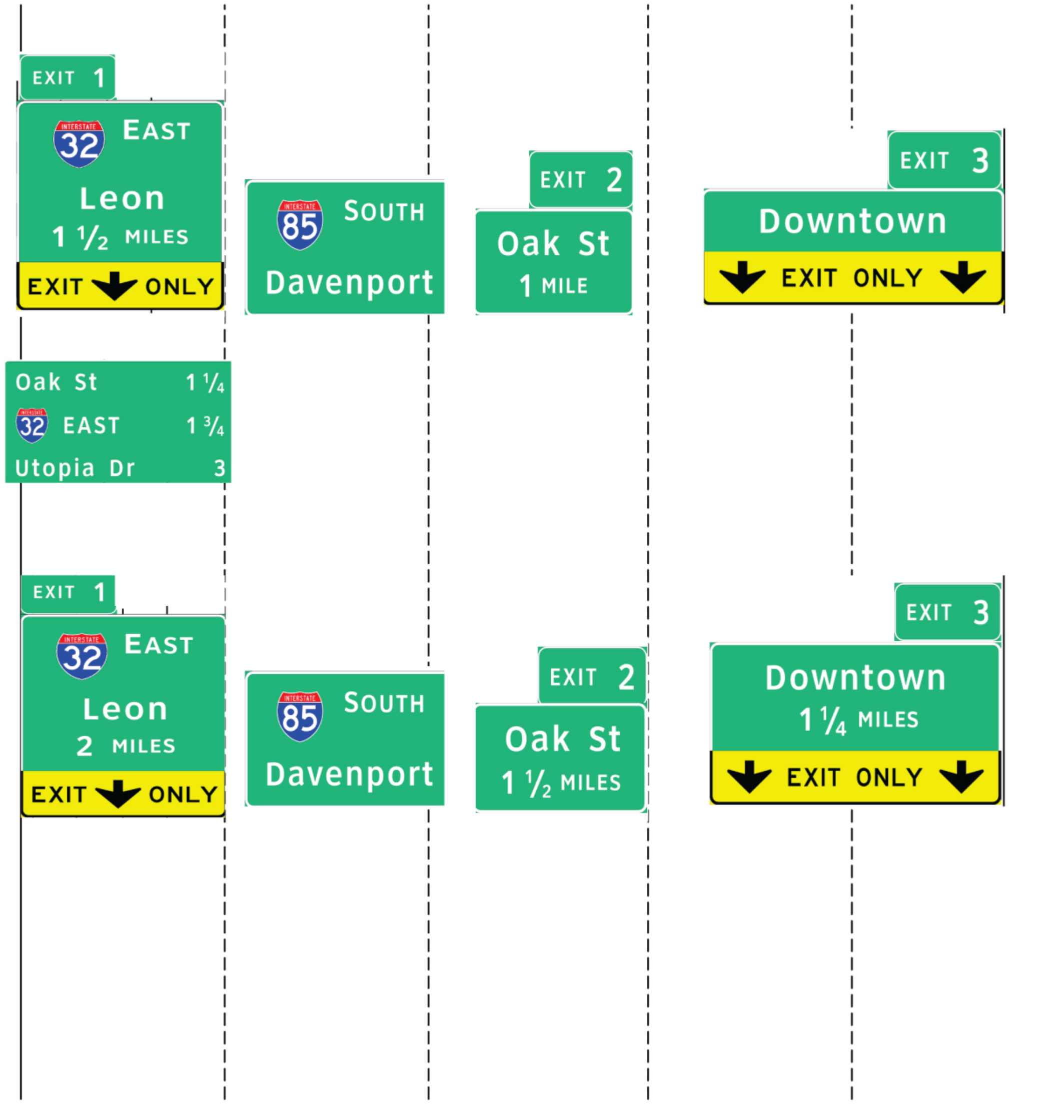


Figure 34. Illustration. SS 5-A: no sign spreading.

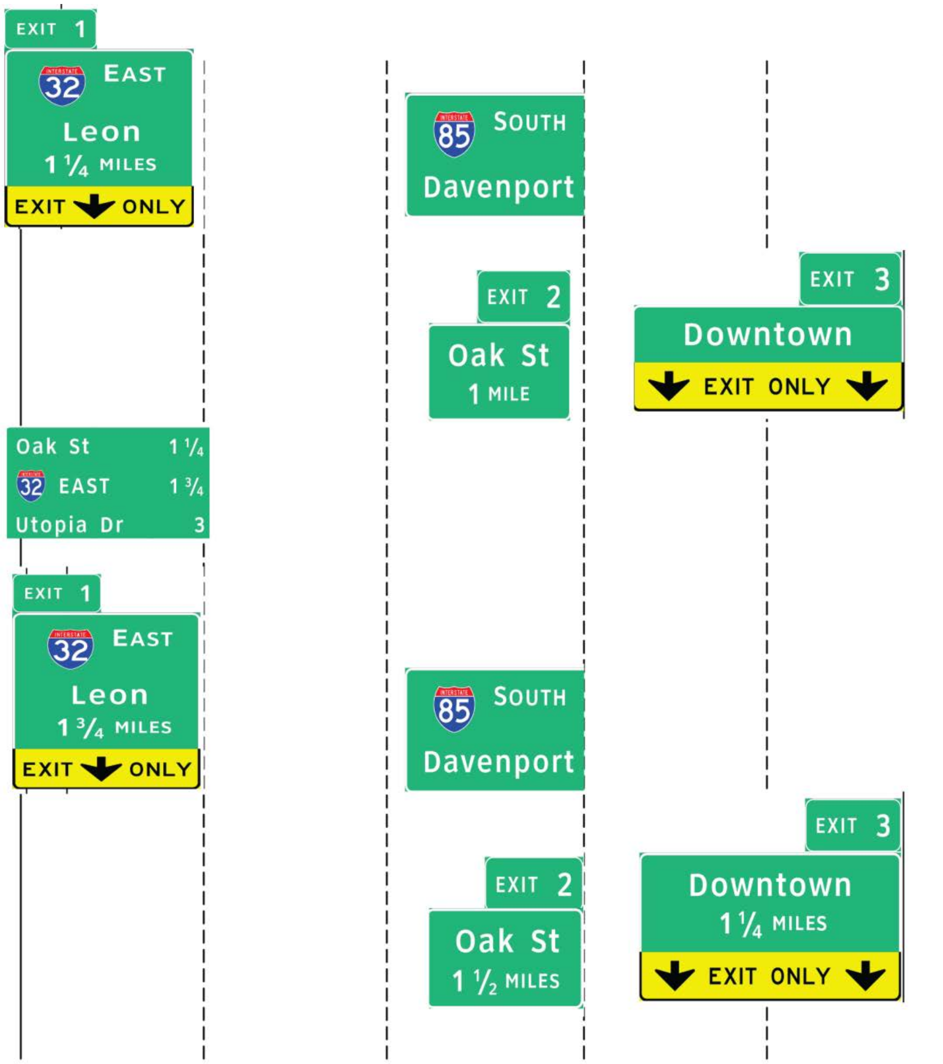


Figure 35. Illustration. SS 5-B: sign spreading.

Observations

Table 13 shows a summary of the number of participants who made correct, incorrect, unnecessary, and swerve lane changes by test variation for topic 5. Note that each participant was assigned one of these codes: C, U, IR, IS, or G. If the participant had more than one type of lane change (e.g., both IR and U), the code was assigned in the following priority order: IR, IS, U, C, and G. Also, a participant could have both a code of S along with a code of IR, IS, U, C, or G.

Table 13. Topic 5: number of participants with lane change type by test variation.

SS	D	SL	N	C	U	✓	IR	IS	×	G	% ✓	% ×	% G	S	?	Scenario
A	T	4	14	7	7	14	0	0	0	0	100	0	0	0	0	5A_T_4
B			14	10	0	10	0	4	4	0	71	29	0	0	0	5B_T_4
A	O	1	14	9	0	9	1	2	3	2	64	21	14	4	2	5A_Oak_1
B			14	8	0	8	1	2	3	3	57	21	21	2	1	5B_Oak_1
A	L	3	14	13	0	13	0	0	0	1	93	0	7	4	2	5A_Leon_3
B			14	13	0	13	0	0	0	1	93	0	7	2	1	5B_Leon_3

D = Destination (T = Through, O = Oak exit, and L = Leon exit).
N = Number of participants driving a particular testing variation.
✓ = Sum of number of participants with correct lane changes.
× = Sum of number of participants with incorrect lane changes.
%✓ = Percent of participants with correct lane changes.
%× = Percent of participants with incorrect lane changes.
%G = Percent of participants with pregore undetermined lane changes.
? = Number of participants making indecisive lane changes. The two swerves are associated with the same participant.

Observations for this topic are as follows:

- When participants were told the destination was Davenport (i.e., they were to stay on the freeway; variations 5A_T_4 and 5B_T_4), SS 5-A had more unnecessary lane changes compared to SS 5-B—half of the participants with SS 5-A had unnecessary lane changes, while SS 5-B had no unnecessary lane changes. Because SS 5-A had more signs on a single SB, the sign for Davenport was farther to the left, which may have resulted in participants trying to position themselves below the Davenport sign, resulting in an unnecessary (but not incorrect) lane change. Because SS 5-B spread the signs across more SBs, the sign for Davenport was closer to the right edge of the freeway compared to the position within SS 5-A (see figure 34 and figure 35). SS 5-B, however, had 4 of the 14 participants make an incorrect straight movement. The drivers should have shifted another lane to the left to avoid being in the two-lane exit only lanes. These findings indicate that the position on the SB of the pull-through sign is important.

- When participants were told the destination was Oak Street (i.e., they would need to make a downstream exit to the right; variations 5A_O_1 and 5B_Oak_1), several incorrect lane changes were made with both SSs. Only slightly more than half of the participants for each SS were in the correct lane at the end of the simulation.

- When participants were told the destination was Leon (i.e., they would need to make a downstream exit to the left; variations 5A_Leon_1 and 5B_Leon_1), almost all of the participants correctly drove the simulation with both SSs.

Key Findings

The lateral position of a pull-through sign on the SB is important. SS 5-A had more unnecessary lane changes compared to SS 5-B—half of the participants with SS 5-A had unnecessary lane changes, while SS 5-B had no unnecessary lane changes. Because SS 5-A had more signs on a single SB, the sign for Davenport was farther to the left, which may have resulted in participants trying to position themselves below the Davenport sign, causing an unnecessary (but not incorrect) lane change. SS 5-B had several participants who incorrectly did not move out of their initial lane when told to go to the through destination (Davenport).

Topic 6

Overview

Topic 6 evaluated driver understanding of the 2009 MUTCD left-exit standards.(1) Only 1- and 0.5-mi advance signs were used to test how quickly drivers identified the left exit and changed lanes as well as if there was confusion on whether it was an exit only or optional exit. As shown in figure 36 and figure 37, SS 6-A had a yellow plaque at the top left, and SS 6-B had a yellow panel at the bottom of the sign.

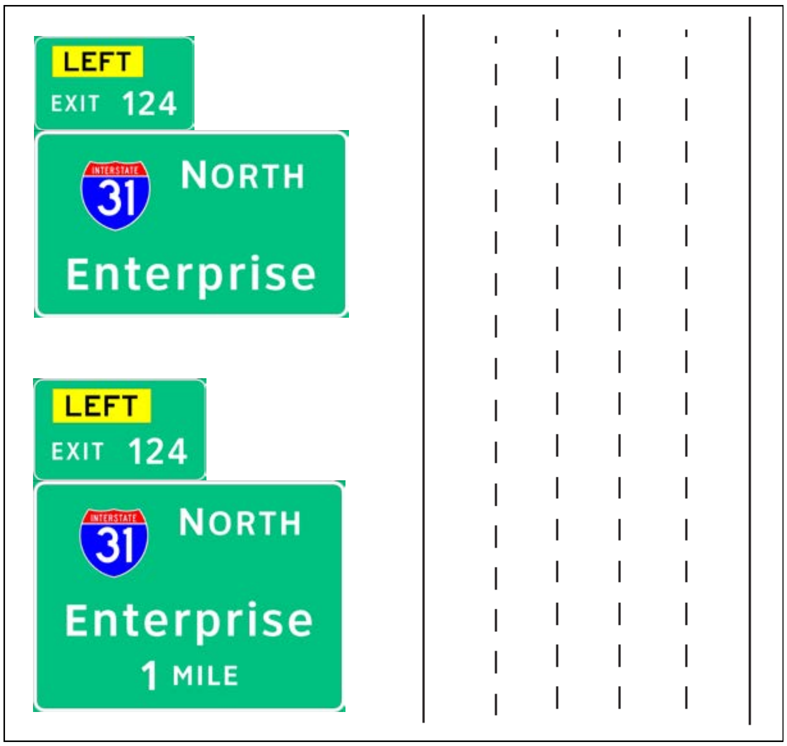


Figure 36. Illustration. SS 6-A: yellow plaque at top left.

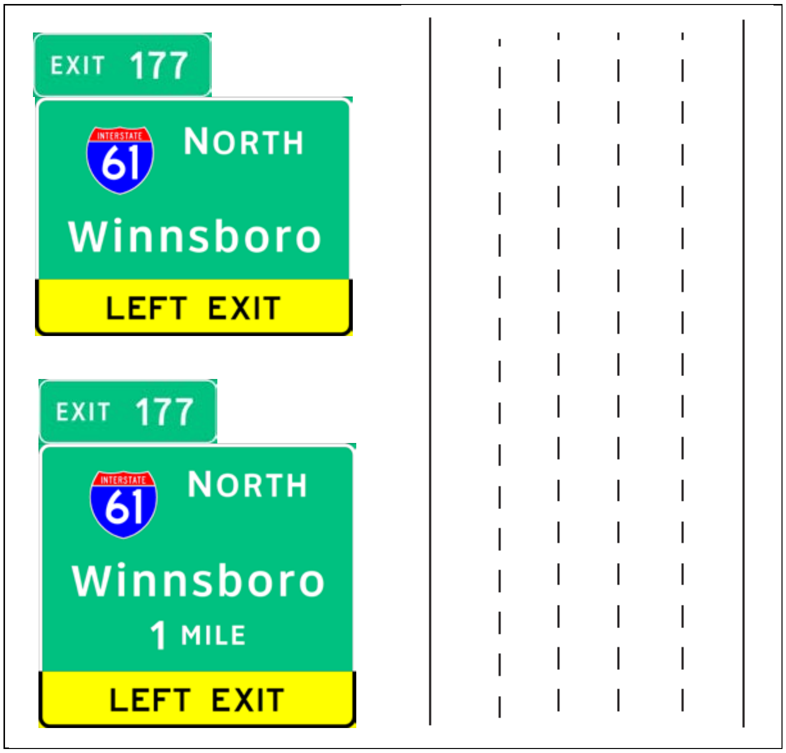


Figure 37. Illustration. SS 6-B: yellow panel at bottom of sign.

Observations

Table 14 shows a summary of the number of participants with correct, incorrect, unnecessary, and pregore undetermined lane changes by test variation for topic 6. Note that each participant was assigned one of these codes: C, H, U, or G. If the participant had more than one type of lane change, the code was assigned in the following priority order: U, H, C, and G.

Table 14. Topic 6: number of participants with lane-change type by test variation.

SS	D	SL	N	C	H	U	✓	✗	G	%✓	%✗	%G	Scenario
A	T	1	14	0	9	5	14	0	0	100	0	0	6A_T_1
B			14	0	6	8	14	0	0	100	0	0	6B_T_1
A	E	1	14	0	14	0	14	0	0	100	0	0	6A_E_1
B			12	0	12	0	12	0	0	100	0	0	6B_E_1[1]
A	E	3	14	13	0	0	13	0	1	93	0	7	6A_E_3
B			13	12	0	0	12	0	1	92	0	8	6B_E_3[2]

D = Destination (T = Through and E = Exit).
N = Number of participants driving a particular testing variation.
✓ = Sum of number of participants with correct lane changes.
✗ = Sum of number of participants with incorrect lane changes.
%✓ = Percent of participants with correct lane changes.
%✗ = Percent of participants with incorrect lane changes.
%G = Percent of participants with pregore undetermined lane changes.
[1] The raw simulator data files for two participants were lost due to saving errors, resulting in only 12 participants for 6B_E_1.
[2] The researcher opened an incorrect simulator file for one participant, resulting in only 13 participants for 6B_E_3.

Observations for this topic are as follows:

- When starting in lane 1 and being told to go through (variation 6X_T_1), all drivers were in position to correctly stay on the freeway; however, some drivers made an unnecessary lane change to avoid being in the left-most lane. The proportion of unnecessary lane changes was slightly higher among drivers with SS 6-B. All drivers with SS 6-B correctly identified the ramp as being on the left, whereas only 85 percent of drivers (2 of 14) with SS 6-A did so.

- When starting in lane 1 and being told to exit (variation 6X_E_1), all drivers were in position to exit correctly. Once they reached lane 1, all of the participants correctly stayed in that lane. All participants identified the left exit correctly in the follow-up question.

- When starting in lane 3 and being told to exit (variation 6X_E_3), most drivers correctly changed lanes to be able to make the left exit; however, one driver in each SS was in the pregore undetermined group. All drivers identified the left exit correctly in the follow-up question.

- Participants' unprompted comments implied that some of them who moved out of the far left lane may have done so for personal preference rather than because they thought the sign indicated they had to or they would be forced to exit.

Key Findings

Generally, for the two SSs tested under this topic, participants understood which side of the road the exit was located. It is unclear if this was because they were cued by the placement of the sign over the left lane, read the word "left" on the signs, or a combination of the two. The placement of the sign over the left lane resulted in the participants correctly avoiding moving across multiple lanes to make a right exit. However, when the participants did not need to make a left exit, they frequently moved out of the left-most lane—even though the lane was not an exit only lane—due to personal preference. A few more of the non-exiting participants seeing SS 6-B with the yellow panel at the bottom of sign moved out of the left-most lane (8 of 14) compared to the participants seeing SS 6-A with the yellow plaque at the top left (5 of 14). For this study, the difference between these two SSs was minimal.

CHAPTER 4. DECISION TOOL TO DEFINE AND QUANTIFY INTERCHANGE COMPLEXITY

Because complexity is typically a qualitative characteristic, the ability to objectively evaluate the complexity of an interchange is somewhat difficult. This difficulty is compounded when trying to compare the complex features of multiple interchanges. This chapter discusses the spreadsheet decision tool developed as a method of quantifying and comparing the complexity of freeway interchanges in the United States. The initial discussion focuses on the steps that guided researchers in developing the spreadsheet, which is then followed by a description of the spreadsheet itself and how practitioners can use it to evaluate the complexity of interchanges under their consideration. The chapter also contains a review of the results researchers obtained from the spreadsheet in an evaluation of the complexity of 28 existing interchanges in 11 States; these study sites ranged from relatively simple to very complex, and results indicate that the spreadsheet generated scores that were generally consistent with researchers' qualitative estimation of the sites' relative complexity. The concluding section of the chapter contains a discussion on what the spreadsheet results mean and how they can be interpreted.

More details on the development of the spreadsheet decision tool are provided in appendix B, and detailed descriptions of each study site can be found in appendix C.

INITIAL SPREADSHEET DEVELOPMENT

Team Discussions

Initially, the research team discussed a variety of methods to develop a format that could apply a consistent set of criteria to measure complexity. A large number of potential variables were considered: geometric design variables, traffic control device variables, driver workload variables, and other categories. Researchers also discussed the basis on which the following variables would be included:

- Interchange-wide variables (e.g., number of levels).
- Route-specific variables (e.g., number of decision points/ramps to travel from an origin to a destination).
- Ramp-specific variables (e.g., left-side or multilane exit).

Finally, researchers discussed how the variables should be scored. That is, what quantity of a particular variable is considered to add complexity, and how does that compare to the complexity of other variables? Individual variables could be assigned threshold values for complexity, and they could be weighted to reflect their complexity relative to other variables. The variables could also be compared to values in the 2011 AASHTO *Green Book*.[(2)]

Given all of these considerations, researchers compiled a list of noteworthy variables and assigned proposed values and weights to them for presentation to practitioners to obtain their feedback on the usefulness and meaningfulness of the initial version of the spreadsheet tool.

The worksheet included 26 variables divided into the following three categories:

- Roadway geometry variables are as follows:
  - Number of concurrent routes.
  - Number of levels.
  - Exit ramps per mile.
  - Entrance ramps per mile.
  - Left exits per mile.
  - Left entrances per mile.
  - Exit ramps with multiple destinations per mile.
  - Multilane exit ramps per mile.
  - Optional/shared exit lanes per mile.
  - Exit only lanes per mile.
  - Lane balance condition.
  - Auxiliary lane as percent of minimum distance (in ft).
- Driver workload challenges variables are as follows:
  - Is the left shoulder less than the minimum width?
  - Is the right shoulder less than the minimum width?
  - Is there a loop on the exit ramp?
  - Is there a taper speed-change lane on the exit ramp?
  - Is there a taper speed-change lane on the entrance ramp?
  - Is the number of general purpose lanes greater than four?
- Driver expectancy violations variables are as follows:
  - Is the ramp straight while the main lanes are curved?
  - Are the approaching main lanes curved (resulting in difficulties in aligning arrows on signs)?

- Is there an entrance within minimum distance downstream of this entrance?
- Is there a short (less than 0.5 mi) weaving section between the entrance and the downstream left exit?
- Is there an entrance ramp followed closely by an exit, and is the auxiliary lane missing? (Based on *Green Book* figure 10-68.)[44]
- Are there more exit lanes than through lanes?
- Are there more entrance lanes than through lanes?
- What is the number of missing legs?

Expert Panel Discussion

In January 2011, TTI conducted an expert panel discussion. Researchers wanted the panel to help identify factors that contribute to the driving complexity of an interchange area and to give their opinion on lists of variables already identified during the research as contributing to complexity. This discussion was limited to design and geometric variables and did not address existing signing or other traffic control devices currently installed at the interchanges. In addition to the four members of the TTI research team, the panel was also composed of six practitioners: three from State transportation, two from FHWA, and one from a State turnpike authority.

Overall, the panel thought the three categories of variables were a good fit for addressing interchange complexity, but they noted that the workload and expectancy categories were related (e.g., when driver expectancy is violated, it increases the workload for the driver and increases the amount of signing needed).

It was further suggested that workload is primarily driven by the density of decisions that a driver must make within an interchange area. In this case, the example stated was that if the decision points for several major destinations were within the interchange area, the workload would be significantly increased. Panelists stated that workload can be reduced through interchange design by spreading the decision points along the corridor and that addressing variables within the design category could eliminate complexity from both workload and expectancy violations. This point emphasizes the need for early coordination of geometric design and signing needs.

Prior to presenting the list of variables to the panel, researchers discussed how to assess the complexity of each of the 26 items listed and how to meaningfully and objectively compare the effects of each variable to the others on the list. Researchers discussed this issue with the panelists, along with some initial ideas on how to accomplish that comparison. The panelists echoed that sentiment and provided their comments and recommendations on how to assess each variable individually and comparatively in a revision of the list.

The panelists offered their suggestions on which variables were important and what their relative weights and scores should be, and they discussed which variables should be added or removed from the initial list of 26 characteristics. Based on the feedback, researchers revised the spreadsheet into its current version, which is described in the “Spreadsheet Tool” section in this chapter.

DEPARTMENT OF TRANSPSORTATION SITES

To determine how well the spreadsheet tool would evaluate interchanges, the research team issued a request to State transportation departments for locations of the most complex interchanges in their respective States. The research team received responses from 11 States documenting 35 interchanges. The 11 States and the number of interchanges are as follows:

- Arizona: Three interchanges.
- Delaware: Three interchanges.
- Georgia: Four interchanges.
- Indiana: Three interchanges.
- Iowa: Three interchanges.
- Maryland: Two interchanges.
- New York: Six interchanges.
- Ohio: Three interchanges.
- Oregon: Two interchanges.
- South Carolina: Three interchanges.
- Virginia: Three interchanges.

After reviewing the information provided by the State transportation departments, the research team used 28 of the interchanges for processing in the spreadsheet. Six of the remaining interchanges (one in Georgia, one in Maryland, and four in New York) contained more than four approaches, which is the capacity of the spreadsheet, while the last site (in Indiana) was not used because of poor image quality on both the aerial and street view pictures available in the Google Earth® mapping service database due to in-progress construction at the time the images were recorded. The locations of the study sites are summarized in table 15; those not used in the spreadsheet tool development are noted.

Table 15. Summary of study sites.

Name	Location
AZ-1	I-10/I-17/US-60
AZ-2	I-10/SR 51/Loop 202
AZ-3	I-17/SR 69
DE-1	I-95/SR 1/SR 7/Churchmans Road
DE-2	I-95/I-295/SR 141
DE-3	I-295/US-13
GA-1*	I-85/I-285 (southwest of Atlanta)
GA-2	I-85/I-285 (northeast of Atlanta)
GA-3	I-85/SR 316
GA-4	I-75/I-16/US-23/SR 401
IN-1	I-65/I-80/I-94
IN-2*	I-70/I-465 (West Leg)
IN-3	I-69/I-465/Binford Boulevard
IA-1	I-35/I-80/I-235 (West Junction)
IA-2	I-380/US-30
IA-3	I-29/I-129 and US-20/US-75
MD-1	I-95/I-695
MD-2*	I-95/495 (Capital Beltway) at I-295/MD 210
NY-1	I-95/I-287/Route 1/Midland Avenue
NY-2*	I-287/I-684/Hutchinson River Parkway
NY-3	Route 9 and Route 44/55
NY-4*	I-890 Exits 4A, 4B, and 4C
NY-5*	I-95/I-278/I-295/I-678/Hutchinson River Parkway (Ref. Route 908A)/Bruckner Boulevard/Zerega Avenue
NY-6*	I-678/Grand Central Parkway (Ref. Route 907M)/Jackie Robinson Parkway (Ref. Route 908B)/Union Turnpike
OH-1	I-90/I-77
OH-2	I-71/I-670
OH-3	I-75/I-71/US-50
OR-1	I-5/I-405/US-30
OR-2	I-5/I-84/US-30
SC-1	I-26/I-126/Bush River Road
SC-2	I-385/I-185 (Toll)/US-276
SC-3	I-77/US-21
VA-1	I-95/I-495/I-395
VA-2	I-395/SR 27
VA-3	I-64/I-264/I-664/SR 13/58/191/460

*Indicates not included in the spreadsheet evaluation.

SPREADSHEET TOOL

The revised spreadsheet decision tool focuses on the following topics:

- Three interchange-wide characteristics.
- A selection of cross section characteristics at the terminus of the speed-change lane of each ramp.
- Ramp-specific characteristics that are dependent on whether the ramp is an entrance ramp or an exit ramp.

A goal during spreadsheet development was to have a format that would be easy for practitioners to understand and use. The format is based on characteristics of each ramp in the interchange. The intent is to document the decision points, along with the associated pieces of information to be processed, that a through driver would encounter while driving on that route from one end of the interchange to the other. The spreadsheet is designed to accommodate up to four routes, which are labeled to correspond to the four cardinal compass directions: NB, southbound (SB), EB, and WB. This format allows users to enter the variables for each ramp that exists along any of the four routes, and the spreadsheet processes a series of calculations to convert those site characteristics into an interchange complexity score that can be compared to other interchanges.

After users enter all of the variables, the spreadsheet calculates a complexity score for each route and for the entire interchange. The maximum possible score for a route and for an interchange overall is 1,000 points. The theoretical minimum is zero points, but the practical minimum is 10 points, which is the score given to any interchange with two levels. The "User Inputs" section in this chapter describes the process of completing the spreadsheet with the revised set of characteristics.

Spreadsheet Development

Researchers entered the information on all 28 study sites into the spreadsheet tool, taking measurements and observations from Google Earth®. While entering the information into the spreadsheet, researchers also monitored the performance of the spreadsheet, checking that each of the dozens of equations processing a particular site contained the proper operators and referenced the correct data. As the data were entered, researchers made changes to equations as needed to produce the correct results. Researchers also considered the scores that were generated as the information for each interchange was entered to begin developing an appreciation of how well the spreadsheet identified the relative complexities of the study sites. A discussion of the complexity scores and their components is provided in more detail in the later sections of this chapter and in appendix B.

In addition, researchers reviewed the format and layout of the spreadsheet for its ability to receive data in a manner that would be intuitive and straightforward for the user. To use the spreadsheet, a user must enter a series of values into the appropriate cells for each ramp on each approach. The research team decided to use shading with colors to indicate the purpose of a cell; the color-coded cells in the spreadsheet guide the user to differentiate between cells that require user input and cells containing labels, equations, and visual boundaries between sections of the spreadsheet. A set of step-by-step instructions is provided in a separate tab of the spreadsheet.

User Inputs

To begin, the user enters basic descriptive information about the interchange (e.g., city and State and primary and secondary routes of the interchange). Next, the user enters the length of the study corridor in each direction measured from the beginning of the most upstream ramp of the interchange to the end of the most downstream ramp. Finally, the user enters the number of vertical levels in the interchange and the number of missing movements for each direction. A missing movement is the condition in which a direct path from one approach to another does not exist; two examples of missing movements are shown by the yellow lines in figure 38. Drivers traveling northeast cannot enter the freeway traveling southeast unless they travel completely through the interchange and make a U-turn. Similarly, drivers traveling northwest cannot access the route to the southwest without taking a circuitous path and backtracking.

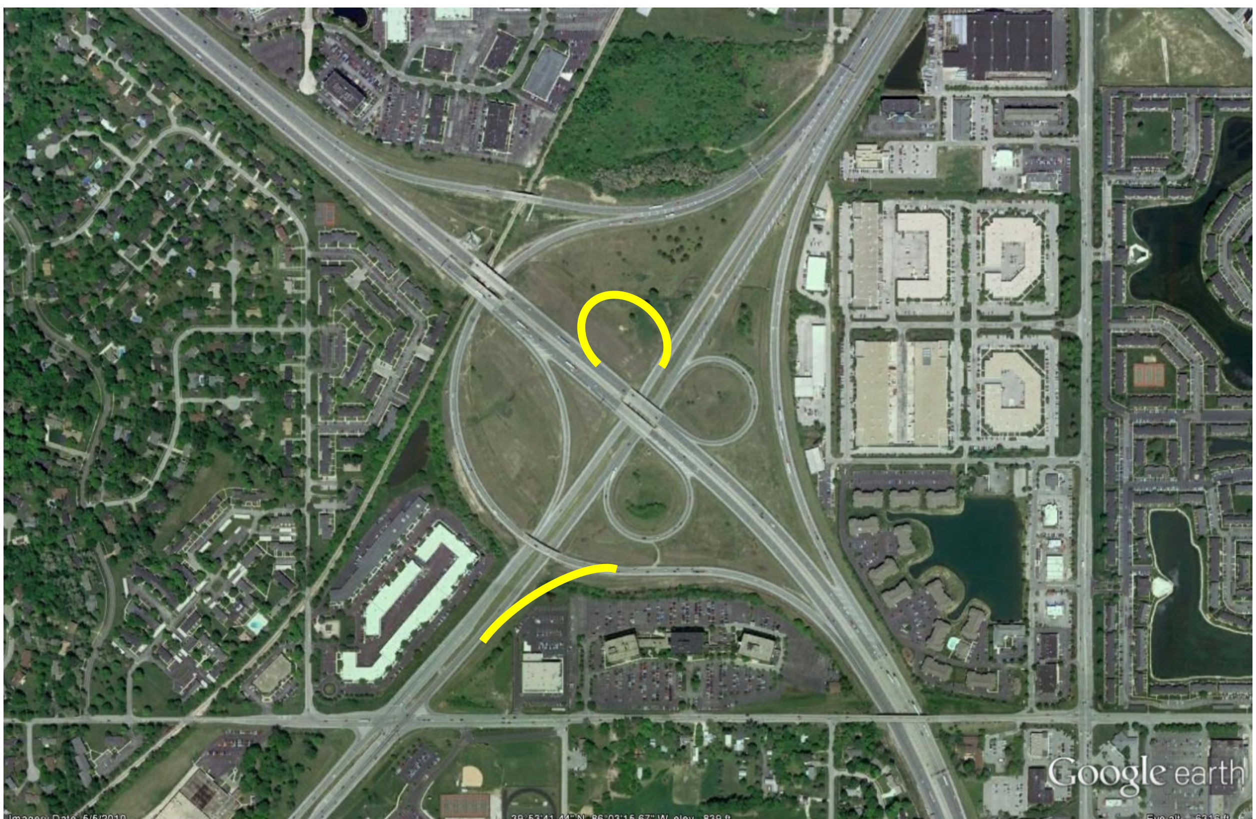


Figure 38. Photo. Example of missing movements.[(45)]

After entering details of interchange-level site characteristics, the user enters ramp-specific characteristics for each ramp in the interchange in the order that a driver would encounter them while driving through the interchange. The user describes each ramp as an entrance or exit ramp, enters the origin or destination of the ramp and the type of ramp, and notes whether the ramp is part of a cloverleaf arrangement.

After entering general characteristics of each ramp, the user enters a series of counts, measurements, and other variables for each ramp. The information for these ramp-specific characteristics can come from plan sheets, in-person field visits, or (as was done in this study) aerial images from Google Earth® or a similar online mapping service. There are 34 ramp-specific characteristics divided into three groups: lanes, exit ramp characteristics, and entrance ramp characteristics. The full list of characteristics for each ramp is shown in table 16. Many of the characteristics in the table are directly measured or observed (e.g., those with units in ft or those that are count variables). Remaining characteristics are based on the user choosing a value (i.e., yes or no). Inputs are formatted in this manner to help remove much of the subjectivity in evaluating an interchange of this type; the inputs require specific answers or numbers and largely eliminate the need for the user to make a determination of the complexity of an individual characteristic.

Table 16. Ramp-specific characteristics for spreadsheet tool.

Group/Characteristic	Unit
Lanes Measured at the Terminus of the Speed Change Lane (SCL)	
Number of general purpose lanes at the start of the ramp	Count
Number of general purpose lanes at the ramp gore	Count
Number of managed lanes	Count
If managed lane is present, what is the separation device? (concrete barrier, candlestick, or paint)	Discrete choice
Left shoulder width (ft)	ft
Is there a concrete barrier at the edge of the left shoulder? (yes/no)	Discrete choice
Right shoulder width (ft)	ft
Is there a concrete barrier at the edge of the right shoulder? (yes/no)	Discrete choice
Number of concurrent routes on the main lanes	Count
Is visual clutter present (e.g., sight distance restricted by overhead bridges, buildings greater than three stories within 30 ft of travel way, etc.) (yes/no)?	Discrete choice
Exit Ramp Characteristics	
Number of exiting lanes	Count
Left exit? (yes/no)	Discrete choice
Number of optional/shared exit lanes	Count
Number of exit only lanes	Count
At this location, is driver expectancy violated because a driver on a main lane has to change lanes to stay on the freeway? (yes/no)	Discrete choice
SCL type (parallel/taper)	Discrete choice
Alignment of ramp proper (loop/curve/straight)	Discrete choice
At this location, is driver expectancy violated because the main lanes are curving away from a straight ramp? (yes/no)	Discrete choice
At this location, is driver expectancy violated because a horizontal curve on the main lanes is so severe that aligning arrows on signs would be difficult? (yes/no)	Discrete choice
Multiple destinations from exit? (yes/no) (includes C-D roads)	Discrete choice
Distance from upstream ramp of interest (ft measured between painted gore points)	ft
Upstream ramp type (entrance/exit)	Discrete choice

Upstream ramp side (left/right)	Discrete choice
If upstream ramp is the entrance, is the auxiliary lane present? (yes/no/not applicable)	Discrete choice
Distance to downstream ramp (ft measured between painted gore points)	ft
Downstream ramp type (entrance/exit)	Discrete choice
Downstream ramp side (left/right)	Discrete choice
Entrance Ramp Characteristics	
Number of entering lanes	Count
Left entrance? (yes/no)	Discrete choice
Entrance lane type (typical/auxiliary/through)	Discrete choice
SCL type (parallel/taper)	Discrete choice
Distance to downstream ramp (ft measured between painted gore points)	ft
Downstream ramp type (entrance/exit)	Discrete choice
Downstream ramp side (left/right)	Discrete choice

Factors, Threshold Values, and Points

After all user inputs are complete, the spreadsheet processes that information based on a set of factors, threshold values, and weights. Factors are those variables that the research team included based on the previous versions of the spreadsheet and the feedback from practitioners. Each factor has high and low threshold values for scoring. The weights are numerical values that assign relative importance to each factor, which are also based on the judgment of the research team supported by review of the previous spreadsheet. The factors, their threshold values, and points assigned based on the threshold value are shown in table 17 for those factors with yes/no answers and table 18 for those factors with numeric values.

Each factor was assigned a high and low threshold value on which to base the complexity impact of that variable. Values above the high threshold were assigned 10 points, values equal to or below the low threshold were zero points, and moderate values (between the high and low thresholds) were given 5 points. For example, if an approach had two concurrent routes through the entire length of the study corridor, the value for that factor was equal to the upper threshold value of 2, so the approach received 5 points for that factor. If the number of concurrent routes was three, then the approach received 10 points. In a similar manner, the value of each factor for each approach was tabulated, and a corresponding point value was assigned in the spreadsheet.

The minimum distance for calculating percentage of auxiliary lane length is 2,000 ft based on figure 10-68 from the 2011 AASHTO *Green Book*.(2) Additionally, the minimum distance between entrance ramps is 1,000 ft.(2) The distance between successive exit ramps (800 ft) and the weaving section length (0.5 mi) were based on engineering judgment, and the minimum widths of left (4 ft) and right (10 ft) shoulders were based on the *Green Book*.(2)

Table 17. Factors (questions) and threshold values used in the spreadsheet.

Label	Factor (In Order of How Information is Added to Spreadsheet)	10 Points (Answer is Yes)	Zero Points (Answer is No)
N	Is left shoulder less than minimum width of 4 ft?	Yes	No
O	Is there a concrete barrier less than minimum width distance of 4 ft to the left of the travel way?	Yes	No
P	Is right shoulder less than minimum width of 10 ft?	Yes	No
Q	Is there a concrete barrier less than minimum width distance of 10 ft to the right of the travel way?	Yes	No
R	Is a loop present on exit ramp?	Yes	No
S	Is a taper SCL present on exit ramp?	Yes	No
T	Is a taper SCL present on entrance ramp?	Yes	No
U	Is the number of general purpose lanes greater than three?	Yes	No
V	Are managed lanes present?	Yes	No
W	Is lane continuity violated?	Yes	No
X	Is there a claustrophobic feeling (e.g., buildings close to freeway)?	Yes	No
Y	Is the ramp straight while the main lanes are curved?	Yes	No
Z	Are the approaching main lanes curved?	Yes	No
AA	Is there an entrance ramp within minimum distance of 1,000 ft downstream of this entrance?	Yes	No
BB	Is there an exit ramp within minimum distance of 800 ft downstream of this exit?	Yes	No
CC	Is there < 0.5-mi weaving section between the entrance and the downstream left exit?	Yes	No
DD	Is there an entrance ramp followed closely by an exit, and is the auxiliary lane missing based on dimensions shown in the 2011 AASHTO *Green Book*?(2)	Yes	No
EE	Is the number of exit lanes equal to or greater than the number of through lanes?	Yes	No
FF	Is the number of entrance lanes equal to or greater than the number of through lanes?	Yes	No

The threshold values for each factor were assigned based on the research team's engineering judgment, reviewer feedback, and available research. For example, it was surmised that an approach with two concurrent routes was not particularly unusual and would not be especially taxing on the driver's mental workload; however, approaches with more than two routes would be more complex and should be scored accordingly. Similarly, the number of levels in an interchange is always at least two. The presence of an interchange is itself an indication of some complexity but not overly so. Therefore, an interchange having two levels has a moderate score of 5 points, while interchanges with three or more levels are assigned a high complexity score of 10 points.

Table 18. Factors (numeric) and threshold values used in the spreadsheet.

Label	Factor (In Order of How Information is Added to Spreadsheet)	10 points (When Value of the Factor > Value Below*)	Zero points (When Value of the Factor ≤ Value Below*)
A	Number of concurrent routes	2.0	1.0
B	Number of levels	2.0	1.0
C	Number of missing movements	2.0	0.99
D	Exit ramps per mile	1.0	0.5
E	Entrance ramps per mile	1.0	0.5
F	Left exits per mile	0.3	0
G	Left entrances per mile	0.3	0
H	Number of exit ramps with multiple destinations per mile	0.3	0
I	Multilane exit ramps per mile	0.3	0
J	Optional/shared exit lanes per mile	0.3	0
K	Exit only lanes per mile	0.3	0
L	Proportion of ramps where lane balance is not satisfied	0 percent	0 percent
M	How much shorter than minimum distance is the shortest auxiliary lane (as a percentage of minimum distance)?	0 percent	0 percent

*A total of 5 points are assigned when the value is equal to or less than the value listed in the 10-point column and greater than the value listed in the zero-point column.

Weights

After point values were calculated, weights were applied in the spreadsheet using the weight values shown in table 19. The 32 factors in table 19 have been rearranged from table 17 and table 18 so that they are presented in descending order of weight. Point values given to each factor for each approach were multiplied by the weight. Continuing the previous example, the moderate score of 5 points for concurrent routes was multiplied by the corresponding weight of 3, resulting in a weighted score of 15 points for concurrent routes on that approach.

Researchers tried a variety of weights to evaluate each factor and develop scores in the spreadsheet that would realistically reflect the characteristics of the sites and the ranking of the sites as estimated by the research team. Like the point values, the weights were also assigned based on the research team's estimation of the relative complexity of each factor supported by the feedback from practitioner reviewers. The values of the weights were also designed to sum to 100 so that a weight could easily be identified as a percentage of the total. With those parameters in place, the research team had a great deal of flexibility to determine how to account for those factors in the eventual complexity score.

Researchers used the weights to provide a measure of the complexity of a given factor relative to other factors. Factors with higher weights were deemed to have a greater impact on complexity than those with lower weights. Table 19 shows that the 32 factors used in the spreadsheet were each given weights between 1 and 5. The factors with the largest weights were lane continuity violations and weaving sections less than 0.5 mi in length. These were considered to be the elements that would contribute the most to driver workload and perceived complexity. The factors with the smallest weights were density of optional/shared exit lanes, presence of auxiliary lanes less than 2,000 ft in length, and number of entrance lanes greater than or equal to the number of through lanes. These were considered to be the least complex of the factors under consideration but still worthy of inclusion in the calculation of a complexity score. A review of table 19 shows that there were an additional 14 factors with a weight of 4, 5 factors with a weight of 3, and 8 factors with a weight of 2. The fact that half of the factors had weights of 4 or 5 is a reflection of the researchers' agreement with reviewers that these factors play a sizeable role in increasing the complexity of an interchange. The assignment of a weight of 1 or 2 does not mean that a factor is not complex but rather that it is not as complex as other factors in the judgment of the research team.

Factors with higher weights are generally concerned with ramp densities, left-side ramps, ramps with multiple destinations, lane balance violations, speed-change lanes with taper designs, more demanding alignments (e.g., loop ramps, curved approaches to ramps, etc.), and a perception of a claustrophobic effect due to large buildings or other items close to the freeway. In the estimation of the research team, these items are more complex and add more to the driver's mental workload than other items. In some cases, a factor was given less weight because researchers believed that another factor also at least partially accounted for its complexity, such as giving a left shoulder less than minimum width a weight of only 2 because the presence of a concrete barrier less than minimum width distance to the left of the travel way was considered to be worth a weight of 4. The location of the concrete barrier is related to the width of the shoulder, but the presence of a barrier increases complexity further because the driver is more concerned about a roadway departure if there is a concrete barrier nearby than if the median is more forgiving.

A factor that is not directly addressed in table 19 is the presence of a C-D road. The way that the spreadsheet treats a C-D road is that it simplifies the operation of the through route on the freeway because the number of access points is reduced. However, when considering the path that an exiting or entering driver must take, it could be argued that a C-D road increases complexity because those drivers have to navigate through at least one additional decision point to reach their destinations. A full exploration of the complexity effects of C-D roads was ultimately beyond the scope of this project, but it is definitely worthy of consideration as a future research topic.

Table 19. Factors and weights used in spreadsheet sorted by weight.

Order	Factors	Weight
W	Is lane continuity violated? (yes/no)	5
CC	Is there < 0.5-mi weaving section between entrance and downstream left exit? (yes/no)	5
Z	Are the approaching main lanes curved? (yes/no)	4
E	Entrance ramps per mile.	4
R	Is a loop present on exit ramp? (yes/no)	4
T	Is a taper SCL present on entrance ramp? (yes/no)	4
S	Is a taper SCL present on exit ramp? (yes/no)	4
U	Is the number of general purpose lanes greater than three? (yes/no)	4
X	Is there a claustrophobic feeling (e.g., buildings close to freeway)? (yes/no)	4
O	Is there a concrete barrier less than minimum width distance of 4 ft to the left of the travel way? (yes/no)	4
AA	Is there an entrance ramp within a minimum distance of 1,000 ft downstream of this entrance? (yes/no)	4
BB	Is there an exit ramp within a minimum distance of 800 ft downstream of this exit? (yes/no)	4
G	Left entrances per mile	4
F	Left exits per mile	4
H	Number of exit ramps w/multiple destinations per mile	4
L	Proportion of ramps where lane balance is not satisfied	4
DD	Is there an entrance ramp followed closely by an exit, and is the auxiliary lane missing based on dimensions shown in the 2011 AASHTO *Green Book*?(2)	3
Y	Is the ramp straight while the main lanes are curved? (yes/no)	3
Q	Is there a concrete barrier less than minimum width distance of 10 ft to the right of the travel way? (yes/no)	3
A	Number of concurrent routes	3
C	Number of missing movements	3
K	Exit only lanes per mile	2
V	Are managed lanes present? (yes/no)	2
D	Exit ramps per mile	2
N	Is the left shoulder less than the minimum width of 4 ft? (yes/no)	2
P	Is the right shoulder less than the minimum width of 10 ft? (yes/no)	2
EE	Is the number of exit lanes equal to or greater than the number of through lanes? (yes/no)	2
I	Multilane exit ramps per mile	2
B	Number of levels	2
M	How much shorter than minimum distance is the shortest auxiliary lane (as a percentage of minimum distance) ?	1
FF	Is the number of entrance lanes equal to or greater than the number of through lanes? (yes/no)	1
J	Optional/shared exit lanes per mile	1

Many of the factors considered in the spreadsheet are discrete choices, and the high threshold value is a reflection that the characteristic, if present on an approach, has a high impact on complexity for that approach. For other factors, the threshold is based on a measurement or a count, and there are values for which the factor may not have a substantial effect on complexity even if it is present at the site. These factors have some flexibility in adjusting the thresholds, if desired, to revise the base points assigned to values of those factors.

Adjusting Weights and Calculating Scores

The base points for each factor are multiplied by their respective weights to produce weighted scores, which are summed to produce a score for the entire approach. Approach scores are averaged to produce the interchange score. Given the limited number of factors with adjustable thresholds, researchers focused on the values of the weights to produce a set of interchange scores that best reflected the relative complexity of the study sites. Researchers tried a variety of weights for the 32 factors. The values shown in table 19 produced results most similar to the research team's qualitative evaluation of the sites, indicating that for these characteristics, weights, and threshold values, the results produced a generally accurate sense of the relative complexity of the interchanges studied. The researchers recognize that other practitioners and spreadsheet users could develop a logical basis for adjusting the weights and thresholds to a different set of values than those shown here; however, they believe that the values used in the spreadsheet are also a valid and reasonable option, and the consistency in the relative scores and groupings supports that conclusion.

All of the weighted factor scores are summed in the spreadsheet to produce a complexity score for the approach. The approach complexity scores are then averaged to produce an overall complexity score for the interchange, ranging between 10 and 1,000 points.

RESULTS

Scores

After all of the site information was entered into the spreadsheet and the weights were optimized, researchers tabulated the scores from all 28 study sites.

Table 20 shows the final scores for each study site. Sites are listed in order of descending complexity based on the judgment of the research team. Cells shaded in gray have spreadsheet scores that are different from their place on the list. A review of the list indicates that the spreadsheet generated scores that were generally consistent with researchers' estimation of the sites' relative complexity. There are two exceptions to the correlation between the scores and the researchers' estimated complexity, both of which are within one ranking of being correlated with the spreadsheet scores.

Table 20. Complexity scores for study sites.

Rank	Site	Interchange Complexity Score	Group
1	OH-2	590.00	1
2	VA-2	571.25	1
3	OH-3	568.75	1
4	AZ-2	466.25	1
5	AZ-1	422.50	1
6	OH-1	398.33	2
7	DE-3	390.00	2
8	OR-1	385.00	2
9	DE-2	373.75	2
10	GA-2	342.50	2
11	VA-1	338.75	2
12	OR-2	321.67	2
13	VA-3	307.50	2
14	NY-3	312.50	2
15	GA-3	291.25	3
16	IA-1	277.50	3
17	MD-1	275.00	3
18	IN-1	266.25	3
19	NY-1	260.00	3
20	SC-2	252.50	3
21	IN-3	256.25	3
22	DE-1	240.00	3
23	IA-2	238.75	3
24	GA-4	231.67	3
25	SC-1	215.00	4
26	AZ-3	215.00	4
27	IA-3	197.50	4
28	SC-3	180.00	4

Note: Gray shading indicates cells have spreadsheet scores that are different from their place on the list.

The sites in table 20 were divided into four distinct groups based on the spreadsheet scores. Sites with similar scores were viewed as having similar levels of complexity. The sites in group 1, the five sites with the highest scores, all had a complexity that was estimated to be much greater than that of the other 23 sites. In fact, the three highest scoring sites had substantially higher scores than the remaining sites, separated from sites 4 and 5 by more than 100 points. Group 2 represented sites that scored between 300 and 400, group 3 represented sites that scored between 230 and 300, and group 4 represented sites with scores below 230. A review of the two exception sites shows that despite their placement on the list, they were still contiguous to the group that contained the sites with similar scores; for example, NY-3 was one place lower in its ranking than its score would suggest, but researchers still considered it to be more complex than any of the group 3 sites. The similarity between exception scores and adjacent scores suggests that the differences in complexity between sites in the same group may not have been particularly significant. This characteristic is discussed in greater detail later in this chapter, but it should be emphasized that the ranking was based on the opinion of the researchers, as were the weights and scores associated with the spreadsheet calculations.

Interpretation of Scores

As mentioned previously, there was a noticeable gap between the highest scores and the remaining scores. In particular, three sites received scores over 550: OH-2, VA-2, and OH-3. These three sites were in constrained urban environments, had unusual geometry, and had high ramp densities with multiple destinations (e.g., see figure 39). As a result, these interchanges received a non-zero score for almost every variable in the spreadsheet on at least one approach. All had at least one approach with a score of 660 or greater, and the EB and WB approaches at VA-2 had scores of 720 and 770, respectively, which were the two highest scores in the database.

There was a substantial drop in score between these interchanges and the fourth site on the list, AZ-2, which also had some unusual geometry but was not as constrained as the first three sites. The fifth highest scoring site, AZ-1, had similarities to AZ-2 but was even less constrained on its speed change lanes and ramp spacing.

The site with the lowest score, SC-3, was submitted because of its closely spaced ramps on an interstate highway intersected with two numbered routes that existed as at-grade city streets (see figure 40). While the geometry of the interchange was unusual, the lower score was a result of the configuration of the ramps. The site had a C-D system that required only one exit and one entrance from the freeway. The NB approach received a score of only 115, which was the second lowest score of any approach in the database. One reason why the site had a low score was because the intersecting numbered routes were not freeways, and their complexity could not be measured in the same way as that of freeway routes. The city streets had traffic signals and other traffic control devices not found on freeways as well as substantially lower speeds, which arguably reduced the complexity of navigating those routes. Regardless if they were less complex, their characteristics prevented them from being directly compared to freeways within the spreadsheet, and thus those routes were not tabulated.

Figure 39. Photo. Configuration of site OH-2.[46]

©2010 Google Earth®

Figure 40. Photo. Configuration of site SC-3.[47]

The other sites in group 4 typically had some unusual geometry in that at least one maneuver to travel from one route to another required using one or more ramps that were on an unusual alignment or were not constructed similar to the ramps for the other maneuvers at the interchange. However, the overall complexity of the interchanges was not nearly as great as the others in the study sites because drivers generally had to face few decision points, there were no left-side ramps, the number of general purpose lanes was low, there were no concurrent routes, and/or the ramp density was low.

Sites in groups 2 and 3 had complexity levels similar to other sites within the same group, reflecting a variety of combinations of ramp densities, left-side ramps, missing movements, travel lane configurations, lateral clearance and roadside environment, ramp geometry and alignment, and auxiliary lane configurations. Sites in group 2 had more characteristics that triggered points on their scores than sites in group 3. Overall, a comparison of sites in group 4 to sites in groups 3, 2, and 1 in table 20 shows sites that had increasingly more factors that contributed to an increased score. The combinations of those factors were not always the same, but the number of factors present at a site generally increased as the group changed from 4 to 1 so that sites in group 4 had few score-generating factors present, while group 1 sites had most (if not all) of those factors present on at least one approach.

DISCUSSION

This chapter described the development of the spreadsheet tool and provided the results of applying the spreadsheet to 28 existing interchanges across the United States. This concluding section discusses the ramifications of those results as well as key characteristics of the spreadsheet and its usefulness.

Features of the Spreadsheet

Key features of the spreadsheet tool include the following:

- The spreadsheet provides a means of objectively comparing the complexity of different interchanges based on a variety of geometric and other variables. It provides a numerical score that is directly comparable to scores from any other interchange. The basis of the spreadsheet is the characteristics of each ramp a driver encounters while driving through any corridor in the interchange.

- The spreadsheet accounts for differences between entrance ramps and exit ramps, frequency of ramps, differences between freeway-to-freeway connector ramps and service ramps, differences between taper and parallel speed-change lanes, presence of managed lanes, presence of narrow shoulders, number of concurrent routes and vertical levels, shared exit lanes, lane continuity and lane balance, and horizontal alignment, among other features.

- The spreadsheet is designed so that a user does not need to physically visit the interchange and take measurements in the roadway to complete it. All of the necessary information can be obtained through as-built plans or a mapping service such as Google Earth®.

- The spreadsheet establishes threshold values for each factor to provide a means of assigning points that increase as the contributing characteristic increases in complexity. The spreadsheet also provides weights to each factor to generate higher scores for characteristics that are relatively more complex than others.

- The spreadsheet checks the distance between successive ramps based on the procedure defined in the 2011 AASHTO *Green Book*.[(2)] This check allows the user to readily determine whether the distance between any two successive ramps is shorter than recommended, identifying a variable that contributes to complexity.

- The spreadsheet has a feature to account for the built environment adjacent to the freeway. A densely built urban environment adds more workload to a driver than a sparsely built rural environment. Similarly, the spreadsheet accounts for the number of lanes on both the ramps and on the general purpose lanes or main lanes. An increased number of lanes also means an increased number of decisions a driver must make to determine what lane is the correct lane for the driver's destination. More travel lanes also typically represent higher traffic volumes, resulting in more demands on a driver's attention while navigating the interchange.

- The spreadsheet accounts for each approach individually as well as collectively. This feature allows a user to identify a particularly complex approach within a high-scoring interchange.

Limitations of the Spreadsheet

Despite all of the features that can be found in the spreadsheet, there are a number of limitations. Some of these were included in discussions by the research team while developing the spreadsheet, while others were discovered during the review and quality control process. A summary of key limitations is as follows:

- By design, the spreadsheet includes only characteristics that can be obtained through Google Earth® or a similar mapping service. This is intended to enable more practitioners to use the spreadsheet without requiring access to certain types of site-specific data, such as traffic volumes, construction history, or other information that may not be readily available.

- The spreadsheet does not directly account for a driver's destination or origin unless the driver is traveling straight through the interchange on the same route from approach to departure. While each exit and entrance ramp is included in the analysis, the spreadsheet does not directly document the series of decisions that an exiting or entering driver would have to make for all of the origin-destination combinations in a given interchange. Specifically, it does not estimate the complexity of a path from one route to another; it only describes complexity along the same route. For example, missing movements were not originally included in the spreadsheet, but consideration for them was added to help describe how some interchanges are more complex because of what is absent rather than what is present.

- The spreadsheet does not account for interactions between factors. Researchers discussed how one factor might affect another so that the combination of the two factors added more complexity than just the sum of the two factors individually. A proper exploration of interaction would be a very time consuming and complicated process and could not be adequately addressed in this study.

- While the spreadsheet does consider C-D roads within the variable for multiple destinations from a single ramp, it is unclear whether the full effect of C-D roads is truly addressed. C-D roads help to remove merging, diverging, and weaving maneuvers from the main lanes, thus helping to reduce complexity for through drivers. However, C-D roads may actually be more complex than traditional ramps because of the need to exit a substantial distance upstream of where a driver would expect to exit. That effect is not captured in the spreadsheet.

- Spreadsheet results do not fully appreciate the effect of adjacent interchanges. While the nearest upstream and downstream ramp is documented within the spreadsheet, the full effect of that ramp as part of another potentially complex interchange is not included in the analysis. Within the study sites compiled for this spreadsheet, there are three sets of interchanges that are either adjoining or in very close proximity. The two Oregon sites

(OR-1 and OR-2) are a short distance apart, and both are constrained by the boundaries of the Willamette River. It is possible that the close proximity of the two interchanges makes traversing them more complex than if they were apart. Two Virginia sites (VA-1 and VA-2) are adjacent on I-395, and all three Delaware sites are close enough that a driver could easily drive through all three in one maneuver, changing routes only once. There could be a cumulative effect of these interchanges being so close together, but a thorough exploration of that effect is beyond the ability of this study.

- The spreadsheet is not designed to accommodate more than four approach legs. The spreadsheet was established to account for four corridors: NB, SB, EB, and WB. Those designations could change somewhat if the interchange in question is not particularly oriented to those directions, but the process for using the spreadsheet is the same if the interchange is quadrivial (i.e., having four roads meeting at a point). However, an arguably more complex interchange is one with more than four approaches (i.e., superquadrivial). The majority of sites submitted for New York are in this category. These interchanges are more complex than those evaluated because of the additional legs that must be considered. Unfortunately, expanding the spreadsheet to account for those additional legs would make for an unwieldy spreadsheet, and it is unclear whether a direct comparison between quadrivial and superquadrivial interchanges would be valid.

- As previously mentioned, the spreadsheet does not account for traffic volumes. An implied connection can be made between number of lanes and traffic volumes, but volumes are not directly requested in the set of input data. Similarly, the volume-to-capacity ratio or the level of service is not requested in the spreadsheet. Those variables could also have an effect on the complexity of an interchange, but they are not design characteristics and were deemphasized for this study.

Additional Considerations

In addition to the features and limitations of the spreadsheet, the following list includes some other items that may be considered when understanding how the spreadsheet functions:

- The topic of missing movements has been mentioned previously in this chapter where a missing movement prevents a driver on a given approach from directly accessing a different approach. It may be possible to go from one to the other but only through a series of maneuvers such as U-turns or multiple exits and entrances. Originally, missing movements were not included because the spreadsheet only evaluated existing ramps; the spreadsheet could not consider a ramp that did not exist. An adjustment was made to include missing movements.

- The results of the spreadsheet (i.e., the scores for each interchange and each individual approach) are dependent on the high/low threshold values and weights, which were subjectively determined by the research team with input from reviewers. Even the fact that the weights were originally designed to generate a 100-point total for ease of observation may affect the results, allowing for a different point total to provide a different means of establishing the weights. The research team believes that the 100-point total is beneficial and aids the user in understanding the results. Researchers also believe the sets of weights and threshold values presented are reasonable, given the consistency in the relative scores and groupings that resulted from the variety of combinations tested. The team also recognizes that a different set of weights and values that produce somewhat different scores could be developed on a reasonable basis.

- A full sensitivity analysis would help determine whether some weights or threshold values are inappropriately affecting the scores. A partial analysis was conducted on selected variables, but a full analysis was not possible in this study. For example, it is unclear whether the number of general purpose lanes is optimally accounted for in the spreadsheet. It is used as a surrogate for traffic volume and provides an indication of complexity if a driver must make additional lane changes, but it is unknown how sensitive the score is to the presence of two through lanes instead of three or four (if the threshold value was changed) and whether the presence of three general purpose lanes is truly as complex as the presence of a concrete barrier within 4 ft of the left side of the travel way. Again, the research team believes that the sets of weights and threshold values presented are reasonable, but the team also recognizes that a reasonable approach could produce a different set of weights and values that produce somewhat different scores.

- Another topic of consideration is how study distance is measured. This spreadsheet includes all the distance a driver must travel to navigate through the interchange, which means that the distance is measured from the point immediately downstream of the nearest ramp in the adjacent upstream interchange to the point of the nearest ramp for the succeeding interchange. This distance may be too large to sufficiently capture the effects of some calculated values, such as ramp density. The added distance may understate a ramp density's effects, particularly for cloverleaf interchanges that have segments of dense ramp locations (i.e., a cluster of ramps) followed by a long distance between ramps, resulting in a lower ramp density over the entire study distance.

- Operating speed and posted speed limit are not accounted for in this spreadsheet, and some of the sites had lower posted speed limits than others with similar or lower scores. For example, NY-3 had a posted limit of 45 mi/h on its major route; however, because of its ramp density and presence of left entrances and exits, it had a higher score than other sites with higher speed limits. It is unclear to what extent lower operating speeds would mitigate some of the complexity in an interchange such as NY-3 compared to other sites with fewer complex elements but higher speeds.

- The use of the average approach score to determine the overall interchange score may deemphasize a particularly complex approach. It is possible that the use of the highest approach score would be beneficial in determining the complexity of an interchange, but that method could also deemphasize a relatively simple approach. As stated before, practitioners could develop reasonable explanations for using either method.

CHAPTER 5. SUMMARY

DRIVING SIMULATOR EVALUATION OF SIGN TREATMENTS

This report discusses the procedure used to develop, test, reduce, and analyze several SSs evaluated in a simulator study. From a list of potential topics identified by the research team as needing evaluations, the following topics were selected for the simulator study:

- Topic 1: Use of option lane.
- Topic 2: Close proximity of two interstate exits.
- Topic 3: Y-split.
- Topic 4: Information spreading (more signs per bridge).
- Topic 5: Information spreading (multiple SBs).
- Topic 6: Left exit.

During the study, test signs were introduced in the simulation along freeway roadways to evaluate drivers' real-time response to the signs. The verbal instructions indicated a starting lane and a destination that the participants were to drive toward. The key recorded measures included lane position, lane change, and distance from SB for the lane change.

Topic 1 tested the understanding and use of different methods to sign for an option lane. The topic evaluated driver understanding of arrow per lane, down arrow per lane, or signing only for the exit and not the through movement. Almost all participants made the correct decision to exit or stay on the freeway; however, many unnecessary lane changes were made with each of the three SSs for those people whose SL was either the far left or the far right. Those drivers who started in the center lane and were given a through route destination were less likely to make unnecessary lane changes compared to all other conditions. The interesting finding is that drivers who started in the center lanes and were told to exit moved to the far right lane, which included an unnecessary lane change. However, drivers who started in the center lane and were given the through destination did not move to the far left lane. This may have been due to some reluctance on their part to move into the left lane, which is typically used for high-speed passing.

Topic 2 studied methods to create signs when two interstate exits were within close proximity, and a need existed to create signs for three destinations (two interchanges/exits and the through lanes). For SS 2-B, which had an arrow-per-lane design, all participants (42) made correct lane change decisions. SS 2-C, which had a diagrammatic sign, also had many correct lane change decisions, with five or more of the seven participants in a group making the correct decision. Of the 42 participants who viewed SS 2-C, only 3 made incorrect lane change decisions. SS 2-A (multiple signs with exit only panels) did not have as favorable results (e.g., 6 of the 42 participants made incorrect lane change decisions). SS 2-A also had more of the participants wanting additional information to make a lane-change decision.

Topic 3 evaluated signs for an upcoming exit that then had a Y-split into two directions. Signing options included a split sign to explore whether it helped to maneuver drivers into the appropriate lane for the Y-split in advance of the initial exit. The split sign showed the two destinations side by side with a vertical white line separation. For SS 3-B, the split sign was used for the two advance signs and at the gore. SS 3-C only used the split sign at the gore with the two advance signs showing the destinations vertically stacked. SS 3-A used the vertical stacked format for both the two advance signs and the gore sign. The lateral location of the destination on the sign was used by the participants in making a lane-change decision. As can be seen in figure 28 and figure 29, several lane changes were made at the first appearance of the split exit sign (at SB I location for SS 3-B and at SB III location for SS 3-C). While several incorrect lane changes were made for each SS, SS 3-B, which used split exit signs at all three SB locations, had the fewest and was judged superior in comparison to the other two arrangements.

Topic 4 evaluated whether it was better to fill an advance single sign with supplemental way-finding information or to spread the information among multiple signs, including ground-mounted signs. Gore signs with advance signs at 1 mi were used to explore if sign spreading on a single bridge or on multiple bridges improves where the lane change is occurring. For most of the variations studied, SS 4-C (sign spreading across two SBs) had the most participants make the correct lane change decision, although SS 4-A (information for next exit stacked on one sign) also had many of the participants correctly making lane positioning decisions. When the destination information was spread across multiple signs on a single bridge, several participants made incorrect lane changes to the left when the instructions were to go to the second destination. These drivers may have been positioning their vehicle into the lane under the sign with their intended destination. This finding indicates that spreading information about the next exit across multiple signs on a single bridge may have unintended consequences if the SB also includes a sign for another exit that is located to the left of the preferred lane.

Topic 5 evaluated the effectiveness of sign spreading when there were many bits of information on one SB. One SS did not have sign spreading (SS 5-A), and the other SS (SS 5-B) had sign spreading across multiple SBs. The lateral position of a pull-through sign on the SB is important. SS 5-A had more unnecessary lane changes compared to SS 5-B: half of the participants with SS 5-A had unnecessary lane changes, while SS 5-B had no unnecessary lane changes. Because SS 5-A had more signs on a single SB, the sign for Davenport was farther to the left, which may have resulted in participants trying to position themselves below the Davenport sign, resulting in an unnecessary (but not incorrect) lane change.

Topic 6 evaluated driver understanding of the 2009 MUTCD left exit standards.(1) Only 1- and 0.5-mi advance signs were used to test how quickly a driver identified the left exit and changed lanes and if there was confusion on whether it was an exit only or optional exit. SS 6-A had a yellow plaque at the top left, and SS 6-B had a yellow panel at the bottom of the sign. Generally, for the two SSs tested under this topic, participants understood which side of the road the exit was located. It is unclear if this was because the participants were cued by the placement of the sign over the left lane, read the word “left” on the signs, or a combination of the two. The placement of the sign over the left lane resulted in the participants correctly avoiding moving across multiple lanes to make a right exit. However, when the participants did not need to make a left exit, they frequently moved out of the left-most lane—even though the lane was not an exit-only lane—due to personal preference. A few more of the non-exiting participants seeing SS 6-B with the yellow panel at the bottom of the sign moved out of the left-most lane (8 of 14) compared to the participants seeing SS 6-A with the yellow plaque at the top left (5 of 14). For this study, the difference between these two SSs was minimal.

DECISION TOOL TO DEFINE AND QUANTIFY INTERCHANGE COMPLEXITY

Researchers were tasked with developing a tool that could aid practitioners in assessing the complexity of a freeway interchange and objectively compare it to other interchanges. The focus of such a tool was on geometric design factors and related effects on driver expectancy and driver workload. Researchers considered a variety of factors and formats, ultimately developing a spreadsheet tool in which users could enter site characteristics and receive a numerical complexity score for a given interchange. After several revisions, researchers settled on a spreadsheet tool that considers the effects of 32 weighted factors on as many as 4 approaches within a given interchange. The weights range in value from 1 to 5, and the sum of the 32 weights is 100 (see table 19). The estimated impact of each factor is given points, which, when multiplied by the weight, produces a weighted score on a 1,000-point scale for each approach and for the interchange as a whole.

To determine how well the spreadsheet tool would evaluate interchanges, the research team used the spreadsheet to review 28 existing sites in 11 States. The sites were submitted by State transportation departments on the basis of their perceived complexity. The 28 sites were divided into 4 distinct groups based on the spreadsheet scores ranging from a high of 590 to a low of 180. Sites with similar scores were in the same group and were viewed as having similar levels of complexity. Researchers tested multiple combinations of weights to develop scores for the 28 sites. While individual site scores changed as the weights changed, the final set of weights produced results similar to the rankings and groupings of the study sites determined by the research team. This indicates that for the characteristics included in this spreadsheet, the results produce a general sense of the relative complexity of the interchanges studied.

In summary, the complex interchange spreadsheet tool is a useful tool for objectively comparing the complexity of multiple interchanges and determining what characteristics contribute to that complexity. There may be other variables that could be useful additions to the factors already included, and it is possible that a different distribution of weights and threshold values may produce a reasonable set of scores that varies from those presented here; however, these scores allow the user to evaluate one or more interchanges to identify potential problems that drivers may face as they travel through those interchanges. Consideration of these issues can help practitioners identify potential countermeasures either through the use of traffic control devices or, ideally, through the use of revised designs to mitigate the site characteristics that are potentially problematic.

APPENDIX A. SIMULATION STUDY

INTRODUCTION

This appendix discusses the procedure used to develop, test, reduce, and analyze the sequence test topics evaluated in the simulator study.

TOPICS FOR TESTING

A list of potential topics was created as a guideline for the types of sign sequences needing evaluations. The initial list included the following items:

- Driver understanding of gore sign down arrow or arrow per lane versus only signing the exit and not the through movement.
- Driver understanding of down arrow per lane versus shared arrow gore sign.
- Driver understanding of advance signs for multilane freeways.
- Driver lane change behavior when encountering lane ends.
- Driver understanding of exit number plaque placement and driver behavior in a sequence of splits and exits. For example, driver comprehension of signage for left lanes that becomes right exits because of a sequence of splits and exits.
- Driver understanding of the 2009 MUTCD left exit standards.[1]
- Driver understanding of exit only sign text to provide confirmation of earlier findings that drivers prefer to get out of an option lane.
- How to sign for distant downstream destinations and challenges with exits being out of order relative to destination proximity.
- Is it better to fill an advance single sign with extra navigation information (i.e., more than two destinations) or to spread the information among multiple signs (possibly ground signs)?
- Which sign elements do drivers read in multisign banks? In what order are they read? Is this lane dependent?
- Driver interpretation of multiple separate exit only panels in the same sign bank.
- Are there limits on the number of lanes that can be effectively communicated by diagrammatic signs (i.e., more than four)?

- Driver interpretation of sign information above one lane that pertains to a different lane. This could include driver assumptions about the pairing of signs with lanes rather than exit order.

- Driver interpretation of route ends signs (typically freeway spurs).

- Driver reading and comprehension of signs with complex yellow panels (i.e., including exit distance and speed limit).

- Driver comprehension of what information goes together on signs with complex layouts.

- How do different sign elements and sign layout options affect drivers' expectations of the upcoming interchange geometry?

- How do different sign elements affect drivers' understanding of the interchange navigation and the destination groupings?

- How to sign for three destinations (legs).

This list was later altered, and topics were assigned to a study using photographs, a TTI simulator study, or both. When deciding which topics should be addressed by the contractor survey and which by the TTI survey, researchers first considered the measures of effectiveness. For topics where it was important to determine how quickly a driver would make a lane choice, a simulator study was desired. If it was only important to know what lane drivers would choose, the contractor survey was a more appropriate and less expensive option. Also, if it was important to see signs in a sequence and for the driver to see their spatial placement on the roadway, the simulator study was more appropriate. While the simulator offered driver immersion and driving data, the laboratory study allowed for quick, inexpensive testing of many different SSs. It is important to note that finalizing the topic list was an iterative process with the division of topics between the TTI simulator study and the contractor survey, as well as the elimination and addition of particular topics.

SIMULATOR STUDY PROCEDURE

TTI houses a Realtime Technologies, Inc. desktop simulator that can be operated with one or three screens depending on study requirements (see figure 41). During the study, test signs were introduced in the simulation along freeway roadways to evaluate drivers' real-time response to the signs. The verbal instructions indicated a starting lane and a destination they were to drive toward. There were three types of destinations: exit, through, or a destination not mentioned on the signs. The starting lane and destination were varied between participants for each SS tested. The simulation environments were designed so that the drivers had ample time to reach an instructed 60–70 mi/h speed before viewing the first SS in each sequence. A speed range was given rather than an exact speed to discourage drivers from focusing their attention too much on the speedometer. The verbal instructions are shown in figure 42. For added realism, the roadside environment housed urban buildings spaced back from the roadway to avoid distraction from the signs. There was no additional traffic so that participants could make uninhibited lane changes and avoid inconsistent and possibly immeasurable distractions.

Figure 41. Photo. Example view of simulator.

Before we get started, I'd like to encourage you to ask questions whenever necessary, but other than that, please keep talking to a minimum.

[Practice (Begin reading as world is started)] The driving simulator you are seated in is an interactive simulator, which means the driving scenes you experience react to your steering and pedal inputs to provide a realistic driving experience. During your drive in the simulator, please drive in a normal fashion. You can adjust your pedals at a position that is comfortable for you. You will only be using the accelerator and brake and will not need to use the clutch on the far left. You will also not need to use your turn signal or any of the buttons on the steering wheel, although it will not hurt anything if you use them.

For the practice session, your task is to get comfortable with driving in the simulator. Go ahead and slowly maneuver onto the roadway and accelerate to a speed of 60 to 70 mi/h. Don't worry about driving at an exact speed limit; just do your best to try to stay in that range.

How are you doing? Practice switching back and forth from the accelerator to the brake to get comfortable with the pedals. We can adjust the pedals' position if you need to. Also, I'd like you to practice changing lanes. You do not have to worry about other vehicles being in your blind spot.

You will drive 15 short drives similar to what you are driving now. At the beginning of each drive, I will give you a lane to start in and then will also give you a destination I'd like you to drive toward. When I give you the destination, please say the name back to me so that I know that you heard me correctly. Let's practice that now. Please start in the second-from-the-left lane. Your destination is Newport. *(Correct the participant if he or she does not move over to the second-from-left lane and say "Newport" back to you.)*

(As the participant approaches the first sign) Ahead you will see signs that will help you navigate to your destination. I only want you to make lane changes as necessary, but please make any necessary lane changes as soon as you are certain you will need to make one. After you pass the signs, please continue driving until I ask you to pull over and stop. When I do that, I will ask you some questions about the signs you saw and the lane choices you made.

(Allow them to pass the signs and then make an appropriate lane change.) Please bring the vehicle to a stop. *(Keep the simulation going, and ask questions in the participant packet.)*

Now we are going to get a little more practice. Please maneuver to the right lane and maintain a speed of 60-70 mi/h. *(When they approach the end of the world)* Please slowly coast to a stop.
[**Save Practice file as instructed on participant packet]**

[Introduction] The experimental sessions will be just like the practice session you just did. Please remember to drive between 60 and 70 mi/h. I will instruct you to start in a particular lane and will give you a destination to drive toward. Please repeat that destination to me. Remember to only make lane changes as necessary, but please make any necessary lane changes as soon as you are certain you will need to make one. I will instruct you when to pull over for the end of the session and then will ask you some questions that you can answer out loud. Do you have any questions? Please let me know if you need to take a break between sessions.

Figure 42. Illustration. Facilitator instructions.

Due to a combination of simulation geometry limitations and study intent, TTI used a variety of methods and interchange geometries to test the SSs. Several topics described in this section tested driver response to advance signs only (i.e., the 1- and 0.5-mi advance signs). After driving past two sets of advance signs, the simulation was stopped before the interchange came into view. With this approach, upcoming roadway geometry was not an influence on driver behavior, and the advance signs could be tested in isolation. This method of testing was sufficient for many topics because effective signing should result in drivers making decisions well before the gore point. Other topics tested driver response to a sequence of signs including advance signs plus gore signs. For these topics, drivers did reach an actual interchange that matched the geometry indicated on the signs.

In a previous version of the work plan, TTI proposed testing some gore signs in isolation without any advance signs. With preliminary testing in the simulator, it was found that sign viewing time in the simulation was shorter than that of the real world at the same speeds and did not give participants sufficient time to safely make a lane choice. As a result, all topics were tested with at least two signs in the sequence.

For each method, the key recorded measures included lane position, lane change, and distance from SB for the lane change. Verbal follow-up questions (e.g., what other lanes could you have been in to reach your destination?) or questions about information on the set of signs pertaining to an alternate destination than assigned were also asked following each drive segment.

STIMULI DEVELOPMENT

The sign stimuli used in this study were developed using SignCAD® traffic sign design software. Along with the built-in standards tables of the software, TTI researchers used the MUTCD and the *Standard Highway Sign Manual* design guidelines to ensure the most accurate and consistent sign representations.(1,48) In several instances, SignCAD® could not create exactly what researchers desired. As a result, Adobe Photoshop® was used to finish the design. Finally, in order to appear more realistic and less cartoon-like in the simulator environment, the sign contrast and saturation were adjusted. Within the simulator environment, signs were viewed at the correct proportion to the roadway dimensions.

EXPERIMENTAL DESIGN

Table 1 lists the number of SSs tested and the number of determined testing variations (SL and instructed destination). Due to the high number of test scenarios, a between-subjects experimental plan was designed that divided the participants and the test scenarios into 6 groups with each participant seeing 15 scenarios, as shown in table 21. The scenarios with an asterisk reflect the second time that a group would drive a simulation from the same topic/SS combination. For example, group 1 would see SS A within topic 1 twice—once when starting in lane 1 and being told to exit (1A_E_1) and the other time starting in lane 3 and being told to go through (1A_T_3). Once reordered, these particular scenarios were separated by many other scenarios so that researchers believed a new SS with new destinations would not be required for the second time the same topic was shown.

Table 21. Test scenarios by topic divided into participant groups.

Topic	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
1	1A_E_1	1A_E_1*	1A_E_2	1A_T_3	1A_T_2	1A_E_2
	1A_T_3*	1A_T_2	1B_E_1	1B_E_2*	1B_E_1	1B_T_2
	1B_E_2	1B_T_3	1B_T_2*	1B_T_3	1C_E_2	1C_E_1*
	1C_T_2	1C_E_2	1C_E_1	1C_T_2	1C_T_3*	1C_T_3
2	2A_2nd_2	2A_1st_2	2A_T_3	2A_T_4	2A_2nd_4	2A_2nd_5
	2B_2nd_5	2B_2nd_4	2B_T_4	2B_T_3	2B_1st_2	2B_2nd_2
	2C_2nd_4	2C_2nd_5	2C_1st_2	2C_2nd_2	2C_T_4	2C_T_3
3	3A_Left_2	3A_Left_3	3A_Right_2	3A_Right_3	3B_Left_2	3B_Left_3
	3B_Right_2	3B_Right_3	3C_Left_2	3C_Left_3	3C_Right_2	3C_Right_3
4	4A_CNV_1	4A_CNV_2	4A_2nd_2	4A_1st_2	4B_CNV_1	4B_CNV_2
	4B_2nd_2	4B_1st_2	4C_CNV_1	4C_CNV_2	4C_2nd_2	4C_1st_2
5	5A_T_4	5A_Oak_1	5A_Leon_3	5A_Leon_3	5A_Oak_1	5A_T_4
	5B_Leon_3	5B_Oak_1	5B_T_4	5B_T_4	5B_Oak_1	5B_Leon_3
6	6A_T_1	6A_T_1	6A_E_1	6A_E_1	6A_E_3	6A_E_3
	6B_E_3	6B_E_3	6B_T_1	6B_T_1	6B_E_1	6B_E_1

*Second time that a group would see a test variation from the same topic/SS combination.

The scenarios in table 21 were reordered to avoid learning effects. The actual experimental order is shown in table 22.

Table 22. Experimental order by participant group.

Experimental Order	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
1	1A_E_1	2C_2nd_5	5B_T_4	4C_CNV_2	2B_1st_2	1C_T_3
2	6A_T_1	1A_T_2	1B_E_1	1B_T_3	1C_E_2	5A_T_4
3	2A_2nd_2	5A_Oak_1	3C_Left_2	6B_T_1	5B_Oak_1	4B_CNV_2
4	3A_Left_2	6B_E_3	6A_E_1	2C_2nd_2	3C_Right_2	2A_2nd_5
5	1C_T_2	3B_Right_3	2B_T_4	1A_T_3	6A_E_3	1A_E_2
6	4A_CNV_1	1C_E_2	4A_2nd_2	3A_Right_3	1A_T_2	6B_E_1
7	2B_2nd_5	4B_1st_2	1C_E_1	5B_T_4	4B_CNV_1	3B_Left_3
8	5A_T_4	2A_1st_2	2C_1st_2	2B_T_3	2A_2nd_4	4C_1st_2
9	6B_E_3	1B_T_3	3A_Right_2	4A_1st_2	1B_E_1	2B_2nd_2
10	3B_Right_2	6A_T_1	1A_E_2	1C_T_2	6B_E_1	5B_Leon_3
11	1B_E_2	3A_Left_3	4C_CNV_1	3C_Left_3	3B_Left_2	6A_E_3
12	4B_2nd_2	4A_CNV_2	6B_T_1	6A_E_1	5A_Oak_1	1B_T_2
13	2C_2nd_4	1A_E_1	5A_Leon_3	2A_T_4	2C_T_4	3C_Right_3
14	1A_T_3	2B_2nd_4	1B_T_2	1B_E_2	1C_T_3	2C_T_3
15	5B_Leon_3	5B_Oak_1	2A_T_3	5A_Leon_3	4C_2nd_2	1C_E_1

PARTICIPANT RECRUITMENT

Participants were recruited through the existing TTI participant database and by distributed flyers. Possible participants were required to be 18 years of age or older and have a current Texas driver's license. A total of 42 participants were recruited—18 in College Station and

24 in Houston. Researchers used Texas demographics as a guide for participant recruitment to obtain a more accurate sample of the driving population in the test cities. Gender and age of licensed drivers were obtained from 2009 FHWA statistics, as seen in table 23.[42] The education breakdown of Texans ages 18 and older was obtained from the U.S. Census Bureau, as seen in table 24.[43] These breakdowns were used as guides, with education taking priority followed by age and then gender.

Table 23. Texas licensed drivers by age and gender (2009).[42]

Age Category	Males (Percent)	Females (Percent)	Total (Percent)
18–25	12	12	12
25–39	30	30	30
40–54	30	30	30
55–64	15	15	15
65–74	8	8	8
75+	5	5	5
Total	**100**	**100**	**100**

Table 24. Texas educational background based on total population 18+ years old.[43]

Educational Attainment	Males (Percent)	Females (Percent)	Total (Percent)
No high school diploma	22	20	21
High school diploma or equivalent (GED)	27	27	27
Some college, no degree	28	31	29
Bachelor’s degree or higher	23	22	23
Total	100	100	100

DATABASE ASSEMBLY

Participant Files

The simulator study was conducted using a Realtime Technologies Inc. desktop simulator that is operated with one or three screens. The scenarios that were evaluated generated a *.plt file for each participant. The *.plt files are delimited files that can be imported into different analysis software for conducting analyses. The parameters recorded in the study are described in table 25.

Table 25. Variables collected in the simulator study.

Variable	Description
Time (s)	Time from the start of simulation in seconds.
Acceleration (°)	Depression of the acceleration pedal in degrees.
Brake (N)	Force on the brake pedal in Newtons.
Steer (rad)	Steering wheel turn angle in radians (negative is counter clockwise).
Road distance	Cumulative distance within a tile (starts over at 0 for new tile) in meters. Generally, but not always, a tile is 200 m long.
Velocity (m/s)	Participant speed in meters per second.
Lane number	Participant lane number.
Lane position (m)	Participant position within a lane measured from the center of the lane in meters.
Distance 1 (m)	Distance from vehicle to first SB in meters.
Distance 2 (m)	Distance from vehicle to second SB in meters.
Distance 3 (m)	Distance from vehicle to third SB in meters.
Distance 4 (m)	Distance from vehicle to fourth SB in meters.
Distance 5 (m)	Distance from vehicle to fifth SB in meters.

1 ft = 0.305 m

Follow-Up Questions

Each participant was asked follow-up questions to quantify his or her experience/choice of lane after the simulator study. These questions were different for each topic. Details on the questions and scores for the answers are provided in the following sections. A sketch of the path taken by the participant along the simulation scenario, along with test question variation, SL, and destination were also recorded by researchers. This information for each participant and scenario was typed into a spreadsheet to develop a dataset for further analysis.

Demographic Information

Demographic information such as age and gender were recorded for each participant. Table 26 lists the variables and their possible values. This information was typed into a spreadsheet for use in further analysis.

Table 26. Demographic information collected.

Variable	Possible Value
City	C or H
Participant	1 through 24
Gender	1 = male and 2 = female
Age	Any number
Race/ethnicity	1 = White, 2 = African American, 3 = Asian, 4 = Hispanic, and 5 = Other
How many miles a year do you drive?	1 = < 10,000, 2 = 10,000–15,000, and 3 = > 15,000
Where do you do the majority of your driving?	1 = rural, 2 = city, and 3 = freeways
Current employment	1 = full, 2 = part, 3 = retired, 4 = student, 5 = homemaker, and 6 = other
Highest level of education	1 = some high school, 2 = high school, 3 = some college, 4 = college graduate, 5 = some graduate school, and 6 = graduate degree
How often do you play video games?	1 = never, 2 = 1–2/months, 3 = 1–2/weeks, 4 = < 1 h/day, 5 = > 1 h/day

DATA REDUCTION

The assembled data subsets of participant files, follow-up questions, and demographic information were used to build databases for analysis. The participant file subset was exported, and participant number and topic information was added to develop a database for further analysis.

Lane Change Labeling

Participant position within a lane was one of the variables collected in the simulation study. A lane was assumed to be 11.81 ft wide, and the lane position was measured from the center of the lane, with negative values when the car moved left of the centerline and positive values when it moved right. Lane change maneuvers and their direction in the participant data subsets were identified by reviewing the change in lane-change position values. A change in lane position (greater than 1.7 in absolute value) from negative to positive indicated a lane change to the left, whereas a change from positive to negative indicated a lane change to the right. A lane change was recorded when the center of the vehicle crossed the lane line.

To determine the impacts of each SS for various combinations of SL and destination, each lane change maneuver was labeled. Performance of each SS was evaluated by a combination of proper lane choice, absence of unnecessary lane changes, and greater distance from the interchange where the lane changes were made. Apart from the correct, incorrect, and unnecessary lane change labels, different labels were used to account for the differences among the topics. Table 8 explains all labels used in building the dataset. These lane changes were checked with the sketch on the participant data sheet for accuracy and notes/comments. Figure 17 shows an example of the labels used to code lane changes. In the figure, the lane numbers are shown on the bottom of the graphic. The driver started on the right shoulder and was told to start in lane 1, which required several positioning lane changes (see codes starting with P). If the driver moved into lane 2 (as shown with the green solid line), a code of C was used at that point. In this topic, an incorrect lane change (labeled as IR) occurred when the driver moved from lane 1 to lane 2 after the exit ramp. An unnecessary lane change was noted if the driver moved from lane 1 to lane 3 (see orange dashed line).

DATA ANALYSIS AND FINDINGS

Demographic Information

Table 27 lists the demographic information for the 42 participants.

Table 27. Demographic information for 42 participants.

Characteristics		Number (Percent)
Age groups	18–24 years old	5 (12)
	25–39 years old	14 (33)
	40–54 years old	12 (29)
	55–64 years old	8 (19)
	65–74 years old	3 (7)
Race	White	27 (64)
	African American	1 (2)
	Asian	0 (0)
	Hispanic	11 (26)
	Other	2 (5)
	More than one race	1 (2)
Employment	Full time	26 (62)
	Part time	5 (12)
	Retired	5 (12)
	Student	4 (10)
	Homemaker	1 (2)
	Other	1 (2)
Gender	Male	20 (48)
	Female	22 (52)
Education	Some high school	3 (7)
	High school graduate	10 (24)
	Some college/vocational	15 (36)
	College graduate	10 (24)
	Some graduate school	0 (0)
	Graduate degree	4 (10)
Miles driven per year	< 10,000 mi	6 (14)
	10,000–15,000 mi	16 (38)
	> 15,000 mi	20 (48)
Normal driving conditions	Rural roads	5 (12)
	City streets	20 (48)
	Freeways	8 (19)
	Mixed	9 (21)

Frequency of playing video games	Never	25 (60)
	1–2 times/month	12 (29)
	1–2 times/week	3 (7)
	< 1 h/day	0 (0)
	> 1 h/day	2 (5)

Topic 1

Overview

Topic 1 involved testing the understanding and use of different methods for signs for an option lane. The topic evaluated driver understanding of arrow per lane, down arrow per lane, or signing only the exit and not the through movement. Full sequence of three SBs was used to test the understanding and use of the option lane as well as the distance from the signs that lane changes were made. As shown in figure 18 through figure 20, SS A had arrow-per-lane signs, SS B had down arrow-per-lane through signs, and SS C had no pull through sign.

The geometry for the topic was three lanes at the start that then split, with two lanes exiting to the right and two lanes going straight (see figure 11). Table 28 presents the testing variations used in the study, and figure 43 shows how lane changes were coded.

Findings

Table 9 shows a summary of the number of participants with correct, incorrect, and unnecessary lane changes by test variation for topic 1. Plots showing the location of the lane changes are provided in figure 43. Table 28 summarizes the findings from the questions, which were asked following the driving portion.

Table 28. Topic 1 testing variations.

SL	Instructed Destination: Goodwell, Marshall, or Jackson (Through)	Instructed Destination: Reading, Deaning, or Louisburg (Exit)
1	No lane change needed.	Exit destination from lane 1 (1X_E_1). Must change lanes (possibility of unnecessary change to lane 3). Codes: 1A_E_1 1B_E_1 1C_E_1
2	Through destination from lane 2 (1X_T_2). No lane change needed (must decide direction, possibility of unnecessary change to lane 1). Codes: 1A_T_2 1B_T_2 1C_T_2	Exit destination from lane 2 (1X_E_2). No lane change needed (must decide direction). Codes: 1A_E_2 1B_E_2 1C_E_2
3	Through destination from lane 3 (1X_T_3). Must change lanes (possibility of unnecessary change to lane 1). Codes: 1A_T_3 1B_T_3 1C_T_3	No lane change needed.

Note: Shaded cells indicate conditions were not tested.

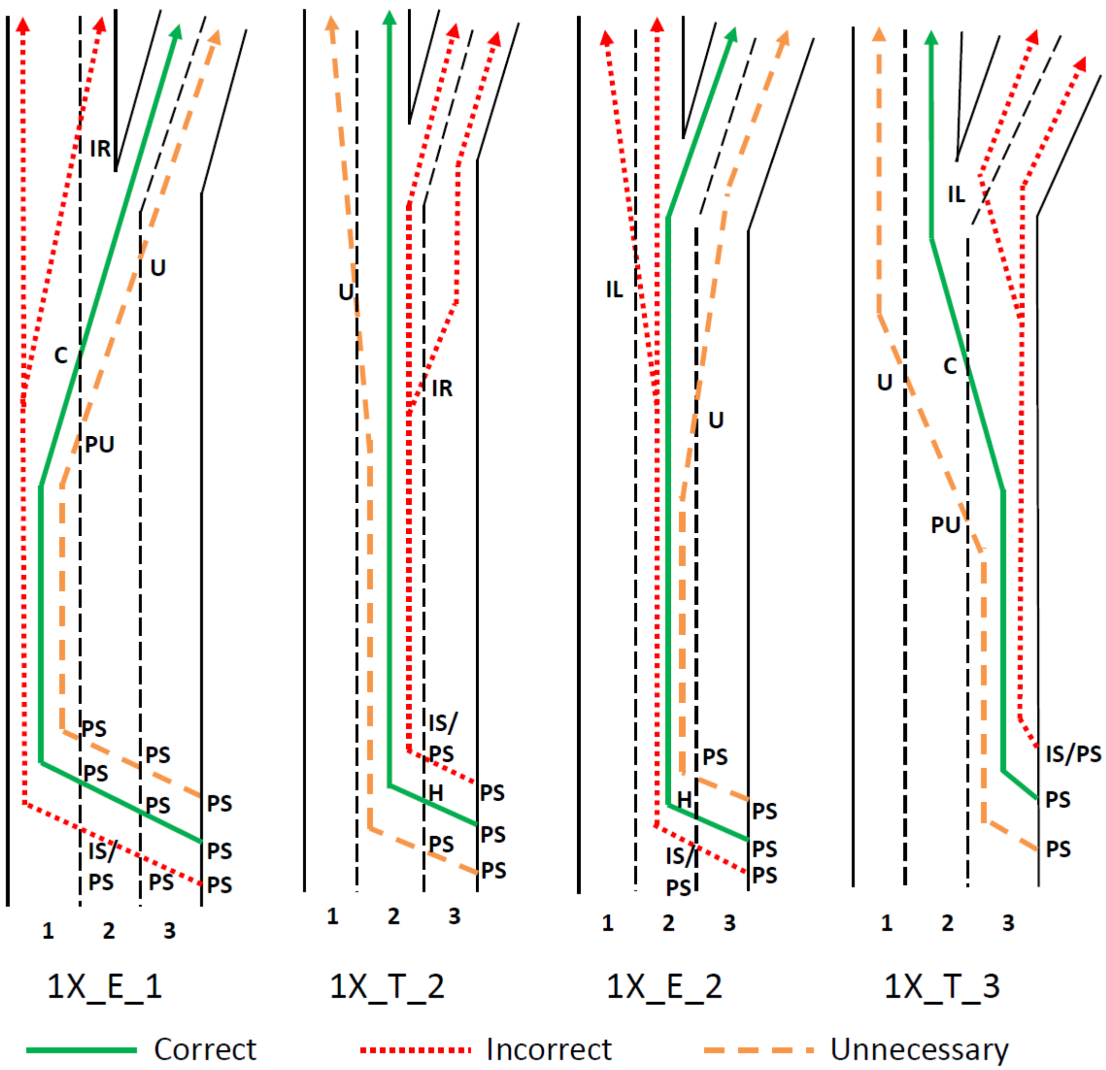


Figure 43. Illustration. Topic 1 lane change coding.

Observations

Observations for this topic are as follows:

- When starting in the left lane (lane 1) and being told to exit (variation 1X_E_1):
    - All drivers correctly exited. Most drivers did make an unnecessary lane change, moving all the way over to lane 3, when lane 2 would have allowed them to exit.
    - Drivers with SS A made their lane changes around SB I, whereas lane changes of drivers with SS B and C had a few more drivers making their decision between SB I and II (see figure 44).
    - Within the follow-up questions, almost all drivers said they had enough time to make a decision and were fully confident of their choice (93 to 100 percent).

- When starting in the center lane (lane 2) and being told to exit (variation 1X_E_2):
    - All drivers correctly exited; however, most drivers made an unnecessary lane change to use the right-most lane (57 to 93 percent of the participants). Only a few of the drivers did not make any lane change (which was preferred). SS B had the most unnecessary lane changes (93 percent), and SS C had the fewest unnecessary lane changes, with 8 (57 percent) compared to 11 or 13 (79 or 93 percent) participants.
    - Most unnecessary lane changes were made near SB I, which was similar for all SSs (see figure 45).
    - All drivers with SS C correctly identified which other lane would lead to their destination and said they had enough time to make the lane choice; however, not all of them were completely confident of their choice.
- When starting in the center lane (lane 2) and being told to go through (variation 1X_T_2):
    - Most drivers stayed in the through lanes. Only one driver, with SS B, made an incorrect lane change to exit. Most drivers did not make any lane change (which is preferred), and a few drivers (between 21 and 29 percent of the participants) made an unnecessary lane change to use the left-most lane.
    - Most drivers with SS A made their unnecessary lane changes around SB I. Most of the unnecessary lane changes for SS B and SS C were beyond SB II (see figure 46).
- When starting in the right lane (lane 3) and being told to go through (variation 1X_T_3):
    - Most drivers made the needed lane changes to stay in the through lanes. Most of the drivers who made the unnecessary lane changes saw SS A. Two drivers with SS C did not make a lane change (which was incorrect) and exited. Note that the name of the through destination for SS C (Jackson) was not present on any of the signs. These drivers made the incorrect decision very early and never corrected. SS A had the highest proportion (71 percent) of drivers who made an unnecessary lane change to use the left-most lane to stay on the freeway.
    - Most drivers made their unnecessary lane changes around SB I. A few of the drivers with SS B and C corrected their position around SB II (see figure 47).
    - Almost all drivers with SS A were completely confident of their choice and said they had enough time to make the lane choice. SS C, without the pull-through sign, had slightly fewer drivers who were confident (71 versus 93 or 100 percent) with their lane selection.
- Overall, participants who viewed SS C were slightly less confident in their lane choice than those who viewed the other two SSs. Participants viewing SS B had the highest confidence.

- Participants were slightly more likely to recall more of the information on the signs (the names of the through and exit destinations) when viewing SS A, which included all information on a single sign and was repeated three times. Overall, participants frequently could not recall the destination for the through lanes when told to exit or the destination for the exit when told to stay on the freeway (percent correct was between 36 and 86 percent; see table 29). Since they did not expect to need that information, the participants did not attempt to retain the information in their memory.

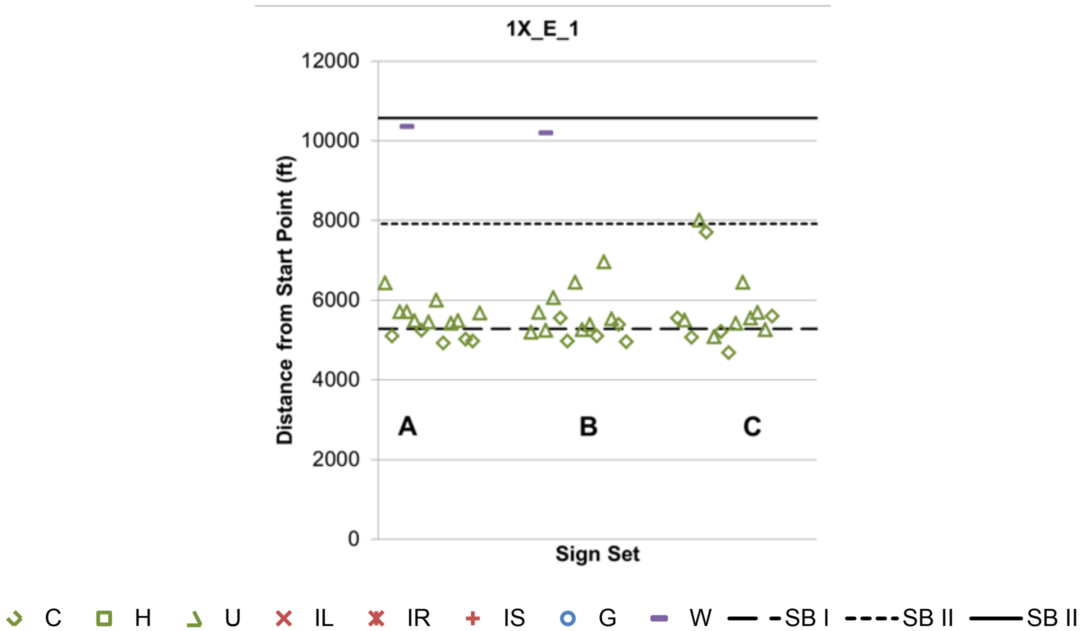


Figure 44. Graph. Topic 1 lane change location 1X_E_1.

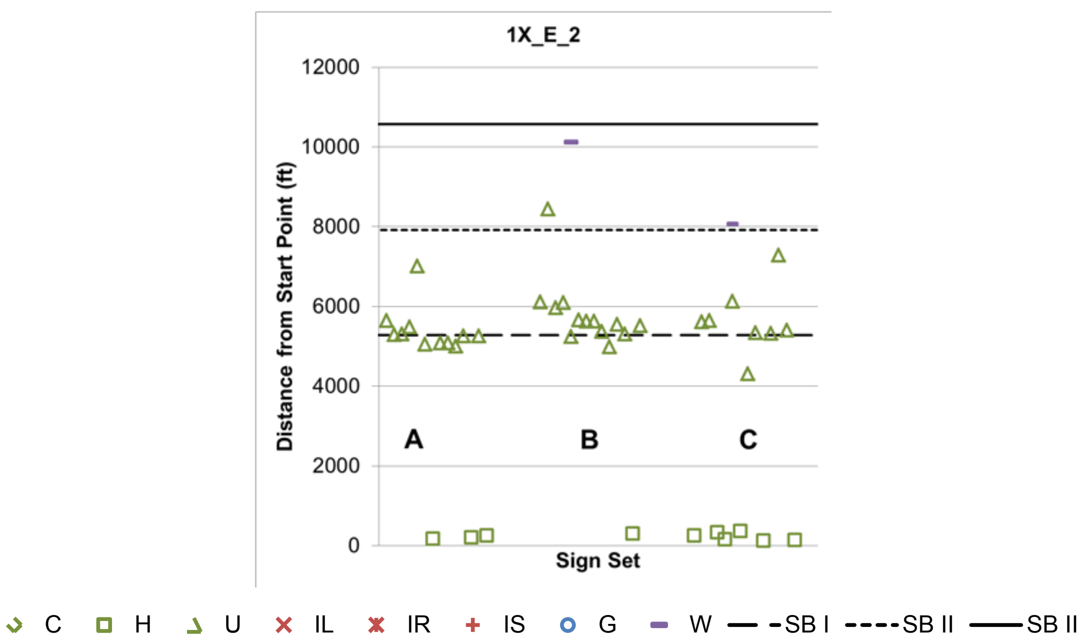


Figure 45. Graph. Topic 1 lane change location 1X_E_2.

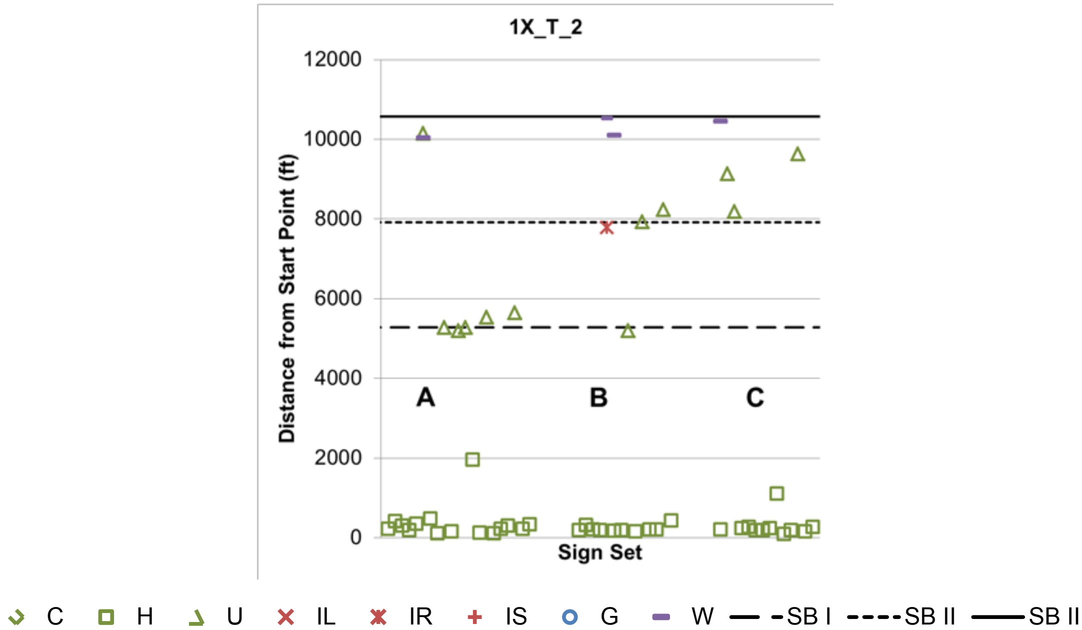


Figure 46. Graph. Topic 1 lane change location 1X_T_2.

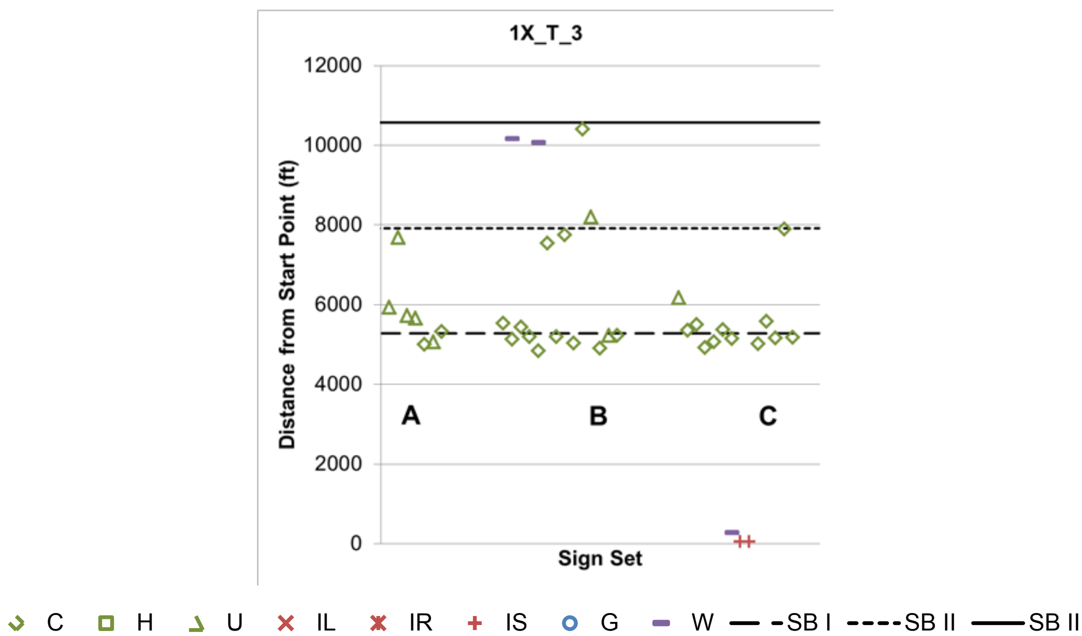


Figure 47. Graph. Topic 1 lane change location 1X_T_3.

Table 29. Topic 1 scores for follow-up questions.

D	SL	SS	Was Leadville a City on the Sign? Percent Correct	Do you Feel Like you Had Enough Time to Make a Lane Choice? Percent Yes	How Confident Were You That You Picked the Correct Lane (1–10[a])? Percent with 10	How Confident Were You That You Picked the Correct Lane (1–10[a])? Weighted Average[b]	Where did the Through Lanes Go? Percent Correct[c]	Where did the Exit Lanes Go? Percent Correct	Scenario
E	1	A	79	100	93	9.4	57	N/A	1A_E_1
		B	57	100	93	9.9	36	N/A	1B_E_1
		C	86	93	100	10.0	N/A	N/A	1C_E_1
	2	A	79	93	79	9.4	50	N/A	1A_E_2
		B	79	100	100	10.0	50	N/A	1B_E_2
		C	64	100	57	9.3	N/A	N/A	1C_E_2
T	2	A	79	100	86	9.2	N/A	86	1A_T_1
		B	100	93	100	10.0	N/A	57	1B_T_1
		C	86	93	64	8.9	N/A	64	1C_T_1
	3	A	71	100	93	9.9	N/A	64	1A_T_2
		B	86	93	100	10.0	N/A	57	1B_T_2
		C	57	86	71	8.4	N/A	57	1C_T_2

D = Destination (E = Exit and T = Through).
[a] Participants were asked to rate 1 through 10, with 10 being the most confident.
[b] Weighted average is the number of participants multiplied by the score provided by the participant divided by the total number of participants who answered the question.
[c] For SS C, the driver would not know where the through lanes were going because the information was not on the sign; therefore, this question was not asked.
N/A = Question not asked.

Key Finding

Almost all participants made the correct decision to exit or stay on the freeway; however, many unnecessary lane changes were made with each of the three SSs for those people whose SL was either the far left or the far right. Drivers who started in the center lane and were given a through route destination were less likely to make unnecessary lane changes compared to all other conditions. The interesting finding here is that drivers who started in the center lane and were told to exit moved to the far right lane, which was an unnecessary lane change. However, drivers who started in the center lane and were given the through destination did not move to the far left lane. This may have been due to some reluctance on their part to move into the left lane, which is typically used for high-speed passing.

Topic 2

Overview

Topic 2 studied methods for signs when two interstate exits were within close proximity and where there was a need to use sign for three destinations (two interchanges/exits and the through lanes). Figure 21 through figure 23 show the SSs studied; only 1.5- and 1-mi advance signs were used to test when drivers changed lanes. The far right lane was an exit only lane, with the second to the right lane acting as an optional exit for the first interstate exit and then becoming an exit only lane for the second exit. Due to the complexity of the signs, SS A did not indicate the second exit as an exit only in any manner in the advance signs. As shown in figure 21 through figure 23, SS A had multiple signs with exit only panels, SS B had arrow-per-lane signs, and SS C had diagrammatic signs.

Table 30 presents the testing variations used in the study, and figure 12 shows a graphic of the geometrics for the portion of the rod the participants drove on. The simulation was ended prior to the participants reaching any of the exits. Figure 48 shows how lane changes were coded.

Table 30. Topic 2 testing variations.

Lane No.	Instructed Destination		
	Longford/Augusta/ Newport (Through)	**Clearwater/Steelville/ Sweetwater (Second Exit)**	**Hutchinson/Pleasanton/ Henderson (First Exit)**
1	No lane change needed.	Must change lanes to lane 4.	Must change lanes to lane 4 (possible unnecessary change to lane 5).
2	No lane change needed.	Second exit destination from lane 2 (2X_2nd_2). Must change lanes to lane 4. Codes: 2A_2nd_2 2B_2nd_2 2C_2nd_2	First exit destination from lane 2 (2X_1st_2). Must change lanes to lane 4 (possible unnecessary—but not incorrect—change to lane 5). Codes: 2A_1st_2 2B_1st_2 2C_1st_2
3	Through destination from lane 3 (2X_T_3). No lane change needed (possible unnecessary lane change to left). Codes: 2A_T_3 2B_T_3 2C_T_3	Must change lanes to lane 4 (possible late lane change to lane 4).	Must change lanes to lane 4 (possible unnecessary change to lane 5).
4	Through destination from lane 4 (2X_T_4). Must move over one lane to left. Codes: 2A_T_4 2B_T_4 2C_T_4	Second exit destination from lane 4 (2X_2nd_4). Must stay in lane (possible lane change to left). Codes: 2A_2nd_4 2B_2nd_4 2C_2nd_4	No lane change needed (possible unnecessary change to lane 5).
5	Must change lanes to lane 3.	Second exit destination from lane 5 (2X_2nd_5). Must change lanes to lane 4 (possible unnecessary change to lane 3). Codes: 2A_2nd_5 2B_2nd_5 2C_2nd_5	No lane change needed.

Note: Shaded cells indicate condition was not tested.

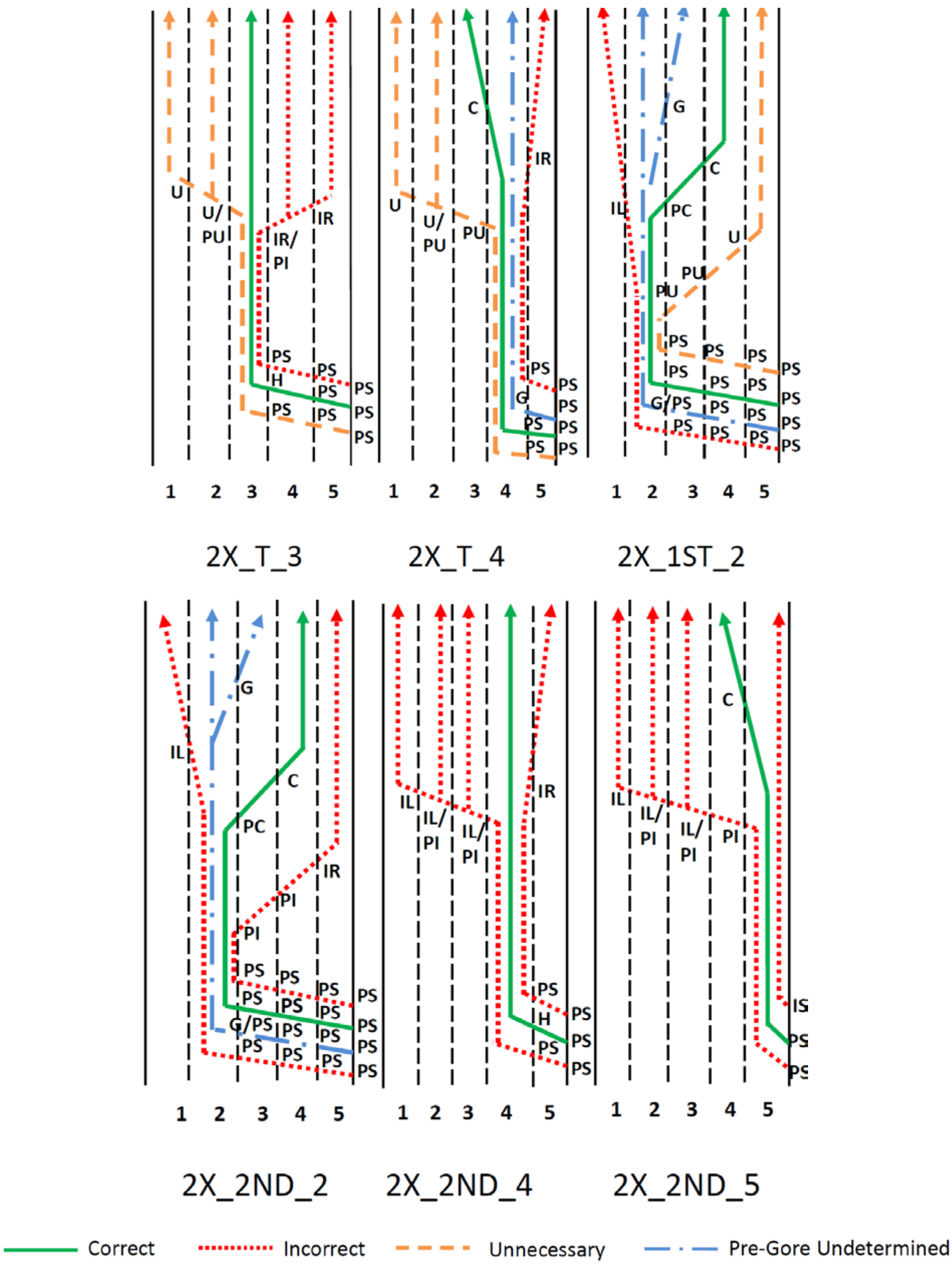


Figure 48. Illustration. Topic 2 lane change coding.

Results

Table 10 shows a summary of the number of participants who made correct, incorrect, unnecessary, or pregore undetermined lane changes by test variation for topic 2. Plots showing the location of the lane changes are provided in figure 49 through figure 54.

Questions asked following the driving portion of this topic were as follows:

- How confident are you that you picked the correct lane (1–10)? (See table 10 for the weighted averages.)
- What about the signs influenced your decision to change lanes or not to change lanes? (Answers are provided verbatim in table 31 through table 33.)
- Why did you change lanes (if they moved out of lane 3)? (Responses are provided in table 34.)

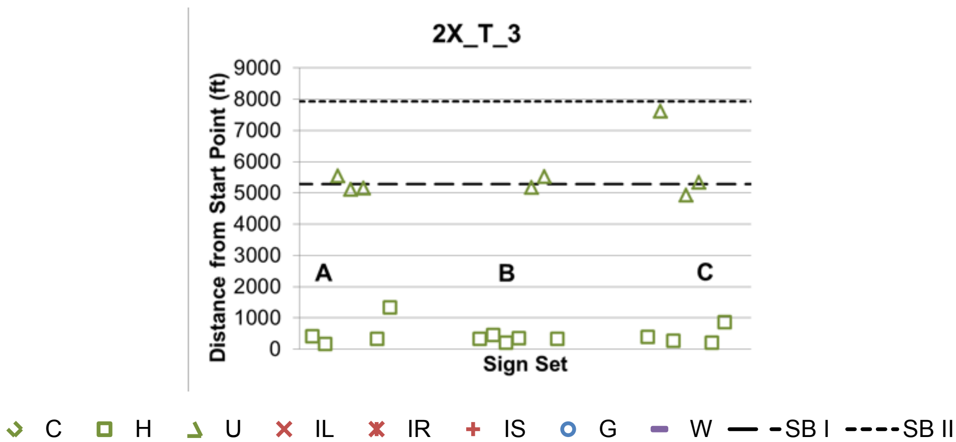


Figure 49. Graph. Topic 2 lane change location 2X_T_3.

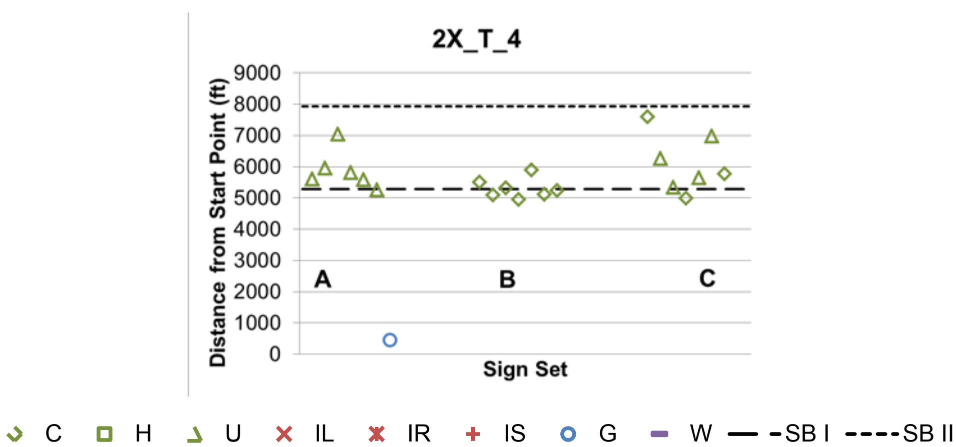


Figure 50. Graph. Topic 2 lane change location 2X_T_4.

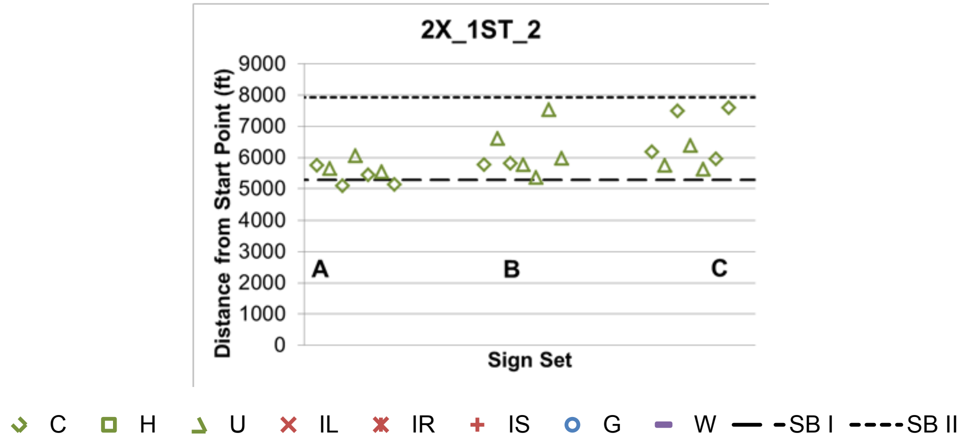


Figure 51. Graph. Topic 2 lane change location 2X_1st_2.

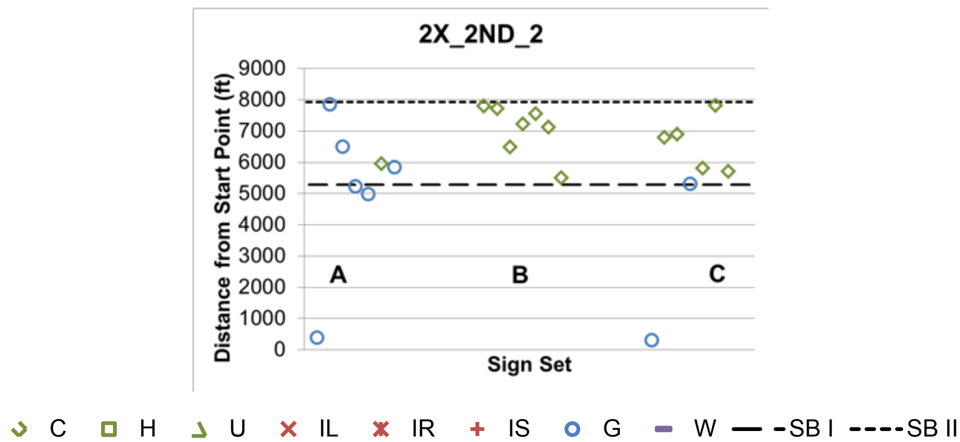


Figure 52. Graph. Topic 2 lane change location 2X_2nd_2.

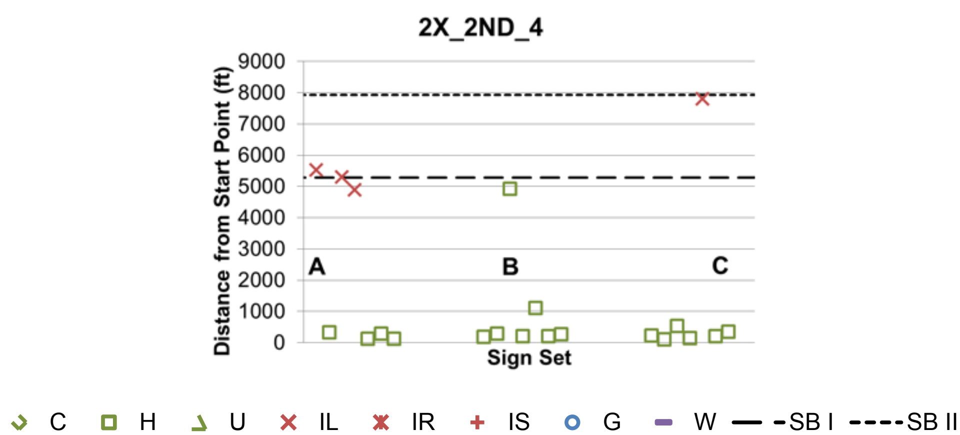


Figure 53. Graph. Topic 2 lane change location 2X_2nd_4.

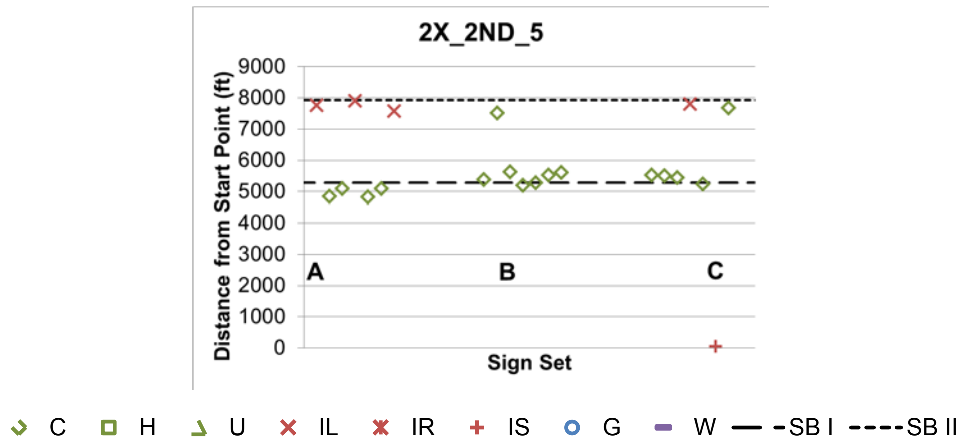


Figure 54. Graph. Topic 2 lane change location 2X_2nd_5.

Table 31. Summary of responses to topic 2 question, "What about the signs influenced your decision to change lanes or not change lanes?"

SS	Starting in Lane 3	Starting in Lane 4
A	• Being on the far left sign with no exit (left exit). • It indicated if I continued straight, I'd head for Longford. • It wasn't an exit only lane, and the Longford sign was all the way to the left like it was a through lane. • The arrow. • The street signs showed the two right lanes going another direction, and the left and middle lanes going north; including Longford. • There was no arrow or exit number telling me to get over. • There wasn't anything indicating I needed to change lanes.	• Because it clearly stated that it was on the left to go there. • Because there were arrows pointing to other destinations other than mine. • I don't know. There wasn't anything to tell me to change lanes. • I wanted to get in the lane under the sign. • Placement on the structure was over on the left. • Sign was on far left of the roadway. • The other right hand three had potential exits coming up, and Longford appears to have an exit coming far away, second from left lane seems most likely to be a through lane.

B	• Three arrows didn't say exit. • Because the arrow was pointing to three specific lanes for Augusta. • I wanted to be away from where everyone was turning. It was a clear sign. • It had three arrows which corresponded to the lanes and the other sign had two arrows, and there were two lanes. • The arrows. • The three arrows showing the three lanes you could be in. • Three solid arrows indicating the left three lanes all pointing towards Augusta.	• A lot of exits coming up on right and Augusta needed to be in one of the three left lanes. • Because three lanes to Augusta, so I moved over to the first one. • First set of signs, I thought I was in the correct lane (second from right). Second set of signs confirmed that I needed to be in one of the three left lanes. • Large sign that had three arrows pointing to Augusta. • The arrows. • There were exit only signs for the other places. • Where I was going was the left three lanes.
C	• Because the tail that led up to Newport was still in this lane. • My lane was going to keep going straight. • Only lane I felt confident in; sign was a little mindboggling. Single arrow was a little difficult. • Other two cities turning off right but Newport straight ahead. Couldn't tell what lanes disappeared with exits. • Showed me that up ahead and two right were the destinations I weren't going to. I'm just a cautious driver and don't want to wait until last minute. • The last two lanes went to Newport. • Wasn't really clear which lanes were going to Newport.	• I saw the arrows for the exits jetting off of the straight arrow, where it said Newport. • Looked like two right lanes exited to right before Newport. • Showed Newport straight ahead and two cities forking to the right. • The arrows. • The white arrow looked like the lanes were splitting, but I'm not familiar with that type of sign, so I wasn't sure if it meant they were exits or the lanes were splitting off. • The wider arrow saying "Newport" was on the left (with other arrows peeling off to right) and the name "Newport" was on the left. • There were lanes being diverted to exits on right hand side.

Note: Observations are for when the participants were told the destination was Longford, Augusta, or Newport (i.e., they were to stay on the freeway).

Table 32. Summary of response to topic 2 question, "What about the signs influenced your decision to change lanes or not to change lanes?"

SS	Observations for When Participants were Told the Destination was Hutchinson, Pleasanton, or Henderson (i.e., First destination)	Observations for When Participants were Told to go to Clearwater, Steelville, or Sweetwater (i.e., Second Destination)
A	• Exit was coming up. • It had arrows over two of the lanes on the right and I needed to be in one of those. • It said "Hutchinson" and gave me an arrow. • The arrows directing what lane direction I needed to be in. • The bright yellow exit on the sign. • There were arrows pointing to two right lanes. • There were signs for three locations and the right was for Hutchinson.	• Clearwater was in the middle, and the other two locations were on the left or right. • I normally like to get over early (closest lane to the right) when I see my street name. • I still had a mile to go and at least a minute to make a decision. • It said Clearwater 1 mile, and I assumed since it was over middle lane I should be in that lane. • The furthest sign to the right indicated the two right lanes—the sign for Clearwater was over the center lane. • The two right lanes were both exit lanes to Longford, even though I know the second from the right was not an exit only, and I still had 1 mile to go. • When I saw the Clearwater 1 $^{1}/_{2}$ mile I knew to move, but should have been over one more lane to the left.
B	• Because they said the exit was coming up. There was a division on the signs. • I could tell it was to the far right, stayed in the second lane to make sure before I got over to extreme right. • Obvious that Pleasanton was one of two right-most lanes. • Sign said 1 mile to Pleasanton and exit arrows pointed to right. • The "exit only." • The arrows. • The immediacy of the exit.	• As I got closer, I could tell that I was in the wrong lane based on the arrows in the sign. • Because I saw the right sign with Steelville to the right. • Because it showed to the right going to Steelville and Pleasanton, they were going towards the same direction. • First sign encouraged me to move over because that lane went someplace else; the second sign reassured me that I should be another lane to the right. • I needed to get over because my exit was more to the right. • The left three lanes were all going straight. • Where it said to exit for Steelville—sign itself.

C	• Henderson was shown on the right hand side. • It showed the exit to Henderson were in the two for right-hand lanes. • It was a right exit for Henderson, so I figured I needed to be closer to the right. • Lower right arrow pointing to closest exit, Henderson. • The arrow curving to the right. • The first was a little confusing; needed to read a bunch of names quickly; but Henderson said 1 mile, so I figured I'd better get over to the right fast. • Wide arrow, looked like two lanes going to Henderson, figured right two lanes would take me to the connect exit.	• Because the directions of the arrows and it showing me which lane would be turning into Sweetwater. • Because you had two exits before Sweetwater, or so it looked like to me. • I knew I was in the wrong lane and would need to get over to the right and it showed two lanes would be exiting. • I know it's a right hand exit because arrow goes to right, but I couldn't tell what lane I needed to be in now to make that exit. • The arrows. • The sign was totally confusing, so I got in a lane where I could go right or straight.

Note: This table covers observations for when the participants started in lane 2.

Table 33. Summary of responses to topic 2 question, "What about the signs influenced your decision to change lanes or not to change lanes?"

SS	Lane 4	Lane 5
A	• Because it said it was coming up in 1 mile and I went to the lane that the sign was over. • Because the lane I was in was not an exit only. • Hutchinson were the two right lanes; Clearwater looked the next exit beyond that. • The next exit was an exit only on the right. • The two arrows going to Hutchinson, only one was exit only. • They were very clear there was still an exit (43) coming up, so I figured I should be in that lane. • Two other cities with exits to the left and right; Clearwater was in the middle.	• Because Hutchinson was coming up and I didn't want to be in that lane just in case. • Because one of the signs showed an exit to the right and Clearwater was straight ahead, so I changed lanes so I wouldn't exit. • Exit only sign for Hutchinson. • I was in the lane that was exiting somewhere else. • The Hutchinson sign had two lanes for exiting (the two far right lanes). • The lane that it was positioned above, the initial lane I was in said exit and you can never tell if you will have the choice to exit or be forced; then the next set of signs, Clearwater was over the lane to my left, so I moved there. • Was in an exit lane that I wasn't supposed to be in.
B	• Because it had a fork to the far right and the lane I was in would go both that way and straight. • Because Pleasanton was definitely going to exit before Steelville. • Counting the arrows and lanes and seeing I was in the same lane as the destination arrow.	• Said far right was exit only (and not for my destination). • Sign had Steelville over the lane. • Steelville was not in the right lane or left, but was in the center, along with another. • The arrow was a bit stronger in the second from right lane, but the thicker/bigger one, you that's where it's going.

	• Pleasantville was two right lanes, but the second to the right continued. • Steelville was the second arrow and the one on the right was exit only. • The exit only was over the far right lane and it didn't show anything that made it look like I needed to move. • The sign indicated my lane would go to Steelville and the other lanes someplace else.	• The separation arrows, and there was another arrow on the right for a different exit with a yellow exit sign. • There was an exit only in the far right lane. • There was Augusta which was the other three lanes, and Pleasantville was right, but my lane looked like either Steelville or Pleasantville.
C	• Because there was a left exit only and a right exit only. • I had an exit coming up before and would probably have an entrance ramp coming in too. • It looked like Henderson was first exit on right, then to Sweetwater could go straight or exit from the lane I was in. • It told me Sweetwater was in that lane I was in. • It was more clear that that lane was going straight ahead and not veering off to the right. • Looked like there was an exit before the one I needed; far right lane would go there. • The third lane or this lane, unsure; the arrows influenced my decision.	• All the arrows—I wasn't sure if Sweetwater was straight or the small arrow pointing right, so I thought I should be in the next lane over to be prepared for what came next. • Because the exit for Newport was north as well as Sweetwater and Newport was straight so I assumed I wouldn't be turning. • It looked like it might be the second to the right turn. • It looked like the thin arrow followed Sweetwater and that was the second lane. • The next exit on the right wasn't Sweetwater and I didn't want to get all the way over because that was Newport. • The order of the names from left to right. • The signage indicated the exit after the first exit would be Sweetwater.

Note: Observations for when the participants were told to go to Clearwater, Steelville, or Sweetwater (i.e., the second destination).

Table 34. Summary of response to topic 2 question, "Why did you change lanes (if they moved out of lane 3)?"

SL	SS	Comment
3	A	• Based on signs with Longford being on far left. • Because Longford was shown to be in the left two lanes.
3	B	• Because I wanted to, and it was still going to the same destination. • I am always more comfortable in the middle lane.
3	C	• Because I saw Henderson and other city exits where to right, and I preferred to not get caught in the wrong lane. • Because the other ones went somewhere else.

Note: Observations for when the participants were told the destination was Longford, Augusta, or Newport (i.e., they were to stay on the freeway).

Observations

Observations for this topic are as follows:

- Some of the participants may not have made necessary lane changes because the simulation stopped before the gore area was reached.
- Observations for when the participants were given the through destination (Longford, Augusta, or Newport) (i.e., the participants were to stay on the freeway; variations 2X_T_3 or 2X_T_4) include the following:
  - In all but one case, the participants made correct lane changes. Several unnecessary lane changes were made by the participants who started in the lane in which they should stay (lane 3, 2X_T_3).
  - When the participants started in lane 4, they were to make at least one lane change to the left. In all cases but one, the participants did make that lane change. In that one case, it is unknown if the participant would have made the lane change because the simulation did not include the actual exit. Therefore, no difference in lane change behavior was seen for the different SSs for this scenario. The location of the lane changes was similar for the different SSs. SS B had no unnecessary lane changes, SS A had six of the seven participants making unnecessary lane changes, and four of the seven participants in SS C made unnecessary lane changes.
  - The participants were slightly more confident with their lane position for SSs A and B.
- Observations for when the participants were told destinations were served by the first exit (Hutchinson, Pleasanton, or Henderson, variation 2X_1st_2) include the following:
  - All of the participants were in the correct position to make the first exit.
  - To make the first exit, participants needed to move from lane 2 to either lanes 4 or 5. If they changed the minimum number of lanes (i.e., to lane 4), then they were coded as C. If the participants made the extra unnecessary lane change to lane 5 (right-most lane), they were coded with an unnecessary lane change (U). Many of the participants did make the additional unnecessary lane change to move into the far right lane of the freeway. A few more participants (five compared to three) made the unnecessary lane change for SS B.
- Observations for when the participants were told destinations were served by the second exit (Clearwater, Steelville, or Sweetwater, variations 2X_2nd _2, 2X_2nd_4, or 2X_2nd_5) include the following:
  - Regardless of the participant's starting lane, all participants were in the correct lane at the end of the simulation for SS B (arrow-per-lane signs). These participants were also confident with their lane choice. On a scale of 0 to 10, most selected 10; those

few that did not select 10 were typically in the condition where their starting position (lane 4) was the lane in which they should stay.

  - Participants seeing SS C (diagrammatic signs) had more correct lane positions than those who saw the multiple signs with exit only panels but not as many as for the arrow-per-lane signs.
  - Six of the seven participants (86 percent) who saw SS A had not changed into the correct lane by the end of the simulation.
  - For SS A and variation 2X_2nd_5, all the participants were very confident (10) that they picked the correct lane, although only four of the participants had made the correct lane change from lane 5 to lane 4. A similar finding was observed for when the participants started in lane 4. Most said they were confident in their lane position; however, three made incorrect lane changes.

- The average confidence ratings for SSs A, B, and C were 9.3, 9.7, and 7.7, respectively. The drivers were most confident with their lane choice for the signs that provided an arrow-per-lane (SS B). Drivers were least confident with the diagrammatic sign (SS C).
- When asked why they made their lane choice, most participants mentioned the arrows on the signs regardless of what SS they were presented, although many who viewed SS A also mentioned that the location of the signs above the roadway was an indication of what lane they should be in.
- Participant responses for the topic 2 question on what influenced their lane decisions showed that drivers relied on arrows for navigation. Even when given a through destination, drivers looked at the arrows for the exiting lanes to help them determine which lanes they should not be in rather than using an approach of determining which lane they should be in. A lack of clear arrow guidance could result in unnecessary lane changes by drivers who want to be confident that they are in a lane that goes to their destination. In addition, comments indicated that some drivers knew they still had more time before needing to make a lane choice.
- There was less confidence in the chosen lanes for drivers who viewed the large diagrammatic sign in SS C.

Key Finding

For SS B, which had an arrow-per-lane design, all participants (42) made correct lane change decisions. SS C, which had a diagrammatic sign, also had many correct lane change decisions, with five or more of the seven participants in a group making the correct decision. Of the 42 participants who viewed SS C, only 3 made incorrect lane change decisions. SS A (multiple signs with exit only panels) did not have as favorable results. For example, 6 of the 42 participants made incorrect lane change decisions. SS A also had more of the participants needing additional information to make a lane change decision.

Topic 3

Overview

Topic 3 evaluated signing for an upcoming exit that had a Y-split into two directions. Researchers looked at how quickly drivers made a lane choice and whether one SS separated drivers into their proper lane more effectively for the upcoming Y-split. Signing options included a split sign to explore if it helped to maneuver drivers into the appropriate lane for the Y-split in advance of the initial exit. The SSs are shown in figure 24 through figure 26. SS A had shared exit signs, SS B had split exit signs both in advance and at the gore, and SS C had shared exit advance signs with a split exit sign at the gore. For SSs A and C, at the Y-split, the city exit on top of the sign branched to the left, and the one on the bottom branched to the right. Figure 55 shows a copy of the MUTCD figure that provides an example of signing for a two-lane exit ramp with two dropped lanes and a bifurcation beyond the mainline gore.(1)

The geometry presented to the driver was three lanes at the beginning with two lanes exiting to the right (geometry in simulator showed that the exit lanes traveled straight and the through lane curved to the left, as shown in figure 13). Participants had to decide whether to follow the through lane that curved to the left or take the exit. The simulation was stopped prior to the physical splitting of the exit into a left fork and a right fork. The testing variations are shown in table 35. Figure 56 shows how lane changes were coded, and figure 30 shows where the lane change occurred.

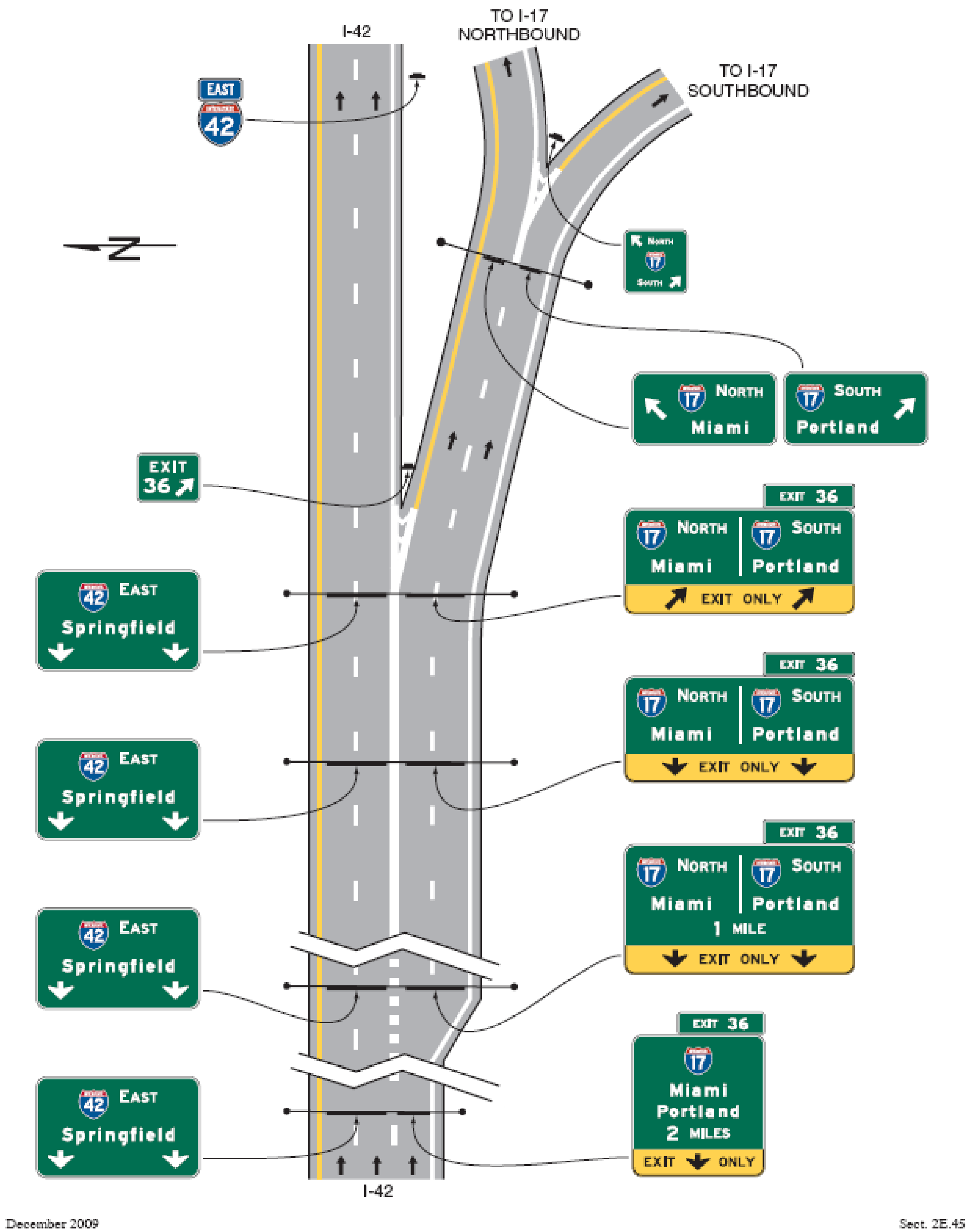


Figure 55. Illustration. MUTCD Figure 2E-34: Example of signing for a two-lane exit ramp with two dropped lanes and a bifurcation beyond the mainline gore.[(1)]

Table 35. Topic 3 testing variations.

SL	Instructed Destination: Murray/ Richey/ Marsing (Through)	Winner/ Edison/Mission (Left Fork)	Groton/ Victor/Walker (Right Fork)
1	Not tested.	Not tested.	Not tested.
2	Not tested.	Left fork destination from lane 2 (3X_Left_2). Must remain in lane. Codes: 3A_Left_2 3B_Left_2 3C_Left_2	Right fork destination from lane 2 (3X_Right_2). Must change lanes. Codes: 3A_Right_2 3B_Right_2 3C_Right_2
3	Not tested.	Left fork destination from lane 3 (3X_Left_3). Must change lanes. Codes: 3A_Left_3 3B_Left_3 3C_Left_3	Right fork destination from lane 3 (3X_Right_3). Must remain in lane. Codes: 3A_Right_3 3B_Right_3 3C_Right_3

Note: Shaded cells indicate that the condition was not tested.

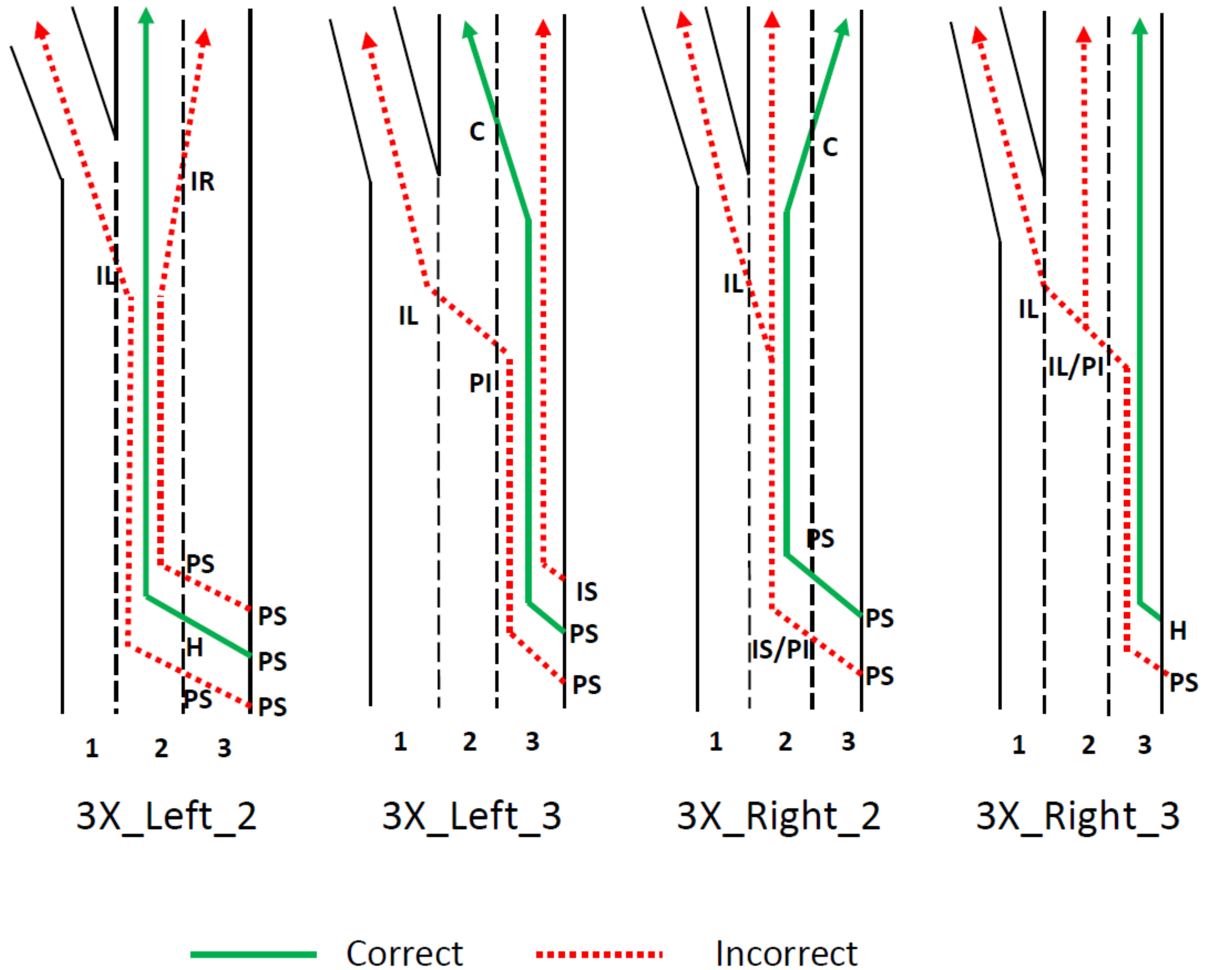


Figure 56. Illustration. Topic 3 lane change coding.

Table 11 shows a summary of the number of participants with correct, incorrect, unnecessary, and swerve lane changes by test variation for topic 3. Plots showing the location of the lane changes are provided in figure 30. Questions asked following the driving segment included the following:

- Which lane do you think you need to be in to get to your destination: right, left, or either? (Table 36 lists the percent correct by test variation.)
- Which exit do you think is coming first: Winner/Edison/Mission or Groton/Victor/Walker? (Table 37 provides the answers to the question.)
- Do you think Winner/Edison/Mission is on the left or right ahead (if they took the exit)? (Table 38 provides the answers to the question.)
- Do you think Groton/Victor/Walker is on the left or right ahead (if they took the exit)? (Table 39 provides the answers to the question.)

Table 36. Topic 3 question, "Which lane do you think you need to be in to get to your destination: right, left, or either?"

SS	SL	Exit Ramp Lane for Assigned Destination	Incorrect	Correct	Percent Correct
A	2	Left	5	2	29
A	2	Right	6	1	14
A	3	Left	5	2	29
A	3	Right	5	2	29
B	2	Left	0	7	100
B	2	Right	0	7	100
B	3	Left	1	6	86
B	3	Right	2	5	71
C	2	Left	1	6	86
C	2	Right	1	6	86
C	3	Left	2	5	71
C	3	Right	1	6	86

Table 37. Topic 3 question, "Which exit do you think is coming first: Winner/Edison/Mission or Groton/Victor/Walker?"

SS	SL	Assigned Fork	Winner, Edison, Mission	Groton, Victor, Walker	Same	I Do Not Know
A	2	Left	6	0	0	1
A	2	Right	4	2	0	1
A	3	Left	2	3	2	0
A	3	Right	6	0	0	1
B	2	Left	0	6	1	0
B	2	Right	0	5	0	2
B	3	Left	0	2	1	4
B	3	Right	0	4	2	1
C	2	Left	0	4	0	3
C	2	Right	3	2	2	0
C	3	Left	3	3	1	0
C	3	Right	1	3	0	3

Table 38. Topic 3 question, "Do you think Winner/Edison/Mission is on the left or right ahead (if the participant took the exit)?"

SS	SL	I Do Not Know	Left	Left/Right	Right
A	2	0	2	1	4
A	3	2	0	0	5
B	2	0	7	0	0
B	3	0	5	0	2
C	2	1	5	0	1
C	3	0	6	0	1

Note: Only participants who were given Winner, Edison, or Mission (i.e., left fork) as their destination were asked this question.

Table 39. Topic 3 question, "Do you think Groton/Victor/Walker is on the left or right ahead (if the participant took the exit)?"

SS	SL	I Do Not Know	Left	Left/Right	Right
A	2	2	0	1	4
A	3	1	1	0	5
B	2	0	0	0	7
B	3	0	0	0	7
C	2	0	0	0	7
C*	3	0	0	0	6

*One participant who was assigned the right fork started in lane 3, viewed SS C, and did not take the exit.

Note: Only participants who were given Groton, Victor, or Walker (i.e., right fork) as their destination were asked this question.

Observations

Observations for this topic are as follows:

- When the destination was the left fork (Winner, Edison, or Mission) and drivers started in lane 2 (variation 3X_Left_2), participants should not have moved out of their starting lane. SS C had the fewest participants making an incorrect lane change. SS A with the destinations stacked had the most incorrect lane changes with all of those incorrect lane changes occurring near the initial SB (see figure 27).

- When the destination was the left fork (Winner, Edison, or Mission) and drivers started in lane 3 (variation 3X_Left_3), all of the participants failed to change lanes into the correct lane in advance of the Y-split with SS A (i.e., the participants did not recognize that the stacking of the cities was associated with lane position). Only half of the participants did so with SS C, which had stacked city names for the first two signs and the divided sign on the final SB. For SS C, four of the seven participants correctly changed their lane near the third SB (see figure 28). SS B had the cities split on the initial SB, and five of the seven participants made the correct lane change near this SB, with another participant making the lane change near the second SB. The remaining participant did not make any lane change in response to the signs.

- When the destination was the right fork (Groton, Victor, or Walker) and drivers started in lane 2 (variation 3X_Right_2), the patterns observed for the left fork situation were similar to the right fork situation. Participants made the correct lane change when they saw the sign with the exits side by side rather than stacked. For SS B, this was the initial SB, while for SS C, this was the final SB. Only one of the participants made a correct lane change for SS A (see figure 29).

- When the destination was the right fork (Groton, Victor, or Walker) and drivers started in lane 3 (variation 3X_Right_3), the SS did not matter. All of the participants stayed in their lane (see figure 30).

- When asked after the simulation had stopped which lane they needed to be in prior to the split, participants were least likely to answer the correct lane with SS A and were most likely to pick the correct lane with SS B.

- When asked which side of the road a destination was on, participants most often answered the side that corresponded to the side of the sign containing the name of the destination for SS B and C. If they had viewed SS A, they most often thought both destinations would exit to the right.

- When destinations were stacked on a sign, drivers were more likely to answer that the exit to the top destination would come first and both exits would be to the right. On a split sign, the drivers were more likely to answer that the destination on the right side of the sign would come first and the exit directions would correspond to the side of the sign the destination was on. The participants' unprompted comments, however, indicated mixed assumptions on destination positioning on a sign and what that meant about when and where the exit would be.

Key Finding

The lateral location of the destination on the sign was used by the participants in making a lane change decision. As can be seen in figure 28 and figure 29, several lane changes were made at the first appearance of the split exit sign (at SB I location for SS B and at SB III location for SS C). While several incorrect lane changes were made for each SS, SS B, which used split exit signs at all three SB locations, had the fewest and was judged superior in comparison to the other two arrangements.

Topic 4

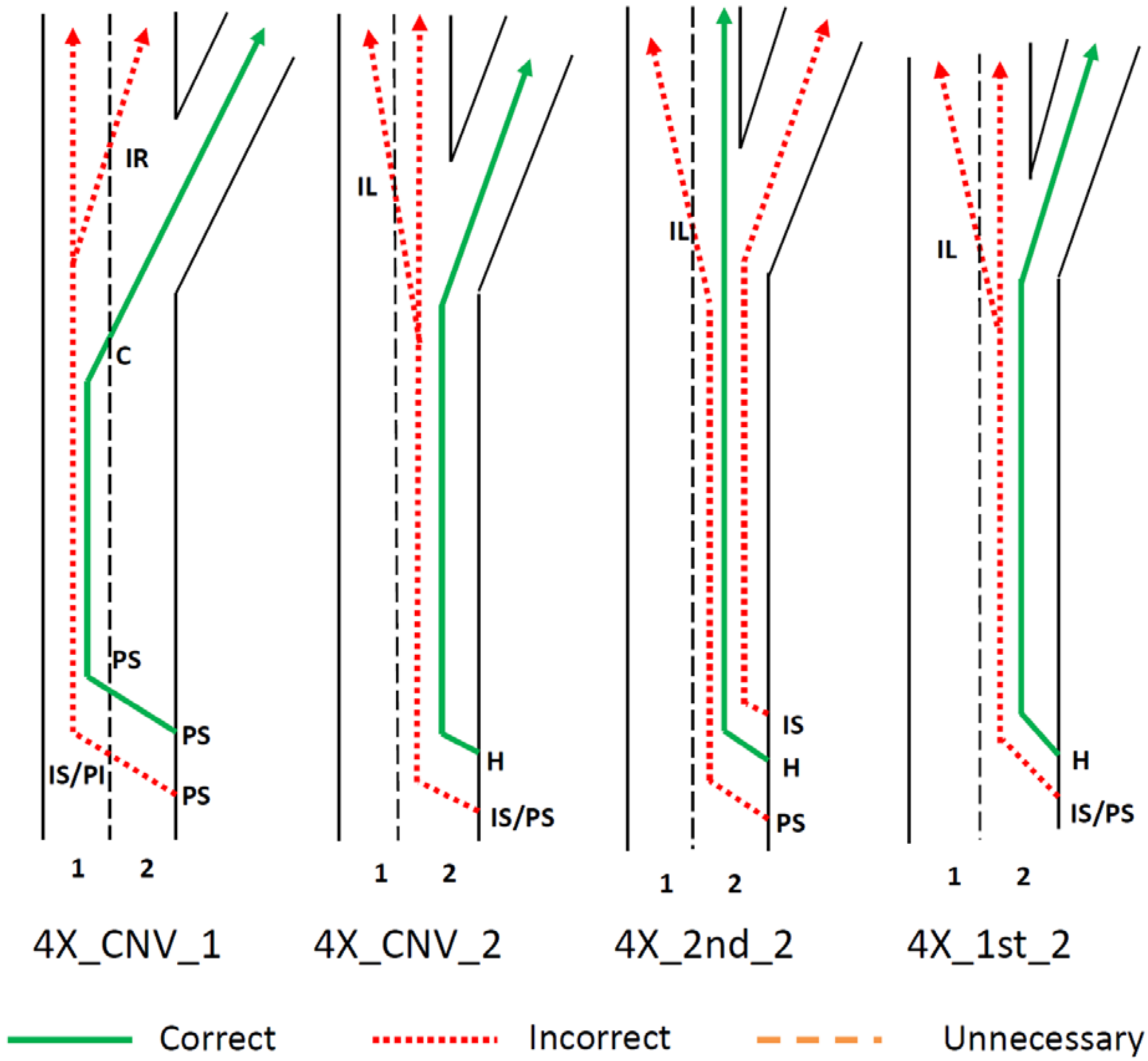
Overview

Topic 4 evaluated whether it was better to fill an advance single sign with supplemental way-finding information or to spread the information among multiple signs including, ground-mounted signs. AASHTO *Guidelines for the Selection of Supplemental Guide Signs for Traffic Generators Adjacent to Freeways* provides a basis for developing State policies for selecting supplemental guide signs for traffic generators adjacent to freeways.[44] For this topic, gore signs with advance signs at 1 mi were used to explore whether sign spreading on a single bridge or on multiple bridges improved where the lane change was occurring. As shown in figure 31 through figure 33, SS A had a single sign with multiple destinations, SS B had split signs on a single SB, and SS C had sign spreading on multiple SBs. All of the SSs had the exit number panels positioned on the upper right. Table 40 shows the testing variations used in the study, and figure 57 shows how lane changes were coded.

Table 40. Topic 4 testing variations.

SL	Instructed Destination: Convention Center	Instructed Destination: Kenston/ Wright/Aspen (Second Exit)	Instructed Destination: Fitch/ Martin/Clark (First Exit)
1	Convention center destination from lane 1 (4X_CNV_1). Must change lanes and take exit. Codes: 4A_CNV_1 4B_CNV_1 4C_CNV_1	No lane change needed.	No lane change needed.
2	Convention center destination from lane 2 (4X_CNV_2). Must remain in lane and take exit. Codes: 4A_CNV_2 4B_CNV_2 4C_CNV_2	Second exit destination from lane 2 (4X_2nd_2). Must pass exit and remain in lane. Codes: 4A_2nd_2 4B_2nd_2 4C_2nd_2	First exit destination from lane 2 (4X_1st_2). Must remain in lane and take exit. Codes: 4A_1st_2 4B_1st_2 4C_1st_2

Note: Shaded cells indicate that the condition was not tested.



Note: See table 28 for meaning of codes.

Figure 57. Illustration. Topic 4 lane change coding.

Results

Table 12 shows a summary of the number of participants with correct, incorrect, unnecessary, and indecisive lane changes by test variation for topic 4. Plots showing the location of the lane changes are provided in figure 58 through figure 61. Questions that were asked following the driving segment include the following:

- What lane would you have gotten in to go to Kenston/Wright/Aspen: left or right? (Answers are provided in table 41.)
- Should you have exited if you wanted to go to the convention center? (Answers are provided in table 42.)
- How did you know to exit (if they took the exit)? (Answers are provided in table 43.)

- How much longer do you drive until you will exit (if they did not take the exit)? (Answers are provided in table 44.)

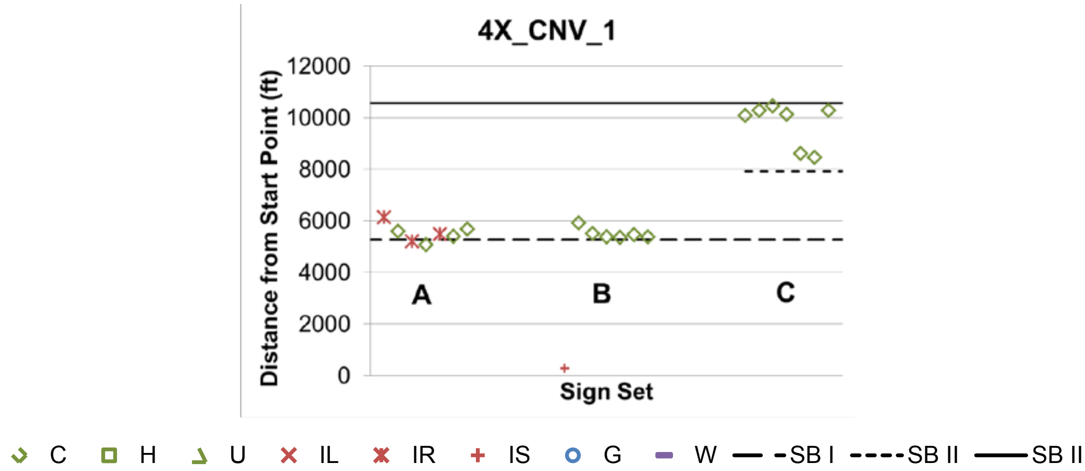


Figure 58. Graph. Topic 4 lane change location 4X_CNV_1.

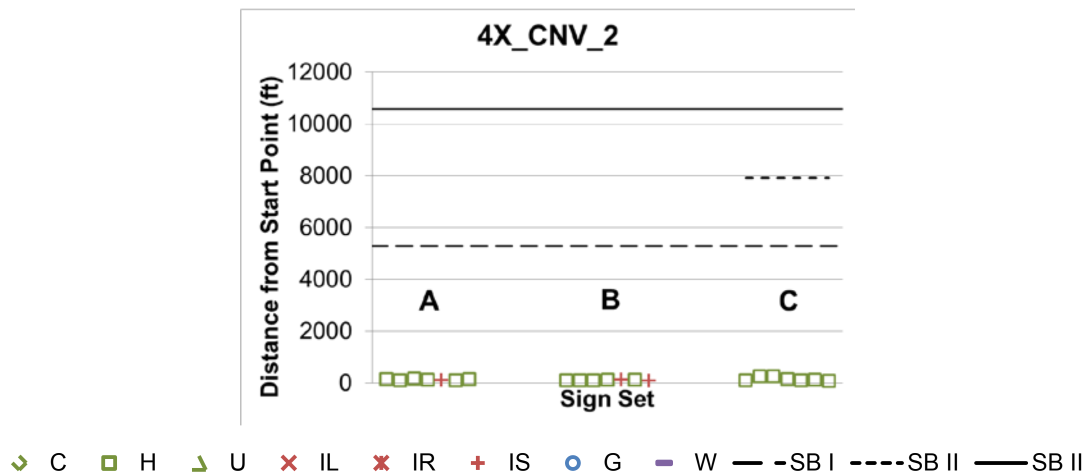


Figure 59. Graph. Topic 4 lane change location 4X_CNV_2.

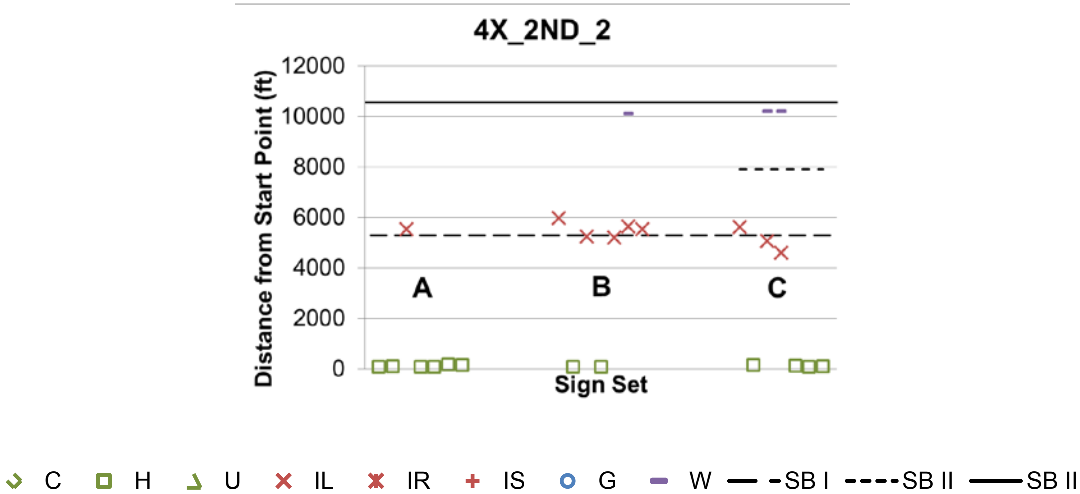


Figure 60. Graph. Topic 4 lane change location 4X_2nd_2.

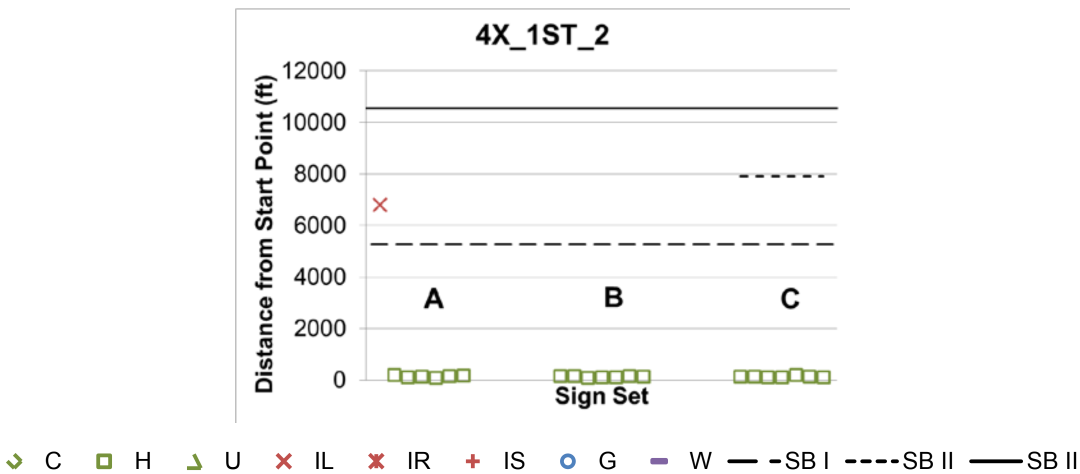


Figure 61. Graph. Topic 4 lane change location 4X_1st_2.

Table 41. Topic 4 question, "What lane would you have gotten in to go to Kenston/Wright/Aspen?"

SL	SS	Either	I Do Not Know	Left	Right	Total
1	A	0	1	6	0	7
1	B	0	0	5	2	7
1	C	0	7	0	0	7
2	A	1	1	4	1	7
2	B	1	0	4	2	7
2	C	0	5	1	1	7

Note: Only participants who were given the Convention Center as a destination were asked this question.

Table 42. Topic 4 question, "Should you have exited if you wanted to go to the Convention Center?"

Destination	SS	I Do Not Know	No	Yes	Total
1st	A	0	1	6	7
1st	B	2	4	1	7
1st	C	0	0	7	7
2nd	A	2	3	2	7
2nd	B	2	2	3	7
2nd	C	2	0	5	7

Note: Participants who were instructed to go to the Convention Center were not asked this question. All participants started in lane 2.

Table 43. Summary of responses to topic 4 question, "How did you know to exit (if they took the exit)?"

SL	SS A	SS B	SS C
1	• Because the sign said convention center under that street. • I saw Fitch with Convention Center. • I should have gone to right because the first sign said it was an exit to both. • Said 5A for convention center on first sign; but didn't say convention center again.	• Because the sign said convention center was at 5A. • I do not know, sign never said. • It said convention center use 5A and that was to Marlin. • It said it was exit 5A. • Sign said "Convention Center use 5A." • The number 5A. • Under Convention Center sign said use exit 5A.	• 5A. • Convention Center sign said 5A. • Convention Center use exit 5A. • Said exit 5A. • Sign said it was exit 5A. • The sign said convention center use 5A. • The sign said to use exit 5A.
2	• Feel like I remember convention center being written next to Finch on first sign. • Fitch Way and Convention Center were the same exit. • Fitch Way sign said Convention Center earlier. • It said Fitch Way/ Convention Center on a sign. • It said Fitch Way/ Convention Center 1 mile. • The first sign had Fitch Way and Convention Center together—assumed same exit.	• Because it said Convention Center use exit 5A. • Convention center sign said use exit 5A. • Sign before last said convention center use 5A. • Sign said Convention Center at 5A.	• Because mile marker 5A was identified for the Convention Center. • Convention center said 5A, went by the numbers. • It said exit 5A. • Said we exit 5A. • Sign said we use exit 5A for Convention Center. • The sign said convention center use 5A. • The sign told me to use exit 5A.

Table 44. Summary of responses to topic 4 question, "How much longer do you drive until you will exit (if they did not take the exit)?"

Destination	SS A	SS B	SS C
Fitch/Martin/ Clark (first exit)	• Saw sign that said Finch Way; no indication of distance.		
Convention Center	• I missed it, originally said Fitch Way/Convention Center, then didn't see convention center on this part. • I do not know, I thought the exit I just passed had been about a mile, but I was expecting more information. I feel like I missed my exit. • 0.5 mi or less. • About 0.25 mi.	• Because I saw sign in middle, it said exit 5A, then when I saw exit 5A, was confused because it said street name, but 5A, so I took it. • It will be the next exit. • About 0.25 mi.	• No responses provided.
Kenston/ Wright/Aspen (second exit)	• 1.5 mi. • 0.5 mi. • 2.5 mi. • Don't know—1st sign said 1.5 mi, but signs were too far apart, but would rather have them too far apart than too close.	• I do not know. • 1.5 mi. • 0.5 mi. • The last sign said 0.5 mi, so I wasn't in the right lane yet.	• Don't know—never said. • 0.5 mi. • About 1 min, 1.5 mi?

Note: Blank cells indicate that the question was not asked because all drivers took the correct exit.

Observations

Observations for this topic are as follows:

- Observations for when the participants were told the destination was the convention center (variation 4X_CNV_1 or 4X_CNV_2) are as follows:
  - Participants viewing SS C (supplemental sign on a separate structure) were always correct in their lane selection regardless of their starting lane.
  - About half of the participants who started in the far left lane missed the exit to the Convention Center with SS A. Only one of the participants who started in lane 2 missed the Convention Center with SS A. This may have been due to the fact that the

advance signs for SS A included a multiple-line sign over lane 2, which may have been difficult for those in lane 1 to read quickly from that position.

- SS B was also associated with participants who missed the exit to the Convention Center. This SS, with the supplemental sign in the center of the SB, also caused several people to incorrectly change lanes to continue through the interchange, suggesting that drivers were aligning themselves with the lateral position of the sign on the bridge.

- SS B and SS A had similar results, indicating these SSs were not as well understood as the sign spreading approach used with SS C. Because only seven participants saw each SS, additional study should be considered for this topic.

- When asked what lane they would have gotten in to go to Kenston/Wright/Aspen when their assigned destination was convention center, more participants who viewed SS C did not know compared to those who viewed SS A and SS B. This suggests that drivers may have been scanning the sign arrays for their target destination and when not found, they quickly dismissed the distractor destinations from memory. The majority of the participants viewing SS A and SS B said the left lane, which was incorrect. The drivers would have needed to stay in the right lane for the downstream exit. There was no indication on the sign that the exit was on the left, although the position of the sign on the SB may have led some of the participants to think the exit was to the left. The fact that drivers who saw SSs A and B recalled the distractor destinations may be due to the fact that they appeared on the same SBs as the convention center target destination sign.

- An Observation for when the participants started in lane 2 and were told the destination was Kenston, Wright, or Aspen Avenue (i.e., second exit; variation 4X_2nd_2) include the following:

  - SS B had the most incorrect lane changes with only two of the seven participants correctly staying in their original lane. The spreading of the information on the single SB caused the sign with the information about the second destination (i.e., to Wright Ave) to be over lane 1, which was the lane five of the seven participants entered. When the sign spreading was across multiple SBs or when the information was stacked on one sign, fewer drivers made the incorrect lane change to the left.

- Observations for when the participants started in lane 2 and were told the destination was Fitch, Martin, or Clark Way (i.e., first exit; variation 4X_1st_2) include the following:

  - Almost all of the participants correctly drove these scenarios. Table 42 shows the results for when participants were asked if they should have exited if they had wanted to go to the convention center. Slightly more participants answered yes correctly when they viewed SS C with the standalone guide sign than those who viewed SSs A and B.

- Table 43 shows that the participants who took the exit said they knew to exit because the Convention Center was mentioned on a sign regardless of the SS they viewed.
- The question presented in table 44 was asked to indirectly determine if any participants realized they missed their exit. Comments indicated that at least two participants viewing SS A knowingly missed their exit, indicating some uncertainty in the signs.
- When asked about the second exit, most participants viewing SS C with sign spreading did not know what lane to be in for that exit, as shown in table 41. This may have been because the SS involved a more engaging thought process in determining where they would need to exit. Of those who viewed SSs B and C, the majority of participants answered that they would incorrectly need to be in the left lane for the second exit, showing drivers tended to maneuver to the lane under the sign with their destination.

Key Finding

For most of the variations studied, SS C (sign spreading across two SBs) had the most participants make the correct lane change decision, although SS A (information for next exit stacked on one sign) also had many of the participants correctly making lane positioning decisions. When the destination information was spread across multiple signs on a single bridge, several participants made incorrect lane changes to the left when the instructions were to go to the second destination. These drivers may have been positioning their vehicles into the lane under the sign with their intended destination. This finding indicates that spreading information about the next exit across multiple signs on a single bridge may have unintended consequences if the SB also includes a sign for another exit that is located to the left of the preferred lane.

Topic 5

Overview

Topic 5 evaluated the effectiveness of sign spreading when there were many bits of information on one SB. The question being explored was, “Does sign spreading affect where lane changes occur?” As shown in figure 34 and figure 35, SS A did not have sign spreading, while SS B had sign spreading across many SBs.

Table 45 presents the testing variations used in the study, and figure 62 shows how lane changes were coded. Because only 1.5- and 1-mi advance signs were used in the simulation, there could be some cases where the needed lane change would have occurred after the simulation was stopped. Therefore, the coding included a pregore undetermined option.

Results

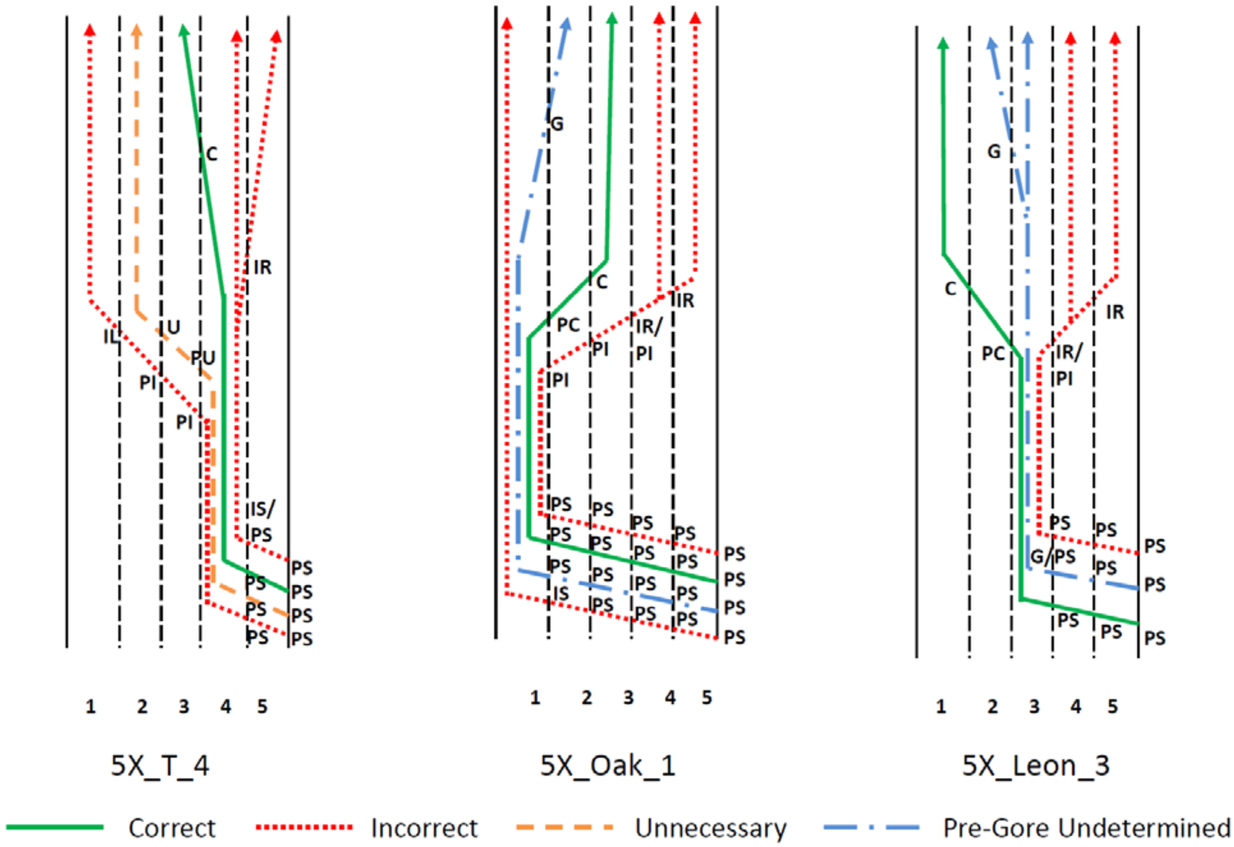
Table 13 shows a summary of the number of participants who made correct, incorrect, unnecessary, and swerve lane changes by test variation for topic 5. Plots showing the location of the lane changes are provided in figure 63 through figure 65.

Table 46 provides the percentage of participants who answered 1 or 10 along with the weighted average for each test variation for the three questions asked following the driving portion of the topic.

Table 45. Topic 5 testing variations.

SL	Instructed Destination: Davenport (Through)	Instructed Destination: Oak St	Instructed Destination: Leon
1	Must change to lane 2.	Oak St. destination from lane 1 (5X_Oak_1). Must change to lane 3. Codes: 5A_Oak_1 5B_Oak_1	No lane change needed.
2	No lane change needed.	Must change to lane 3.	Must change to lane 1.
3	No lane change needed.	No lane change needed.	Leon destination from lane 3 (5X_Leon_3). Must change to lane 1. Codes: 5A_Leon_3 5B_Leon_4
4	Through destination from lane 4 (5X_T_4). Must change to lane 3. Codes: 5A_T_4 5B_T_4	Must change to lane 3.	Must change to lane 1.
5	Must change to lane 3.	Must change to lane 3.	Must change to lane 1.

Note: Shaded cells indicate that the condition was not tested.



Note: See table 28 for meaning of codes.

Figure 62. Illustration. Topic 5 lane change coding.

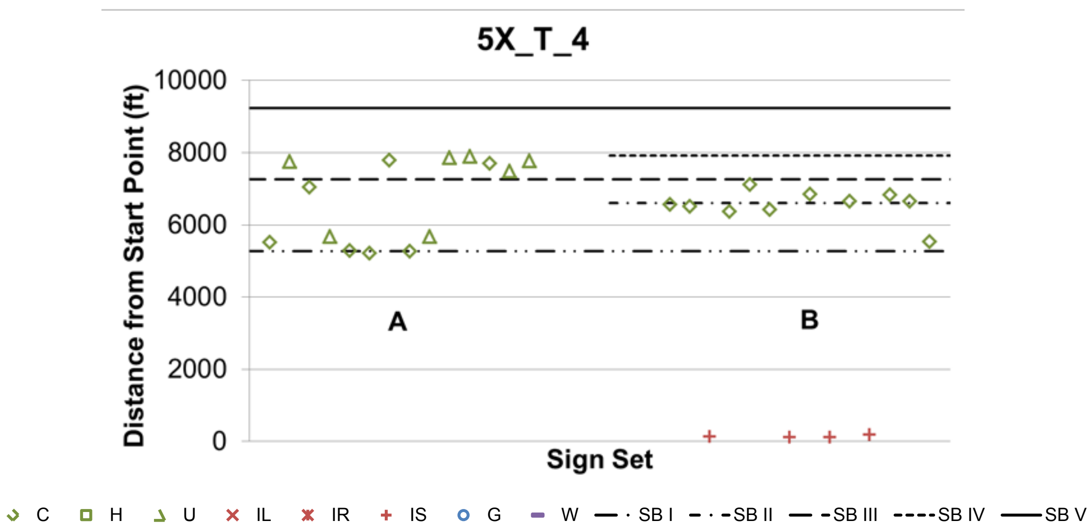


Figure 63. Graph. Topic 5 lane change location 5X_T_4.

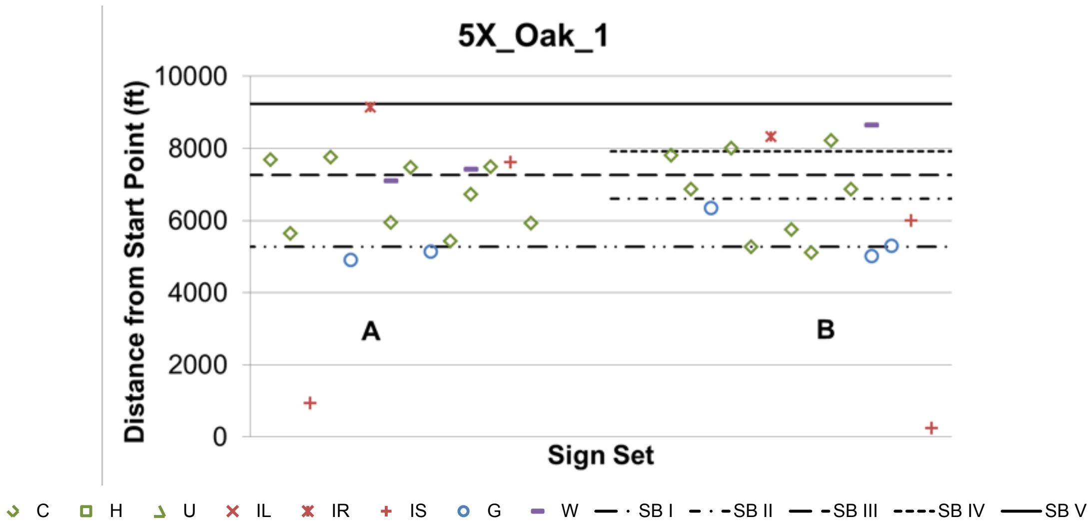


Figure 64. Graph. Topic 5 lane change location 5X_Oak_1.

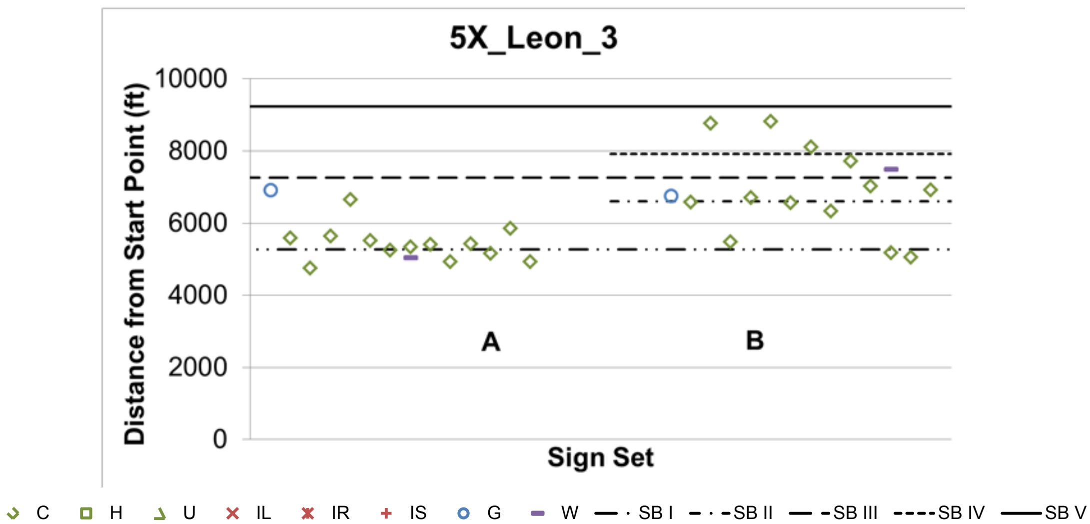


Figure 65. Graph. Topic 5 lane change location 5X_Leon_3.

Table 46. Topic 5 responses to questions.

Scenario	How Confident are you that you Picked the Correct Lane? (Scale of 1 to 10 with 10 Being Most Confident)		Was that Too Much Information at One Time? (Scale of 1 to 10 with 1 being an Okay Amount and 10 Being too Much Information)			How Closely Spaced Do you Think the Signs Were? (Scale of 1 to 10, with 1 Being Okay and 10 Being Way too Close)		
	Percent with 10	Weighted	Percent with 1	Percent with 10	Weighted	Percent with 1	Percent with 10	Weighted
5A_Leon_3	93	9.4	21	7	4.6	N/A	N/A	N/A
5A_Oak_1	50	8.5	36	7	4.1	N/A	N/A	N/A
5A_T_4	86	9.8	21	7	5.1	N/A	N/A	N/A
5B_Leon_3	86	9.3	N/A	N/A	N/A	29	7	4.1
5B_Oak_1	36	7.7	N/A	N/A	N/A	43	0	3.4
5B_T_4	100	10.0	N/A	N/A	N/A	29	0	3.9

N/A = Question not asked.

Observations

Observations for this topic are as follows:

- Observations for when the participants were told the destination was Davenport (i.e., they were to stay on the freeway; variations 5A_T_4 or 5B_T_4) include the following:
  - SS A had more unnecessary lane changes compared to SS B; half of the participants with SS A had unnecessary lane changes, while SS B had no unnecessary lane changes. Because SS A had more signs on a single SB, the sign for Davenport was farther to the left, which may have resulted in participants trying to position themselves below the Davenport sign, resulting in an unnecessary—but not incorrect—lane change. Because SS B spread the signs across more SBs, the sign for Davenport was closer to the right edge of the freeway compared to the position within SS A (see figure 66 through figure 68). SS B, however, had 4 of the 14 participants make an incorrect straight movement. The drivers should have shifted another lane to the left to avoid being in the two exit-only lanes. These findings indicate that the position on the SB of the pull-through sign is important.
  - Almost all of the participants were confident they were in the correct lane for Davenport.
- Observations for when the participants were told the destination was Oak Street (i.e., they would need to make a downstream exit to the right; variations 5A_Oak_1 or 5B_Oak_1) include the following:
  - Several incorrect lane changes were made with both SSs. Only slightly more than half of the participants for each SS were in the correct lane at the end of the simulation. The location of the lane changes for both SSs was varied (see figure 64).

- The participants were not as confident that they were in the correct lane for the Oak Street exit compared to the responses for Davenport or Leon; however, the weighted score was still high (7.7 or 8.5).

- Observations for when the participants were told the destination was Leon (i.e., they would need to make a downstream exit to the left; variations 5A_Leon_1 or 5B_Leon_1) include the following:

  - Almost all of the participants correctly drove the simulation with both SSs. Correct position occurred earlier in the simulation for SS A compared to SS B (see figure 65).

  - The participants were very confident they were in the correct lane for Leon (weighted score of 9.4 or 9.3 on a scale of 10).

- All participants were asked their confidence in their lane selection. Participants' unprompted comments indicated that several gave a low confidence rating because they knew they had not yet maneuvered to the correct lane.

- All participants who viewed SS A were asked about the quantity of information viewed at one time, with 1 being an okay amount and 10 being too much information. Only one participant in each group that saw SS A believed there was way too much information at one time. Most felt it was more toward 1 than 10.

- Participants who viewed SS B were asked how closely spaced they felt the signs were. Generally, the participants did not feel the signs were placed too closely. At most, only one of the participants in a group who saw SS B said the signs were way too closely spaced. Most felt it was more toward 1 than 10.

Note: Notice the position of the Davenport sign.

Figure 66. Screenshot. SS 5-A: no sign spreading.

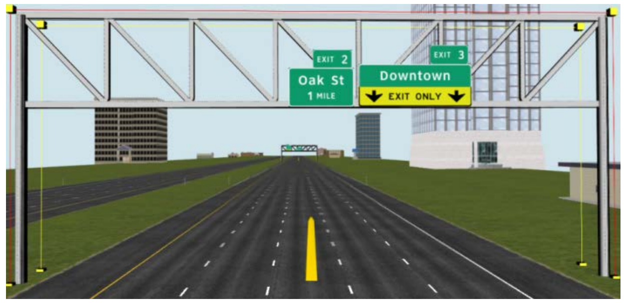
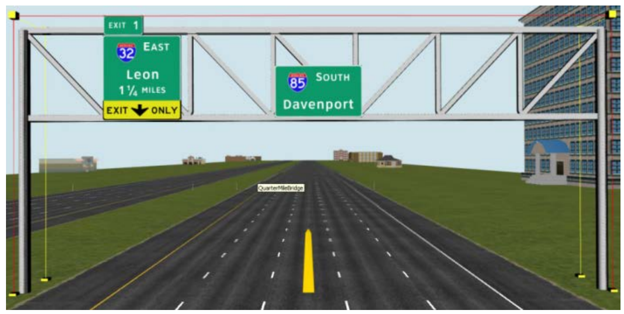


Figure 67. Screenshot. SS 5-B: initial signs viewed when sign spreading is used.



Note: Notice the position of the Davenport sign when sign spreading is used.

Figure 68. Screenshot. SS 5-B: sign spreading across SBs.

Key Finding

The lateral position of a pull-through sign on the SB is important. SS A had more unnecessary lane changes compared to SS B; half of the participants with SS A had unnecessary lane changes, while SS B had no unnecessary lane changes. Because SS A had more signs on a single SB, the sign for Davenport was farther to the left, which may have resulted in participants trying to position themselves below the Davenport sign, causing in an unnecessary—but not incorrect—lane change. SS B had several participants who incorrectly did not move out of their initial lane when told to go to the through destination (Davenport).

Topic 6

Overview

Topic 6 evaluated driver understanding of the 2009 MUTCD left exit standards.(1) Only 1- and 0.5-mi advance signs were used to test how quickly drivers identified the left exit and changed lanes and whether there was confusion on whether it was an exit only or optional exit. As figure 36 and figure 37 show, SS A had a yellow plaque at the top left, and SS B had a yellow panel at the bottom of the sign. Table 47 presents the testing variations used in the study, and figure 69 shows how lane changes were coded.

Table 47 Topic 6 testing variations.

SL	Instructed Destination	
	Longmont or Youngstown (Through)	**Enterprise or Winnsboro (Exit)**
1	Through destination from lane 1 (6X_T_1). No lane change needed (possible unnecessary change to lane 2). Codes: 6A_T_1 6B_T_1	Exit destination from lane 1 (6X_E_1). Must remain in lane to exit. Codes: 6A_E_1 6B_E_1
2	No lane change needed.	Must change to lane 1.
3	No lane change needed.	Exit destination from lane 3 (6X_E_3). Must change to lane 1. Codes: 6A_E_3 6B_E_3
4	No lane change needed.	Must change to lane 1.
5	No lane change needed.	Must change to lane 1.

Note: Shaded cells indicate that the condition was not tested.

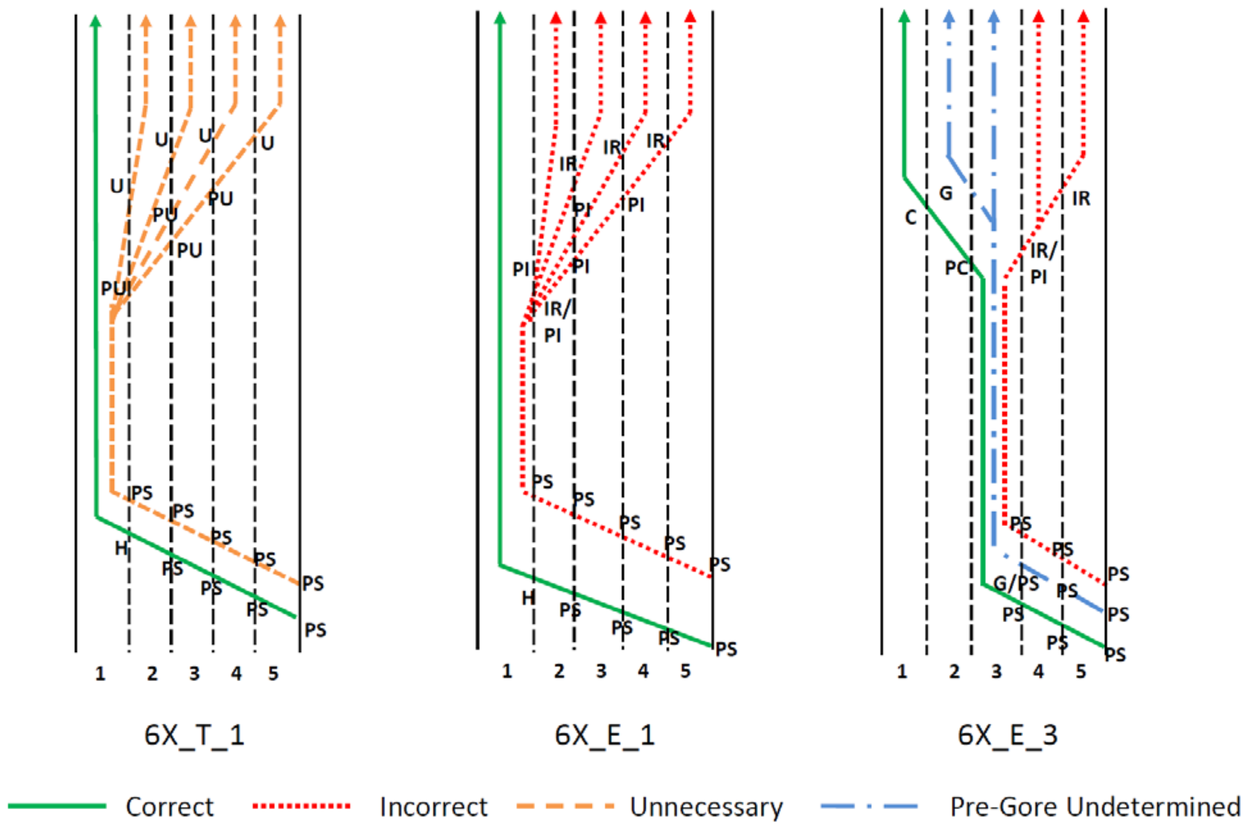


Figure 69. Illustration. Topic 6 lane change coding.

Results

Table 14 shows a summary of the number of participants with correct, incorrect, unnecessary, and pregore undetermined lane changes by test variation for topic 6. Plots showing the location of the lane changes are provided in figure 70 through figure 72. Table 48 summarizes the findings from the questions asked following the driving portion.

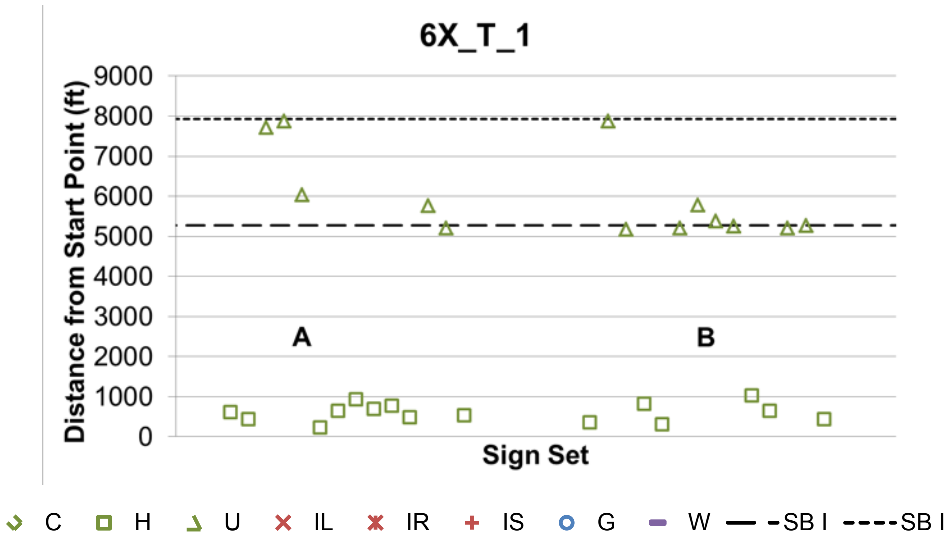


Figure 70. Graph. Topic 6 lane change location 6X_T_1.

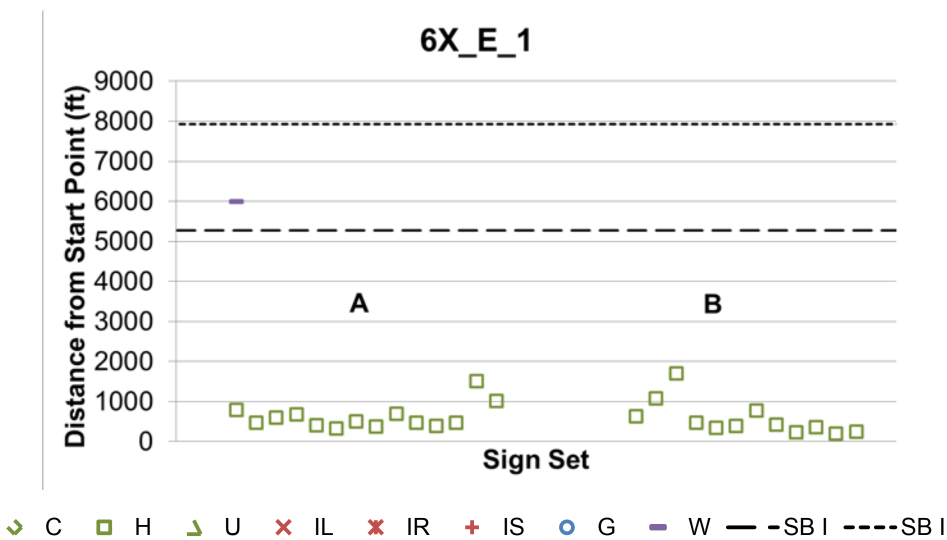


Figure 71. Graph. Topic 6 lane change location 6X_E_1.

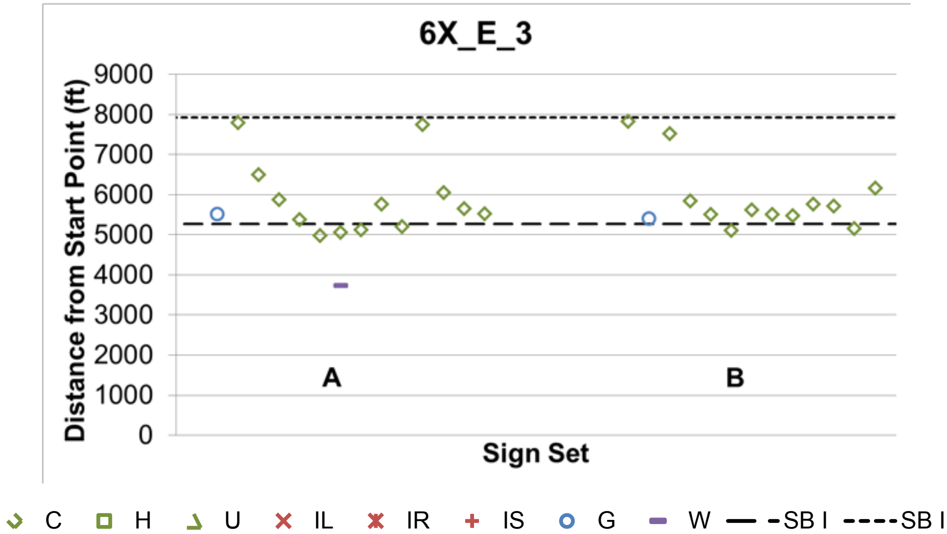


Figure 72. Graph. Topic 6 lane change location 6X_E_3.

Table 48. Topic 6 scores for follow-up questions.

Destination	SL	SS	Percent Correct for "Is the ramp to Enterprise/Winsborro on the left or the right?"
Through	1	A	85
		B	100
Exit	1	A	100
		B	100
	3	A	100
		B	100

Observations

Observations for this topic are as follows:

- Observations for when participants were told to start in lane 1 and go through (variation 6X_T_1) include the following:
  - All drivers were in position to correctly stay on the freeway. Some drivers did make an unnecessary lane change to avoid being in the left-most lane. The proportion of unnecessary lane changes was slightly higher among drivers with SS B.
  - Drivers with SS B made more unnecessary lane changes just after SB I when compared with drivers of SS A (see figure 70).
  - All drivers with SS B correctly identified the ramp as being on the left, whereas only 85 percent of drivers (12 of 14) with SS A did so.

- Observations for when participants were told to start in lane 1 and exit (variation 6X_E_1) include the following:
    - All drivers were in position to correctly exit. Once they reached lane 1, all of the participants correctly stayed in that lane.
    - All lane changes were made around the same distance from the start point for both SSs.
    - All drivers identified the left exit correctly in the follow-up question.
- Observations for when participants were told to start in lane 3 and exit (variation 6X_E_3) include the following:
    - Most drivers correctly changed lanes to be able to make the left exit; however, one driver in each SS was in the pregore undetermined group.
    - All lane changes were made around the same distance from the start point for both SSs.
    - All drivers identified the left exit correctly in the follow-up question.
- Participants' unprompted comments implied that some of the participants who moved out of the far left lane may have done so for personal preference rather than because they thought the sign indicated they had to or they would be forced to exit.

Key Finding

Generally, for the two SSs tested under this topic, participants understood which side of the road the exit was located. It is unclear if this was because the participants were cued by the placement of the sign over the left lane, read the word "left" on the signs, or a combination of the two. The placement of the sign over the left lane resulted in participants correctly avoiding traveling across multiple lanes to make a right exit. However, when the participants did not need to make a left exit, they frequently moved out of the left-most lane (even though the lane was not an exit only lane) due to personal preference. A few more of the non-exiting participants seeing SS B with the yellow panel at the bottom of the sign moved out of the left-most lane (8 of 14) compared to the participants seeing SS A with the yellow plaque at the top left (5 of 14). For this study, the difference between these two SSs was minimal.

SUMMARY

This appendix discussed the procedure used to develop, test, reduce, and analyze several SSs evaluated in a simulator study. From a list of potential topics identified by the research team as needing evaluation, the following topics were selected for the simulator study:

- Topic 1: Option lane.
- Topic 2: Close proximity of two interstate exits.

- Topic 3: Y-split.
- Topic 4: Information spreading (more signs per bridge).
- Topic 5: Information spreading (multiple SBs).
- Topic 6: Left exit.

During the study, test signs were introduced in the simulation along freeways to evaluate drivers' real-time response to the signs. The verbal instructions indicated a starting lane and a destination the participants were to drive toward. The key recorded measures included lane position, lane change, and distance from SB for the lane change.

Topic 1 tested the understanding and use of different methods to sign for an option lane. The topic evaluated driver understanding of arrow per lane, down arrow per lane, or signing only the exit and not the through movement. Almost all participants made the correct decision to exit or stay on the freeway; however, many unnecessary lane changes were made with each of the three SSs for those participants whose SL was either the far left or the far right. Drivers who started in the center lane and were given a through route destination were less likely to make unnecessary lane changes compared to all other conditions. The interesting finding is that drivers who started in the center lanes and were told to exit moved to the far right lane, which included an unnecessary lane change. However, drivers who started in the center lane and were given the through destination did not move to the far left lane. This may have been due to some reluctance on their part to move into the left lane, which is typically used for high-speed passing.

Topic 2 studied sign methods when two interstate exits were within close proximity and when a need existed to sign for three destinations (two interchanges/exits and the through lanes). For the SS that had an arrow-per-lane design, all participants (42) made correct lane change decisions. The SS that had a diagrammatic sign also had many correct lane change decisions, with five or more of the seven participants in a group making the correct decision. Of the 42 participants who viewed the diagrammatic sign, only three made incorrect lane-change decisions. The SS with exit only panels did not have as favorable results (e.g., 6 of the 42 participants made incorrect lane change decisions).

Topic 3 evaluated signing for an upcoming exit that had a Y-split into two directions. Signing options included a split sign to determine whether it helped maneuver drivers into the appropriate lane for the Y-split in advance of the initial exit. The split sign showed the two destinations side by side with a vertical white line separation. For SS B, the split sign was used for the two advance signs and at the gore. SS C only used the split sign at the gore with the two advance signs showing the destinations vertically stacked. SS A used the vertical stacked format for both the two advance signs and the gore sign. The data indicated that the lateral location of the destination on the sign was used by the participants in making a lane change decision. Several lane changes were made at the first appearance of the split exit sign (at the first advance sign location for SS B and near the gore sign for SS C). While several incorrect lane changes were made for each SS, the SS that used split signs at all three SB locations had the fewest.

Topic 4 evaluated whether it was better to fill an advance single sign with supplemental way-finding information or to spread the information among multiple signs, including ground-mounted signs. Gore signs with advance signs at 1 mi were used to explore whether sign spreading on a single bridge or on multiple bridges improved where the lane change was occurring. For most of the variations studied, the SS with sign spreading across two SBs had the most participants make the correct lane change decision, although the SS with information for the next exit stacked on one sign also had many of the participants correctly making lane positioning decisions. When the destination information was spread across multiple signs on a single bridge, several participants made incorrect lane changes to the left when the instructions were to go to the second destination. These drivers may have been positioning their vehicles into the lane under the sign with their intended destination. This finding indicates that spreading information about the next exit across multiple signs on a single bridge may have unintended consequences if the SB also includes a sign for another exit that is located to the left of the preferred lane.

Topic 5 evaluated the effectiveness of sign spreading when there were many bits of information on one SB. SS A did not have sign spreading, and SS B had sign spreading across many SBs. The findings indicated that the lateral position of a pull-through sign on the SB is important. SS A had more unnecessary lane changes compared to SS B; half of the participants with SS A had unnecessary lane changes, while SS B had no unnecessary lane changes. Because SS A had more signs on a single SB, the sign for Davenport was farther to the left, which may have resulted in participants trying to position themselves below the Davenport sign, resulting in an unnecessary—but not incorrect—lane change. SS B had several participants who incorrectly did not move out of their initial lane when told to go to the through destination (Davenport).

Topic 6 evaluated driver understanding of the 2009 MUTCD left exit standards.[1] Only 1- and 0.5-mi advance signs were used to test how quickly drivers identified the left exit and changed lanes and if there was confusion on whether it was an exit only or optional exit. SS A had a yellow plaque at the top left, and SS B had a yellow panel at the bottom of the sign. Generally, for the two SSs tested under this topic, participants understood which side of the road the exit was located. It is unclear if this was because the participants were cued by the placement of the sign over the left lane, read the word “left” on the signs, or a combination of the two. The placement of the sign over the left lane resulted in the participants correctly avoiding moving across multiple lanes to make a right exit. However, when the participants did not need to make a left exit, they frequently moved out of the left-most lane (even though the lane was not an exit only lane) due to personal preference. A few more of the non-exiting participants seeing SS B with the yellow panel at the bottom of the sign moved out of the left-most lane (8 of 14) compared to the participants seeing SS A with the yellow plaque at the top left (5 of 14). Overall, for this study, the difference between these two SSs was minimal.

APPENDIX B. COMPLEX INTERCHANGES SPREADSHEET TOOL

OVERVIEW

This appendix describes the spreadsheet tool developed as a method to evaluate and compare the complexity of freeway interchanges in the United States. It initially discusses the steps that led the research team to develop the spreadsheet in its current form and then provides a description of the spreadsheet itself and a review of the results obtained from the spreadsheet on existing sites. The concluding section examines what those results mean and how they can be interpreted.

INITIAL SPREADSHEET DEVELOPMENT

Team Discussions

Initially, the research team discussed a variety of methods to develop a format to apply a consistent set of criteria to measure complexity. Many potential variables were considered: geometric design variables, traffic control device variables, driver workload variables, etc. Researchers also discussed the basis on which the variables would be included as follows:

- Interchange-wide variables (e.g., number of levels).
- Route-specific variables (e.g., number of decision points/ramps to travel from an origin to a destination).
- Ramp-specific variables (e.g., left-side or multilane exit).

Finally, researchers discussed how the variables should be scored. That is, what quantity of a particular variable is considered to add complexity and how does that compare to the complexity of other variables? Individual variables could be assigned threshold values for complexity, and they could be weighted to reflect their complexity relative to other variables. The variables could also be compared to values in the 2011 AASHTO *Green Book*.(2)

Given all of these considerations, researchers compiled a list of noteworthy variables and assigned proposed values and weights to them to present to practitioners to obtain their feedback on the usefulness and meaningfulness of the initial version of the spreadsheet tool. The worksheet included 26 variables divided into the following three categories:

- Roadway geometry variables are as follows:
    - Number of concurrent routes.
    - Number of levels.
    - Exit ramps per mile.
    - Entrance ramps per mile.

  - Left exits per mile.
  - Left entrances per mile.
  - Exit ramps with multiple destinations per mile.
  - Multilane exit ramps per mile.
  - Optional/shared exit lanes per mile.
  - Exit only lanes per mile.
  - Lane balance condition.
  - Auxiliary lane as percent of minimum distance (in ft).
- Driver workload challenges are as follows:
  - Is the left shoulder less than the minimum width?
  - Is the right shoulder less than the minimum width?
  - Is there a loop on the exit ramp?
  - Is there a taper speed-change lane on the exit ramp?
  - Is there a taper speed-change lane on the entrance ramp?
  - Is the number of general purpose lanes greater than four?
- Driver expectancy violations are as follows:
  - Is the ramp straight while the main lanes are curved?
  - Are the approaching main lanes curved (resulting in difficulties in aligning arrows on signs)?
  - Is there an entrance within minimum distance downstream of this entrance?
  - Is there a short (less than 0.5 mi) weaving section between the entrance and the downstream left exit?
  - Is an entrance ramp followed closely by an exit, and is the auxiliary lane missing? (Based on *Green Book* figure 10-68.)[2]
  - Are there more exit lanes than through lanes?

- Are there more entrance lanes than through lanes?
- What is the number of missing legs?

Expert Panel Discussion

In January 2011, TTI conducted an expert panel discussion. Researchers wanted the panel to assist in identifying factors that contribute to the driving complexity of an interchange area and to give their opinion on variables already identified during the research as contributing to complexity. This discussion was limited to design and geometric variables and did not address existing signing or other traffic control devices currently installed at the interchanges. In addition to four members of the TTI research team, the panel was composed of six practitioners: three from State transportation departments, two from FHWA, and one from a State turnpike authority.

Researchers showed three examples of interchanges that some may deem complex, and they asked panelists to give their impressions of which interchange was the most complex. The panelists then reviewed the 26 variables, which the researchers presented with explanations behind their reasoning.

Overall, the panel thought the three categories of variables were a good fit for addressing interchange complexity, but they noted that the workload and expectancy categories were related (e.g., when driver expectancy is violated, it increases the workload for the driver and increases the amount of signing needed).

It was further suggested that workload is primarily driven by the density of decisions that a driver must make within an interchange area. In this case, the example provided was that if the decision points for several major destinations were within the interchange area, the workload would be significantly increased. Furthermore, workload can be reduced through design of the interchange by spreading the decision points along the corridor, and addressing variables within the design category could eliminate complexity from both workload and expectancy violations. This point emphasized the need for early coordination of geometric design and signing needs.

Prior to presenting the list of variables to the panel, researchers discussed how to assess the complexity of each of the variables and how to meaningfully and objectively compare the effects of each variable to the others on the list. Researchers discussed this issue with the panelists along with some initial ideas on how to accomplish that comparison. The panelists provided their comments and recommendations on how to assess each variable individually and comparatively in a revision of the list.

The panelists offered their input and suggestions on which variables were important and what their relative weights and scores should be, and they offered suggestions on which variables should be added or removed from the initial list of 26 characteristics. Based on the feedback, researchers revised the spreadsheet into its current version.

DEPARTMENT OF TRANSPORTATION SITES

To determine how well the spreadsheet tool would evaluate interchanges, the research team issued a request to State transportation departments to send the team the locations of the most complex interchanges in their respective States. The research team received responses from 11 States, documenting 35 interchanges. The 11 States and number of reported interchanges include the following:

- Arizona: Three interchanges.
- Delaware: Three interchanges.
- Georgia: Four interchanges.
- Indiana: Three interchanges.
- Iowa: Three interchanges.
- Maryland: Two interchanges.
- New York: Six interchanges.
- Ohio: Three interchanges.
- Oregon: Two interchanges.
- South Carolina: Three interchanges.
- Virginia: Three interchanges.

A 12th State, Wyoming, did respond to the request for information but stated that it did not have any interchanges that its transportation department classified as complex.

After reviewing the information provided by the State transportation departments, the research team used 28 of the interchanges for processing in the spreadsheet. Six of the remaining interchanges (one in Georgia, one in Maryland, and four in New York) contained more than four approaches (which is the capacity of the spreadsheet), while the last site (in Indiana) was not used because of poor image quality on both the aerial and street view pictures available in the Google Earth® mapping service database due to construction at the time the images were recorded. The locations of the study sites are summarized in table 15. Those not used in the spreadsheet tool development are noted.

SPREADSHEET TOOL

In its current version, the spreadsheet focuses on the following characteristics:

- Three interchange-wide characteristics.

- A selection of cross section characteristics at the terminus of the speed-change lane of each ramp.

- Ramp-specific characteristics that are dependent on whether the ramp is an entrance ramp or an exit ramp.

A goal during spreadsheet development was to have a format that would be easy for practitioners to understand and use. The format of the spreadsheet is based on characteristics of each ramp present at the interchange. The intent is to document the decision points, along with the associated pieces of information to be processed, that driver would encounter while driving on that route from one end of the interchange to the other. The spreadsheet is designed to accommodate up to four routes, which are labeled to correspond to the four cardinal compass directions: NB, SB, EB, and WB. This format allows the user to enter the variables for each ramp that exists along any of the four routes, and then the spreadsheet processes a series of calculations to convert those site characteristics into an interchange complexity score that can be compared to other interchanges.

After the user enters all of the variables, the spreadsheet calculates a complexity score for each route and for the entire interchange. The maximum possible score for a route and for an interchange overall is 1,000 points. The theoretical minimum is zero points, but the practical minimum is 10 points, which is the score given to any interchange with two levels. The "User Inputs" section of this chapter describes the process of completing the spreadsheet with the revised set of characteristics.

Spreadsheet Development

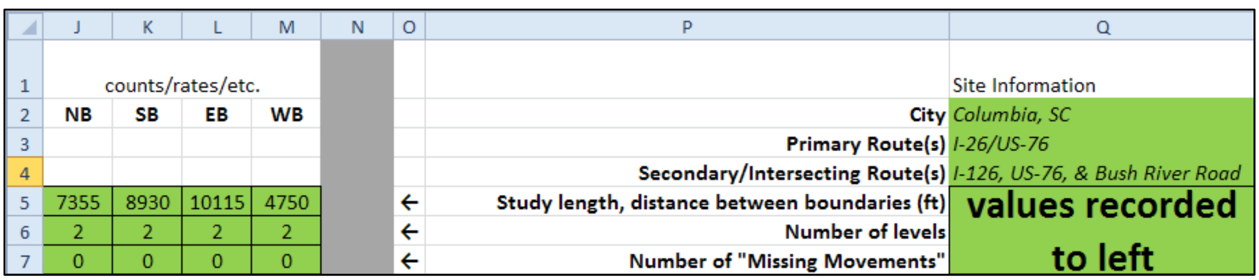
Researchers entered the information on all 28 study sites into the spreadsheet tool, taking measurements and observations from Google Earth®. While entering the information into the spreadsheet, researchers were also monitoring the performance of the spreadsheet, checking that each of the dozens of equations processing a particular site contained the proper operators and referenced the correct data. As the data were entered, researchers made changes to equations as needed to produce the correct results. Researchers also considered the scores that were generated as the information for each interchange was entered, to begin developing an appreciation of how well the spreadsheet identified the relative complexities of the study sites. Discussion of the complexity scores and their components is provided in more detail in the later sections of this appendix.

In addition, researchers reviewed the format and layout of the spreadsheet for its ability to receive data in a manner that would be intuitive and straightforward for the user. The research team decided to use color shading to indicate the purpose of a cell. In general, the areas shaded green are those that are intended for the user to enter values, the areas in white are calculations and equations, and black or gray cells provide visual boundaries on the screen. White, black, and gray cells need no input, and the user should skip those cells when entering data. This color scheme format is intended to help the user focus on the areas that require input (e.g., site characteristics) and avoid cells that do not need input and may even cause errors in the spreadsheet if changed (e.g., built-in equations).

User Inputs

To use the spreadsheet, a user must enter a series of values into the appropriate cells for each ramp on each approach. Cells in the spreadsheet that receive user input are shaded green to differentiate them from white cells containing labels and equations and black or gray cells that provide visual boundaries between sections of the spreadsheet. A set of step-by-step instructions is provided in one tab of the spreadsheet; those instructions are summarized in the following section of this appendix.

To begin, users enter basic descriptive information about the interchange. Figure 73 shows this area of the spreadsheet. Users first enter the city where the interchange is located, and then they enter the primary and secondary routes of the interchange (see column Q). Next, users enter the length of the study corridor in each direction measured from the beginning of the most upstream ramp of the interchange to the end of the most downstream ramp; this information is entered in columns J through M. Finally, users enter the number of vertical levels in the interchange and the number of missing movements for each direction, also in columns J through M. A *missing movement* is defined as the condition in which a direct path from one approach to another does not exist. Examples of missing movements are shown by the yellow lines in figure 38. Drivers traveling northeast cannot enter the freeway traveling southeast unless they travel completely through the interchange and make a U-turn. Similarly, drivers traveling northwest cannot access the route to the southwest without taking a circuitous path and backtracking.



	J	K	L	M	N	O	P	Q
1	counts/rates/etc.							Site Information
2	NB	SB	EB	WB			City	Columbia, SC
3							Primary Route(s)	I-26/US-76
4							Secondary/Intersecting Route(s)	I-126, US-76, & Bush River Road
5	7355	8930	10115	4750		←	Study length, distance between boundaries (ft)	values recorded to left
6	2	2	2	2		←	Number of levels	
7	0	0	0	0		←	Number of "Missing Movements"	

Figure 73. Screenshot. Portion of spreadsheet containing interchange information.

After entering details on the interchange-level site characteristics, the users enter ramp-specific characteristics for each ramp in the interchange. Within the spreadsheet, ramps are numbered in the order that a driver would encounter them while driving through the interchange, as shown in columns R through U in figure 74. Each ramp is described as an entrance or exit ramp. Additionally, the origin or destination of the ramp and the type of ramp are recorded, and it is noted whether the ramp is part of a cloverleaf arrangement.

After entering general characteristics of each ramp, users enter a series of counts, measurements, and other variables for each ramp. The information for these ramp-specific characteristics can come from plan sheets, in-person field visits, or (as was done in this study) aerial images from Google Earth® or a similar online mapping service. There are 34 ramp-specific characteristics divided into three groups: lanes, exit ramp characteristics, and entrance ramp characteristics. The full list of characteristics for each ramp is shown in table 16.

	N	O	P	Q	R	S	T	U	V	W	X
1				Site Information							
2			City	*Columbia, SC*							
3			Primary Route(s)	*I-26/US-76*	*I-126/US76*	*I-126/US76*	*I-26/US76*	*I-26/US76*			
4			Secondary/Intersecting Route(s)	*I-126, US-76, & Bush River Road*							
5		←	Study length, distance between boundaries (ft)	**values recorded to left**							
6		←	Number of levels								
7		←	Number of "Missing Movements"								
8			Direction of Travel		NB	NB	NB	NB	NB	NB	NB
9			Ramp		1	2	3	4	5	6	7
10											
11		General Characteristics									
12			Entrance/Exit		Exit	Exit	Entrance	Entrance			
13			Origin/Destination		I-26 EB	I-26 WB C-D Road & I-20 EB	I-26 WB	Bush River Rd			
14			Fwy-to-Fwy, Service Ramp, or Managed Lane?		Fwy	Fwy	Fwy	Service			
15			Cloverleaf?		No	No	No	No			

Figure 74. Screenshot. Portion of spreadsheet containing ramp description.

Many of the characteristics in table 16 are directly measured or observed (e.g., those with units of feet or those that are count variables). Remaining characteristics are entered based on users choosing one of a predetermined set of possible values (i.e., yes or no). Some of these choice variables may also involve a measurement, but the actual input is based on a binary (or sometimes trinary) decision. These inputs are formatted in this manner to help remove much of the subjectivity that could be involved in evaluating an interchange of this type; the inputs require specific answers or numbers and largely eliminate the need for the user to make a determination of the complexity of an individual characteristic. There are three exceptions to this: the visual clutter variable in the lane group and the two characteristics on curves approaching an exit ramp. These exceptions require some judgment on the part of the user, but making that determination could be done through a review of a photolog of the roadside area or a mapping service such as the street-view feature in Google Earth®.

Spreadsheet users enter the values of the lane characteristics for the first ramp in the NB direction, and then, depending on whether the ramp is an entrance ramp or an exit ramp, they enter the values for the appropriate group of ramp characteristics. This process is then repeated for each remaining ramp in the NB direction followed by ramps in the SB, EB, and WB directions. In the event that a particular approach does not exist (e.g., the interchange has only three approach legs), the corresponding set of ramp inputs is omitted in the data entry process.

When the user inputs have all been entered, the spreadsheet performs four interim calculations to prepare the data for use in tabulating complexity scores, as shown in rows 54 through 58 in figure 75. The through lane-to-exit lane (or entrance lane) ratio is calculated to determine whether an excessive number of ramp lanes makes an interchange more complex, particularly if there are more ramp lanes than through lanes. The auxiliary lane length downstream of each entrance ramp is calculated to compare with criteria from the *Green Book* on appropriate lengths of auxiliary lanes.[2] The lane balance calculation checks whether the number of lanes available downstream of the ramp is at least as great as the number of lanes upstream of the ramp. These items are discussed further in the "Factors, Threshold Values, and Points" section.

	N	O	P	Q	R	S	T	U
43			Downstream Ramp Type (Entrance/Exit)		Exit	Entrance		
44			Downstream Ramp Side (Left/Right)		Right	Right		
45		**Entrance Ramp Characteristics**						
46			Number of Entering Lanes				2	1
47			Left Entrance? (Yes/No)				No	No
48			Entrance lane type (Typical/Auxiliary/Through)				Through	Aux
49			SCL Type (Parallel/Taper)				Parallel	Parallel
50			Distance to Downstream Ramp (ft, measured between painted gore points)				150	1165
51			Downstream Ramp Type (Entrance/Exit)				Entrance	Exit
52			Downstream Ramp Side (Left/Right)				Right	Right
53								
54		**Interim Calculations**						
55			Through-lane-to-exit-lane ratio (calc)		4.0	3.0		
56			Through-lane-to-entrance-lane ratio (calc)				2.0	4.0
57			Auxiliary lane length downstream of entrance ramp (ft)					1165
58			lane balance		1	1	1	0

Figure 75. Screenshot. Portion of spreadsheet containing interim calculations.

Factors, Threshold Values, and Points

After all of the user inputs are stored in the spreadsheet and the interim calculations are completed, the spreadsheet processes that information based on a set of factors, threshold values, and weights. Factors include variables that the research team defined as important based on the previous versions of the spreadsheet and the feedback from practitioners. Each factor has high and low threshold values for scoring. The weights are numerical values that assign relative importance to each factor based on the judgment of the research team supported by a review of the previous spreadsheet. The factors, their threshold values, and points that would be assigned based on the threshold value are shown in table 17 for those factors with yes or no answers and table 18 for those factors with numeric values.

Each factor was assigned a high and low threshold value on which to base the impact of that variable on complexity for the given interchange. Values above the high threshold were assigned 10 points, values equal to or below the low threshold were zero points, and moderate values (between the high and low thresholds) were given 5 points. Using the example shown in figure 76, the NB approach has two concurrent routes (row 60) through the entire length of the study corridor (column J). The number of concurrent routes is equal to the upper threshold value of 2, so the NB approach receives 5 points (column F). The SB approach also has two concurrent routes and receives the same 5 points (columns K and G). The EB and WB approaches contain only one route, which is equal to the low threshold value; therefore, the EB and WB approaches receive zero points for this factor (columns L, M, H, and I). In a similar manner, the value of each factor was tabulated, and a corresponding point value was assigned in the spreadsheet.

The minimum distance for calculating percentage of auxiliary lane length is 2,000 ft, and the minimum distance between entrance ramps is 1,000 ft.[2] The distance between successive exit ramps (800 ft) and the weaving section length (0.5 mi) were based on engineering judgment, and the minimum widths of left (4 ft) and right (10 ft) shoulders were based on the *Green Book*.[2]

	F	G	H	I	J	K	L	M	N	O	P	Q
1	points (max of 10)				counts/rates/etc.							Site Information
2	NB	SB	EB	WB	NB	SB	EB	WB			City	Columbia, SC
3											Primary Route(s)	I-26/US-76
4											Secondary/Intersecting Route(s)	I-126, US-76, & Bush River Road
59									UNITS		FACTORS	ck value
60	5	5	0	0	2	2	1	1	count		Number of concurrent routes	
61	5	5	5	5	2	2	2	2	count		Number of levels	
62	0	0	0	0	0	0	0	0	count		Number of "Missing Movements"	
63	10	10	5	0	1.44	1.18	0.52	0.00	per mi		Exit ramps/mi	
64	10	5	0	10	1.44	0.59	0.00	1.11	per mi		Entrance ramps/mi	
65	0	0	0	0	0.00	0.00	0.00	0.00	per mi		Left exits/mi	
66	0	0	0	0	0.00	0.00	0.00	0.00	per mi		Left entrances/mi	
67	0	0	10	0	0.00	0.00	0.52	0.00	per mi		Number of exit ramps w/multiple destinations/mi	
68	0	10	10	0	0.00	0.59	0.52	0.00	per mi		Multilane exit ramps/mi	
69	0	10	0	0	0.00	0.59	0.00	0.00	per mi		Optional/shared exit lanes/mi	
70	10	10	10	0	1.44	1.18	1.04	0.00	per mi		"Exit only" lanes/mi	

Figure 76. Screenshot. Example of factor scores.

The threshold values for each factor were assigned based on the research team's engineering judgment, reviewer feedback, and available research. For example, it was surmised that an approach with two concurrent routes was not particularly unusual and would not be especially taxing on the driver's mental workload; however, approaches with more than two routes would be more complex and should be scored higher accordingly. Similarly, the number of levels in an interchange is always at least two. The presence of an interchange is an indication of some complexity, but not overly so. Therefore, an interchange having two levels has a moderate score of 5 points, while interchanges with three or more levels are assigned a high complexity score of 10 points.

Weights

Once the point values were assigned, weights were applied in the spreadsheet using the values in table 19. The point values given to each factor for each approach were multiplied by the weight. Figure 77 shows a continuation of the example in figure 76. For the NB and SB approaches, the moderate score of 5 points for concurrent routes was multiplied by the corresponding weight of 3, resulting in a weighted score of 15 points (row 60, columns B and C). The zero-point scores for the EB and WB approaches were also multiplied by 3, producing weighted scores of zero points in columns D and E of row 60.

Similar to the point values, the weights were also assigned based on the research team's estimation of the relative complexity of each factor, supported by the feedback from practitioner reviewers. The values of the weights were also designed to sum to 100 so that a weight could easily be identified as a percentage of the total.

	B	C	D	E	F	G	H	I	N	O	P	Q
1	weight*points				points (max of 10)							Site Information
2	NB	SB	EB	WB	NB	SB	EB	WB			City	Columbia, SC
3											Primary Route(s)	I-26/US-76
4											Secondary/Intersecting Route(s)	I-126, US-76, & Bush River Road
59									UNITS		FACTORS	ck value
60	15	15	0	0	5	5	0	0	count		Number of concurrent routes	
61	10	10	10	10	5	5	5	5	count		Number of levels	
62	0	0	0	0	0	0	0	0	count		Number of "Missing Movements"	
63	20	20	10	0	10	10	5	0	per mi		Exit ramps/mi	
64	40	20	0	40	10	5	0	10	per mi		Entrance ramps/mi	
65	0	0	0	0	0	0	0	0	per mi		Left exits/mi	
66	0	0	0	0	0	0	0	0	per mi		Left entrances/mi	
67	0	0	40	0	0	0	10	0	per mi		Number of exit ramps w/multiple destinations/mi	
68	0	20	20	0	0	10	10	0	per mi		Multilane exit ramps/mi	
69	0	10	0	0	0	10	0	0	per mi		Optional/shared exit lanes/mi	
70	20	20	20	0	10	10	10	0	per mi		"Exit only" lanes/mi	

Figure 77. Screenshot. Example of weighted factor scores.

Researchers tried a variety of combinations of weights to evaluate each factor and develop scores in the spreadsheet that would realistically reflect the characteristics of the sites studied and the ranking of the sites as estimated by the research team. As mentioned previously, the goal was to develop a method of comparing the complexity of various interchanges based on an objective scale. Researchers determined that the numerical score used should have a base of 100 points. In addition, the list of factors shown in table 17 and table 18 were determined based on feedback from reviewers and practitioners as well as the researchers' own personal experience and professional judgment. With those parameters in place, the research team had a great deal of flexibility to determine how to account for those factors in the eventual complexity score. The 32 factors in table 19 have been rearranged from table 17 and table 18 so that they are presented in descending order of weight.

Researchers used the weights to provide a measure of the complexity of a given factor relative to other factors. Factors with higher weights were deemed to have a greater impact on complexity than those with lower weights. Table 19 shows that the 32 factors used in the spreadsheet were each given weights between 1 and 5. The factors with the largest weights were lane continuity violations and weaving sections less than 0.5 mi in length; these were considered to be the elements that would contribute the most to driver workload and perceived complexity. The factors with the smallest weights were density of optional/shared exit lanes, presence of auxiliary lanes less than 2,000 ft in length, and number of entrance lanes greater than or equal to the number of through lanes. These were considered to be the least complex of the factors under consideration but still worthy of inclusion in the calculation of a complexity score. A review of table 19 shows that there were an additional 14 factors with a weight of 4, 5 factors with a weight of 3, and 8 factors with a weight of 2. The fact that half of the factors had weights of 4 or 5 is a reflection of the researchers' agreement with reviewers that these factors play a sizeable role in increasing the complexity of an interchange. The assignment of a weight of 1 or 2 does not mean that a factor is not complex but rather that it is not as complex as other factors in the judgment of the research team.

The factors with higher weights are generally those concerned with ramp densities, left-side ramps, ramps with multiple destinations, lane balance violations, speed-change lanes with taper designs, more demanding alignments (e.g., loop ramps, curved approaches to ramps, etc.), and a perception of a claustrophobic effect due to large buildings or other items close to the freeway.

In the estimation of the research team, these items are more complex and add more to the driver's mental workload than other items, such as the number of vertical levels in the interchange, the presence of adjacent managed lanes, or the number of concurrent routes on an approach. In some cases, a factor was given less weight because researchers believed that another factor also at least partially accounted for its complexity, such as giving a left shoulder less than minimum width a weight of only 2 because the presence of a concrete barrier less than minimum width distance to the left of the travel way was considered to be worth a weight of 4. The location of the concrete barrier is a reflection of the width of the shoulder, but the presence of a barrier increases complexity further because the driver is more concerned about a roadway departure if there is a concrete barrier nearby than if the roadside is more forgiving.

A factor that is not directly addressed in table 19 is the presence of a C-D road. The way that the spreadsheet treats a C-D road is that it simplifies the operation of the through route on the freeway because the number of access points is reduced. However, when considering the path that an exiting or entering driver must take, it could be argued that a C-D road increases complexity because those drivers have to navigate through at least one additional decision point to reach their destinations. A full exploration of the complexity effects of C-D roads is ultimately beyond the scope of this project, but it is definitely worthy of consideration as a potential research topic for a future project.

Each factor was given base points based on its threshold value. Table 17 and table 18 show the threshold values assigned to each factor to determine whether the characteristics of that factor had a high, moderate, or low effect on a specific site. Researchers set the threshold values based on their judgment of what constituted an amount that increased complexity. For example, researchers determined that an approach with only one route had a minimal impact on complexity, two concurrent routes would have a moderate effect, and more than two concurrent routes would have a high impact. Low-impact factors were given base points of zero, so even a factor that had a high weight would not affect the interchange's final score if that factor had a minimal presence.

Many of the factors considered in the spreadsheet are discrete choices, and the high threshold value is a reflection that the characteristic is present on an approach and has a high impact on complexity for that approach. For other factors, the threshold is based on a measurement or a count, and there are values for which the factor may not have a substantial effect on complexity even if it is present at the site. These factors have some flexibility in adjusting the thresholds, if desired, to revise the base points assigned to values of those factors.

Adjusting Weights

The base points for each factor are multiplied by their respective weights to produce weighted scores, which are summed to produce a score for the entire approach; approach scores are averaged to produce the interchange score. Given the limited number of factors with adjustable thresholds, researchers focused on the values of the weights to produce a set of interchange scores that best reflected the relative complexity of the study sites. Researchers tried a variety of combinations of weights for the 32 factors such as increasing some weights as high as 6 and balancing those increases with decreases in other factors to maintain the overall sum of 100. Each new set of weights produced different scores for each interchange. The values shown in table 19 produced similar results as the groupings of the study sites done by the research team, indicating that for the characteristics included in this spreadsheet and for the weights and threshold values shown in the table, the results produced a general sense of the relative complexity of the interchanges studied. The researchers recognize that other practitioners and spreadsheet users could develop a logical basis for adjusting the weights and thresholds to a different set of values than those shown in this appendix; however, researchers believe that the values used in the spreadsheet are also a valid and reasonable option, and the consistency in the relative scores and groupings supports that conclusion.

Calculating Scores

All of the weighted factor scores are summed in the spreadsheet to produce a complexity score for the approach. The approach complexity scores are then averaged to produce an overall complexity score for the interchange. An example of this scoring is shown in figure 78.

	A	B	C	D	E	N	O	P	Q
1	Interchange Score		weight*points						Site Information
2		**NB**	**SB**	**EB**	**WB**			**City**	*Columbia, SC*
3								**Primary Route(s)**	*I-26/US-76*
4								**Secondary/Intersecting Route(s)**	*I-126, US-76, & Bush River Road*
59						**UNITS**		**FACTORS**	ck value
90		0	0	0	0	count		Is the number of exit lanes equal to or greater than the number of through lanes? (yes/no)	
91		0	0	0	0	count		Is the number of entrance lanes equal to or greater than the number of through lanes? (yes/no)	
92									
93	215	315	285	210	50				
94									

Figure 78. Screenshot. Example of approach and overall complexity scores.

The maximum possible score for an approach (and for an interchange overall) is 1,000 points. The theoretical minimum is zero points, although the practical minimum is 10 points because a two-level interchange will receive a weighted score of 10 points for this characteristic. In the example in figure 78, the interchange has an overall score of 215, which is a relatively low score, suggesting a low level of complexity. The overall score is the average of scores from the individual approaches, which ranged from a low of 50 to a high of 315 at this site. The primary route of this interchange was located on the north-south corridor, so it is reasonable that the more complex scores would appear on those approaches. The EB corridor also had some complex elements, but the WB approach had non-zero scores for only two factors: number of levels and entrance ramps per mile. As mentioned previously, the score for having two levels is inherent in every interchange, so the only additional complexity element in the interchange for the WB corridor was the presence of entrance ramps at a rate of greater than 1.0 per mile.

RESULTS

Scores

After all of the site information was entered into the spreadsheet and the weights were optimized, researchers tabulated the scores from all 28 study sites. Table 20 shows the scores for each study site generated by the final version of the spreadsheet. Sites are listed in order of descending complexity based on the judgment of the research team. Sites shaded gray have spreadsheet scores that are different from their place on the list. A review of the list indicates that the spreadsheet generated scores that were generally consistent with researchers' estimation of the sites' relative complexity. There are two exceptions to the correlation between the scores and the researchers' estimated complexity, both of which are within one ranking of being correlated with the spreadsheet scores.

The sites in table 20 were divided into four distinct groups based on the spreadsheet scores. Sites with similar scores were viewed as having similar levels of complexity. Group 1 was composed of the five sites with the highest scores, and all had complexity that was estimated to be much greater than that of the other 23 sites. In fact, the three highest-scoring sites had much higher scores than the remaining sites, separated from sites 4 and 5 by more than 100 points. Group 2 represented sites that scored between 300 and 400, group 3 was made up of sites between 230 and 300, and group 4 contained sites with sub-230 scores. A review of the two exception sites shows that despite their placement on the list, they were still contiguous to the group that contained the sites with similar scores. For example, NY-3 was one place lower in its ranking than its score would suggest, but researchers still considered it to be more complex than any of the group 3 sites. The similarity between exception scores and adjacent scores suggests that the differences in complexity between sites in the same group may not have been particularly significant. This characteristic will be discussed in greater detail later in this appendix, but it should be emphasized that the ranking was based on the opinion of the researchers, as were the weights and scores associated with the spreadsheet calculations. It is possible that a practitioner could logically rank some of the sites in table 20 differently or develop a set of weights and scores that correlates all 28 scores with their rankings. Further details on the two exception sites and on the rankings, weights, and scores in general are provided in the following sections.

Score Exceptions

The first exception site in table 20 is NY-3 (ranked 14th on the list), although its score was not considerably different than the site ranked above it. This site was an interchange with unusual geometry that utilized a series of exit only lanes and indirect paths to accommodate all of the possible movements from each approach. For all of the left-turn movements, it was necessary to travel through the interchange and make a U-turn to arrive at the desired destination. In addition, all of the ramps were on the left side of the travel way, so even right-turn maneuvers required entering or exiting the major route on the left. The geometry was also somewhat constrained, which produced high scores for exit ramp density, narrow shoulders, and a claustrophobic effect. The site with the next highest rank (VA-3) had a much larger footprint and had seven numbered routes on its four legs (including three interstate routes that terminated at the interchange) compared to the three routes at NY-3. The Virginia site also had some unique alignments for several of its access ramps, and it had higher posted speed limits (60 mi/h) than the New York site (45 or 35 mi/h), prompting researchers to give the Virginia site a higher rank.

The second exception site was SC-2, which had a score that was lower than its place on the list (ranked 20th). This site had two missing movements and some very unusual geometry that placed two interstate highways parallel to each other for a short distance (see figure 79). Because of this arrangement, the ramp densities were low, and there were no points added for concurrent routes. The interchange was arranged such that the ramps typically had ample speed-change lanes, so the scores for those characteristics were also low. However, particularly for unfamiliar drivers, traversing this interchange and determining the most appropriate path to take to arrive at a desired destination could be quite challenging. As a result, researchers elevated its place on the list in table 20.

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Figure 79. Photo. Configuration of site SC-2.(49)

Interpretation of Scores

As mentioned previously, there was a noticeable gap between the highest scores and the remaining scores. In particular, three sites received scores over 550: OH-2, VA-2, and OH-3. These three sites were in constrained urban environments, had unusual geometries, and had high ramp densities with multiple destinations (e.g., the aerial view of OH-2 in figure 39). As a result, these interchanges received a non-zero score for almost every variable in the spreadsheet on at least one approach. All had at least one approach with a score of 660 or greater, and the EB and WB approaches at VA-2 had scores of 720 and 770, respectively, which were the two highest scores in the database.

There was a substantial drop in score between these interchanges and the fourth site on the list, AZ-2. AZ-2 also had some unusual geometry, but it was not as constrained as the first three sites. The fifth highest-scoring site, AZ-1, had similarities to AZ-2 but was even less constrained on its speed-change lanes and ramp spacing.

The site with the lowest score, SC-3, was submitted because of its closely spaced ramps on an interstate highway intersected with two numbered routes that existed as at-grade city streets (see figure 40). While the geometry of the interchange was unusual, the lower score was a result of the configuration of the ramps. The site had a C-D system that required only one exit and one entrance from the freeway. The NB approach received a score of only 115, which was the second-lowest score of any approach in the database. One important reason why the site had a low score was because the intersecting numbered routes were not freeways, and their complexity could not be measured in the same way as that of freeway routes. The city streets had traffic signals and other traffic control devices not found on freeways, as well as substantially lower speeds, which arguably reduced the complexity of navigating those routes. Regardless if they were less complex, their characteristics prevented them from being directly compared to freeways within the spreadsheet, and thus those routes were not tabulated.

It should also be noted that because the C-D road system removes entering and exiting traffic from the main lanes of the freeway with just one entrance and one exit, the effect of the ramp configuration on the complexity score was low. The research team discussed this effect, as well as effects on other C-D sites, to consider whether the presence of a C-D road actually increases or decreases complexity. This concept is discussed further in the explanation of weights and points section.

The other sites in group 4 typically had some unusual geometry in that at least one maneuver to travel from one route to another required using one or more ramps that were on an unusual alignment or were not constructed similar to the ramps for the other maneuvers at the interchange. However, the overall complexity of the interchanges was not nearly as great as the others in the study sites because drivers generally had to face few decision points, there were no left-side ramps, the number of general purpose lanes was low, there were no concurrent routes, and/or the ramp density was low.

Sites in groups 2 and 3 had complexity levels similar to other sites within the same group, reflecting a variety of combinations of ramp densities, left-side ramps, missing movements, travel lane configurations, lateral clearance and roadside environment, ramp geometry and alignment, and auxiliary lane configurations. Sites in group 2 had more characteristics that triggered points on their scores than sites in group 3. Overall, a comparison of sites in group 4 to sites in groups 1–3 in table 20 shows sites that had increasingly more factors that contributed to an increased score. The combinations of those factors were not always the same, but the number of factors present at a site generally increased as the group changed from 4 to 1, so that sites in group 4 had few score-generating factors present, while group 1 sites had most (if not all) of those factors present on at least one approach.

DISCUSSION

The previous sections in this appendix described the activities taken by the research team to develop the spreadsheet tool and provided the results of applying the spreadsheet to 28 existing interchanges across the United States. This concluding section discusses the ramifications of those results as well as key characteristics of the spreadsheet and its usefulness.

Features of the Spreadsheet

The following list provides a summary of the features of the spreadsheet tool:

- The spreadsheet provides a means of objectively comparing the complexity of different interchanges based on a variety of geometric and other variables. The spreadsheet provides a numerical score that is directly comparable to scores from any other interchange. The basis of the spreadsheet is the characteristics of each ramp a driver encounters while driving through any corridor in the interchange.

- The spreadsheet accounts for differences between entrance ramps and exit ramps, frequency of ramps, differences between freeway-to-freeway connector ramps and service ramps, differences between taper and parallel speed-change lanes, presence of managed lanes, presence of narrow shoulders, number of concurrent routes and vertical levels, shared exit lanes, lane continuity and lane balance, and horizontal alignment, among other features.

- The spreadsheet is designed so that a user can complete the spreadsheet from the office. There is no need to physically visit the interchange and take measurements in the roadway. All of the necessary information can be obtained through as-built plans or a mapping service such as Google Earth®.

- The spreadsheet establishes threshold values for each factor to provide a means of assigning points that increase as the contributing characteristic increases in complexity. The spreadsheet also provides weights to each factor to generate higher scores for characteristics that are relatively more complex than others.

- The spreadsheet checks the distance between successive ramps based on the procedure defined in the 2011 AASHTO *Green Book*.[(2)] This check allows the user to readily determine whether the distance between any two successive ramps is shorter than recommended, identifying a variable that contributes to complexity.

- The spreadsheet has a feature to account for the built environment adjacent to the freeway. A densely built urban environment adds more workload to a driver than a sparsely built rural environment. Similarly, the spreadsheet accounts for the number of lanes on both the ramps and on the general purpose lanes or main lanes. An increased number of lanes also means an increased number of decisions a driver must make to determine what lane is the correct lane for the driver’s destination. More travel lanes also typically represent higher traffic volumes, resulting in more demands on a driver’s attention while navigating the interchange.

- The spreadsheet accounts for each approach individually as well as collectively. This feature allows a user to identify a particularly complex approach within a high-scoring interchange.

Limitations of the Spreadsheet

Despite all of the features that can be found in the spreadsheet, there are a number of limitations as well. Some of these were included in discussions by the research team while developing the spreadsheet, while others were discovered during the review and quality control process. Key limitations include the following:

- By design, the spreadsheet includes only characteristics that can be obtained through Google Earth® or a similar mapping service. This is intended to enable more practitioners to use the spreadsheet without requiring access to certain types of site-specific data such as traffic volumes, construction history, or other information that may not be readily available.

- The spreadsheet does not directly account for a driver's destination or origin unless the driver is traveling straight through the interchange on the same route from approach to departure. While each exit and entrance ramp is included in the analysis, the spreadsheet does not directly document the series of decisions an exiting or entering driver would have to make for all of the origin-destination combinations in a given interchange. In other words, it does not estimate the complexity of a path from one route to another; it only describes complexity along the same route. For example, missing movements were not originally included in the spreadsheet, but consideration for the missing movements was added to help describe how some interchanges are more complex because of what is absent rather than what is present.

- The spreadsheet does not account for interactions between factors. There was a great deal of discussion during the early steps in the process to develop the spreadsheet concerning how one factor might affect another so that the combination of the two factors added more complexity than just the sum of the two factors individually. A proper exploration of interaction would be a very time consuming and complicated process and could not be adequately addressed in this study.

- While the spreadsheet does consider C-D roads within the variable for multiple destinations from a single ramp, it is unclear whether the full effect of C-D roads is truly addressed. C-D roads help remove merging, diverging, and weaving maneuvers from the main lanes, thus helping reduce complexity for through drivers. However, C-D roads may actually be more complex than traditional ramps because of the need to exit a substantial distance upstream of where a driver would expect to exit. That effect is not captured in the spreadsheet.

- The spreadsheet does not fully capture the effect of adjacent interchanges. While the nearest upstream and downstream ramp is documented within the spreadsheet, the full effect of that ramp as part of another potentially complex interchange is not included in the analysis. Within the study sites compiled for this spreadsheet, there were three sets of interchanges that are either adjoining or in very close proximity. The two Oregon sites (OR-1 and OR-2) are a short distance apart, and both are constrained by the boundaries of the Willamette River. It is possible that the close proximity of the two interchanges makes traversing them more complex than if they were apart.

Two Virginia sites (VA-1 and VA-2) are adjacent on I-395, and all three Delaware sites are close enough that a driver could easily drive through all three in one maneuver, changing routes only once. There could be a cumulative effect of these interchanges being so close together, but a thorough exploration of that effect is beyond the ability of this study.

- The spreadsheet is not designed to accommodate more than four approach legs. The spreadsheet was established to account for four corridors—NB, SB, EB, and WB. Those designations could change somewhat if the interchange in question is not particularly oriented to those directions, but the process for using the spreadsheet is the same if the interchange is quadrivial (i.e., having four roads meeting at a point). However, an arguably more complex interchange is one with more than four approaches (i.e., superquadrivial). The majority of those submitted for New York are in this category. It is reasonable that these interchanges are more complex than those evaluated because of the additional legs that must be considered. Unfortunately, expanding the spreadsheet to account for those additional legs would make for an unwieldy spreadsheet, and it is unclear whether a direct comparison between quadrivial and superquadrivial interchanges would be valid.

- As previously mentioned, the spreadsheet does not account for traffic volumes. An implied connection can be made between the number of lanes and traffic volumes, but volumes are not directly requested in the set of input data. Similarly, the volume-to-capacity ratio or the level of service is not requested in the spreadsheet. Those variables could also have an effect on the complexity of an interchange, but they are not design characteristics and were deemphasized for this study.

Additional Considerations

In addition to the features and limitations of the spreadsheet, additional items that may be considered in understanding how the spreadsheet functions are provided in the following list (these items could also be topics for further exploration):

- The topic of missing movements has been mentioned previously in this appendix. The concept is that a missing movement prevents a driver on a given approach from directly accessing a different approach. It may be possible to go from one to the other but only through a series of maneuvers such as U-turns or multiple exits and entrances. Originally, missing movements were not included because the spreadsheet only evaluated existing ramps—the spreadsheet could not consider a ramp that did not exist. An adjustment was made to include missing movements, but it is unclear whether the scoring or weight properly quantifies the relative complexity of this site characteristic.

- The results of the spreadsheet (i.e., the scores for each interchange and each individual approach) are dependent on the high/low threshold values and weights, which were subjectively determined by the research team with input from reviewers. Even the fact that the weights were originally designed to generate a 100-point total for ease of observation may affect the results; allowing for a different point total could provide a different means of establishing the weights. The research team believes that the 100-point total is beneficial and aids the user in understanding the results. Researchers also believe the sets of weights and threshold values presented are reasonable, given the consistency in the relative scores and groupings that resulted from the variety of combinations tested. The team also recognizes that a different set of weights and values that produce somewhat different scores could be developed on a reasonable basis.

- A full sensitivity analysis would help determine whether some weights or threshold values are inappropriately affecting the scores. A partial analysis was conducted on selected variables, but a full analysis was not possible in this study. For example, it is unclear whether the number of general purpose lanes is optimally accounted for in the spreadsheet. It is used as a surrogate for traffic volume and provides an indication of complexity if a driver must make additional lane changes, but it is unknown how sensitive the score is to the presence of two through lanes instead of three or four (if the threshold value was changed) and whether the presence of three general purpose lanes is truly as complex as the presence of a concrete barrier within 4 ft of the left side of the travel way. The research team believes that the sets of weights and threshold values presented are reasonable, but the team also recognizes that a reasonable approach could produce a different set of weights and values with somewhat different scores.

- Another topic of consideration is how study distance is measured. The spreadsheet includes all of the distance a driver must travel to navigate through the interchange, which means that the distance is measured from the point immediately downstream of the nearest ramp in the adjacent upstream interchange to the point of the nearest ramp for the succeeding interchange. This distance may be too large to sufficiently capture the effects of some calculated values, such as ramp density. The added distance may understate ramp density effects, particularly for cloverleaf interchanges that have segments of dense ramp locations (i.e., a cluster of ramps) followed by a long distance between ramps, resulting in a lower ramp density over the entire study distance.

- The use of the average approach score to determine the overall interchange score may deemphasize a particularly complex approach. It is possible that the use of the highest approach score would be beneficial in determining the complexity of an interchange, but that method could also deemphasize a relatively simple approach. As stated previously, practitioners could develop reasonable explanations for using either method.

- Operating speed and posted speed limit are not accounted for in this spreadsheet, and some of the sites had lower posted speed limits than others with similar or lower scores. For example, NY-3 had a posted limit of 45 mi/h on its major route; however, because of its ramp density and presence of left entrances and exits, it had a higher score than other sites with higher speed limits. It is unclear to what extent lower operating speeds would mitigate some of the complexity in an interchange such as NY-3 compared to other sites with fewer complex elements but higher speeds.

SUMMARY

Researchers were tasked with developing a tool that could aid practitioners in assessing the complexity of a freeway interchange and objectively compare it to other interchanges. The focus of such a tool was on geometric design factors and related effects on driver expectancy and driver workload. Researchers considered a variety of factors and formats, ultimately developing a spreadsheet tool in which users could enter site characteristics and receive a numerical complexity score for a given interchange. After several revisions, researchers settled on a spreadsheet tool that considers the effects of 32 weighted factors on as many as 4 approaches within a given interchange. The weights range in value from 1 to 5, and the sum of the 32 weights is 100 (see table 19). The estimated impact of each factor is given points, which, when multiplied by the weight, produces a weighted score on a 1,000-point scale for each approach and for the interchange as a whole.

To determine how well the spreadsheet tool would evaluate interchanges, the research team used the spreadsheet to review 28 existing sites in 11 States. The sites were submitted by State transportation departments on the basis of their perceived complexity. The 28 sites were divided into 4 distinct groups based on the spreadsheet scores ranging from a high of 590 to a low of 180. Sites with similar scores were in the same group and were viewed as having similar levels of complexity. Researchers tested multiple combinations of weights to develop scores for the 28 sites. While individual site scores changed as the weights changed, the final set of weights produced results similar to the rankings and groupings of the study sites determined by the research team. This indicates that for the characteristics included in this spreadsheet, the results produced a general sense of the relative complexity of the interchanges studied.

In summary, the complex interchange spreadsheet tool is a useful tool for objectively comparing the complexity of multiple interchanges and determining what characteristics contribute to that complexity. There may be other variables that could be useful additions to the factors already included, and it is possible that a different distribution of weights and threshold values may produce a reasonable set of scores that varies from those presented in this report; however, these scores allow the user to evaluate one or more interchanges to identify potential problems that drivers may face as they travel through those interchanges. Consideration of these issues can help practitioners identify potential countermeasures either through the use of traffic control devices or, ideally, through the use of revised designs to mitigate the site characteristics that are potentially problematic.

APPENDIX C. DESCRIPTION OF SURVEY SITES USED IN DEVELOPING THE SPREADSHEET TOOL

This appendix contains descriptions of each of the 28 interchanges used in developing the complex interchange spreadsheet tool. The descriptions each contain an aerial photograph, a brief description of the interchange's location and routes, and a summary of the characteristics used in the spreadsheet.

Information for site AZ-1 is as follows:

- **Site**: AZ-1.
- **Location**: Phoenix, AZ.
- Primary route: I-10.
- **Secondary/intersecting routes**: I-17/US-60.

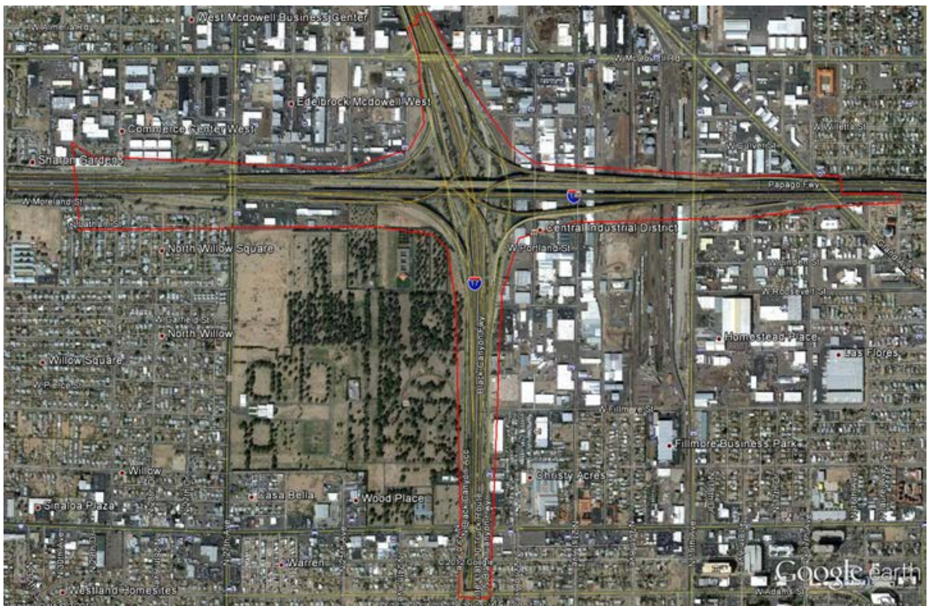

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Figure 80. Photo. Aerial view of site AZ-1.[50]

Table 49. Characteristics of AZ-1.

Variable	NB	SB	EB	WB
Study length (ft)	9,010	9,590	13,755	12,665
Number of concurrent routes	2	2	1	1
Number of levels	4	4	4	4
Number of missing movements	0	0	0	0
Number of ramps	4	4	5	4
Exit ramps per mile	1.17	1.10	1.15	0.83
Entrance ramps per mile	1.17	1.10	0.77	0.83
Left exits per mile	0.00	0.00	0.00	0.00
Left entrances per mile	0.00	0.00	0.00	0.00
Number of exit ramps with multiple destinations per mile	0.59	0.55	0.00	0.42
Multilane exit ramps per mile	0.59	0.55	0.38	0.42
Optional/shared exit lanes per mile	0.59	1.10	0.77	0.42
Exit only lanes per mile	1.17	1.10	0.77	0.83
Score	355	505	490	470
Overall score	455			

Information for site AZ-2 is as follows:

- **Site**: AZ-2.
- **Location**: Phoenix, AZ.
- **Primary routes**: I-10 and SR 51.
- **Secondary/intersecting routes**: SR 51 and LP 202.

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Figure 81. Photo. Aerial view of site AZ-2.[51]

Table 50. Characteristics of AZ-2.

Variable	NB	SB	EB	WB
Study length (ft)	9,450	10,555	5,555	10,455
Number of concurrent routes	1	1.125	1	1
Number of levels	4	4	4	4
Number of missing movements	0	0	0	0
Number of ramps	4	8	2	7
Exit ramps per mile	1.68	1.50	1.90	1.52
Entrance ramps per mile	0.56	2.00	0.00	2.02
Left exits per mile	0.56	0.50	0.95	0.51
Left entrances per mile	0.00	1.00	0.00	0.00
Number of exit ramps with multiple destinations per mile	0.00	0.00	0.95	1.01
Multilane exit ramps per mile	0.56	0.50	0.95	0.00
Optional/shared exit lanes per mile	1.68	0.50	1.90	0.00
Exit only lanes per mile	0.56	1.50	1.90	1.52
Score	440	605	370	620
Overall score	508.75			

Information for site AZ-3 is as follows:

- **Site:** AZ-3.
- **Location:** Prescott, AZ.
- **Primary route:** I-17.
- **Secondary/intersecting route:** SR 69.

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Figure 82. Photo. Aerial view of site AZ-3.(52)

Table 51. Characteristics of AZ-3.

Variable	NB	SB	EB	WB
Study length (ft)	46,355	46,360	6,945	4,305
Number of concurrent routes	1	1	1	1
Number of levels	2	2	2	2
Number of missing movements	0	0	0	0
Number of ramps	2	4	2	2
Exit ramps per mile	0.11	0.23	0.76	1.23
Entrance ramps per mile	0.11	0.23	0.76	1.23
Left exits per mile	0.00	0.00	0.00	0.00
Left entrances per mile	0.00	0.00	0.00	0.00
Number of exit ramps with multiple destinations per mile	0.11	0.00	0.00	0.00
Multilane exit ramps per mile	0.00	0.00	0.00	0.00
Optional/shared exit lanes per mile	0.11	0.11	0.00	1.23
Exit only lanes per mile	0.00	0.11	0.76	0.00
Score	154	230	270	300
Overall score	236.25			

Information for site DE-1 is as follows:

- **Site**: DE-1.
- **Location**: Wilmington, DE.
- **Primary route**: I-95.
- **Secondary/intersecting routes**: SR 1/SR 7 and Churchmans Road.

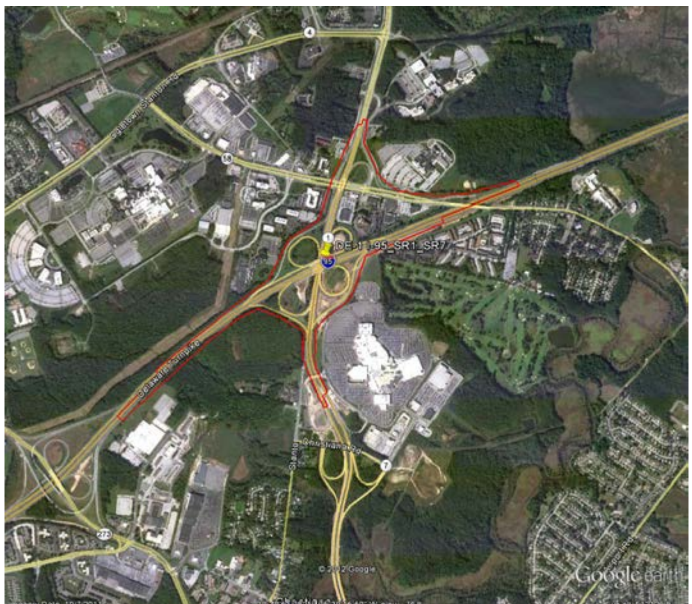

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Figure 83. Photo. Aerial view of site DE-1.(53)

Table 52. Characteristics of DE-1.

Variable	NB	SB	EB	WB
Study length (ft)	6,300	6,642	16,405	19,255
Number of concurrent routes	2	2	1	1
Number of levels	2	2	2	2
Number of missing movements	0	0	0	0
Number of ramps	5	3	4	3
Exit ramps per mile	2.51	0.79	0.64	0.55
Entrance ramps per mile	1.68	1.59	0.64	0.27
Left exits per mile	0.00	0.00	0.00	0.00
Left entrances per mile	0.00	0.00	0.00	0.00
Number of exit ramps with multiple destinations per mile	0.00	0.79	0.00	0.27
Multilane exit ramps per mile	0.00	0.79	0.00	0.00
Optional/shared exit lanes per mile	0.84	0.79	0.00	0.00
Exit only lanes per mile	1.68	0.79	0.64	0.55
Score	375	325	170	170
Overall score	260			

Information for site DE-2 is as follows:

- **Site:** DE-2.
- **Location:** Wilmington, DE.
- **Primary routes:** I-95/I-295.
- **Secondary/intersecting routes:** US-202/SR 141.

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Figure 84. Photo. Aerial view of site DE-2.(54)

Table 53. Characteristics of DE-2.

Variable	NB	SB	EB	WB
Study length (ft)	4,855	3,625	10,320	17,405
Number of concurrent routes	2	2	1	1
Number of levels	2	2	2	2
Number of missing movements	0	0	1	0
Number of ramps	5	4	2	3
Exit ramps per mile	2.18	4.37	0.51	0.30
Entrance ramps per mile	3.26	1.46	0.51	0.61
Left exits per mile	1.09	1.46	0.00	0.00
Left entrances per mile	0.00	0.00	0.51	0.30
Number of exit ramps with multiple destinations per mile	0.00	0.00	0.51	0.30
Multilane exit ramps per mile	0.00	0.00	0.51	0.30
Optional/shared exit lanes per mile	1.09	2.91	0.51	0.00
Exit only lanes per mile	1.09	1.46	0.51	0.61
Score	465	435	335	420
Overall score	413.75			

Information for site DE-3 is as follows:

- **Site**: DE-3.
- **Location**: Wilmington, DE.
- **Primary route**: I-295.
- **Secondary/intersecting routes**: SR 13/US-40.

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Figure 85. Photo. Aerial view of site DE-3.(55)

Table 54. Characteristics of DE-3.

Variable	NB	SB	EB	WB
Study length (ft)	3,085	1,990	10,010	9,180
Number of concurrent routes	2	2	1	1
Number of levels	2	2	2	2
Number of missing movements	0	0	0	0
Number of ramps	5	4	4	3
Exit ramps per mile	1.71	5.31	1.05	0.58
Entrance ramps per mile	6.85	5.31	1.05	1.15
Left exits per mile	1.71	2.65	0.00	0.00
Left entrances per mile	5.13	2.65	0.53	0.58
Number of exit ramps with multiple destinations per mile	0.00	2.65	0.00	0.58
Multilane exit ramps per mile	1.71	0.00	0.00	0.58
Optional/shared exit lanes per mile	1.71	0.00	0.00	0.00
Exit only lanes per mile	1.71	5.31	1.05	1.15
Score	465	465	360	390
Overall score	420			

Information for site GA-2 is as follows:

- **Site:** GA-2.
- **Location:** Atlanta, GA.
- **Primary routes:** I-85/SR 403.
- **Secondary/intersecting route:** I-285.

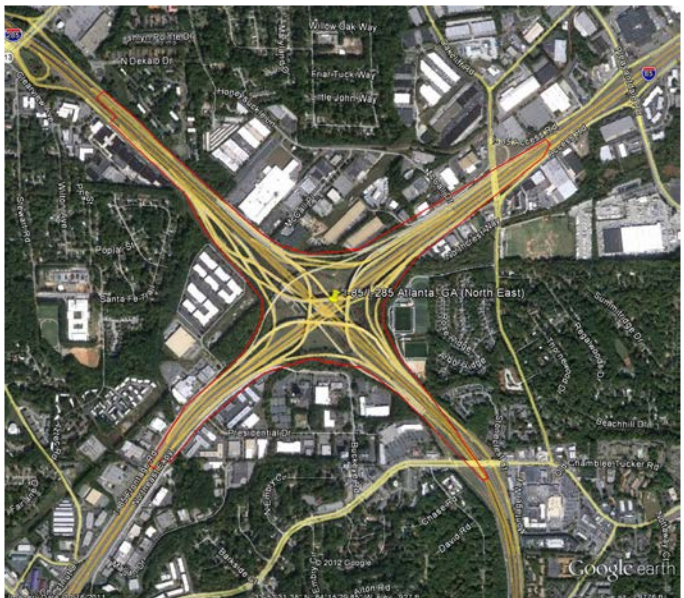

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Figure 86. Photo. Aerial view of site GA-2.[56]

Table 55. Characteristics of GA-2.

Variable	NB	SB	EB	WB
Study length (ft)	12,215	12,090	11,530	9,065
Number of concurrent routes	2	2	1	1
Number of levels	3	3	3	3
Number of missing movements	0	0	0	0
Number of ramps	4	4	4	3
Exit ramps per mile	0.86	0.87	0.92	0.58
Entrance ramps per mile	0.86	0.87	0.92	1.16
Left exits per mile	0.00	0.00	0.00	0.00
Left entrances per mile	0.00	0.00	0.00	0.00
Number of exit ramps with multiple destinations per mile	0.43	0.44	0.46	0.00
Multilane exit ramps per mile	0.43	0.87	0.92	0.00
Optional/shared exit lanes per mile	0.43	0.87	0.46	0.00
Exit only lanes per mile	0.86	0.87	1.37	0.58
Score	415	415	350	300
Overall score	370			

Information for site GA-3 is as follows:

- **Site:** GA-3.
- **Location:** Atlanta, GA.
- **Primary routes:** I-85/SR 403.
- **Secondary/intersecting route:** SR 316.

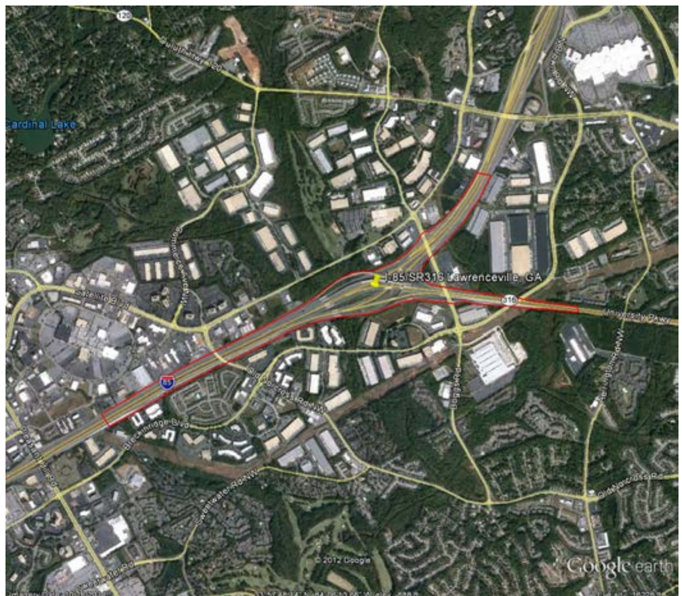

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Figure 87. Photo. Aerial view of site GA-3.[57]

Table 56. Characteristics of GA-3.

Variable	NB	SB	EB	WB
Study length (ft)	17,450	16,095	8,285	13,920
Number of concurrent routes	2	2	1	1
Number of levels	2	2	2	2
Number of missing movements	0	1	0	0
Number of ramps	4	4	2	4
Exit ramps per mile	0.91	0.33	0.00	1.52
Entrance ramps per mile	0.30	0.98	1.27	0.00
Left exits per mile	0.30	0.00	0.00	0.76
Left entrances per mile	0.00	0.33	0.64	0.00
Number of exit ramps with multiple destinations per mile	0.30	0.00	0.00	0.00
Multilane exit ramps per mile	0.61	0.00	0.00	0.00
Optional/shared exit lanes per mile	0.61	0.00	0.00	0.76
Exit only lanes per mile	0.91	0.33	0.00	0.76
Score	435	250	200	380
Overall score	316.25			

Information for site GA-4 is as follows:

- **Site:** GA-4.
- **Location:** Macon, GA.
- **Primary routes:** I-75/SR 401.
- **Secondary/intersecting routes:** I-16/SR 404.

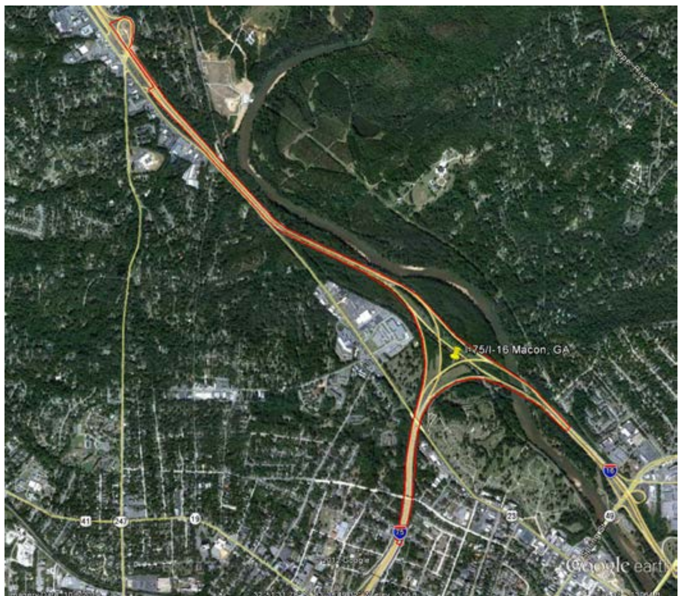

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Figure 88. Photo. Aerial view of site GA-4.[58]

Table 57. Characteristics of GA-4.

Variable	NB	SB	EB	WB
Study length (ft)	5,810	12,025	2,400	8,680
Number of concurrent routes	2	2	2	2
Number of levels	2	2	2	2
Number of missing movements	0	0	0	0
Number of ramps	1	2	1	1
Exit ramps per mile	0.91	0.44	0.00	0.00
Entrance ramps per mile	0.00	0.44	2.20	0.61
Left exits per mile	0.00	0.44	0.00	0.00
Left entrances per mile	0.00	0.44	2.20	0.00
Number of exit ramps with multiple destinations per mile	0.00	0.00	0.00	0.00
Multilane exit ramps per mile	0.91	0.00	0.00	0.00
Optional/shared exit lanes per mile	0.00	0.00	0.00	0.00
Exit only lanes per mile	1.82	0.44	0.00	0.00
Score	295	265	225	105
Overall score	222.5			

Information for site IN-1 is as follows:

- **Site**: IN-1.
- **Location**: Gary, IN.
- **Primary routes**: I-80/I-94/US-6.
- **Secondary/intersecting route**: I-65.

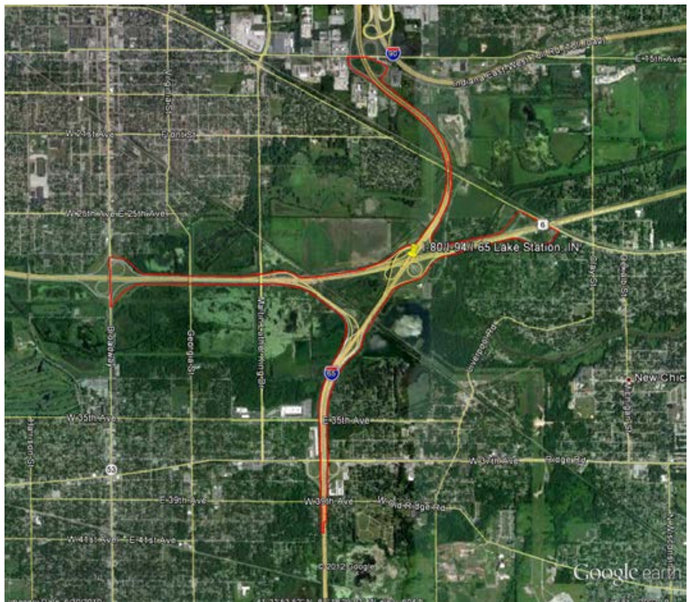

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Figure 89. Photo. Aerial view of site IN-1.[59]

Table 58. Characteristics of IN-1.

Variable	NB	SB	EB	WB
Study length (ft)	16,330	15,650	24,575	10,605
Number of concurrent routes	1	1	3	3
Number of levels	2	2	2	2
Number of missing movements	0	0	0	0
Number of ramps	4	4	3	4
Exit ramps per mile	0.65	0.67	0.43	0.50
Entrance ramps per mile	0.65	0.67	0.21	1.49
Left exits per mile	0.00	0.00	0.00	0.00
Left entrances per mile	0.00	0.00	0.00	0.00
Number of exit ramps with multiple destinations per mile	0.00	0.34	0.43	0.50
Multilane exit ramps per mile	0.32	0.00	0.21	0.50
Optional/shared exit lanes per mile	0.00	0.00	0.21	0.50
Exit only lanes per mile	0.97	0.67	0.43	0.50
Score	330	230	365	250
Overall score	293.75			

Information for site IN-3 is as follows:

- **Site**: IN-3.
- **Location**: Indianapolis, IN.
- **Primary routes**: I-69/SR 37/Binford Boulevard.
- **Secondary/intersecting routes**: I-465/US-421/US-31.

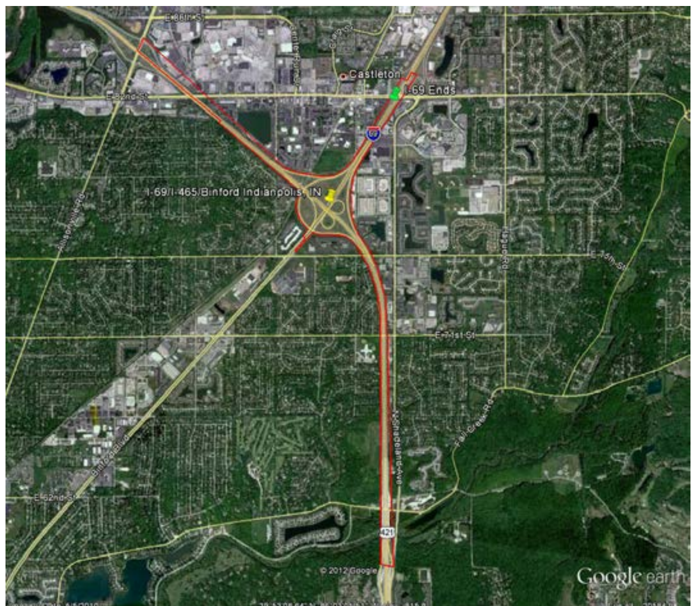

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Figure 90. Photo. Aerial view of site IN-3.[60]

Table 59. Characteristics of IN-3.

Variable	NB	SB	EB	WB
Study length (ft)	5,105	6,605	18,015	17,915
Number of concurrent routes	3	2.5	3	3
Number of levels	2	2	2	2
Number of missing movements	1	0	0	1
Number of ramps	3	2	3	3
Exit ramps per mile	1.03	0.80	0.59	0.29
Entrance ramps per mile	2.07	0.80	0.29	0.59
Left exits per mile	0.00	0.00	0.00	0.00
Left entrances per mile	0.00	0.00	0.00	0.00
Number of exit ramps with multiple destinations per mile	0.00	0.80	0.00	0.00
Multilane exit ramps per mile	0.00	0.80	0.00	0.29
Optional/shared exit lanes per mile	0.00	0.80	0.00	0.29
Exit only lanes per mile	1.03	1.60	0.59	0.29
Score	325	330	220	235
Overall score	277.5			

Information for site IA-1 is as follows:

- **Site:** IA-1.
- **Location:** Des Moines, IA.
- **Primary routes:** I-80/I-35.
- **Secondary/intersecting routes:** I-235/I-35.

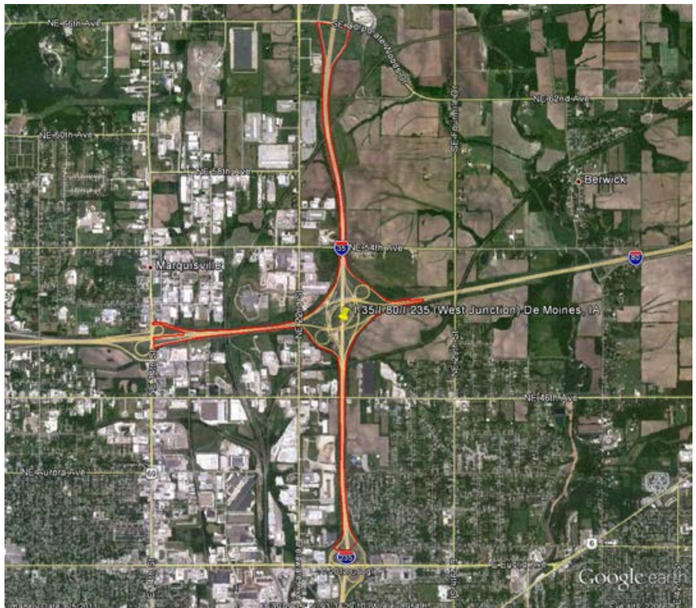

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Figure 91. Photo. Aerial view of site IA-1.[61]

Table 60. Characteristics of IA-1.

Variable	NB	SB	EB	WB
Study length (ft)	15,105	15,775	18,159	17,100
Number of concurrent routes	1.333	1.333	1.25	1.25
Number of levels	2	2	2	2
Number of missing movements	0	0	0	0
Number of ramps	3	3	4	4
Exit ramps per mile	0.35	0.33	0.58	0.62
Entrance ramps per mile	0.70	0.67	0.58	0.62
Left exits per mile	0.00	0.00	0.29	0.31
Left entrances per mile	0.00	0.00	0.00	0.00
Number of exit ramps with multiple destinations per mile	0.35	0.33	0.00	0.00
Multilane exit ramps per mile	0.35	0.33	0.00	0.00
Optional/shared exit lanes per mile	0.00	0.00	0.00	0.31
Exit only lanes per mile	0.70	0.67	0.58	0.31
Score	345	305	275	375
Overall score	325			

Information for site IA-2 is as follows:

- **Site**: IA-2.
- **Location**: Cedar Rapids, IA.
- **Primary routes**: I-380/SR and 27/US-218.
- **Secondary/intersecting routes**: US-30/US-151/US-28.

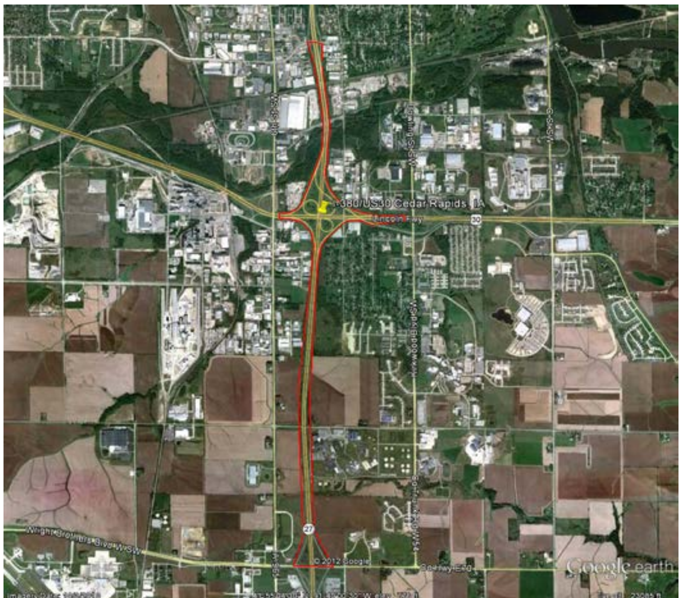

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Figure 92. Photo. Aerial view of site IA-2.[62]

Table 61. Characteristics of IA-2.

Variable	NB	SB	EB	WB
Study length (ft)	17,250	17,030	5,775	5,815
Number of concurrent routes	2	1.667	2	2.5
Number of levels	2	2	2	2
Number of missing movements	0	0	0	0
Number of ramps	4	3	4	4
Exit ramps per mile	0.61	0.31	1.83	1.82
Entrance ramps per mile	0.61	0.62	1.83	1.82
Left exits per mile	0.00	0.00	0.00	0.00
Left entrances per mile	0.00	0.00	0.00	0.00
Number of exit ramps with multiple destinations per mile	0.00	0.31	0.00	0.00
Multilane exit ramps per mile	0.00	0.31	0.00	0.00
Optional/shared exit lanes per mile	0.31	0.31	0.00	0.00
Exit only lanes per mile	0.31	0.31	1.83	1.82
Score	255	245	295	270
Overall score	266.25			

Information for site IA-3 is as follows:

- **Site**: IA-3.
- **Location**: Sioux Falls, IA.
- **Primary route**: I-29.
- **Secondary/intersecting routes**: I-129 and US-75/US-20.

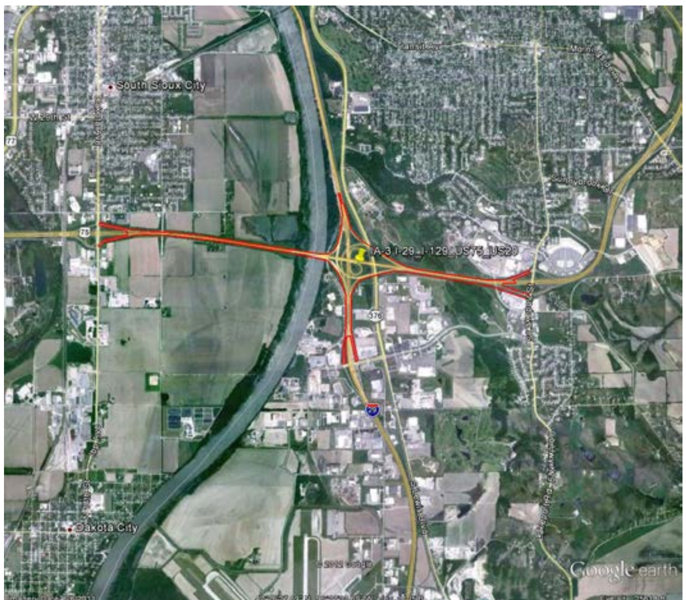

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Figure 93. Photo. Aerial view of site IA-3.(63)

Table 62. Characteristics of IA-3.

Variable	NB	SB	EB	WB
Study length (ft)	18,055	17,625	14,595	15,290
Number of concurrent routes	1	1	2.333	2.333
Number of levels	2	2	2	2
Number of missing movements	0	0	0	0
Number of ramps	4	2	2	3
Exit ramps per mile	0.58	0.30	0.72	0.35
Entrance ramps per mile	0.58	0.30	0.36	0.69
Left exits per mile	0.00	0.00	0.00	0.00
Left entrances per mile	0.00	0.00	0.00	0.00
Number of exit ramps with multiple destinations per mile	0.00	0.30	0.00	0.35
Multilane exit ramps per mile	0.00	0.00	0.00	0.35
Optional/shared exit lanes per mile	0.00	0.00	0.72	0.35
Exit only lanes per mile	0.58	0.30	0.00	0.35
Score	210	145	280	280
Overall score	228.75			

Information for site MD-1 is as follows:

- **Site:** MD-1.
- **Location:** Baltimore, MD.
- **Primary route:** I-95.
- **Secondary/intersecting route:** I-695.

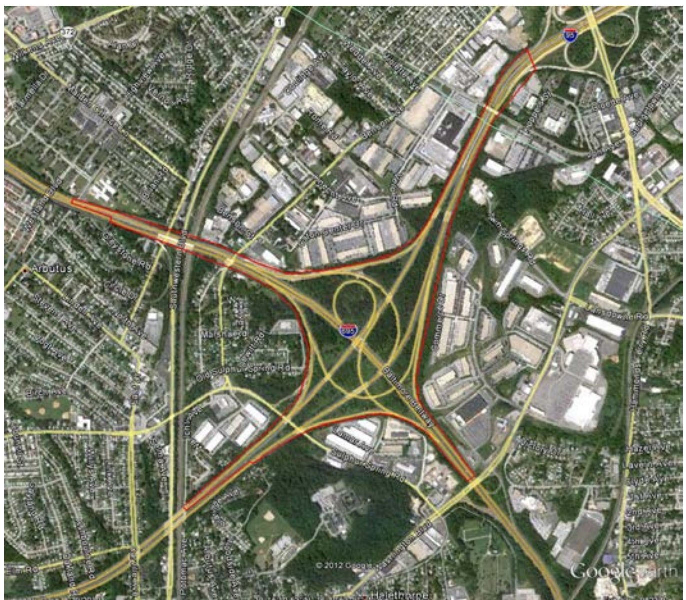

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Figure 94. Photo. Aerial view of site MD-1.(64)

Table 63. Characteristics of MD-1.

Variable	NB	SB	EB	WB
Study length (ft)	13,450	6,520	7,770	7,755
Number of concurrent routes	1	1	1	1
Number of levels	2	2	2	2
Number of missing movements	0	0	0	0
Number of ramps	3	3	2	3
Exit ramps per mile	0.79	1.62	0.68	1.36
Entrance ramps per mile	0.39	0.81	0.68	0.68
Left exits per mile	0.39	0.81	0.00	0.00
Left entrances per mile	0.00	0.00	0.00	0.00
Number of exit ramps with multiple destinations per mile	0.00	0.00	0.68	0.00
Multilane exit ramps per mile	0.00	0.00	0.68	0.00
Optional/shared exit lanes per mile	0.00	0.00	0.68	0.00
Exit only lanes per mile	0.79	1.62	1.36	1.36
Score	260	270	380	310
Overall score	305			

Information for site NY-1 is as follows:

- **Site:** NY-1.
- **Location:** Port Chester, NY.
- **Primary route:** I-95.
- **Secondary/intersecting route:** I-287.

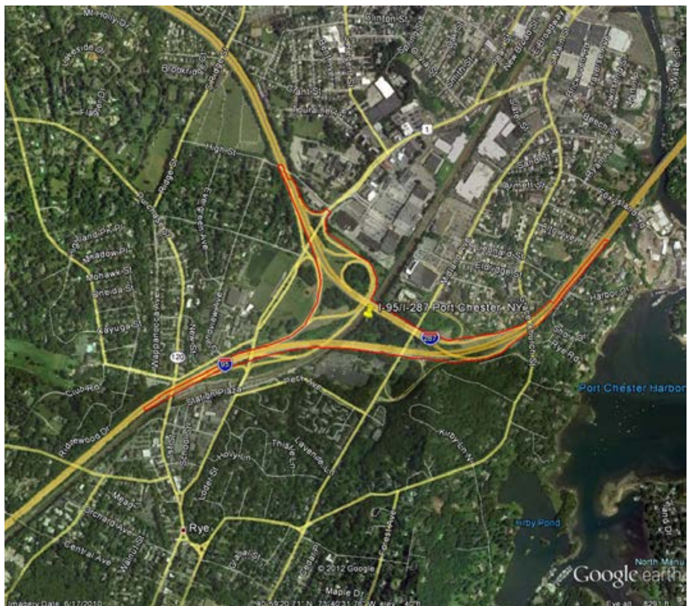

Figure 95. Photo. Aerial view of site NY-1.(65)

Table 64. Characteristics of NY-1.

Variable	NB	SB	EB	WB
Study length (ft)	15,700	15,730	14,165	9,500
Number of concurrent routes	1	1	1	1
Number of levels	2	2	2	2
Number of missing movements	0	0	0	0
Number of ramps	4	2	3	5
Exit ramps per mile	1.01	0.34	0.75	1.11
Entrance ramps per mile	0.34	0.34	0.37	1.67
Left exits per mile	0.00	0.00	0.00	0.00
Left entrances per mile	0.00	0.00	0.00	0.00
Number of exit ramps with multiple destinations per mile	0.00	0.34	0.00	0.00
Multilane exit ramps per mile	0.00	0.00	0.00	0.00
Optional/shared exit lanes per mile	0.00	0.00	0.00	0.56
Exit only lanes per mile	1.01	0.34	0.75	0.56
Score	200	300	280	360
Overall score	285			

Information for site NY-3 is as follows:

- **Site**: NY-3.
- **Location**: Poughkeepsie, NY.
- **Primary routes**: US-44/SR 55.
- **Secondary/intersecting route**: US-9.

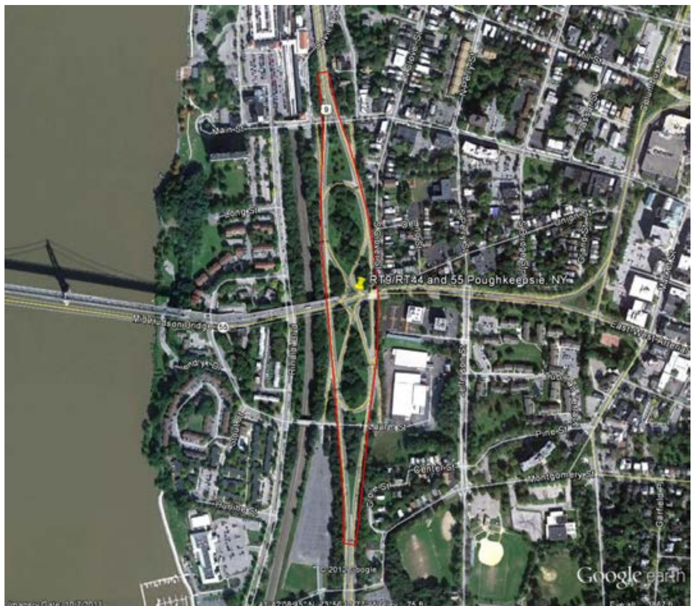

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Figure 96. Photo. Aerial view of site NY-3.[66]

Table 65. Characteristics of NY-3.

Variable	NB	SB	EB	WB
Study length (ft)	3,270	2,820	10,055	10,150
Number of concurrent routes	1	1	2	2
Number of levels	2	2	2	2
Number of missing movements	0	0	0	0
Number of ramps	6	6	2	2
Exit ramps per mile	3.23	5.62	0.53	0.52
Entrance ramps per mile	4.84	5.62	0.53	0.52
Left exits per mile	3.23	3.74	0.00	0.00
Left entrances per mile	3.23	3.74	0.00	0.00
Number of exit ramps with multiple destinations per mile	0.00	0.00	0.00	0.00
Multilane exit ramps per mile	0.00	0.00	0.00	0.00
Optional/shared exit lanes per mile	1.61	1.87	0.00	0.00
Exit only lanes per mile	3.23	3.74	0.53	0.52
Score	490	470	235	195
Overall score	347.5			

Information for site OH-1 is as follows:

- **Site**: OH-1.
- **Location**: Cleveland, OH.
- **Primary route**: I-90.
- **Secondary/intersecting route**: I-77.

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Figure 97. Photo. Aerial view of site OH-1.[(67)]

Table 66. Characteristics of OH-1.

Variable	NB	SB	EB	WB
Study length (ft)	7,235	8,505	0	1,785
Number of concurrent routes	1	1	0	1
Number of levels	2	2	0	2
Number of missing movements	0	0	0	1
Number of ramps	5	4	0	3
Exit ramps per mile	2.92	0.62	0	8.87
Entrance ramps per mile	0.73	1.86	0	0.00
Left exits per mile	0.00	0.00	0	2.96
Left entrances per mile	0.00	0.00	0	0.00
Number of exit ramps with multiple destinations per mile	0.00	0.00	0	5.92
Multilane exit ramps per mile	0.00	0.00	0	2.96
Optional/shared exit lanes per mile	0.73	0.62	0	5.92
Exit only lanes per mile	2.19	0.00	0	5.92
Score	480	360	—	465
Overall score	435			

— Indicates no score was generated because EB approach was not present.

Information for site OH-2 is as follows:

- **Site**: OH-2.
- **Location**: Columbus, OH.
- **Primary routes**: I-71.
- **Secondary/intersecting route**: I-670.

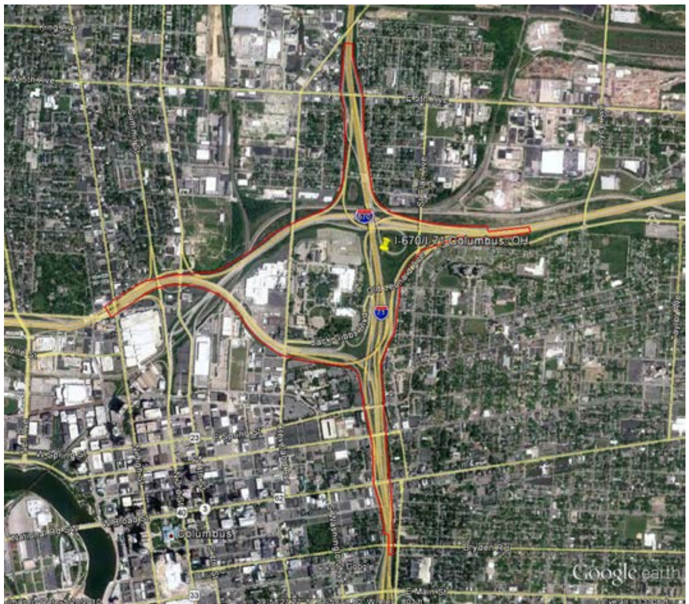

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Figure 98. Photo. Aerial view of site OH-2.[(68)]

Table 67. Characteristics of OH-2.

Variable	NB	SB	EB	WB
Study length (ft)	12,160	10,840	14,815	13,430
Number of concurrent routes	1	1	1	1
Number of levels	2	2	2	2
Number of missing movements	0	0	0	0
Number of ramps	8	9	8	6
Exit ramps per mile	1.30	1.95	1.43	1.18
Entrance ramps per mile	2.17	0.97	1.43	1.18
Left exits per mile	0.43	0.49	0.71	0.39
Left entrances per mile	0.43	0.00	0.36	0.39
Number of exit ramps with multiple destinations per mile	0.00	0.49	0.36	0.39
Multilane exit ramps per mile	0.43	0.49	0.71	0.79
Optional/shared exit lanes per mile	0.87	0.97	0.36	0.79
Exit only lanes per mile	0.87	1.95	1.78	1.18
Score	700	520	680	610
Overall score	627.5			

Information for site OH-3 is as follows:

- **Site**: OH-3.
- **Location**: Cincinnati, OH.
- **Primary route**: I-71.
- **Secondary/intersecting routes**: I-75/US-52.

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Figure 99. Photo. Aerial view of site OH-3.(69)

Table 68. Characteristics of OH-3.

Variable	NB	SB	EB	WB
Study length (ft)	8,410	7,945	6,485	8,530
Number of concurrent routes	1.5	1.25	1	1.6
Number of levels	3	3	3	3
Number of missing movements	0	1	1	0
Number of ramps	4	4	4	5
Exit ramps per mile	1.88	1.33	1.63	1.24
Entrance ramps per mile	0.63	1.33	1.63	1.86
Left exits per mile	0.00	0.66	0.00	0.62
Left entrances per mile	0.00	1.33	1.63	0.00
Number of exit ramps with multiple destinations per mile	0.63	0.66	0.81	0.62
Multilane exit ramps per mile	0.63	1.33	0.81	0.62
Optional/shared exit lanes per mile	1.26	0.66	0.00	0.00
Exit only lanes per mile	1.26	1.99	2.44	1.86
Score	565	730	625	495
Overall score	603.75			

Information for site OR-1 is as follows:

- **Site**: OR-1.
- **Location**: Portland, OR.
- **Primary route**: I-5.
- **Secondary/intersecting routes**: I-405/US-30/Fremont Bridge.

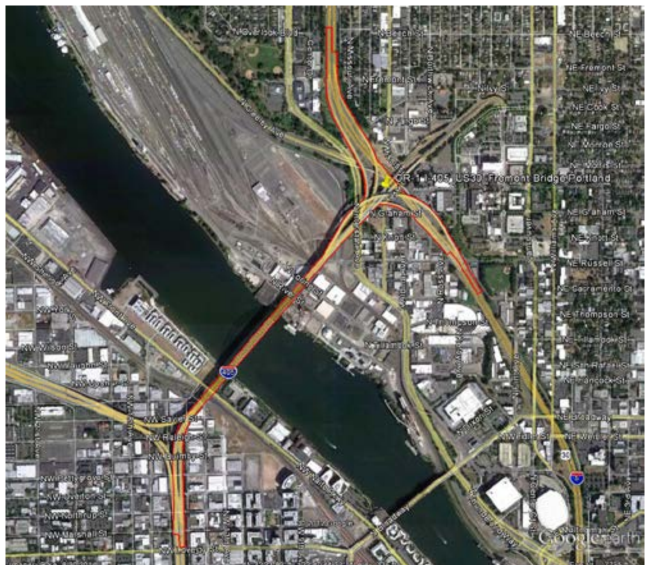

Figure 100. Photo. Aerial view of site OR-1.(70)

Table 69. Characteristics of OR-1.

Variable	NB	SB	EB	WB
Study length (ft)	6,220	6,580	8,340	5,760
Number of concurrent routes	1	1	1.25	1.5
Number of levels	4	4	4	4
Number of missing movements	0	0	0	0
Number of ramps	3	3	4	4
Exit ramps per mile	1.70	0.80	1.90	0.92
Entrance ramps per mile	0.85	1.60	0.63	2.75
Left exits per mile	0.00	0.00	1.27	0.00
Left entrances per mile	0.00	0.00	0.63	0.00
Number of exit ramps with multiple destinations per mile	0.00	0.80	0.63	0.00
Multilane exit ramps per mile	0.85	0.80	0.63	0.92
Optional/shared exit lanes per mile	1.70	0.00	1.27	0.92
Exit only lanes per mile	0.85	1.60	1.27	0.92
Score	380	370	465	415
Overall score	407.5			

Information for site OR-2 is as follows:

- **Site**: OR-2.
- **Location**: Portland, OR.
- **Primary routes**: I-5 and US-30.
- **Secondary/intersecting routes**: I-84/US-30.

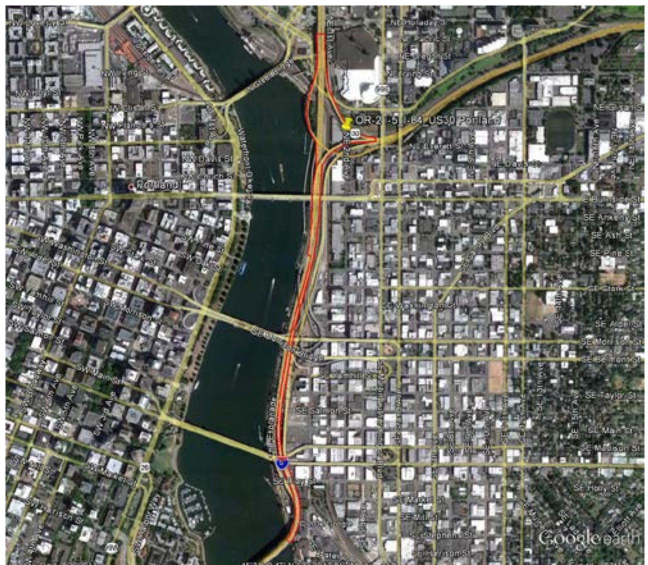

Figure 101. Photo. Aerial view of site OR-2.[(71)]

Table 70. Characteristics of OR-2.

Variable	NB	SB	EB	WB
Study length (ft)	1,275	9,715	0	5,885
Number of concurrent routes	1.333	1.333	0	2
Number of levels	3	3	0	3
Number of missing movements	0	0	0	0
Number of ramps	3	3	0	1
Exit ramps per mile	0.00	1.09	0	0.90
Entrance ramps per mile	4.14	0.54	0	0.00
Left exits per mile	0.00	0.00	0	0.00
Left entrances per mile	0.00	0.00	0	0.00
Number of exit ramps with multiple destinations per mile	0.00	0.54	0	0.00
Multilane exit ramps per mile	4.14	0.00	0	0.90
Optional/shared exit lanes per mile	4.14	0.54	0	0.90
Exit only lanes per mile	4.14	0.54	0	0.90
Score	395	325	—	295
Overall score	338.33			

— Indicates no score was generated because the EB approach was not present.

Information for site SC-1 is as follows:

- **Site**: SC-1.
- **Location**: Columbia, SC.
- **Primary routes**: I-26/US-76.
- **Secondary/intersecting routes**: I-126, US-76, and Bush River Road.

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Figure 102. Photo. Aerial view of site SC-1.(72)

Table 71. Characteristics of SC-1.

Variable	NB	SB	EB	WB
Study length (ft)	7,355	8,930	10,115	4,750
Number of concurrent routes	2	2	1	1
Number of levels	2	2	2	2
Number of missing movements	0	0	0	0
Number of ramps	4	3	1	1
Exit ramps per mile	1.44	1.18	0.52	0.00
Entrance ramps per mile	1.44	0.59	0.00	1.11
Left exits per mile	0.00	0.00	0.00	0.00
Left entrances per mile	0.00	0.00	0.00	0.00
Number of exit ramps with multiple destinations per mile	0.00	0.00	0.52	0.00
Multilane exit ramps per mile	0.00	0.59	0.52	0.00
Optional/shared exit lanes per mile	0.00	0.59	0.00	0.00
Exit only lanes per mile	1.44	1.18	1.04	0.00
Score	345	315	240	50
Overall score	237.5			

Information for site SC-2 is as follows:

- **Site**: SC-2.
- **Location**: Mauldin, SC.
- **Primary routes**: I-185 and I-385.
- **Secondary/intersecting routes**: I-385 and US-276.

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Figure 103. Photo. Aerial view of site SC-2.(73)

Table 72. Characteristics of SC-2.

Variable	NB	SB	EB	WB
Study length (ft)	22,720	16,200	16,055	14,460
Number of concurrent routes	1	1	1	1
Number of levels	3	3	3	3
Number of missing movements	1	1	0	0
Number of ramps	4	3	3	4
Exit ramps per mile	0.70	0.65	0.33	0.73
Entrance ramps per mile	0.23	0.33	0.66	0.73
Left exits per mile	0.00	0.00	0.00	0.00
Left entrances per mile	0.00	0.00	0.00	0.00
Number of exit ramps with multiple destinations per mile	0.00	0.65	0.33	0.37
Multilane exit ramps per mile	0.00	0.00	0.00	0.37
Optional/shared exit lanes per mile	0.46	0.33	0.00	0.37
Exit only lanes per mile	0.23	0.33	0.33	0.73
Score	260	255	200	370
Overall score	271.25			

Information for site SC-3 is as follows:

- **Site**: SC-3.
- **Location**: Rock Hill, SC.
- **Primary route**: I-77.
- **Secondary/intersecting route**: US-21.

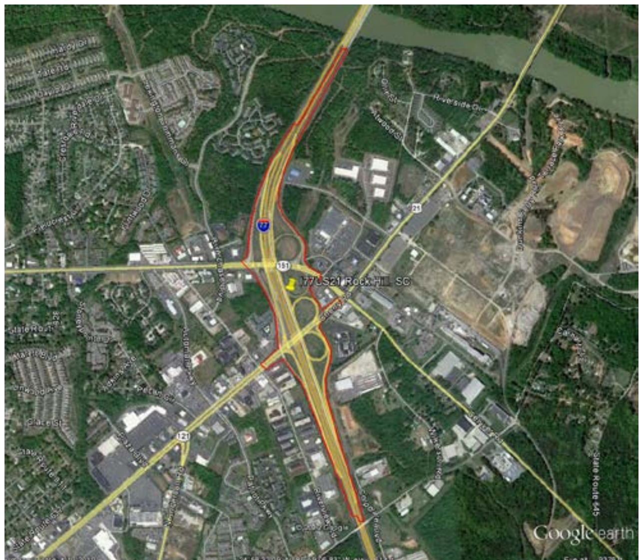

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Figure 104. Photo. Aerial view of site SC-3.[74]

Table 73. Characteristics of SC-3.

Variable	NB	SB	EB	WB
Study length (ft)	20,390	19,460	0	0
Number of concurrent routes	1	1	0	0
Number of levels	2	2	0	0
Number of missing movements	0	0	0	0
Number of ramps	2	2	0	0
Exit ramps per mile	0.26	0.27	0	0
Entrance ramps per mile	0.26	0.27	0	0
Left exits per mile	0.00	0.00	0	0
Left entrances per mile	0.00	0.00	0	0
Number of exit ramps with multiple destinations per mile	0.26	0.27	0	0
Multilane exit ramps per mile	0.00	0.27	0	0
Optional/shared exit lanes per mile	0.26	0.27	0	0
Exit only lanes per mile	0.00	0.27	0	0
Score	115	270	—	—
Overall score	192.5			

— Indicates no score was generated because EB and WB approaches were not present.

Information for site VA-1 is as follows:

- **Site**: VA-1.
- **Location**: Springfield, VA.
- **Primary routes**: I-95/I-395 Connector.
- **Secondary/intersecting route(s)**: I-495.

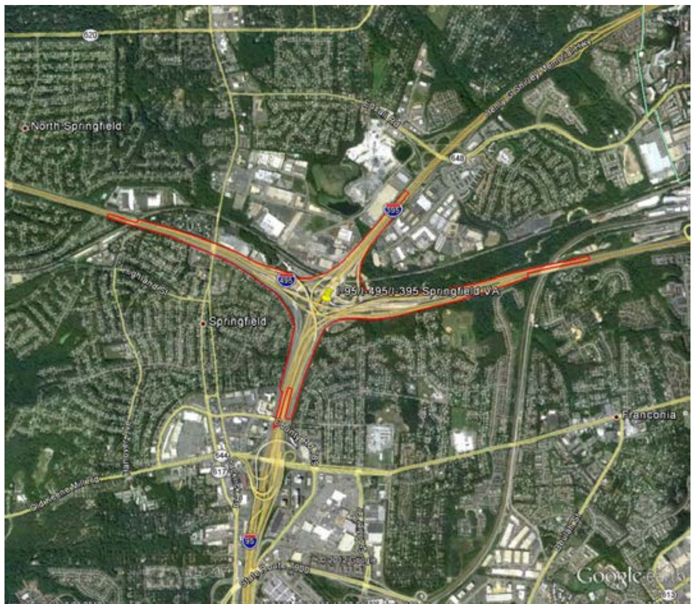

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Figure 105. Photo. Aerial view of site VA-1.[75]

Table 74. Characteristics of VA-1.

Variable	NB	SB	EB	WB
Study length (ft)	8,850	11,130	22,230	21,005
Number of concurrent routes	1	1	1.5	1.25
Number of levels	4	4	4	4
Number of missing movements	0	0	0	0
Number of ramps	3	4	4	4
Exit ramps per mile	0.60	0.95	0.48	0.75
Entrance ramps per mile	1.19	0.95	0.48	0.25
Left exits per mile	0.00	0.00	0.00	0.25
Left entrances per mile	0.00	0.47	0.24	0.00
Number of exit ramps with multiple destinations per mile	0.00	0.95	0.24	0.25
Multilane exit ramps per mile	0.60	0.95	0.48	0.25
Optional/shared exit lanes per mile	0.00	0.95	0.24	0.00
Exit only lanes per mile	1.19	1.42	0.95	1.01
Score	340	470	330	325
Overall score	366.25			

Information for site VA-2 is as follows:

- **Site**: VA-2.
- **Location**: Washington, DC.
- **Primary route**: I-395.
- **Secondary/intersecting route**: SR 27.

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Figure 106. Photo. Aerial view of site VA-2.[76]

Table 75. Characteristics of VA-2.

Variable	NB	SB	EB	WB
Study length (ft)	11,920	11,560	11,070	8,420
Number of concurrent routes	1	1	1	1.2
Number of levels	2	2	2	2
Number of missing movements	0	1	0	1
Number of ramps	6	5	10	12
Exit ramps per mile	1.77	0.46	1.91	2.51
Entrance ramps per mile	0.89	1.83	2.86	1.88
Left exits per mile	0.44	0.00	0.00	1.25
Left entrances per mile	0.00	0.46	0.48	0.00
Number of exit ramps with multiple destinations per mile	0.44	0.46	1.43	0.63
Multilane exit ramps per mile	0.00	0.00	0.95	0.63
Optional/shared exit lanes per mile	0.00	0.00	0.95	0.63
Exit only lanes per mile	1.77	0.46	1.91	3.14
Score	460	385	750	790
Overall score	596.25			

Information for site VA-3 is as follows:

- **Site:** VA-3.
- **Location**: Norfolk, VA.
- **Primary routes**: I-664.
- **Secondary/intersecting routes**: I-64, I-264, US-13, US-58, US-460, and SR 191.

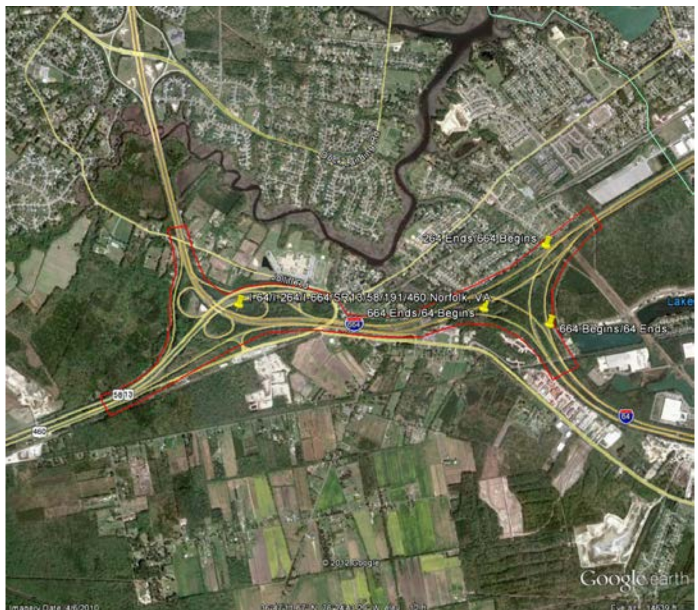

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Figure 107. Photo. Aerial view of site VA-3.(77)

Table 76. Characteristics of VA-3.

Variable	NB	SB	EB	WB
Study length (ft)	23,105	19,080	8,165	10,960
Number of concurrent routes	1	1.143	2	1
Number of levels	2	2	2	2
Number of missing movements	0	0	0	0
Number of ramps	5	7	4	2
Exit ramps per mile	0.46	1.11	1.29	0.48
Entrance ramps per mile	0.69	0.55	1.29	0.48
Left exits per mile	0.00	0.00	0.00	0.48
Left entrances per mile	0.23	0.00	0.00	0.00
Number of exit ramps with multiple destinations per mile	0.00	0.00	0.00	0.00
Multilane exit ramps per mile	0.23	0.28	0.65	0.00
Optional/shared exit lanes per mile	0.00	0.00	0.00	0.00
Exit only lanes per mile	0.91	1.38	1.94	0.48
Score	330	415	345	210
Overall score	325			

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