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16. Abstract

Pavement marking technology has advanced to allow for the use of large multi-color symbols to be placed on the pavement as a means of providing drivers with another source of information from which they can make good driving decisions. This project focused on the use of such in-lane pavement markings to provide the driver with lane guidance and warning information near freeway interchanges. More specifically, researchers evaluated the design and application issues that are associated with the use of pavement marking symbols. The information gathered during this project was used to create a set of guidelines for the use of pavement marking symbols at freeway interchanges.

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GUIDELINES FOR THE USE OF PAVEMENT MARKING SYMBOLS AT FREEWAY INTERCHANGES: FINAL REPORT

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation. This report is not intended for construction, bidding, or permit purposes. The engineer in charge of the project was Brooke R. Ullman, P.E. # 95927. The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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CHAPTER 1. INTRODUCTION

Pavement marking technology has advanced to allow for the use of large multi-color symbols to be placed on the pavement as a means of providing drivers with another source of information from which they can make good driving decisions. This project focused on the use of such in-lane pavement markings to provide the driver with lane guidance and warning information near freeway interchanges. More specifically, researchers evaluated the design and application issues that are associated with the use of pavement marking symbols.

OBJECTIVES

The primary objective of this research was to identify appropriate in-lane pavement marking characteristics and sequences for use near freeway interchanges. To reach this end, researchers went through several interim steps of evaluation. Initially, a review of the state-of-the-practice was conducted to identify candidate pavement marking symbols for evaluation. Following this initial review, researchers used three different methods of evaluating the identified alternatives. First, a closed-course study evaluated driver detection and recognition of different symbol characteristics. Second, two human factors surveys evaluated driver comprehension, recognition time, and preference for different designs and applications. Finally, researchers conducted a field evaluation of marking alternatives. From this information, researchers developed a set of design and application guidelines regarding the use of pavement marking symbols at freeway exits and interchanges

BACKGROUND AND SIGNIFICANCE OF WORK

TxDOT project 0-4471, "Evaluation of Horizontal Signing Applications," was completed in 2005. This project, conducted by the Texas Transportation Institute (TTI), had three main tasks: material durability evaluation, driver comprehension testing, and before-after field evaluations of speed and wrong-way movements (*1*, *2*).

The evaluation of the durability of pre-formed thermoplastic marking materials took place over a three-year period on concrete, asphalt, and chip-seal pavements. These tests included 1-ft square sections of colored material, in addition to the standard white used for most symbols and text. The results showed that several vendors offered products that maintained their presence and retroreflectivity over the test period. For blue and red markings, like those that would be used on an interstate shield, the colors faded over time and did not stay in the color specifications beyond one year. They still appeared blue and red to the naked eye, but they were lighter tones of the colors indicating some pigment bleaching.

The driver comprehension testing was conducted using laptop computers displaying digitally edited photos of word and symbol messages for application at horizontal curves for speed mitigation and to provide directional guidance on frontage roads. These surveys included a few questions pertaining to route markers at freeway interchanges as shown below in Figure 1. Participants were asked, *"What do you think the marking in the right hand lane means?"* Responses indicated that many people misinterpreted these symbols to mean that they were currently on the marked route rather than that the designated lane would lead them to the marked route.

Figure 1. Examples of Edited Photos.

The next step within this project was to conduct field evaluations of markings. On-road measures of speed were used to evaluate horizontal signing (both symbols and text) intended to reduce speed at entries to horizontal curves on rural roadways and expressways. A field assessment of wrong-way movements on a two-way frontage road before and after placement of directional arrows on the pavement was also conducted.

In addition to the research activities associated with this project, an extensive literature review was conducted. This review concluded that:

- When a driver experiences a high-stress driving situation or when he or she is presented with too much information, he or she may be expected to focus on the more important tasks of control and guidance and will tend to look at the road and less at side or overhead mounted signing.
- Drivers tend to spend most of their time focusing on the roadway in front of them, and any object or sign that appears in this region will more likely be observed than a sign that appears in their peripheral vision.
- Roadside signs can be missed by drivers due to visual clutter (billboards, etc.) or other traffic (heavy trucks, etc.). A redundant method of information dissemination increases the likelihood of the critical information getting to drivers.
- Any symbols developed for use as horizontal signs should have large simple components and should be visually unique to the highest possible degree.

Visual Acuity and Reading Distances for Horizontal Signing

One problem, which past research has not adequately addressed, is determining the proper size of horizontal signing messages. Project 0-4471 mathematically applied sign legibility research to pavement markings to determine optimal size and elongation as shown in Figure 2 (*2*).

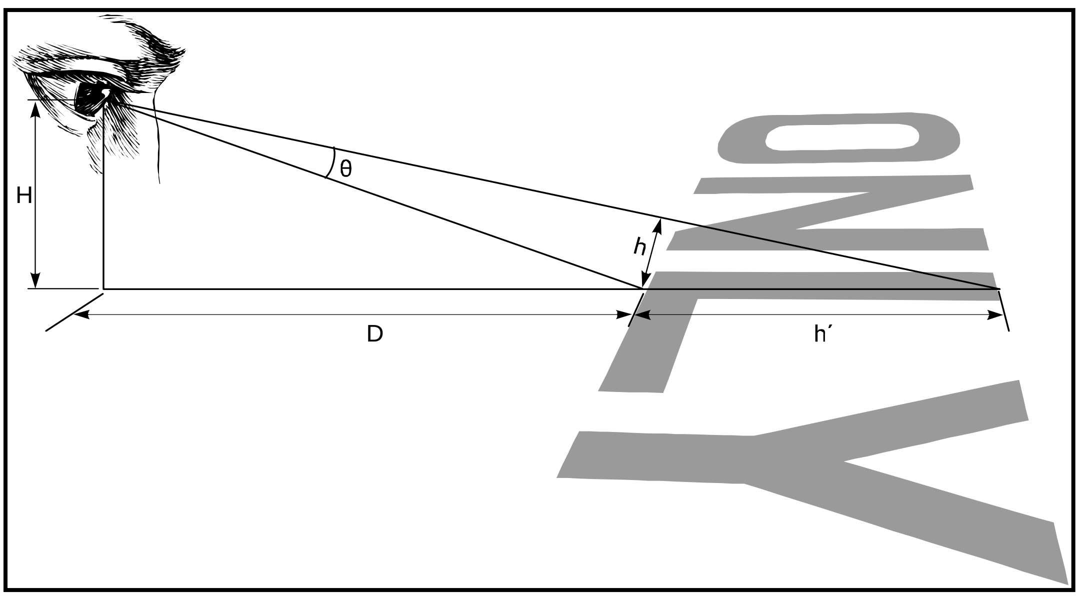


Figure 2. Viewing Distance Calculations for Horizontal Signing.

These calculations were never validated in the field, however. To some extent, applications of materials will be limited to what is available from vendors. Current TxDOT standards found in the Standard Highway Sign Designs for Texas book specify three sizes of interstate route shields: 15 ft, 17.5 ft, and 20 ft (*3*). For lane direction arrows, only one size is provided and is intended for use at intersections. However, some districts have applied these arrow sizes for use on freeway lane drops and optional lanes. The current project addresses size and elongation for both arrows and route markers.

Another issue of interest that has not yet been fully evaluated is nighttime visibility of horizontal signing. This characteristic is dependent on the reach of vehicle headlamps and the retroreflectivity levels of the pavement marking material. However, the retroreflectivity of dark colored pavement markings, such as blue or red, is inherently very low. Due to this limitation, the use of dark colors in horizontal signing may need to be limited to areas with overhead roadway lighting. Another thought is that visibility may also be enhanced through the use of a contrasting border around the symbol.

Driver Comprehension of Lane Drops and Optional Lanes

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.

A study in the mid-1970s found that an "Exit Only" plaque was helpful in the case of a right lane drop. The researchers also recommended diagrammatic signs for left lane drops (*4*). Also, a TTI study from 1990 determined drivers often misunderstand the situation when an optional exit lane is present in conjunction with a lane drop. The addition of an "Exit Only" plaque on the advance guide sign over the lane with the forced maneuver did not improve their understanding. Ultimately, this study recommended using modified diagrammatic signs for the right exit optional interchange geometry with an arrow marking each lane (*5*). The recommended modified diagrammatic signs with one arrow for each lane were also supported by previous research (*6*, *7*). A 1996 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. This study also found the use of a "May Exit" plaque marking optional exit lanes helped drivers (*8*).

A study in 1993 by TTI of lane use arrow pavement markings at freeway lane drops utilized both surveys and field studies (*9*). The field studies demonstrated that the installation of lane drop markings can cause a shift in motorist lane change locations in advance of a lane drop. The data showed that drivers move into or out of the exiting lane farther upstream of the lane drop in the period after markings were installed than in the period before markings were installed. For the 800 ft immediately upstream of the gore at one site, fewer vehicles left the exit lane in the after period than in the before period. In the area between 1700 and 1000 ft upstream of the gore, more vehicles left the exit lane in the after period than in the before period. Before and after studies also revealed that the number of erratic maneuvers within the entire study segment decreased with the installation of lane use arrow markings.

The National Cooperative Highway Research Program (NCHRP) completed a study in 2003 in which they evaluated guide signing at freeway lane drops. In this study, a driving simulator was used to evaluate the reactions of 96 subjects. Subjects drove through a right exit optional freeway interchange and were asked to drive to a given destination using the guide signs to navigate. Roughly one-third of drivers made unnecessary lane changes, again highlighting the fact that drivers often misunderstand optional exit lanes. 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 (*10*).

A TTI study from 2006 also evaluating guide signing at freeway lane drops determined that drivers are likely to make unnecessary lane changes when an "Exit Only" plaque is present regardless of the type of sign. 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 (*11*).

CHAPTER 2. STATE-OF-THE-PRACTICE

The research team conducted a review of current practices, both within Texas and across the country, to identify how in-lane pavement markings symbols are currently being used near freeway interchanges. This review includes the current published guidance to determine the foundation of the standards various districts are using.

BACKGROUND

There is not a great deal of guidance currently available for pavement markings used in freeway lane designation applications. Due to this fact, many TxDOT engineers begin their designs using standards from existing markings in another district. Often these standards come from the Houston District, which was the first Texas district to use the markings in this type of application. The Standard Highway Signs (SHS) manual (*12*) and also the Manual on Uniform Traffic Control Devices (MUTCD) (*13*) provide some guidance on the dimensions of the markings, both the symbols and the text, but do not sufficiently address the combination of markings that should be used, the sequence of the marking sets, or placement locations. This research aimed to provide guidance for these holes through this state-of-practice review and a combination of human factors and field studies.

In practice, three main types of markings are seen in the freeway interchange applications: text, route shields, and arrows. Various symbols can also be used, such as the airport symbol used in Houston, but these symbols are rare and not included in the scope of this research. The text usually consists of a cardinal direction and sometimes the word “ONLY” or even “KEEP RIGHT” or “KEEP LEFT.” The arrows match the geometry of the lane either straight, curved, angled, or possibly a shared arrow.

Because these markings are used on high speed roadways, they must be elongated or “stretched” to improve legibility at these speeds. The SHS manual shows three sizes of interstate shields that have been elongated for pavement application on high speed facilities. It does not provide any guidance on determining which size should be used for a specific situation. As seen later in this report, shield F, shown on the left in Figure 3, with general dimensions of 6-ft wide and 15-ft tall is the size that the interviewed districts use for interstate shields. The overall size of the US highway shields used in practice is also similar to these dimensions. Neither the SHS manual nor MUTCD gives any guidance to shield dimensions other than the interstate shield.

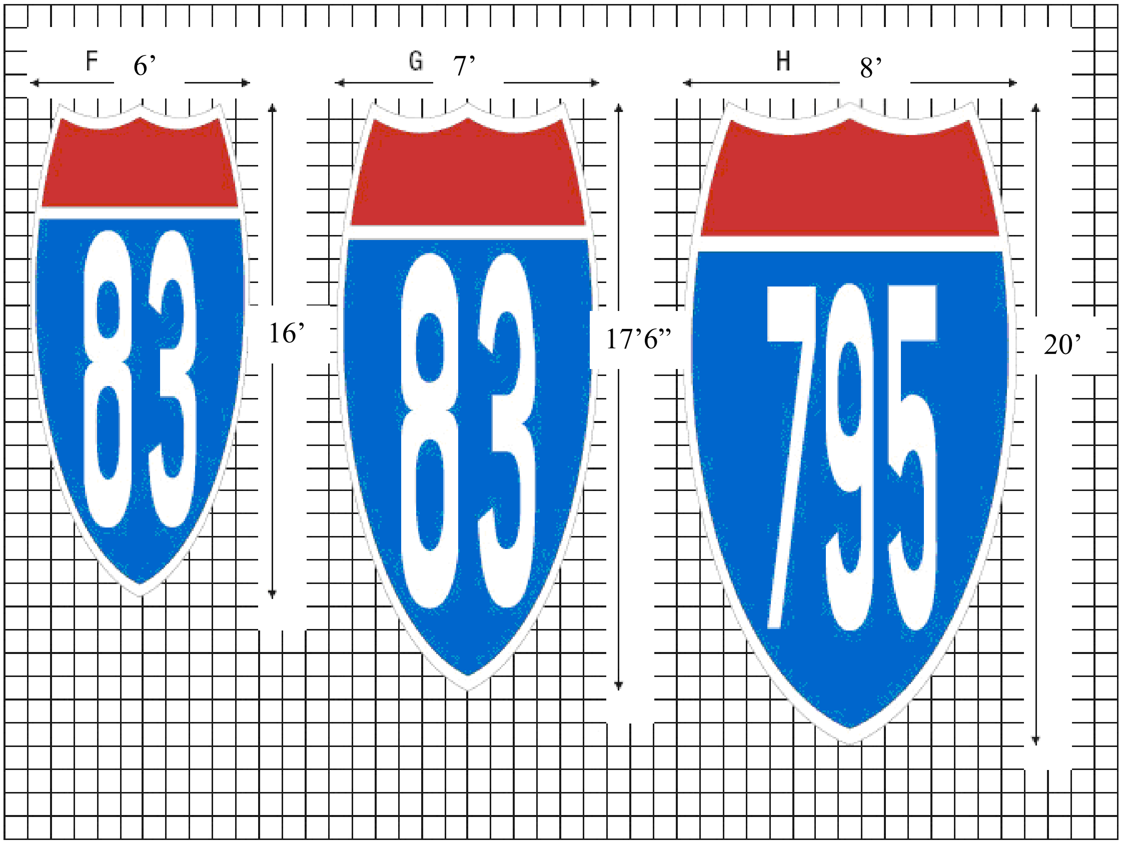


Figure 3. Standard Highway Signs Manual Interstate Pavement Marking Dimensions.

The SHS manual also provides some examples of elongated arrows that can be used on high-speed pavement facilities (see Figure 4).

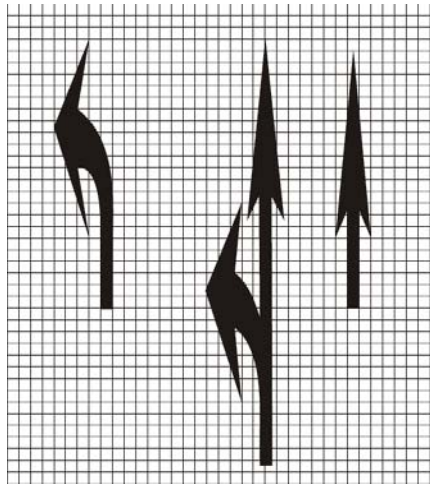


Figure 4. Standard Highway Signs Manual Optional Narrow Enlongated Arrows.

Figure 5 shows the MUTCD dimensions for the word "ONLY" for pavement marking use. Although cardinal directions are not individually referenced in one of the manuals, the SHS manual shows the letters of the entire alphabet elongated for pavement application.

Figure 5. MUTCD Example of Elongated Letters for Pavement Markings.

FINDINGS

Seven TxDOT districts were interviewed for this study:

- Houston,
- San Antonio,

- El Paso,
- Corpus Christi,
- Austin,
- Dallas, and
- Ft Worth.

All of the above districts except for El Paso either currently use or have plans in the near future to use pavement marking symbols at controlled access freeway to freeway interchanges. El Paso has immediate plans to use pavement marking symbols in advance of a signalized interchange. Although some of the details of the El Paso plan are mentioned in this report, they cannot be directly compared to the other district applications. Houston has also used the pavement marking symbols for lane guidance on a frontage road approaching a freeway to freeway interchange. Although this use on a frontage road may be another appropriate use of the symbols, it is not covered in the scope of this project.

MARKING SPECIFICATIONS

Not all of the districts interviewed use all three types of route shield markings, but they were consistent in the dimensions when they did use the same markers. Several mentioned they used the Houston specifications in developing their plans. Houston stated that their specifications were developed through a combination of brainstorming and teamwork while following existing practices from other types of pavement markings. The actual dimensions of the Texas highway shield marker used by Corpus Christi is unknown by the researchers, but judging from video footage and preliminary plans, it is assumed they use comparable dimensions to the other cities. Figure 6 and Figure 7 show the Houston specifications. El Paso, in their signalized intersection application, used the same dimensions of the shields in Figure 7.

Figure 8 shows the Houston dimensions for the cardinal direction text often used in combination with the route marker.

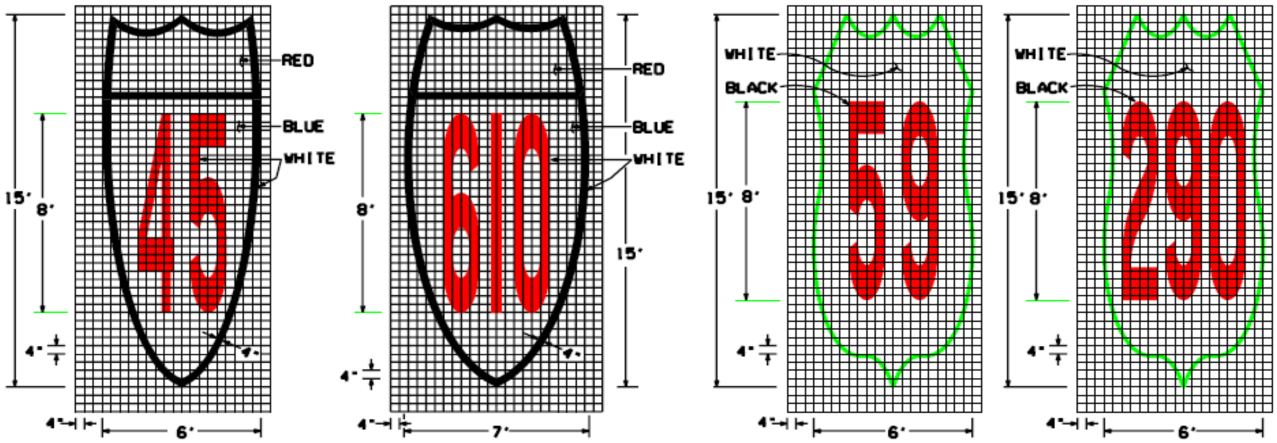


Figure 6. Houston's Secifications for Interstate and US Highway Pavement Marking Shields.

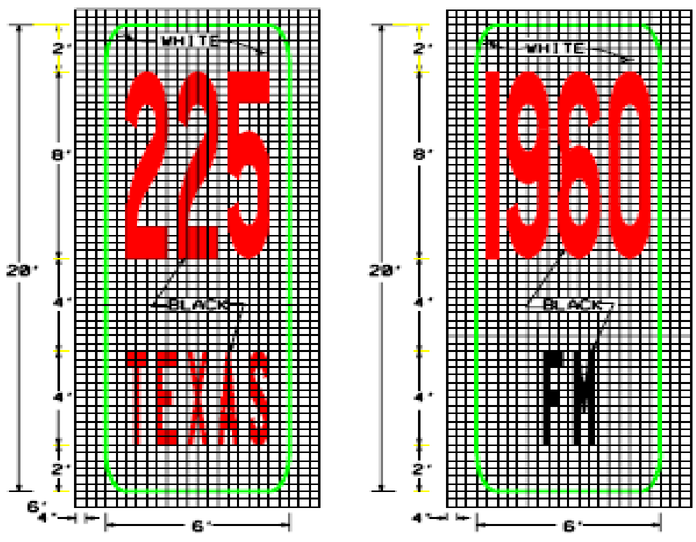


Figure 7. Houston's Specifications for Texas Highway and Farm-to-Market Road Pavement Markers.

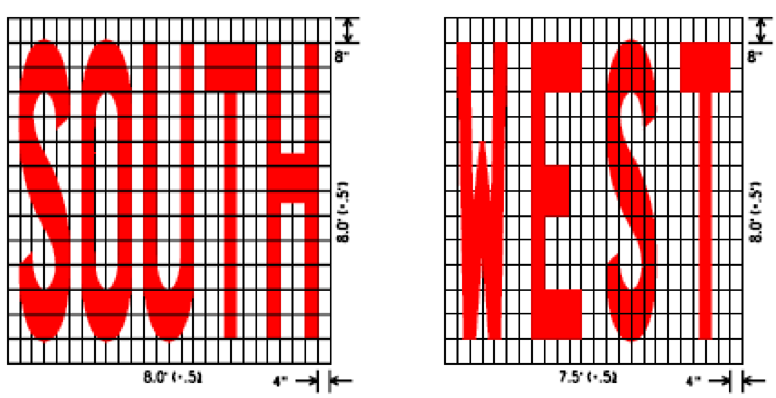


Figure 8. Houston Specifications for Cardinal Direction Pavement Marking Text.

MARKING SEQUENCES

Special consideration should not only be given to the pavement symbols chosen for these applications but also to the order that they will appear to the driver. Several times the interviewees stated that the purpose of the markings was to *supplement* the existing guide signs on the roadway and should be used efficiently because their application can be expensive and maintenance will be required.

The districts were asked about the application of the pavement marking symbols in three different types of lanes:

- exit only lanes,
- through lanes, and
- optional lanes.

Table 1 shows each district's approach to laying down the four types of markings (cardinal direction, route shield, arrow, and the word "ONLY"). Not every type of marking was used in every situation. These various alternatives were studied in the following phases of this project.

As shown in Table 1, most districts interviewed use the same order of symbols and markings. Dallas was the main exception to the trend. Also, where it is Houston's, San Antonio's, and Corpus Christi's format to mark through and exit lanes, Austin and Dallas typically not mark the through lanes unless they find a uniqueness to the location where engineering judgment dictates that all lanes should be marked. The most variation among current practice, and perhaps where the most amount of research needs to be conducted, involves how to mark a shared or split lane. Houston typically chooses to place no markings in a shared or split lane. San Antonio is considering the opposite approach by placing roadway shields, cardinal directions, and a shared arrow. The other districts offer even more alternatives as shown in the table below.

Table 1. Marking Sequences in Practice for Exit Only, Through, and Shared Lanes.

		Houston	**San Antonio**	**Corpus Christi**	**Austin**	**Dallas**
Exit Only Lanes	↑ ↑ **Direction of Travel** ↑ ↑	Cardinal Direction Shield Arrow "ONLY"	Cardinal Direction Shield Arrow "ONLY"	Cardinal Direction Shield Turn Arrow "ONLY"	Cardinal Direction Shield Arrow "ONLY"	Turn Arrow "ONLY" Shield Cardinal Direction
Through Only Lanes		Cardinal Direction Shield Arrow "ONLY"	Cardinal Direction Shield Arrow "ONLY"	Cardinal Direction Shield Straight Arrow "ONLY"	*typically will not be marked	*blank*
Shared/Split Lanes		*blank*	Through Direction Through Shield Exit Direction Exit Shield Shared Arrow	Shared Arrow	*typically will not be marked	Exit Shield Through Shield

** The Austin District information is for future applications. At the time of this report, Austin did not have any of these type of markings installed in the field.*

MARKING SPACING

The spacing of the markings with respect to the gore, and also with respect to each other within each sequence, is where all of the interviewed districts stated the most amount of engineering judgment is required. Existing signs and sign structures, other traffic control devices, and the geometry of the road, including horizontal and vertical curvature, and sight distance should be considered. Table 2 displays the collected information on the current practice regarding pavement marking spacing.

For all the districts, the placement of the markings with respect to the gore is not clear. Some districts start by placing the markings closest to the gore and working their way upstream, while others will start upstream and work their way in. Generally the current practice is to place three sets of markings before the gore or decision point. San Antonio plans to begin the pavement markings the farthest out at a distance of 1 mile.

With regard to the marking spacing within each sequence of markings, 80 ft is a common distance reported, but a couple of districts also "clump" specific markings. For example, San Antonio generally will space the markings 80 ft from each other but will place the cardinal direction only 40 ft from the corresponding shield in order to better associate the two together. Similarly Dallas will clump the corresponding shield and direction together and also the arrow and the text "ONLY" together.

Table 2. Placement of Pavement Markings in Current Practice.

	Houston	San Antonio	Corpus Christi	Austin	Dallas
Placement of Markings from Gore	Begin markings 1/2 mile back, with consideration of overhead sign placement, try to place 3 sets of markings.	Begin 1 mile back from gore, and place the markings between the overhead signs.	Generally place closest set of markings ~150'-200' upstream, and place the remaining 2 sets with consideration of entrance/exit ramps	Typically begin 1/2 mile back with the first set of markings, taking into consideration existing signs and other traffic control devices.	Top of shield is 800' from the gore. Top of the arrow is 300' from the gore.
Placement of Markings with Respect to Each Other	80' from marking to marking	80' from marking to marking except for 40' between the shield and cardinal direction.	80' from the base of one symbol to the next.	n/a	80' from top of the shield to the top of the cardinal direction. 80' from the base of the arrow to the top of "ONLY."

n/a = not available

RECOMMENDATIONS AND FEEDBACK

Most recommendations from the districts interviewed centered on application and maintenance. The longevity of the markings can be an issue due to the wear and loss of reflectivity from tire tread and the fact that the markings are applied in pieces and therefore can come up in pieces. The markings are not manufactured with spare pieces or segments, so when a piece comes up, the entire marking must be replaced. Recommended prevention included application to a clean surface and using a good sealer.

All districts interviewed expressed nothing but positive feedback for these pavement marking applications, and there have even been public requests for the markings to be added in other locations.

CHAPTER 3. HUMAN FACTORS LABORATORY STUDY – PHASE 1

STUDY DESIGN

Tasks 1 and 2 of this project identified the alternatives evaluated during the motorist survey. Based on the information gained through this earlier work, researchers identified five topic areas for inclusion in a comprehension evaluation. These topic areas were:

- symbol versus text highway identification,
- staggered application pattern,
- pavement markings in an optional lane,
- pavement markings in a single exit lane, and
- marking all lanes or only exit lanes.

The specific treatments included in each of these topic areas will be displayed in the appropriate section in the results portion of this document. Due to time constraints, researchers were not able to display each treatment in the five topic areas in every survey. To ensure participants' active attention, researchers did not want the survey time to exceed 15 to 20 minutes. As such, eight different versions of the survey were created. Each version displayed nine pavement marking treatments. To avoid the occurrence of primacy bias, the order in which the treatments were displayed was interchanged for different versions of the survey. Researchers conducted 15 surveys for each of the eight versions.

Survey Instrument

Each survey consisted of three parts: comprehension, layout preference, and order of information preference. During the survey a researcher would sit with the participant and write down responses to the questions asked. The following sections further discuss the parts of the survey.

Comprehension of Symbolic Pavement Marking Alternatives

Still pictures and videos were used to determine motorist's comprehension of in-lane symbol pavement markings. The video format was utilized when researchers felt it would be beneficial to display the treatment in a more driver perspective format that was not possible in the static images.

Researchers gave the participants instructions indicating they were to imagine driving down a specific highway and were to take a different highway to get to their destination. Researchers explained that participants would approach an interchange with another highway and see signs and pavement markings for that interchange.

Two different scenarios were evaluated.

- Scenario A: The participant would want to exit off the current highway at the interchange to reach their destination.
- Scenario B: The participant would need to determine that they had to continue through the interchange on the current highway to reach their destination highway.

While both scenarios would see the same treatment, the destination highway given in the instructions would be different. For example, those viewing Figure 9 in Scenario A would be told: *"Imagine you are on Interstate 58, and eventually plan to exit to US Highway 43."* (Therefore, the participant should exit at this interchange to reach their destination.)

In Scenario B, the participants were told: *"Imagine you are on Interstate 58, and eventually plan to exit to US Highway 51."* (This would imply that the participant would need to continue on their current highway to reach their destination [US-51].)

Figure 9. Static Image Example.

The questions asked following each treatment in the comprehension evaluations were as follows:

1. Please tell me all the lane(s) that will take you where you need to go?

2. On a scale from 1 to 7 (with 7 being completely confident and 1 being completely unconfident), how confident are you in your answer?
3. Which of the lanes that you listed above would you most want to be in at this point, and why?

A researcher would write the participant's responses for each question on an answer sheet.

Layout Preference

The second part of the survey was to determine motorist's symbol pavement marking preferences. Included in this part of the survey was the comparison of:

- text versus symbol pavement markings,
- staggered versus un-staggered pavement markings, and
- pavement markings on all lanes versus just exit lanes.

First, the participants were told that they would see two pavement marking symbol layouts that were intended to give information about what lane to take to get to their destination. These treatments remained displayed on the computer screen while the participants answered the following questions:

1. Which of the two pavement marking symbol layouts do you prefer?
2. Why do you prefer the layout you selected?
3. Why did you <u>not</u> select the other layout of pavement markings?

Again, the researchers wrote the participant's responses on an answer form.

Order of Information within a Pavement Marking Application

The final part of the survey was intended to determine what order of information is most easily understood by motorists and to identify what information was considered critical to the participants. Two scenarios were included: symbolic pavement markings to inform motorists of an optional lane and of an exit only lane. Half of the survey participants were presented with each situation.

Information presented to the participants as possible elements to be included in an optional lane were:

- primary direction (i.e., west),
- primary highway shield (i.e., Interstate 66),
- exit direction (i.e., north),
- exiting highway shield (i.e., US Highway 37), and
- optional arrow.

In the exit only lane scenario, the following five elements were presented to participants:

- “Exit” text,
- “Only” text,
- right turn arrow graphic,
- exiting highway shield (i.e., Interstate 15), and
- exiting highway cardinal direction (i.e., south).

Each pavement marking element was placed on an index card and shuffled to randomize the order. The cards were then given to the participants who were told that their advice was needed on determining what pavement marking information a driver needed to decide what lane they should be in to reach their destination.

Participants were shown a drawing of a highway with a red car placed in the lane they were to imagine themselves driving in. For the optional lane application the drawing showed a four-lane highway, and the red vehicle was located in the second lane. They could either continue straight on Interstate 66 and/or exit onto US Highway 37. The participants that viewed the exit lane only application were shown a drawing of a three-lane highway with the red vehicle located in the right exit only and told they could continue straight on Interstate 31 or exit onto Interstate 15. Both groups were asked to use the index cards to select the information they felt would be best in providing that information to the driver. The participants were not required to use all of the informational elements given to them. Once participants selected the information they felt was needed, they were asked to place the cards in the order that they would like to see this information on the roadway pavement.

In addition to order of preference, a rating of this information was conducted. The index cards were placed on the table and the participants were asked to rate each information element on how helpful that pavement marking is in letting the driver know what options are available from that lane using a scale of 1 to 5, with 5 meaning very helpful and 1 meaning not helpful.

Survey Protocol

Researchers reviewed different technologies available to conduct the motorist surveys including using a vehicle simulator and variations of static or dynamic software on a computer screen. However, based on comments from the committee and review of available technologies, researchers determined that the most desirable form at this time was to use a dynamic (or video) format on a computer screen. Therefore, the human factors studies were conducted using a laptop computer. However, it was not necessary for the participants to have any computer experience.

This study method had the advantage of offering a driver perspective of a marking sequence not possible with static images; however, it was still preferable to the vehicle simulator in that it was "portable" and could be administered at several locations. When video clips were presented to the participants, the video would play all the way through one time and then a researcher asked the participant questions. The video of each treatment shown was approximately 18 seconds long.

Static format displays (still pictures) were also used for portions of the study, when researchers felt there was no need for a moving drive-through view of the pavement markings being evaluated (e.g., preference of application alternatives). In these cases, a sequence of images displayed overhead signs and then the pavement markings to the participants. Each of these images was shown for a limited time of four seconds to better simulate realistic exposure time when driving. Again, after the participant had viewed the images they were asked questions by a researcher.

Locations

TTI conducted the laboratory studies in four cities in Texas to obtain a diverse opinion or sample of drivers: Dallas, El Paso, Houston, and San Antonio. Test subjects were approached at random through direct one-on-one contact at various Texas Department of Public Safety (DPS) driver licensing stations in the four selected cities. At each location 120 surveys were conducted for a total of 480 surveys total.

Participant Demographics

A total of 480 participants were recruited for this survey. All participants were required to be over the age of 18 and have a current Texas driver's license. The participants were selected based on a demographic sample of the driving population of Texas with regard to gender, age, and education level. The statistics utilized for age and gender were obtained from the United States Department of Transportation – Federal Highway Administration Statistics for 2005. The education level statistics were based on the Texas information from the United States Census Bureau for the year 2006. Table 3 shows the desired sample in parenthesis compared to the sample obtained in italics. Overall, it is believed that the results obtained in this study represent Texas drivers reasonably well.

Table 3. Phase 1 Laboratory Study Demographic Sample.

Age	Education Level				Total (n=480)
	High School Diploma or Less (235)		Some College + (245)		
	Male	Female	Male	Female	
18-39	(56) *58*	(52) *50*	(52) *54*	(52) *50*	(212) *212*
40-54	(36) *32*	(36) *42*	(40) *38*	(36) *40*	(148) *152*
55+	(28) *26*	(28) *27*	(32) *43*	(32) *20*	(120) *116*
Total	(120) *116*	(116) *119*	(124) *135*	(120) 110	(480) *480*

NOTE: *Numbers in italics represent the sample population obtained.*

In addition to the obtaining gender, age category, and last level of education completed; the participants were also asked how often they travel on freeways. Overall:

- 70 percent drive on freeways on a daily basis,
- 23 percent drive on freeways weekly,
- 4 percent drive on the freeways on a monthly basis,
- 2 percent drive on the freeways once or twice a year, and
- 1 percent surveyed had never driven on freeways.

RESULTS

Data analysis was divided into six sections according to the topic area being evaluated and a final section for the order of information preference exercise. The primary portion of the analysis determined participant comprehension of the pavement markings treatment based on their identification of the lanes that would reach their destination. Researchers performed confidence interval tests and Bernoulli test of proportions to determine if the identified differences among the treatments evaluated were statistically significant.

The data were divided into three categories for both the exit (Scenario A) and through (Scenario B) scenarios: those that answered correctly, those that answered partially correct, or those that included only part of the correct answer. Those responses considered incorrect were all answers that included one or more of the incorrect lanes. It should be noted that lane numbers will be used for describing the following data. In all cases lanes will be numbered from the left starting with lane 1 in the left most lane of the treatment and increasing as you cross lanes to the right across the roadway (e.g., lane 2, 3, etc.).

Symbol versus Text Highway Identification

For the symbol versus text highway identification, researchers wanted to determine if motorist understanding increased through the use of highway shield symbols as opposed to a text version of the highway designation. Figure 10 shows the treatments displayed for both scenarios examined. Note that these treatments were displayed statically on the computer for four seconds and then automatically turned off. An image of the appropriate guide sign preceded each treatment.

Treatment 1a. Shields

Treatment 1b. Text

Figure 10. Use of Symbol versus Text.

Comprehension

The initial portion of the data analysis for this section evaluated whether a participant could correctly identify which lane would lead to their destination either as an exiting motorist (exit roadway onto US-43) or by proceeding through the interchange on I-58 in lanes 1 and 2. Table 4 shows the percentage of responses for each treatment for the two decision scenarios.

Table 4. Text versus Symbol Comprehension Percentages.

Responses (%)	Exit		Through	
	1a. Symbol	**1b. Text**	**1a. Symbol**	**1b. Text**
Correct	92	92	90	93
Incorrect	8	8	10	7

As shown in Table 4, both treatments were understood equally well with approximately 90 percent of the participants correctly identifying a lane that would lead to their destination. This was supported by the confidence level reported by the participants with all of the participants indicating they were confident (i.e., confidence level 7, 6, or 5) in their lane selection.

To further assess how well participants understood what lanes could be used for their scenario, researchers asked them to identify which lane they would specifically want to be driving in and why they preferred that lane.

In the exiting scenario, all of the participants who had correctly identified the exit lane (92 percent for each treatment) again selected that lane as their preferred driving lane. Additionally, researchers noted an another 4 and 5 percent of the participants for Treatment 1a and 1b, respectively, also selected the right exit lane (i.e., lane 3) as their preferred driving lane. This percentage indicates that although the participants were not fully-confident which lanes would take them to their destination; they would have correctly selected a lane that reached their destination.

The lane selection for the participants who were to proceed through the interchange (or select lanes 1 and 2) was not as clear cut as for those exiting. Table 5 shows the percentages of participants selecting each lane as their preferred travel lane.

Table 5. Percent of Participants Selecting Each Lane as Preferred Travel Path – Through Traffic Scenario.

Treatment	Percent of Responses (n=120)		
	Lane 1	**Lane 2**	**Lane 3**
1b. Text Through	14	81	5
1a. Symbol Through	21	69	10

Table 5 shows that the majority of the participants selected lane 2 as the lane they would most want to be in at this time. Again, 90 percent or higher of the participants selected an appropriate lane to reach their destination for both treatments.

Preference

All of the participants were also asked to identify which of the two treatments (text versus symbol) they preferred. An overwhelming majority, 93 percent, preferred the symbol pavement marking treatment. When asked to explain why they selected this alternative, the majority of these individuals (92 percent) felt the symbols were more visible, more colorful, and simpler to identify. The remaining 8 percent based their reason for preferring the symbols on the fact that the shields made it easier to identify highway type. When those same individuals who preferred the symbol were asked why they did not select the text layout there were three main reasons reported:

1) the text took longer to read,
2) text was harder to see, and
3) the text blended in with the traditional lane line pavement markings.

The 7 percent of the participants that preferred the text pavement markings over the symbol treatment stated that the text identified the type of highway and that the text was easier to read. They did not like the symbol treatment because they did not want to have to figure out what the symbols meant (highway type), and the symbol was not as easy to read as the text.

Summary

Both of the evaluated treatments were understood at a level higher than 90 percent comprehension. Overall for this comparison, researchers believe that either type of marking could work equally well in meeting the motorist information needs at the interchange. However, researchers would like to study this issue further (text versus symbol markings) as it is believed that in a limited viewing time application, there may be an unrealized advantage to the use of shields as far as rapid road type identification is concerned.

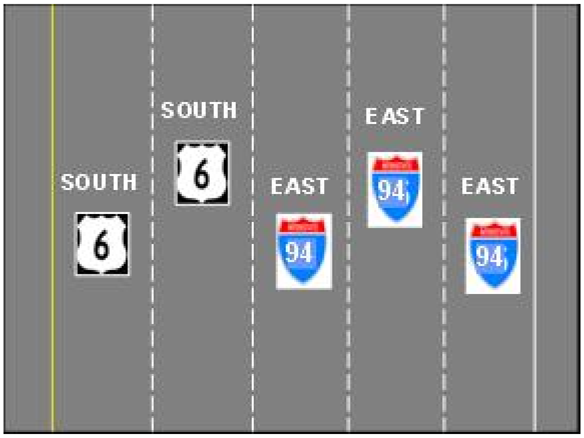
Staggered Application

The next section looks at the possibility of a benefit being gained in identification of highway pavement marking symbols across multiple lanes through a staggered pattern application as opposed to a traditional line application (Figure 11). The treatments were shown in video format to offer advantages of driver perspective not possible with static images. This comparison was evaluated to identify if staggering of the symbols could be used to address vehicle obscuration concerns and if the staggered pattern had an adverse impact on comprehension and perception. Additionally, the use of a staggered pattern breaks up the "wall" of information that is created by the line application.

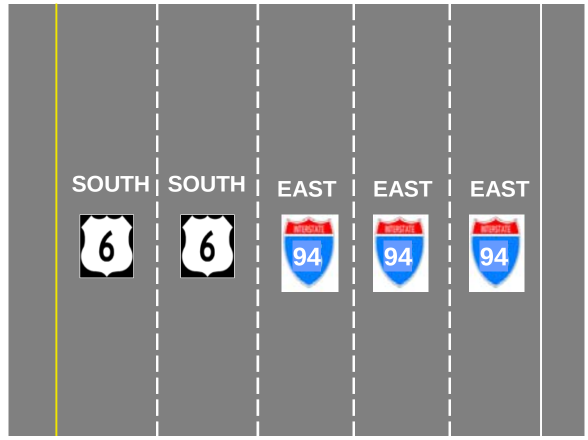
Another factor evaluated in this section was to see if the use of multiple types of highway shields (e.g., US highway and interstate) had a different result than an application with only a single highway type (e.g., only interstate shields). In this case, researchers wanted to identify if the staggered application would be of greater benefit in one of these two types of applications.

Again, two different scenarios were examined: one where participants needed to identify that they were continuing as through traffic past this interchange and one where they were given information to exit at this interchange. It should be noted that for the multiple highway type situation, the through movement was on US Highway 6, and in the single highway type situation, it was Interstate 27. Both exiting scenarios directed drivers to take Interstate 94.

Multiple Highway Types

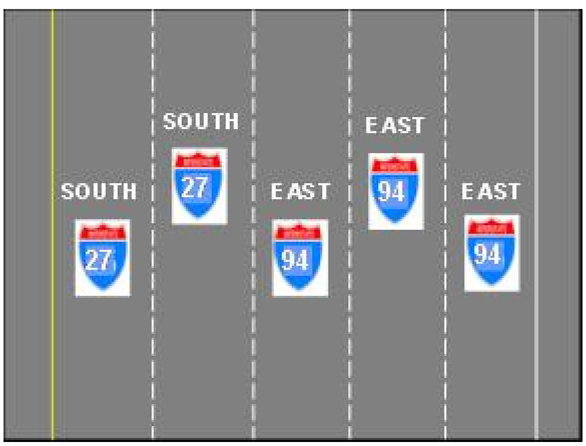


Treatment 2a. Staggered Layout
(US-6 & I-94)



Treatment 2b. Line Layout
(US-6 & I-94)

Single Highway Type



Treatment 2c. Staggered Layout
(I-27 & I-94)

Treatment 2d. Line Layout
(I-27 & I-94)

Figure 11. Staggered Application Evaluation.

Comprehension

Motorist comprehension of the four treatments in this section was evaluated through their ability to select all of the lanes that would take them to their intended destination.

Table 6 shows the percentage of participants who correctly, partially correctly, or incorrectly identified the lanes leading to their destination.

Table 6. Staggered versus Line Application Comprehension.

Response	Single Highway Shield Type				Multiple Highway Shield Types			
	Exit		Thru		Exit		Thru	
	Stag.	Line	Stag.	Line	Stag.	Line	Stag.	Line
All Correct	78	85	58	75	77	77	73	68
Partially Correct	7	5	10	15	21	20	7	9
All + Partially Correct	85	90	68 [a]	90 [a]	98	97	80	77
Incorrect	15	10	32	10	2	3	20	23

[a] difference in comprehension percentage was statistically significant ($\alpha = 0.05$)

In Table 6, researchers added the percentage of participants who selected at least one of the appropriate travel lanes (partially correct) to those who had selected all of the correct lanes. Comparing the staggered applications to the line applications, there was not a clear indication as to which layout was better comprehended by the participants. In the single highway type situation, the through traffic had a statistically significant difference with the line application having been better understood than the staggered application. However, for the other three scenarios there was no significant difference.

The second part of the questioning involved in the comprehension analysis was to determine which lane the participant would want to drive in and why they preferred that lane. This analysis helps us to understand what the participant was thinking with regard to lane availability. Table 7 and Table 8 show participant responses for the exiting and through traffic scenarios, respectively.

Table 7. Travel Lane Preference for Staggered versus Line Application – Exit Scenario.

Highway Type Group	Treatment	Percent of Responses				
		Lane 1	Lane 2	Lane 3	Lane 4	Lane 5
Single	Staggered	0	3	15	55	27
	Line	0	0	14	58	28
Multiple	Staggered	0	0	13	57	30
	Line	3	0	32	41	24

As Table 7 shows, lane 4 was the most frequently selected lane to drive in for all of the treatments when presented with the exiting traffic scenario. When asked to identify why they would drive in this lane, the participants' primary reasoning was that using the middle lane gave flexibility to move in either direction. Interestingly, even for those participants who did not identify all of the correct lanes that could be used for the exiting situation, all but 6 percent of the respondents selected an appropriate lane to achieve their destination. This percentage indicates that although the participants were not able to retain all of the information presented in the graphics for all of the scenarios, the majority of participants could at least identify a single correct lane to use.

Table 8. Travel Lane Preference for Staggered versus Line Application – Through Scenario.

Highway Type Group	Treatment	Percent of Responses				
		Lane 1	Lane 2	Lane 3	Lane 4	Lane 5
Single	Staggered	17	55	13	7	8
	Line	15	78	5	2	0
Multiple	Staggered	22	60	13	2	3
	Line	15	62	13	3	7

Table 8 indicates that for all of the treatment options, the highest percentage of participants chose to travel in lane 2 (between 55 and 78 percent). The top reasons for selecting lane 2 were:

- more options,
- the lane is closer to the exit they will need to take further downstream (assuming future exit is on the right), and
- takes me where I need to go.

Looking at the participants who did not select an appropriate lane to reach their destination, there were 23 and 7 percent who would have made an incorrect lane choice for the line treatment and 28 and 18 percent for the staggered treatment.

This evaluation shows no difference in comprehension between the application patterns tested. Therefore, if conditions (or TxDOT preference) called for the use of staggered application markings for an interchange, there should be no adverse effects on the motorists.

Preference

The participants were shown pictures of the staggered treatment (Treatment 2a) and the standard single line treatment (Treatment 2b) side-by-side and asked to identify the option they preferred. Seventy-seven percent of participants stated they preferred the standard line treatment for the pavement markings. The majority of these participants (92 percent) believed the single line was easier to read all at once and that the information was clearer. Twenty-three percent of participants who preferred the staggered treatment option believed that their selection was easier to see, stating that if a driver missed one marking, they could see the next one, and that this staggered treatment made it easier to read all of the information.

Summary

Based on the results of the comprehension portion of this analysis, there was no significant difference between the application patterns. However, there was a clear preference for the standard line application of pavement markings. Based on current marking standards and motorist preference, researchers recommend that TxDOT not change their current practices with regard to alignment of the pavement markings. However, if conditions call for the use of staggered application to account for vehicle occlusion, there should not be adverse effects due to this application pattern.

Optional Lane

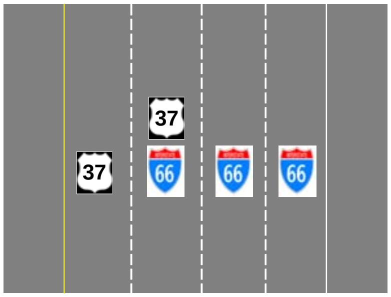
This part of the survey evaluated alternative marking patterns for optional lanes at major freeway interchanges. Figure 12 shows the treatments evaluated. As in the previous sections, these alternatives will be presented as both exit and through traffic treatments. The participants were all told to imagine that they were on Interstate 66. Therefore, the exiting scenario group would exit at US Highway 37, while the other participants would continue on Interstate 66 past this interchange. This set of alternatives was again displayed using simulated video clips of an interchange approach providing the participants with an improved driver perspective on the pavement marking sequence.

Table 9 shows the percentage of participants correctly, partially correctly, and incorrectly identifying the lanes available to their destination for each of the treatments shown in Figure 12. In this case, researchers believed that the identification of the split lane was the primary concern; therefore, the partially correct responses are all of those participants who identified their correct lanes minus the split lane.

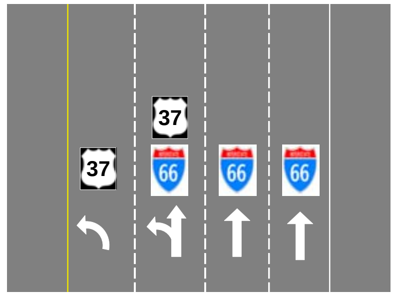
Table 9. Optional Lane Alternatives Comparison.

Treatment	Percent Responses					
	Exit			Through		
	Correct	Correct Except Optional Lane	Incorrect	Correct	Correct Except Optional Lane	Incorrect
3a. Shields only	82	13	5	43	17	40
3b. Shields w/arrows first	78	10	12	52	23	25
3c. Optional ln. w/no symbols	28[a]	65	7	20[b]	48	32
3d. Optional ln. w/arrows only	52[a]	45	53	23[b]	35	42
3e. Shields w/arrow in middle	63[a]	30	7	50	23	27
3f. Shields w/arrows first w/cardinal directions	72[a]	22	6	43	22	35
3g. Shields w/arrows in middle w/cardinal direction	63[a]	27	10	38	20	42
3h. Arrows only	65[a]	25	10	50	17	33

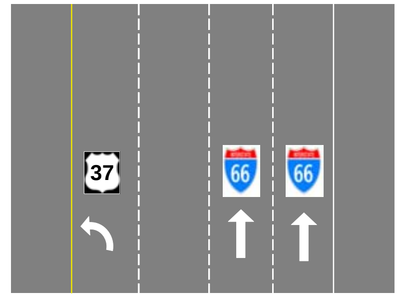
[a] difference in comprehension percentage was statistically significant compared to Treatment 3a (α =0.05)
[b] difference in comprehension percentage was statistically significant compared to Treatment 3b (α =0.05)



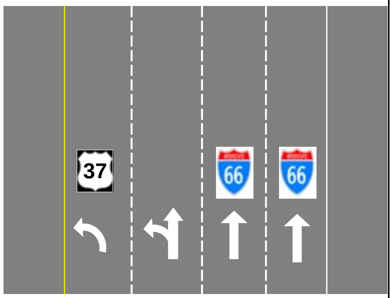
Treatment 3a. Shields Only



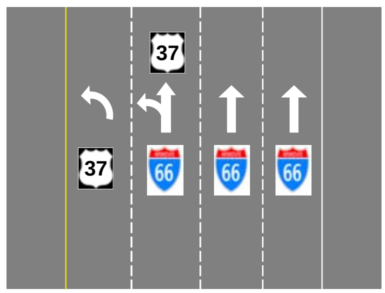
Treatment 3b. Shields w/ Arrows First



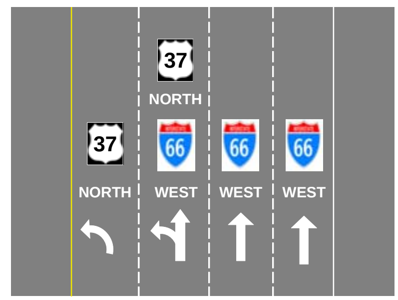
Treatment 3c. One Lane w/ no Symbols



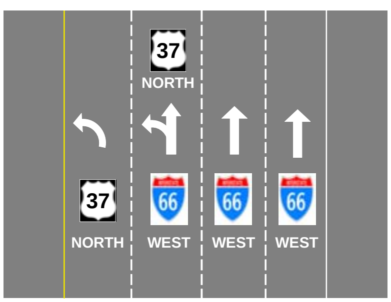
Treatment 3d. One Lane w/ Arrows Only



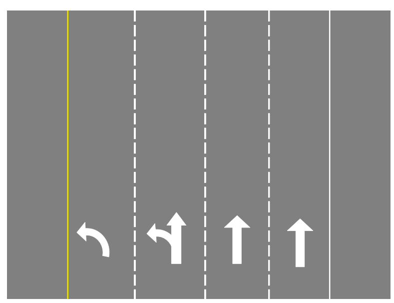
Treatment 3e. Shields w/ arrows in Middle



Treatment 3f. Shields w/ arrows First w/ Cardinal Directions



Treatment 3g. Shields w/ Arrow in Middle w/ Cardinal Directions



Treatment 3h. Arrows Only

Figure 12. Optional Lane Alternatives.

For the exiting scenario, the treatment with shields only was understood the best by 82 percent of the participants, followed by the treatment with the shields with arrows placed first with 78 percent. There was a statistically significant difference between the shield only display

(Treatment 3a) and all other alternatives evaluated except the shield with arrows first treatment (Treatment 3b).

On the other hand, the through traffic scenario shows that the shield with arrows first (Treatment 3b) was understood the best with a 52 percent comprehension rate. The application with the shields with the arrows in the middle treatment (Treatment 3e) and arrows only (Treatment 3h) were next highest in understanding with each receiving 50 percent correct responses. Researchers noted that the through traffic treatments had better comprehension rates when arrows were included in the pavement marking applications. Researchers believe this could be because the "exit" highway designation is not shown at the interchange and could have caused some uncertainty, so the participants made greater use of cues such as arrows in identifying route choice.

The alternative least understood for both the exit and through scenarios was when the optional lane had no in-lane pavement markings (Treatment 3c) at 28 and 20 percent, respectively for the two scenarios. A lane with no confirmation or information provided to the participants caused confusion as to where that lane led. This confusion was further illustrated by the greater percentage of participants who were able to identify all other correct lanes for this treatment, but who excluded the optional lane in their response. As such, a significant percent of the participants (between 65 and 48 percent, respectively) selected just lane 1 as the appropriate lane to follow in the exiting scenario and lanes 3 and 4 for the through scenario. Additionally, Treatment 3d with only arrows (no shields) in the optional lane also had a significant portion of the respondents selecting all but the optional lane at 45 percent for the exiting scenario and 35 percent for the through scenario.

Further evaluation of the results also indicated that motorist comprehension improved when shields were included in as part of the optional lane treatment (Treatments 3a, b, e, f, and g) compared to those where there were no shields in this lane (Treatments 3c, d, and h). Additionally, when the multiple shields were included for the optional lane together and above the arrows (Treatments 3b and f) these treatments were consistently better understood than those where the arrows were placed in the middle of the dual-shields for the optional lane (Treatments 3e and g). Results also indicated that the cardinal direction (Treatments 3f and g) did not provide a benefit for motorist comprehension when the highway shield types are different.

When asked which lane they would most want to travel in at this time, Table 10 and Table 11 show the participants' responses for the exiting and through scenarios, respectively.

Table 10. Percent of Responses Preferring Each Travel Lane for Optional Lane Alternatives – Exit Traffic.

Treatments	Percent Responses (n=60)			
	Lane 1	Lane 2	Lane 3	Lane 4
3a. Shields only	62	36	0	2
3b. Shields w/arrows first	63	37	0	0
3c. One lane w/no symbols	87	9	2	2
3d. One lane w/arrows only	88	12	0	0
3e. Shields w/arrow in middle	79	21	0	0
3f. Shields w/arrows first w/cardinal directions	80	20	0	0
3g. Shields w/arrows in middle w/cardinal direction	74	23	3	0
3h. Arrows only	66	30	2	2

For the exiting scenario, the majority of the participants selected lane 1 as their preferred travel lane. The top reason in all alternatives was that the exit lane leads only to US 37. The majority of those that selected lane 2 stated their reason for selecting this lane was that it gave them more options. This desire to stay in the dually designated lane may reveal some indecision on the part of the participants as to whether they have selected the correct highway. Additionally, researchers noted that there was a particularly high percentage of participants selecting lane 1 for the Treatment 3c and d (optional lane with no symbols and arrows only) at 87 and 88 percent, respectively. This high percentage was not surprising as researchers had already identified that there was lower comprehension of the lane use for the optional lane for these treatments.

Table 11. Percent of Responses Preferring Each Travel Lane for Optional Lane Alternatives – Through Traffic.

Treatment	Percent Responses (n=60)			
	Lane 1	Lane 2	Lane 3	Lane 4
3a. Shields only	2	30	47	21
3b. Shields w/arrows first	3	12	60	25
3c. One lane w/no symbols	8	20	55	17
3d. One lane w/arrows only	5	21	54	20
3e. Shields w/arrow in middle	2	24	60	14
3f. Shields w/arrows first w/cardinal directions	5	20	47	28
3g. Shields w/arrows in middle w/cardinal direction	3	25	55	17
3h. Arrows only	7	22	61	10

In the through-traffic scenario (Table 11), the majority of the participants selected lane 3 as their preferred travel lane. The three main reasons reported for this selection were:

1) middle lane gives more options,
2) middle lane has less merging traffic, and
3) participants needed to go straight because they had not seen their exit.

Even within the participants who did not identify all of the correct lanes to continue ahead, those who had selected lane 3 as their travel lane gave reasoning that indicates they knew this lane was appropriate to reach their destination.

Optional Lane Summary

Researchers identified several points that should be considered in the application of markings when an interchange has an optional lane. First, based on the initial comprehension numbers as well as the travel lane selections for the exiting traffic, highway identification markings should be included in the optional lane to aid in motorist understanding. Also, these shields should be placed together in the pavement marking sequence and not split by the optional lane arrow. Researchers did not note any confusion by the survey participants arising from the fact that the exit highway shields were not aligned in the shield information in the optional lane application as compared to the adjacent lane.

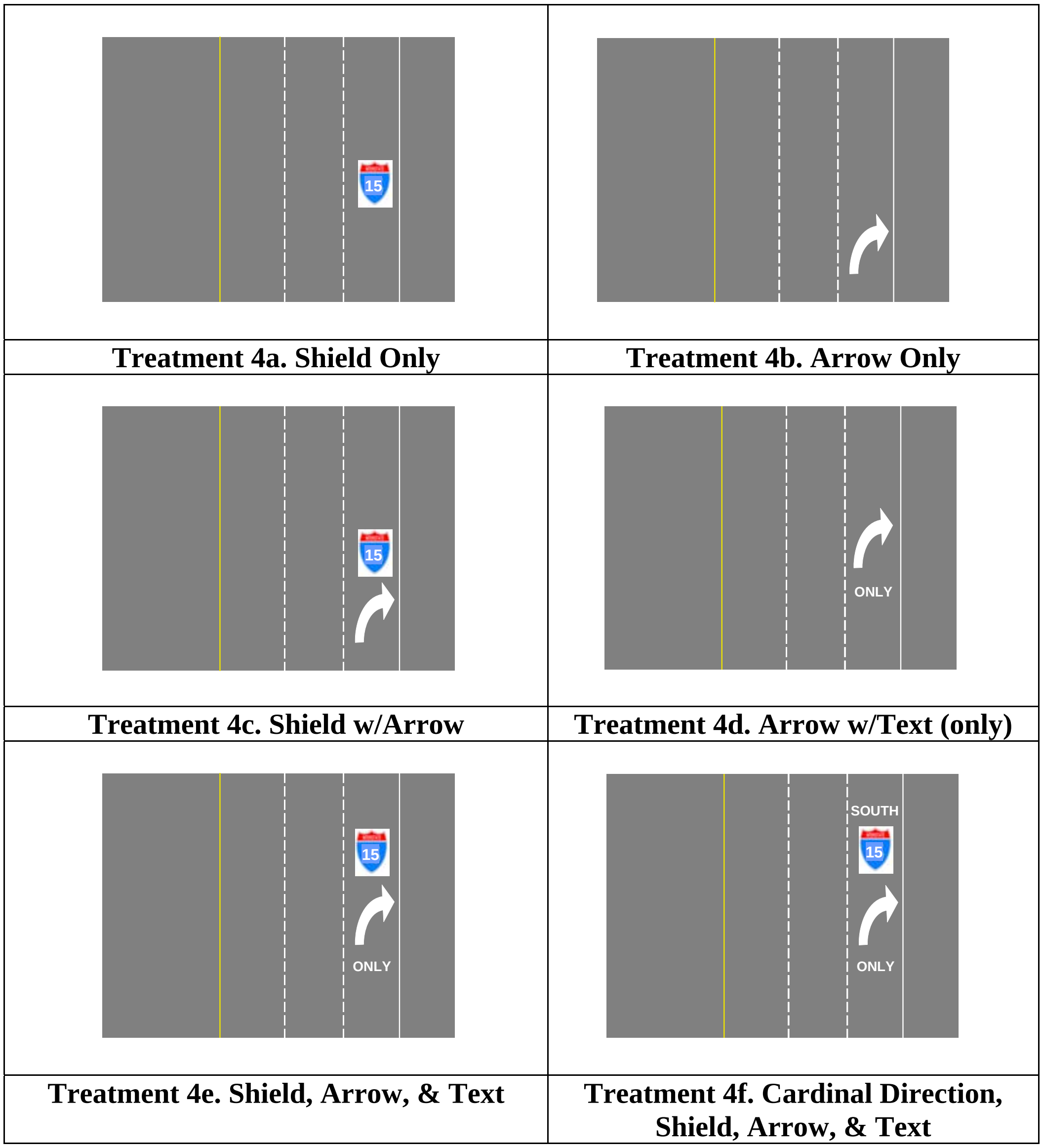
Additionally, both comprehension of all lanes and lane selection supported the need to provide lane markings in all lanes compared to just non-optional lanes. When this was not done in the evaluated treatments, there was confusion regarding the use of the optional lane.

In looking at the through scenario comprehension, researchers believe that there is a benefit to unsure motorists in providing arrows along with the highway indication shields. However, as this benefit was not observed uniformly within the through and exiting traffic scenarios, researchers will further evaluate to verify the recommendations included in this report with regard to the use of arrows and shields at freeway interchanges. The next evaluation shall include scenarios with shields alone, arrows and shields, and arrows alone to validate the benefit of these markings. Furthermore researchers will investigate the positioning of arrows either before or after the highway identification shields.

Finally, researchers found that when different highway types were used, there was no benefit gained from adding cardinal directions to the pavement marking information. Researchers know that this information is at times critical (e.g., when both directions of an optional lane have the same highway designation); however, they recommend that careful consideration is given before directions are used as part of in-lane pavement marking applications as they do not have benefits at all interchanges.

Exit Lane Information

This portion of the survey aimed at determining what information should be provided in a single exit lane. Figure 13 shows the six alternatives in pavement markings that were evaluated. These markings were again displayed through video clips to give a driving perspective of the markings sequence.



Treatment 4a. Shield Only

Treatment 4b. Arrow Only

Treatment 4c. Shield w/Arrow

Treatment 4d. Arrow w/Text (only)

Treatment 4e. Shield, Arrow, & Text

Treatment 4f. Cardinal Direction, Shield, Arrow, & Text

Figure 13. Exit Lane Alternatives.

Comprehension percentages for all of the treatments are provided in Table 12. A participant's response was considered correct for the exiting scenario if they selected lane 3 as their only available travel lane. For the through traffic scenario, participants needed to select both lane 1 and 2 as available to reach their destination in order to be correct. The partially correct responses for the through scenario are participants who selected either lane 1 or 2, but not both as available travel lanes.

Table 12. Exit Lane Alternatives Comparison.

Treatment	Percent Responses					
	Exit			Through		
	Correct	Partial	Incorrect	Correct	Partial	Incorrect
4a. Shield only	96	n/a	4	48	35	17
4b. Arrow only	93	n/a	7	55	37	8
4c. Shield w/arrow	95	n/a	5	72 [a]	20	8
4d. Arrow w/text only	93	n/a	7	65	22	13
4e. Shield, arrow, & text	90	n/a	10	67 [a]	25	8
4f. Cardinal direction, shield, arrow, & text	98	n/a	2	64 [a]	23	13

n/a = this response was not applicable as there was only one correct travel lane.
[a] difference in comprehension percentage was statistically significant compared to Treatment 4a (α =0.05)

As illustrated in Table 12, all of the treatments were understood very well by the participants who were presented with an exiting scenario with 90 percent or higher comprehension. This result indicates that any of the alternatives would be appropriate for use in identifying the exit lane for the exiting traffic.

Additionally, when asked what lane they would prefer to travel in at this point, all the correct exiting traffic participants selected lane 3 as their preferred lane to be in. Interestingly, of the incorrect participants, less than 3 percent of participants selected a lane other than 3 for all of the alternatives. This small percentage supports the conclusion stated above that all treatments were well understood in the exiting scenario.

However, the through traffic participants did not understand the alternatives as well as the exit traffic participants. This scenario showed a much greater fluctuation in the comprehension percentages between treatments. Treatment 4c (shield with arrow) was understood the best of the treatments tested with comprehension of 72 percent. Alternatively, Treatment 4a (shield only) had the lowest comprehension. There was a statistically significant difference between Treatment 4a and Treatments 4c, 4e, and 4f for this scenario. This result indicates to researchers that the addition of the turning arrow along with a highway shield helped the participants realize that to continue they needed to stay out of lane 3. When asked the confidence level of their selection, those who selected lane 1 were very confident (range 7, 6, and 5), while those who selected lanes 2 and 3 were not as confident with some showing confidence levels as low as 2.

Table 13 shows the preferred travel lane for each of the through traffic scenario participants. In this case, lane 2 was selected most frequently for all treatments. This result is a product of the participants wanting to be in the middle lane when traveling through as opposed to the far left lane. Reasons for selecting lane 1 included: to stay straight on Interstate 15, less merging, and to make my exit. Based on the responses obtained for those who selected lane 3, researchers believe that these participants were confused and thought they needed to exit at this interchange. Researchers feel this idea may have been exaggerated by the fact that the study was focusing on pavement markings and lane 3 was the only lane containing pavement markings.

Table 13. Percent of Participants Selecting Each Travel Lane – Through Traffic.

Treatment	Percent Responses		
	Lane 1	Lane 2	Lane 3
4a. Shield only	20	64	16
4b. Arrow only	12	81	7
4c. Shield w/arrow	15	78	7
4d. Arrow w/text only	10	78	12
4e. Shield, arrow, & text	13	80	7
4f. Cardinal direction, shield, arrow, & text	17	71	12

Summary

Based on the results from the surveys, researchers recommend the use of both a highway shield and an arrow in an exit lane when this lane is being marked. This recommendation is based on the fact that this treatment was understood the best for through traffic and that all treatments were acceptable for the exiting traffic. At this time, researchers do not believe that this issue requires a field evaluation as any of the tested treatments worked well for the exiting traffic (which is the primary audience for these markings) and details needed at a specific interchange would be highly location specific.

Exit Lane versus All Lanes Having Pavement Markings

Researchers conducted one final comparison with the data collected to look at the use of in-lane pavement markings strictly in an exit lane versus being placed in all lanes. This comparison involved combining results from previous discussions. More specifically, researchers looked at the comprehension results from the first section where all lanes were marked (Treatment 1b) and the previous section where only the exit lane was marked (Treatment 4a). Table 14 shows the comprehension results for these two alternatives.

Table 14. Pavement Markings on All Lanes versus Exit Lane Only.

Responses	Exit		Through	
	Treatment 4a Exit Lane (%)	**Treatment 1b All Lanes (%)**	**Treatment 4a Exit Lane (%)**	**Treatment 1b All Lanes (%)**
Correct	96	92	48	49
Partially Correct	0	0	35	41
Incorrect	4	8	17	10

As can be seen in Table 14, there was no significant change in comprehension when marking all of the lanes in this type of situation as opposed to only the exit lane. However, when participants were asked for their preference regarding this topic, there was a majority (65 percent) who thought it was better to mark all lanes. Figure 14 shows the graphics used for this comparison.

Preference for the pavement markings on all lanes was based on the fact that the markings confirmed what road they were on and what lanes went where. Participants believed that marking only the exit lane was not enough information and might cause a driver to miss the exit or be confused.

Treatment 5a. All Lanes

Treatment 5b. Exit Lane Only

Figure 14. All versus Exit Lane Only Markings.

Of the 35 percent that preferred the exit lanes only application, the primary reasons included: 1) less distracting and 2) need time to make a change to exit. Others indicated that drivers already knew what highway they were on and did not need that information. As such, when asked why they did not select the all lanes applications, 58 percent stated that it was just too much information, 20 percent said it made them look a lot of places, and another 20 percent stated they already knew what highway they were on.

In summary, researchers do not recommend the use of in-lane pavement markings on all lanes at simple one-right lane exit interchanges. Although there was a preference for this information, there is no discernable benefit in understanding through their use. Researchers recommend saving the application of such markings for areas with more complex or difficult interchange locations (e.g., optional lane situations).

Order of Information within Applications

The order of information to be included in a symbolic pavement marking application is an issue that is subject to a great deal of debate. The purpose of this exercise was to identify what information a motorist would choose to have displayed in the lane and in what order. Both optional lanes and single exit lane scenarios were evaluated.

Optional Lane

The five pieces of information available to a participant during the optional lane exercise were:

- primary direction (i.e., west),
- primary highway shield (i.e., Interstate 66),
- exit direction (i.e., north),
- exiting highway shield (i.e., US Highway 37), and
- optional arrow.

When researchers asked participants to place the units of information in the order they would like to see them placed on the roadway, the results ended up very sporadic. There were only two orders of information sequences that received more than 7 percent of the participants identifying them. These sequences were:

- using the "optional arrow" (25 percent) and
- a sequence of the exiting highway shield, then direction, followed by the optional arrow graphic (7 percent).

All the remaining combinations received less than 4 percent of the participant responses.

Given the sporadic nature of the overall sequences, researchers evaluated the general placement of specific elements for the pavement marking symbols within the applications to determine if there was any continuity among the participant responses. Table 15 shows the sequence position where the participants felt that each pavement marking should be placed based on the order that a driver would encounter the symbols. It should be noted that participants also had the choice not to use an information element within their information sequence so not all participants selected all of the message elements.

Table 15. Selection of Optional Lane Information Elements in Sequence.

Sequence Position	Information Element (n=240)				
	Primary Highway Direction	Primary Highway Shield	Exiting Highway Direction	Exiting Highway Shield	Optional Arrow Graphic
Not Selected	69%	54%	54%	33%	4%
1st	2%	11%	7%	21%	57%
2nd	7%	12%	18%	28%	9%
3rd	7%	11%	11%	11%	22%
4th	7%	8%	6%	5%	2%
5th	8%	4%	4%	2%	6%

Note: Position designation is based on the order a driver would encounter the symbols.

Results show that over half of the participants felt they did not need the primary highway direction or shield or the exiting highway direction (69, 54, and 54 percent, respectively, did not include this information in their sequence). However, the majority did believe that the optional arrow graphic needed to be included in the sequence and over half of the participants believed that it should be placed first in the sequence. Additionally, 67 percent of the participants believed that the exiting highway shield should be used in this type of situation. This indicates to researchers that although not all of the participants chose both highway shields to be used in the sequence during this exercise, the participants did place value on the highway shield designation type of information within their selections.

In addition to the organizational exercise, a rating of the information elements was also conducted using a scale of 1 to 5, with 5 meaning the information was very helpful and 1 meaning not helpful. Table 16 shows the average rating for each information element.

Table 16. Optional Lane Information Elements Ratings.

Pavement Marking Displayed	Average Rating (5 – highest; 1 – lowest)
Primary Highway Direction	2.9
Primary Highway Shield	3.5
Exiting Highway Direction	3.1
Exiting Highway Shield	4.0
Optional Arrow Graphic	4.6

Noting that higher values are the desired result of this rating system, researchers determined this process compared very closely with the results of the sequence exercise. Again the optional arrow graphic was the most desirable piece of information to the participants followed by the exiting highway and through highway shields. The cardinal directions for the two highways received the lowest ratings during this evaluation.

Exit Only Lane

The five pieces of information available to a participant during the exit only lane exercise were:

- "Exit" text,
- "Only" text,
- right turn arrow graphic,
- exiting highway shield (i.e., Interstate 15), and
- exiting highway cardinal direction (i.e., south).

When researchers asked the participants to place the information elements in the order they would like to see them appear on the roadway, the results were again sporadic. There were only two orders of information that received more than 4 percent of the participants: 1) exiting highway shield, cardinal direction, "Exit," "Only," and arrow graphic had 9 percent of respondents selecting this sequence, and 2) exiting highway shield and arrow graphic was suggested by 4 percent. All the remaining combinations of pavement marking sequences received less than 3 percent of the responses. Table 17 shows where in the sequence of information the participants felt that each element should be placed, if at all.

Table 17. Selection of Exit Lane Information Elements in Sequence.

Order of Pavement Markings Displayed	Information Elements (n=240)				
	"Exit"	"Only"	Right Turn Arrow	Exiting Highway Shield	Exiting Highway Direction
Not Selected	21%	25%	11%	14%	43%
1st	19%	6%	25%	43%	7%
2nd	21%	23%	15%	17%	21%
3rd	28%	17%	19%	11%	11%
4th	10%	21%	10%	12%	9%
5th	1%	8%	20%	3%	9%
Total	100%	100%	100%	100%	100%

As with the optional lane scenario, there were a significant portion of the participants (43 percent) who believed the highway direction did not need to be included in the information sequence. For the information that participants did include in their sequences, the researchers found almost half of the participants (43 percent) felt the exiting highway shield should be placed first in the sequence. This response indicates to researchers that participants found this information to be valuable in their decision making process. This response was also true of the arrow and the "Exit" text information, which had 40 percent of the participants placing this information in either the first or second position within the sequence of information.

Again, the participants were asked to rate each information element on how helpful it was in letting the driver know what choices were available from that lane. This rating used a scale of 1 to 5, with 5 meaning very helpful and 1 meaning not helpful. Table 18 shows the average rating for each information element.

Table 18. Exit Lane Information Element Ratings.

Pavement Marking Displayed	Average Rating (5 – highest; 1 – lowest)
"Exit"	4.1
"Only"	3.9
Right Turn Arrow	4.1
Exiting Highway Shield	4.4
Exiting Highway Direction	3.4

With 5 being the best possible rating in this exercise, three of the elements received ratings that were above a 4. These elements were: exiting highway shield, right turn arrow, and "Exit".

This rating did not surprise researchers as these elements were also the elements that were placed first in the sequences created earlier indicating a level of desirability toward this information by the participants. It should be noted that while the other two message elements may have been rated slightly lower they were still rated positively with ratings between 3 and 4.

Summary

Although the order of information exercise did not achieve the information researchers were hoping for (i.e., to establish a definite sequence for the elements within the application), it did provide good insight into what key elements to include within a symbol pavement marking application. The following were the key elements for each of the scenarios:

Optional Lane:

1- Optional arrow graphic
2- Exiting highway shield
3- Primary highway shield

Exit Only Lane:

1- Exiting highway shield
2- Right turn arrow
3- "Exit" text

SUMMARY OF RECOMMENDATIONS

Symbol versus Text Highway Identification

For symbol versus text pavement markings to identify highway route designations, researchers believe that either type of marking could work equally well in meeting the motorist information needs at the interchange. However, researchers would like to study this issue further (text versus symbol markings) as it is believed that in a limited viewing time application there may be a so far unrealized advantage to the use of shields as far as rapid road type identification is concerned.

Staggered Application

Based on current marking standards and motorist preference, researchers would recommend that TxDOT not change current practices with regard to alignment of the pavement markings. However, if conditions call for the use of staggered application to account for vehicle occlusion, there should not be adverse effects due to this application pattern.

Optional Lane

Researchers identified several points that should be considered in the application of markings when an interchange has an optional use lane.

- Agencies need to provide lane markings in the optional lane if there are markings in any of the lanes.
- Highway identification shields should be included in the optional lane to aid in motorist understanding.
- The highway shields should be placed together in the pavement marking sequence and not divided around an optional lane arrow (i.e., Treatment 3e).
- Further evaluation will be conducted on whether arrows should be used along with highway designation shields at the interchanges or if one or the other of these pieces of information will suffice.
- Finally, researchers found that when different highway types were used there was no benefit gained from adding cardinal directions to the pavement marking information. However, as this information is at times critical (e.g., when both directions of an interchange have the same highway designation), researchers recommend that directions not be used as part of in-lane pavement marking applications unless they are required.

Exit Lane Information

Based on results from the surveys, researchers recommend the use of the exiting highway shield with right turn arrow treatment. This recommendation is based on the fact that it was understood the best for through traffic and any treatment garnered acceptable levels of understanding for the exiting traffic. At this time, researchers do not believe that this issue requires a field evaluation.

Additionally, researchers do not recommend the use of in-lane pavement markings on all lanes at simple single lane exit interchanges. Although there is a preference for this information there was no discernable benefit in understanding through their use. Researchers recommend saving the application of such markings for areas with more complex or difficult interchange locations (e.g., optional lane situations).

CHAPTER 4. HUMAN FACTORS LABORATORY STUDY – PHASE 2

There are several questions that the phase 1 study answered; however, there were still a few points that researchers felt needed to be answered and/or verified. These points are as follows.

- Is there a benefit to the use of both arrows and shields at an interchange area or can one or the other suffice in providing information to the motorist?
- Is there a benefit for motorists in having a highway shield symbol as compared to text representing the highway designation?

To address these questions, researchers designed a second laboratory study to be administered to drivers.

STUDY DESIGN

Treatments

For each of the study questions identified, a separate set of treatments was created for use in this study. First, for the evaluation of what sequence of markings should be used (i.e., evaluating if shields and/or arrows should be used), researchers created video segments portraying an approach to a freeway interchange. Figure 15 illustrates the treatments created within the videos. Note that for each of the treatment categories, several different variations were created using different combinations of highway route designations (i.e., different numbers and left/right locations).

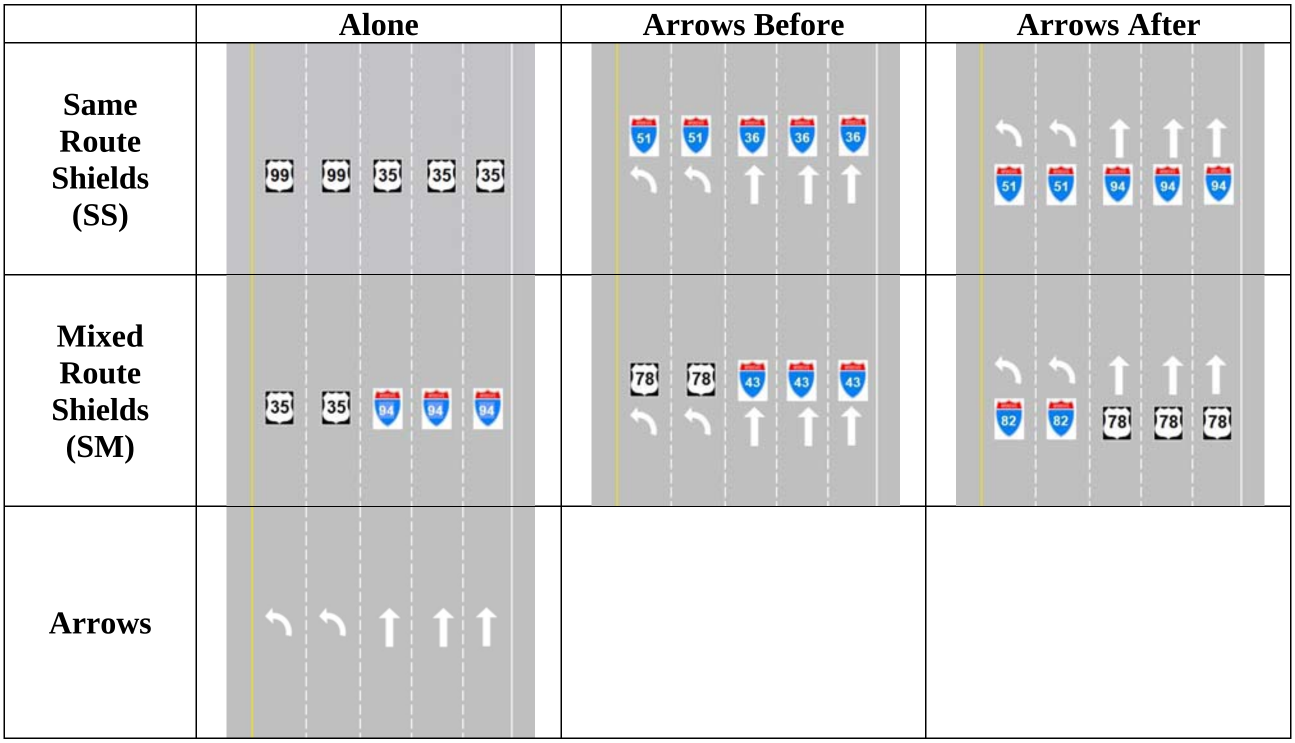


Figure 15. Pavement Marking Sequence Treatments.

The second set of treatments addressed the hypothesis that a driver could more quickly recognize a highway route shield as compared to equivalent text for that route. Figure 16 shows the four categories of treatments evaluated. Again, different variations of these treatments were created by using different combinations of highway route designations.

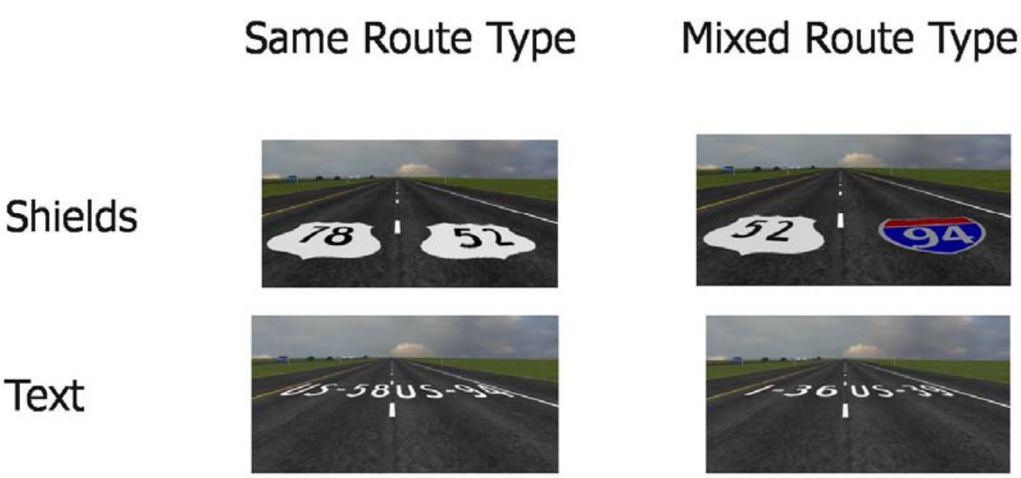


Figure 16. Recognition Task Treatment Categories.

Study Tasks

Comprehension Task

The first task identified for this study was a comprehension task addressing what sequence of information should be used for in-lane pavement markings. Figure 15 identified the treatments used for this task.

For this evaluation, participants were presented with video clips simulating an interchange area. Each video was preceded by instructions that the participant was to follow a specific highway to reach their destination. At the end of each video clip, participants were asked three questions about their driving decisions based on the information they saw in the video:

1. Do you need to change lanes to reach your destination? (Yes or No)
2. If you need to change lanes, which lane would you move to? (Select Lane 1-5)
3. Please indicate your confidence in your selection? (Scale of 1-5, where 1 = 0 percent confident and 5= 100 percent confident)

Recall Task

To address the question of recognition time, researchers employed two different study techniques. The first of these techniques was a recall task. During this portion of the study, participants were shown a still image of a two-lane roadway with either text or shield in-lane pavement markings. Figure 17 shows an example of the images used for this task.

Figure 17. Response Time Task Example Image.

As before, each treatment was preceded by a screen identifying for the participant what highway they needed to follow to their destination. Then researchers displayed the image for a very short exposure time, and after the participant viewed the image, researchers asked two questions:

1. What lane do you need to be in to reach your destination? (Left or Right)
2. Please indicate your confidence in your selection. (Scale of 1-5)

Table 19 shows the exposure times used for this study. Researchers selected a range of increasing exposure times for the images from 50-500 milliseconds. The selection of these exposure times were based on a pilot evaluation that showed that higher exposure times (i.e., larger than 500 milliseconds) were not effective for this task as they were universally recognized independent of treatment.

Table 19. Recall Task Exposure Times.

Exposure Time (milliseconds)	50	100	150	200	250	300	350	500
Increase Increment (milliseconds)	--	50	50	50	50	50	50	150

Reaction Time Task

The second technique used to address the question of recognition time was a reaction time task. This task also used still images; however, in this case the images stayed on the screen until the participant selected which lane they would use to reach their destination (i.e., left or right lane). The images again simulated a two-lane roadway with either text or shield pavement markings in each lane (Figure 17). Prior to the reaction time section of the study, participants were instructed what highway to follow to reach their destination for the next several images and to press “left” or “right” on the response pad as soon as they determined which lane they needed to be in. Once the participant selected the appropriate lane, the next reaction time image would immediately appear and the participant would again respond with a lane selection.

Survey Instrument

To randomize the order in which participants saw the study treatments, two survey versions were created. Each survey had the same basic design including a series of three to five comprehension videos, eight recall images, and eight reaction time images in each section. The survey was composed of four sections, with each section instructing the participant to follow a different highway to reach their destination. Table 20 displays one example of the survey format. Sub-versions of each survey were created to vary the exposure times assigned to the recall treatments.

Table 20. Phase 2 Survey Design.

Survey Design	
Destination	
I-94	5 Comprehension Videos
	8 Recall Images
	8 Reaction Time Images
US 78	3 Comprehension Videos
	8 Recall Images
	8 Reaction Time Images
US 65	3 Comprehension Videos
	8 Recall Images
	8 Reaction Time Images
I-36	5 Comprehension Videos
	8 Recall Images
	8 Reaction Time Images

Survey Administration

To administer the survey, researchers used a computer based stimulus presentation software package. This software allowed the researchers to create a series of events presented in a survey format. The software was loaded onto five laptops allowing for a maximum number of participants at any time. Laptops were selected to ensure that participants viewed similar monitor dimensions regardless of which computer they were stationed at. Each laptop used a response pad to allow participants to enter their responses to survey questions. The response pad had seven buttons side by side which allowed for a more simplified method of responding for the participant than a standard keyboard (Figure 18). Researchers felt that using the response pad would minimize error in answering as well as make participants who were unfamiliar with the use of a computer more comfortable with the equipment. Survey questions were designed so all responses could be answered with: Left/Right, Yes/No or multiple choice of 1-5.

Figure 18. Participant Response Pad.

Study Locations

Researchers collected data in four cities throughout Texas: Houston, San Antonio, El Paso, and Dallas. TTI has field offices in each of these cities, making the locations ideal due to available office space. It was determined that 128 participants would be recruited at each location for a total of 512 participants. In some cities, in order to reach the demographic goal, researchers also collected data in non-TTI sites including Texas Department of Public Safety Driver License offices in San Antonio and El Paso and a senior citizens center in Plano.

Participant Recruitment

Participants were recruited using TTI's current participant database pool as well as through local recruiting efforts. An email or phone call was made to previous research participants in the data collection locations who had expressed an interest in future TTI research.

Fliers were placed in the buildings containing TTI offices and distributed to surrounding offices. As participants completed the survey, they were asked to indicate their interest in future research studies.

Demographics

A demographic sample of the Texas driving population based on age, gender, and education level was used as a guide for subject selection. Statistics regarding ages and gender were obtained from the United States Department of Transportation – Federal Highway Administration Statistics for 2005. The education level statistics were based on Texas information from the United States Census Bureau, Community Survey 2006. Table 21 shows the demographic sample obtained based on cross-referencing the gender, age, and education level of the Texas population. The numbers in italics represent the percentage of the sample population obtained. As shown in Table 21, the actual sample very closely matched the age demographics established for the study. However, there were slightly more females and fewer males. In addition, there were more educated in both the male and female categories and fewer male and females in the high school or less category.

Table 21. Phase 2 Survey Demographics (n=514).

	Education Level				
	High School Diploma or Less (49%)		**Some College (51%)**		
Age Category	**Male**	**Female**	**Male**	**Female**	**Total**
18-39 (44%)	(11) *9*	(11) *9*	(11) *12*	(11) *14*	(44) *44*
40-54 (31%)	(8) *6*	(7) *7*	(8) *8*	(8) *10*	(31) *31*
55+ (25%)	(6) *4*	(6) *6*	(7) *8*	(6) *7*	(25) *25*
Total	(25) *19*	(24) *22*	(26) *28*	(25) *31*	*100*

Laboratory Session Protocol

The study set-up allowed for a total of five survey participants at any time. Before beginning the study, participants were informed the survey would last approximately 20 minutes and provided both a demographic and consent form to complete. Once the paperwork was finished, a general description of the study was provided along with instructions for answering survey questions using the response pad. Prior to the participant starting a new task for the first time, instructions were presented detailing the task and providing an example or “practice” run. Once the example task was completed, a screen appeared asking the participant to raise their hand to notify the researcher. The researcher asked if the participant had any questions regarding the task and when the participant was ready, the researcher advanced the survey to the next section. At the conclusion of the survey, participants were given an opportunity to ask questions and compensated for their participation.

RESULTS

In-Lane Pavement Marking Sequences

Seven different sequences of pavement markings were evaluated to address the question of what sequence of information is most beneficial to a driver (Figure 15). The following two figures illustrate the crucial points learned from this portion of the study. In these figures, the following identifiers are used for the different sequences of pavement marking displays evaluated:

- SS = same highway route designation shields for all lanes (e.g., all interstate route markers);
- SS arrow = same highway route designation shields for all lanes followed by arrows;
- Arrows SS = same highway route designation shields for all lanes preceded by arrows;
- SM = use of mixed highway route shields across the lanes (e.g., identifying both a US Highway and an Interstate);
- SM arrow = use of mixed highway route shields followed by arrows;
- Arrow SM = use of mixed highway route shields preceded by arrows; and
- Arrows only = arrows used alone (i.e., without accompanying highway route shields).

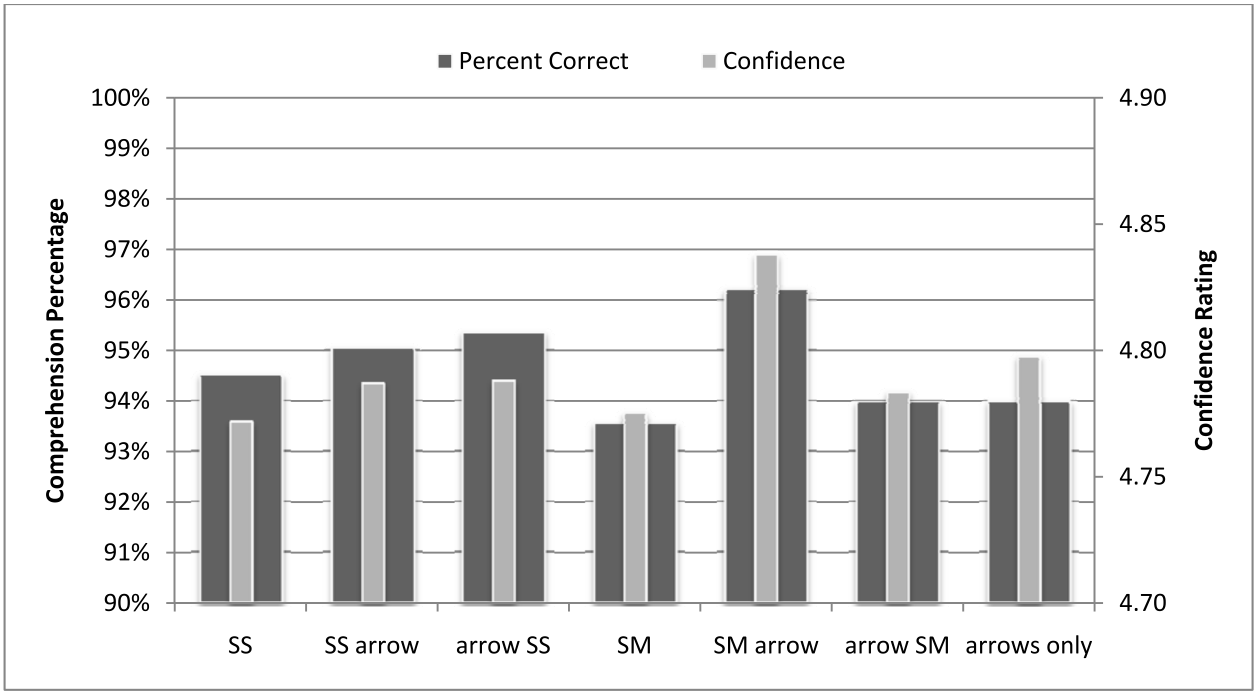


Figure 19. Comprehension Percentage and Confidence Ratings.

Figure 19 shows two different values for this analysis. The first set of values (the wider bar) is the percentage of participants who correctly identified if they needed to change lanes for a given scenario for each of the treatment categories. As can be seen all of the treatments were well understood with over 93 percent of the participants correctly identifying the appropriate action. The second set of values are the average confidence ratings given by participants with regard to their decisions (i.e., the closer this number is to 5 the more confident the participants were). As can be seen, the level of confidence was very high for all of the treatments and closely mimicked the changes in comprehension rate with higher comprehension also garnering higher confidence. Although the image shows that there were minor variations in both sets of values, none of these differences were statistically significant.

As a second way to analyze this information, researchers also wanted to look at the efficiency of lane changing behavior identified by participants. Researchers considered two points in identifying what would be considered ideal lane change behavior for the situations. First, if the scenario already showed a view to the participant as being in a lane that would reach their destination, then the ideal behavior was to make no lane changes. Secondly, if the view was not from a lane leading to the identified destination, the ideal reaction was to move to the closest available lane that would take the driver where they needed to go. Researchers classified these as ideal changes as they can help accomplish two different points in the interchange area:

- increase safety by reducing the number of lane changes occurring within the interchange area, and
- increase mobility by making better use of all available lanes leading to a destination.

Figure 20 shows the percent of participants who made the ideal lane change decisions for each of the different treatment sequences.

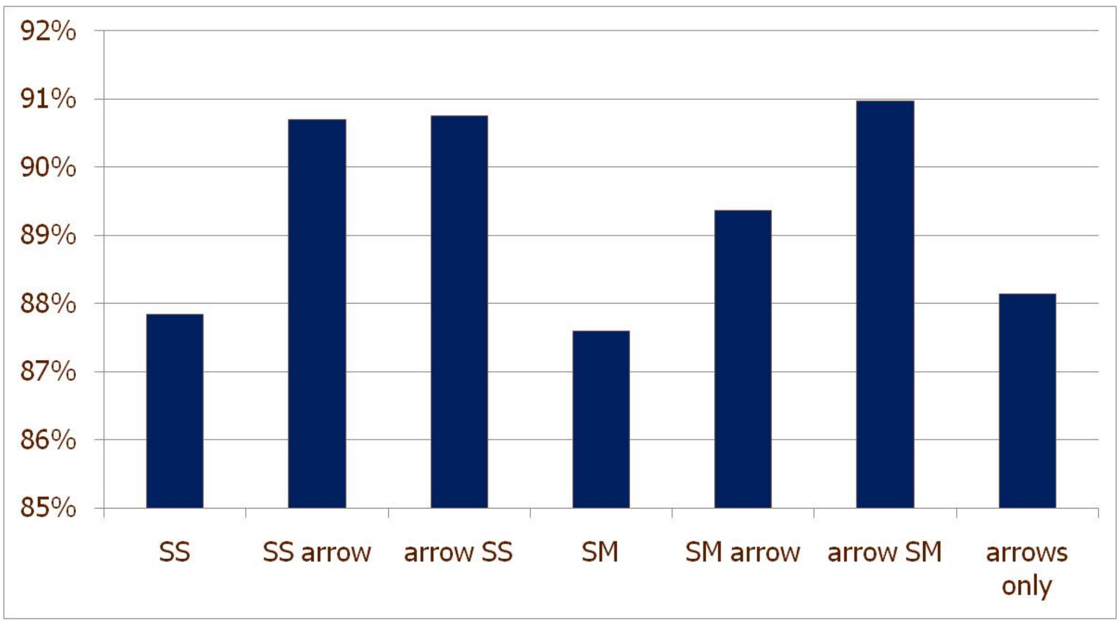


Figure 20. Percent of Ideal Lane Change Behaviors.

This analysis shows that there was an improvement in lane selection when shields and arrows are used in combination as compared to either shields or arrows alone. Although this increase was not large (approximately 2–4 percent), the change was found to be statistically significant using a test of proportions. Therefore, researchers believe that the use of both shields and arrows in combination would garner the greatest improvement in conditions and understanding near an interchange.

Additionally, looking at the placement of arrows either before or after the route shields, there was no statistically significant difference in the drivers' decisions based on the sequence order, and therefore researchers believe that the decision of sequence should be made based on current markings (e.g., do arrows already exist and whether it would be simple to add shields either before or after) and engineering judgment.

Recognition of Markings

Reaction Time

The reaction times for the different treatment types were compiled, and the descriptive statistics are presented in Table 22. The treatment identifiers used in the analysis are as follows:

- SM = use of mixed highway route shields across the lanes (e.g., identifying both a US Highway and an Interstate);
- SS = same highway route designation shields for all lanes (e.g., all interstate route markers);
- TM = use of mixed highway route text across the lanes (e.g., identifying both a US Highway and an Interstate as text); and
- TS = same highway route designation text for all lanes (e.g., all interstate route text).

Note that the number of observations across the different treatments varied a large amount. This variation occurred because the first trial for each of the reaction time sections was eliminated after researchers observed that these images had extraordinarily high viewing times as compared to other images within the same treatment type. Researchers surmised that many participants "forgot" that they needed to press the button to make the stimulus disappear since the prior set of questions had a computer-controlled exposure time.

Table 22. Summary of Results for Reaction Time Measures.

Statistics	Treatment Categories			
	SM	SS	TM	TS
Average	1.06	1.20	1.34	1.28
Standard Deviation	0.65	0.74	0.93	0.82
Minimum	0.37	0.31	0.30	0.32
Maximum	8.86	7.99	9.31	9.51
Median	0.90	1.00	1.07	1.04
85^{th} Percentile	1.43	1.65	1.90	1.80
Number of observations	2539	4055	3549	3550

To determine if there was a statistically significant change in the participants' reactions based on the treatment categories, researchers performed a one-way Analysis of Variance (ANOVA). The ANOVA test revealed that the effect of treatment category was statistically significant, which means that the average values were different from each other ($F_{3, 13,689}=64.5$, $p < 0.001$). Post-hoc tests comparing individual pairs of means showed all possible paired comparisons were statistically significant as well.

On the other hand, because the number of observations for each treatment was quite large and the range of response times was also quite large, the statistical significance is not necessarily an indication of a meaningful practical significance. The ranges of reaction times, and subsequent error bars, shown in Figure 21 show that the responses for the four treatment groups overlap each other to a great extent. The magnitude of the differences among the means ranges from 0.06 seconds to 0.28 seconds, which at highway speeds is a negligible difference.

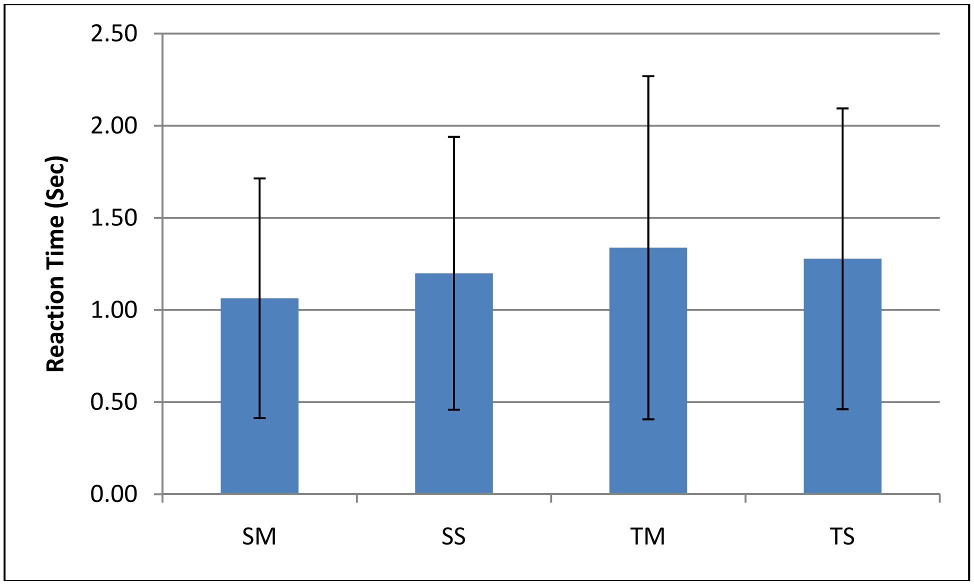


Figure 21. Reaction Times by Treatment Categories.

Another way to look at these changes is to evaluate the cumulative understanding of the participants for each of the four categories. Figure 22 shows that there is a minor separation between both the mixed and same shields as compared to their equivalent text. This change again illustrates that although the difference is small, there is an improvement in reaction time for shields compared to text in-lane pavement markings.

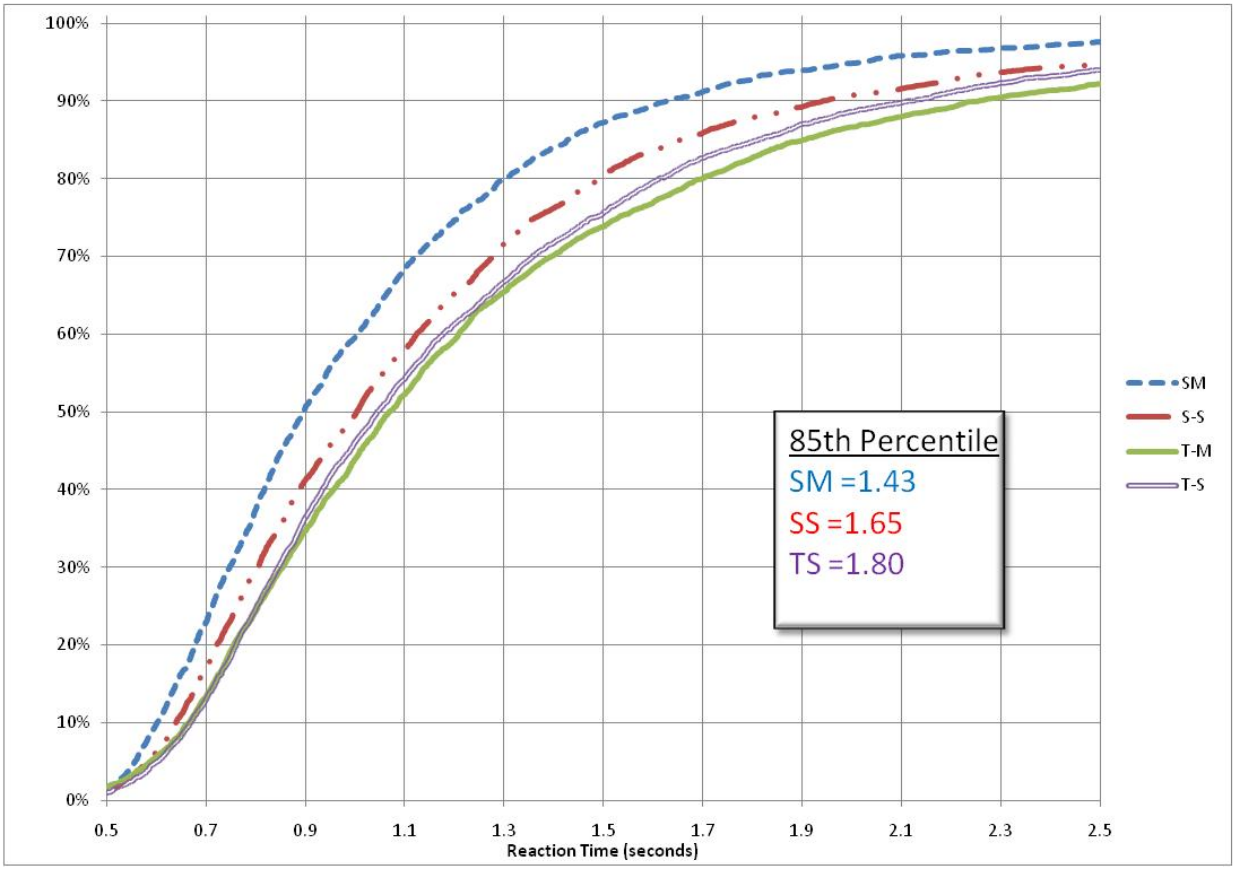


Figure 22. Cumulative Comprehension for Reaction Time Data.

Recall Task

The second evaluation conducted with regard to the recognition analysis was a limited exposure time recall task. This task used the same four treatment categories as those for the reaction time evaluation. For this analysis, the primary analysis was what percentage of the participants were able to correctly identify a highway route for a given exposure time. Figure 23 shows the percentage of participants who correctly identified a highway route based on the four treatment categories.

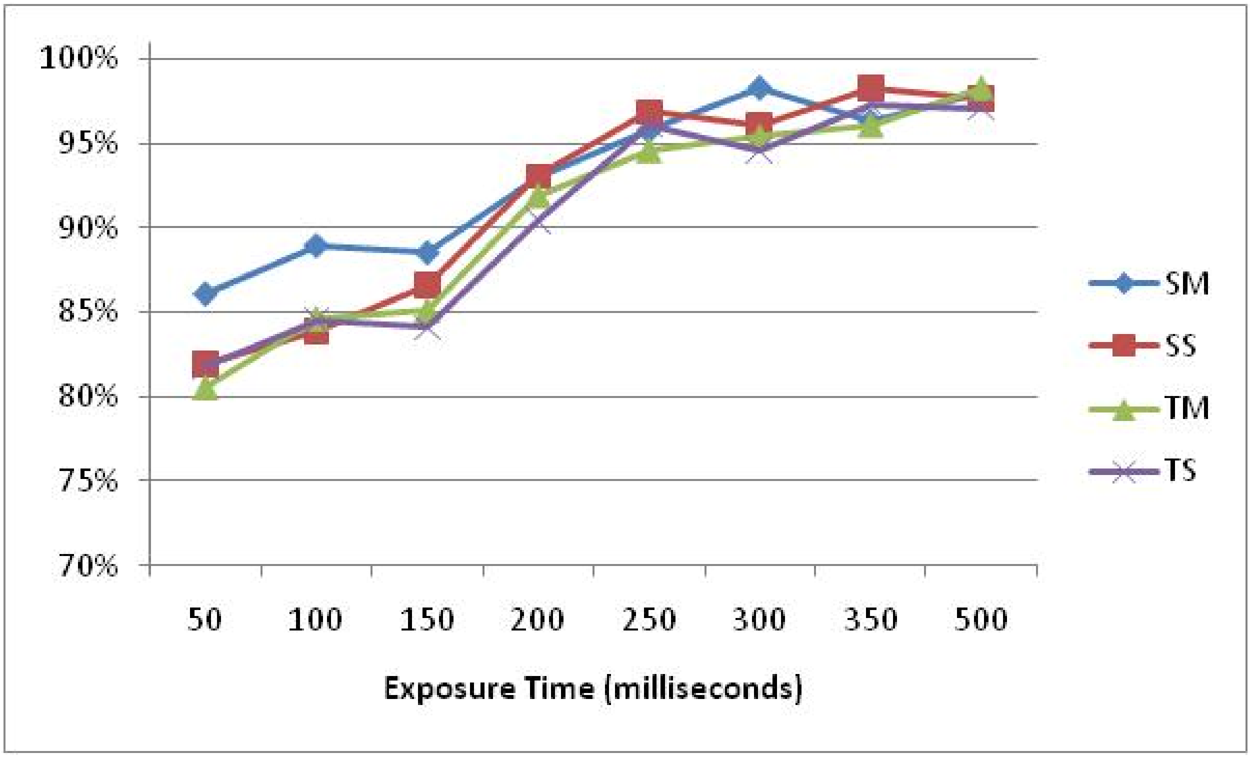


Figure 23. Correct Recall by Treatment Type.

As can be seen, there was a significant improvement (~5 percent) in the number of correct responses at the lower exposure times for the mixed route shield treatment as compared to the other three treatments. This improvement was not unexpected as in the mixed route shield images there would not be reading or number recognition required for the participant to correctly identify the appropriate highway as with the other three conditions. They simply needed to distinguish between an interstate and US highway shield to make the appropriate change, which is an easier task as there are color and shape cues that can be used in this recognition.

Conclusion

Based on the three tasks that were used to address the question of shield versus text recognition for highway route identification, researchers believe there is a benefit gained by the use of highway shields as in-lane pavement markings. Primarily, when shields have mixed highway designation routes, the benefit is highest for a driver in identifying the appropriate highway even before a route number is legible. Additionally, there was a minor improvement in the reaction time of participants for the shields as compared to equivalent text. This difference may not provide a practical change in available reaction time; however, it does illustrate a value gained through the use of shield markings.

CHAPTER 5. CLOSED-COURSE EVALUATION

Another concern regarding the use of in-lane pavement markings is the determination of appropriate physical characteristics for the markings. The study detailed in this chapter was a closed-course evaluation aimed at evaluating the design issues of size and contrast borders and how these elements affect the legibility of a pavement marking symbol for a driver.

TREATMENTS

Based on current practices by TxDOT for the use of in-lane pavement marking words and symbols, researchers identified three categories of markings that are commonly used at interchanges: text, arrows, and highway shields. Therefore, this study included each of these different types of markings within the study treatments. Additionally, researchers identified two basic characteristics of the symbol markings that were in question with regard to their effect on legibility distance: size and contrast border use. Based on this information, researchers selected different sizes and border options for inclusion in the study. This selection ensured that current TxDOT practices were being evaluated for comparison between current practices and study results for the treatment variables. Table 23 contains details on the different treatments included in this study.

All participants viewed all of the treatments listed above with the exception of the two directions identified for the arrows (left and left-through). In this case each participant only viewed one of the two treatment direction options. This was necessary because the markings created for this study used the same left turn arrow portion of the marking for both the left and left-through arrow treatments. Therefore each of the participants only viewed one of the two arrow direction options for each of the sizes (either left or left-through).

Table 23. Study Treatments.

Marking Type	Size (feet)	Contrast Border
Text	8*	No
	10	No
Arrow	12 Left/Left-Through	No
	12 Left/Left-Through	Yes
	20 Left/Left-Through	No
	36 Left/Left-Through	No
Shields	15 Interstate*	No
	20 Interstate	No
	36 Interstate	No
	15 US Highway*	No
	15 US Highway*	Yes

** Indicates TxDOT current practice.*

STUDY DESIGN

The primary objective of this study was to obtain legibility distances for different designs and sizes of in-lane symbol pavement markings to determine how the design alternatives impact a motorist's ability to view the marking. Prior to beginning the study, each participant met with researchers at a staging area to be provided with initial instructions, to perform a standard visual acuity (Snellen) screening, as well as a color-blindness screening. These screenings provided comparison information for data reduction and ensured that all participants had at least minimal levels of acceptable vision prior to beginning the study. No participant had to be disqualified from study participation based on the visual screening.

The legibility study was conducted as a dynamic study with the participant operating the test vehicle along a designated closed course. Each participant ran through the designated course twice, once at 40 mph and once at 60 mph. A study administrator was present in the vehicle with the participant to provide instructions, operate data collection equipment, and record verbal responses from the participant. The test vehicle used for this evaluation was equipped with a distance measuring instrument (DMI) to allow researchers to record the location where participants identified each symbol.

During each test run, the participant was asked to identify 11 pavement markings situated along their route. Figure 24 shows the course layout for the test runs. Participants began at either Start Point 1 or 2 and drove past the line of pavement markings ahead of them. Drivers then turned the car around and began at the opposite start point and drove over the opposite line of symbol markings.

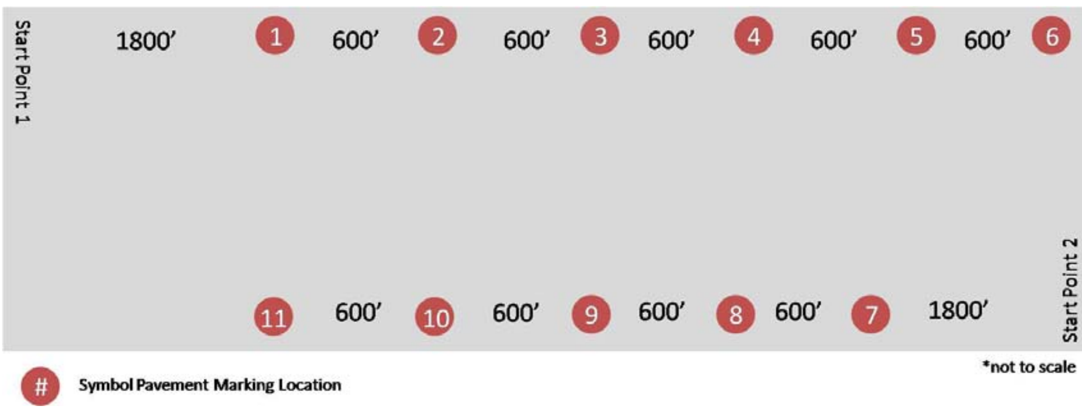


Figure 24. Closed-Course Layout.

To collect the desired legibility information during the test runs, participants stated out loud to a researcher when they identified the information provided by the pavement marking. This analysis includes only the distance at which the participant correctly identified all information provided by the marking (e.g., arrow and direction) and does not reflect incorrect responses.

Researchers built in a break time between the two test runs to reduce the learning effects that could occur through multiple runs over the same pavement markings. During the break, researchers asked distracter questions unrelated to the study to further reduce the learning effects.

Participant Demographics

Participants for this study were recruited from the Bryan-College Station, Texas, area. A total of 30 participants were included in this portion of the study. All participants were required to have a current Texas driver's license in order to qualify as a participant in the legibility study.

The participants were selected based on a demographic sample of the driving population of Texas with regard to gender, age, and education level as shown in Table 24. The statistics utilized for age and gender were obtained from the United States Department of Transportation –

Federal Highway Administration Statistics for 2005. The education level statistics were based on the Texas information from the United States Census Bureau for the year 2006.

Table 24. Study Demographic Sample.

Age	**Education Level**				**Total (n=30)**
	High School Diploma or Less (15)		**Some College + (15)**		
	Male	**Female**	**Male**	**Female**	
18-39	(4) *4*	(3) *3*	(3) *3*	(3) *3*	(13) *13*
40-54	(2) *2*	(2) *2*	(3) *2*	(2) *3*	(9) *9*
55+	(2) *2*	(2) *2*	(2) *2*	(2) *2*	(8) *8*
Total	(8) *8*	(7) *7*	(8) *7*	(7) *8*	(30) *30*

NOTE: *Numbers in italics represent the sample population obtained. Numbers in parentheses are original goals based on demographics.*

Data Analysis

The initial data analysis step was to use the distance information collected in the field for each symbol and convert this information to a legibility distance by subtracting out the distance of the pavement marking from the test run start point. Note that negative numbers for the legibility distance imply that the person did not relay the information from the pavement marking to the researcher until the car was on top of or slightly beyond the marking. The visibility distance garnered from this experiment should be evaluated only as relative to each other as the recorded data would take into account any error time introduced by the participant verbalizing their recognition and a researcher's reaction time in stopping the distance measuring instrument.

Once legibility distance was calculated, researchers computed several data set values for each of the pavement marking symbols. These numbers included:

- average legibility distance,
- 85th percentile legibility distance,
- standard deviation of the data set, and
- median legibility distance.

Researchers utilized analysis of variance and Tukey's honestly significant difference (HSD) procedure to determine if there were significant differences among the mean legibility distances within each pavement marking symbol group (i.e., text markings, highway shield markings, and arrow markings). This analysis allowed researchers to assess whether size and contrast border had a significant impact on the legibility distance of each type of pavement marking symbol group. Researchers used a 95 percent level of confidence ($\alpha = 0.05$) for all statistical analyses. Due to the unbalanced design of the experiment (i.e., not all symbol types at all sizes and not all symbols with contrast border), researchers did not run an ANOVA between pavement marking symbol groups.

Through the statistical analysis described above, researchers determined that the vehicle speed (40 or 60 mph) did not significantly impact the mean legibility distances. Therefore, the data presented herein is based on the combined results from both test runs for all of the participants.

STUDY RESULTS

Size Assessment

Size was one of the primary issues related to symbol pavement markings evaluated during this closed-course study. Researchers focused on this issue during the research to address questions as to whether an increase in pavement marking size yields a proportional benefit to the driver in terms of legibility distance and thereby viewing time. This increase in viewing time can be critical to a driver as it will afford them a greater time in which to make driving or lane changing decisions at an interchange area. In this section, three groups of pavement markings will be discussed:

- text markings,
- highway shield markings, and
- arrow markings.

Text Markings

Researchers evaluated two sizes of text pavement markings for this study: 8 and 10 ft. Figure 25 shows the two pavement markings used for this portion of the study. The words used for the text portion of this study were created based on the use of alphabet characters common to standard highway signing or pavement markings (i.e., researchers only included words that had letters that would likely be used in pavement markings).

a) 8 foot Text **b) 10 foot Text**

Figure 25. Text Pavement Markings.

Table 25 shows the average legibility distance for each of these pavement markings along with the difference in legibility distance and viewing time between the two alternatives. For the two sizes of text evaluated in this study, there was a statistically significant improvement in visibility distance for the 10-ft letters as opposed to the 8-ft letters. This size change garnered an 82 ft increase in the legibility distance for the text pavement marking. Assuming a speed of 55 mph near the interchange area, this increase in legibility distance would equate to one extra second of viewing time for the 10-ft text compared to 8-ft text. These results support the hypothesis that an increase in the pavement marking size would improve motorist decision making as it will give an increased amount of viewing and decision making time when the larger letters are used.

Table 25. Legibility Data Analysis for Text Pavement Markings.

Marking Description	Legibility Distance (ft)
8 ft Text	50
10 ft Text	132
Difference in Legibility Distance (10 ft – 8 ft)	82
Viewing Time Difference	+ 1 second

Highway Shield Markings

Four highway shields were included in the size evaluation portion of this study: three sizes of Interstate shields and one size of US Highway shield. Figure 26 shows images of the pavement markings used during this study.

a) 15 foot Interstate Shield

b) 20 foot Interstate Shield

c) 36 foot Interstate Shield

d) 15 foot US Highway Shield

Figure 26. Highway Shield Pavement Markings.

Tables 26 and 27 below show the average legibility distance for each shield and a comparison of the differences between these legibility distances.

Table 26. Average Shield Legibility Distance.

Marking Description	Legibility Distance		
	15' (ft)	20' (ft)	36' (ft)
Interstate	47	43	115
US Highway	53		

Note: Shaded cells represent variations not included in evaluation

Table 27. Comparison of Shield Legibility Distances.

Shields Compared		Difference between Shields	
Symbol 1 (S1)	Symbol 2 (S2)	Legibility Distance (ft) (S1 – S2)	Viewing Time (sec)
36'	15'	68	0.8
36'	20'	72	0.9
20'	15'	-4	-0.1
15'	15'	6	0.1

Within the interstate shield size comparison, researchers identified a 68-ft increase in the legibility distance between the 15-ft shield and the 36-ft shield as well an increase of 72 ft between the 20-ft shield and the 36-ft shield, both of these differences were found to be statistically significant. When the changes in legibility distance are converted into viewing times, these changes resulted in nearly one second of increased viewing time for a 36-ft pavement marking as compared to either the 15- or 20-ft markings. Again, the increase in viewing time could have a direct impact on a driver's ability to make decisions in a timely manner when approaching an interchange area. However, researchers note that vehicle occlusion of these markings is not taken into consideration in this assumption of decision time increase. No significant differences in legibility distance were found between the 15- and 20-ft interstate shields or the two 15-ft shields.

Arrow Markings

The third group of markings included in this study was arrow markings. For this comparison, researchers included three sizes of arrows: 12, 20, and 36 ft. These symbols were presented during the study as both "left turn" arrows and "left turn or through" optional lane arrows with the left turn portion of the arrow being the specified size. It should be noted that for each arrow size participants only saw one of the directional variations (i.e., either "left" or "left and through"). Figure 27 and Figure 28 show the arrows that were included in this evaluation.

Figure 27. "Left Turn" Pavement Marking Symbols.

12 foot 20 foot 36 foot

Figure 28. "Left and Through" Pavement Marking Symbols.

Table 28 identifies the average legibility distance for each set of arrows evaluated. To further identify how the size impacted the available viewing time of each arrow, researchers compared the different sizes to identify the benefits of changing size. This information is included in Table 29.

Table 28. Average Arrow Legibility Distances.

Marking Description	Legibility Distance		
	12' (ft)	20' (ft)	36' (ft)
	197	105	269
	206	169	223

Note: Sizes given are for the left-turn portion of the arrow, the thru portion will add height to the overall pavement marking.

Table 29. Comparison of Arrow Legibility Distances.

Shields Compared		Difference between Shields	
Symbol 1 (S1)	Symbol 2 (S2)	Legibility Distance(ft) (S1 – S2)	Viewing Time (sec)
 20'	 12'	-92	-1.1
 36'	 12'	72	0.9
 36'	 20'	164	2.0
 20'	 12'	-37	-0.5
 36'	 12'	17	0.2
 36'	 20'	54	0.7

As illustrated in Table 29, there was very little difference between the legibility distances for the different sized arrows in the "left and through" group and these differences were not statistically significant. Furthermore, a practical look at the difference in viewing times achieved by increasing the arrow size shows very little benefit obtained by increasing the size of the "left and through" arrow (less than one second of viewing time). While not shown in Table 29, researchers also identified that for each size evaluated, there was no significant difference between the "left" and "left and through" visibility.

The final set of arrows was the "left turn" arrow. This group had much greater changes in legibility distance. This was most obviously observed when evaluating the 36-ft arrow compared to the 20- and 12-ft arrows with the differences being 164 and 72 ft, respectively. Using a statistical analysis, researchers determined that only the 36-ft versus 20-ft arrow difference was significant using a confidence interval of 95 percent; however, if the confidence interval was widened to 90 percent then the difference between the 36- and 12-ft arrows was statistically significant. More importantly, in looking at practical differences in viewing times, researchers argue that the difference in viewing time of 0.9 seconds between the 12- and 36-ft arrows is a noteworthy increase in the available time for drivers to make lane selection decisions.

One data irregularity identified during this evaluation was the difference between the 12- and 20-ft arrows. The 92-ft difference in legibility distance for these two arrows was statistically significant with the 12-ft arrow's legibility being greater than the 20-ft arrow's. Researchers believe this abnormality may be attributable to an incongruity in the elongation of the 20-ft arrow that researchers observed during a visual field inspection of the pavement markings.

More specifically, in looking at the pictures in Figure 27, it can be seen that the enlargement of the 20- and 36-ft arrows as compared to the 12-ft arrow was not consistent. While the 36-ft arrow was elongated a significant amount in the travel direction (or length) as compared to the width across the lane, the 20-ft arrow was not grown proportionally but was widened excessively as compared to its enlargement in length. Researchers believe that this difference in the parameters used for elongation could be a contributing factor to the inconsistency seen in the data set as it would make it more difficult to distinguish the arrows direction at a distance and lead to shorter legibility distances for the 20-ft arrow.

Summary

In each of the three discussions above regarding the different types of pavement marking symbols, size had a significant impact on legibility distance. However, in all but the text group of pavement markings, there needed to be a significant increase in size to realize this impact (e.g., from 15- to 36-ft highway shields). Given the significant impact this size change would have on the cost of pavement markings for an interchange, researchers are not convinced that larger pavement marking symbols would be justified at most interchange installations. Looking at a practical analysis of this information, Figure 29 shows the changes in viewing time afforded by the different changes in symbol pavement marking size from small (12 or 15 ft) to medium (20 ft) to large (36 ft). In this figure, the information has been grouped by size change proportions (e.g., a change from a small symbol to a large symbol).

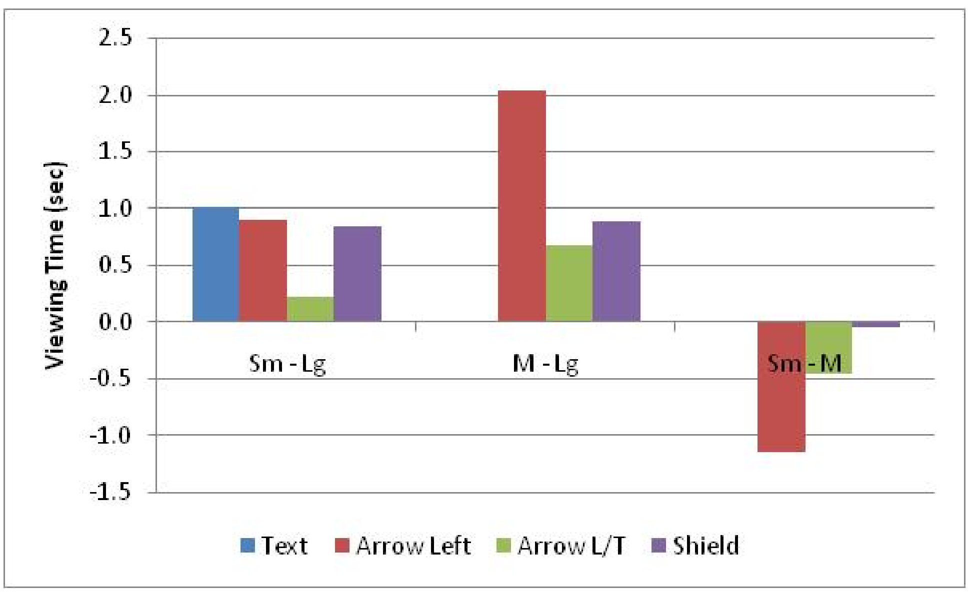


Figure 29. Change in Viewing Time Grouped by Size Change.

This figure illustrates that the changes in viewing time are minimal for most of the size increases (less than one second). The researchers believe this amount of benefit to decision time could also be gained through careful placement of markings further from the decision point instead of increasing the size of pavement markings installed. This is particularly true when markings are placed at locations where high levels of congestion are the normal operating conditions and drivers may not be able to see the marking at a greater distance due to occlusion of the marking by traffic in the lane.

Contrast Border Assessment

The second feature evaluated for the pavement markings was the use of a contrasting black border around a white pavement marking and how the border would affect the legibility distance of that marking when placed on a concrete surface. This study included three different markings both with and without the contrast border: “left turn” 12-ft arrow, “left and through” 12-ft optional lane arrow, and a 15-ft US Highway shield. Figure 30 shows these three sets of pavement markings.

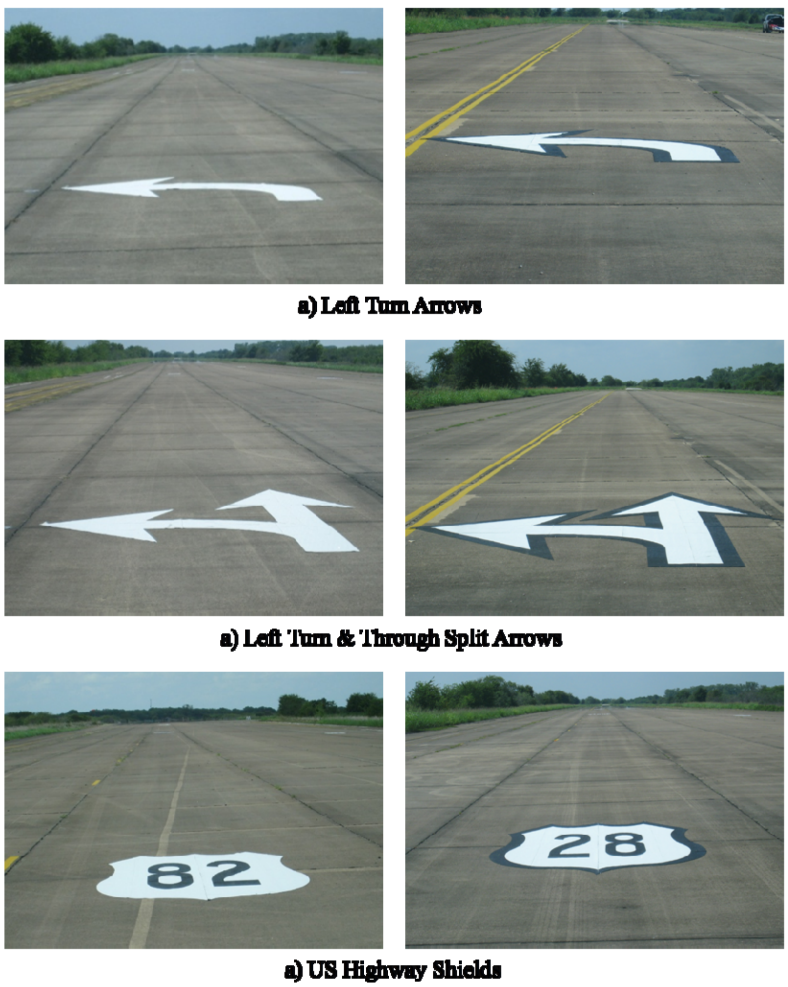


Figure 30. Contrast Border Pavement Markings.

Table 30 shows the legibility distances for each of these markings and identifies the difference in legibility distance achieved through the introduction of a contrast border.

Table 30. Analysis of Legibility Distance for Pavement Markings with Contrast Borders.

Marking Description	Legibility Distance (ft)			Viewing Time Change (sec)
	With Contrast Border	Without Contrast Border	Difference	
 12’	240	198	42	0.5
 12’	183	206	-23	-0.3
 15’	85	53	32	0.4

For all three of the symbols evaluated for the use of contrast borders with white pavement markings, there were no statistical differences in legibility distances for the two conditions (with and without border). Additionally, from a practical standpoint the small values identified for changes in viewing time afforded by the addition of the contrast border (less than 0.5 seconds) did not provide a significant benefit to a driver in terms of decision making. One interesting finding for this data set was that the contrast border on the optional direction arrow actually decreased the legibility distance identified. Researchers believe this negative change may be a product of the two arrow heads bleeding together when the border was added. This is something that must be considered if contrast borders are added to complex shapes such as optional arrows or text.

Researchers note the concrete surface used during this evaluation was not a new concrete pavement and therefore had darkened through use and time. Although the benefits were not significant in this scenario, researchers believe the legibility distances identified in this study for the use of a contrast border may not adequately represent the real-world benefit that could be achieved on newly placed concrete. This issue requires further investigation on a different pavement surface to validate or negate the results obtained during this closed-course evaluation.

CHAPTER 6. FIELD EVALUATION

Freeway interchanges with lane drops, double lane exits with optional lanes, and other unusual geometries violate driver expectations and may result in late lane changes and erratic movements near the gore. In-lane pavement markings have the potential to reiterate the information available on overhead signs, which depicts the upcoming interchange geometry. Receiving this information early on and in multiple ways allows drivers to make better driving decisions and make lane changes further upstream. This has the potential to reduce late lane changes and erratic movements near the gore. Additionally, the human factors studies discussed previously found that drivers prefer to use exit only or through only lanes as opposed to optional lanes. Assuming this is the case in the field, it results in a decreased utilization of available roadway capacity near the gore area. Additional confirmation from in-lane pavement markings that the optional lane can be used for both the exit or through movements could lead to an increased utilization of this lane. As part of this research project, TTI researchers designed and conducted field studies at freeway interchanges to evaluate the operational impacts of the following in-lane pavement marking scenarios:

- the addition of route shields and cardinal directions (e.g., north) where directional arrows and "ONLY" text were already present,
- the addition of route shields where no other in-lane pavement markings existed, and
- the addition of directional arrows where no other in-lane pavement markings existed.

STUDY LOCATIONS

Researchers conducted the field studies at one site in the San Antonio District and two sites in the El Paso District. Site 1 was located in San Antonio at the interchange of I-35S and I-410S on the east side of town. At this interchange, the leftmost lane, considered lane 1, is an exit only lane that goes to I-410S. Lane 2 is the optional lane shared between both freeways. Lanes 3, 4, and 5 on the right continue through to I-35S. Several sets of directional arrows and "ONLY" text were already installed in advance of the interchange, so at this site researchers evaluated the addition of route shields and cardinal directions (which were already being installed by TxDOT).

Site 2 and Site 3 were located in El Paso at the interchange of I-10 and US 54. Site 2 was on I-10E upstream of the US 54 exit. At this site, the three left lanes continue through to I-10E and two right lanes are exit only lanes that go US 54. Site 3 was on US 54W upstream of the I-10E exit. At this site, the two left lanes continue through to US 54W and the two right lanes are exit only lanes that go to I-10E. There were no existing in-lane pavement markings at either of these sites. At Site 2, researchers installed and evaluated route shields, while at Site 3 researchers installed and evaluated directional arrows.

Researchers planned to use data from two additional sites in the San Antonio District; however, data from neither of these sites were ultimately used. At one site, information provided on an overhead guide sign regarding a lane drop further downstream conflicted with the in-lane pavement markings, thus, potentially negatively impacting the results. At the other site, the installation of the in-lane pavement markings was delayed due to construction upstream of the site; thus, researchers were not able to collect "after" data.

DATA COLLECTION

At each site, researchers collected data before and after the installation of the in-lane pavement markings. Table 31 contains a description of each site and the study location, the time periods during which data were collected, and when the markings were installed. The following sections describe in more detail the data collection methodologies at each site.

Table 31. Data Collection Summary.

	Site 1	Site 2	Site 3
Site location	I-35S at I-410S	I-10E at US 54	US54W at I-10E
Site length	~2700 ft	~2900 ft	~2700 ft
Study length	~550 ft	~1200 ft	~1800 ft
Study area	~900 ft to 1450 ft upstream of gore	~1200 ft upstream of gore	~1800 ft upstream of gore
Before period	7/8/08 – 7/11/08	6/29/2009 – 7/2/09	6/29/2009 – 7/2/09
Marking installation	10/12/08	7/6/09 – 7/709	7/8/09
After period	4/23/09 – 4/24/09	7/20/09 – 7/23/09	7/20/09 – 7/23/09

Site 1

Figure 31 and Figure 32 contain the before and after pavement marking plans, respectively, for Site 1. For the before period the only route guidance information provided to motorists included: directional arrows on the pavement, "ONLY" text on the pavement, and overhead guide signs. Upstream of the I-410S exit, motorists passed over four sets of directional arrows and "ONLY" markings before reaching the cantilever overhead sign that indicated that lane 1 (or the inside lane) was an exit only lane to I-410S. Three additional sets of directional arrows and "ONLY" markings were located between the cantilever overhead sign and the overhead sign bridge at the exit ramp. Data for the before period were collected from Tuesday, July 8, 2008, to Friday, July 11, 2008.

Two sets of route shields and cardinal directions were installed in all five lanes on October 12, 2008. One set of shields and cardinal directions was located at the beginning of the study site (approximately 2500 ft upstream of the exit ramp gore). The second set of shields was added approximately 650 ft upstream of the gore. To accommodate the addition of the first set of route shields and cardinal directions, the first set of existing directional arrows and "ONLY" markings were removed and a new set of directional arrows and "ONLY" markings across four lanes was added upstream of the first set of route shields and cardinal directions. Directional arrows and "ONLY" markings were also added in the two through lanes upstream of the second set of route shields and cardinal directions. Data for the after period were collected on Thursday, April 23, 2009, and Friday, April 24, 2009.

Both the before and the after data were collected through use of a traffic monitoring camera at the TransGuide Traffic Management Center (TMC) in San Antonio. The view from the TransGuide camera only included the segment of roadway downstream of the cantilever overhead sign (i.e., the bottom half of each figure).

Site 2

Figure 33 shows the route guidance information provided during the before and after periods at Site 2. In the before period there were only two overhead sign bridges that showed the upcoming lane designations: one located approximately 0.5 mile upstream of the exit ramp and one located at the exit ramp. There were no existing in-lane pavement markings. Data for the before period were collected from Monday, June 29, 2009, to Thursday, July 2, 2009.

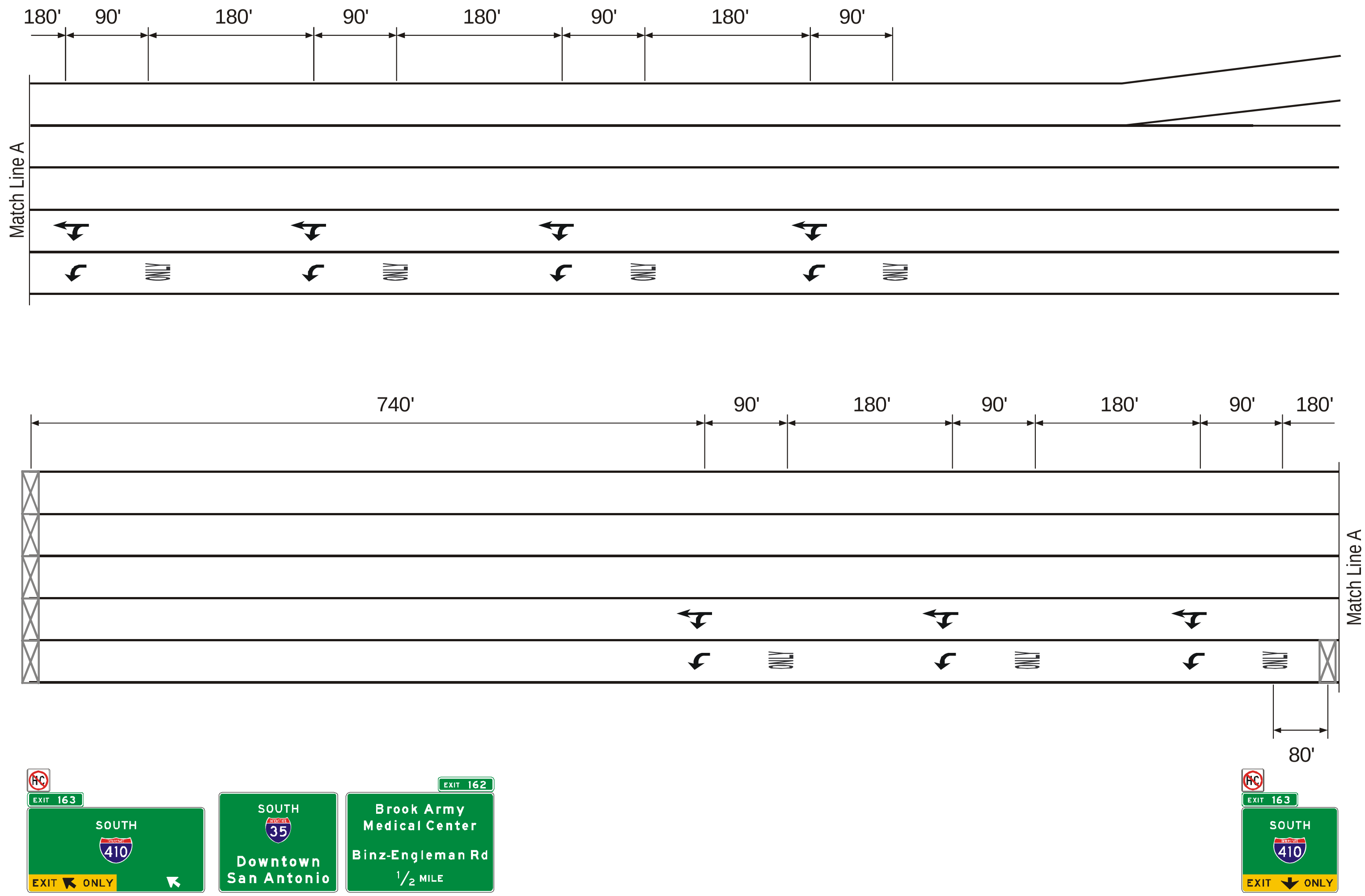


Figure 31. Site 1 Before Conditions.

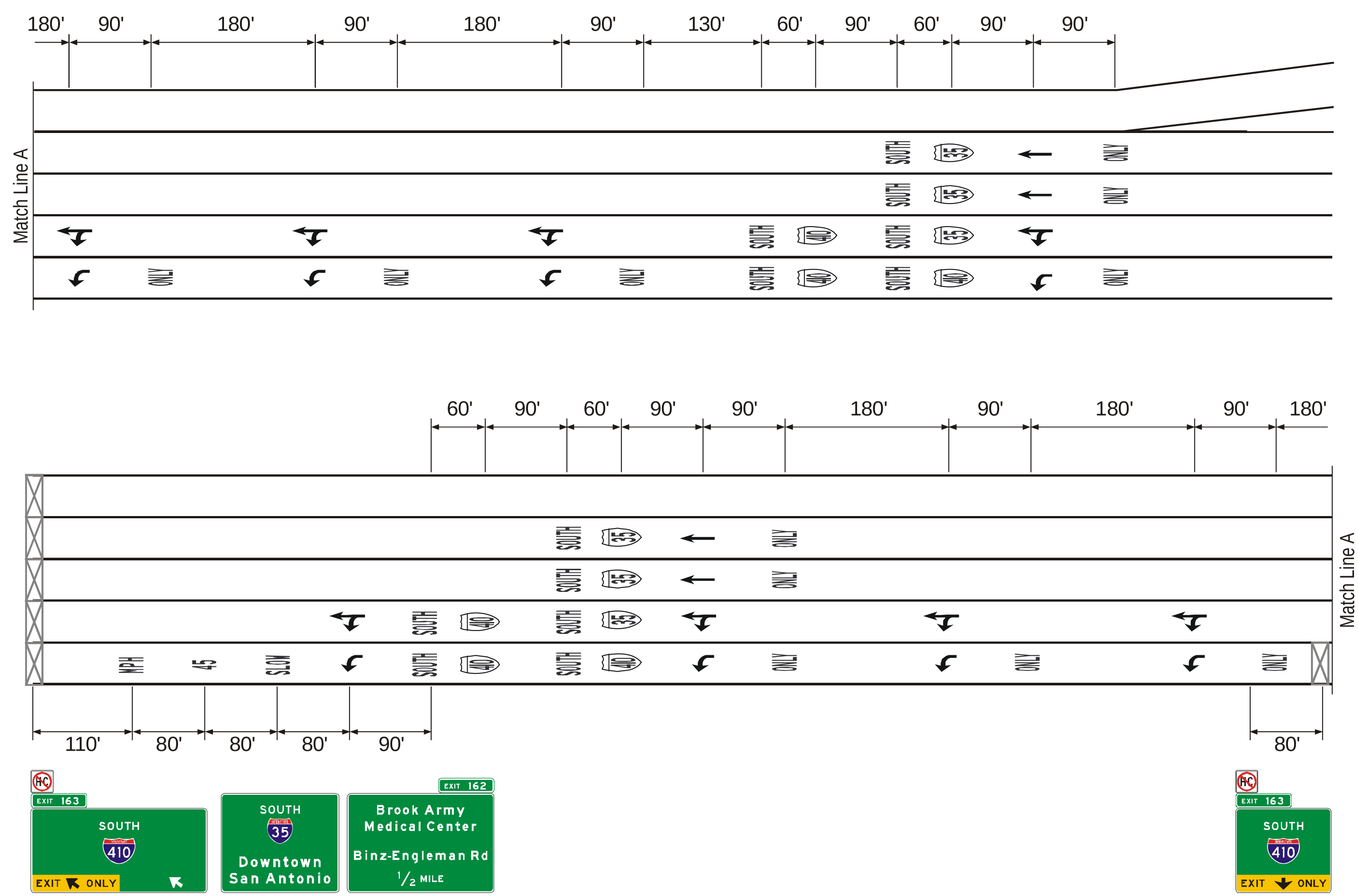


Figure 32. Site 1 After Conditions.

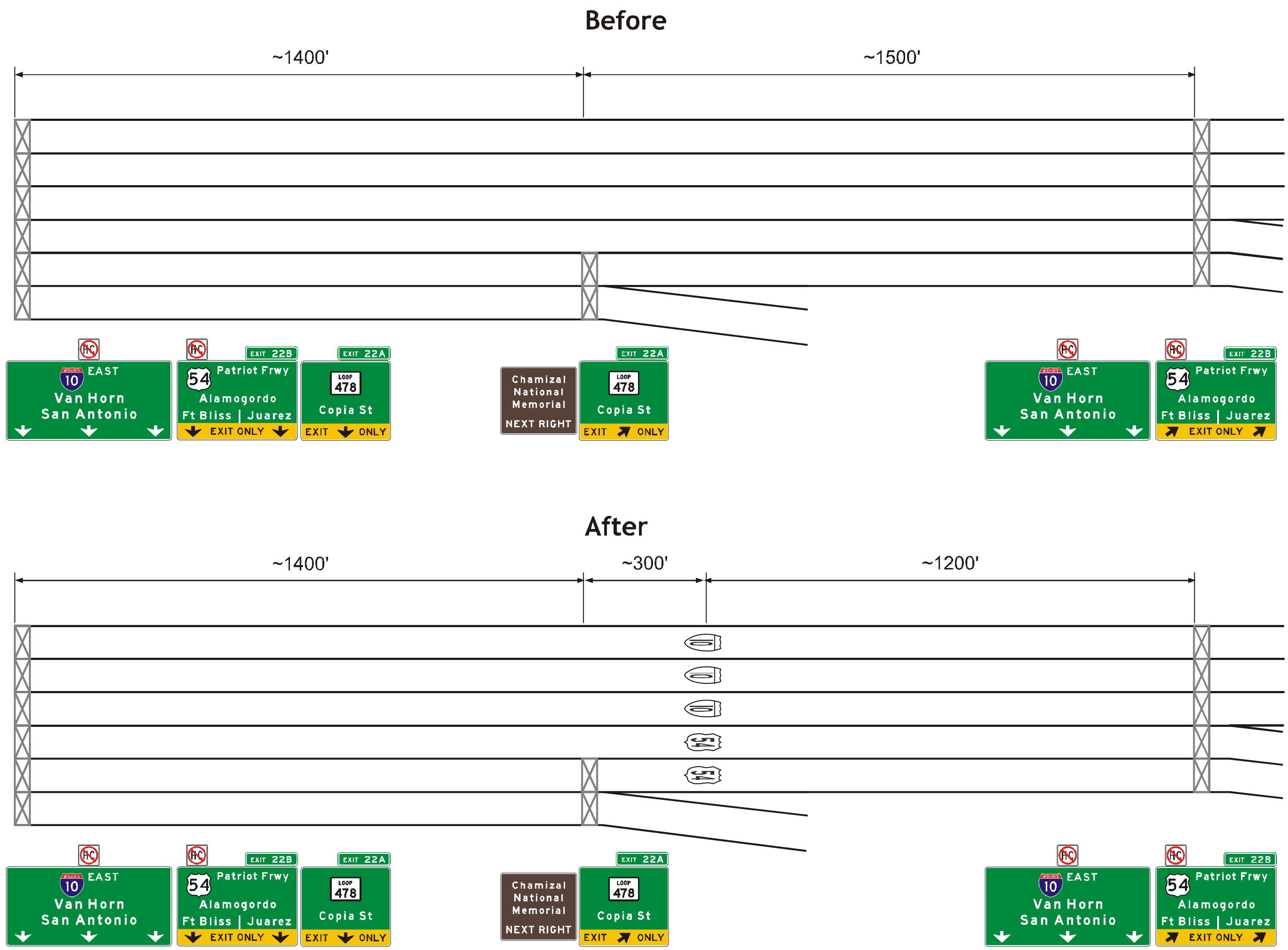


Figure 33. Site 2 Before and After Conditions.

Route shields were installed in all five lanes approximately 1200 ft upstream of the exit ramp gore. While the researchers would have preferred to install the route shields about half way between the two overhead sign bridges, this location would have placed the markings in the immediate vicinity of the Copia Street exit ramp. Due to budget limitations, researchers could not purchase a route shield for the Copia Street exit only lane (i.e., Loop 478); thus, the decision was made to locate the in-lane pavement markings just downstream of the Copia Street exit.

The installation required two nights due to the complex work zone traffic control needed to close multiple lanes on I-10 and the time needed to install the markings and allow them to cure before reopening the travel lanes. On the first night (Monday, July 6, 2009) researchers, TxDOT personnel, and a representative from the manufacturer installed the two US 54 shields and the rightmost I-10 shield. On the second night (Tuesday, July 7, 2009) the remaining two I-10 shields were installed. Figure 34 is a picture of the route shields installed on I-10E. Following an adjustment period to account for any novelty effects, a second set of after data were collected from Monday, July 20, 2009, to Thursday, July 23, 2009.

Figure 34. Route Shields on I-10E in El Paso.

Both the before and the after data were collected through use of a traffic monitoring camera at the TransVista TMC in El Paso. The view from the TransVista camera only included the segment of roadway downstream of the Copia Street exit (i.e., from approximately 300 ft upstream of the route shields to the US 54 exit).

Site 3

Figure 35 shows the route guidance information provided during the before and after periods at Site 3. In the before period there were three overhead sign bridges that showed the upcoming lane designations: one located approximately 0.5 mile upstream of the exit ramp, one located approximately 0.15 mile upstream of the exit ramp, and one located at the exit ramp. There were no existing in-lane pavement markings. Data for the before period were collected from Monday, June 29, 2009, to Thursday, July 2, 2009.

Directional arrows were installed in all four lanes approximately 1800 ft upstream of the exit ramp gore at night on Wednesday, July 8, 2009. This location was about half way between the first two overhead sign bridges. Figure 36 is picture of the route shields installed on US 54W. Following an adjustment period to account for any novelty effects, the after data were collected from Monday, July 20, 2009, to Thursday, July 23, 2009.

Both the before and the after data were collected through use of a traffic monitoring camera at the TransVista TMC in El Paso and the TTI video trailer. The view from the TransVista camera only included the 1000 ft segment of roadway immediately downstream of the directional arrows. The TTI trailer was used to capture video of the remaining roadway segment (approximately 800 ft upstream of the I-10E exit).

DATA REDUCTION AND ANALYSIS

At each study site and for each time period, researchers counted the number of vehicles in each lane entering the study area and the number of lane changes initiated in the study area in 15- minute increments. For the lane change counts, researchers also identified the lane where the lane change was initiated and completed (e.g., vehicle moved from lane 2 to lane 3). A description of the traffic flow (either free flow or congested), the weather conditions, and any other items that might affect the quality of the data (e.g., presence of emergency vehicles, diversion of the cameras, etc.) were noted for each 15- minute time period. Multiple screenings of each video in real time were required to gather all the desired data.

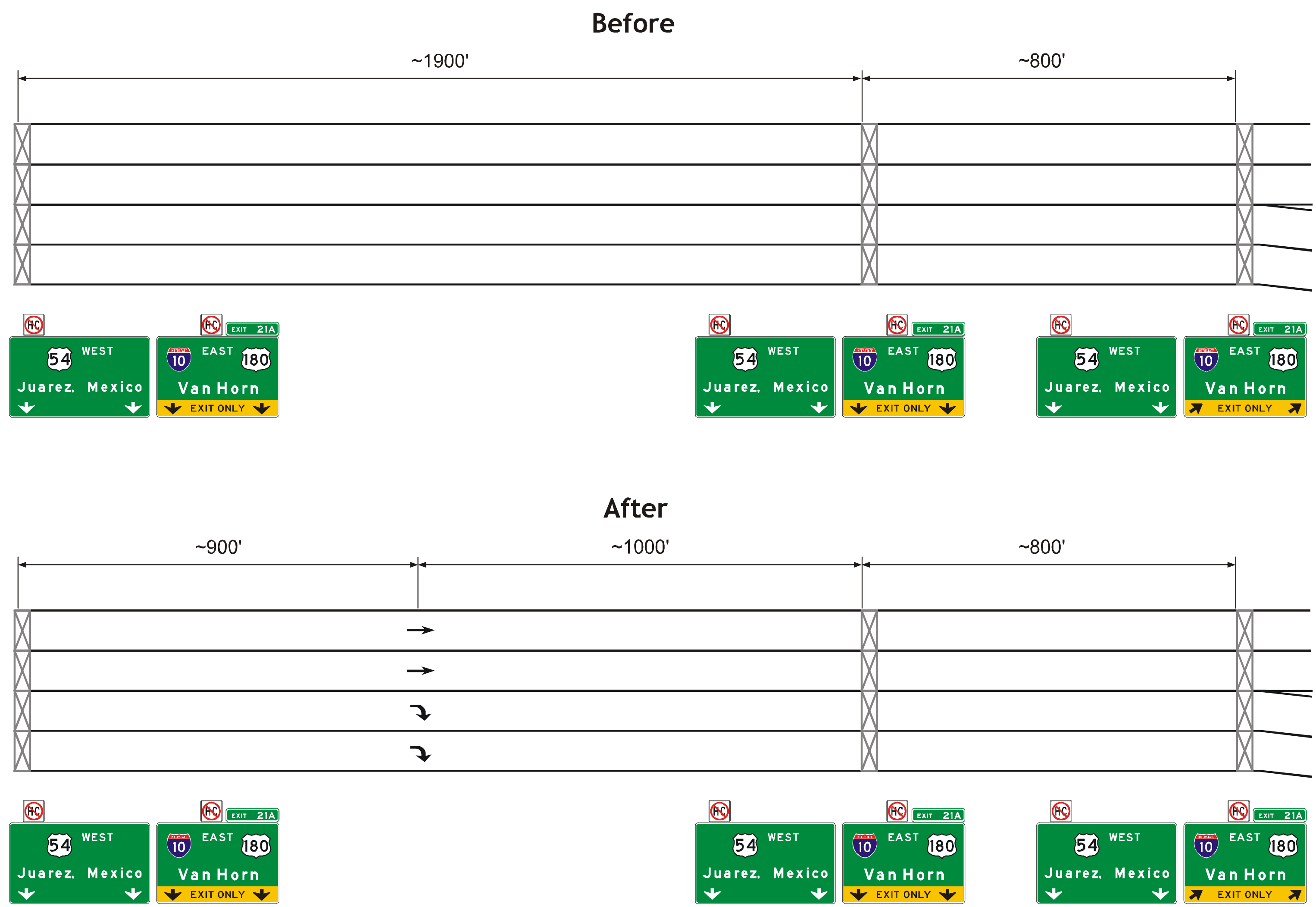


Figure 35. Site 3 Before and After Conditions.

Figure 36. Directional Arrows on US 54W in El Paso.

At Site 2 and Site 3, researchers separated the lane change counts into two sections: 1) from immediately downstream of the in-lane pavement marking to approximately 360 ft upstream of the exit ramp gore and 2) from approximately 360 ft upstream of the exit ramp gore to the exit ramp gore. Researchers considered the later of these to be last minute lane changes. Unfortunately, at Site 1 the camera view in the after period did not allow researchers to accurately count the number of lane changes in the area approximately 900 ft upstream of the exit ramp gore; thus, data in both time periods were only reduced in the area approximately 900 ft to 1450 ft upstream of the exit ramp gore area (or the 550 ft area from the cantilever overhead sign to immediately upstream of the "ONLY" markings in three lanes). A difference between the camera views in the before and after period also occurred among the three camera views at Site 3 resulting in less available video for some segments of the roadway.

Table 32 contains a summary of the data collection and reduction efforts. In total, researchers collected over 250 hours of data at the three sites (over 141 hours of before data and approximately 112 hours of after data). Unfortunately, video had to be removed for several reasons. Obviously, any instances where the cameras were diverted from the interchange were removed. Researchers also removed all data when there was wet pavement or when traffic was congested since these conditions may have hindered the visibility of the in-lane pavement markings. In addition, researchers removed all data during twilight and nighttime conditions because the TMC and TTI cameras did not focus well enough under these conditions to accurately discern the individual lanes and vehicles. Lastly, researchers removed data when emergency (e.g., police) or other vehicles (e.g., stalled vehicle on shoulder) were present in the study area since these vehicles may have changed the traffic flow and distribution of traffic among the travel lanes. Overall, researchers reduced 93 hours of before data and 56 hours of after data. This data set included all weekdays (Monday through Friday) and ranged from 7:00 a.m. to 6:00 p.m.

Table 32. Summary of Data Reduction Efforts.

	Site1	Site 2	Site 3
Before Period Data			
Collected (h:m:s)	50:37:14	45:30:00	45:00:00
Removed (h:m:s)	21:37:14	20:00:00	6:30:00
Reduced (h:m:s)	29:00:00	25:30:00	38:30:00
After Period Data			
Collected (h:m:s)	24:00:00	43:59:57	43:59:57
Removed (h:m:s)	12:00:00	23:14:57	20:44:57
Reduced (h:m:s)	12:00:00	20:45:00	23:15:00

For each 15-minute period within the final data set, researchers computed the total number of vehicles entering the study area. When obtainable, researchers also used the individual lane volume counts and lane change maneuver counts in each 15-minute period to calculate the volume in each lane and the total volume approximately 360 ft upstream of the exit ramp gore. Researchers then computed the lane change rate and unnecessary lane change rate for each section of roadway of interest. Unnecessary lane changes included lane changes out of lane into another lane that went to the same destination and extra lane changes (i.e., initial lane change was needed to change destinations, but the second lane change was not needed). The exact lane change maneuvers included in the unnecessary data set varied by site since the lane designations differed among all three sites. Researchers used tests of equality of proportions to determine whether the measures of effectiveness significantly differed between the before and after periods.

When comparing changes in motorist behavior in a before-and-after study, researchers should investigate potential influences, other than the item being studied (i.e., in-lane pavement markings), to determine whether they affect the results. As discussed previously, researchers removed data when there was wet pavement, when traffic was congested, and when emergency (e.g., police) or other vehicles (e.g., stalled vehicle on shoulder) were present, since these conditions were expected to affect the results. In addition, statistical analyses (α=0.05 or a 95 percent level of confidence) were used to determine if the overall traffic volume did or did not change between the before and after period (Table 33).

Table 33. Comparison of Before and After Freeway Hourly Volumes.

	Before [a]	After [a]	Z Statistic [b]	Change [c]
Site 1	4952	5242	0.91	+6%
Site 2				
7:00 a.m. to 6:00 p.m.	4931	5413	-2.44	+10%
7:00 a.m. to 3:00 p.m.	4833	4855	-0.15	< +1%
Site 3	2039	2012	0.31	-1%

[a] Freeway hourly volumes were measured at the beginning of the study area and represent the average of the 60-minute time periods used in the comparison.
[b] The two means were not considered to be equal if the computed Z statistic was greater than 1.96 or less than -1.96 based on a 95 percent level of confidence (α=0.05).
[c] The difference between the after and before periods divided by the before period.

At Site 1 and Site 3, the analysis showed that there were no differences in the before and after traffic volumes. Surprisingly, the traffic volume at Site 2 was determined to be significantly higher during the after period. Further investigation found that the statistical difference in the volume was only occurring in the time period from 3:00 p.m. to 6:00 p.m. Researchers hypothesized that the before period traffic volumes were lower during this afternoon time period due to a smaller portion of commuter traffic being present. The before period was the week prior to the July 4th holiday, which occurred on a Saturday. Researchers purposefully did not collect data on Friday, July 3; however, it appears that the afternoon traffic patterns were impacted earlier that week as well. To account for the significant difference in traffic volumes at Site 2, researchers decided to only analyze data between 7:00 a.m. and 3:00 p.m. This further reduced the data set for Site 2 (i.e., an additional 12.5 hours of data were removed from the Site 2 "reduced" hours in Table 32). These reductions resulted in researchers using 21.25 hours of before data and 12.5 hours of after data in the Site 2 analysis.

RESULTS

Site 1

Table 34 contains a comparison of the before and after data at Site 1. As discussed previously the camera view in the after period did not allow researchers to accurately count the number of lane changes in the area approximately 900 ft upstream of the exit ramp gore. Thus, researchers could not compute the lane distribution and lane change rates for the segment of roadway nearest the gore. The entire study area was from approximately 900 ft to 1450 ft upstream of the exit ramp gore area and about 1050 ft downstream of the first set of route shields and cardinal directions.

Overall there was a significant change in the percent of traffic in each lane entering the study between the before and after periods. After the installation of the route shields and cardinal directions upstream of the study area, a larger portion of the traffic stream utilized the optional lane (i.e., lane 2). Researchers believe that this increase in the use of lane 2 is an indication that motorists better understood that lane 2 could go to either to I-35S or I-410S after the installation of the new in-lane pavement markings.

In the after period, there was also a significant decrease in the overall lane change rate (from 93.4 to 76.4). Researchers believe that this reduction in lane change maneuvers is an indication that motorists were making lane changes farther upstream (i.e., downstream of the first set of new in-lane pavement markings, but upstream of the study area). While motorists could be waiting longer to make their lane changes (i.e., downstream of the study area closer to the gore), researchers think this is unlikely since there is an evident change in the traffic distribution entering the study area in the after period. Unfortunately, camera views did not allow researchers to verify these conclusions.

Researchers also examined the change in unnecessary lane changes. At Site 1 the following maneuvers were considered to be unnecessary: drivers that moved out of lane 2 into lane 1 or lane 3 (these drivers could have remained in lane 2 to reach either destination) and drivers that moved from lane 1 to lane 3 and vice versa (these drivers could have just moved to lane 2 to reach their destination, but instead they moved over extra lanes). These types of maneuvers reduce the capacity of the roadway and increase the potential for conflicts. As shown in Table 34, the unnecessary lane change rate significantly decreased from 43.9 to 38.2 after the installation of the new in-lane pavement markings. Researchers expect a reduction in these types of maneuvers to improve operations and safety.

Table 34. Comparison of Site 1 Before and After Data.

Measures	1450 ft to 900 ft Upstream of Gore			360 ft Nearest to Gore		
	Before	After	Change	Before	After	Change
Percent of traffic in each lane [a]						
Lane 1	28.6%	26.6%	-2.0%			
Lane 2	34.8%	36.2%	+1.4%			
Lane 3	36.6%	37.2%	+0.6%			
Chi-Square Test Results	Distributions are significantly different [b]					
Lane change rate (per 1000 vehicles & 1000 ft) [c]						
Total	93.4	76.4	-17.0			
Z Test of Proportions Results	Proportions are significantly different [d]					
Unnecessary lane change rate (per 1000 vehicles & 1000 ft) [e]						
Total	43.9	38.2	-5.7			
Z Test of Proportions Results	Proportions are significantly different [f]					

Shaded region indicates that data could not be reduced and analyzed.
[a] Lane distribution was measured at the beginning of each segment.
[b] $X^2 = 66.290 > X^2_{Crit\ (2,\ 0.05)} = 5.991$.
[c] Lane changes initiated within the each segment. Rates determined by dividing the number of lane changes by the number of vehicles entering the segment and by 550 ft (segment length), then multiplying by 1000 ft and 1000 vehicles.
[d] $Z = 7.57 > Z_{(0.025)} = 1.96$.
[e] Unnecessary lane changes were defined as lane changes from lane 1 to lane 3, from lane 3 to lane 1, from lane 2 to lane 1, and from lane 2 to lane 3. Rates determined by dividing the number of lane changes by the number of vehicles entering the segment and by 550 ft (segment length), then multiplying by 1000 ft and 1000 vehicles.
[f] $Z = 3.63 > Z_{(0.025)} = 1.96$.

The volumes and lane change maneuvers for lanes 4 and 5 were not considered since the primary lanes of interest were lane 2 (the optional lane) and the two adjacent lanes (lane 1 and lane 3). Although some vehicles did move from either of these lanes into the lanes of interest, the proportion of drivers making these movements was extremely small and thus not included in the data analysis.

Site 2

Table 35 contains a comparison of the before and after data at Site 2. At Site 2, route shields were installed in all five lanes approximately 1200 ft upstream of the exit ramp gore. The study area included the segment of roadway immediately downstream of the in-lane pavement markings to the exit ramp gore. Researchers divided the study area into two roadway segments: one from 1240 ft to 360 ft upstream of the gore and the second from 360 ft upstream of the gore to the gore.

Overall there was a significant change in the percent of traffic in each lane entering the study and in the roadway section 360 ft nearest the gore between the before and after periods. After the installation of the route shields, a larger portion of the traffic stream utilized lane 4 (i.e., the inside exit only lane to US 54). Researchers believe that this increase in the use of lane 4 is an indication that motorists better understood that lane 4 (not just lane 5) could go to US 54 after the installation of the route shields.

As expected the lane change rate significantly increased (from 138.9 to 145.3) in the section of roadway immediately downstream of the route shield markings (from 1240 ft to 360 ft upstream of the gore) and significantly decreased (from 35.0 to 26.5) in the section of roadway immediately upstream of the gore (360 ft). Researchers believe that these data indicate motorists were making lane changes farther upstream of the exit after the installation of the route shield in-lane pavement markings. In addition, the unnecessary lane change rate in both roadway sections significantly decreased after the installation of the shields. Again, researchers expect a reduction in these types of maneuvers to improve operations and safety.

Site 3

Table 36 contains a comparison of the before and after data at Site 3. At Site 3, directional arrows were installed in all five lanes approximately 1800 ft upstream of the exit ramp gore. The study area included the segment of roadway approximately 375 ft downstream of the in-lane pavement markings to the exit ramp gore. Researchers divided the study area into two roadway segments: one from 1425 ft to 360 ft upstream of the gore and the second from 360 ft upstream of the gore to the gore. Unfortunately, due to a difference between the camera views in the before and after periods researchers had to remove some of the lane change maneuver data. Thus, researchers could not compute the traffic distribution entering the area 360 ft nearest the gore.

Table 35. Comparison of Site 2 Before and After Data.

Measures	1240 ft to 360 ft Upstream of Gore			360 ft Nearest to Gore		
	Before	**After**	**Change**	**Before**	**After**	**Change**
Percent of traffic in each lane [a]						
Lane 1	22.6%	22.1%	-0.5%	23.4%	23.2%	-0.2%
Lane 2	26.3%	24.9%	-1.4%	28.0%	26.9%	-1.1%
Lane 3	25.5%	25.1%	-0.4%	28.3%	27.4%	-0.9%
Lane 4	12.8%	15.3%	+2.5%	8.6%	11.0%	+2.4%
Lane 5	12.8%	12.6%	-0.2%	11.7%	11.5%	-0.2%
Chi-Square Test Results	Distributions are significantly different [b]			Distributions are significantly different [c]		
Lane change rate (per 1000 vehicles & 1000 ft) [d]						
Total	138.9	145.3	+6.4	35.0	26.5	-8.5
Z Test of Proportions Results	Proportions are significantly different [e]			Proportions are significantly different [f]		
Unnecessary lane change rate (per 1000 vehicles & 1000 ft) [g]						
Total	3.8	2.8	-1.0	0.9	0.3	-0.6
Z Test of Proportions Results	Proportions are significantly different [f]			Proportions are significantly different [g]		

[a] Lane distribution was measured at the beginning of each segment.
[b] $X^2 = 217.849 > X^2_{Crit\,(4,\,0.05)} = 9.488$.
[c] $X^2 = 248.950 > X^2_{Crit\,(4,\,0.05)} = 9.488$.
[d] Lane changes initiated within the each segment. Rates determined by dividing the number of lane changes by the number of vehicles entering the segment and by the segment length (either 880 ft or 360 ft), then multiplying by 1000 ft and 1000 vehicles.
[e] $Z = -3.36 > Z_{(0.025)} = -1.96$.
[f] $Z = 5.66 > Z_{(0.025)} = 1.96$.
[g] Unnecessary lane changes were defined as lane changes from lane 1 to lane 5, from lane 2 to lane 5, from lane 3 to lane 5, from lane 4 to lanes 1 and 2, and from lane 5 to lanes 1 and 2. All of these maneuvers included extra lane changes. Rates determined by dividing the number of lane changes by the number of vehicles entering the segment and by the segment length (either 880 ft or 360 ft), then multiplying by 1000 ft and 1000 vehicles.

Table 36. Comparison of Site 3 Before and After Data.

Measures	1425 ft to 360 ft Upstream of Gore [a]			360 ft Nearest to Gore		
	Before	After	Change	Before	After	Change
Percent of traffic in each lane [b]						
Lane 1	7.5%	7.9%	+0.4%			
Lane 2	23.6%	24.1%	+0.5%			
Lane 3	48.4%	48.4%	0.0%			
Lane 4	20.6%	19.6%	-1.0%			
Chi-Square Test Results	Distributions are significantly different [c]					
Lane change rate (per 1000 vehicles & 1000 ft) [d]						
Total	23.8	20.4	-3.4	29.1	18.0	-11.1
Z Test of Proportions Results	Proportions are significantly different [e]			Proportions are significantly different [f]		
Unnecessary lane change rate (per 1000 vehicles & 1000 ft) [g]						
Total	0.4	0.2	-0.2	0.6	0.4	-0.2
Z Test of Proportions Results	Proportions are significantly different [h]			Proportions are not significantly different [i]		

Shaded region indicates that data could not be reduced and analyzed.

[a] Due to the TTI camera positions, researchers could not view approximately 95 ft of roadway in this section; thus, the actual distance over which data were collected was 970 ft.

[b] Lane distribution was measured at the beginning of each segment.

[c] $X^2 = 22.455 > X^2_{Crit\ (3,\ 0.05)} = 7.815$.

[d] Lane changes initiated within the each segment. Rates determined by dividing the number of lane changes by the number of vehicles entering the segment and by the segment length (either 970 ft or 360 ft), then multiplying by 1000 ft and 1000 vehicles.

[e] $Z = 4.77 > Z_{(0.025)} = 1.96$.

[f] $Z = 7.36 > Z_{(0.025)} = 1.96$.

[g] Unnecessary lane changes were defined as lane changes from lane 1 to lane 4, from lane 2 to lane 4, from lane 3 to lane 1, and from lane 4 to lane 1. Rates determined by dividing the number of lane changes by the number of vehicles entering the segment and by the segment length (either 970 ft or 360 ft), then multiplying by 1000 ft and 1000 vehicles.

[h] $Z = 2.67 > Z_{(0.025)} = 1.96$.

[i] $Z = 0.97 < Z_{(0.025)} = 1.96$.

Overall there was a significant change in the percent of traffic in each lane entering the study between the before and after periods. After the installation of the directional arrows, a smaller portion of the traffic stream utilized lane 4 (i.e., the outside exit only lane to I-10E) and a larger portion used lane 1 and lane 2 (i.e., through lanes on US 54W). An entrance ramp onto US 54 was located approximately 1000 ft upstream of the in-lane pavement markings; thus, a certain portion of the traffic entering US 54 in lane 4 upstream of the study area would be expected to go through on US 54. Researchers believe that the shift in the traffic distribution after the installation of the directional arrows is an indication that motorists better understood that lanes 3 and 4 went to I-10E.

At Site 3 the lane change rate significantly decreased in the section of roadway approximately 375 ft downstream of the directional arrows to 360 ft upstream of the gore and in the section of roadway 360 ft nearest the gore (from 23.8 to 20.4 and from 29.1 to 18.0, respectively). Researchers believe these data indicate motorists made lane changes upstream of the study area after the installation of the directional arrows. While the directional arrows significantly decreased the unnecessary lane change rate in the roadway section 1425 ft to 360 ft upstream of the gore (from 0.4 to 0.2), they did not significantly impact the unnecessary lane changing behavior near the gore.

SUMMARY

TTI researchers designed and conducted field studies at freeway interchanges to evaluate the operational impacts of route shield and directional arrow in-lane pavement markings. The addition of route shields and cardinal directions to the existing directional arrows and "ONLY" text at Site 1 resulted in better utilization of the optional lane. In addition, motorists made lane changes farther upstream of the exit and fewer unnecessary lane changes after the installation of the in-lane pavement markings. Similar positive findings were found at Site 2 where no existing in-lane pavement markings existed and only route shields were installed. While the addition of directional arrows at Site 3 also positively impacted the lane distributions and lane change rate, the effect on the unnecessary lane changes was not as evident. Overall, researchers concluded that the installation of in-lane pavement markings (either route shields or directional arrows) improved the operations, and thus potentially the safety, at the interchanges studied. In addition, there is evidence to suggest that using a combination of route shields and directional arrows may be more beneficial to motorists then using only directional arrows.

CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

Pavement marking technology has advanced to allow for the use of large multi-color symbols to be placed on the pavement as a means of providing drivers with another source of information from which they can make good driving decisions. This project focused on the use of such in-lane pavement markings to provide the driver with lane guidance and warning information near freeway interchanges. More specifically, researchers evaluated the design and application issues that are associated with the use of pavement marking symbols through a series of field and human factors studies.

BASIC RECOMMENDATIONS

Based on the information gained through both the human factors laboratory studies and the field studies, researchers have developed basic recommendations for what information should be placed as in-lane pavement markings near an interchange. More detailed guidelines presented in tabular format with situation examples are included in the Appendix. The following bullets outline the basic recommendations.

- Shields should be used as opposed to text for highway identification.
- Arrow and shield markings should be used in combination.
- Simple single lane exits (particularly traditional right exits) only need pavement marking symbols to be placed in the exit lane.
- If in-lane pavement markings are used at complex interchanges (e.g., optional lanes, multi-lane exits, etc.), they should be applied to all lanes.
- Optional lane symbol pavement markings should provide the same basic information as other lanes at that interchange (i.e., show both highway shields and an option arrow).
- Order of information in the optional lane should be:
    - primary (through traffic) highway shield first and exiting route shield second and
    - arrows preceding the highway route shields.
- Do not stagger lane markings. Install same symbols in a single line.
- The use of cardinal directions should be limited.

- The size of pavement marking symbols recommended for standard freeway interchanges are:
    - shields 15-ft long and
    - arrows 12-ft long.
- Contrast borders on pavement marking symbols are not required.
- Markings should be placed after motorist has passed at least one overhead guide sign for the interchange. Thereby this is a reinforcement of the information from the sign and not the primary information source.
- The in-lane pavement marking symbols should be placed far enough upstream of the decision point that it allows a motorist to safely change lanes based on the information provided.

DISCUSSION OF GUIDELINES

Guidelines for the application of in-lane pavement markings symbols are important for many reasons. First, the standardization of information to be placed helps a driver with regard to expectations while driving. Additionally, creating a set of guidelines for what information should be used at an interchange ensures that drivers are receiving the best possible benefit from this information. Lastly, this information can help engineers in decision making when faced with installation of these types of markings at a new interchange. All of these points led researchers to create guidelines aimed at answering the following questions.

- Should in-lane pavement markings be installed at this interchange?
- What information should the in-lane pavement markings provide?
- In what sequence should this information appear?
- Where should the in-lane pavement markings be placed in the interchange area?

The guidelines provided from this project are contained in the Appendix. The information behind these guidelines includes both the recommendations gained from all of the studies conducted during this project and rules-of-thumb based on engineering judgment and experience. The guidelines provide not only the basic direction of what should be done in relation to placing pavement marking symbols at an interchange, but also provide examples in many cases to help illustrate the point.

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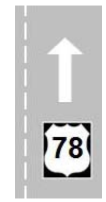
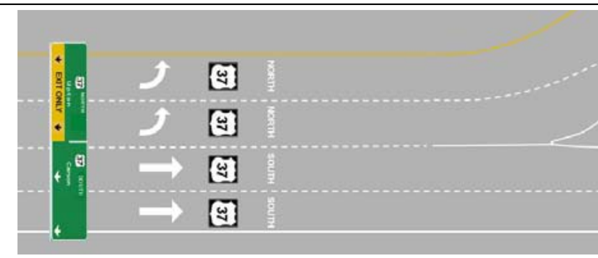
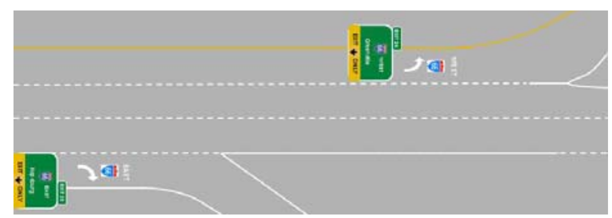
APPENDIX

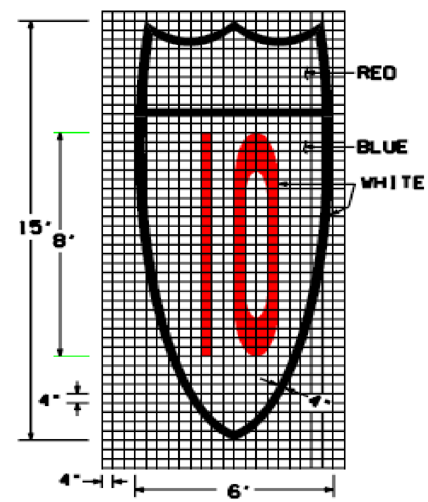
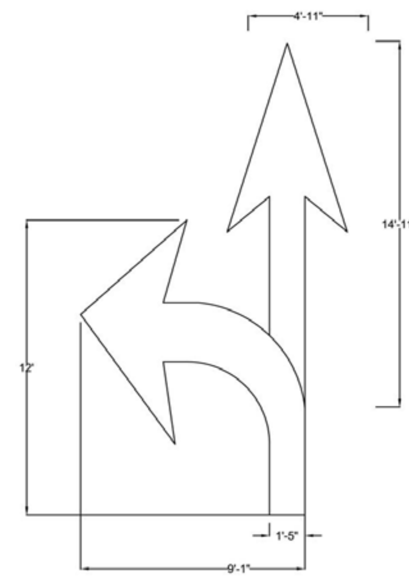
Guidelines for the Use of In-Lane Pavement Markings Symbols

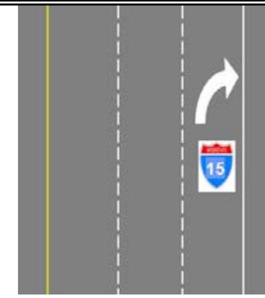
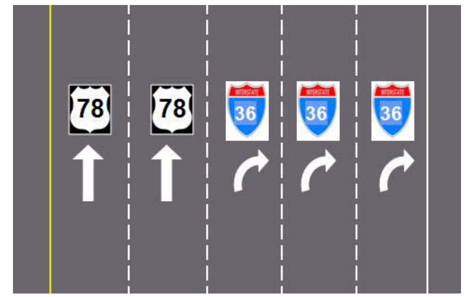
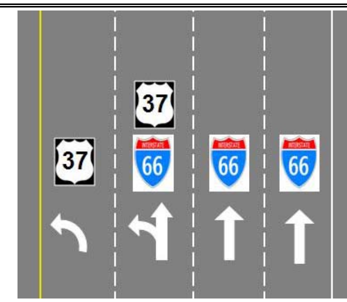
Site Selection Criteria

Topic	General Guidance	Further Details	Example
Crash Analysis	Analysis of crash history to determine if late lane changing could be a problem at the interchange.	• High number of crashes at the gore • Crash attenuator hit frequently • Is there a positive benefit/cost ratio for installation based on these costs?	Could be based on a benefit/cost analysis of the comparative cost to replace a crash attenuator versus buying in-lane pavement markings.
Volume and LOS	Is there underutilization of the option lane?	When unsure of the lane use assignments, drivers will be less likely to use these lanes.	
	Is there underutilization or adjacent lanes leading to different destinations?		
	Is there unexpected or unexplained congestion at an interchange?	Underutilization of a specific lane or excess lane changing maneuvers could cause congestion in an area not expected from volume/capacity analyses.	
Public Feedback	Public calls about a specific interchange area.	Public may comment on: • lack of information or signs • confusing lane assignment • unexpected geometry	

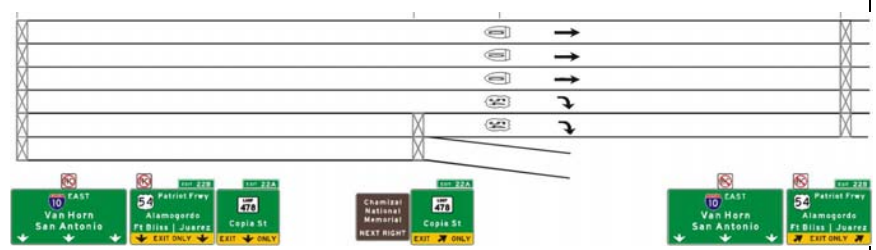
Symbol Design Criteria

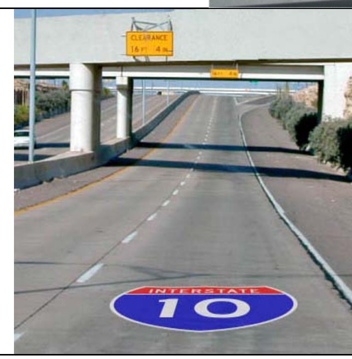
Topic	General Guidance	Further Details	Example
Markings Selection	Shields should be used as opposed to text.	Better target value Equal understanding when legible	
	Shields and arrows should be used in combination.	Order of symbol sequence is not critical. Arrows may be placed either before or after shield.	 or 
	Direction Text (i.e., North, South, East, West) should be used only when critical to lane selection options.	At a single location the same highway designation (e.g., US-37) splits in two different directions and motorists must select appropriate lanes in the interchange area. A single highway designation (e.g., I-35) exits at two separate locations (i.e., North traffic exits a significant distance before South traffic).	 

Topic	General Guidance	Further Details	Example
Marking Size	Shields 15-ft long Arrows 12-ft long	Contrast borders are not required for all installations. Shield width will be approximately 6 ft, but will depend on the numerals in the highway route number. Arrow width is approximately: • Turn ~ 9 ft • Straight ~ 5 ft	 

Topic	General Guidance	Further Details	Example
Simple One Lane Exit	Put in-lane markings only in the exit lane.	This is particularly true for right exits.	
Complex Interchanges	In-lane pavement markings should be applied in all lanes.	Examples of complex interchanges: • Left exit • Multi-lane exits • Optional lanes	
	Optional lanes should be marked with the same basic information as other lanes at the interchange.	Optional lanes information: 1st – Optional (or split) arrow (before the shields) 2nd – Primary highway shield 3rd – Exiting highway shield	

Installation Criteria

Topic	General Guidance	Further Details	Example
Location along Road Section	Markings should be placed after motorist has passed at least one overhead guide sign for the interchange.	The symbols are reinforcement of the information from the guide sign and not the primary information source.	
Location within Lane	Do not stagger lane markings.	Install similar symbols in a single line.	
	Align symbol in center of lane.	This will keep the in-lane markings out of wheel paths as much as possible.	

Topic	General Guidance	Further Details	Example
Placement Tips	Not on a downhill slope.	Limits the visibility distance because of the curvature.	Example of Uphill Improved View: 
	Not under a bridge or other object that will cast a shadow on the highway.	This placement would obscure visibility of the markings.	 Example: Marking is placed before the shadows being cast by the overhead bridge deck.
	Not immediately under the sign bridges.	If markings are in the same location as the signs they do not have the effect of giving the information a second time.	
	Not so near a decision point that it does not allow for safe lane changes.	To make the information useful to a driver they need to have time (and distance) to react to the pavement markings.	