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16. Abstract

This report documents the results of laboratory studies to assess motorist interpretations of the following symbols used or initially seen as potential freeway lane control signals: red X, yellow X, green downward arrow, yellow downward diagonal arrow, yellow downward arrow, circle-slash (i.e., the universal "do not" symbol), and a red X superimposed on a green arrow. The effects of flashing the red X, green arrow, and yellow arrows upon motorist interpretations were also evaluated.

Results indicate that the red X and green arrow are well understood and convey a clear, consistent meaning to drivers. Also, the yellow diagonal arrow conveys a clear, consistent message to exit a lane. The yellow X and downward arrow elicited a wide range of interpretations by motorists, and these interpretations change depending on what other LCS symbols are present in an overall LCS array at a location. Flashing displays were not found to significantly affect motorist interpretations.

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DRIVER INTERPRETATIONS OF EXISTING AND POTENTIAL LANE CONTROL SIGNAL SYMBOLS FOR FREEWAY TRAFFIC MANAGEMENT

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Research Report 1298-1
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The Texas A&M University System
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November 1993

IMPLEMENTATION STATEMENT

The results of the laboratory studies reported herein provide valuable insight into motorist perceptions and possible behavior in response to LCS systems for freeway traffic management. With respect to specific recommendations from the laboratory studies, field experimentation with the yellow diagonal arrow appears to be warranted at this time. The diagonal arrow provides a more consistent interpretation of the action desired from motorists relative to a yellow X, and its use in lieu of the yellow X needs to be explored in greater detail. The practical implications of implementing a yellow diagonal arrow on a freeway facility containing more than two or three lanes per direction were not addressed in this research. Additional work is needed to explore these and other practical ramifications of a diagonal arrow versus a yellow X before a definite change can be recommended.

Also, the results of the studies suggest that motorists in Ft. Worth have, as a group, a better understanding of the definitions and purposes of LCS. Although not verified directly as part of this research, it is hypothesized that the educational efforts of TxDOT District officials via the changeable message signs have been successful. This would suggest that motorists can be taught the meaning of LCS and that educational efforts by the Department may be quite beneficial to motorists as the LCS components of the freeway traffic management systems throughout Texas are brought on line. This education will be particularly important if an attempt is made to utilize a downward yellow arrow as a cautionary symbol on freeway LCS arrays.

DISCLAIMER

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 views or policies of the Texas Department of Transportation (TxDOT) or the Federal Highway Administration (FHWA). This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. Mr. Gerald L. Ullman (Texas P.E. registration #66876) was the engineer in charge of the study.

ACKNOWLEDGEMENT

This study was conducted in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration. The laboratory studies reported upon herein were conducted primarily at Department of Public Safety (DPS) driver licensing stations in Houston, Ft. Worth, and San Antonio, Texas. The authors would like to thank the many DPS officers from these locations who cooperated and assisted in this research effort. Mr. Ray Derr, P.E., of the Texas Department of Transportation served as Technical Panel chairman of this study; his contributions throughout the study are also gratefully acknowledged. The authors also wish to thank Dr. R. Dale Huchingson of the Texas Transportation Institute (TTI) for lending valuable human factors expertise to the study. The authors appreciate the statistical expertise that was provided by Drs. Olga Pendelton and Edward Miller of TTI. Finally, the authors are grateful to Mr. Stephen Ranft and Ms. Elizabeth Crowe, P.E. of TTI for their help in conducting the laboratory studies.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SUMMARY

Four laboratory studies were conducted to investigate how motorists interpret existing and proposed symbols for freeway LCS systems. Efforts were made to explore the role of other symbols in an overall LCS array upon interpretations of a given symbol, and whether that interpretation changed depending upon its mode of presentation (i.e., steady versus flashing displays). The findings from these laboratory studies are consolidated below.

Interpretation of *MUTCD* Symbols For Freeway LCS

The *MUTCD* currently allows three symbols to be used for freeway traffic management purposes: (1) a green downward arrow to indicate a lane is open and that travel is permitted, (2) a yellow X to indicate that a lane is about to be closed and that motorists should begin to vacate the lane, and (3) a red X to indicate that a lane is closed and that travel in that lane is prohibited. The results of the laboratory studies support the use of both the green arrow and the red X for these purposes. Nearly all subjects participating in the studies correctly interpreted the green arrow, and over 80 percent of subjects correctly interpreted the red X. Data collected in these studies also indicate that the red X is viewed as requiring a reaction by motorists (to exit the lane) within 0.10 mi. (0.16 km.) after it is displayed.

Interpretations of both the green arrow and the red X were not affected by the presence of other symbols in an overall LCS array at a location, and were fairly consistent across three different study locations statewide (Ft. Worth, Houston, and San Antonio). A slightly greater percentage of correct interpretations of the red X was noted from Ft. Worth subjects. This was assumed to be due to the ongoing display of LCS symbol definitions by TxDOT District officials on the changeable message signs along the I-35W corridor.

Whereas the green arrow and red X generate a common and consistent interpretation among Texas motorists, the yellow X was found to elicit widely varying responses depending on the context in which it was used. When displayed in conjunction with green arrows only in an LCS array, motorist interpretations of the yellow X are more

consistent with its intended meaning of an impending lane closure and the need to vacate the lane. When presented in conjunction with a red X, however, motorists appear less likely to associate a yellow X with an impending lane closure and the need to exit the lane. Rather, they are likely to believe that the symbol indicates congestion or other hazards in the lane downstream for which they simply need to slow down and be careful.

Potential of a Yellow Downward Diagonal Arrow to Replace the Yellow X

Interpretations of a yellow downward diagonal arrow were investigated in laboratory studies for use in place of the yellow X as a potential transition LCS (given the lack of a common and consistent interpretation of the yellow X by motorists). The studies showed that this symbol provides a clear message about the proper action to take as a driver in that lane (i.e., to exit the lane in the direction of the arrow). The message to exit the lane is maintained regardless of whether or not a red X is present in the LCS array or of the direction that the arrow is pointing. However, the diagonal arrow does not automatically indicate to motorists exactly why they need to vacate a lane; the responses obtained for the lane condition implied by the diagonal arrow were as varied as those for the yellow X. The yellow X does appear to be interpreted by motorists as requiring action more quickly than a diagonal arrow, when displayed with green arrows only. When displayed in conjunction with a red X and a green arrow, the yellow X and diagonal arrow elicited the same estimate of urgency from the subjects.

Potential of a Yellow Downward Arrow as a Cautionary Symbol in Freeway LCS Systems

Another non-standard symbol examined in the laboratory studies was a yellow downward arrow. This symbol was considered to be a candidate for indicating to motorists that they should take added caution when travelling in that lane, but that it is not necessary for them to exit the lane (a symbol for this purpose does not currently exist in the *MUTCD*). Study results showed that the downward arrow suffered from the same lack of a consistent and common meaning as the yellow X. The interpretation also varied depending on whether or not there were red X's in the LCS array. In terms of the drivers proper reaction to this symbol, motorists appear divided as to whether to stay in the lane

but slow down or to exit the lane as long as another lane is available (i.e., a green arrow is in the LCS array). If the LCS array contains only yellow downward arrows and red X's, almost all motorists recognize that they should remain in the lane under the arrow (but are divided as to whether it is important for them to slow down and be careful). It appears that any attempt to utilize this symbol for freeway LCS will require an extensive driver education effort prior to implementation. Even then, it may be difficult to predict how motorists will interpret the symbol in unusual or complex LCS arrays.

Potential of Flashing LCS Symbols

The effect of flashing various LCS symbols upon motorist interpretations were explored in the laboratory studies. The results indicated that flashing has no significant effect upon motorist interpretations of the yellow diagonal arrow or the red X. Conversely, motorists were confused by a flashing green arrow. Whereas they assumed that it represented a non-normal condition, it was not immediately clear to them whether they should exit the lane, slow down, exit the freeway, etc. Flashing the yellow downward arrow had little effect upon motorist interpretations at two of the study locations, but did result in different interpretations from Houston motorists. This anomaly was attributed to the fact that the transit agency in Houston displays a flashing yellow downward arrow at merge and diverge points on its transitways. Some of these occur at slip ramps between the transitway and the adjacent freeway lanes. Motorists in Houston tended to associate the flashing yellow arrow with the need to exit the lane, which would be consistent with how it is applied at these transitway slip ramps.

1. INTRODUCTION

Most transportation agencies recognize that urban traffic congestion cannot be overcome strictly through additional roadway construction. Rather, ways must be found to make more effective use of the roadway capacity that is already available. One way many agencies are making better use of available freeway capacity is through the implementation of computerized traffic management systems. These systems have existed in some form since the 1960s on freeways in Chicago, Los Angeles, and Detroit. Congestion levels in other cities have reached the point that many agencies are now pursuing systems of their own. The recent thrust of Intelligent Highway Vehicle Systems (IVHS) nationwide has provided many jurisdictions with the political impetus, research and development, and funding capabilities necessary to obtain these systems.

Traffic management systems involve both the collection of real-time traffic data and the control and management of that traffic. Traffic data collection is accomplished with inductive loop detection, closed-circuit television, or other means. Similarly, traffic management and control is accomplished with ramp metering, incident response programs, signal timing adjustments on adjacent surface streets, and real-time motorist information systems to warn motorists about downstream conditions and/or advise them how to alter their travel routes. This information can be disseminated through various mechanisms, including changeable message signs, highway advisory radio, and overhead lane control signals.

Lane control signals (LCS) have been or are being installed on freeways in several major metropolitan areas in Texas. The purpose of these signals is to symbolically portray the current status of each freeway lane. LCS have been in existence for over 30 years. Historically, the most prevalent use of LCS has been for the operation of reversible lanes (as shown in Figure 1-1). However, the Manual of Uniform Traffic Control Devices (MUTCD) (1) does allow LCS on freeways when it is desirable to keep traffic out of certain lanes at certain hours, to indicate that a lane ends at the terminus of a freeway or to indicate that a lane is temporarily blocked by an accident, stalled vehicle, etc. (see Figure 1-2).

Figure 1-1. Lane Control Signals on High-Occupancy Reversible Lanes in Houston.

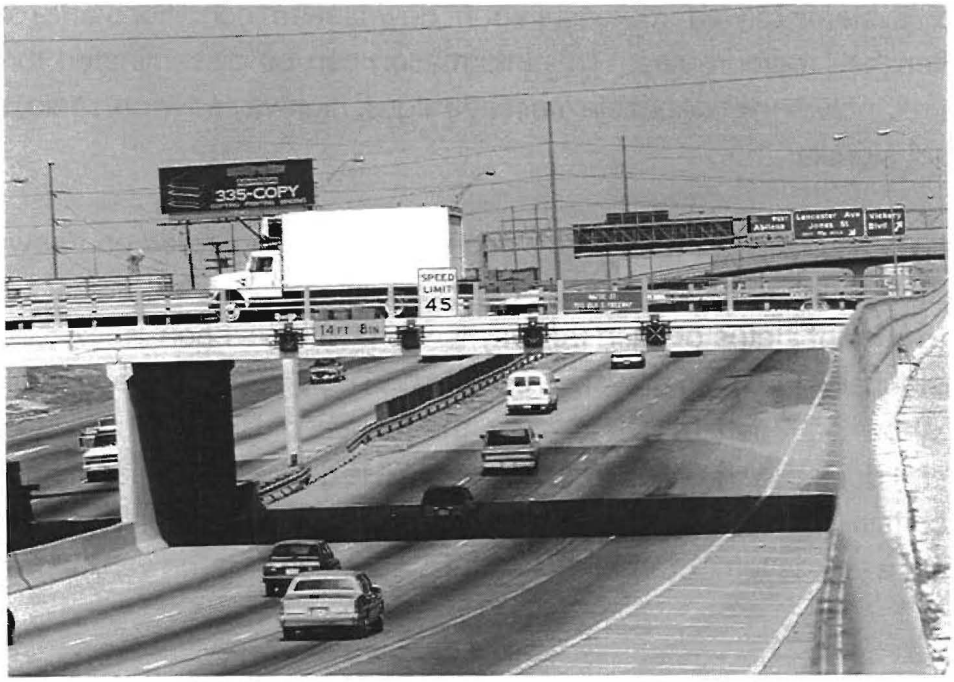

Figure 1-2. Freeway Lane Control Signals on I-35W in Ft. Worth.

Currently, the MUTCD allows the use of four LCS symbol displays:

- A downward green arrow -- to indicate that the lane is open and that a driver is permitted to drive in the lane over which the arrow is located,

- A steady yellow X -- to indicate to a driver that he or she should prepare to vacate the lane because a signal change is being made to a red X (similar to the use of yellow indications at intersection traffic signals),

- A flashing yellow X -- to indicate that a driver is permitted to use the lane over which the signal is located for a left turn (applicable to arterial streets only), and

- A red X -- to indicate that the lane over which it is displayed is closed to that direction of traffic, and that a driver shall not drive in that lane.

However, other LCS symbols are being used in unique ways on some Texas roadways. In Houston, for example, the Harris County Toll Authority utilizes a flashing green arrow at toll plazas to indicate that a specific booth is for vehicles having exact change. Meanwhile, the Harris County Metropolitan Transit Authority uses a flashing downward yellow arrow at selected merge points on its barrier-separated transitway to indicate the need for caution and slower speed.

Many questions remain unanswered regarding the design, installation, and operation of LCS in freeway driving environments. A variety of different LCS hardware technologies, symbol displays, light intensities, and color combinations are available, but little objective data has been collected to determine which are most appropriate for freeway conditions and which will be most readily recognized, understood, and responded to by drivers. Furthermore, the interrelationships between roadway geometrics, traffic conditions, LCS installations, and driver responses have also not been examined to any degree. In response to these needs, the Texas Department of Transportation and the Federal Highway Administration sponsored research by the Texas Transportation Institute to improve guidelines regarding the design, installation, and operation of freeway lane control signals.

Overview of the Report

This report summarizes the results of several laboratory studies conducted to determine motorist interpretations of existing LCS symbols in a freeway-type driving environment, and interpretations of several candidate symbols not currently in the MUTCD but which have potential application for use in freeway LCS systems. The report consists of eight chapters. Chapter 2 summarizes the literature relevant to the design and operation of LCS. Chapter 3 presents the overall research approach taken in the laboratory studies and the objectives identified for each of four studies that were conducted. The experimental procedures and results of these four studies are then documented in Chapters 4 through 7. The report concludes with Chapter 8, which summarizes the study findings and presents recommendations for implementation.

2. BACKGROUND

Laboratory Studies of Lane Control Signal Symbol Interpretation

Previous human factors research regarding motorist comprehension of LCS has not been extensive. One study was performed by Forbes et al. (2) over 30 years ago. Various LCS symbols were tested to indicate a need to exit a given lane or to indicate that a given lane could be used for travel:

- Red, yellow, and green balls (as seen in traffic signals indications);
- Red and yellow Xs;
- Red and green arrows (pointed either up or down); and
- A red diagonal slash superimposed on a green arrow .

Based on the results of their studies, the researchers concluded that a red X was most often associated with an interpretation to not drive in that lane (63 percent) and least often associated with an undesirable interpretation to stop in the lane (5 percent). Meanwhile, a green upward arrow was interpreted as indicating a lane was available for travel by almost all (93 percent) subjects. However, it appeared that the results were dependent upon the experimental method used to assess interpretation. Specifically, an "open response" format (where motorists are not given predefined choices to choose from) resulted in more undesired interpretations (i.e., to stop in the lane) of the red X and several of the other symbols. Whereas only 5 percent of the subjects selected a "stop" response from a list of potential responses, the "stop" response was given by 37 percent of the subjects when they had to determine their own interpretation of the red X. It is important to note that at the time of the Forbes study, the color red had not yet been adopted as the standard color for "stop" or "do not enter" (wrong way) indications. However, red and green balls were being used for stop and go indications on traffic signals (3).

Forbes et al. also evaluated motorist interpretations of a yellow X. Overall, they found subject interpretations of the symbol to be quite varied, ranging from "do not drive in the lane" (15 percent of subjects examined) to "warning [use caution] in lane" (48 percent) to "drive slow in lane" (25 percent).

In the 1970s, Dudek et al. conducted human factors research on real-time motorist information systems (4). One topic of research was the potential use of arrows and X's on a trailer-mounted roadside sign to indicate which freeway lanes were closed or blocked and which lanes were open. Interestingly, researchers found that the color of X's and arrows displayed on a sign board did not affect motorist comprehension of which lanes were supposedly closed on the freeway. However, it was a roadside sign that was the topic of study and not freeway LCS displays per se. Placing the LCS directly over each travel lane may provide a better visual anchor of the signals to the lanes.

A simple lane open/lane closed display configuration via green arrows and red Xs (with an optional yellow X displayed when transitioning between them) has proven to be adequate when signalizing reversible lane operations. The objectives and goals of LCS in a freeway driving environment has led researchers to explore other symbol indications that could provide additional information to motorists. For example, a transportation agency may wish to inform drivers that travel in a given lane is possible, but that extra caution should be used.

Carlson and Lari proposed the use of a downward yellow arrow for that purpose on a short section of I-94 in Minneapolis where a freeway LCS system was installed (5). The researchers conducted a short mail-out survey of motorists to determine likely interpretations of the yellow arrow in both a steady and flashing mode. Motorists were also asked about their interpretations of the red X, the steady and the flashing yellow X, and the green arrow. Respondents chose the most correct interpretation of each symbol from a list of four to five candidate answers. Correct responses for the red X and green arrow were said to be "Do not use this lane" and "You may use this lane," respectively. The researchers also proposed that a steady yellow downward arrow ("This lane will be closed shortly [RED X will be displayed]") has a different interpretation than a flashing yellow arrow ("You may use this lane, but should use extra caution"). For purposes of that study, the correct interpretation of the steady and flashing yellow X were said to be identical to those of the respective yellow arrows.

The researchers found that approximately 80 percent of the subjects selected "Do not drive in this lane" as the meaning of the red X, whereas 98 percent selected "You may use this lane" as the meaning of the green downward arrow. These percentages were consistent with the findings of the earlier Forbes study. As Table 2-1 illustrates though,

the responses to the yellow displays were again less consistent. The steady yellow arrow was interpreted most often (84 percent of the time) to mean that the lane could be used, but that extra caution should be taken. Subjects were divided on the meanings of the flashing yellow arrow, the flashing yellow X, and the steady yellow X symbols between being able to use the lane with caution and needing to exit the lane. A sizeable portion of the subject group also indicated they were unsure of the correct meaning of these symbols. It was noted that since all subjects responded to all yellow indications, many may have attempted to provide different answers to each type of symbol and were thus unsure of all but the first symbol considered (which was, coincidently, the steady yellow arrow). Even so, the interpretations selected by researchers as "correct" for any of the yellow indications were not overwhelmingly chosen by the subjects participating in the survey.

TABLE 2-1. SUMMARY OF SUBJECT RESPONSES TO YELLOW DOWN ARROW AND YELLOW X (4)

Response	% of Responses			
	Yellow Down Arrow		Yellow X	
	St	Fl	St	Fl
Do not use this lane	1	1	3	2
You may use this lane, but should use extra caution	84	50	59	36
This lane will be closed shortly (RED X displayed)	9	35	21	40
Do not change lanes	1	0	0	1
Unsure	5	14	17	21

St = steady display
Fl = flashing display

Although not used extensively on freeways in the United States, lane control signals have become an integral part of the freeway-type (i.e. motorway) systems in Canada and Europe. As in the U.S., the red X and green arrow are commonly used to indicate lane closed and lane open conditions. However, the transition from a green arrow to a red X is not accomplished with a yellow X, but with diagonal yellow arrows pointing to the lane where motorists should move.

A search of the literature identified only one study that considered motorist interpretations of the diagonal yellow arrow. It was conducted by Engel et al. for the Ontario Ministry of Transportation (6). Subjects evaluated the legibility and meaning of actual downward and diagonal arrow signal heads of different vendors in an outdoor setting (in a parking lot). The researchers reported that 85 percent correctly interpreted the symbols to mean either move to the left or move to the right, depending on the direction of the arrow. The researchers noted that flashing the different displays did not significantly alter subject comprehension. The sample was limited to forty motorists, and the displays were not evaluated in either an actual or simulated driving perspective. Nevertheless, it did appear that the downward and diagonal yellow arrow symbols were well understood.

Field Evaluations of Freeway LCS

The purpose of LCS on freeways is to inform motorists of the condition of the lanes downstream so that they may take appropriate action, thereby improving both the safety and the operational efficiency of the roadway. This could manifest itself in terms of lower accidents, reduced conflicts and erratic maneuvers, increased flow rates, and less severe speed changes. Limited field studies to date suggest that LCS can have an operational and safety effect under certain conditions. Unfortunately, the database is still quite limited, and the influence of geometrics, traffic characteristics, and LCS control policies upon driver responses to the LCS has not been fully documented.

Red X and green arrow lane control signals were included on the John C. Lodge Freeway in Detroit, Michigan as part of a freeway surveillance and control research effort in the early 1960s. Studies indicated that the red X signals had minimal effect on freeway throughput and lane-changing activity, but did seem to encourage drivers to exit the closed

System (MTCSS) in the Netherlands demonstrated a 16 percent total accident reduction, with an even greater 36 percent reduction in secondary accidents (8). The MTCSS LCS system can display advisory speeds and certain words as well as LCS symbols, so the true effect of LCS alone cannot be determined. Nevertheless, it appears that there are positive benefits to be gained through the implementation of LCS in an overall traffic management system.

Case study analyses of LCS implementation during incidents on the I-94 system in Minneapolis showed that lane volumes were influenced by the display of LCS symbols upstream. Lane volumes upstream of congestion were reduced 7 to 11 percent (5). These reductions were consistent with a study by Burford of a combined lane control-changeable message sign (CMS) system installed in Austin, Texas (9). In Austin, a set of two LCS displays and a CMS were installed on each approach to a section of I-35 where express lanes were retrofitted above the existing freeway. When the LCS indicated that one or two lanes were closed on the freeway downstream, a 7 to 12 percent reduction in the corresponding lane volumes occurred at various points upstream. The CMS had a slight additional effect on lane distribution, but not to the extent of the LCS.

Summary

The few laboratory studies that have been performed to assess motorist interpretations of LCS indicate that the green arrow is understood by essentially all motorists. As a rule, 95 to 98 percent of subjects in the various studies perceived the arrow as indicating that a lane is open and that travel in the lane is permitted. Although not quite as uniformly comprehended as the green arrow, the red X also seems to have a fairly strong inherent meaning to motorists. In the studies cited, 63 to 80 percent of subjects perceived the red X as indicating that they should not drive in the lane under that symbol. However, a small segment of motorists (5 to 12 percent) appear to focus strictly on the color (red) of the symbol and state that they would stop if they saw the red X. Although such behavior would not be expected to occur in an actual freeway driving situation, it is evident that not all motorists immediately think of exiting the lane upon seeing a red X.

There is even more variation in the interpretations of the meaning associated with a yellow X as a freeway LCS symbol. In the few studies where a yellow X was considered, the two most common interpretations were that:

- Drivers should use caution and slow down when in that lane, and
- Drivers should not drive in that lane.

In general, the first response is given slightly more often, even though the definition of the yellow X in the MUTCD is more consistent with the second response. Of course, a lack of a consensus on the meaning of a yellow X does not automatically suggest that there will be operational problems associated with its use. However, it is contrary to some of the basic requirements of a traffic control device, namely:

- to convey a clear, simple meaning, and
- to command respect of road users.

Other yellow symbols (downward and diagonal arrows) have been proposed for freeway LCS and implemented outside of the U.S. However, these symbols require a more thorough analysis before being considered for use in the U.S.

Field tests suggest that it may be possible to reduce accident potential through implementation of freeway LCS in urban areas. Operationally, it appears possible to encourage some motorists to shift from closed lanes to open lanes farther upstream. However, it does not appear that LCS can significantly increase flow rates past temporary bottlenecks or to dramatically reduce operating speeds. The need for more research is evident, though, to better understand the influence that traffic volumes, geometrics, other motorist information displays, etc. have upon LCS effectiveness.

3. OBJECTIVES OF LABORATORY STUDIES

Freeway LCS Interpretation Issues

The design and operation of a successful freeway lane control signal system should be based on a thorough understanding of motorist perceptions and reactions to the system under all types of roadway, traffic, and environmental conditions. Unfortunately, the review of past research by TxDOT and TTI study personnel elicited many more questions than answers regarding motorist interpretations of existing or proposed freeway LCS in Texas. For example:

- How do Texas motorists currently interpret the existing MUTCD LCS symbols as they might apply in a freeway driving environment?

- How do motorists interpret alternative LCS symbols such as the yellow diagonal or downward arrows (not currently in the MUTCD but previously proposed or in experimental use for freeway control)?

- Are the interpretations of each LCS symbol consistent, or do they depend on the overall display configuration (i.e., the other symbols also shown in adjacent lanes) they see as they travel a section of freeway?

- Do the interpretations vary according to regions within the state (due to how they are used on other facilities, for example), or are they likely to be consistent statewide?

- Does flashing a particular symbol alter how it is interpreted?

In addition to these interpretation questions, there are many visibility and placement issues which must also be taken into consideration in freeway LCS design and operation. However, the focus of the laboratory studies described in this report was subsequently limited to the motorist interpretation questions listed above.

Objectives by Study

A total of four laboratory studies were designed and conducted as part of Study 1298. The first study was devoted to an investigation of motorist interpretation of the symbols currently allowed by the MUTCD for freeway use (green arrow, yellow X, and red X). The second and third studies focused on interpretations of yellow diagonal and downward arrows, not currently allowed in the MUTCD but used in Europe and Canada. The fourth and final study was designed to examine alternatives to the steady red X as a lane closed indication, and to explore the effects of flashing the red X and the green arrow upon symbol interpretation. The specific objectives set forth for each laboratory study are presented below.

Study #1:

1. Determine current motorist interpretations of the standard MUTCD LCS symbols presented in a simulated freeway driving scene, and

2. Determine whether interpretations of the symbols are dependent upon the other symbols displayed in other lanes in an LCS array across the freeway at a location.

Study #2:

1. Compare how motorists interpret a yellow X, a yellow downward arrow and a yellow downward diagonal arrow (to be referred to as the diagonal arrow herein) when displayed in conjunction with a red X and a green arrow,

2. Determine if flashing the yellow downward and diagonal arrows affects motorist interpretations of the symbols (measured relative to steady displays of the same symbols), and

3. Determine if motorist interpretations of the LCS symbols differ between major urban areas in Texas.

Study #3:

1. Determine if motorist interpretations of yellow diagonal and downward arrows are dependent upon whether or not they are displayed in conjunction with a red X, and

2. Determine if there is a difference in motorist interpretation of the urgency implied by the yellow X and yellow diagonal arrow in needing to exit a lane (for those subjects interpreting the symbols to indicate the need to exit the lane).

Study #4:

1. Determine if the universal "do not" symbol (circle-slash) or a red X superimposed over a green arrow is interpreted more consistently than a red X as indicating that a given travel lane is closed,

2. Determine motorist interpretation of a flashing red X, and

3. Determine motorist interpretation of a flashing green arrow (proposed as another possible transitory signal from a green arrow to a red X).

Study Protocol

The same study protocol was employed during each of the four laboratory studies. Subjects were recruited to view simulated freeway scenes (three-dimensional perspectives) that included overhead freeway LCS displayed over each lane (representing an LCS array at that location). The symbols shown over each lane were varied to create several LCS array alternatives. Subjects were asked to view a given alternative and envision themselves driving in a specified lane. Subjects were then asked to indicate what the LCS symbol over that lane meant about the condition of that lane, and what action they should take as a motorist travelling in that lane. Responses were recorded as stated (i.e., an open-response format) so as to not bias subject interpretations.

The studies differed slightly with respect to their experimental design. In the first study, subjects viewed only one of the scenes to protect against learning effects that might result from seeing and responding to multiple scenes. However, this approach did not allow subjects to directly compare the alternative symbols. Consequently, subjects in the subsequent studies viewed all alternative display arrays. Chapters 5 through 7 describe the procedures and results of studies 2, 3, and 4, respectively.

Scope of Analysis

The laboratory studies were limited to motorist interpretations of alternative LCS arrays at a single hypothetical location on a freeway. Visual stimuli were used in the studies to suggest driving on a tangent section of freeway. However, no attempt was made to simulate the presence of other traffic on the freeway or to simulate the effect of sequential LCS arrays encountered as a motorist travels along a section of freeway. Thus, the results of the studies should not be assumed to reflect expected behavior in the field. Rather, they should be used only to assess relative differences in motorist perceptions and interpretations between the various LCS symbols examined.

4. STUDY PROCEDURES AND RESULTS FOR STUDY #1

Laboratory Stimuli

Recall that the objectives of Study #1 were as follows:

1. Determine current motorist interpretations of the standard MUTCD LCS symbols presented in a simulated freeway driving scene, and

2. Determine whether interpretations of the symbols are dependent upon the other symbols displayed in other lanes in an LCS array across the freeway at a location.

To address these objectives, motorists were shown color drawings of a hypothetical freeway scene that included a sign structure with freeway LCS attached over each of the four travel lanes. In each drawing, a combination of red Xs, yellow Xs, and green arrows were shown in the LCS over each lane. For each subject, the survey took approximately 5 minutes to perform. Subjects were recruited from licensed drivers attending an automobile show at the Astrodome complex in Houston, Texas. The study was performed over a ten-day period in January 1992.

Figures 4-1 through 4-5 illustrate the visual stimuli presented to motorists. In each scene, the identical four-lane freeway section was displayed. Lanes were numbered 1 through 4 beginning with the median lane. Five different LCS arrays were created, varying the symbols presented and the lanes over which the symbols were positioned. The arrays were created only to test the influence of various symbol combinations as such, upon the interpretation of each symbol. As such, they should <u>not</u> be taken to represent desired or proper LCS design or operational policy. The illustrations presented here were modified to a black-and-white copy for reproduction purposes. The actual drawings viewed by motorists were in color.

Figure 4-1 illustrates LCS array A. In this scene, all three symbols were presented to the subjects. A red X was displayed over lane 1, yellow Xs were displayed over lanes 2 and 3, and a green arrow was displayed over lane 4. This might indicate a situation

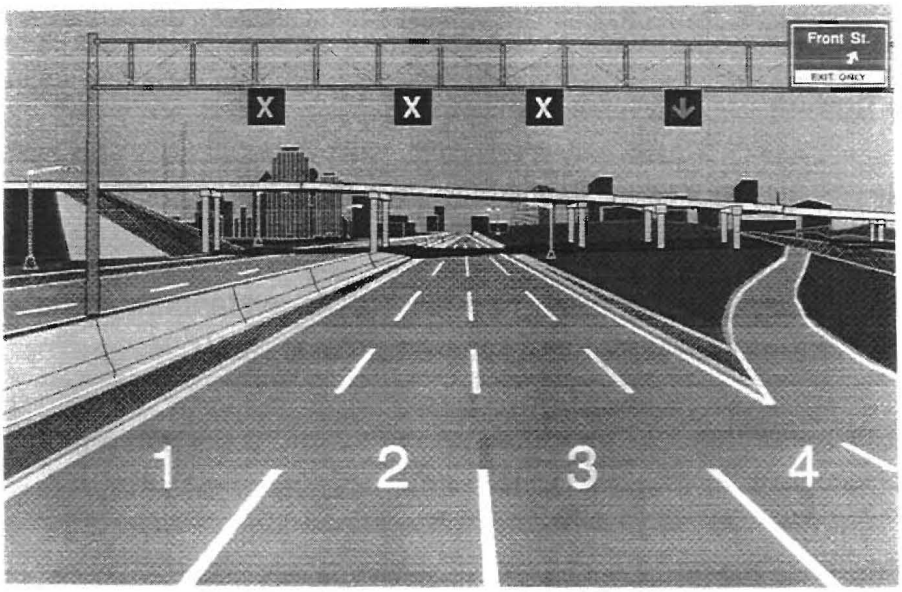

Figure 4-1. LCS Array A (Red X, Yellow X, Yellow X, Green Arrow).

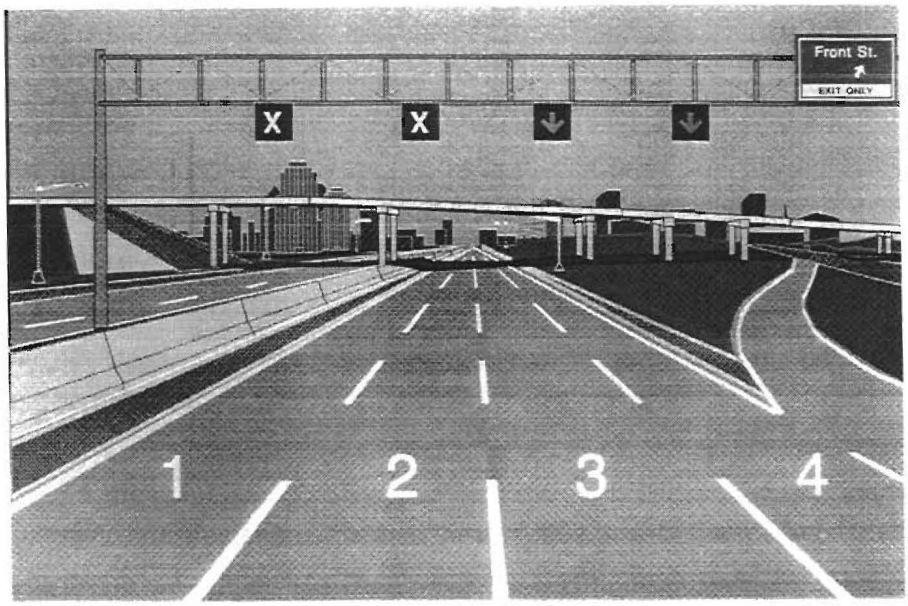

Figure 4-2. LCS Array B (Yellow X, Yellow X, Green Arrow, Green Arrow).

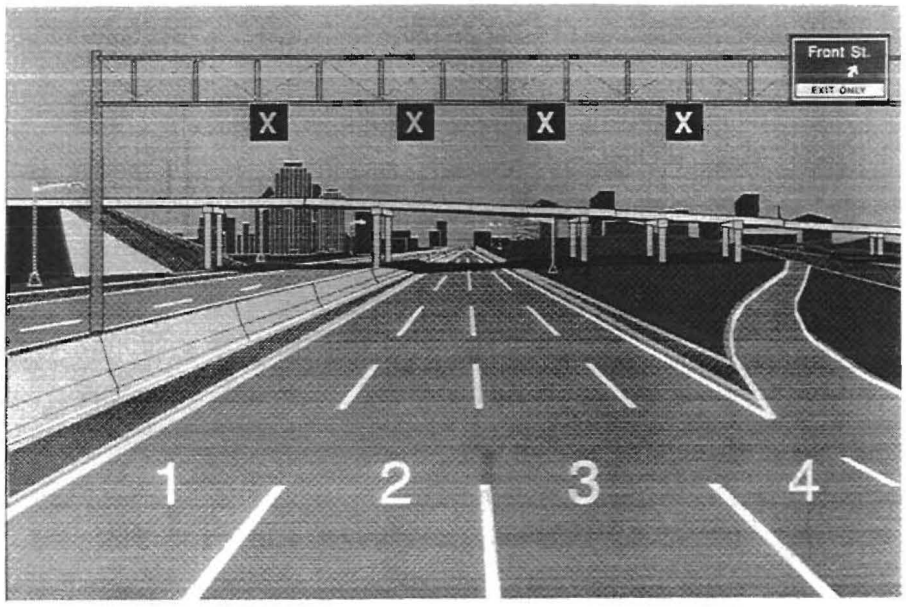

Figure 4-3. LCS Array C (Red X, Red X, Yellow X, Yellow X).

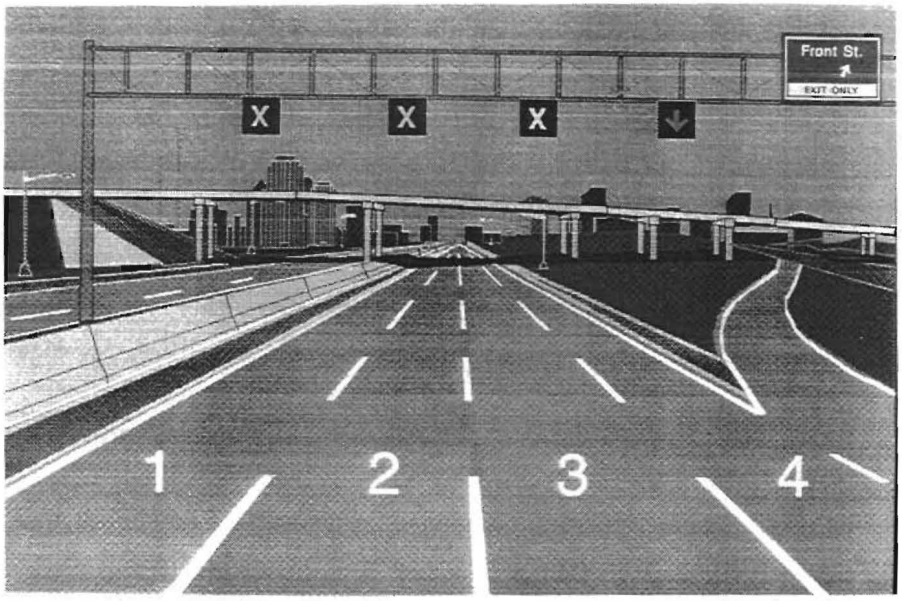

Figure 4-4. LCS Array D (Red X, Red X, Yellow X, Green Arrow).

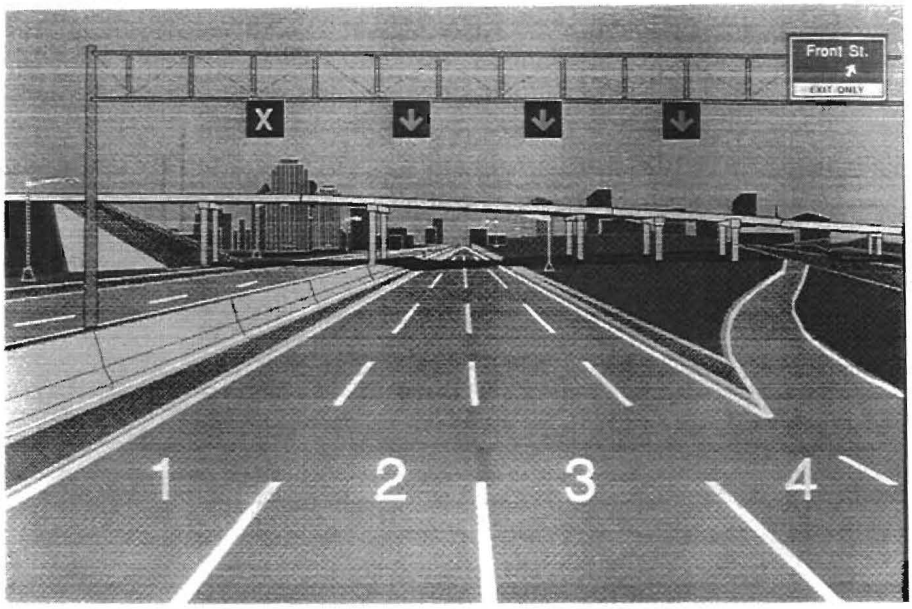

Figure 4-5. LCS Array E (Red X, Green Arrow, Green Arrow, Green Arrow).

where the median lane had already been closed, and an incident in the two middle lanes requires that they also be closed a short distance downstream.

In Figure 4-2, only two symbols were used to create LCS array B. Yellow Xs were placed over lanes 1 and 2, with green arrows located over lanes 3 and 4. In comparison, LCS array C is shown in Figure 4-3. Again, only two symbols were presented, those being red X's over lanes 1 and 2, and yellow Xs over lanes 3 and 4. This latter scene might be indicative of a situation where the two left lanes were already closed and an incident in the right two lanes forced the transportation agency to begin to close the entire freeway (i.e., they will require all motorists to exit at a ramp farther downstream).

Figure 4-4 presents LCS array D, consisting of red X's over lanes 1 and 2, a yellow X over lane 3, and a green arrow over lane 4. Note that this scene is similar to LCS array A (Figure 4-1) in that all three symbols are visible in the same display. Finally, LCS array E is shown in Figure 4-5. In this display, a red X is presented over lane 1, with green arrows placed over the three remaining lanes.

Experimental Plan

Each subject recruited was allowed to view and respond to only one particular LCS array. In this way, an elaborate experimental design to counterbalance learning effects was not required (although a larger sample size was required). As stated earlier, the subjects were asked to envision themselves driving in each lane where a different LCS symbol was displayed. In Figure 4-1, for example, subjects were asked to first envision themselves driving in lane 1 to evaluate the red X, then in lane 2 to evaluate the yellow X, and then in lane 4 to evaluate the green arrow. On the other hand, subjects viewing Figure 4-2 were asked to envision themselves first in lane 1 to evaluate the yellow X, and then in lane 3 to evaluate the green arrow. An open-ended response format was used in the study.

The study was designed to evaluate each LCS symbol in conjunction with one or both of the other possible LCS symbols now allowed in the MUTCD for freeway traffic management purposes. That is, the yellow X was evaluated in one array with only green arrows present, in another with only red X's present, and in still another with both green arrows and red X's visible to the subject. The green arrow and red X were likewise examined. To summarize, Table 4-1 documents the overall experimental design of the study, indicating which symbols were present in which arrays. LCS arrays A and D contain all three symbols, whereas the other arrays involve only two symbols.

It should be noted that the longitudinal dimension of a freeway LCS system, which could have a significant effect upon motorist interpretations, was not simulated in this study. Nevertheless, the data from this study are useful in assessing the effect of an entire LCS array upon the interpretations of individual symbols. Also, situations may arise in which some of the arrays presented in this study could be seen by motorists who had not encountered upstream LCS arrays (if an incident occurred at the beginning of a freeway section equipped with LCS, for example, or if a motorist entered the freeway immediately upstream of a lane blockage and only saw one set of LCS prior to reaching the blockage).

TABLE 4-1. EXPERIMENTAL DESIGN: STUDY #1

	LCS Array				
Symbol	A	B	C	D	E
Green Arrow	*	*	-	*	*
Yellow X	*	*	*	*	-
Red X	*	-	*	*	*

* denotes symbol was present in that particular array
- denotes symbol was not present in that particular array

Data Reduction

Table 4-2 summarizes the basic demographic distribution of subjects recruited during this study. Each display configuration was viewed by 73 to 75 subjects, for a total of 371 responses. Overall, the study group was over represented by males (73 percent males versus 27 percent females) and by the younger age categories (more drivers younger than 25 and fewer drivers older than 55) in comparison to Texas population statistics (12). This was expected, given the type of event which the subjects were attending (i.e., an automobile show), and suggests that survey subjects may not have had quite as much previous driving experience upon which to base their interpretations as would have been desired in this study. However, the major emphasis was on obtaining consistent demographic distributions across the various LCS arrays evaluated (which was successfully accomplished by survey administrators).

Results

Interpretation of the Downward Green Arrow

Responses obtained from this study support the findings of previous research which have shown that most motorists associate a green arrow with a lane that is open

TABLE 4-2. COMPARISON OF TEXAS AND STUDY #1 DEMOGRAPHICS

	Percent of Drivers	
Age	Texas Statistics*	Study Statistics
less than 25	19	34
25 to 39	34	38
40 to 54	23	23
greater than 55	24	7
Gender		
Males	49	73
Females	51	27

* Source: 1990 U.S. Census of Housing and Population

and available for travel. Table 4-3 presents the percent of subjects viewing each LCS array who believed the green arrow meant that the corresponding lane was open. Overall, the percent of subjects responding to the green arrow in this manner was very high, exceeding 85 percent for all arrays.

The responses to LCS arrays A and D were more consistent with each other, as were arrays B and E. This is not surprising, given the similarity of the two sets of arrays. Subjects viewing arrays B and E were asked to envision themselves in lane 3 when answering questions about the green arrows, whereas subjects viewing LCS arrays A and D envisioned themselves in lane 4. Also, it is interesting to note that a small number of subjects viewing arrays A and D (where only one green arrow existed in the array and was positioned over the shoulder lane) perceived the green arrow to mean that the lane was for exiting traffic. These small variations in the data were not found to be statistically significant (based on a chi-square test of independence). However, the data does suggest that some subjects may consider leaving the freeway when confronted with an array that shows most of the freeway as closed or closing soon (three of the four lanes were shown as closed or closing in arrays A and D).

TABLE 4-3. SUBJECT INTERPRETATIONS OF THE GREEN ARROW: STUDY #1

	Percent of Subjects Responding			
	LCS Array			
Interpretation of Lane Condition:	A	B	D	E
"Lane is open"	85	93	87	97
"Lane is for exiting"	7	-	7	-
Other	8	7	6	3
Interpretation of Proper Driving Action:				
"Stay in lane/proceed as normal"	87	90	87	99
"Slow down and be watchful"	5	4	3	1
Other	8	6	10	-

- responses total less than 1 percent

When subjects were asked what action they would take if driving in the lane over which a green arrow was displayed, most indicated they would remain in that lane and proceed as normal. The percentages of this response for each LCS array are shown in Table 4-3. The percentage of "proceed normal" responses for arrays A and D were slightly lower than for arrays B and E, although again not enough to be considered statistically significant.

Interpretation of the Red X

Table 4-4 presents the three most common interpretations of the meaning of the red X with respect to the condition of the lane over which it is positioned. Most subjects perceived the red X to mean that the lane is closed or blocked. A small proportion (3 to 7 percent) believed that the red X indicated that there was oncoming traffic in that lane. There was also a small proportion (less than 5 percent) who had no idea what the red X meant (none of the subjects were confused by the green arrow). Statistically, the responses were consistent from array to array. Also, the responses were similar to those obtained in past studies of LCS.

Subject interpretations as to the proper action to take for a driver in a lane under a red X are also summarized in Table 4-4. Most subjects stated they would exit that lane, but a few indicated they would stop in the lane. Whether or not these few subjects were thinking that there would be traffic stopped in front of them that would require them to stop as well could not be ascertained. However, it appears that the initial reaction of these individuals would not be to exit (or attempt to exit) the travel lane over which a red X was displayed (at least in the absence of other visual cues such as traffic in front of them exiting the lane). Also, a small portion of the subject group stated they would exit the freeway if seeing the red X over their lane. The responses were not statistically different from array to array, indicating that the interpretation of the red X was not dependent on what other symbols were present in the LCS array at a location. Although there was not enough statistical evidence to indicate differences in responses to the red X by array, one can tell that responses to arrays A, C, and D were much closer to each other than were responses to array E. Array E is the only one where there was more than 1 open lane shown (result that array B had no open lanes indicated via a green arrow). Also, array E is the only one where a red X is presented without a yellow X also in the display.

Interpretation of the Yellow X

Table 4-5 illustrates subject interpretations of the yellow X for each of the different LCS arrays. Unlike responses to the green arrow and red X, responses to the yellow X differed dramatically depending on the array viewed by the subject. As can be seen, most subjects (between 67 and 76 percent) viewing arrays A, C, and D perceived the yellow X to mean that there were dangerous conditions ahead in the travel lane. Meanwhile, a few subjects believed the indication meant that the lane was closed ahead or about to be closed. However, these trends were reversed for LCS array B, when there was not a red X displayed in conjunction with the yellow X. Only 21 percent of the subjects viewing this array perceived the yellow X as indicative of dangerous conditions in the lane, whereas 45 percent believed that the yellow X meant that the lane was closed ahead or about to be closed. Unlike responses to either the green arrow or the red X, subjects gave a wide range of "unique" interpretations of the yellow X. These unique answers, when consolidated, represented nearly one-fourth of the yellow X responses for some of the arrays.

TABLE 4-4. SUBJECT INTERPRETATIONS OF THE RED X: STUDY #1

	Percent of Subjects Responding			
	LCS Array			
Interpretation of Lane Condition:	A	C	D	E
"Lane is closed"	81	84	80	81
"Lane is for oncoming traffic"	4	7	6	3
"I don't know"	4	1	4	4
Other	11	8	10	12
Interpretation of Proper Driving Action:				
"Exit the lane"	77	79	80	89
"Exit the freeway"	7	3	5	7
"Stop in lane"	12	10	8	3
Other	4	8	7	1

The yellow X also caused more confusion for the subjects than either the red X or green arrow. Between 6 and 11 percent of the subjects did not know what was meant by the yellow X. Overall, a chi-square test of independence between lane condition responses for the yellow X and LCS array was statistically significant at a 5 percent level of significance ($X^2 = 49.8 > X^2_{(0.05, 9)} = 16.9$). Also, given the intended meaning of the yellow X to indicate an upcoming closure of a travel lane as defined in the MUTCD, it is apparent that most motorists in Texas do not inherently associate the symbol with an impending lane closure under most of the LCS arrays tested in this study.

Table 4-5 also presents the most common responses given by subjects as to the proper action to take when the yellow X is displayed over a travel lane. Again, substantial differences in responses existed between LCS arrays which were verified through statistical testing ($X^2 = 93.7 > X^2_{(0.05, 9)} = 16.9$). For LCS arrays A and D, subjects as a group were split between interpreting the yellow X as requiring them to (a) exit the lane, or (b) staying in the lane but proceeding cautiously at a slower speed. For array B, most

TABLE 4-5. SUBJECT INTERPRETATIONS OF THE YELLOW X: STUDY #1

	Percent of Subjects Responding			
	LCS Array			
Interpretation of Lane Condition:	A	B	C	D
"Hazard or danger in lane"	76	21	67	68
"Lane is closed or will be closing"	5	45	3	11
"I don't know"	11	9	6	6
Other	8	25	24	15
Interpretation of Proper Driving Action:				
"Exit the lane"	35	72	1	57
"Exit the freeway"	-	-	7	1
"Slow down/proceed cautiously in lane"	45	15	70	35
"Stay in lane/proceed normally"	7	3	15	4
Other	13	10	7	3

- responses total less than 1 percent

subjects (72 percent) indicated that the proper action would be to exit the lane, with only 15 percent stating that they should stay in the lane but proceed cautiously. For array C, very few subjects indicated that they should change lanes, whereas 70 percent stated they would proceed in that lane slowly and cautiously.

The responses obtained for LCS array C were not unexpected, given that the display contained only red and yellow X's. This display did not present any clear alternatives to subjects of other lanes into which they could move, so they apparently assumed that the lanes under the yellow X's were preferable to those under the red X's. This explanation of subject responses is further supported by the fact that a significant proportion of the subjects (15 percent) who viewed array C indicated that the proper response would be to proceed normally in the lane under a yellow X. A few subjects (7 percent) did indicate that they would exit the freeway if the yellow X in LCS array C was encountered.

Finally, it is interesting to note the similarity of responses of the proper actions to the yellow X in array B and the red X in the other LCS arrays. Array B contained only yellow X's and green arrows. When presented with this array, most (72 percent) of the subjects believed that the correct action for that lane would be to exit that lane. This percentage is only slightly less than those for the same response to a red X. In the absence of a red X, subjects appeared to focus on the type of symbol being displayed (an "X") and assume the proper response would be to exit that lane. In other words, if a red X was not present in the array, subject interpretations of a yellow X were more consistent with those intended by the MUTCD.

Discussion and Summary

In general, the results of this study were similar to those of previous LCS studies with respect to the interpretations of the green arrow and red X. This laboratory study did show that motorist interpretations of these two symbols were generally consistent regardless of the other LCS symbols displayed in an overall array. However, the interpretation of a yellow X, currently allowed in the MUTCD, was found to depend upon the other symbols present in an overall LCS array. When displayed in conjunction with green arrows only, the yellow X is most likely to be interpreted as indicating a lane blockage or closure ahead and requiring an exit maneuver out of the lane. This interpretation is most consistent with that intended by the MUTCD for the yellow X. However, when displayed in conjunction with a red X, subjects were more likely to interpret the yellow X as a cautionary symbol, and were not as likely to associate its display over a lane as indicating a need to exit that lane.

5. STUDY PROCEDURES AND RESULTS FOR STUDY #2

Laboratory Stimuli

The second study was designed to compare motorist interpretations of the yellow X (the symbol allowed in the MUTCD as a transition symbol between a red X and a green arrow) to a yellow diagonal arrow. In addition, the interpretation of a yellow downward arrow was also explored as a potential cautionary symbol in Texas freeway LCS systems. At the present time, there is no nationally-accepted symbol that indicates to motorists to use extra caution when travelling in a lane (but that it is not necessary to exit that lane). The second study was also designed to compare motorists' interpretations of both the yellow diagonal and downward arrows displayed in a flashing versus a steady mode. Finally, the study was conducted in three different locations statewide to investigate whether any differences in interpretations existed from one city to the next.

In the same manner as for the first study, drawings were constructed of a hypothetical freeway scene that included a sign structure with freeway LCS attached over each of the travel lanes. Unlike the first study, however, a much more simple freeway perspective was used to eliminate as much visual clutter as possible from the laboratory stimuli. Figure 5-1 illustrates the scene used in the second study. In each LCS array tested, a red X was displayed over the left lane, one of the yellow symbols (an X, a diagonal arrow to the right, or a downward arrow) was displayed over the middle lane, and a green arrow was shown over the right lane. This particular LCS array was used because it appeared to elicit the most confusion and widely varying responses for the yellow X in the first study. Color copies were again used; the black-and-white reproduction shown in Figure 5-1 is for illustrative purposes only.

In order to simulate the dynamics of a flashing LCS symbol, special display units were constructed. The units measured approximately 11 inches high by 14 inches wide by 12 inches deep and contained a 12-volt DC power converter, three automobile flashers, toggle switches, and automobile light bulbs (those used in rear taillights or turn signals). The light bulbs were suspended inside the unit, and connected to the toggle switches and flashers. Photos of the display units are shown in Figure 5-2.

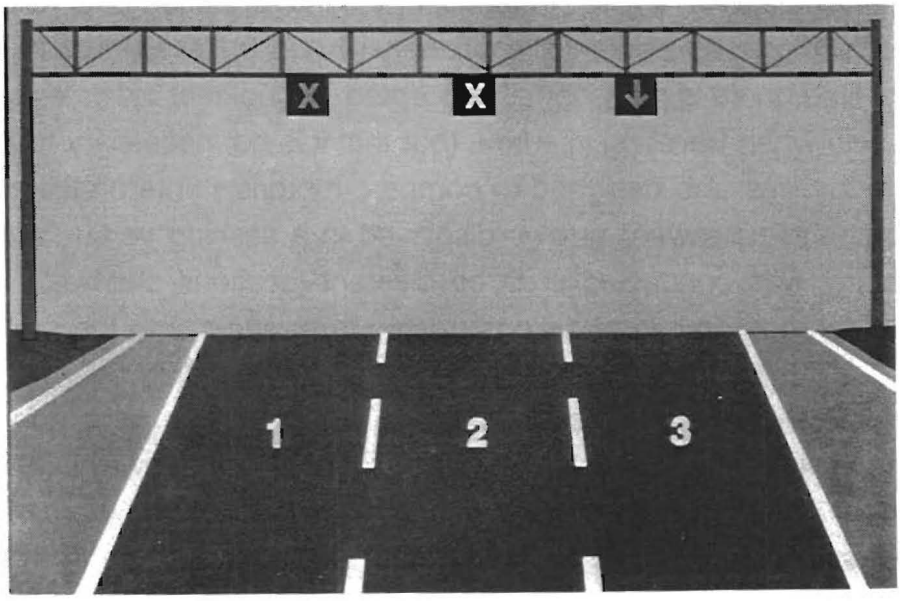

Figure 5-1. Typical LCS Array Used in Study #2.

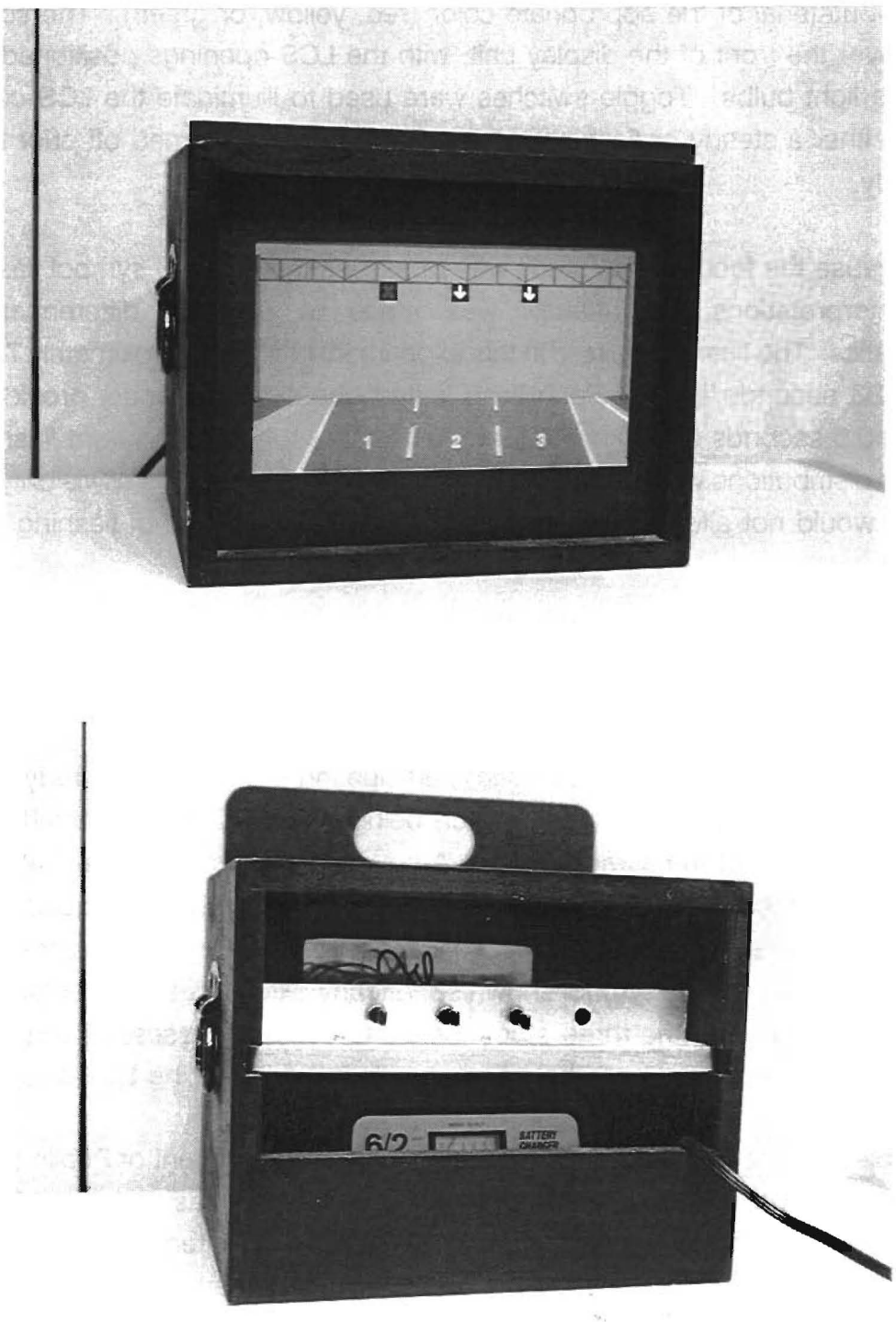

Figure 5-2. Display Units for Study #2.

The LCS symbols in each of the arrays were cut out and the opening covered with transparent material of the appropriate color (red, yellow, or green). The scenes were then slid over the front of the display unit, with the LCS openings positioned directly in front of the light bulbs. Toggle switches were used to illuminate the LCS cut-out from behind in either a steady or flashing mode. The lights were turned off prior to the start of the study.

Because the focus of the study was to assess the effect of symbol flashing upon subject interpretations, no attempt was made to evaluate differences in flash characteristics. The flashers utilized in this experiment blinked approximately 72 times per minute (0.83 seconds/flash). Each flash lasted about 0.3 seconds, providing slightly more than 0.5 seconds of darkness between flashes. Whereas different flash rates and on-off time distributions would likely affect LCS target value and overall visibility, it was felt that these would not alter motorist perceptions of the meanings of flashing symbols in general.

Experimental Plan

Unlike the first study, each subject participating in the second study viewed and responded to each one of the yellow symbols being evaluated. This included both steady and flashing modes of the same symbol. A counterbalanced experimental design was employed to balance the order of the yellow symbols to which the subjects responded. For the first LCS array evaluated, subjects provided interpretations of the green arrow, red X, and the particular yellow symbol shown so that any differences in green arrow and red X interpretations among the three study locations could be assessed. In subsequent scenes, subjects evaluated only the different yellow symbol in the LCS array.

Subjects were recruited as they stood in line at Department of Public Safety driver licensing stations in Houston, San Antonio, and Ft. Worth, Texas. A total of 250 subjects were recruited at each location. Subjects were asked to interpret what each symbol indicated about the condition of the lane, and what action they should take as a driver in that lane. Different survey administrators were used at each of the locations. However, one supervisor travelled to each location and trained each set of administrators so as to maintain as much uniformity in data collection procedures as possible. The supervisor

also monitored the administrators during the studies to see that responses were being recorded correctly and uniformly.

Again, the longitudinal dimension of a freeway LCS system was not simulated in this experiment. Also, subjects were not asked directly to compare and contrast the intended meanings of steady and flashing displays of the same symbol. Rather, the types of responses given for each display mode of the symbol were compared after the survey to deterrnine whether significant differences existed between them.

Data Reduction

Table 5-1 summarizes the basic demographic distribution of subjects recruited for this study. Overall, the study group was comparable to statewide population statistics for Texas (although not just licensed drivers) with respect to age and gender. Significant differences between survey locations and with statewide statistics did exist with respect to race and education. Specifically, a higher proportion of survey respondents in San Antonio were Hispanic (42 percent versus 26 percent statewide). Several subjects participating in San Antonio could not speak English, and were administered the survey with the aid of a Spanish-English translator. Also, the survey sample at each location tended to be more highly educated than the overall statewide population, particularly in Houston.

Different survey administrators were used in the three different locations. One study supervisor travelled to all three locations to train these administrators so as to obtain the data in a consistent manner. However, upon completion of the studies, it was determined that the lane condition responses obtained for the various yellow indications were not always complete, and so could not be used. Consequently, the evaluation focused solely on the proper driving action responses provided by the subjects for each of the symbols examined (green arrow, red X, yellow X, yellow diagonal arrow, and yellow downward arrow).

TABLE 5-1. COMPARISON OF TEXAS AND STUDY #2 DEMOGRAPHICS

	Percent of Drivers			
		Study Statistics		
Age	Texas Statistics*	Houston	S. Antonio	Ft. Worth
less than 25	19	19	20	22
25 to 39	34	42	33	41
40 to 54	23	26	37	27
greater than 55	24	13	10	10
Gender				
Males	49	60	47	51
Females	51	40	53	49
Race				
Caucasian	61	68	49	74
African-American	12	13	4	13
Hispanic	26	13	42	9
Asian	NA	5	2	2
Other	2	1	3	2
Education				
less than high school	28	8	15	11
high school graduate	26	19	20	22
some college	28	30	30	35
college graduate	18	43	35	32

* Source: 1990 U.S. Census of Population and Housing

NA Data Not Available

Results

Green Arrow and Red X Interpretations

Table 5-2 presents a tabular summary of subject responses to the green arrow across the three survey locations. Since the findings in study #1 indicated that both the green arrow and red X were interpreted consistently regardless of what other symbols were present in an overall LCS array, the responses to each were combined for all the different yellow symbols displayed at each survey location (visual inspection of the data suggested that responses were consistent at each location regardless of what yellow symbol was present in the visual scene).

TABLE 5-2. SUBJECT INTERPRETATIONS OF THE GREEN ARROW: STUDY #2

	Percent of Subjects Responding		
	Survey Location		
Interpretation of Proper Driving Action:	Houston	San Antonio	Ft. Worth
"Stay in lane/proceed as normal"	94	93	96
"Slow down and be watchful"	4	4	3
"Exit the lane"	-	1	-
Other	2	2	1

- responses total less than 1 percent

Interaction between survey location and driving action responses:
$X^2 = 2.8 < X^2_{(0.05, 4)} = 9.5 \therefore$ responses do not differ by location

Overall, subject interpretations (averaged across all three locations) of the green arrow were consistent with those of study #1. When asked what action they would take if driving in the lane over which a green arrow was displayed, most subjects (94 percent) indicated they would remain in that lane and proceed as normal.

Table 5-3 presents subject responses to the red X at the three survey locations. On average, 84 percent of the subjects said the proper driving response to a red X would be to exit the lane, a value again consistent with those of study #1. Another 8 percent of the subjects said they would stop in the lane. Although these subjects were not questioned further to determine exactly why they thought they should stop, the initial response of these few individuals was not to exit the travel lane over which a red X was displayed.

TABLE 5-3. SUBJECT INTERPRETATIONS OF THE RED X: STUDY #2

	Percent of Subjects Responding		
	Survey Location		
Interpretation of Proper Driving Action:	Houston	San Antonio	Ft. Worth
"Exit the lane"	80	82	90
"Drive cautiously/slow down"	6	7	2
"Stop in lane"	11	7	5
Other	3	4	3

Interaction between survey location and driving action responses:
$X^2 = 15.2 > X^2_{(0.05, 6)} = 12.6 \therefore$ responses differ by survey location

To assess the consistency of responses across the three survey locations, categorical data analysis techniques (similar to an analysis-of-variance of numeric data) were employed to assess the interaction between survey location and proper driving action responses for each symbol (11). High degrees of interaction indicate that the responses differed by location for the Red X. Chi-square interaction statistics values for both symbols are shown in Tables 5-2 and 5-3.

For the green arrow, proper driving action responses were consistent across survey locations. However, subject interpretations of the proper driving action implied by

a red X differed significantly by location. Upon closer examination of Table 5-3, it is evident that more Ft. Worth subjects believed the proper action in response to red X was to exit the lane. It should be noted that the TxDOT District Office in Ft. Worth has been displaying changeable message signs on I-35W which define a green arrow, yellow X, and red X to motorists (Figure 5-3). As shown, the red X is defined as "lane closed" on these signs, which may explain the higher percentage of exit lane responses from the Ft. Worth subjects. These findings suggest a potential benefit may be achieved through future educational campaigns to inform motorists of the desired reactions to the LCS symbols.

Figure 5-3. CMS Message displayed in Ft. Worth.

Interpretation of the Yellow X

Table 5-4 illustrates the distribution of subject responses regarding the proper driving action responses to the yellow X (tested in conjunction with the red X and green arrow symbols). Although Ft. Worth subjects provided an "exit the lane" response slightly more often than those subjects from San Antonio and Houston, this difference was not statistically significant. However, the distribution of responses was different than those obtained in study #1 for the similar LCS array. Whereas only 35 to 57 percent of the subjects in study #1 provided an "exit the lane" response to a yellow X displayed in conjunction with both a red X and green arrow (see Table 4-5 on page 24), 72 to 83 percent of the subjects in study #2 responded in this way.

TABLE 5-4. SUBJECT INTERPRETATIONS OF THE YELLOW X: STUDY #2

	Percent of Subjects Responding		
	Survey Location		
Interpretation of Proper Driving Action:	Houston	San Antonio	Ft. Worth
"Exit the lane"	72	75	83
"Slow down/proceed cautiously in lane"	22	19	12
"Stay in lane/proceed normally"	2	3	3
Other	4	3	2

Interaction between survey location and driving action responses:
$X^2 = 11.0 < X^2_{(0.05, 6)} = 12.2 \therefore$ responses do not differ by survey location

It must be remembered that the protocol for the two laboratory studies were not identical. For one thing, scenes in study #2 contained three lanes compared to four lanes shown in scenes for study #1. Also, each subject in the first study evaluated only 1 particular LCS array, whereas subjects in study #2 provided responses to all of the LCS arrays. To establish a more consistent basis for comparison between study #1 and study #2, the responses of subjects which saw the LCS array containing the yellow X first were computed separately and are shown in Table 5-5, along with the distributions of responses from study #1. As can be seen, 48 to 64 percent of those subjects seeing the yellow X first thought they should exit the lane, much lower than the 72 - 83 percent of the entire subject group who responded that way in study #2. This response was also more consistent with the 35 to 57 percent who responded that way for study #1. Meanwhile, 30 to 46 percent of subjects from both studies believed that they should slow down and proceed cautiously in the lane under a yellow X. It cannot be said which values (Table 5-4 or Table 5-5) are a better measure of the interpretation of the yellow X. Nevertheless, the fact that there are differences further emphasizes the fact that the symbol does not convey a clear, consistent message to motorists in all situations.

TABLE 5-5. COMPARISON OF INTERPRETATIONS OF THE YELLOW X AS FIRST YELLOW SYMBOL SEEN: STUDY #1 VERSUS STUDY #2

	Percent of Subjects Responding	
Interpretation of Proper Driving Action:	Study #1	Study #2
"Exit the lane"	35-57	48-64
"Slow down/proceed cautiously in lane"	35-45	30-46
"Stay in lane/proceed normally"	4-7	2-6
Other	3-13	0-4

Interpretation of the Steady and Flashing Yellow Diagonal Arrow

Table 5-6 summarizes the distribution of common subject interpretations of a steady diagonal yellow arrow displayed in conjunction with a red X and green arrow. An overwhelming majority (93 to 97 percent) of the subjects stated that they should exit the lane (in the direction of the arrow). In terms of the proper driving action to take in response to a flashing yellow diagonal arrow, 92 to 94 percent of the subjects indicated that they would exit that lane. Therefore, flashing the diagonal arrow appeared to have no effect on interpretations.

The effect of both display modes (steady or flashing) and survey location upon subject responses were evaluated statistically through categorical data analysis techniques. Responses to the diagonal arrow did not differ by location nor by display mode (steady or flashing). A few of the subjects did comment that the flashing displays implied more urgency, but many stated that there was no difference between the different display modes. Finally, unlike the yellow X, the order of evaluation did not appear to affect the subjects. The responses of those subjects who saw the diagonal arrow first were not significantly different than the distributions shown in Table 5-6. It appears from these data that the yellow diagonal arrow presents a more consistent message to motorists to exit a lane than the yellow X (when displayed in conjunction with a red X and a green arrow).

Interpretation of the Yellow Downward Arrow

Table 5-7 summarizes the responses provided for both the steady and flashing downward yellow arrow, proposed as a cautionary symbol in Texas freeway LCS systems. Generally, subjects were divided as to what the proper driving action should be in response to a steady downward arrow displayed in a given travel lane. Between 43 and 59 percent of the subjects felt that they should exit the lane, in contrast to the 31 to 48 percent who felt that they should slow down and proceed cautiously in that lane. Between 2 and 17 percent of the subjects stated that they should stay in the lane and proceed as normal.

TABLE 5-6. SUBJECT INTERPRETATIONS OF THE YELLOW DIAGONAL ARROW: STUDY #2

Steady Display			
	Percent of Subjects Responding		
	Survey Location		
Interpretation of Proper Driving Action:	Houston	San Antonio	Ft. Worth
"Exit the lane"	93	95	97
"Slow down/proceed cautiously in lane"	3	3	1
"Stay in lane/proceed normally"	3	1	1
Other	1	1	1

Flashing Display			
	Percent of Subjects Responding		
	Study Location		
Interpretation of Proper Driving Action:	Houston	San Antonio	Ft. Worth
"Exit the lane"	92	94	93
"Slow down/proceed cautiously in lane"	4	3	4
"Stay in lane/proceed normally"	3	1	2
Other	1	2	1

Interaction between display mode, survey location, and responses:
$X^2 = 9.72 < X^2_{(0.05, 12)} = 21.03$ ∴ responses do not differ by survey location or display mode

The responses to the flashing downward yellow arrow (shown in the lower portion of Table 5-7) follow the same general trends as for the steady arrow. For this symbol, between 45 and 63 percent of the subjects felt that they should exit the lane, with another 28 to 43 percent believing that they needed only to slow down and proceed cautiously in the lane. Only 4 to 6 percent of the subjects indicated they should stay in the lane and proceed normally.

TABLE 5-7. SUBJECT INTERPRETATIONS OF THE YELLOW DOWNWARD ARROW: STUDY #2

Steady Display			
	Percent of Subjects Responding		
	Survey Location		
Interpretation of Proper Driving Action:	Houston	San Antonio	Ft. Worth
"Exit the lane"	43	40	59
"Slow down/proceed cautiously in lane"	35	48	31
"Stay in lane/proceed normally"	17	6	2
Other	5	6	8

Flashing Display			
	Percent of Subjects Responding		
	Survey Location		
Interpretation of Proper Driving Action:	Houston	San Antonio	Ft. Worth
"Exit the lane"	56	45	63
"Slow down/proceed cautiously in lane"	34	43	28
"Stay in lane/proceed normally"	6	4	4
Other	3	8	5

Interaction between display mode, survey location, and responses:
$X^2 = 61.7 > X^2_{(0.05, 12)} = 21.0 \therefore$ responses differ

contribution by display mode
$X^2 = 9.7 > X^2_{(0.05, 2)} = 6.0$

contribution by survey location
$X^2 = 42.8 > X^2_{(0.05, 4)} = 9.5$

A three-way categorical data analysis of the downward arrow found both survey location and display mode affected subject responses, with survey location having more of an influence than display mode. Specifically, San Antonio subjects responded differently than those from either Houston or Ft. Worth, and was the only location where a "slow down/proceed cautiously in lane" response was more prevalent than an "exit the lane" response. With respect to display mode, subjects from both San Antonio and Ft. Worth provided similar responses to the steady and flashing downward arrows. However, the responses from Houston were substantially different when the arrow was flashing than when it was displayed in a steady mode. The Harris County Metropolitan Transit Authority (METRO) in Houston has been displaying a flashing downward yellow arrow on the reversible high-occupancy vehicle (HOV) lanes constructed in the median of several of the radial freeways in the region. Generally, these arrows are located at HOV lane diverge points where motorists can reenter the mixed-flow freeway travel lanes. This may explain why more Houston subjects associated the flashing downward arrow with an "exit the lane" response.

Discussion and Summary

Comparing the Interpretations of the Yellow X and Yellow Diagonal Arrow

The results of this laboratory study indicate that the yellow diagonal arrow provides a clearer message to exit a lane than does a yellow X, when displayed in conjunction with a red X and a green arrow. Between 93 and 97 percent of subjects viewing a diagonal arrow believe that they should exit that lane, compared to the 72 to 83 percent of subjects viewing a yellow X. Furthermore, this percentage drops to between 48 and 64 percent for subjects who evaluated the yellow X before seeing a diagonal arrow or downward arrow suggesting that learning effects may have partially biased the yellow X responses. In comparison, the diagonal arrow responses were consistent regardless of where in the experimental order that symbol was evaluated.

It is interesting to note that, overall, the yellow diagonal arrow received more "exit the lane" responses than even the red X. In Ft. Worth, where TxDOT has been displaying informational messages to teach drivers the meanings of LCS symbols, the difference was not dramatic (90 percent chose an "exit the lane" response for the red X, and 97 percent

chose an "exit the lane" response for the diagonal arrow). At the other locations, however, the differences were more substantial. No attempt was made to compare how the red X and diagonal arrow were interpreted with respect to the urgency of exiting the lane or the importance of not moving back into that lane. Therefore, one should not conclude that a diagonal arrow should be used in lieu of a red X. Rather, it would seem that the diagonal arrow could be an effective transition from a green arrow to a red X in a freeway driving environment, providing strong positive guidance in that transition regarding (a) the need to exit, and (b) the proper direction of movement out of the lane.

Use of a Downward Yellow Arrow in Freeway LCS

In reversible lane operations on urban arterials, there is little need for a LCS symbol to indicate that drivers travelling in a given lane should use caution and possibly reduce their speed. However, on freeways where travel speeds are much higher, such a symbol could be beneficial. A downward yellow arrow was proposed as this type of symbol for exploration in this laboratory study. The study results showed that subjects do not automatically associate that symbol with a message of caution and need for slower travel in a given lane. Specifically, more subjects (40 to 59 percent) believed it meant to exit the lane than believed it meant to use caution and slow down while in that lane (31 to 48 percent). Furthermore, interpretations by subjects differed depending on the location of the survey. In general, the downward arrow (when displayed with a red X and green arrow) was shown to lack a clear and consistent meaning among the motorists.

Steady versus Flashing Display Modes for the Yellow Arrows

The display mode (steady or flashing) had no appreciable effect upon subject interpretations of the yellow diagonal arrow. On the other hand, a small difference was detected in interpretations of steady and flashing yellow downward arrows. This difference existed primarily with the Houston subjects, where flashing downward arrows are being used at selected locations on the barrier-separated HOV lanes in the center of the freeway. At the other two survey locations, there was little difference in the way drivers interpret the steady and flashing display mode.

Based on these results, attempts to use steady and flashing arrow displays for different purposes in freeway LCS operations should be avoided. The data collected in this study, however, did not fully explore the differences in these display modes with respect to their target value, implied sense of urgency, or overall visibility. Limited data elsewhere (8) suggests that flashing LCS symbols reduces their legibility distance slightly under certain conditions. Additional research is necessary to fully explore these factors before making a final decision on the usefulness of flashing displays for LCS.

Consistency of Subject Interpretations Across Survey Locations

Statistical analyses indicated that the green arrow and yellow diagonal arrow were all consistently interpreted regardless of the location (Houston, San Antonio, and Ft. Worth) where subjects were surveyed. Meanwhile, the red X, yellow X, and yellow downward arrows were interpreted differently by subjects at the different survey locations. Subjects in Ft. Worth responded more consistently to the red and yellow X's (more subjects indicating that the symbols required an "exit the lane" response) than subjects at the other locations. Houston subjects, on the other hand, interpreted the yellow downward arrow somewhat differently than subjects in Ft. Worth or San Antonio. Taken together, these results are believed to be due to the exposure drivers in those cities have received concerning these symbols. The educational effort by TxDOT in Ft. Worth using the CMS display to teach motorists LCS symbol meanings appears to have been successful (judging by the more consistent interpretations of the X's by those subjects). Subject interpretations of the downward arrow in Houston are consistent with how it is currently being applied on the HOV lanes.

6. STUDY PROCEDURES AND RESULTS FOR STUDY #3

Laboratory Stimuli

The findings from study #2 suggested that the yellow diagonal arrow provided a more consistent message to motorists to exit a travel lane than the yellow X when shown in conjunction with a red X and a green arrow over adjacent freeway travel lanes. Study #3 was initiated to determine whether motorist's interpretations of the yellow diagonal arrow differ when displayed with and without a red X (recall that the yellow X did display such a dependency in study #1). The yellow X was also evaluated in study #3 as a control against which interpretations of the diagonal arrow could be compared. In addition, the effect of lane position (left lane or right lane) upon yellow symbol interpretations *in the absence of a red X* was explored. Differences in interpretation of the yellow arrow pointing to the left versus pointing to the right (when displayed in the middle lane in conjunction with the red X over the right or left lanes, respectively) were also examined. The specific scenarios evaluated in study #3 regarding the yellow X and diagonal arrow were as follows:

- A yellow X or diagonal arrow (pointing downward to the right) positioned over the inside left lane of a three-lane freeway section, and downward green arrows positioned over the center and right lanes (LCS arrays A and B);
- A yellow X or diagonal arrow (pointing downward to the left) positioned over the right lane, and downward green arrows positioned over the left and middle lanes (LCS arrays C and D);
- A red X positioned over the left lane, the yellow X or diagonal arrow over the middle lane (pointing to the right), and a green arrow over the right lane (LCS arrays E and F); and
- A red X positioned over the right lane, the yellow X or diagonal arrow over the middle lane (pointing to the left), and a green arrow over the left lane (LCS arrays G and H).

These scenarios are depicted graphically in Figures 6-1 through 6-4.

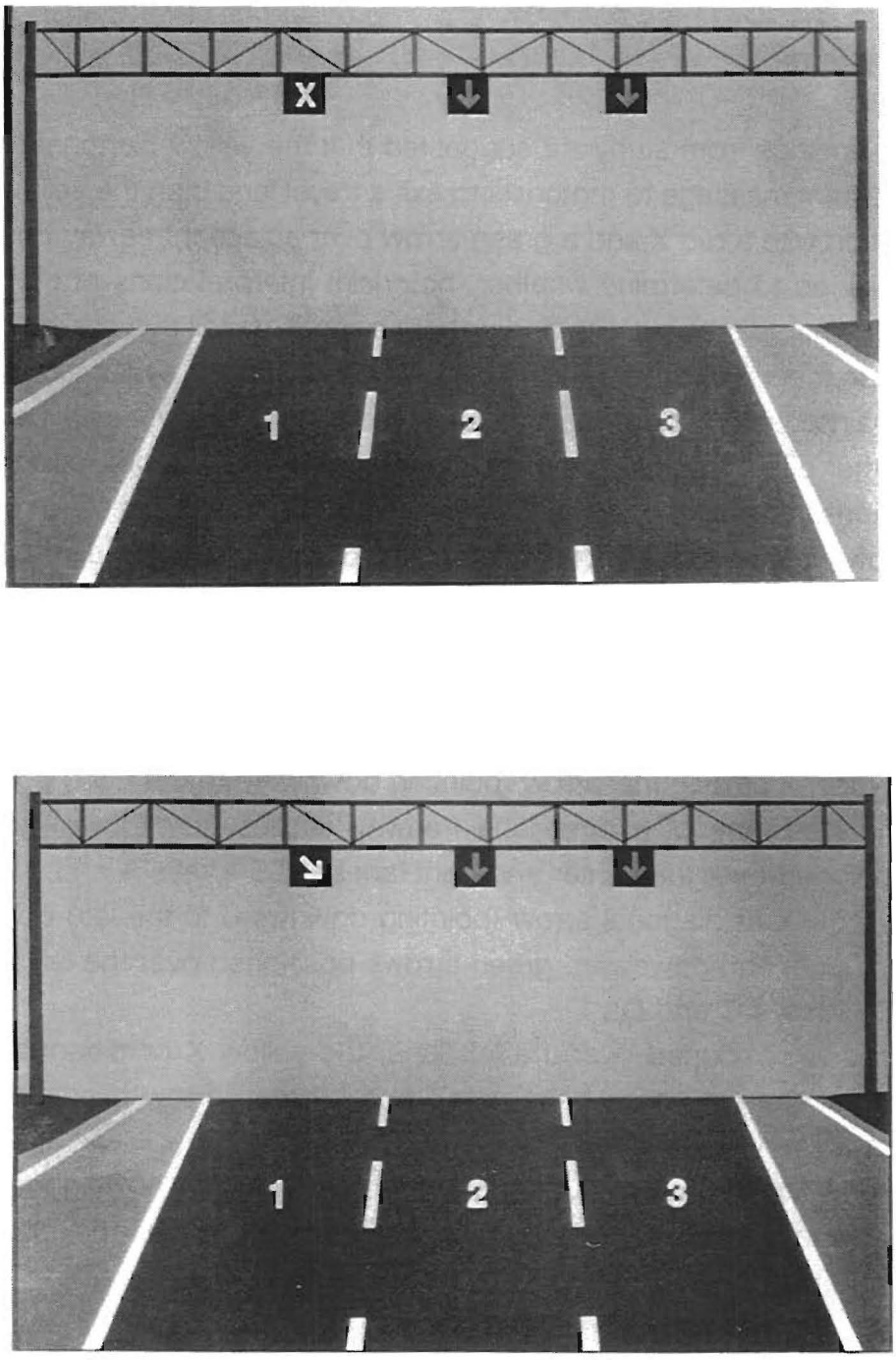

Figure 6-1. LCS Arrays A and B (Yellow Symbol, Green Arrow, Green Arrow).

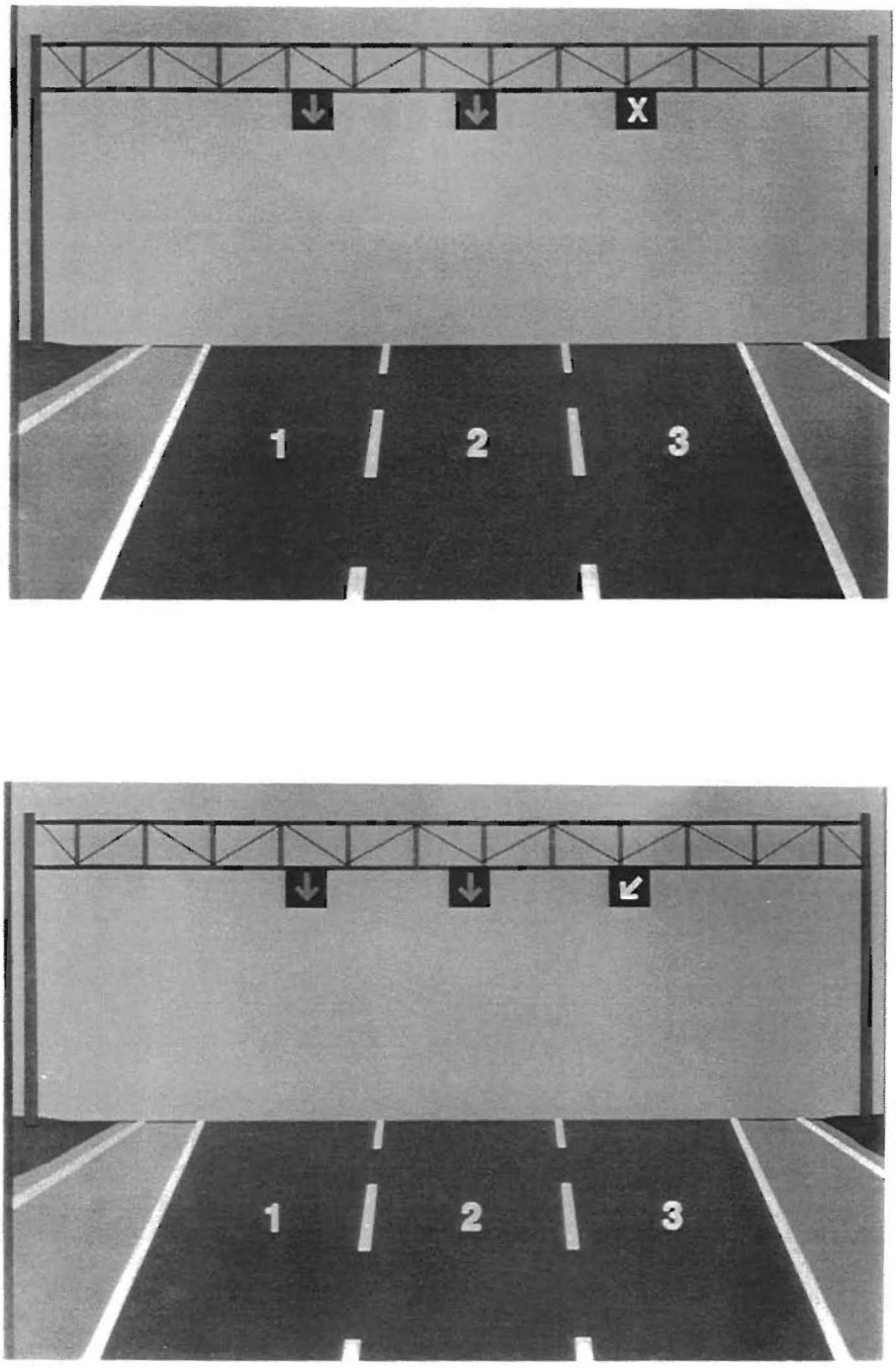

Figure 6-2. LCS Arrays C and D (Green Arrow, Green Arrow, Yellow Symbol).

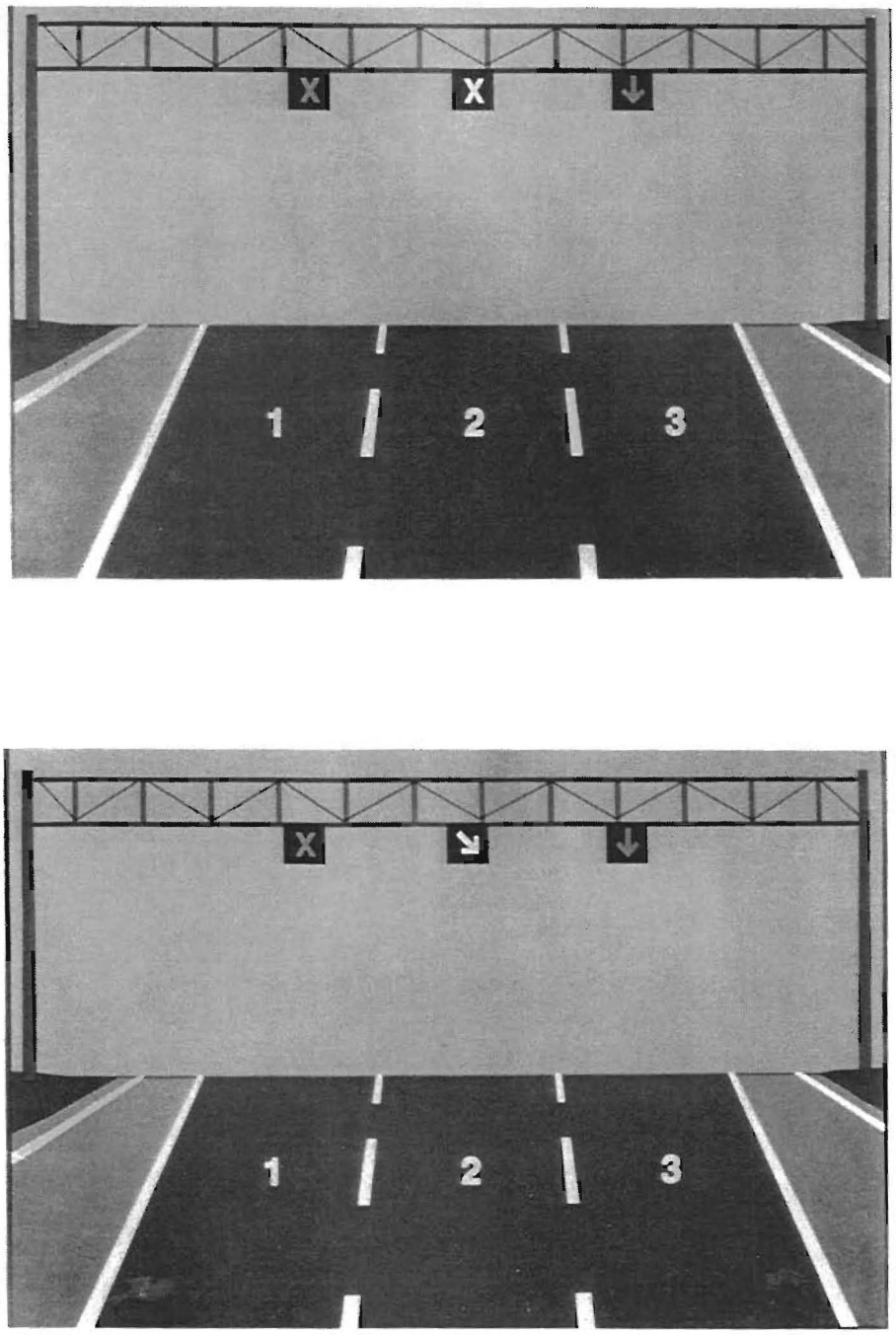

Figure 6-3. LCS Arrays E and F (Red X, Yellow Symbol, Green Arrow).

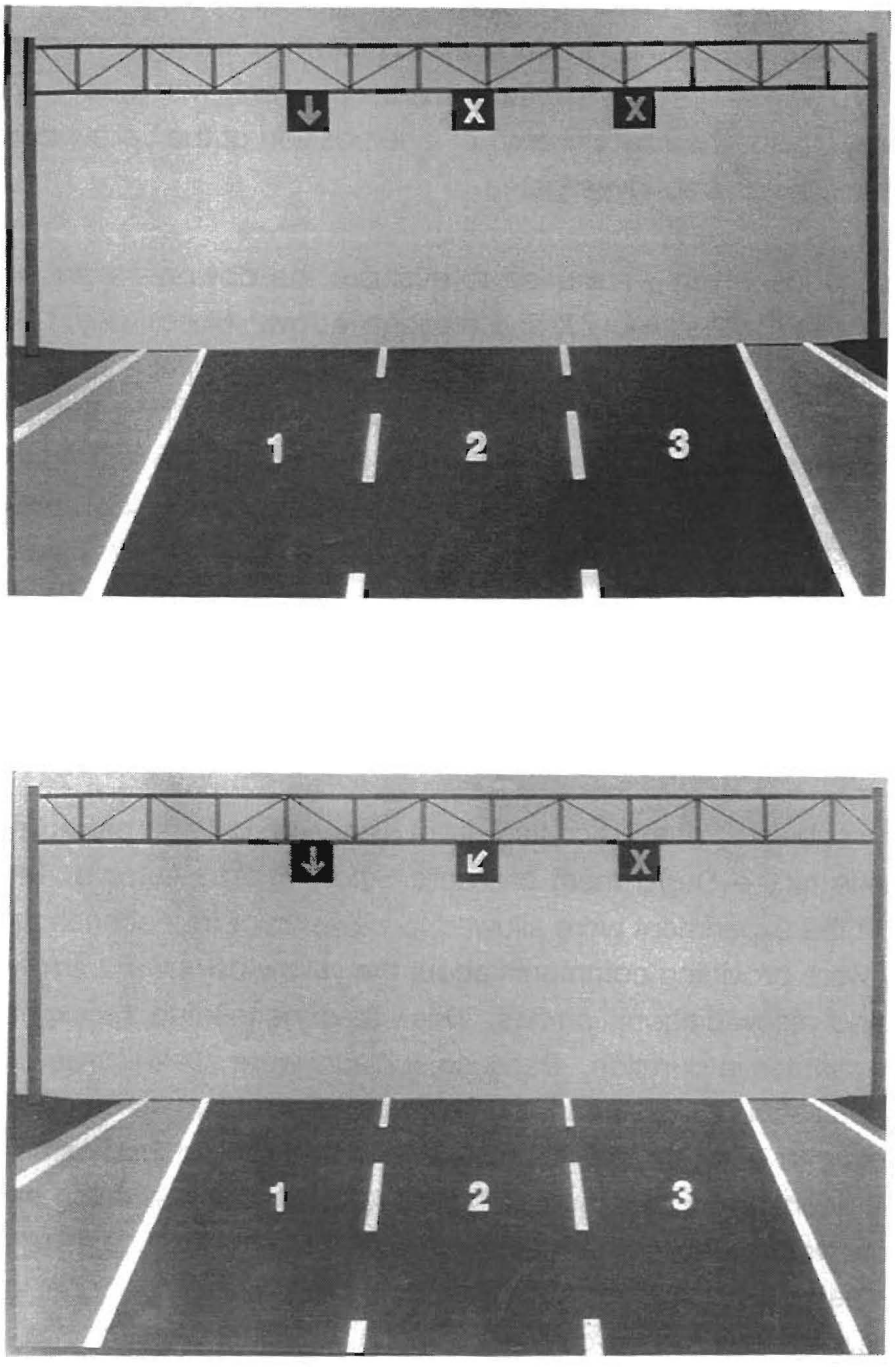

Figure 6-4. LCS Arrays G and H (Green Arrow, Yellow Symbol, Red X).

Further analysis of the downward yellow arrow was also included in study #3. The yellow downward arrow did not generate a single common interpretation among motorists in study #2, where the arrow was shown in conjunction with a red X and a green arrow. Further analyses were performed in study #3 to determine whether interpretations of the yellow downward were more consistent when presented only with red X's or green arrows in the LCS array. Also, the effect (if any) of lane position of the yellow downward arrow upon interpretation was also investigated.

The scenarios which were used to evaluate the downward arrow were slightly different than those for the yellow X and diagonal arrow. Specifically, LCS arrays were studied that included a single yellow downward arrow in combination with two green arrows or two red X's in the other two adjacent lanes (LCS arrays I, J, K, and L). The yellow downward arrow was studied in both the left median lane and right shoulder lane in an attempt to identify any effect that the lane position of the yellow arrow had upon its interpretation. Figures 6-5 and 6-6 illustrate the LCS arrays for the yellow downward arrow.

Experimental Plan

Survey subjects were recruited from licensed drivers patronizing a Driver's Licensing Office of the Department of Public Safety in San Antonio, Texas. Subjects participating in the experiment were allowed to view two or four scenes depending upon whether they were providing comments about the yellow downward arrow or comparing the yellow X and yellow diagonal arrows. This was done to keep the experiment for each subject a few minutes in duration. Because subjects were asked to view more than one scenario, a quasi-counterbalanced study design was used to account for possible learning affects and other biases which may have been introduced as a result of seeing one particular scenario before another. However, subjects evaluating the yellow X and diagonal arrow were always presented the arrays containing only the yellow symbol and green arrow before any arrays containing a red X. This was done to eliminate the possible influence that a red X would have upon subsequent evaluations of the yellow X. For the yellow downward arrow, a fully counterbalanced study design was employed.

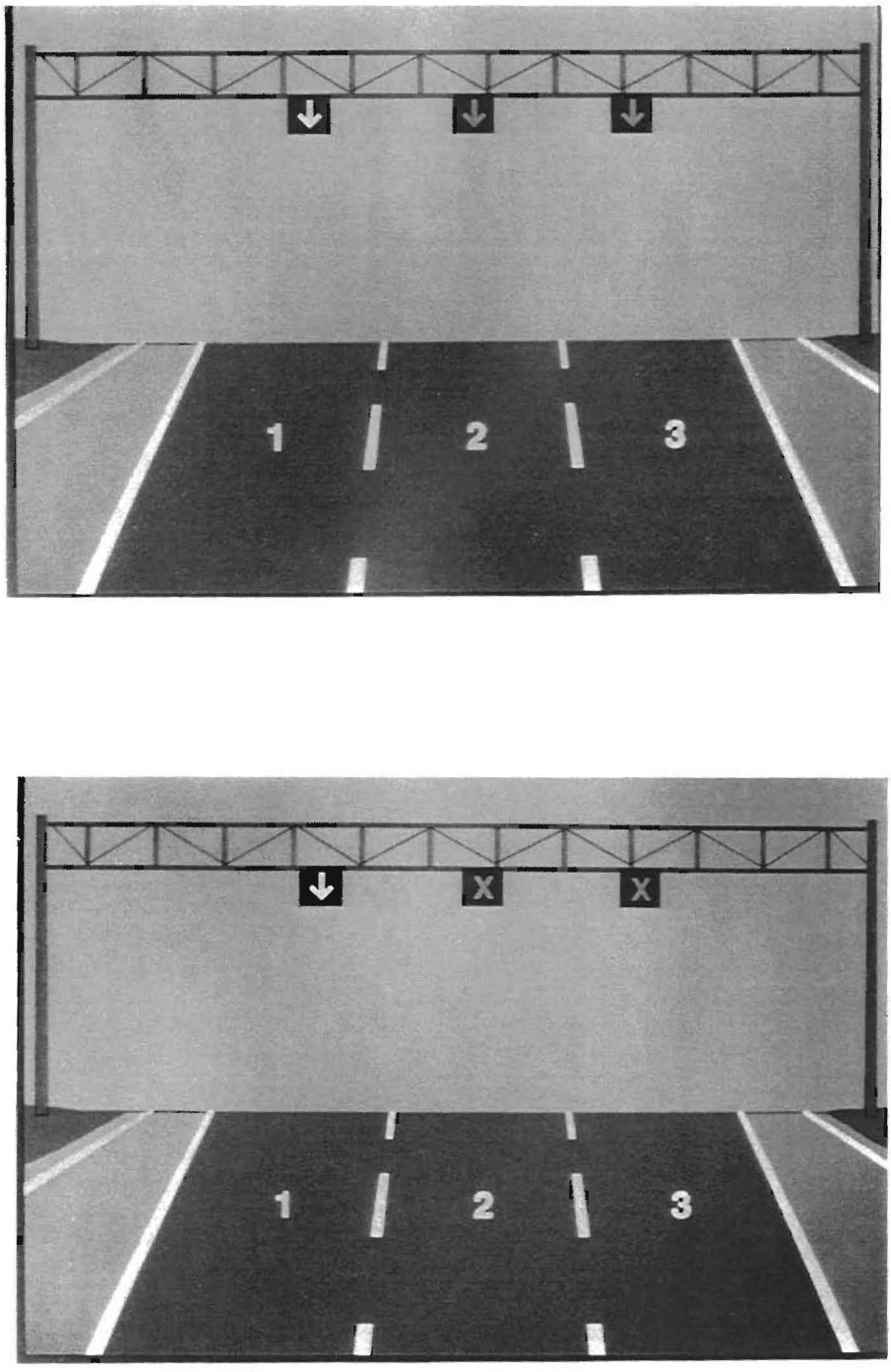

Figure 6-5. LCS Arrays I and J (Yellow Arrow, Green Arrow or Red X in Other Lanes).

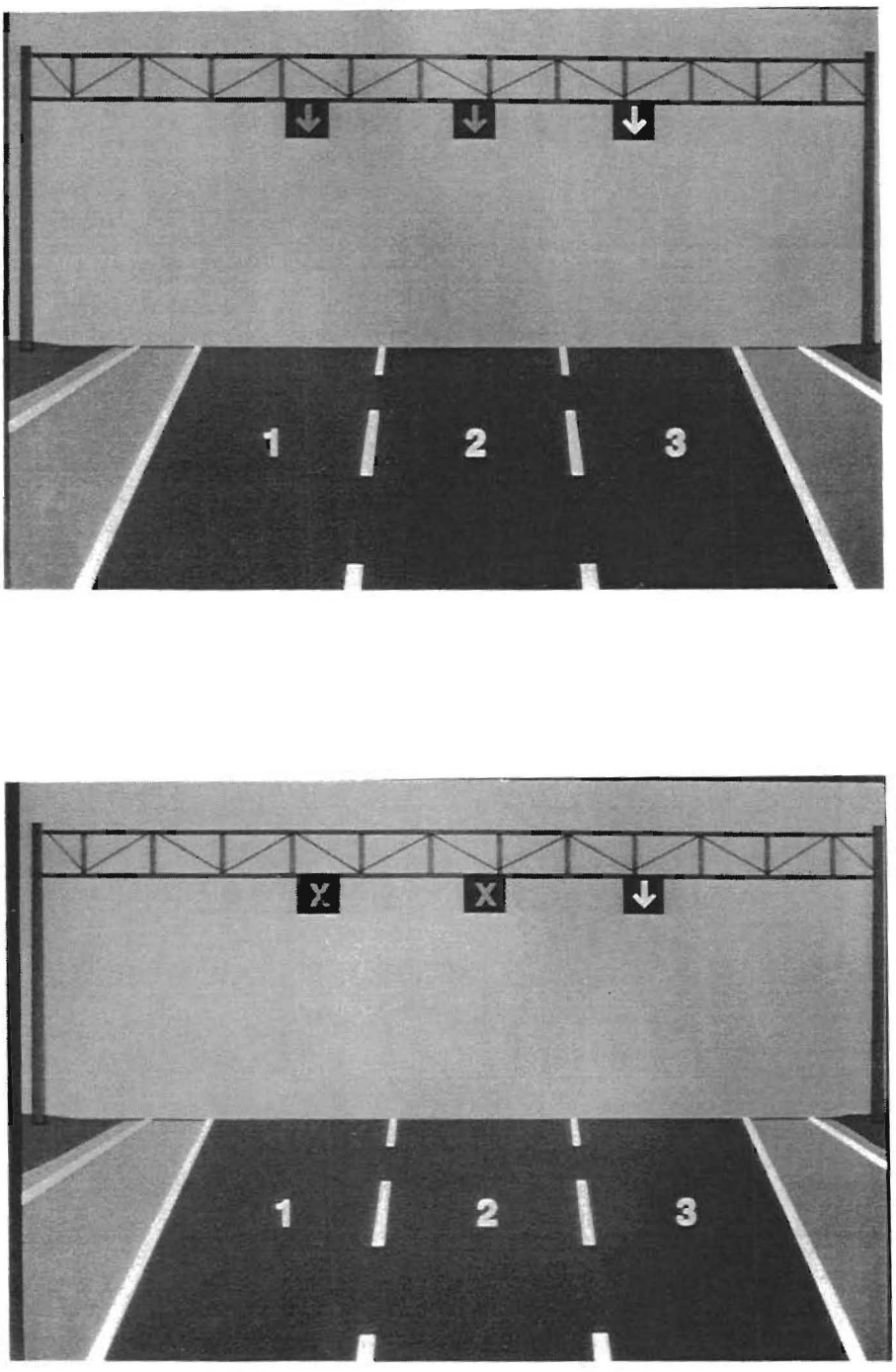

Figure 6-6. LCS Arrays K and L (Green Arrow or Red X in Two Lanes, Yellow Arrow).

Survey administration in study #3 was expanded slightly from that of the previous studies. After subjects were presented a specific LCS scenario, they were asked to envision themselves driving in a particular lane and then queried as to what they would do in response to the symbol located above their lane; what they felt the symbol indicated about the condition and status of that lane; and how far downstream they felt action was required in response to the symbol shown above their lane (if any action at all was implied by the symbol).

Data Reduction

Table 6-1 summarizes the basic demographic distribution of subjects recruited to participate in this study. Overall, the frequency of subjects in the male, young (less than 25), Hispanic, and college-educated subgroups were slightly higher than the averages for the state of Texas.

After reviewing the response data obtained, it was noted that interpretations of the yellow arrow presented in the middle lane were essentially identical regardless of whether it pointed downward left or downward right (with a red X and a green arrow positioned over the right and left lanes). Consequently, these responses were consolidated into a single group representing the yellow diagonal arrow interpretations when a red X and a green arrow were present. Statistical analyses were then performed to determine whether subject responses to the yellow X and yellow diagonal arrow differed when only green arrows were present, whether the responses differed for each symbol depending on whether it was in the left or the right lane, and whether the responses differed from those obtained when a red X and green arrow were present in the LCS array.

Results

Interpretations of the Yellow X and Yellow Diagonal Arrow

Table 6-2 summarizes the responses obtained from subjects when asked about the lane condition implied by the yellow X and the yellow diagonal arrow as presented in LCS arrays A through D (with two green arrows over the adjacent lanes). Generally

TABLE 6-1. COMPARISON OF TEXAS AND STUDY #3 DEMOGRAPHICS

	Percent of Drivers	
Age	Texas Statistics*	Study Statistics
less than 25	19	28
25 to 39	34	35
40 to 54	23	28
greater than 55	24	9
Gender		
Males	49	55
Females	51	45
Race		
Caucasian	61	61
African-American	12	4
Hispanic	26	31
Asian	NA	1
Other	2	3
Education		
less than high school	28	11
high school graduate	26	19
some college	28	33
college graduate	18	37

* Source: 1990 U.S. Census of Population and Housing

speaking, the responses were fairly similar for three of the four arrays. The responses to the yellow diagonal arrow displayed in the right lane were slightly different, though.

Whereas 55 to 59 percent of subjects said that the yellow X (in either the left or right lane) and the yellow diagonal arrow (in the left lane) meant that the lane ahead was

TABLE 6-2. SUBJECT INTERPRETATIONS OF THE LANE CONDITION IMPLIED BY THE YELLOW X AND YELLOW DIAGONAL ARROW WHEN DISPLAYED WITH TWO GREEN ARROWS: STUDY #3

Interpretation of Lane Condition	Percent of Subjects Responding	
	Yellow X	Yellow Diagonal Arrow
Yellow Symbol in Left Lane:		
"Lane is Closed or Blocked Ahead"	59	55
"Lane Physically Ends Ahead"	12	17
"HOV or Contraflow Lane"	3	1
"Lane is Congested Ahead"	3	3
"Unsure"	4	1
Other	23	23
Yellow Symbol in Right Lane:		
"Lane is Closed or Blocked Ahead"	58	43
"Lane Physically Ends Ahead"	10	25
"HOV or Contraflow Lane"	2	1
"Lane is Congested Ahead"	2	5
"Unsure"	2	1
Other	26	25

Responses to yellow diagonal arrow in right lane are significantly different than responses to yellow X in right lane ($z=3.29$)

closed or blocked, only 43 percent gave this interpretation to the yellow diagonal arrow when displayed over the right lane. Conversely, the second most common response for both symbols was that it meant that the lane physically ended downstream. For the three similar arrays, 10 to 17 percent of the subjects gave that response, compared to 25 percent of the subjects interpreting the diagonal arrow when displayed over the right lane. Interestingly, only a few subjects felt that either yellow symbol meant that the lane was congested, and only a few thought the lanes were for high-occupancy vehicles/contraflow travel. Only a few subjects indicated that they were unsure about what the yellow symbols meant. However, about one-fourth of the subjects offered unique answers to this question which were placed into the "other" category.

Table 6-3 presents subject interpretations of the yellow X and yellow diagonal arrows for the arrays that included both a red X and a green arrow as well as the yellow symbol. Overall, the responses were nearly identical for both yellow symbols. Sixty percent of subjects perceived the yellow X and diagonal arrow to mean that the lane is closed or blocked ahead. Only 5 to 8 percent of the subjects felt that the symbols meant that the lane physically ended ahead, whereas 13 to 14 percent believed that both symbols meant that the lane was congested ahead.

TABLE 6-3. SUBJECT INTERPRETATIONS OF THE LANE CONDITION IMPLIED BY THE YELLOW X AND YELLOW DIAGONAL ARROW WHEN DISPLAYED WITH A RED X AND A GREEN ARROW: STUDY #3

	Percent of Subjects Responding	
Interpretation of Lane Condition	Yellow X	Yellow Diagonal Arrow
Yellow Symbol in Middle Lane:		
"Lane is Closed or Blocked Ahead"	60	60
"Lane Physically Ends Ahead"	5	8
"HOV or Contraflow Lane"	1	-
"Lane is Congested Ahead"	14	13
"Unsure"	2	1
Other	18	18

- Responses differ by less than 1 percent

Responses for the yellow diagonal arrow when displayed in the right lane with two green arrows (see Table 6-2) are significantly different than responses to both yellow symbols when displayed with a red X and a green arrow ($z=3.56$)

Statistical comparisons of the responses for this study were accomplished by testing the difference in the proportion of subjects giving a specific response for each LCS array. This approach was used in lieu of categorical data analysis techniques because the study design was not as simple as for study #2. Using this approach, the

interpretations of the yellow diagonal arrow when displayed in the right lane with two green arrows (LCS array D in Figure 6-2) were significantly different than the yellow X displayed over the right lane with two green arrows in the array (LCS array C). Furthermore, interpretations of the yellow diagonal arrow in the right lane were also significantly different than the diagonal arrow displayed in the middle lane with a red X and a green arrow (LCS arrays F and H). Based on the responses received, it appears that displaying a diagonal arrow in the right lane in conjunction with green arrows in adjacent lanes gave more motorists the impression that the lane was about to physically end (i.e., a lane drop).

The actions subjects said they should take if they encountered the yellow symbol in each array are presented in Tables 6-4 and 6-5. In both tables, a large majority of subjects believed they should exit the lane in the direction of a lane under a green arrow. Table 6-4, which presents the data for the yellow X and diagonal arrow when displayed over the left or right lanes in conjunction with two green arrows, shows that 91 to 97 percent of the subjects indicated that they should exit from the lane under the yellow symbol to a lane under a green arrow. In comparison, only 1 to 5 percent of the subjects said they should slow down and stay in the lane under the yellow symbol. Very few subjects were unsure of what they should do in response to the symbols, or provided unique answers (labelled "other" responses).

Table 6-5 shows subject interpretations of the proper driving action to the yellow symbols when they were displayed over the middle lane in conjunction with a red X and a green arrow in the LCS array. Again, most (87 to 98 percent) of the subjects said that they should exit the lane. However, the yellow X received a significantly lower percentage of these responses as compared to the yellow diagonal arrow. Conversely, only 2 percent of subjects said they should slow down and stay in the lane under a yellow diagonal arrow, whereas 11 percent of the subjects responded in that manner for the yellow X. These responses are fairly consistent with those obtained in study #2 for the yellow X and diagonal arrow and reported in Tables 5-5 and 5-7, respectively.

The responses for the yellow X in Table 6-5 (when a red X and a green arrow were present in the LCS array) are significantly different than those for the yellow diagonal arrow in the same array, and are also different than the response to the yellow X when positioned over the left lane and displayed with two green arrows in the array.

TABLE 6-4. SUBJECT INTERPRETATIONS OF THE PROPER DRIVING ACTION IN RESPONSE TO THE YELLOW X AND YELLOW DIAGONAL ARROW WHEN DISPLAYED WITH TWO GREEN ARROWS: STUDY #3

	Percent of Subjects Responding	
Interpretation of Proper Driving Action	Yellow X	Yellow Diagonal Arrow
Yellow Symbol in Left Lane:		
"Exit to Lane Under a Green Arrow"	94	99
"Slow Down and Stay in Lane"	5	1
"Unsure"	-	-
Other	1	-
Yellow Symbol in Right Lane:		
"Exit to Lane Under a Green Arrow"	91	97
"Slow Down and Stay in Lane"	6	2
"Unsure"	1	-
Other	2	1

- Responses total less than 1 percent

As a final comparison between the yellow X and yellow diagonal arrow, subject interpretations of the urgency to respond to the symbols was assessed. Urgency was measured by the researchers by asking for the subject's estimate of the distance downstream that a response needed to be made from the point where a yellow symbol was presented. Subject estimates (again obtained in an open-ended response format) were consolidated into discrete intervals to facilitate analysis. Only those subjects who stated that the proper reaction to the yellow symbol was to exit the lane were used in this analysis (sample sizes for the other types of responses were not large enough to draw meaningful conclusions from them). For comparison purposes, estimates were also obtained for the red X.

Figure 6-7 presents a cumulative distribution of the distance subjects estimated that a response to the yellow symbol (X or diagonal arrow) needed to be made, categorized by whether or not a red X was also in the LCS array. The data for the red X itself are

TABLE 6-5. SUBJECT INTERPRETATIONS OF THE PROPER DRIVING ACTION TO THE YELLOW X AND YELLOW DIAGONAL ARROW WHEN DISPLAYED WITH A RED X AND A GREEN ARROW: STUDY #3

	Percent of Subjects Responding	
Interpretation of Proper Driving Action	Yellow X	Yellow Diagonal Arrow
Yellow Symbol in Middle Lane:		
"Exit to Lane Under a Green Arrow"	87	98
"Slow Down and Stay in Lane"	11	2
"Unsure"	1	-
Other	1	-

- Responses total less than 1 percent

Responses to the yellow X in middle lane are significantly different than those for a yellow diagonal arrow in the middle lane ($z=4.37$). The responses are also different than those of the yellow X in the left lane displayed with two green arrows ($z=2.56$)

also shown. As stated earlier, initial analyses showed no significant differences existed between the left and right lane arrays (arrays E, F, G, and H) for each symbol when no red X was present, and so these were consolidated into a single no-red-X category.

As the graph indicates, a higher percentage (33 percent) of subjects believed that they needed to respond as soon as possible (zero distance downstream) to the yellow X when no red X was present than any of the other three categories (yellow X and diagonal arrow with a red X and green arrow, and the yellow diagonal arrow with two green arrows). The yellow diagonal arrow displayed in conjunction with two green arrows was perceived by 25 percent of the subjects as requiring action as soon as possible. In essence, the yellow X conveyed a greater sense of urgency to respond than the yellow diagonal arrow to some subjects when it was presented in conjunction with green arrows over adjacent lanes. However, the yellow X was not seen as urgent a symbol as the red X by subjects as evidenced by the 42 percent who believed they should respond to the red X as soon as possible. When a red X and green arrow were added to the LCS array,

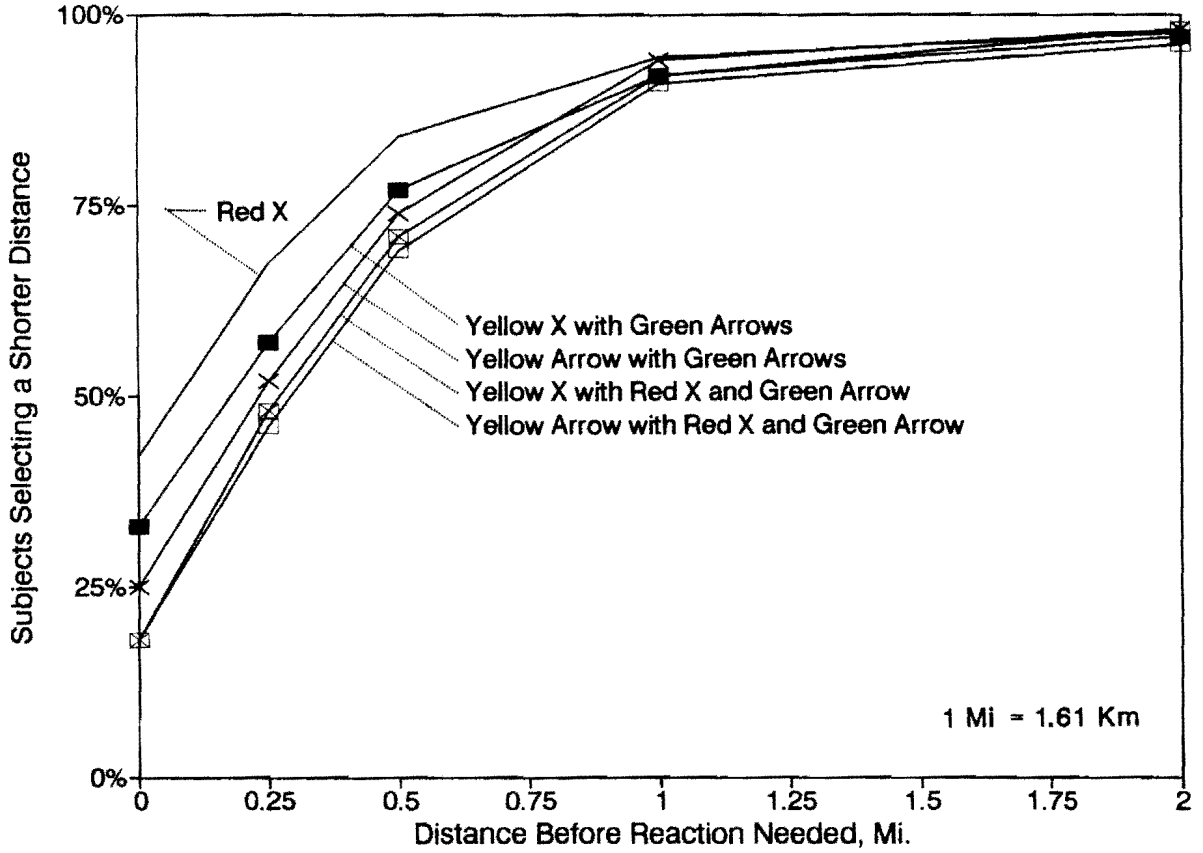

Figure 6-7. Response Distance to Yellow Symbols.

there was no significant difference between the yellow X and yellow diagonal arrow in the percentage of subjects perceiving that action was required as soon as possible.

As can be seen in Figure 6-7, the approximate reaction distances of the 50th-percentile subject were very similar for the two yellow symbols, with and without the red X. In general, these distances differ by less than 0.10 mi. (0.16 km.) Thus, although the yellow X (with two green arrows) affected the number of subjects providing an "as soon as possible" response, neither yellow symbol or specific LCS array significantly affected the median subject's estimate of the distance indicated by the symbols for a driving action to occur. In comparison, the 50th percentile subject believed that an action (exit the lane) was required within 0.10 mil (0.16 km.) beyond the red X symbol, again illustrating the

higher sense of urgency placed on the symbol of subjects than on any of the yellow symbols tested.

Interpretations of the Yellow Downward Arrow

Table 6-6 presents the common interpretations given by subjects with respect to the meaning of the yellow downward arrow. As was the case in study #2, subjects as a group did not agree upon a single common meaning of the symbol. The common interpretations were that the yellow downward arrow meant that the "lane is congested ahead," the "lane is closed or blocked ahead," or the "lane is open." However, none of these interpretations garnered more than one-half of the subjects responses, regardless of the LCS array evaluated.

Comparing the "left lane" and "right lane" data in Table 6-6, it does not appear that interpretations of the yellow downward arrow depend on the lane over which the arrow is positioned. However, substantial differences are evident in the interpretations of the arrow depending on whether or not the display includes green arrows or red Xs over the adjacent lanes in the LCS array. When displayed in conjunction with green arrows, subjects gave numerous responses as to the lane condition implied by the symbol. Most of these were unique and had to be consolidated into an "other" category (which contained 39 to 46 percent of the subject responses). Also, none of the subjects interpreted the yellow downward in these LCS arrays as indicating the "lane is open."

Referring again to Table 6-6, interpretations of the yellow downward arrow when displayed in conjunction with two red X's in adjacent lanes were dramatically different than when displayed with green arrows. In these arrays, 39 percent of the subjects felt the yellow downward arrow meant that the lane was congested ahead. Also, a significant number of subjects (26 to 31 percent) responded that the yellow arrow indicated that the lane was open. Significantly fewer responses (19 to 21 percent) were so unique that they had to be grouped into the "other" category.

The differences in yellow downward arrow interpretation between the red X and green arrow arrays appears consistent with the theory that motorists base those interpretations on the other symbols present in the array. When displayed with green

TABLE 6-6. SUBJECT INTERPRETATIONS OF THE LANE CONDITION IMPLIED BY THE YELLOW DOWNWARD ARROW: STUDY #3

Interpretation of Lane Condition	Percent of Subjects Responding			
	With Red Xs		With Green Arrows	
	Left Lane	Right Lane	Left Lane	Right Lane
"Lane is Closed or Blocked Ahead"	11	14	27	26
"Lane is Congested Ahead"	39	39	21	22
"HOV or Contraflow Lane"	-	-	4	3
"Lane is for Exiting Traffic"	6	7	7	7
"Pavement Damage Ahead"	-	-	9	-
"Lane is Open"	31	26	-	-
Other	19	21	39	46

- Responses total less than 1 percent

arrows, an interpretation different from the "lane is open" response commonly associated with the green arrow is provided by subjects (note that no subjects interpreted the yellow arrow as indicating the "lane is open" when green arrows were in the display). Conversely, when the yellow arrow was shown with red Xs over the adjacent lanes, fewer subjects interpreted the arrow as meaning that the "lane is closed or blocked ahead" (a meaning commonly attributed to the red X), instead interpreting the symbol to mean that the "lane is open."

Subject responses as to how they should react when shown a downward yellow arrow in a freeway LCS array are presented in Table 6-7. Overall, the answers were more consistent than they were for the interpretation of the meaning of that symbol. Generally speaking, subjects either chose "slow down and stay in the lane" or "exit the lane" responses. There was little difference in responses of the yellow arrow in the left lane or right lane when presented in conjunction with green arrows over the adjacent lanes. As the table illustrates, between 40 and 43 percent of the subjects selected an "exit the lane" response for the yellow arrow for arrays containing green arrows, and an additional 51 to 56 percent felt that they should "slow down and stay in lane." Only 4 to 6 percent of the subjects said they should continue in the lane as normal (without slowing down). Conversely, red Xs presented with a yellow downward arrow generated a much different distribution of responses. Specifically, no one indicated they would exit the lane under the yellow downward arrow, whereas 29 to 33 percent of the subjects said they would slow down and stay in the lane, and 64 to 67 percent said they would stay in the lane and continue as normal.

The responses given by motorists are logical given the arrays that were presented. When green arrows are shown in the LCS array, providing subjects an alternative lane in which to drive, many interpreted the yellow arrow as indicating the need to exit. However, when the red Xs were shown, no clear alternative to the lane under the yellow arrow was evident, and most subjects said they would do nothing different (i.e., they would continue as normal in that lane).

As with the yellow X and yellow diagonal arrow, subject assessments of the urgency implied by a yellow downward arrow was examined by asking them how soon (in distance) they needed to react after seeing the arrow. This question was relevant only for those subjects who previously indicated they would exit the lane or slow down in

TABLE 6-7. SUBJECT INTERPRETATIONS OF THE PROPER DRIVING ACTION IN RESPONSE TO THE YELLOW DOWNWARD ARROW: STUDY #3

Interpretation of Proper Driving Action	Percent of Subjects Responding			
	With Red Xs		With Green Arrows	
	Left Lane	Right Lane	Left Lane	Right Lane
"Exit the Lane"	-	-	40	43
"Stay in Lane and Slow Down"	29	33	56	51
"Stay in Lane and Proceed as Normal"	67	64	4	6
Other	4	3	-	-

- Responses total less than 1 percent

response to the arrow. Over one-half (55 to 58 percent) of the subjects indicated that they needed to respond within 0.25 mi (0.40 km) of the symbol. This is similar to the responses obtained for the yellow X and downward diagonal arrow discussed previously. The estimate was consistent regardless of the lane position of the yellow arrow (left or right lane) or the other type of symbol (green arrow or red X) in the LCS array. Unfortunately, the sample size was not large enough to allow a comparison of estimates according to the type of reaction cited (i.e., a merge lane or a lane drop).

Discussion and Summary

Laboratory study #3 was conducted to determine the consistency of interpretations of the yellow downward diagonal arrow and yellow downward arrow as a function of the lane position over which they were located and the other symbols presented in the LCS array. The results of the study can be summarized as follows:

- The meaning implied by a yellow diagonal arrow appears to depend slightly on whether or not the arrow was positioned over the left or the right lane when shown in an LCS array with green arrows over adjacent lanes. Specifically, a slightly greater number of subjects felt that the diagonal arrow over the right lane meant that the lane was physically ending downstream (i.e., a merge lane or a lane drop) as compared to being positioned over the left lane.

- The meaning implied by a yellow X did not differ significantly depending on the lane over which it was positioned, or whether it was displayed only with green arrows or with both a red X and a green arrow over the adjacent lanes.

- The proper reaction to a yellow diagonal arrow did not differ significantly depending on its lane position in the LCS array or whether it was shown with a red X and green arrow together. Conversely, subject responses to the yellow X again displayed significant differences depending on whether the LCS array contained only the two green arrows or a red X and green arrow combination.

- Some subjects appeared to perceive the yellow X as requiring a more urgent response (in terms of the distance from the symbol that a reaction was required)

than the yellow diagonal arrow when displayed in conjunction with two green arrows. A significantly higher percentage of subjects said they would respond as soon as possible to the yellow X than said they would to a yellow diagonal arrow. However, when displayed in conjunction with a red X and green arrow, no significant differences in perceived urgency was detected between the yellow X and the diagonal arrow. Despite these differences in "as soon as possible" responses, the median reaction distance to the yellow X or diagonal arrow was nearly identical regardless of the LCS array in which it was shown.

- Subject interpretations of the meaning of and proper driving reaction to the yellow downward arrow were found to depend on whether it was shown in conjunction with green arrows or red X only in a LCS array. However, no significant differences were detected as a function of the lane over which the yellow downward arrow was positioned. There were no significant differences in the urgency to respond implied by the yellow downward arrow, either.

Given these results, it appears that a yellow diagonal arrow may generate a more consistent interpretation among motorists in terms of the proper driving action (i.e., to exit the lane). However, motorists may not assume they need to exit the lane for the same reasons for all LCS arrays displaying a diagonal arrow. It could be argued that the driving action taken in response to the symbol is more important than the reason subjects believe they need to react. However, responses obtained in a laboratory setting regarding subject-reported driving behavior will likely be much different than their actual behavior if observed in the field. Hence, both measures of symbol interpretation need to be considered in future design and operational policies established for freeway LCS.

With respect to the interpretation of the yellow downward arrow, study #3 results again indicate that the symbol does not convey a common meaning to motorists. Also, the meaning appears to change depending on the other symbols in the LCS array. Given this lack of stability, agencies should be cautioned against using this symbol under multiple LCS array configurations without extensive educational campaigns or other techniques to teach motorists an intended meaning of the symbol. Even then, agencies should be cautioned to use the yellow downward arrow for only a limited number of situations, where the consequences of misinterpretation would be minimal.

7. STUDY PROCEDURES AND RESULTS FOR STUDY #4

Laboratory Stimuli

The fourth laboratory study consisted of three objectives. The first objective was to evaluate a universal "do not" symbol (i.e., a red circle with a slash through it) and a red X superimposed on a green arrow as alternatives to the basic red X for freeway LCS. Figure 7-1 illustrates the circle-slash symbol. These symbols were examined to see whether they might convey a "lane closed" message even more consistently than the red X currently used for this purpose (recall from studies #1 and #2 that 80 to 85 percent of Texas drivers currently interpret the red X in this way).

The second objective was to determine if motorist interpretations of a red X might be affected by flashing the symbol rather than displaying it in a steady mode. It was felt that if interpretations were not affected by flashing (as the results of study #2 showed for the yellow diagonal arrow), some operating agencies might explore the possibility of flashing the red X to attract attention to the LCS. Conversely, a different interpretation (as a transition between the green arrow and red X, for example) might also be of interest to operating agencies if it was more consistent than existing LCS symbols now allowed in the MUTCD.

The final objective of study #4 was to determine how motorists interpret a flashing green arrow. In Studies #2 and #3, interpretations of a downward yellow arrow were explored, in the hope that they would indicate that motorists are allowed to travel in a given lane, but should use caution (due to an incident in an adjacent lane or on the shoulder, for example). In study #4, the flashing green arrow was examined to see whether it too would generate a "use caution but remain in the lane" type of interpretation consistently among drivers.

A hypothetical freeway scene was used that included a sign structure with freeway LCS attached over each of three travel lanes (see Figure 7-1). For all of the alternatives examined, steady green arrows were displayed over the two right lanes. The symbol over the left lane was then altered to one of the alternatives. The display units constructed for

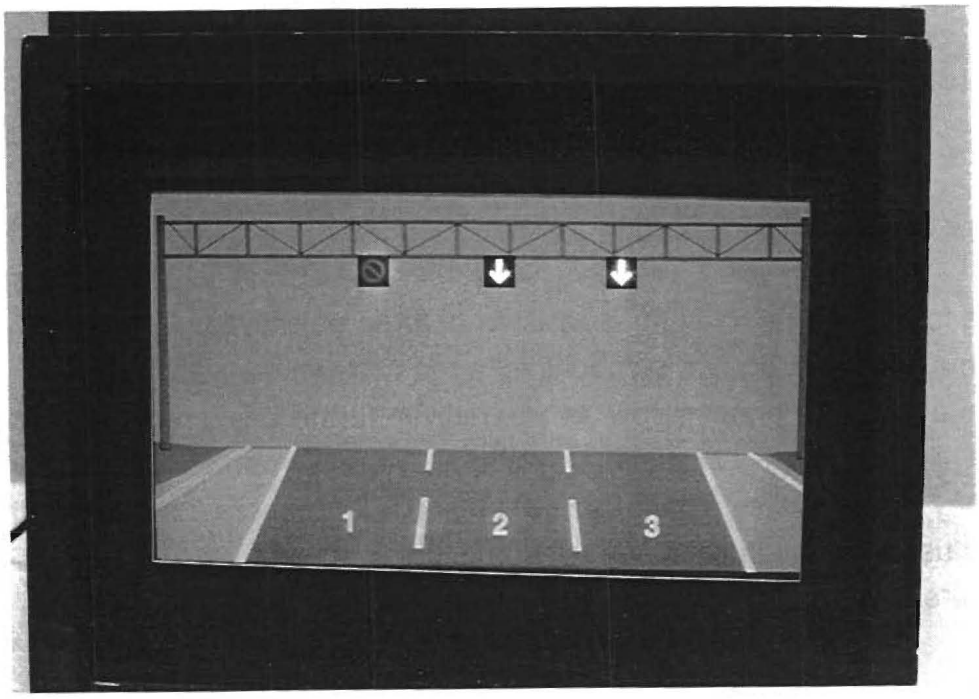

Figure 7-1. Example of Red Circle-Slash Symbol Evaluated in Study #4.

Study #2 were again used in this study to simulate the flashing red X and green arrow symbols.

Experimental Plan

Subjects were recruited as they stood in line at the Department of Public Safety driver licensing stations in Houston and Ft. Worth, Texas. Drivers in Houston were asked to interpret the flashing red X (in comparison to a steady red X) or a flashing green arrow, whereas drivers in Ft. Worth evaluated either the circle-slash or the red X/green arrow combination (each subject evaluated only one symbol alternative). A total of 50 subjects evaluated each symbol. Subjects were asked to interpret what each symbol indicated about the condition of the lane, and what action they should take as a driver in that lane. However, difficulties in survey administration again resulted in some incomplete or confusing responses to requests for lane condition interpretations. Consequently, only the proper driving action responses were used in this analysis.

In general, the study groups were comparable to those of the other experiments from the Houston and Ft. Worth sites, and were similar to statewide population statistics for Texas with respect to age, gender, and education.

Results

Interpretations of the Circle-Slash and Red X/Green Arrow Symbols

Table 7-1 presents a tabular summary of subject responses to the circle-slash and red X/green arrow combination. For comparison purposes, subject interpretations of a steady red X (displayed in conjunction with green arrows over adjacent lanes) from Ft. Worth subjects in experiment 2 are also shown in the table. The table illustrates that neither alternative symbol generated more "exit the lane" responses than the steady red X. Rather, more subjects decided that they would observe other drivers and wait for additional instructions before responding, indicating that the symbol created some degree of confusion and indecision among those subjects. Slightly fewer subjects said they would stop in response to the red X/green arrow than for the basic red X display (0 percent versus 8 percent, respectively). However, this may simply be a result of increased confusion over the symbol (i.e., not knowing whether the symbol means to stop or to go). Given that neither alternative symbol increased the number of "exit the lane" responses, no formal statistical tests comparing the responses to the steady red X were performed.

Interpretations of the Flashing Red X and Green Arrow Symbols

Table 7-2 presents a comparison of the proper driving action responses to the flashing red X from Houston subjects to those for a steady red X. From this table, it appears that the flashing display had only a minimal effect upon subject interpretations of the proper driving action to take (relative to the responses given for a steady red X). Whereas 84 percent of the subjects believed that they should exit the lane under a steady red X display, 78 percent felt this way when the red X was flashing. Conversely, a slight increase occurred in the number of subjects indicating that they would stop in response to the symbol (12 percent for the flashing red X versus 8 percent for the steady red X),

TABLE 7-1. SUBJECT INTERPRETATIONS OF RED X ALTERNATIVES: STUDY #4

Interpretation of Proper Driving Reaction:	Percent of Subjects Responding		
	Red X	Red X/ Green Arrow	Circle-Slash
"Exit the lane"	84	70	68
"Drive cautiously/slow down"	4	6	6
"Stop in lane"	8	-	2
"Observe others/ wait for instructions"	-	18	14
Other	4	6	10

- responses total less than 1 percent

and in the percent who would slow down and drive cautiously in the lane (8 percent for the flashing red X versus 4 percent for the steady red X). Statistically speaking, however, there were no significant differences in interpretations between the two symbols.

Table 7-3 summarizes subject interpretations of the flashing green arrow, displayed in conjunction with two steady green arrows (over the middle and shoulder lanes, respectively). For comparison purposes, subject interpretations of the downward yellow arrow (displayed in conjunction with two green arrows as well) and the steady green arrow (with a downward yellow arrow) are also shown in the table. Overall, subject interpretations of the flashing green arrow are considerably different than either the steady green or steady yellow arrows. Specifically, a lower percentage of subjects provided a "stay in lane and proceed as normal" response for the flashing green arrow than for the steady green arrow (46 percent versus 94 percent, respectively). Meanwhile, fewer subjects viewing the flashing green arrow provided a "stay in lane and slow down" type of response than for the steady downward yellow arrow (20 percent versus 50 percent, respectively). Finally, fewer subjects felt that they should exit the lane in response to the flashing green arrow than did subjects viewing the yellow arrow (30 percent versus 47 percent, respectively).

TABLE 7-2. SUBJECT INTERPRETATIONS OF FLASHING RED X: STUDY #4

	Percent of Subjects Responding	
Interpretation of Proper Driving Action:	Red X	Flashing Red X
"Exit the lane"	84	78
"Stay in lane and slow down"	4	8
"Stop in lane"	8	12
Other	4	2

Interaction between display type and responses:
$X^2 = 1.53 < X^2_{(0.05,3)} = 7.81$ ∴ responses do not differ by type of display

As shown at the bottom of Table 7-3, these differences in responses were verified statistically (using the procedures discussed in Chapter 5). Overall, it appears that the flashing green arrow would be less effective than even the steady downward yellow arrow as a symbol for indicating the need to slow down and drive cautiously in a given lane.

Discussion and Summary

Study #4 was designed to investigate the interpretations of two alternatives to a steady red X (the universal circle-slash and the red X superimposed over the green arrow) as well as flashing red X and green arrow symbols (all displayed in conjunction with steady green arrows over two other travel lanes). The results of the experiments can be summarized as follows:

- Compared to a steady red X, neither the circle-slash nor the red X/green arrow combination symbols resulted in greater percentages of subjects believing they should exit the lane over which the symbol is displayed. Thus, there is no reason to prefer them to the steady red X to indicate that a freeway lane is closed and that travel in that lane should be terminated.

TABLE 7-3. SUBJECT INTERPRETATIONS OF FLASHING GREEN ARROW: STUDY #4

Interpretation of Proper Driving Action:	Percent of Subjects Responding		
	Flashing Green Arrow	Steady Yellow Downward Arrow[a]	Steady Green Arrow
"Stay in lane/proceed as normal"	46	3	94
"Drive cautiously/slow down"	20	50	4
"Exit the lane"	30	47	-
Other	4	-	2

[a] responses from experiment 3 (yellow arrow, green arrow, green arrow display)

Interaction between responses for flashing green arrow and yellow arrow displays: $X^2 = 53.6 > X^2_{(0.01,3)} = 11.3$ ∴ responses do differ between displays

Interaction between responses for flashing and steady green arrow displays: $X^2 = 71.7 > X^2_{(0.01,3)} = 11.3$ ∴ responses do differ between displays

- Subject interpretations of a flashing red X were not significantly different than interpretations of the steady red X. Whether a flashing red X would be useful in increasing the attention-getting value of that symbol was not examined in this study, however.

- A flashing green arrow (displayed in conjunction with steady green arrows over adjacent travel lanes) appears to convey to most subjects that a special driving action is needed. Only 46 percent of subjects indicated that they would stay in the lane and proceed normally if a flashing green arrow were situated over the lane, compared to 94 percent of subjects who evaluated a steady green arrow. However, few subjects provided a "stay in lane and slow down" response for that symbol (20 percent).

8. CONCLUSIONS AND RECOMMENDATIONS

Conclusions Regarding Laboratory Studies of Freeway LCS

Four laboratory studies were conducted to investigate how motorists interpret existing and proposed symbols for freeway LCS systems. Efforts were made to explore the role of other symbols in an overall LCS array upon interpretations of a given symbol, and whether that interpretation changed depending upon its mode of presentation (i.e., steady versus flashing displays). The findings from these laboratory studies are consolidated below.

Interpretation of MUTCD Symbols For Freeway LCS

The MUTCD currently allows three symbols to be used for freeway traffic management purposes: (1) a green downward arrow to indicate a lane is open and that travel is permitted, (2) a yellow X to indicate that a lane is about to be closed and that motorists should begin to vacate the lane, and (3) a red X to indicate that a lane is closed and that travel in that lane is prohibited. The results of the laboratory studies support the use of both the green arrow and the red X for these purposes. Nearly all subjects participating in the studies correctly interpreted the green arrow, and over 80 percent of subjects correctly interpreted the red X. Data collected in these studies also indicate that the red X is viewed as requiring a reaction by motorists (to exit the lane) within 0.10 mi. (0.16 km.) after it is displayed.

Furthermore, interpretations of both the green arrow and the red X were not affected by the presence of other symbols in an overall LCS array at a location, and were fairly consistent across three different study locations statewide (Ft. Worth, Houston, and San Antonio). A slightly greater percentage of correct interpretations of the red X was noted from Ft. Worth subjects. This was assumed to be due to the ongoing display of LCS symbol definitions by TxDOT District officials on the changeable message signs along the I-35W corridor.

Whereas the green arrow and red X generate a common and consistent interpretation among Texas motorists, the yellow X was found to elicit widely varying responses depending on the context in which it was used. When displayed in conjunction with green arrows only in an LCS array, motorist interpretations of the yellow X are more consistent with its intended meaning of an impending lane closure and the need to vacate the lane. When presented in conjunction with a red X, however, motorists appear less likely to associate a yellow X with an impending lane closure and the need to exit the lane. Rather, they are just as likely to believe that the symbol indicates congestion or other hazards in the lane downstream for which they simply need to slow down and be careful.

Potential of a Yellow Downward Diagonal Arrow to Replace the Yellow X

Interpretations of a yellow downward diagonal arrow were investigated in laboratory studies for use in place of the yellow X as a potential transition LCS (given the lack of a common and consistent interpretation of the yellow X by motorists). The studies showed that this symbol provides a clear message about the proper action to take as a driver in that lane (i.e., to exit the lane in the direction of the arrow). Overall, 95 percent or more motorists provided this interpretation for the diagonal arrow. The message to exit the lane is maintained regardless of whether or not a red X is present in the LCS array or of the direction that the arrow is pointing. The diagonal arrow does not automatically indicate to motorists exactly why they need to vacate a lane; the responses obtained for the lane condition implied by the diagonal arrow were as varied as those for the yellow X. For example, when presented over a right lane in conjunction with green arrows over adjacent lanes, a few motorists believe the diagonal arrow indicates that the lane physically ends downstream (i.e., that a lane drop occurs). Consequently, the use of the diagonal arrow appears to be most appropriate in conjunction with a red X downstream (the red X implies a consistent "lane closed" message to motorists, which is important in keeping motorists in other lanes from considering moving into the closed lane). The yellow X does appear to be interpreted by motorists as requiring action more quickly than a diagonal arrow, when displayed with green arrows only. When displayed in conjunction with a red X and a green arrow, the yellow X and diagonal arrow elicited the same estimate of urgency from the subjects.

Potential of a Yellow Downward Arrow as a Cautionary Symbol in Freeway LCS Systems

Another non-standard symbol examined in the laboratory studies was a yellow downward arrow. This symbol was considered to be a candidate for indicating to motorists that they should take added caution when travelling in that lane, but that it is not necessary for them to exit the lane (a symbol for this purpose does not currently exist in the MUTCD). Study results showed that the downward arrow suffered from the same lack of a consistent and common meaning as the yellow X. A wide range of meanings for the yellow downward arrow were offered by subjects with respect to the condition it implied about that lane. The interpretation also varied depending on whether or not there were red X's in the LCS array. In terms of the drivers proper reaction to this symbol, motorists appear divided as to whether to stay in the lane but slow down or to exit the lane as long as another lane is available (i.e., a green arrow is in the LCS array). If the LCS array contains only yellow downward arrows and red X's, almost all motorists recognize that they should remain in the lane under the arrow (but are divided as to whether it is important for them to slow down and be careful).

The yellow downward arrow was not found to present a clear and single common meaning to motorists. It appears that any attempt to utilize this symbol for freeway LCS will require an extensive driver education effort prior to implementation. Even then, it may be difficult to predict how motorists will interpret the symbol in unusual or complex LCS arrays.

Potential of Other Symbols

A limited amount of data were collected on symbols considered in lieu of the red X. These were the universal "do not" symbol (a circle with a slash through it), and a green arrow with a red X superimposed on it. The data showed no reason to change from the red X for showing that a lane is closed and that travel in that lane is prohibited.

Potential of Flashing LCS Symbols

The effect of flashing various LCS symbols upon motorist interpretations were explored in the laboratory studies. The results indicated that flashing has no significant effect upon motorist interpretations of the yellow diagonal arrow or the red X. Conversely, motorists were confused by a flashing green arrow. Whereas they assumed that it represented a non-normal condition, it was not immediately clear to them whether they should exit the lane, slow down, exit the freeway, etc. Flashing the yellow downward arrow had little effect upon motorist interpretations at two of the study locations, but did result in different interpretations from Houston motorists. This anomaly was attributed to the fact that the transit agency in Houston displays a flashing yellow downward arrow at merge and diverge points on its transitways. Some of these occur at slip ramps between the transitway and the adjacent freeway lanes. Motorists in Houston tended to associate the flashing yellow arrow with the need to exit the lane, which would be consistent with how it is applied at these transitway slip ramps.

Recommendations

The results of the laboratory studies provide valuable insight into motorist perceptions and possible behavior in response to LCS systems for freeway traffic management. However, these results do not automatically transfer into actual motorist behavior. Field research is needed to determine how motorists respond in actual driving situations.

With respect to specific recommendations from the laboratory studies, additional lab study and field experimentation with the yellow diagonal arrow appears to be warranted at this time. The diagonal arrow provides a more consistent interpretation of the action desired from motorists relative to a yellow X, and its use in lieu of the yellow X needs to be explored in greater detail. The practical implications of implementing a yellow diagonal arrow on a freeway facility containing more than two or three lanes per direction were not addressed in this research. Additional work is needed to explore these and other practical ramifications of a diagonal arrow versus a yellow X before a definite change can be recommended.

Finally, the results of the studies suggest that motorists in Ft. Worth have, as a group, a better understanding of the definitions and purposes of LCS. LCS have existed on I-35W in this city since 1988 (although not used in real-time traffic management). Although not verified directly as part of this research, it is hypothesized that the educational efforts of TxDOT District officials via the changeable message signs have been successful. This would suggest that motorists can be taught the meaning of LCS and that educational efforts by the Department may be quite beneficial to motorists as the LCS components of the freeway traffic management systems throughout Texas are brought on line.

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