Motorist Interpretation of MUTCD Freeway Lane Control Signals

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The results of a human factors laboratory study designed to investigate current motorist interpretations of lane control signals in a freeway driving environment are presented. Subjects were recruited to view a drawing of a freeway scene that included a sign structure supporting lane control signals over each lane. The type of symbols displayed over the lanes were then varied. Subjects were asked what they believed each signal indicated about the condition of the lane under the signal and what the correct driving response would be to that signal. The results of the study showed that most subjects interpreted the green arrow as indicating that a lane was open and that they would proceed in that lane as normal. The red X was most commonly interpreted as indicating that the lane was closed and that drivers should exit that lane. However, interpretations of the yellow X, defined in the *Manual of Uniform Traffic Control Devices* as a transition signal between the green arrow and the red X, were not as consistent. More important, the interpretation of this symbol was shown to be dependent on what other symbols were present in the overall display configuration at a given point on the freeway.

According to the *Manual of Uniform Traffic Control Devices* (MUTCD), "lane-use control signals (LCS) are special overhead signals having indications used to permit or prohibit the use of special lanes of a street or highway or to indicate the impending prohibition of use" (*1*). The MUTCD allows the use of four LCS 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 that a driver 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.

In the United States, LCSs are most commonly used for controlling reversible lane operations on arterial streets, bridges, and tunnels. However, the MUTCD does allow LCSs on freeways when it is desired to keep traffic out of certain lanes at certain hours, to indicate that a lane ends at the terminus of a freeway, and to indicate that a lane is temporarily blocked by an accident, stalled vehicle, or the like.

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Motorists traveling on freeways may also see LCSs used for purposes other than the active management of the main travel lanes. In Houston, Texas, for example, freeway drivers see LCSs installed over the high-occupancy vehicle reversible transitways in the median of the freeways to indicate the proper direction of traffic flow and on toll facilities at toll plazas to indicate which booths are open to traffic, which are closed, which give receipts or require exact change, and so forth.

Concern over the actual motorist interpretations of, and response to, currently accepted LCSs in a freeway driving environment prompted the Texas Department of Transportation (TxDOT) to sponsor research on freeway LCSs in order to develop improved design, installation, and operations guidelines for their use. This paper presents the results of an evaluation of current motorist interpretations of existing LCS symbols in a freeway driving environment.

BACKGROUND

Previous human factors research on motorist comprehension of LCSs has been limited. One study was performed by Forbes et al. more than 30 years ago (*2*). 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. On the basis of the results of their studies, the researchers concluded that a red X was most often associated with the desired interpretation (to exit a lane) and least often associated with an undesirable interpretation (to stop in the lane). Meanwhile, a green upward arrow was correctly interpreted as indicating that a lane was available for travel by almost all subjects. However, the results also suggested that the experimental method used affected the relative distribution of what were defined as desired and undesired interpretations. Specifically, an open response format (where motorists are not given predefined choices to choose from) resulted in more undesired interpretations of the red X.

The researchers also evaluated subject interpretations of a yellow X. Overall, they found subject interpretations of the symbol to be somewhat ambiguous. Subjects interpretations ranged from "do not drive in the lane" to "warning (take caution) in lane" to "drive slow in lane."

In the 1970s Dudek et al. conducted human factors research for the design of real-time motorist information systems (*3*). 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 ones were open. They 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, comprehension was improved dramatically if the title "Lane Condition" or "Lane Blocked" was at the top of the sign. However, it must be remembered that this research was limited to roadside sign designs. Placing the LCS directly over each travel lane visually anchors the signals to the lanes, providing an interpretation cue that is not inherently present in roadside signs.

Recently, Lavellee et al. performed limited research of lane control signal comprehension with Canadian motorists (*4*). In general, the results of that research were similar to those of Forbes et al. with respect to the red X and green arrow. Unfortunately, they did not examine comprehension of a yellow X.

As can be seen, the data base regarding motorist interpretation of LCSs is limited. Data are needed on the current motorist understanding of LCS displays in a freeway driving environment. Furthermore, one of the more important issues regarding freeway LCSs that has not yet been evaluated is the degree to which interpretations of individual symbols are dependent on what other symbols are displayed at a location. In actual freeway applications, motorists are exposed to an entire LCS display configuration, from which they must assess the condition of the lanes and decide the appropriate actions to take. Hence, it is possible that a LCS symbol may be interpreted very differently if the overall display configurations are dramatically different.

STUDY METHOD

Objectives and Method

Two objectives were identified for this study:

1. Determine current motorist interpretations of the standard MUTCD LCS displays in a simulated freeway driving scene, and
2. Determine whether interpretations of the various LCS symbols are dependent on the other LCS symbols displayed in an overall freeway LCS configuration.

To address these objectives, a laboratory experiment was constructed to evaluate motorist interpretations of LCSs. Motorists were shown color drawings of a hypothetical freeway scene that included a sign structure with freeway LCSs attached over each of four travel lanes. In each drawing, some combination of red X's, yellow X's, and green arrows was shown in the LCS signal heads over each lane. A subject was asked to view one of the drawings and imagine themselves driving in a specific travel lane. Subjects were then asked what the symbol meant about the condition of the lane and what would be the proper action for a driver in that lane. Subjects were then asked to consider themselves in a different driving lane (one with a different LCS symbol overhead) and again assess the lane condition and proper action. This was repeated until the subjects had evaluated all the symbols in that display configuration (i.e., freeway drawing).

Subject responses to these questions were recorded as stated (i.e., an open response format) for subsequent categorization and analysis. The survey took approximately 5 min to perform. Subjects were recruited from licensed drivers attending an automobile show at the Astrodome complex in Houston. The study was performed over 10 days in January 1992.

Survey Stimuli

Figures 1 through 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 LCS configurations were created, in which the symbols presented and the lanes over which the symbols were positioned were varied. The illustrations presented in this paper were modified to black-and-white copy for reproduction purposes. The actual drawings viewed by motorists were in color.

Figure 1 illustrates Display Configuration A. In this scene, all three symbols were presented to the subjects. A red X was displayed over Lane 1, yellow X's were displayed over Lanes 2 and 3, and a green arrow was displayed over Lane 4. This might indicate a situation in which the median lane has already been closed and an incident in the two middle lanes requires that they be closed a short distance downstream.

Only two symbols were used to create Display Configuration B (Figure 2). Yellow X's were placed over Lanes 1 and 2 and green arrows over Lanes 3 and 4. In comparison, Display Configuration C is shown in Figure 3. Again, only two symbols were presented: red X's over Lanes 1 and 2 and yellow X's over Lanes 3 and 4. This latter scene would indicate a situation in which two lanes are already closed and an incident in the right two lanes is forcing the transportation agency to close the freeway entirely.

Figure 4 presents Display Configuration 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 the first scene (Figure 1) in that all three symbols are visible in the same display configuration. Finally, Display Configuration E is shown in Figure 5. In this display, a red X is presented over Lane 1, and green arrows are placed over the three remaining lanes.

Experimental Plan

Each subject recruited was allowed to view and respond to only one particular LCS configuration. In this way, an elaborate experimental design to counterbalance learning effects was not required. As stated earlier, motorists were asked to envision themselves driving in each lane where a different LCS symbol was displayed. In Figure 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. However, subjects viewing Figure 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.

The experiment was designed to evaluate each LCS symbol in conjunction with one or both of the other symbols present in the configuration—that is, the yellow X was evaluated in

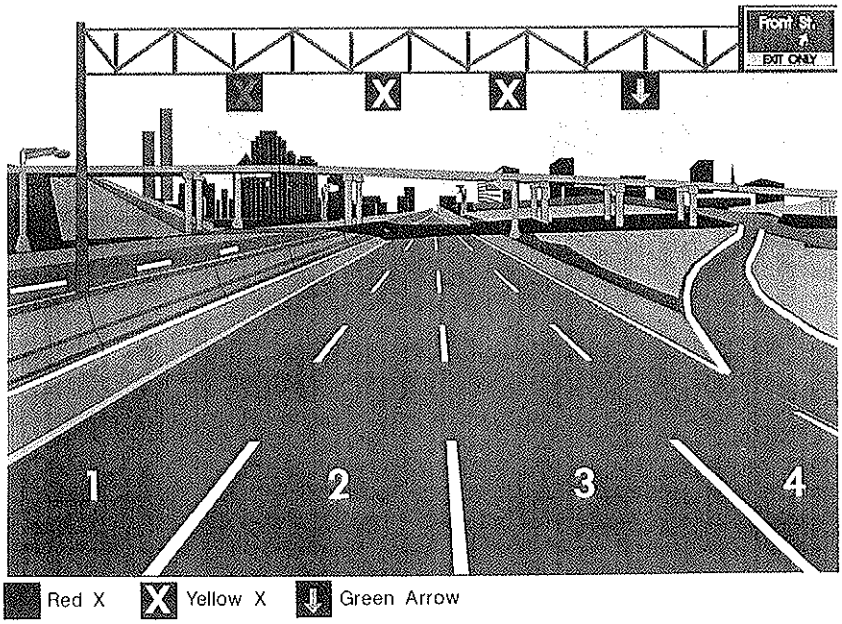

FIGURE 1 Display Configuration A.

one configuration with only green arrows present, in another with only red X's present, and in another with both green arrows and red X's present. The green arrow and red X were likewise examined. To summarize, Table 1 documents the overall experimental design of the study, indicating which symbols were present in which display configuration. As the table indicates, each symbol was included in four of the five configurations. Configurations A and D contain all three symbols, whereas the other configurations contain a combination of two symbols.

It should be noted that the longitudinal dimension of a freeway LCS system was not simulated in this experiment. Motorists traveling on a freeway outfitted with LCSs are likely to pass several LCS display configurations as they approach a lane blockage, and the upstream configurations already encountered would probably also have some influence on motorist interpretations of the symbols in the configuration being viewed. However, the data from this experiment are useful in assessing the effect of an entire display configuration on the interpretations of individual symbols. And situations may

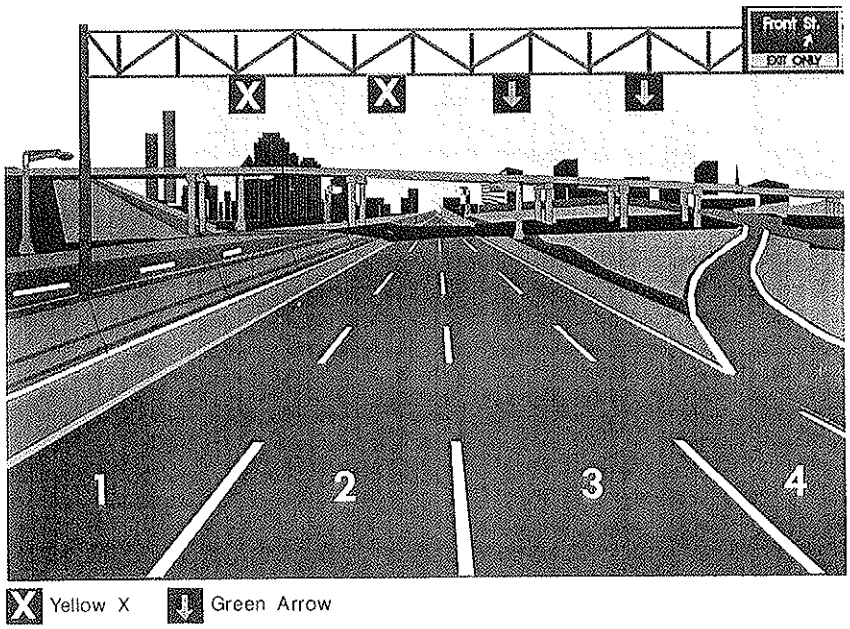

FIGURE 2 Display Configuration B.

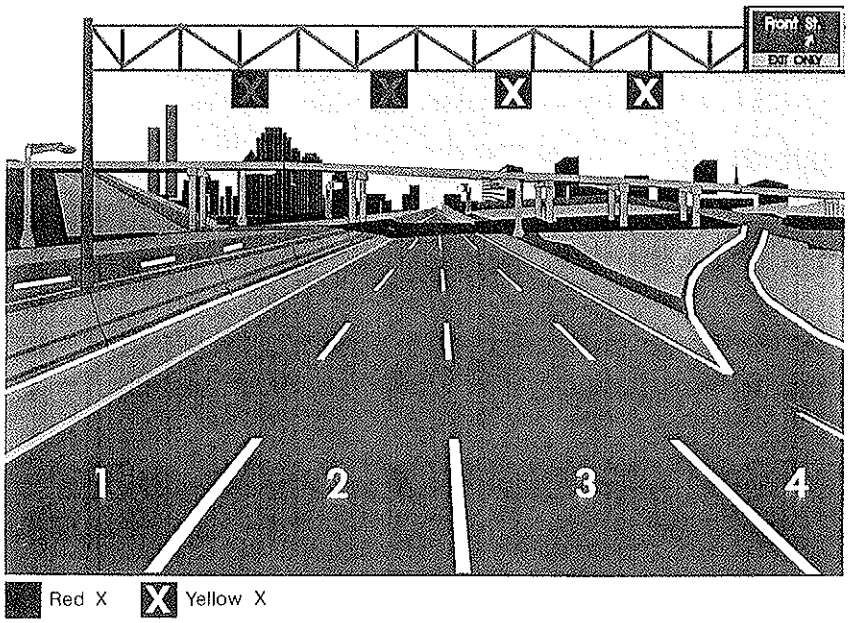

FIGURE 3 Display Configuration C.

arise in which such configurations could be encountered by motorists who had not encountered upstream LCS displays (if an incident occurred at the beginning of a freeway section equipped with LCSs, for example, or if a motorist entered the freeway immediately upstream of a lane blockage and sees only one set of LCSs before reaching the blockage).

Data Reduction

Table 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 overrepresented by

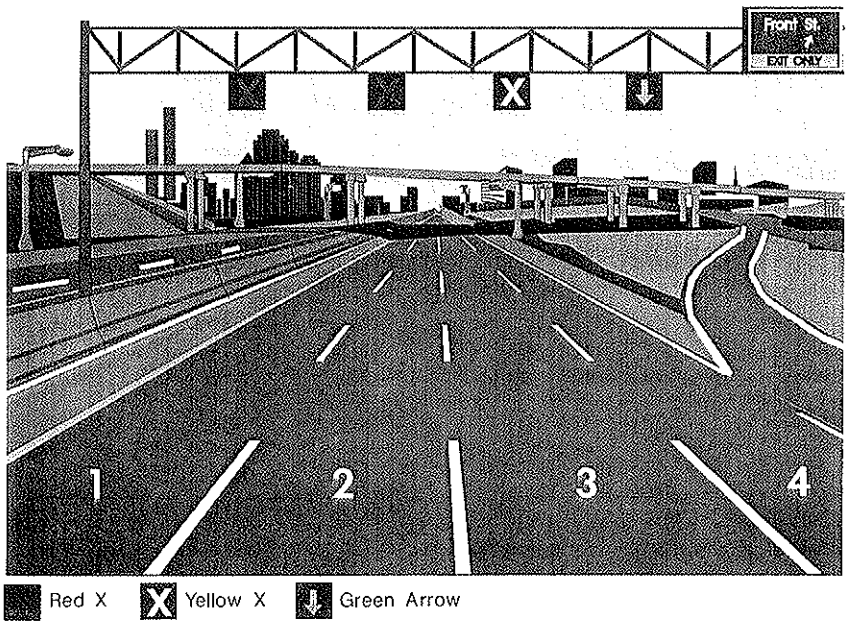

FIGURE 4 Display Configuration D.

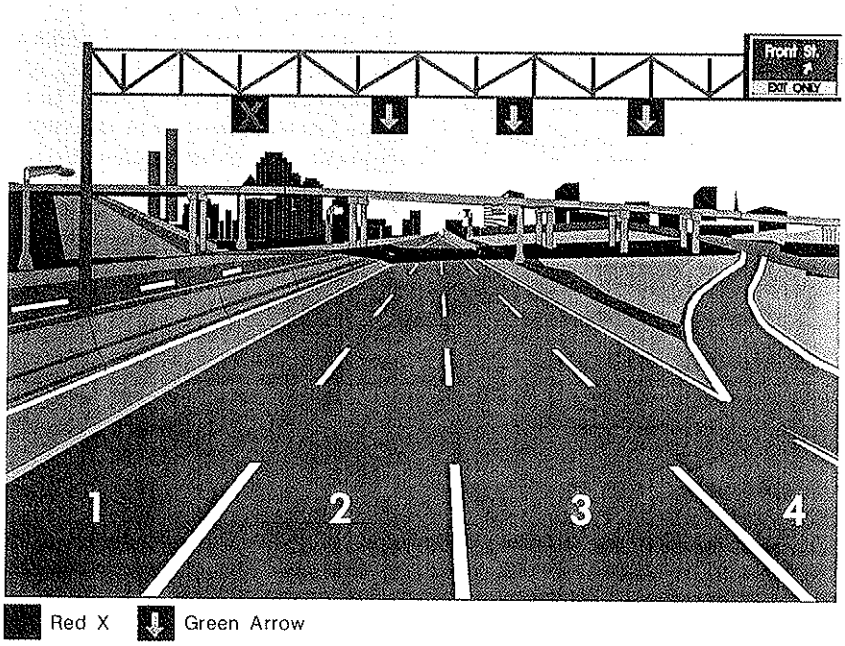

FIGURE 5 Display Configuration E.

men (73 percent men versus 27 percent women) and by the younger age categories (more drivers younger than 25 and fewer drivers older than 55) when compared with national driver licensing statistics (5,p.2). This was expected, given the type of event that the subjects were attending (an automobile show), and suggests that survey subjects may not have had as much previous driving experience on which to base their interpretations as would have been desired in this study. However, the major emphasis was on keeping the demographic distributions as consistent as possible from configuration to configuration (which was done successfully by survey administrators).

RESULTS

Interpretation of Downward Green Arrow

Previous research has shown the green arrow to have an implicit meaning among most motorists that the lane under a green arrow is open and that it is allowable to drive in that lane. Data from this study support that contention. Table 3 gives the percentage of subjects viewing each display configuration who believed that the green arrow meant that the corresponding lane was open. Overall, the percentage of subjects responding to the green arrow in this manner was very high, exceeding 85 percent for all display configurations. Averaging all configurations, it was found that 91 percent of the subjects believed the lane to be open.

Slight differences were detected, however, in responses to the green arrow from configuration to configuration. The responses to Configurations A and D were slightly more consistent with each other, as were those to Configurations B and E. Subjects viewing Configurations B and E were asked to envision themselves in Lane 3 when answering questions about the green arrows. Conversely, subjects viewing Configurations A and D envisioned themselves in Lane 4 (the only lane under a green arrow in those figures). A small number of subjects viewing Configurations A and D perceived the green arrow to mean that the lane was for exiting traffic, possibly confusing the LCS indication with a lane drop or exit sign indication.

When subjects were asked what they would do if driving in the lane over which a green arrow was displayed, most indicated that they would remain in that lane and proceed as normal. The configuration-by-configuration percentages of this

TABLE 1 Experimental Design

	Display Configuration				
Symbol	A	B	C	D	E
Green Arrow	*	*		*	*
Yellow X	*	*	*	*	
Red X	*		*	*	*

* denotes symbol was present in that particular display configuration

TABLE 2 Comparison of National and Study Driver Demographics

	Percent of Drivers	
Age	National Statistics (5)	Study Statistics
less than 25	17	34
25 to 39	35	38
40 to 54	23	23
greater than 55	25	7
Gender		
Males	52	73
Females	48	27

response are also presented in Table 3. Again, though, the percentage of "proceed normal" responses for Configurations A and D were slightly lower than for Configurations B and E. A few subjects viewing Configurations A and D stated that they would slow down and be watchful of downstream hazards and merging traffic, whereas none of the subjects viewing Configurations B and E responded this way.

Interpretation of Red X

Table 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 (less than 5 percent) believed that the red X indicated that there was oncoming traffic in that lane. There was a small proportion (also less than 5 percent) who had no idea what the red X meant (none of the subjects were confused by the green arrow). In general, the responses were consistent from configuration to configuration (no statistically significant differences were found based on a χ^2-test of independence between response categories and display configuration), and the responses were similar to those obtained in past studies of LCSs.

Summaries of subject interpretations as to the proper action for a driver in a lane under a red X are also given in Table 4. Most subjects stated that they would exit that lane (on average, 81 percent responded this way), but a few indicated that they would stop in the lane. Whether these few subjects were thinking that there would be traffic stopped in front of them that would require them to stop also was not ascertained. However, 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). The responses were also found to be very consistent from configuration to configuration, indicating that the interpretation of the red X was not dependent on what other symbols were present in the overall LCS display configuration.

Interpretation of Yellow X

Table 5 gives subject responses for each of the display configurations regarding the meaning of the yellow X with respect to the condition of the lane. Unlike responses to the green arrow and red X, responses to the yellow X differed dramatically depending on the display configuration viewed by the subject. As can be seen, most subjects (between 67 and 76 percent) viewing Configurations 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 that the indication meant that the lane was closed ahead or about to be closed. However, these trends were reversed for Configuration B. Only 21 percent of the subjects viewing Configuration B 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.

The yellow X also caused more confusion for the subjects than either the red X or green arrow. About twice as many subjects had no idea what the yellow X meant as those who did not understand the red X (8 percent versus 4 percent, respectively), further suggesting interpretation problems with that indication. Overall, a χ^2-test of independence between lane condition responses for the yellow X and display configuration was found to be statistically significant at a 5 percent level ($\chi^2 = 49.8$, $\chi^2_{critical} = 16.9$). Also, given the intended meaning of the yellow X to indicate an upcoming closure of

TABLE 3 Subject Interpretations of Green Arrow

	Percent of Subjects Responding				
	Configuration				
Interpretation of Lane Condition	A	B	D	E	Ave
"Lane is open"	85	93	87	97	91
"Lane is for exiting"	7	-	7	-	3
Other	8	7	6	3	6
Interpretation of Proper Driving Action					
"Stay in lane/proceed as normal"	87	90	87	99	92
"Slow down and be watchful"	5	4	3	1	3
Other	8	6	10	-	5

- responses total less than 1 percent

TABLE 4 Subject Interpretations of Red X

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

a travel lane as defined in the MUTCD, it is apparent that most motorists do not inherently associate the signal with an impending lane closure under most of the display configurations tested in this study.

Table 5 presents the most common responses given by subjects as to the proper action when the yellow X is displayed over a travel lane. Again, substantial differences were apparent between configurations and verified through statistical testing ($\chi^2 = 93.7$, $\chi^2_{critical} = 16.9$). For Configurations A and D, subjects as a group were split between those who interpreted the yellow X as requiring them to exit the lane and those who interpreted it to mean that they should stay in the lane but proceed cautiously at a slower speed. For Configuration B, most 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 Configuration 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 Configuration C are 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 that they could move to, so apparently they 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 Configuration C indicated that the proper response would be to proceed normally in the lane under a yellow X. It should be noted that a few subjects (7 percent) did indicate that they would exit the freeway if the yellow X in Configuration C was encountered. Very few subjects viewing the other configurations gave this response.

Finally, it is interesting to note the similarity of responses of the proper actions to the yellow X in Configuration B and the red X in the other configurations. Configuration B contains only yellow X's and green arrows. When presented with this display, most (72 percent) of the subjects believed that the correct action from 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 appear to focus on the type of symbol being displayed (an X) and assume that the proper response would be to exit that lane. Apparently, if a red X is not present in the display, subject interpretations of a yellow X are more consistent with those intended by the MUTCD.

TABLE 5 Subject Interpretations of Yellow X

	Percent of Subjects Responding				
	Configuration				
Interpretation of Lane Condition	A	B	C	D	Ave
"Hazard or danger in lane"	76	21	67	68	58
"Lane is closed or will be closing"	5	45	3	11	16
"I don't know"	11	9	6	6	8
Other	8	25	24	15	18
Interpretation of Proper Driving Action					
"Exit the lane"	35	72	1	57	41
"Exit the freeway"	-	-	7	1	2
"Slow down/proceed cautiously in lane"	45	15	70	35	41
"Stay in lane/proceed normally"	7	3	15	4	7
Other	13	10	7	3	9

- responses total less than 1 percent

SUMMARY

This study has explored the current interpretations of LCSs in a freeway driving situation. In general, the results are similar to those of past studies. The study does suggest, however, that motorist interpretations of the various LCS symbols currently in the MUTCD depend to some degree on the other symbols present in an overall LCS display. This dependency is most noticeable for the yellow X. When displayed with green arrows only, this symbol is most likely to be interpreted as indicating a lane blockage or closure ahead and requiring an exit maneuver out of the lane over which the yellow X is displayed. This interpretation is most consistent with that intended by the MUTCD. However, when displayed with a red X, subjects are more likely to interpret the yellow X as a cautionary symbol and not to associate its display over a lane as indicating a need to exit that lane.

Whether these differences in interpretation result in different behavior by motorists when encountering these symbols on actual freeway sections has yet to be determined. Nevertheless, this research serves as an important starting point to illustrate the complexity of operating freeway LCSs in real time and the need to consider operating strategies from the perspective of the freeway motorist who must try and understand what message is trying to be conveyed.

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