Motorist Interpretation of Yellow X and Yellow Diagonal Arrow in Freeway Lane Control Signal Array

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Licensed driver interpretation of the Manual of Uniform Traffic Control Devices (MUTCD)-approved and experimental transition symbols in a lane control signal (LCS) array is documented. The two symbols tested were the yellow X (MUTCD approved) and the yellow downward diagonal arrow (experimental). These two symbols were displayed in a scene depicting a three-lane freeway section containing one LCS array. The various LCS arrays were representative of typical LCS configurations for a median lane closure. Each transition symbol was tested in combination with two green down arrows and in an array containing one red X and one green down arrow. Overall, the study showed the yellow downward diagonal arrow to be interpreted more consistently and "correctly" given its intended use than the yellow X. Subject responses varied more for the yellow X than for the yellow downward diagonal arrow when a red X was included in the LCS array. In addition, subjects were more likely to interpret the yellow X in a manner that was considered "incorrect" given the intended use of the yellow transition symbols—a problem that was magnified when a red X was incorporated into the LCS array. Subject interpretation of the yellow transition symbols was also affected by the introduction of a red X into the LCS array. The most preferred subject interpretation of the yellow X and yellow downward diagonal arrow was the same when the transition symbols were displayed in an LCS array either with or without a red X. The meaning offered most frequently by subjects was "lane closed, blocked, or closing." The second most common interpretation of both the yellow X and yellow downward diagonal arrow varied somewhat, however. When displayed with two green down arrows "lane ends physically" was the second most frequent interpretation, whereas introduction of a red X into the LCS array altered subject perception and "lane is congested" became the second most popular meaning.

The Manual on Uniform Traffic Control Devices (MUTCD) (*1*) defines lane use control signals (LCSs) as special overhead signals having symbols that are used to indicate whether the use of a specific lane or lanes of a street or highway is permitted or prohibited, or to indicate the impending prohibition of use. In the United States LCSs have most commonly been used for reversible-lane control. However, the MUTCD also points out several instances in which LCS may be appropriate where there is no intent or need to reverse traffic flow. Most of these applications involve freeways and include the following (*1*):

1. On a freeway, where it is desired to keep traffic out of certain lanes at certain hours to facilitate the merging of traffic from an entrance or exit ramp or other freeway;
2. On a freeway near its terminus, to indicate a lane that ends; and
3. On a freeway or long bridge to indicate a lane that may be temporarily blocked by an accident, a breakdown, or some other incident.

The MUTCD (*1*) currently specifies only one symbol for use when transitioning the status of a lane from open (green down arrow) to closed (red X). A steady yellow X may be used to indicate to a driver that he or she should prepare to vacate the lane above which it is displayed because a signal change is being made to a red X. Previous research has indicated that motorists may not fully understand the intended meaning of and proper response to the yellow X, especially if it is displayed concurrently with a red X in the same LCS array (*2, 3*). Although motorist understanding of the yellow X appeared to be somewhat limited, an outdoor laboratory study conducted by Lavallée et al. (*4*) and Engel et al. (*5*), using actual LCS heads, found that 85 percent of the observers identified yellow downward diagonal arrows pointing right or left as meaning merge right or merge left, respectively.

Questions raised as a result of these studies have prompted the Texas Department of Transportation, in cooperation with FHWA, to sponsor research to determine the suitability of another transition symbol, the yellow downward diagonal arrow, for use in place of the yellow X. This paper presents the results of a laboratory study conducted to document motorist interpretation of MUTCD-approved and experimental transition symbols in a lane control signal array. Whereas all approved and several experimental LCS symbols were tested, this report focuses primarily on motorist interpretation of the yellow X and yellow downward diagonal arrow. The term array as used here refers to a combination of two or more lane control signals facing one direction of traffic at a single location.

BACKGROUND

Although several reports documenting motorist comprehension of green down arrow and red X LCS symbols were identified in the literature review, only a few were found that chronicle motorist interpretation of and reaction to a yellow transition symbol. Of the three yellow transition symbols identified in the literature review (that is the yellow X, the yellow down arrow, and the yellow downward diagonal arrow), studies examining motorist understanding of the yellow X were found to be the most prominent.

Using slightly different survey instruments, Forbes et al. (*6*), Carlson and Lari (*7*), and Ullman et al. (*3*) found that subject interpretations of the yellow X were somewhat inconsistent. Both Ullman et al. and Forbes subjects were shown full-color pictorial representations of LCS arrays in a freeway environment, whereas

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Carlson and Lari subjects were presented with black and white graphical depictions of LCS symbols on the questionnaire they were asked to complete. Although no attempt was made by Carlson and Lari to depict the LCS symbols in a freeway environment, most of the survey subjects had been exposed to them in the field while driving through the Lowry Hill Tunnel on I-94 in Minnesota.

Subject interpretations of the yellow X in the three studies included "do not drive in this lane"; "warning (take caution) in lane"; and "drive slow in lane" among others, indicating that there may be some confusion about the proper driving response required. In addition, Ullman et al., observed that driver interpretation of the yellow X was further influenced by the presence of a red X in the LCS array, making the interpretation less consistent with that intended by MUTCD.

Carlson and Lari (*7*) and Ullman et al. (*3*) also surveyed motorists to determine their interpretation of the yellow down arrow. Although further research may reveal a more appropriate use for this particular symbol, subject interpretations suggest that it would perform no better than a yellow X given the objective of encouraging motorists to exit the lane above which it is displayed. Carlson and Lari also conducted operational tests of the yellow down arrow and the yellow X in the I-94 Lowry Hill Tunnel. During normal operations on this facility, green down arrows were displayed above all travel lanes. However, when an incident occurred, a red X was displayed above the obstructed lane(s) and a flashing yellow X or yellow down arrow was displayed above any other lane(s) which was affected by the incident but not blocked. (Steady yellow symbols were used to transition LCS indications from the green down arrow to the red X.) Green down arrows remained over the lanes that were not affected by the incident or the resulting congestion. Results of these studies indicated that drivers do respond to information conveyed by LCSs by shifting from incident to nonincident lanes. No field studies were found that documented motorist reaction to the yellow downward diagonal arrow.

For a more detailed review and critique of the previously mentioned studies or for information about motorist interpretation of the red X, green down arrow, and additional experimental LCS symbols, the reader is encouraged to refer to Wohlschlaeger (*8*) and Ullman et al. (*3*).

OBJECTIVES

Three objectives were identified for this study:

1. To determine the degree to which the interpretation of and reaction to the yellow X and yellow downward diagonal arrow vary with respect to the other symbols present in the LCS array.
2. To identify the yellow symbol with the most consistent driver interpretation over the various freeway LCS arrays investigated.
3. To determine the urgency with which drivers expect action to be required when presented a yellow transition symbol in a freeway driving situation.

STUDY METHOD

To address the objectives of this study, a laboratory experiment was constructed to evaluate motorist response to, interpretation of, and perceived urgency of response to MUTCD-approved and experimental transition symbols in an LCS array. The investigation consisted of person-to-person surveys of licensed motorists solicited from the patronage of a San Antonio, Texas, Department of Public Safety (DPS) Drivers' License Station. As such, subjects were limited to licensed drivers who were present at the drivers' license station on the days of the study and who agreed to participate.

Each subject was required to sit through a 2-min introduction. Including the introduction, each survey took approximately 10 min to conduct. Slightly more than 240 usable questionnaires were collected over a 2-wk period.

Survey Stimuli

The LCS array configurations investigated are indicated in Table 1. Figures 1 and 2 illustrate the visual stimuli presented to motorists. The actual drawings used were color reproductions and were larger [27.5 by 21.25 cm (11 by 8.5 in.)]. They have been modified to black and white for reproduction purposes. An identical three-lane section was used for each freeway scene. Four different LCS arrays were created by varying the symbols presented and the lanes over which they were positioned. Numbers were placed in the freeway travel lanes for use as a reference during survey administration. Vehicles were intentionally left out of the drawing to eliminate subject confusion when answering survey questions.

Upon presentation of a particular LCS array, subjects were asked (*a*) what they would do in response to the LCS symbol shown above a certain lane, and (*b*) what they felt that particular symbol indicated about the condition or status of that lane, or both. In addition, if they indicated that a response other than "continue in lane" would be appropriate, subjects were asked to provide an estimate of how far downstream they would expect to have to respond. Survey participants were also asked to identify what differences, if any, they felt were implicit in the use of the two yellow transition symbols. An open-ended response format was used to avoid biasing the subjects.

Experimental Plan

Each participant was shown all four freeway scenes; however, the order in which they were presented was varied for each group. The arrays shown and the order in which they were shown to each of four groups can be seen in Table 2.

The first scene shown to all subjects (Scene A) consisted of one of the yellow transition symbols (yellow X or yellow downward diagonal arrow) along with two green down arrows. The second scene (Scene B) provided subjects with the opportunity to make a side-by-side comparison of the two yellow transition symbols. The two LCS arrays shown in Scenes A and B (Arrays 1 and 2) are indicative of displays that a transportation agency may use to indi-

TABLE 1 Lane Control Signal Arrays

Array No.	Inside Lane (Lane 1)	Middle Lane (Lane 2)	Outside Lane (Lane 3)
1	yellow x	green ↓	green ↓
2	yellow ↘	green ↓	green ↓
3	red X	yellow X	green ↓
4	red X	yellow ↘	green ↓

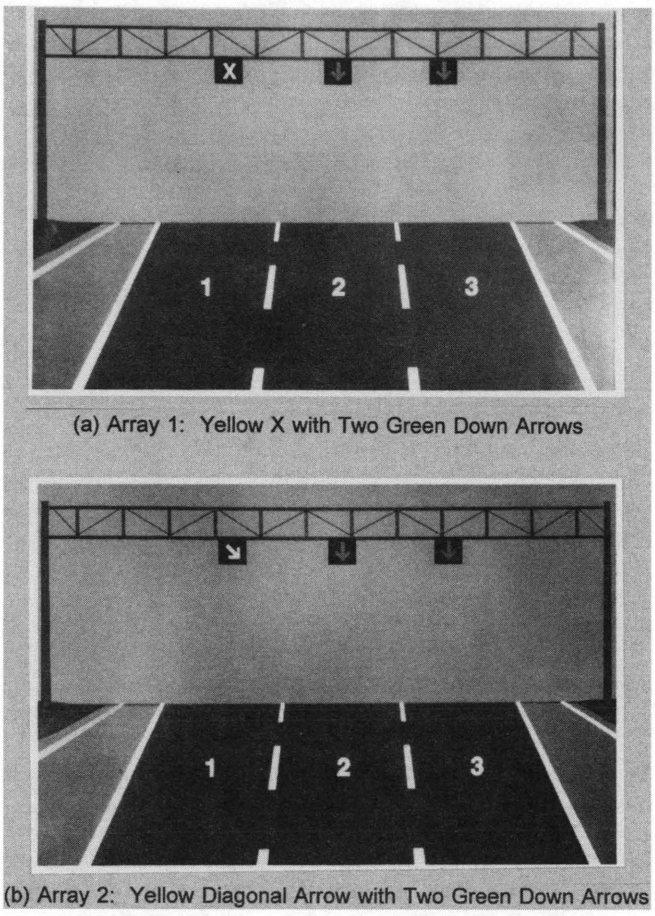

FIGURE 1 Freeway scenes shown to subjects participating in survey: Arrays 1 and 2.

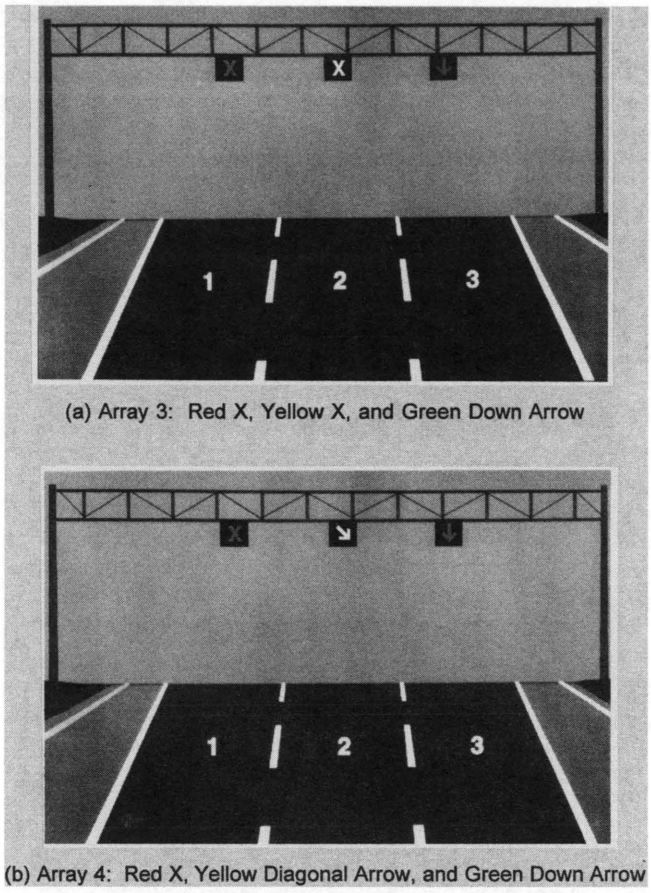

FIGURE 2 Freeway scenes shown to subjects participating in survey: Arrays 3 and 4.

cate that the inside lane (Lane 1) of a freeway will be closed ahead because of an incident.

The LCS array shown in Scene C contained one of the yellow transition symbols in conjunction with a red X and green down arrow. The LCS array shown in Scene D was similar to that shown in Scene C but exposed the subject to the candidate yellow symbol not shown in Scene C. These two LCS array configurations (Arrays 3 and 4) might be used by a transportation agency to inform motorists that the inside lane (Lane 1) was already closed and that incident conditions required the closure of the middle lane (Lane 2) further downstream.

Data Reduction

The answers to the survey questions were categorized by the authors and entered into a spreadsheet by group number, scene, symbol, question, and response. After compiling these answers, the percentage of response was calculated for each group number, scene, symbol, and question. Although answers varied slightly because of the survey format (i.e., open-ended response), it was not difficult to compile answers into larger-answer categories. Subject answers that did not clearly fit into one of the more definitive answer categories were categorized as "other." After determining that answers did not vary significantly across subject groups or as a result of the LCS array exposure order, the subject groups were combined and then separated into four categories corresponding to the four LCS arrays shown in Figures 1 and 2. The four categories included the following:

1. Yellow X without a red X present in the LCS array (YX);
2. Yellow downward diagonal arrow without a red X present in the LCS array (YDA);
3. Yellow X with a red X present [YX(RX)]; and
4. Yellow diagonal arrow with a red X present [YDA(RX)].

Test of proportions analyses were then conducted on the percentage of response in each answer category to determine whether subject answers about the candidate yellow symbols (a) varied with respect to the yellow symbol shown in the LCS array or (b) varied with respect to the other symbols shown in the LCS array (i.e., the presence or absence of the red X). Each test of proportions analysis conducted took on the following basic structure:

1. H_0: $p_1 = p_2$
2. H_1: $p_1 \neq p_2$
3. Level of significance: $a = 0.005$
4. Critical region: $|z| > z_{a/2} = 2.81$
5. Test statistic:

TABLE 2 Lane Control Signal Array Sequence Groupings

	Array Sequence by Scene			
Group No.	Scene A	Scene B	Scene C	Scene D
I	Array 1	Arrays 1 and 2	Array 3	Array 4
II	Array 2	Arrays 2 and 1	Array 3	Array 4
III	Array 1	Arrays 2 and 1	Array 4	Array 3
IV	Array 2	Arrays 1 and 2	Array 4	Array 3

$$z = \frac{\hat{p}_1 - \hat{p}_2}{\sqrt{\hat{p}\,\hat{q}\,[(1/n_1 + (1/n_2)]}} \quad (1)$$

Where p_1 and p_2 are the two population proportions of the attribute under investigation and

$$\left(\hat{p}_1 = \frac{x_1}{n_1}\right), \left(\hat{p}_2 = \frac{x_2}{n_2}\right), \text{ and } \left(\hat{p} = \frac{x_1 + x_2}{n_1 + n_2}\right) \quad (2\text{-}4)$$

where

x_i = the number of subjects whose answers fit within the indicated category i;
n_i = the total number of subjects in the sample population for the indicated category i; and
$\hat{q} = 1 - \hat{p}$.

The very low significance level ($a = 0.005$) was selected to account for the multiple comparisons made with the same set of data. For example, did the responses to the yellow x differ (*a*) between subject groups, (*b*) because of LCS array exposure order, (*c*) from the responses given for the yellow diagonal arrow, or (*d*) from the responses indicated to the yellow X when it was displayed in conjunction with the red X? The lower level of significance, therefore, was used so that the experiment-wide level of significance would be statistically acceptable ($\alpha \leq 0.5$). No statistical analyses of the subjects' perceived urgency of response were performed.

STUDY RESULTS

Demographics

Table 3 summarizes the basic demographic distribution of subjects recruited to participate in this study. Overall, the 240 survey subjects included more men and Hispanics and were younger and more educated than both the Texas and U.S. averages. Although some of the more unusual answers may or may not be given if another 240 subjects were surveyed, it is felt, given the sample size, that the overall breakdown of responses into the various answer categories would remain essentially the same.

There is no apparent explanation for the higher percentage of men participating in the study. One possible factor contributing to this may have been that the person soliciting subjects to participate

TABLE 3 Comparison of United States, Texas, and Survey Subject Demographics

		Percent of Drivers (9, 10)		
Question	Response	U. S.*	Texas*	Study Subjects
Gender	Male	51.3	51.5	60.6
	Female	48.7	48.5	39.4
Age Category	Less than 25	15.1	15.2	34.4
	25 to 39	35.4	37.2	31.5
	40 to 54	24.9	25.2	26.6
	Over 55	24.6	22.4	7.5
Ethnic Background	European-American	73.8	60.1	63.9
	African-American	11.1	9.5	5.8
	Latin-American/Hispanic	8.1	20.2	27.0
	Pacific-American	2.7	1.5	1.2
	American Indian/Eskimo	0.7	0.3	1.2
	Other	3.6	8.4	0.9
Education	Less than high school	24.6	28.1	12.0
	High school graduate	30.1	26.0	22.4
	Some College	20.8	22.9	29.9
	College Graduate	24.5	23.1	35.7

*Information on ethnicity and education includes general population (not just licensed drivers)

in the survey was a woman. Perhaps men were more willing to participate because of this, or it may have been that women were less likely to participate given that the survey administrator was a man.

The higher percentage of subjects in the youngest age category was not totally unexpected because drivers licensed in the state of Texas can renew their drivers' license by mail if they have an unblemished driving record. Because older drivers are usually safer drivers and can therefore renew their license by mail, it was not surprising that more younger than older drivers would be patronizing the DPS Drivers' License Station. The high percentage of Latin-American drivers participating in the survey was not surprising either. San Antonio, Texas, is known for its rich Hispanic heritage, and many of the residents are of Mexican descent.

The fact that more of the survey subjects had received a college education than was evident in both the Texas and national averages was a bit unanticipated. Although outside comments were rare and highly discouraged by the survey administrators, it may have been that the DPS patrons who chose not to participate in the study were concerned that family members or others standing nearby might be critical of their answers.

Subjects' Indicated Response to Yellow Transition Symbols

Freeway LCSs should convey a clear message and produce a consistent response from all drivers if they are to be truly effective tools for managing freeway traffic at major interchanges or during incidents, or both. Table 4 summarizes the percentage of subject responses in each of the yellow transition symbol categories.

When viewing the two LCS arrays that contained one of the yellow transition symbols and two green down arrows only (Arrays 1 and 2), a significantly higher percentage of subjects indicated that they would respond to the yellow downward diagonal arrow by moving to the lane with the green down arrow (98.8 percent) than would respond similarly to the yellow X (93.8 percent).

After a red X was added into the LCS array, 97.9 percent of the subjects responding to the yellow downward diagonal arrow continued to indicate that they would respond by moving to the lane with the green down arrow (a decrease of less than 1 percent). On the other hand, only 89.2 percent of the subjects indicated that they would respond similarly to the yellow X after the addition of a red X into the freeway LCS array (a decrease of about 4.5 percent). This difference between the two candidate yellow symbols was also found to be statistically significant. Introduction of the red X into the LCS array containing the yellow X also seemed to create some confusion among survey respondents causing them to be "unsure" of the proper driving response.

Subjects' Interpretation of Yellow Transition Symbols

Not only was it important to understand how subjects were likely to respond to the yellow transition symbols, it was also important to understand why subjects chose their particular response. Thus, subject interpretation of the yellow transition symbols was also explored. A summary of subject interpretations of the yellow symbol categories can be found in Table 5.

The interpretation given most frequently for all of the yellow symbol categories was that the "lane is closed, blocked, or closing." Excluding the "other" category, the interpretation offered second most frequently for both yellow transition symbols without the red X was that the "lane ends physically," an interpretation survey subjects felt was slightly more appropriate for the yellow downward diagonal arrow than for the yellow X.

After adding a red X into the LCS array, the most frequent interpretation for both yellow transition symbols remained "lane is closed, blocked, or closing." However, the second most preferred subject interpretation of both yellow transition symbols changed to "lane is congested," an increase that was found to be statistically significant. In addition, the percentage of subjects who offered the interpretation "lane ends physically" decreased significantly for both yellow transition symbols after the addition of a red X into the LCS array. When a red X was added to the LCS array, the yellow transition symbol was moved to the center lane. It seemed logical then that with three travel lanes visible, survey subjects were less

TABLE 4 Subjects' Indicated Response to Yellow Transition Symbol Categories

	Percent of Subjects Responding to Candidate Yellow Symbol Category							
Response to Symbol	YX		YDA		YX(RX)		YDA(RX)	
Move to the lane with the green arrow	90.5		96.3		82.6		94.6	
Slow and move to the lane with green arrow	3.3	93.8	2.5	98.8	6.6	89.2	3.3	97.9
Stay in lane	2.5		0.8		1.7		0.4	
Slow and stay in lane	2.9		0.4		6.6		1.3	
Stop	0.8		--		--		--	
Stop and continue slowly	--	6.2	--	1.2	0.4	10.8	--	2.1
Unsure	--		--		1.7		--	
Other	--		--		0.4		0.4	
Total	100.0		100.0		100.0		100.0	

YX = Yellow X; YDA = Yellow Diagonal Arrow; YX(RX) = Yellow X with red X; YDA(RX) = Yellow Diagonal Arrow with red X

TABLE 5 Subjects' Interpretation of Yellow Transition Symbol Categories

	Percent of Subjects Responding to Candidate Yellow Symbol Category			
Meaning of Symbol	YX	YDA	YX(RX)	YDA(RX)
Lane is closed or blocked	57.3	51.5	50.2	57.3
	59.0	55.2	57.7	63.1
Lane closing ahead	1.7	3.7	7.5	5.8
Lane ends physically	12.4	17.0	5.0	5.8
High occupancy vehicle lane	1.2	--	--	--
Contraflow lane	1.7	0.8	0.8	--
Exit lane	1.2	0.4		0.4
Lane is congested	2.9	2.5	13.7	13.3
Road splits	--	--	0.4	0.8
Pavement damage in lane	0.9	--	1.2	--
Unsure	3.7	0.8	2.5	2.1
Other	17.0	23.3	18.7	14.5
Total	100.0	100.0	100.0	100.0

YX = Yellow X; YDA = Yellow Diagonal Arrow; YX(RX) = Yellow X with red X;YDA(RX) = Yellow Diagonal Arrow with red X

likely to indicate that the yellow transition symbol indicated that the lane would be physically ending.

Subjects' Perceived Urgency of Response to Yellow Transition Symbols

Subjects' perceived urgency of response was also studied to discern the differences in subject understanding of the two yellow transition symbols. This was determined by asking subjects how soon they felt action was required in response to the yellow transition symbols.

Only those subjects who indicated that they would respond to the yellow transition symbols by "moving to the lane with the green arrow" were used in this analysis (sample sizes for other responses were not large enough to draw meaningful conclusions from them). This included those subjects who gave the response "move to lane with green arrow," as well as those subjects who responded "slow and move to lane with green arrow."

Figure 3 shows the cumulative proportion of subjects' perceived distance to the lane change maneuver for each of the four yellow transition symbol categories. Although most subjects (around 93 percent) felt they would respond within 1.61 km (1 mi), there were slight differences between perceived distances to the lane change maneuver for the four LCS arrays studied.

When displayed with green down arrows only, the yellow X appeared to command a more urgent response by survey participants. Approximately 35 percent of the subjects indicated that it would be appropriate to respond to the yellow X "as soon as possible," and 56 percent indicated that it would be appropriate to respond within 0.40 km (¼ mi) or less. The yellow downward diagonal arrow was a relatively close second. Approximately 26 percent stated that a lane change maneuver should be initiated "as soon as possible," whereas 52 percent said 0.40 km (¼ mi) or less. The yellow X and the yellow downward diagonal arrow shown with a red X tied for third (18 percent of the subjects asserted that it would be appropriate to respond "as soon as possible" to the yellow X (17 percent for the yellow downward diagonal arrow) and 43 percent indicated 0.40 km (¼ mi) or less for the yellow X (45 percent for the yellow downward diagonal arrow)).

Figure 4 shows the frequency with which subject responses fell into the various distance groupings for each of the yellow transition symbol categories. The majority of subjects (36 percent) who indicated that they would respond to the yellow X by moving to the lane with the green down arrow, indicated that they would do so as soon as possible. Those subjects responding similarly to the yellow downward diagonal arrow with two green down arrows however, were equally as likely (26 percent) to respond as soon as possible as they were to respond at a distance less than or equal to 0.40 km (¼ mi).

While subjects appeared to assign more urgency to the yellow X when the yellow transition symbols were displayed with green down arrows only, this trend was reversed when a red X was introduced into the LCS array. The majority of subjects (29 percent) who offered the response "move to the lane with the green down arrow" for the yellow X with a red X shown concurrently, indicated they would do so at a distance greater than 0.40 km (¼ mi) yet less than or equal to 0.81 km (½ mi). Subjects responding to the yellow downward diagonal arrow with the red X present in the LCS array, on the other hand, were most likely (28 percent) to initiate a response that was not immediate but was at a distance less than or equal to 0.40 km (¼ mi).

Although both the yellow X and yellow downward diagonal arrow were affected by the introduction of a red X into the LCS array, the yellow X was again affected to a greater degree. As explained previously, it seemed that when subjects viewed an array with one of the yellow transition symbols and two green down arrows, they tended to focus on the symbol being displayed. However, when the yellow transition symbol was displayed in the LCS

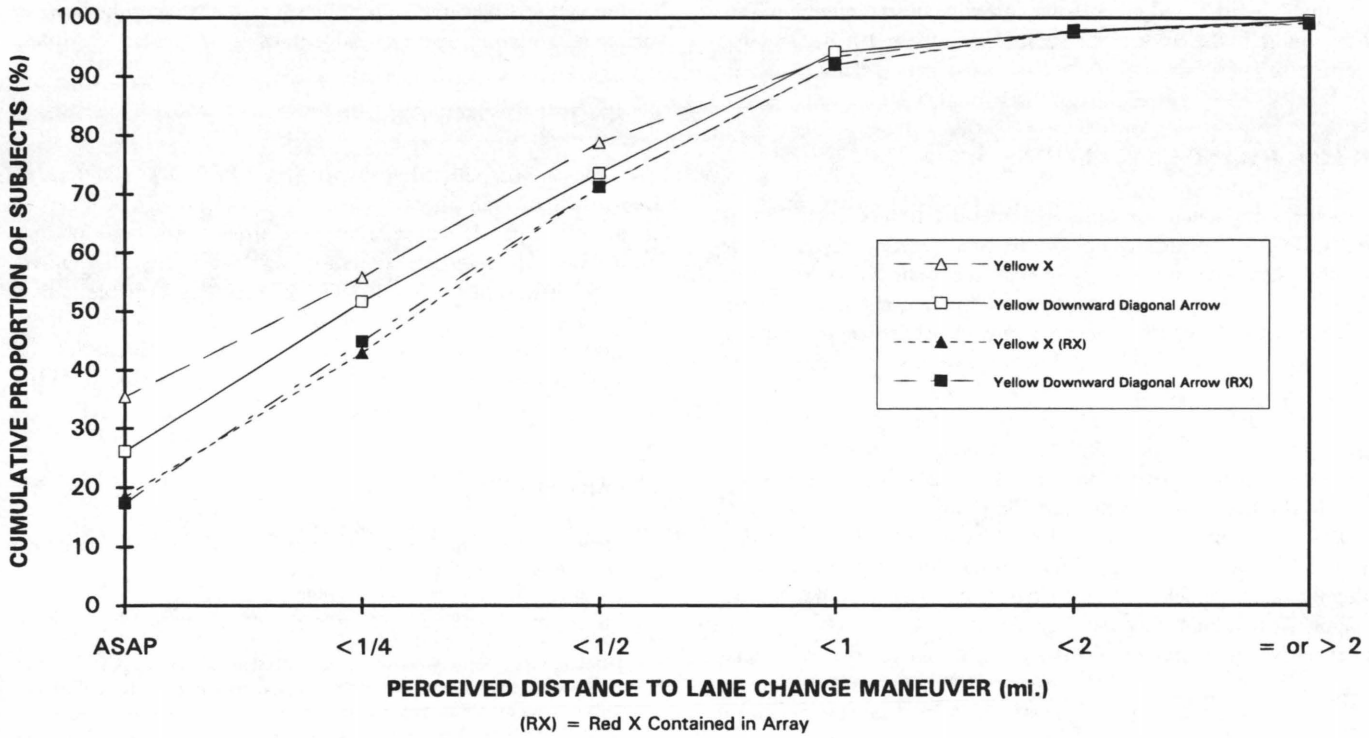

FIGURE 3 Cumulative proportion of subjects responding to "move to the lane with the green arrow" for the yellow transition symbol category indicated.

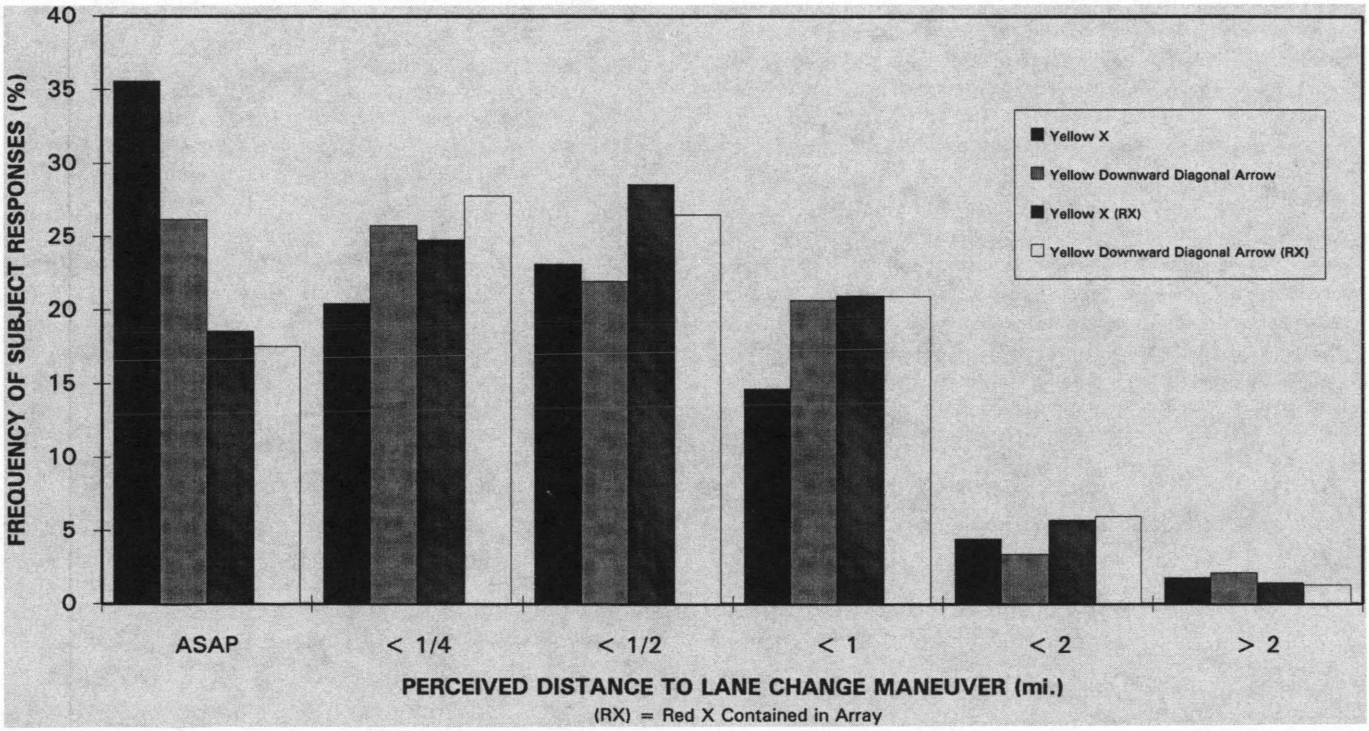

FIGURE 4 Frequency of subject responses for subjects responding to "move to the lane with the green arrow" for the yellow transition symbol category indicated.

array with a red X and green down arrow, subjects' attention was drawn more to the color of the symbols and the red X became the worse case.

SUMMARY AND CONCLUSIONS

This study has documented motorist interpretation of the yellow X and yellow downward diagonal arrow in a freeway LCS array. In general, the results of this study indicate that both yellow transition symbols are affected somewhat by the introduction of a red X into the LCS array. However, although the majority of subjects indicated a reaction that was considered "correct" given the intended meaning of the yellow transition symbols, the frequency with which subjects indicated an "incorrect" reaction for the yellow downward diagonal arrow was significantly lower than it was for the yellow X. Of the two yellow transition symbols investigated, the yellow downward diagonal arrow appeared to produce the least variation and confusion among survey subjects. There was also less of a disparity in subject perceived distance to the lane change maneuver after the red X was added to the LCS array for the yellow downward diagonal arrow than there was for the yellow X.

Truly effective freeway LCS symbols should convey a clear message and elicit a consistent response from all motorists if they are to be useful tools for managing freeway traffic at major interchanges or during incidents, or both. This should be true whether drivers have been educated about their use, or if they are seeing them for the first time.

The results of the study of subjects' indicated reaction to the yellow transition symbols showed that the yellow downward diagonal arrow was better than the yellow X for persuading subjects to initiate a lane change maneuver. Therefore, the yellow downward diagonal arrow is recommended for evaluation as a suitable alternative to the yellow X for use when changing the status of a freeway lane from open (green down arrow) to closed (red X). Further research is needed to determine whether these relationships will indeed hold true for drivers who are actually traveling on the mainlanes of a freeway.

As a result of the studies conducted by the Texas Transportation Institute (TTI), The Texas Department of Transportation (TxDOT) is currently seeking approval from FHWA to initiate field experiments using the yellow downward diagonal arrow in freeway LCS systems. TxDOT is also working with researchers at TTI to determine scenarios appropriate for LCS use and their corresponding LCS array configurations and to solve legibility issues about LCS displays. In addition to these, research should be conducted with the aim toward standardizing symbolic information signs in the hopes of eliminating driver confusion as they transfer between the freeway main lanes, high-occupancy-vehicle transitways, and toll facilities.

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REFERENCES

1. *Manual on Uniform Traffic Control Devices.* FHWA, U.S. Department of Transportation, Washington, D.C., 1988.
2. Ullman, G. L. Motorist Interpretations of MUTCD Freeway Lane Control Signals. In *Transportation Research Record 1403,* TRB, National Research Council, Washington, D.C., 1993, pp. 49–56.
3. Ullman, G. L., S. D. Wohlschlaeger, C.L. Dudek, and P. Wiles. *Driver Interpretation of Existing and Potential Lane Control Signal Symbols for Freeway Traffic Management.* Research Report FHWA/TX-93/1298-1. Texas Transportation Institute, College Station, Nov. 1993.
4. Lavallée, P., D. Sims, S. Stewart, and M. Lau. Multimessage Fiber-Optic Lane-Control Signs for Freeway Applications. In *Journal of Transportation Engineering,* Vol. 116, No. 6, Nov./Dec. 1990, pp. 725–733.
5. Engel, G. R., M. Townsend, and W. Dougherty. *Preliminary Evaluation of Prototype Lane Control Signs.* Research and Development Branch, Ontario Ministry of Transportation, Downsview, Ontario, Canada, July 1988.
6. Forbes, T. W., E. Gervais, and T. Allen. Effectiveness of Symbols for Lane Control Signals. In *Bulletin 244,* HRB, National Research Council, Washington, D.C., 1960, pp. 16–29.
7. Carlson, G. C., and A. Z. Lari. *Evaluation of the Use of Downward Yellow Arrows in the I-94 Lane Control Signal System.* Minnesota Department of Transportation, Traffic Systems and Research Section, St. Paul, Aug. 1982.
8. Wohlschlaeger, S. D. *Motorist Interpretation of Potential Transition Symbols in a Freeway Lane Control Signal Array.* M.S. thesis. Texas A&M University, College Station, May 1994.
9. *Highway Statistics 1991.* U.S. Department of Transportation, FHWA, Administration, Washington, D.C., 1991.
10. *1990 U.S. Census of Population and Housing.* Bureau of the Census, U.S. Department of Commerce, Economics and Statistics Administration, Washington, D.C., 1990.

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