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16. Abstract

This report documents the research performed to assess the effectiveness and applicability of yellow diagonal and downward arrows for freeway traffic management purposes. Researchers examined motorist understanding of and perceived usefulness of the arrows through surveys of San Antonio motorists where these indications are being utilized as part of the TransGuide system. These results were compared to similar data obtained from motorists in Fort Worth where TxDOT operates a traffic management system utilizing a yellow X. Researchers also interviewed operators of the TransGuide system to assess their opinions of the yellow arrow indications, and to identify any difficulties they have experienced in utilizing these symbols in their daily traffic management activities. Finally, researchers performed a series of field studies to assess how drivers respond to yellow diagonal arrows and yellow Xs used to transition between a lane open and a lane closed conditioon.

Data collected through this research effort indicates that the use of both the yellow diagonal and downward arrows for freeway traffic management purposes are perceived positively by TransGuide system operators and the motoring public. Furthermore, no evidence of operational problems or difficulties due to the use of either of these non-standard symbols has been collected through field studies in San Antonio. Similar statements can be made concerning the yellow X. Motorists in Fort Worth rate this symbol fairly highly once they see it used in a freeway driving situation. Field studies suggest that the number of drivers exiting a closed lane when first encountering the yellow X symbol equals or exceeds those who would exit for the yellow diagonal arrow.

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YELLOW TRANSITION LANE CONTROL SIGNAL SYMBOLS FOR FREEWAY TRAFFIC MANAGEMENT

by

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Research Report 1498-2
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Sponsored by the
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IMPLEMENTATION RECOMMENDATIONS

Data collected through this research effort indicates that TransGuide system operators and the motoring public both positively perceive the yellow diagonal and downward arrows for freeway traffic management purposes. Furthermore, no evidence of operational problems or difficulties due the use of either of these non-standard symbols has been collected through field studies in San Antonio. Similar statements can be made concerning the yellow X. Motorists in Fort Worth rate this symbol fairly highly once they see it used in a freeway driving situation. Field studies suggest that the number of drivers exiting a closed lane when first encountering the yellow X symbol equals or exceeds those who would exit for the yellow diagonal arrow.

Based on the results of these study efforts, one cannot say for certain that the utilization of a yellow diagonal arrow in lieu of a yellow X results in improved freeway operations or effectiveness of a motorist information component in a freeway traffic management system. In fact, from the operations data collected to date, it appears that the two symbols are interchangeable. However, it is possible that the performance measures used in these studies were not sensitive to the operational differences that may exist between the two types of transition symbols. TTI recommends two specific actions TxDot should take as a result of this research.

1. The results of the motorist survey in Fort Worth still suggest one difficulty with the yellow X in that it does not convey a strong inherent message to motorists about how they should respond. It appears that drivers are able to ascertain the intended meaning fairly easily once they see it actually used in a freeway driving situation, though. TxDOT should therefor establishes a policy to display the yellow X only in conjunction with green arrows at a given LCS array.

2. If TxDOT wishes to consider the use of more complex LCS arrays in its traffic management efforts (those that included the display of red Xs, yellow symbols, and green arrows at a single location), it would be wise for TxDOT to pursue a change to the MUTCD to allow the use of the yellow diagonal arrow for freeway traffic management purposes.

Experiences regarding the yellow downward arrow at TransGuide do not indicate any problems with its continued use. Benefits accrued because of its utilization seem limited primarily to intangibles (better driver awareness of shoulder vehicle stalls, improved emergency response location abilities, etc.) at this time. TxDOT may wish to pursue a change to the MUTCD to use this symbol for freeway traffic management as well.

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 is not intended to constitute a standard, specification, or regulation, nor is it intended for construction, bidding or permit purposes. The engineer in charge of the study was Dr. Gerald L. Ullman, P.E. #66876.

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SUMMARY

This report documents the research performed to assess the effectiveness and applicability of yellow diagonal and downward arrows for freeway traffic management purposes. Researchers surveyed San Antonio motorists about their understanding and perceived usefulness of the arrows used as part of the TransGuide system. These results were compared to similar data obtained from motorists in Fort Worth where TxDOT operates a traffic management system utilizing a yellow X. Researchers also interviewed operators of the TransGuide system to assess operator opinions of the yellow arrow indications and to identify any difficulties they have experienced in utilizing these symbols in their daily traffic management activities. Finally, researchers conducted field studies to assess how drivers respond to yellow diagonal arrows used to transition between a lane open (green arrow) and a lane closed (red X). These were compared to driver response to a yellow X, currently the MUTCD-accepted symbol for accomplishing this transition.

The results of the motorist surveys indicate that both the yellow diagonal and downward arrows are perceived positively in actual freeway driving situations. The ratings are very similar to those given for the yellow X by Fort Worth motorists. However, evidence again suggests that the yellow X does not possess a strong inherent meaning with motorists (as was noted by earlier laboratory research). However, once motorists can see the symbol used in an actual freeway driving context, they can deduce its intended message.

The TransGuide system operators indicated that no accidents had occurred that were attributable to either the yellow diagonal or downward arrows. Operators' impressions of the effectiveness of the yellow diagonal arrow are generally favorable. They agree that most drivers do appear to respond to the arrows, although there are always those who wait to the last minute to exit a given lane. Favorable operators' responses were obtained about the effectiveness of the yellow downward arrow as well. As they noted, however, it is difficult to identify specific driving actions (speed reductions, reduced lane changing, etc.) from the CCTV or other data to determine objectively how the indications are influencing drivers. An unexpected benefit obtained from the downward arrows is that emergency personnel can find incident and vehicle stall locations on the shoulders as they patrol the freeways more quickly because the arrow gives them advance warning about its location.

The operators felt that incidents in the vicinity of lane drops and additions were the most difficult to treat and manage with LCS (including the yellow arrow symbols). However, these difficulties are not due to the yellow indications themselves but rather to the dilemma of trying to convey information upstream where one type of roadway cross-section exists about conditions downstream where a different cross-section exists. There was some discussion among operators about the potential of having the arrows flash to increase their conspicuity. They felt that flashing CMS messages attracted more attention, and a flashing arrow might do the same. More extensive public information and driver training regarding the intended meaning of the downward yellow arrow was recommended by a few of the operators.

Field study data from San Antonio showed very little difference in how drivers respond to a yellow diagonal arrow and a yellow X in a freeway driving environment under the conditions studied. Statistically, neither closed-lane volume distributions nor lane-changing frequencies were significantly different at any of the sites where both yellow indications were tested. However, the yellow indications at both San Antonio and Fort Worth locations were studied in an array consisting of only yellow symbols (arrows or Xs) and green arrows. In these types of LCS array configurations, past research has shown that motorists commonly interpret the yellow X (as they do the yellow diagonal arrow) as indicating the need to vacate the lane. Consequently, one would expect driver response to both symbols to be similar in these types of LCS arrays. A question that still remains is whether or not the yellow X could be displayed in conjunction with a red X and green arrow (s) at an array location and achieve the same results as would occur if a yellow diagonal arrow was displayed at that location. TransGuide does not display these types of LCS arrays to motorists, and so these more complex LCS arrays were not evaluated in the field studies.

1. INTRODUCTION

Lane control signals (LCS) are an integral component of the freeway surveillance and control systems now being designed and implemented by the Texas Department of Transportation (TxDOT) in the major urban areas of Texas. System operators use the LCS to display to motorists in real-time the status of individual freeway lanes (i.e., which lanes are open, which are about to be closed, which ones are closed, etc.). Generally speaking, guidance on the use of LCS is limited to a short discussion contained in the *Manual of Uniform Traffic Control Devices* (MUTCD) (*1*). Presently, the MUTCD allows only three symbols to be used on freeway facilities:

- a green arrow to indicate to motorists that a lane is open and available for travel,
- a yellow X to indicate that a lane is about to be closed and that drivers should prepare to vacate the lane, and
- a red X to indicate that a lane is closed and not available to drivers for travel.

Laboratory research results in Texas concerning driver comprehension of LCS in freeway applications indicated that many motorists may not interpret the yellow X as intended in the MUTCD (*2*, *3*). In addition, driver interpretations of this symbol may vary depending on what other LCS symbols are displayed over adjacent lanes at the same location.

In addition, existing LCS symbols for freeway traffic management do not provide operating agencies a means for indicating to motorists that a lane is open but that additional caution by motorists in a lane is warranted. For example, it may be beneficial to convey to motorists in a shoulder freeway lane that extra caution should be exercised because of a downstream incident on the shoulder. These existing deficiencies in current LCS standards limit the potential effectiveness of LCS as an urban freeway traffic management tool.

FIELD EXPERIMENTATION WITH NON-STANDARD FREEWAY LCS

Given the lack of guidance regarding LCS use for urban freeway traffic management purposes, TxDOT requested permission from the Federal Highway Administration (FHWA) to experiment with LCS symbols not currently in the MUTCD. Two specific symbols were of interest to TxDOT:

1. a yellow diagonal arrow (pointing downward to the right or the left depending on direction of driver movement desired), and

2. a yellow downward arrow (identical in design to the downward green arrow now allowed but presented in yellow).

Several European countries utilize the yellow diagonal arrow in advance of closed or blocked lanes on their freeway LCS systems (*4*). The Ontario Ministry of Transportation also utilizes diagonal yellow arrows in its freeway LCS (*5*). Both jurisdictions have reported favorable experiences with this symbol, citing its advantages in providing positive guidance to motorists about what they should do. In Texas, the yellow X and yellow diagonal arrow have both been evaluated in laboratory studies of driver comprehension (*2*). Table 1 summarizes the distribution of interpretations for the yellow diagonal arrow presented with and without a red X in the same LCS array at a location. Researchers compared these findings to those obtained for a yellow X under the same scenarios.

TABLE 1-1. Driver Interpretations of Yellow Freeway LCS Indications (*2,3*)

Driver Interpretation of Proper Response	Yellow ↘		Yellow X	
	With Red X	W/O Red X	With Red X	W/O Red X
"Exit to Lane Under a Green Arrow"	98%	99%	87%	91%
"Slow Down and Stay in Lane"	2%	1%	11%	6%
"Unsure"	-	-	1%	1%
Other	-	-	1%	2%

These results represent the best possible performance obtained for the yellow X. Additional laboratory studies found only 35 to 72 percent of drivers would interpret the yellow X as indicating the need to exit to a lane under a green arrow (*3*), depending on whether or not a red X was present in the display.

Meanwhile, the use of a yellow downward arrow has previously been examined for freeway applications in the U.S. on a test basis. The Minnesota Department of Transportation conducted studies of a flashing yellow downward arrow on I-35W in Minneapolis in the early 1980s. Surveys conducted by MnDOT showed that most (80 percent) subjects considered a downward yellow arrow to indicate that they could use the lane, but should use extra caution. More recent studies in Texas (*2*) found slightly less consistent results, with 33 to 97 percent of subjects interpreting the symbol in this way depending on whether or not a red X was also in the LCS array.

COMPONENTS OF THE EVALUATION PLAN

TxDOT received permission from FHWA to experiment with both the yellow diagonal and the downward arrows. As part of the approval process, a plan to evaluate the use of the experimental devices was required. The plan approved by FHWA to evaluate the LCS consisted of three main components described below.

- *Motorist Surveys* --Motorists coming into regular contact with the LCS were to be surveyed to assess their level of understanding of the diagonal and downward yellow arrows, their perceptions of the usefulness of LCS, and any problems or deficiencies in how the LCS are being used.

- *System Operator Interviews* -- Interviews were to be conducted of the traffic management control center operators who deployed the yellow diagonal arrow and downward arrow during actual lane blockage conditions. Operator perceptions and experiences with the symbols would be identified. Situations where the use of either the downward or diagonal yellow arrows was seen as particularly useful were of interest, as were any special situations where the operators found it somewhat difficult to apply the yellow arrows effectively.

- *Field Evaluations* -- Comparisons of traffic approaching the yellow diagonal arrow and the yellow X as transition symbols from a green arrow to a red X were to be conducted where possible. Both single-lane and multiple-lane blockages existing in the peak and off-peak periods were of interest. Particular measures of effectiveness included the distribution of traffic across available freeway lanes; volumes exiting and entering the freeway to determine what effect alternative LCS displays have upon upstream diversion rates; and any erratic maneuvers occurring at the upstream end of the freeway queue.

In September 1993, TxDOT sponsored and initiated SPR Study 1498 (Study of Visibility, Spacing, and Operations Issues of Freeway Lane Control Signals in Texas) in cooperation with FHWA, and performed by the Texas Transportation Institute. One of the tasks of that study was to provide the research support specified in the TxDOT request to experiment. This report documents the results of that research.

REPORT ORGANIZATION

Chapter 2 presents the survey results of motorist perceptions and experiences with the yellow X, yellow diagonal arrow, and yellow downward arrow. Researchers surveyed motorists in both San Antonio and Fort Worth, Texas. The traffic management systems in San Antonio (TransGuide) utilize the yellow diagonal and downward arrows on freeway LCS, whereas the system in Fort Worth uses the yellow X to transition between a green arrow and red X.

Chapter 3 documents the results of an expert panel meeting held in March 1996 with the TxDOT operators of the TransGuide system. Researchers obtained operator perceptions about the effectiveness of the yellow diagonal and downward arrows. Examples of particularly unusual experiences using the arrows or the LCS in general were also identified at the meeting.

Chapter 4 summarizes the results of field studies conducted to determine driver responses to the yellow diagonal arrow and yellow X. Researchers conducted a limited number of studies in San Antonio of both the yellow X and yellow diagonal arrow symbols for a period of time to direct and compare driver behavioral data. Researchers embellished upon these results with additional studies in both Fort Worth and San Antonio. In these additional studies, researchers collected data under normal operating conditions and a lane blockage condition that involved the use of the yellow X or yellow diagonal arrow, respectively.

Chapter 5 summarizes the findings from the motorist surveys, operator panel meeting, and field studies. The implications of these findings relative to the potential addition of the yellow diagonal arrow and yellow downward arrow to the MUTCD are discussed as well.

2. MOTORIST SURVEY RESULTS

This chapter documents the results of two motorist surveys performed in San Antonio and Forth Worth, Texas to determine motorist perceptions of and experiences with the freeway LCS being utilized for freeway traffic management in those cities. In San Antonio, researchers emphasized motorist interpretations and experiences with the yellow diagonal and downward arrows, symbols not currently in the MUTCD but which laboratory studies suggest are better understood by drivers as indicating a need to begin to vacate a travel lane. In Fort Worth, researchers emphasized interpretations of the yellow X, the MUTCD-accepted transition symbol between a green arrow and a red X.

SAN ANTONIO SURVEY

As part of a TransGuide evaluation project, the TTI-San Antonio office created a "panel" of commuters who live in the suburbs and work in the downtown area. These individuals use one or more sections of freeway under TransGuide operation on a regular basis. Whenever major incidents occur on one of the TransGuide freeways, TTI can mail out surveys to members of the panel to determine if and how the incident affected the panelist's travel behavior, and whether the information presented by TransGuide via the changeable message signs and lane control signals assisted the panelist.

In March 1996, researchers distributed a supplemental survey to this panel to assess their awareness and perceptions of the lane control signal symbols being used in San Antonio. A copy of the survey form is included in Appendix A. In the first part of the survey, researchers asked the panelist to identify which symbols he or she had seen displayed on the LCS while traveling on San Antonio freeways. The panelist was then asked whether the yellow downward and diagonal arrows were helpful, or if the arrows were confusing. If the panelist indicated that the arrows were confusing, researchers asked him or her to describe a specific situation where an arrow indication was encountered while driving and what was confusing about the situation. Researchers also asked panelists to provide suggestions about the lane control signals that they felt would reduce this confusion.

Survey Results

Approximately 600 surveys were delivered to the San Antonio panel. Panelists returned slightly more than one-half (344)of these surveys. Table 2-1 describes the panel's self-reported level of exposure to the various lane control signal symbols being used on San Antonio freeways. As expected, most panelist (86 percent) reported seeing the green arrow. Meanwhile, 65 percent of the panelists reported seeing the red X used. With respect to the yellow arrow indications, over one-half of the panel (58 percent) indicated that they had seen the yellow downward arrow displayed over a freeway lane at least once during their San Antonio travels. Almost one-third (30 percent) of the panel had seen the yellow diagonal arrow used. Finally, about one-sixth of the panel (16 percent) indicated that they had seen all of the symbols.

TABLE 2-1. San Antonio Panelists' Exposure to the Lane Control Signal Symbols

Symbol seen at least once	No. Of Responses	Percent
Green Arrow	294	86
Red X	225	65
Yellow Downward Arrow	199	58
Yellow Diagonal Arrow	102	30
All symbols	56	16

Table 2-2 presents panelists' opinions regarding the usefulness and clarity of the yellow downward arrow . Overall, 86 percent of the panel members indicated that the arrow was helpful to them. Similarly, only 6 percent of the panel felt that the arrow was a confusing symbol to them. However, it should be noted that panelists were not actually questioned on the meaning of the yellow downward arrow. Consequently, panelists may not perceive the symbol as confusing, but may still interpret the symbol quite differently from its intended meaning.

TABLE 2-2. San Antonio Panelists' Perceptions of the Yellow Downward Arrow

Statement	All Survey Responses	
	Number	Percent
Arrow is helpful	264	86
Arrow is not helpful	42	14
	306	100
Arrow is confusing	19	6
Arrow is not confusing	285	94
	304	100

It appears that encountering the yellow downward arrow in a freeway context (where motorists can see how it is being used in relation to other visual cues present) did have an impact upon panelists' perceptions of that symbol. As shown in Figure 2-1, panelists who have actually seen the yellow downward arrow were more likely to rate the symbol as helpful than were those panelists who had not seen the symbol used on local freeways. Similarly, panel members who had seen the arrow used were less likely to consider that symbol confusing to them.

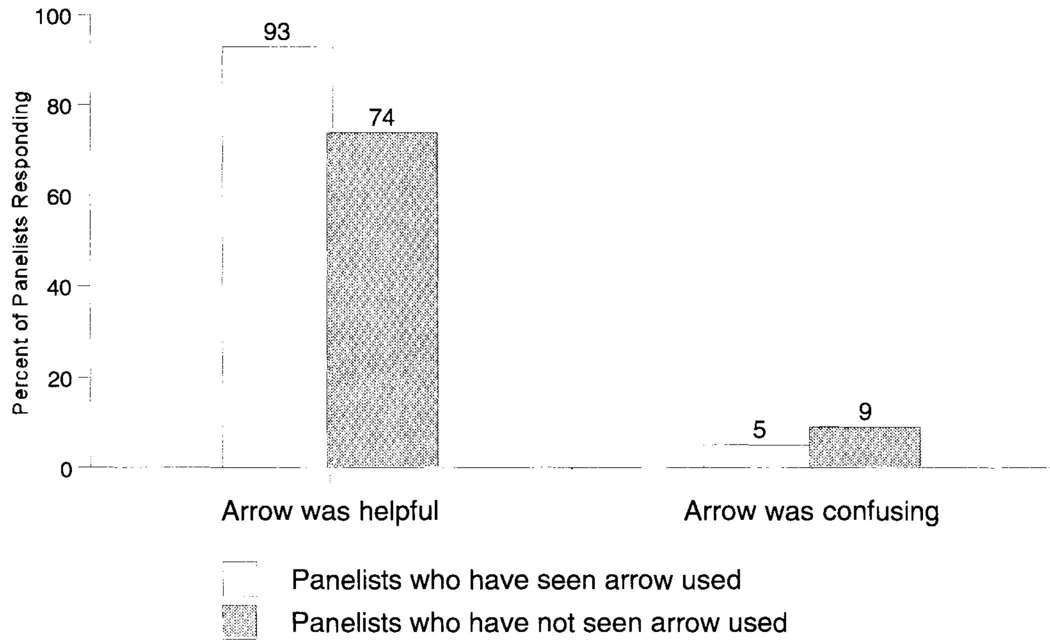

FIGURE 2-1. Effect of Seeing Yellow Downward Arrow in Freeway Context Upon San Antonio Panelists' Assessments of Helpfulness and Clarity

Table 2-3 summarizes panelists' opinions regarding the usefulness and clarity of the yellow diagonal arrow. Overall, panelists rated this symbol slightly less helpful (only 75 percent of the panel rated it as such) and slightly more confusing (12 percent) than they did the yellow downward arrow. This finding is somewhat contrary to previous laboratory studies (*2,3*) which showed the diagonal arrow to have a more consistent meaning and to be more likely to convey an intended action to motorists than the downward arrow. However, it again appears that the assessments in this survey were dependent on whether or not the panelists had actually seen the diagonal arrow in a freeway driving context. Figure 2-2 illustrates the difference in panelists' assessments of the diagonal arrow for those who had seen the arrow used on San Antonio freeways versus those who had not. Those who had seen the diagonal arrow used were very likely to rate it as helpful (93 percent rated it in this manner), whereas those who had not seen it used were less likely to rate it this way (only 65 percent rated it as helpful). In contrast, exposure to the use of the diagonal arrow did not affect panelists likelihood of rating it as confusing (12 percent of both groups rated the diagonal arrow as confusing).

TABLE 2-3. San Antonio Panelists' Perceptions of the Yellow Diagonal Arrow

Statement	All Survey Responses	
	No.	Percent
Arrow is helpful Arrow is not helpful	208 69 277	75 25 100
Arrow is confusing Arrow is not confusing	34 250 284	12 88 100

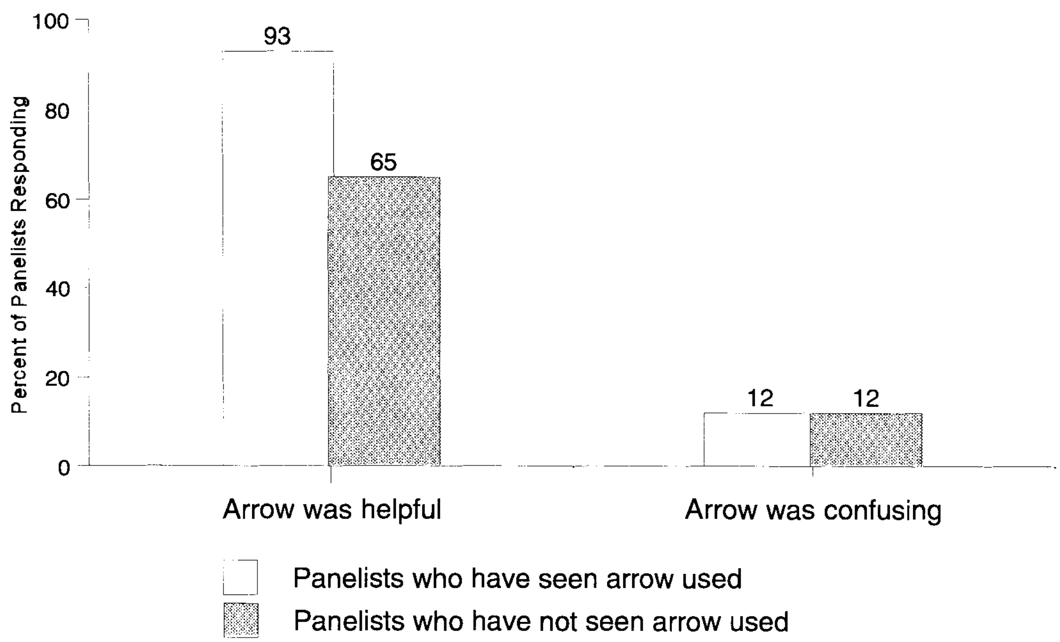

FIGURE 2-2. Effect of Seeing Yellow Diagonal Arrow in Freeway Context Upon San Antonio Panelists' Assessments of Helpfulness and Clarity

Researchers asked those panelists who rated either the downward or diagonal arrow as confusing to describe a specific driving situation where the arrow was confusing to them. Of the 344 panelists responding, 43 (13 percent) provided documentation of at least one confusing incident they had encountered relating to the lane control signals. Table 2-4 provides a breakdown of these incidents by the type of symbol displayed. Again, the diagonal arrow was the most often reported symbol involved in a confusing situation (70 percent of the confusing incidents related to the diagonal arrow). This represents 29 percent of the panelists who reported seeing the diagonal arrow used at least once on local freeways. In contrast, the yellow downward arrow was listed in 26 percent of the confusing incidents identified by panelists. This represents only 6 percent of the panelists who had seen the downward arrow used at least once on San Antonio freeways.

TABLE 2-4. Confusing Lane Control Signal Situations (San Antonio Panelists)

Symbol Encountered in Confusing Situation	All responses	
	No.	Percent
Yellow Diagonal Arrow	30	70
Yellow Downward Arrow	11	26
Both Arrows	1	2
Red X	1	2
	43	100

Table 2-5 presents a breakdown of the general categories of problems panelists reported as confusing. The most common comment for both the diagonal and downward arrow was that the panelist did not know what the arrow meant. Several panelists also reported that there were "conflicting" symbols on sequential signs (i.e., pointing left and then pointing right on the next array). Given the error-checking and training that has occurred for TransGuide operators, it is more likely that the panelists were in error in recalling the direction of one or the other arrows rather than that a true conflicting message actually occurring on the freeway. It is also possible that motorists saw the LCS being manipulated in real-time (TransGuide operators report changing LCS indications often in major incidents as lanes close and reopen for emergency medical vehicles, heavy duty debris removal trucks, and other equipment arriving and leaving the incident scene).

TABLE 2-5 Confusing Situation Categories (San Antonio Panelists)

Comment	Frequency
Yellow Diagonal Arrow:	
"Don't know what the arrow means"	9
"Wasn't sure what lane the arrow meant"	5
"Arrow said to change lanes, but there was no accident downstream"	2
"Arrows on sequential signs conflicted with each other"	2
"Wasn't sure whether to change lanes or exit the freeway"	1
"Arrows conflicted with message on CMS"	1
"Saw the arrow blink - what does that mean"	1
"Too many arrows to comprehend at some locations"	1
"Did not know what roadway it referred to (US 281 or I-35)"	1
"Poor visibility (fog)"	1
Other miscellaneous	6
Yellow Downward Arrow:	
"Did not know what it meant"	5
"Arrow was on for no reason"	2
"Arrow was located too far upstream of congestion"	1
"Arrow was not located far enough upstream of congestion"	1
Other miscellaneous	2

FORT WORTH SURVEY

In July 1996, TTI researchers conducted one-on-one surveys of motorist perceptions of and experiences with freeway LCS at the Texas Department of Public Safety Driver's License Renewal Center in Fort Worth. The freeway traffic management system in Fort Worth utilizes the three symbols currently in the MUTCD: a green downward arrow, a yellow X, and a red X (LCS on some sections of freeway have the ability to display a yellow downward arrow, but these are not generally used). A copy of the Fort Worth survey is also included in Appendix A.

In the first part of the survey, researchers asked motorists to identify which symbols they had seen displayed on the LCS while traveling on Fort Worth freeways. Researchers then asked the motorists whether the yellow X symbol was helpful to them, or if it was confusing. If motorists indicated that the yellow X was confusing, researchers asked them to describe a specific driving situation where the yellow X indication was encountered and describe what was confusing about the situation. Researchers also asked motorists to provide suggestions about the lane control signals that they felt would reduce this confusion. A total of 100 surveys were completed at this location.

Survey Results

Table 2-6 describes the motorists' self-reported level of exposure to the various lane control signal symbols being used in Fort Worth. As the table illustrates, 70 percent of those surveyed had encountered the green arrow, 64 percent had encountered a yellow X, and 65 percent had encountered a red X. Only 17 percent of those surveyed did not indicate seeing at least one of the symbols while driving in Fort Worth.

TABLE 2-6. Forth Worth Motorists' Exposure to Freeway LCS Symbols

Symbol seen at least once	Percent of All Survey Responses
Green Arrow	20
Yellow X	14
Red X	15
All symbols	50
None of the symbols	17

Table 2-7 presents the participants' opinions regarding usefulness and clarity of the yellow X. Overall, 78 percent of the motorists surveyed rated the yellow X as helpful, and only 18 percent thought the yellow X was confusing. As was seen in the responses to the San Antonio survey, the ratings did differ significantly depending on whether or not the survey respondents had encountered a yellow X in an actual driving environment (see Figure 2-3).

TABLE 2-7. Fort Worth Motorists' Perceptions of the Yellow X

Statement	Percent of All Survey Responses
Yellow X is helpful	78
Yellow X is not helpful	22
	100
Yellow X is confusing	18
Yellow X is not confusing	82
	100

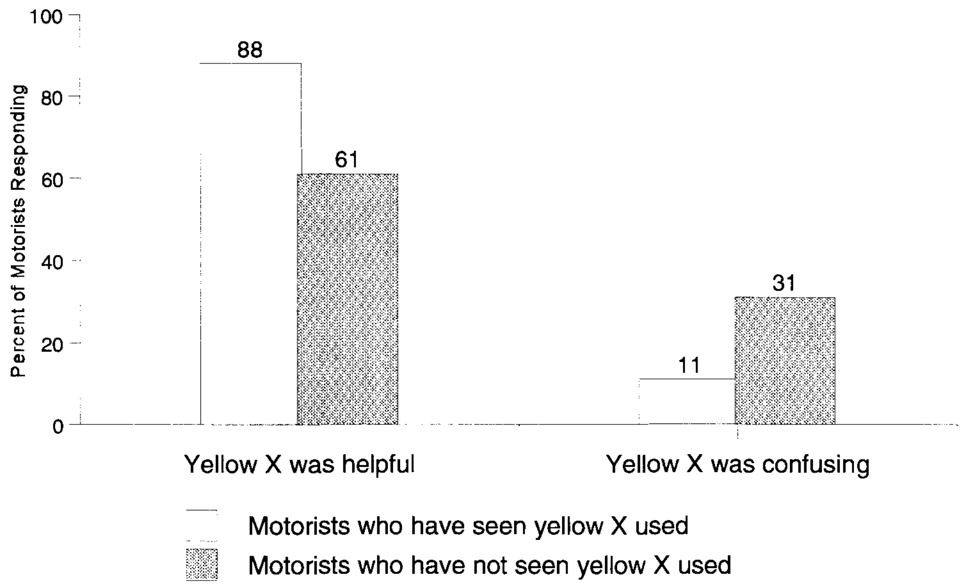

FIGURE 2-3. Effect of Seeing Yellow X in Freeway Context Upon Fort Worth Panelists' Assessments of Helpfulness and Clarity

Of those who had seen the yellow X used, 88 percent rated the symbol as helpful, and only 11 percent rated it as confusing. In contrast, only 61 percent of those who had not actually encountered the yellow X while driving thought it was helpful, and 31 percent of those rated the symbol as confusing.

Researchers asked those participants who stated that the yellow X was confusing to describe a specific driving situation where it was confusing to them. Thirteen percent of those surveyed provided information on a specifically confusing situation involving the LCS. The rather small sample of comments did not allow for a meaningful analysis. Two of the thirteen comments stated that they did not know what the yellow X meant, whereas two other motorists commented that they did not know which lane the yellow X was meant for.

A question added to the bottom of the Fort Worth survey asked the respondents if they felt the LCS should remain on at all times or only be turned on when needed to indicate that a lane is closed ahead. Researchers then asked survey participants for reasons why they felt the signals should remain on or stay off unless needed. The distribution of responses to the first part of the question was as follows:

"LCS should remain on at all times"	47%
"LCS should be turned on only when a lane is closed"	24%
No preference	29%

A larger percentage of motorists surveyed indicated that the LCS should remain on at all times. However, it should be noted that this value does not represent a majority of those sampled.

For those subjects who felt the LCS should remain on at all times, Table 2-8 summarizes the categories of reasons the subjects used to justify their opinion. The most common reason given for leaving the LCS on was the perception that the signal is an information source to drivers regardless of whether or not a problem exists on the freeway. Other reasons given are as shown in the table.

Table 2-9 summarizes the reasons given by motorists who felt the LCS should remain off unless there is a lane closure. Generally speaking, the most common reason for this group of motorists was that continually displaying a green indication makes them so commonplace that motorists ignore them and will not notice them when a lane closure condition is actually displayed. Interestingly, only three subjects mentioned an energy cost savings as a reason not to display LCS all the time. It is also interesting to note that several subjects in both groups felt that the option they selected would be less confusing to motorists.

TABLE 2-8. Reasons Fort Worth Motorists Gave for Leaving LCS on all the Time

Category	Frequency
Helps to inform motorists of which lanes are open or closed, and helps them to be more aware of traffic conditions	19
Less confusing to motorists	7
Improves traffic flow	6
For safety reasons	2
To be consistent	2
Assume LCSs are out of order otherwise	1
Other	3
No responses	7

TABLE 2-9. Reasons Fort Worth Motorists Gave for Leaving LCS Off Unless Needed

Category	Frequency
Will be more effective when on/ motorists will take for granted and tend to ignore if on all the time	12
Less confusing to motorists	4
Conserve energy	3
Other	3
No response	2

SUMMARY

The results of the San Antonio survey indicate generally positive experiences with and perceptions of both the yellow diagonal arrow and yellow downward arrow in actual freeway driving situations. A large majority of survey respondents rated both types of yellow arrows as helpful to them, and only a small portion of the survey sample felt either arrow symbol was confusing. The ratings are very similar to those given for the yellow X by Fort Worth motorists. The only statistically significant difference between surveys existed for motorists who had not seen the yellow transition symbol actually used in a driving situation. In San Antonio, 12 percent of those types of motorists rated the yellow diagonal arrow as confusing. In Fort Worth, over 30 percent of motorists who had not actually seen the yellow X used on the freeways rated that symbol as confusing. Interestingly, this difference in percentages was non-existent for motorists who had seen the symbol used in an actual driving situation (12 percent of the San Antonio motorists who had seen the arrow used rated it as confusing, whereas 11 percent of the Fort Worth motorists who had seen the yellow X used and it as confusing). These results suggest that the yellow X does not possess a strong inherent meaning with motorists (as earlier laboratory research suggested). However, once motorists can see the symbol used in an actual freeway driving context, they can deduce its intended message.

A greater percentage of respondents from the San Antonio survey indicated that they had experienced a confusing situation involving the yellow diagonal arrow than did respondents from Fort Worth who had experienced a confusing situation involving the yellow X (29 percent versus 16 percent, respectively). However, it must be remembered that the two survey groups were obtained in different ways. The San Antonio respondents were actually panel members who agreed to provide information on their driving perceptions and behaviors over time in order to evaluate the TransGuide system. As such, they were predisposed towards assessing the effects of the system components (i.e., LCS, CMS) upon their driving behavior. In contrast, researchers recruited the Fort Worth survey group from motorists waiting in line to renew their driver's licenses at the local DPS office and who may have had little incentive to critique their recent driving experiences.

Finally, although more Fort Worth survey respondents indicated a preference for LCS to remain on all the time, this is the current operating procedure in Fort Worth. The responses may simply reflect a natural human resistance to changing those things with which one has become accustomed. It is possible that another survey in a location where the LCS operating procedure is to leave them off all the time, or a location without LCS at all, would result in a different distribution of responses.

3. TRANSGUIDE SYSTEM OPERATOR EXPERIENCES WITH THE YELLOW DIAGONAL AND DOWNWARD ARROWS

INTRODUCTION

TransGuide in San Antonio relies upon both CMS and LCS to communicate real-time traffic condition information to freeway motorists. Since TransGuide began operations in the Fall of 1995, operators of the system have been utilizing these information components daily to manage incidents and schedule lane closures and other roadway events as they occur.

The LCS components of TransGuide use a yellow diagonal arrow to convey to motorists that a lane is changing from open to closed (blocked). It is a transition symbol between the green arrow (lane open) and red X (lane closed). The LCS can also display a yellow downward arrow, identical to the green arrow except for its color, as a means of indicating that a lane is open but that extra caution should be used. Currently, the MUTCD does not recognize either of these symbols. As part of the evaluation plan to assess the effectiveness and practicality of these non-MUTCD symbols for freeway traffic management, TTI researchers interviewed system operators of TransGuide in March 1996. The purpose of the meeting was to obtain operator impressions of the effectiveness of the two types of yellow arrow indications for communicating with motorists, and to identify any particular problems they may have encountered due to these symbols when attempting to apply the LCS to a particular roadway event.

MEETING PROTOCOL

In general, researchers followed a focus group protocol for the meeting. In this way, individual participants could discuss opinions, concerns, etc. about a topic of interest to the researchers and receive input from others who may have similar or opposing views. The researchers could also get a sense of whether various comments being made were common to several individuals or if some disagreement existed. The strength of the focus group technique is in its ability to generate open discussions and additional insight into topics that would not be possible through simple one-on-one interviews or formal survey techniques.

Nine operators of TransGuide were able to attend the focus group meeting. Eight of the operators were male, and all had some college or were college graduates. Ages of the operators ranged from 23 to 49 years. Four of the operators had been employed by TxDOT for less than five years, and two had been with TxDOT for more than ten years. All but one of the operators had been a resident of San Antonio for more than five years.

DISCUSSION RESULTS

With respect to the use of the yellow arrows, the operators could not think of a specific instance where they noticed driver behavioral problems that would suggest that drivers were confused by either the diagonal or downward yellow arrows. They indicated that no accidents had occurred that were attributable to the yellow arrows, either. The following paragraphs provide more detailed information concerning operator impressions of the yellow arrows.

General Impressions of the Yellow Arrow Symbols

Yellow Diagonal Arrow

Operators of the TransGuide system generally agreed that over the approximate 35 to 40 kilometers of freeway that they manage, incidents and maintenance activities require them to activate yellow diagonal arrows approximately 7 to 10 times per week. The most common display configuration used is a red X over the closed lane at the first two LCS arrays upstream of the blockage, and then display a yellow diagonal arrow over that lane at the LCS array (if available) preceding that.

Operators' impressions of the effectiveness of the yellow diagonal arrow are generally favorable. They agree that most drivers appear to respond to the arrows, although there are always those who wait to the last minute to exit a given lane. The operators also felt that during daylight hours, it may be more difficult for drivers to notice the arrows (the symbols are much more visible at night or in cloudy conditions).

The operators also noted that the presence of, and information provided on, CMSs in conjunction with the LCS significantly affects driver responses. The operators cited one particular incident in which glass was scattered on two inside travel lanes, and they had diagonal arrows displayed upstream telling drivers to move to the right. They also had a message on a CMS that said "Debris on Roadway - Merge Right." Drivers initially merged to the right, but when they could not see a problem in the left lanes, they moved back into those lanes and ran over the glass. Operators eventually modified the message to read "Glass on Roadway - Merge Right." Drivers moved out of the left lanes and stayed out of them until the LCS and CMS indicated that the lanes were open to traffic. The operators agreed that the CMSs and LCSs must function as a system.

Yellow Downward Arrow

In contrast to the diagonal arrow, yellow downward arrows are used much more frequently within the TransGuide system. Operators estimated that this symbol is used as much as 10 times per day. This symbol is used primarily over the median or shoulder lanes to indicate the presence of stalled vehicles on the shoulders, or on freeway-to-freeway connectors to indicate congestion or lane blockages on the freeway to which motorists are connecting.

Researchers obtained favorable operators' responses about the effectiveness of the yellow downward arrow as well. As they noted, however, it is difficult to identify specific driving actions (speed reductions, reduced lane changing, etc.) from the CCTV or other data to determine objectively how the indications are influencing drivers. The yellow downward arrow also appears to provide an unexpected benefit as well. It seems that emergency and service personnel appreciate the use of the downward arrow indications because it helps them to pinpoint incident and vehicle stall locations on the shoulders as they patrol the freeways.

Use of the Yellow Arrow Indications in TransGuide Operations

The TransGuide system relies on a library of preplanned "scenarios" to determine how to establish both the LCS and CMS messages for a given freeway incident. These scenarios are defined by the time of day, the location of the incident, and the number of lanes that are blocked. Operators input incident location and lanes blocked, and the system pulls up the appropriate scenario. The operator then accepts or modifies that scenario depending on the specifics of the incident (such as changing the word "Debris" on a CMS message to the word "Glass").

The operators indicated that they do have to modify the LCS arrays from time to time in response to unusual conditions that arise during an incident. One operator noted that an incident is dynamic, and the number of lanes closed at any one time depends on how long it has been out there, whether response vehicles have arrived, and what type of specialized response equipment is needed to clear the incident (i.e., a heavy-duty tow truck for truck incidents). Oftentimes, the operators will pull up several incident scenarios (with different numbers of lanes blocked) for a given incident location. That way, they can review and modify the upstream LCS arrays and CMS messages very quickly as the characteristics of the incident change.

At the boundaries of the TransGuide system, operators did state that if fewer than three LCS arrays are available upstream of an incident, they will display red Xs over the closed lane on whatever LCS arrays are available. Only when there are three LCS arrays available will the most upstream array display a yellow diagonal arrow. Consequently, it appears that most motorists wait until they reach the first red X indication before exiting the blocked lane or lanes. Most likely, they have established expectancies about the approximate distance they have between when they first encounter a red X and when they will actually reach the location of the lane blockage. This makes it somewhat difficult to assess how effective a yellow diagonal arrow is upon traffic behavior. However, the operators do feel that the arrows are helpful in preparing drivers for the upcoming lane change.

The operators generally put up a yellow downward arrow on the first upstream LCS array from a stalled vehicle on the shoulder or a congested freeway-to-freeway connector . They did not feel the need to provide more advance information to motorists for these conditions since it was not necessary for motorists to make significant adjustments in their driving behavior.

Situations Difficult to Treat With LCS

Generally speaking, the operators felt that incidents in the vicinity of lane drops and additions were the most difficult to treat and manage with LCS. However, these difficulties are not due to the yellow arrow indications themselves but rather to the dilemma of trying to convey information upstream where one type of roadway cross-section exists about conditions downstream where a different cross-section exists. Another type of difficulty encountered by operators is at the boundaries of TransGuide operations when an incident is located outbound beyond the limits of TransGuide surveillance. They want to provide information on the upstream CMSs and LCSs if they can, but until they receive information about the incident from police or other sources, they cannot. Again, however, this is not a problem that is due to the yellow arrow indications.

Operators did recall one incident that gave them trouble with respect to the LCS arrays. A major accident had occurred in the left two lanes of the freeway. The operators set the LCS arrays to indicate closed lanes ahead. While that incident was still being cleared, a vehicle stalled in one of the remaining open lanes. Operators decided to give preference to the major incident and left green arrows over the lanes not involved in the initial incident, because of concerns about further confusing the motorists. However, it was one situation in which operators knew the lane was blocked, but they had to display a green arrow over the lane anyway. The operators did note that traffic backed up in all lanes for a significant distance upstream of the incident, such that the effect and use of the LCS was probably not as significant as it might have been if traffic volumes had been low.

Concluding Comments

It was the general consensus of the group that both the yellow diagonal and yellow downward arrows were effective means of communicating with motorists. Because the situations in which the diagonal arrow is used tend to be more severe and have a more significant impact upon traffic, operators believe that both CMS and LCS are necessary to properly convey lane status information. It may not be possible to always measure driver responses to the yellow diagonal arrow, but it may still serve a useful purpose in getting motorists to start thinking and preparing for a lane change (which they appear to initiate after they reach the first LCS array where a red X is being displayed).

With respect to the yellow downward arrow, operators see it as useful but not quite as critical to traffic operations. There was some discussion within the group about the potential of having the arrows flash to increase their conspicuity. They felt that flashing CMS messages attracted more attention, and a flashing arrow might do the same. A few of the operators recommended more extensive public information and driver training regarding the intended meaning of the downward yellow arrow.

4. OPERATIONAL STUDIES OF THE YELLOW X AND YELLOW DIAGONAL ARROW LANE CONTROL SIGNAL SYMBOLS

INTRODUCTION

Researchers conducted a series of field studies as part of Study 1498 to assess the effect of the yellow diagonal arrow upon freeway traffic operations in advance of lane blockages. The TransGuide system in San Antonio is currently the only location statewide that has the capability of displaying the yellow diagonal arrow in an LCS array. In fact, they rely on this symbol (rather than on the yellow X that is recognized by the MUTCD) as their primary transition symbol between the green arrow and red X during the day-to-day operation of the system. The focus of the studies documented in this chapter was to compare the effect of the yellow diagonal arrow upon driver behavior, relative to the effect achievable by the yellow X.

One of the concerns early on in the evaluation was the influence of learning effects and expectancies developed by drivers about either of these transition symbols, depending upon which one the traffic management system in their city uses most regularly. In particular, since TransGuide in San Antonio uses the yellow diagonal arrow for managing lane blockages, TxDOT personnel were concerned about conducting numerous evaluations of the yellow X in that city for fear of confusing the motorists and reducing the credibility of the system. Therefore, researchers decided that they would conduct a limited number of studies in San Antonio of both the yellow diagonal arrow and yellow X at a given location for a short period of time to directly compare driver response. Rersearchers would then conduct additional studies focusing exclusively upon driver response to the yellow diagonal arrow in San Antonio. Researchers would also conduct studies in Fort Worth that focused exclusively upon driver response to the yellow X.

STUDY PROCEDURES

Researchers used the same basic data collection and analysis procedures in all of the field studies conducted for this evaluation. Researchers used video cameras (either the CCTV cameras operated by the TxDOT traffic management systems or the researchers' portable units) at each lane blockage studied to record traffic approaching the first upstream LCS (where system operators displayed either a yellow X or a yellow diagonal arrow). Researchers obtained video data during the times that the yellow LCS symbols were activated and lanes were blocked, and for 30 minutes to one hour after the incident when all lanes were clear and green arrows were displayed over each lane.

The video data were reduced to determine, where possible, three basic types of data:

- The distribution of traffic volumes across the available lanes (measured directly underneath the LCS array),
- The lane-changing frequencies between the open and closed lanes (measured over a 76-meter distance immediately downstream of the LCS array), and
- Erratic maneuvers (severe braking, lane-changing back and forth between open and closed lanes, etc., occurring either upstream or immediately downstream of the LCS array).

Researchers considered lane distribution data both in absolute and in relative terms. Researchers used the absolute change in the percent of traffic in a given lane (for example, from 22 percent before the incident to 20 percent during the incident) to assess the statistical significance of the LCS system (based on a test of proportions). However, to normalize the effect of the LCS from location to location, the absolute change in the percent of traffic using a lane was divided by the original percent of traffic using that lane. In the previous example, the two percent reduction in the percent of traffic using the inside lane actually represents a 9 percent ($2 \div 22 = 0.09$) relative reduction. If the normal traffic volume in that lane had represented 30 percent of all traffic, the relative effect on that lane would have been a 6.7 percent reduction ($2 \div 30 = 0.067$). These relative comparisons were only calculated if the absolute changes were statistically significant, however.

Researchers computed lane-changing frequency as the absolute number of changes to and from a given lane divided by the total amount of traffic using that lane. This measure provides further indication of (a) whether or not motorists are being encouraged to vacate a closed lane, and (b) whether they are being discouraged from moving from other lanes into that lane farther downstream.

STUDY RESULTS

Direct Comparisons of the Yellow X and Yellow Diagonal Arrow - San Antonio

Site Characteristics

Appendix B documents the results of four studies conducted in San Antonio where both the yellow diagonal arrow and the yellow X were each displayed for a period of time upstream of a freeway lane blockage. These studies consisted of both single-lane and multiple-lane blockages located in one direction of six-, eight-, and ten-lane sections of freeway. Table 4-1 summarizes the characteristics of each direct comparison evaluation site.

These evaluations were all located upstream of roadway construction and/or maintenance work lane closures. Contractors performed these closures during daylight, off-peak traffic conditions. Regular advance warning signs as per MUTCD requirements for the closures were utilized at each site. However, the LCS arrays activated with the yellow indications were generally far enough upstream not be affected by these signs. Two of the evaluation sites did not have CMSs located upstream of the first LCS array, whereas the two remaining sites did have CMSs present.

TABLE 4-1. Characteristics of Direct Comparison Evaluation Sites

Site	Location	Number of Lanes	Number of Lanes Blocked	LCS Configuration
1	I-10 EB @ Nogalitos	4	1	YGGG
2	I-10 WB @ I-35	5	1	GYGGG
3	I-10 WB @ Roland	3	2	YYG
4	I-10 WB @ Roland	3	2	GYY

Evaluation Results

Table 4-2 summarizes the percent of traffic in the closed lane or lanes at each site. The percentages are slightly higher when the yellow diagonal was being displayed at three of the four sites. However, none of these were found to be statistically significant (at a 95 percent level of confidence) at any of the sites.

TABLE 4-2. Closed Lane Distributions: Yellow X Versus Yellow Diagonal Arrow

Site	Lanes Blocked	Percent of Traffic in Closed Lane (s)	
		Yellow X	Yellow ↘
1	inside lane	16.3	17.2
2	2nd inside lane	20.0	21.2
3	2 inside lanes	52.6	55.2
4	2 outside lanes[a]	82.8	80.3

[a] A CMS indicating closed lanes was displayed in conjunction with the LCS at this site

Table 4-3 presents the lane-changing frequencies observed at those sites where data were available (roadway geometrics at the first site did not allow lane-changing behavior to be observed). Again, researchers found no statistical differences in driver response to the yellow X or the yellow diagonal arrow.

TABLE 4-3. Lane-Changing Frequencies: Yellow X Versus Yellow Diagonal Arrow

Site	Lanes Blocked	Percent of Traffic Exiting Closed Lane (s)		Percent of Traffic Entering Closed Lane (s)	
		Yellow X	Yellow ↘	Yellow X	Yellow ↘
1	inside lane	--.-[a]	--.-	--.-	--.-
2	2nd inside lane	5.3	4.8	4.8	3.5
3	2 inside lanes	2.2	3.8	2.1	4.0
4	2 outside lanes	6.6	6.5	1.2	1.1

[a] data were not available at this site

Although researchers monitored traffic behavior (via the videotapes) at each of the four sites, they did not observe any particular instances of any type of erratic maneuvers at any of the sites that would suggest driver misunderstanding or confusion about either of the yellow transition symbols examined.

Effect of Yellow Diagonal Arrow Relative to Normal Traffic Conditions - San Antonio

Site Characteristics

Appendix B also contains results of San Antonio studies that compared driver responses when a yellow diagonal arrow was displayed upstream of a lane closure to driver responses when no lane closures were present (all LCS displayed green arrows). Normal "control" data were available at sites 1, 3, and 4 as listed above. Also, data for the yellow diagonal arrow and a control condition were available from an additional site (labeled as case study E in Appendix B).

Table 4-4 presents the amount of traffic in the closed lanes where a yellow diagonal arrow (sometimes in conjunction with a CMS) was displayed. Also shown in that table is the percent of traffic normally using those lanes in the absence of a lane closure. Only the reduction in the last row of Table 4-4 was statistically significant, although in all cases the percentages were lower than for the control condition. These small changes support comments by the TransGuide operators (see Chapter 3) who believed that most motorists waited until they were closer to the lane blockage (i.e., when they reached a red X) before they vacated the lane. Nevertheless, they do suggest that the arrows do have some effect upon motorist behavior, even a significant distance upstream of the actual point of closure.

TABLE 4-4. Closed Lane Distributions: Yellow Diagonal Arrow Versus a Control

Site	Lanes Blocked	Percent of Traffic in Closed Lane (s)	
		Yellow ↘	Control Condition
1	inside lane	17.2	18.9
3	2 inside lanes	55.2	59.6
4	2 outside lanes[a]	80.3	81.9
5	inside lane[a]	10.3	20.4

[a] A CMS indicating closed lanes was displayed in conjunction with the LCS at this site

Table 4-5 summarizes the lane changing frequencies measured just downstream of the LCS array under lane closure and normal "control" conditions at three sites. Researchers found no statistically significant differences at any of the sites, indicating that the yellow diagonal arrow had minimal impact upon lane-changing frequencies at the sites examined in this study. However, the values from the sample of traffic reported in Table 4-5 at two of the three locations are consistent with expectations; namely, the percentages exiting the closed lanes are slightly higher when the diagonal arrow was present (relative to the control condition), and the percent of traffic entering the closed lanes was slightly lower.

The exception to these patterns occurs at site 5. Given the reduction in lane distribution percentages that had already occurred at that location by the time motorists reached the LCS array (see Table 4-4), these lane-changing values may simply indicate that all motorists who were going to vacate the lane had done so prior to reaching the region where researchers monitored lane changing. Once again, there were no erratic maneuvers to report in the vicinity of the LCS at any of the sites.

TABLE 4-5. Lane-Changing Frequencies: Yellow Diagonal Arrow Versus Control

Site	Lanes Blocked	Percent of Traffic Exiting Closed Lane (s)		Percent of Traffic Entering Closed Lane (s)	
		Yellow ↘	Control Condition	Yellow ↘	Control Condition
3	2 inside lanes	3.8	2.0	4.0	3.7
4	2 outside lanes	6.5	3.7	1.1	2.0
5	inside lane	0.5	2.6	5.3	2.6

Effect of Yellow X Relative to Normal Traffic Conditions - Fort Worth

Site Characteristics

To complement the studies conducted on the yellow diagonal arrow in San Antonio, researchers conducted a series of four studies in 1995 on I-35W in Fort Worth between I-20 and I-30. TxDOT operates an interim Traffic Management Center out of its satellite office building at the southern end of this freeway section. The freeway section includes loop detectors, CCTV, CMSs, and LCSs. Appendix C documents in detail the traffic behavior observed upstream of those four lane blockage sites. Table 4-6 summarizes the general roadway and lane closure characteristics of the four sites.

Study Results

Table 4-7 summarizes the changes in closed lane traffic distributions observed at four site locations in Fort Worth at the location of LCS arrays where a yellow X was being displayed. At Sites 3 and 4, TxDOT utilized yellow Xs on two LCS arrays in a series to facilitate the lane closure. Consequently, data from both LCS array locations are presented for those sites.

TABLE 4-6. Characteristics of Fort Worth Sites

Site	Location	Number of Lanes	Number of Lanes Blocked	LCS Configuration
1	I-35W NB @ Allen	4	1	YGGG
2	I-35W SB @ Seminary	4	2	YYGG
3	I-35W NB @ Hattie	4	1 (2 near incident)	YGGG, YYGG
4	I-35W NB @ Hattie	4	1 (2 near incident)	YGGG, YYGG

TABLE 4-7. Closed Lane Distributions: Yellow X Versus a Control

Site	Lanes Blocked	Percent of Traffic in Closed Lane (s)	
		Yellow X	Control Condition
1	inside lane	13.6	17.0
2	2 inside lanes	40.9	50.8
3a[a]	inside lane	11.9	18.5
3b[a]	2 inside lanes	33.5	45.0
4a[a]	inside lane	24.6	18.5
4b[a]	2 inside lanes	52.4	45.0

[a] A single yellow X was displayed at the most upstream LCS at these sites, followed by an array that had two yellow Xs displayed

As Table 4-7 illustrates, the percent of the traffic at each site that was in the closed lane at the LCS array decreased significantly at three of the four sites. At sites 1 and 3a, where a single yellow X was displayed over the inside lane, the shift in traffic from the closed lane ranged between 3.4 percent and 6.6 percent of the total freeway traffic volumes. For the two lane closure display at Sites 2 and 3b, the shift in traffic from the closed lanes ranged from 9.9 to 11.5 percent of the total traffic volumes at each location. If one considers only the traffic in the closed lanes (that for which the yellow X indications are primarily intended), these shifts in traffic represent between 19 and 36 percent reduction in expected traffic volumes in the closed lane(s) (dividing the percentage shift by the percentage of traffic in the closed lane during the control condition).

Also evident in Table 4-7 is the fact that the yellow X at Site 4 did not reduce traffic percentages in the closed lane(s). However, traffic queued in the open lanes at these LCS array locations, whereas it was not in the closed lanes. Researchers observed many motorists deliberately staying in the closed lane (and in some cases, moving from the open lane to the closed lanes) in order to bypass part of the queue at this site. As a result, the numbers in Table 4-7 for Site 4 more directly reflect the influence of traffic congestion upstream of a lane blockage rather than an effect of the yellow X.

Table 4-8 documents the effect of the yellow X upon lane-changing behavior at the four Fort Worth sites. All but one of the sites for which data were available experienced a significant increase in the percent of traffic exiting the lane or lanes under a yellow X, relative to the lane-changing behavior that normally occurs at that location (the control condition). Meanwhile, the percent of traffic entering into the closed lane or lanes at these sites remained unchanged or was slightly lower when the yellow X was displayed.

The lone exception to this trend again occurred at Site 4a. Here, the amount of traffic exiting the closed lane was unchanged from normal lane-changing rates, but the percent of traffic entering the closed lane was significantly higher than occurred for normal traffic conditions. As already stated, a traffic queue in the open lanes and a lack of queuing in the closed lane at that location apparently encouraged some motorists to move into that closed (but uncongested) lane to bypass some of the queue.

As was the case for the studies conducted in San Antonio, there were no instances of any type of erratic maneuvers observed at any of the sites.

TABLE 4-8. Lane-Changing Frequencies: Yellow X Versus Control

Site	Lanes Blocked	Percent of Traffic Exiting Closed Lane (s)		Percent of Traffic Entering Closed Lane (s)	
		Yellow X	Control Condition	Yellow X	Control Condition
1	inside lane	9.2	3.0	2.0	1.5
2	2 inside lanes	19.8	2.1	2.9	2.7
3	2 inside lanes	-----[a]	-----[a]	-----[a]	-----[a]
4a	inside lane	5.1	4.2	14.7	1.5
4b	2 inside lanes	6.8	1.6	0.8	2.9

[a] data not available at this site

INTERPRETATION OF RESULTS

The data from San Antonio indicate that, operationally, very little difference exists between how drivers respond to a yellow diagonal arrow and a yellow X in a freeway driving environment. Statistically, neither closed-lane volume distributions nor lane-changing frequencies were significantly different at any of the sites where both yellow indications were tested. However, although no strong statistical inferences can be drawn from these data, it is interesting to note that the closed-lane percentage values were slightly lower at three of the four sites when the yellow X was displayed, relative to those recorded when the yellow diagonal arrow was displayed. These support the results of laboratory research that suggested motorists who interpret both the yellow X and the yellow diagonal arrow as indicating the need to exit a lane place slightly more urgency with the yellow X indication (*6*). Slightly more than 35 percent of motorists surveyed in that earlier study believed they should exit a lane under a yellow X as soon as possible, compared to slightly more than 25 percent of those who responded that way for the yellow diagonal arrow.

At first glance, the yellow LCS symbol versus control lane distributions (Tables 4-4 and 4-7), suggests that the responses in terms of vacating the closed lane(s) were more substantial for the yellow X in Fort Worth than for the yellow diagonal arrow in San Antonio. However, although these data are useful in assessing the effectiveness of the LCS information system, readers should exercise caution when attempting to compare directly between the two study locations. The operational practice in San Antonio is to display red Xs over closed lanes at the first two LCS arrays upstream of the lane blockage, and then display a yellow diagonal arrow.

Over time, drivers may have become aware that they have considerable time once they see the yellow arrow before it will be absolutely necessary for them to vacate the lane. Consequently, the urgency to exit the lane once they see the yellow arrow may be less than for motorists who respond to the yellow X in Fort Worth.

Another hypothesis for the differences in driver response data from San Antonio and Fort Worth is that, because the freeway geometrics in the downtown San Antonio area are quite complex, drivers cannot always respond immediately to a yellow LCS display they encounter. Rather, they can do so only after negotiating merging and diverging traffic, identifying their appropriate destination lane, etc. In contrast to San Antonio, the freeway section in Fort Worth where LCS and other traffic management system instrumentation is located has much simpler geometrics and lower driver workload demands.

As a final note, researchers studied the yellow indications at both San Antonio and Fort Worth locations in an array consisting of only yellow symbols (arrows or Xs) and green arrows. In these types of LCS array configurations, the yellow X is commonly interpreted (as is the yellow diagonal arrow) to indicate the need to vacate the lane. Consequently, one would expect driver response to both symbols to be similar in these type of LCS arrays. The major question that arises, however, is whether or not the yellow X could be displayed in conjunction with a red X and green arrow(s) at an array location, and achieve the same results as would occur by displaying a yellow diagonal arrow.

5. SUMMARY AND RECOMMENDATIONS

SUMMARY

This report has documented the research performed to assess the effectiveness and applicability of yellow diagonal and downward arrows for freeway traffic management purposes. Researchers investigated motorist understanding of and perceived usefulness of the arrows through surveys of San Antonio motorists where these indications are being utilized as part of the TransGuide system. These results were compared to similar data obtained from motorists in Fort Worth where TxDOT operates a traffic management system utilizing a yellow X. Researchers also conducted interviews with operators of the TransGuide system to assess their opinions of the yellow arrow indications and to identify any difficulties they have experienced in utilizing these symbols in their daily traffic management activities. Finally, researchers performed a series of field studies to assess how drivers respond to yellow diagonal arrows used to transition between a lane open (green arrow) and a lane closed (red X). These were considered in relation to driver response to a yellow X that is currently the MUTCD-accepted symbol for accomplishing this transition.

The results of the surveys indicate motorists perceive both the yellow diagonal and downward arrows positively in actual freeway driving situations. A large majority of survey respondents rated both types of yellow arrows as helpful to them, and only a small portion of the survey sample felt either arrow symbol was confusing. The ratings are very similar to those given for the yellow X by Fort Worth motorists. The only statistically significant difference between survey groups existed for motorists who had not seen the yellow transition symbol actually used in a driving situation. In San Antonio, 12 percent of those types of motorists rated the yellow diagonal arrow as confusing. In Fort Worth, over 30 percent of motorists who had not actually seen the yellow X used on the freeways rated that symbol as confusing. The difference in percentages was non-existent for motorists who had seen one of the symbols used in an actual driving situation. These results suggest that the yellow X does not possess a strong inherent meaning with motorists (as was suggested by the earlier laboratory research). However, once motorists can see the symbol used in an actual freeway driving context, they can deduce its intended message.

The TransGuide system operators could not think of specific driver behavioral problems they had observed that would suggest that drivers were confused by either the diagonal or downward yellow arrows in San Antonio. They indicated that no accidents had occurred that were attributable to the yellow arrows, either. Operators' impressions of the effectiveness of the yellow diagonal arrow are generally favorable. They agree that most drivers do appear to respond to the arrows, although there are always those who wait to the last minute to exit a given lane. Researchers obtained favorable operators' responses about the effectiveness of the yellow downward arrow as well. As operators noted, however, it is difficult to identify specific driving actions (speed reductions, reduced lane changing, etc.) from the CCTV or other data to determine objectively how the indications are influencing drivers. An unexpected benefit obtained from the downward arrows is that emergency personnel can find incident and vehicle stall locations on the shoulders more quickly as they patrol the freeways because the arrow gives them advance warning about its location.

The operators felt that incidents in the vicinity of lane drops and additions were the most difficult to treat and manage with LCS (including the yellow arrow symbols). However, these difficulties are not due to the yellow indications themselves, but rather to the dilemma of trying to convey information upstream where one type of roadway cross-section exists about conditions downstream where a different cross-section exists. Operators also experience difficulties at the boundaries of TransGuide system when an incident is located outbound beyond the limits of TransGuide surveillance. They want to provide information on the upstream CMSs and LCSs if they can, but until they receive information about the incident from police or other sources, they cannot. Again, however, this is not a problem that is due to the yellow arrow indications. There was some discussion among operators about the potential of having the arrows flash to increase their conspicuity. Operators felt that flashing CMS messages attracted more attention, and a flashing arrow might do the same. Some of the operators recommended more extensive public information and driver training regarding the intended meaning of the downward yellow arrow.

The data from San Antonio showed very little difference in how drivers respond to a yellow diagonal arrow and a yellow X in a freeway driving environment under the conditions studied. Statistically, neither closed-lane volume distributions nor lane-changing frequencies were significantly different at any of the sites where both yellow indications were tested. However, the yellow indications at both San Antonio and Fort Worth locations were studied in an array consisting of only yellow symbols (arrows or Xs) and green arrows. In these types of LCS array configurations, the yellow X is commonly interpreted (as is the yellow diagonal arrow) as indicating the need to vacate the lane. Consequently, one would expect driver response to both symbols to be similar in these types of LCS arrays. The major question that still remains is whether or not the yellow X could be displayed in conjunction with red Xs and green arrow(s) at an array location, and achieve the same results as would occur if a yellow diagonal arrow was displayed at that location.

RECOMMENDATIONS

Data collected through this research effort indicates that TransGuide operators and the motoring public perceive the use of both the yellow diagonal and downward arrows for freeway traffic management purposes positively. Furthermore, no evidence of operational problems or difficulties due to the use of either of these non-standard symbols has been collected through field studies in San Antonio. Similar statements can be made concerning the yellow X. Motorists in Fort Worth rate this symbol fairly highly once they see it used in a freeway driving situation. Field studies suggest that the number of drivers exiting a closed lane when first encountering the yellow X symbol equals or exceeds the number that would for the yellow diagonal arrow.

Based on the results of these study efforts, one cannot say for certain that the utilization of a yellow diagonal arrow in lieu of a yellow X results in improved freeway operations or effectiveness of a motorist information component in a freeway traffic management system. In fact, it appears that the two symbols are interchangeable from the operations data collected to date. However, it is possible that the performance measures used in these studies were not sensitive to the operational differences that may exist between the two types of transition symbols.

The results of the motorist survey in Fort Worth still suggest an inherent difficulty with the yellow X in that it does not convey a strong inherent message to motorists about how they should respond to it. It appears that drivers are able to ascertain the intended meaning fairly easily once they see it actually used in a freeway driving situation, though. If TxDOT establishes a policy to allow the yellow X to be displayed only in conjunction with green arrows at a given LCS array, it is likely that system performance would be similar regardless of whether the yellow X or the yellow diagonal arrow is used as the transition LCS symbol. If, however, TxDOT were to consider the use of more complex LCS arrays in its traffic management efforts (those that included the display of red Xs, yellow Xs or arrows, and green arrows at a single location), the lack of a consistent inherent meaning for the yellow X could make it less desirable than the yellow diagonal arrow for use in Texas. In this scenario, TxDOT would be well advised to pursue a acceptance of the yellow diagonal arrow in the MUTCD.

As with the yellow diagonal arrow, experiences regarding the yellow downward arrow do not indicate any problems with its continued use within TransGuide. Benefits accrued because of its use seem limited primarily to intangibles (better driver awareness of shoulder vehicle stalls, improved emergency response location abilities, etc.) at this time. Pursuit of the acceptance and inclusion of the yellow downward arrow into the MUTCD would also seem logical for TxDOT as well.

6. REFERENCES

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APPENDIX A: MOTORIST SURVEYS

The next few questions relate specifically to your perceptions of the lane control signals in place throughout the downtown area. These small square signals installed over each lane are designed to inform you which lanes are open for travel and which are blocked or about to be blocked downstream.

1. **Please check ( ) which of the following lane control signals you have seen on local freeways**

___ ___ ___ ___ ___

2. **Overall, do you feel that the yellow diagonal arrow signals provide helpful information to you?**
   Yes _____ No _____

3. **Have you been in any driving situation where the yellow diagonal arrow signals displayed were confusing to you?**
   Yes _____ No _____

4. **Overall, do you feel that the yellow downward arrow signals provide helpful information to you?**
   Yes _____ No _____

5. **Have you been in any driving situation where the yellow downward arrow signals displayed were confusing to you?**
   Yes _____ No _____

If you answered YES to Questions 3 or 5, please answer the following:

6. **Think back and describe in as much detail as you can each confusing situation that you experienced when the *yellow diagonal arrow or yellow downward arrow* was displayed.**

   Time of day: ___________ **Freeway:** ______________ **Direction:** ____________

   What was it that was confusing to you about this situation?

   ____

   ____

   Do you have any suggestions that might help eliminate this type of confusion?______________

   ____

   ____

If you have experienced more than one situation where the lane control signals were confusing to you, please attach additional sheets as needed.

7. **If any additional information is needed regarding this survey, may we contact you by phone?**
   Yes _____ No_____

   If yes, telephone number: _____________________ **Time preference:** _______________

Thank you for your time and participation!

The next few questions relate specifically to your perceptions of the lane control signals in place on portions of the Fort Worth freeway system. These small square signals installed over each lane are designed to inform you which lanes are open for travel and which are blocked or about to be blocked downstream.

1. **Please check ( ) which of the following lane control signals you have seen on local freeways**

_____ _____ _____

2. **Overall, do you feel that the yellow X signals provide helpful information to you?**

   Yes _____ No _____

3. **Have you been in any driving situation where the yellow X signals displayed were confusing to you?**

   Yes _____ No _____

If you answered YES to Question 3, please answer the following:

4. **Think back and describe in as much detail as you can each confusing situation that you experienced when the *yellow X* was displayed. If you have experienced more than one situation where the lane control signals were confusing to you, please describe them on the back of this survey.**

   Time of day: __________ **Freeway:** ____________________ **Direction:** ____________

   What was it that was confusing to you about this situation?

   ____

   ____

   Do you have any suggestions that might help eliminate this type of confusion?

   ____

   ____

5. **If any additional information is needed regarding this survey, may we contact you by phone?**

   Yes _____ No_____

   If yes, telephone number: ____________________ **Time preference:** ______________

6. Do you think that lane control signals should remain on at all times, or only be turned on when needed to indicate that a lane is closed ahead?

_____ **on at all times**

_____ **turned on only when a lane is closed ahead**

Why do you feel this way? ____

____

____

APPENDIX B: SAN ANTONIO FIELD STUDIES

INTRODUCTION

The goal of the research documented in this appendix was to determine how motorists respond to a yellow diagonal arrow in an actual driving environment. Researchers evaluated driver responses to the yellow diagonal arrow and compared them to responses to the yellow X and to a control condition involving no lane blockage and green arrows displayed over all travel lanes. In order for a complete evaluation of the yellow diagonal arrow, researchers specified the following study objectives:

- Determine if there was a significant difference between the effect of the yellow X and the yellow diagonal arrow as evidenced by the lane distribution, the lane changing frequency, and erratic maneuvers.

- Determine if the presence of changeable message signs (CMSs) further influenced the difference between the effectiveness of a yellow X and a yellow diagonal arrow.

STUDY PROCEDURES

Study Site

The Texas Department of Transportation currently operates LCS arrays on I-10, I-35, and I-37 in San Antonio, Texas. The LCS system has been implemented on a 39 kilometer (24 mile) stretch of roadway that surrounds the downtown area. The LCS arrays are spaced approximately every 1.6 kilometers (1 mile), except near an interchange where the spacing is approximately every 0.8 kilometer (0.5 mile). Back panels are also installed on the LCSs to aid visibility. Each individual display in an array is placed directly over the lane that corresponds to the symbol. The LCS system is capable of using the yellow X or the yellow diagonal arrow as the transition symbol between a downward green arrow and a red X.

Also, CMSs are located at selected points along the LCS system. When the CMSs are activated, they describe the problem on the roadway ahead and inform the motorists of the proper action to take. TransGuide operators control both the LCSs and the CMSs . Operators detect problems on the freeway through closed-circuit television cameras, loop detectors, and by other authorities. All of these methods provide the interactive real-time information necessary to control the LCS system.

Data Collection

The data for this research was obtained at I-10E and Nogalitos, at I-10W after the interchange with I-35S, at I-10W and Roland Ave. (US 87), and at I-35 and Pine Street during the day with dry pavement conditions. These studies were conducted at locations where roadway maintenance necessitated the closure of one or more lanes. Researchers filmed traffic upstream of the closures with an 8 mm video camera. Researchers obtained yellow X and yellow diagonal arrow data without CMS at I-10E and Nogalitos, and at I-10W after the interchange with I-35S. The data collected on I-10W and Roland Ave. consisted of both the yellow X and yellow diagonal arrow, with and without CMS. An open lane condition (all downward green arrows) used as the control was evaluated at I-10E and Nogalitos and at I-10W and Roland Ave. At a fourth location (I-35 SB @ Pine Street), researchers were able to obtain video data for a yellow diagonal arrow over the inside lane and a control condition (researchers collected no data using a yellow X over the inside lane)

Data Reduction

Researchers evaluated the videos taken at each location to determine lane distribution volumes directly beneath the LCS array, lane changing frequency within approximately 76 meters (250 feet) downstream of the LCS array, and erratic maneuvers within approximately 76 meters (250 feet) upstream of the LCS array. For this study, an erratic maneuver was defined as indecisive lane changing between two lanes or braking for no apparent reason. Researchers evaluated the response to the yellow X and the yellow diagonal arrow both with and without a CMS to determine if CMSs further influenced the difference between the effect of the two symbols.

RESULTS

Researchers evaluated lane distribution volumes and erratic maneuvers at each of the study locations. However, due to site visibility constraints, the lane changing frequency was evaluated at only three sites. Study results for each site are described below on a case-by-case basis.

Case Study A

On Tuesday, May 14, 1996, maintenance work at I-10E and Nogalitos resulted in the inside of four freeway lanes being closed. The roadway alignment upstream of the LCS array was generally straight. However, a horizontal curve existed downstream of the LCS array. Also, traffic entered the freeway at a ramp located immediately adjacent to the LCS array studied. No CMS or orange construction signs were visible to motorists approaching the LCSs.

For this case study, three conditions were monitored (yellow X with downward green arrows, yellow diagonal arrow with downward green arrows, and all downward green arrows). As shown by the lane distribution percentages for this location in Figure B-1, there was no significant difference in motorist response to the yellow X or the yellow diagonal arrow. There was also no significant difference between the lane distribution when the two yellow symbols were displayed and the distribution when a downward green arrow (i.e. no lane closure condition) was displayed. In other words, it appears that motorists did not respond to the yellow symbols by the time they reached the first LCS array at this site. Limited visibility of the LCSs could have affected the amount of time the motorist had to respond. Drivers also had no previous warning such as a CMS or other orange construction signs to aid them in their interpretation of the signals. Lastly, traffic volumes were considerably higher in the open lanes than in the closed lane. This may have reduced the desirability of moving from the lane under a yellow symbol to a lane under a downward green arrow.

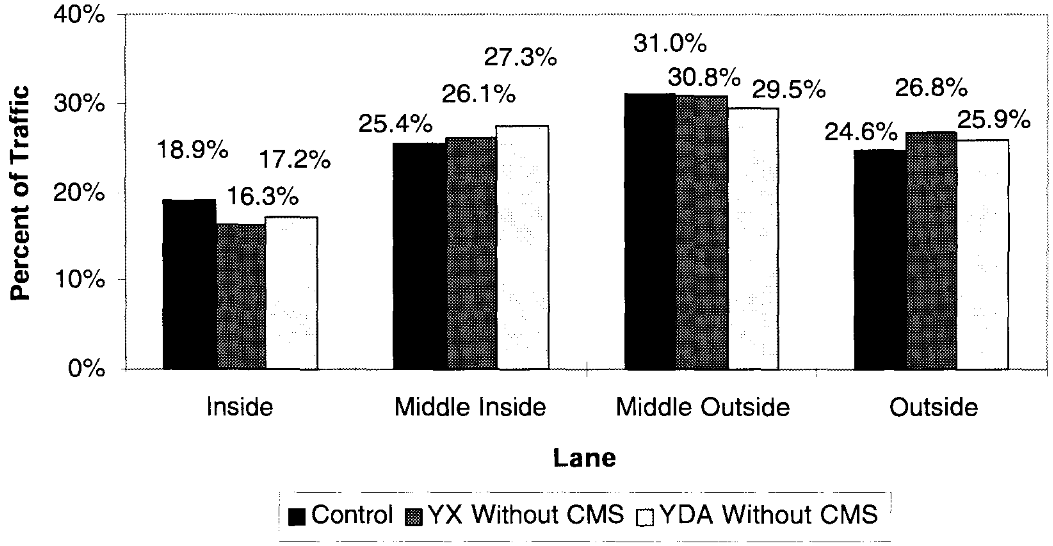


FIGURE B-1. Lane Distribution Percentages for Case Study A (Inside Lane Blocked)

Unfortunately, the lane change movements could not be evaluated at this site because of the horizontal curve downstream of the LCS array. It should be noted, however, that there was also no erratic behavior within approximately 76 meters (250 feet) upstream of the LCS array when either yellow symbol was displayed.

Case Study B

On Thursday, June 20, 1996, maintenance work at I-10W and I-35S resulted in the middle inside lane of five freeway lanes being closed. The roadway upstream of the LCS array at this location was also straight. However, I-10W (inside, middle inside, and middle lanes) and I-35 (middle outside and outside) merged approximately 305 meters (1000 feet) upstream of the LCS array. Also, the roadway splits into an upper (inside and middle inside lanes) and lower level (middle, middle outside, and outside lanes) approximately 457 meters (1500 feet) downstream of the LCS array. Therefore, the LCS array was located in a weaving section. A CMS was located at an LCS array approximately 229 meters (750 feet) downstream of the initial LCS array. The first road construction signs for the closure were at the merge of the traffic from I-10W and I-35S.

For this case study, researchers monitored only the yellow X and the yellow diagonal arrow. As shown by the lane distribution percentages for this location in Figure B-2, there was again no significant difference in driver response to the yellow X and the yellow diagonal arrow.

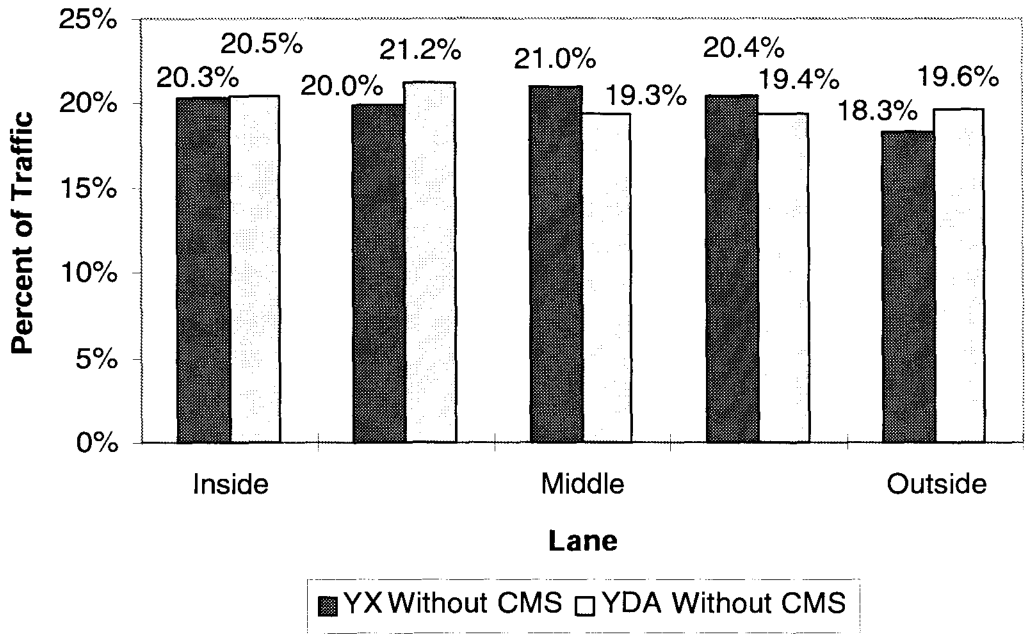


FIGURE B-2. Lane Distribution Percentages for Case Study B (Middle Inside Lane Closed)

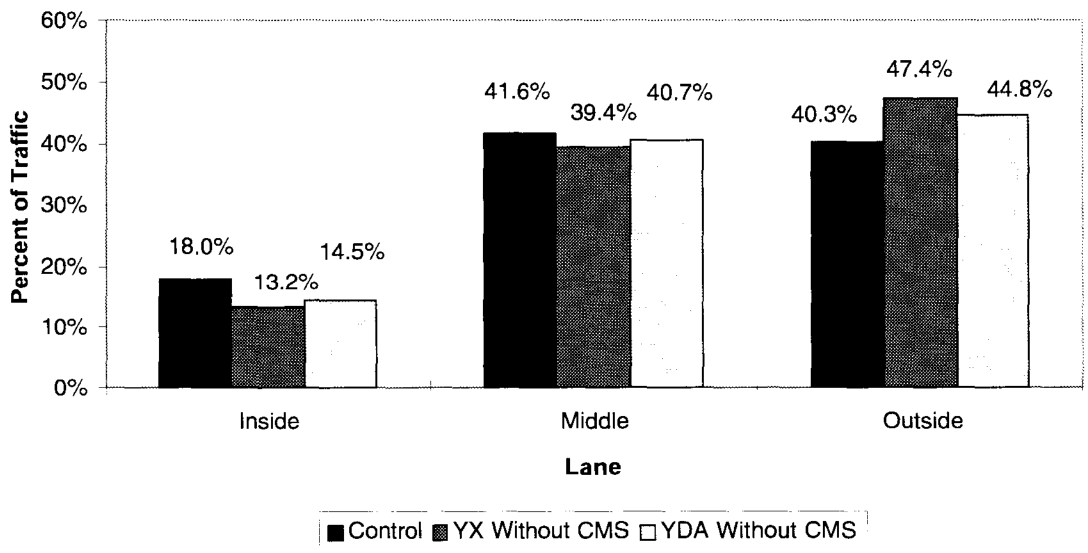
Researchers also evaluated the lane change movements within approximately 76 meters (250 feet) downstream of the initial LCS array. No significant difference in lane changing frequency was detected between the yellow X and the yellow diagonal arrow. Since the LCS array was located in the middle of a weaving section, it is likely that the lane change movements were in large part affected by other factors besides the LCS array. No erratic behavior was observed within approximately 76 meters (250 feet) upstream of the LCS array when either yellow symbol was displayed.

Case Study C

On Wednesday, April 3, 1996, maintenance work at I-10W and Roland Ave. (US 87) resulted in the inside and middle lanes being closed. The roadway upstream of the LCS array included a horizontal curve to the right and an entrance ramp adjacent to the LCS array. A CMS was mounted directly over the inside shoulder at the LCS array location. The first orange road construction signs for the closure were also located at the LCS array. Other road construction signs were visible further downstream of the initial LCS array.

For this case study, the yellow X and yellow diagonal arrow without a CMS were evaluated, as was a control (open lane) condition. In terms of lane distribution percentages for this location (Figure B-3), no significant difference existed between the yellow X and the yellow diagonal arrow. However, in the amount of traffic in the inside lane for both yellow symbols decreased when compared to an open lane condition. The reduction for the yellow X was statistically significant, but the decrease observed for the yellow diagonal arrow was not. The lack of statistical significance for the yellow diagonal arrow was most likely due to a lower sample size (the lane closure was removed before more data could be collected). Meanwhile, the percent of traffic in the middle lane was similar for all three symbols. The lack of a difference measured in the middle lane could also be due to more limited sight distance to the LCS and CMS from the middle lane (i.e., traffic in the inside lane had a longer sight distance to the LCS and CMS).

FIGURE B-3. Lane Distribution Percentages for Case Study C (Two Inside Lanes Closed)



Researchers evaluated the lane change movements within approximately 76 meters (250 feet) downstream of the initial LCS array, and found no significant difference between the yellow X and the yellow diagonal arrow. There was also no significant difference between the two yellow symbols and the open lane condition. Researchers detected no erratic behavior within approximately 76 meters (250 feet) upstream of the LCS array when either yellow symbol was displayed.

Case Study D

Also on April 3, 1996, the maintenance work at I-10W and Roland Ave. (US 87) resulted in the middle and outside lanes being closed. Here, researchers monitored the yellow X symbol, the yellow diagonal arrow symbol, and the control (open lane) condition. The CMS was also activated during part of the testing.

As shown by the lane distribution percentages for this location in Figure B-4, there was again no significant difference between the yellow X and the yellow diagonal arrow (both conditions also had a CMS activated). Also, researchers could not detect significant differences in lane distributions when the two yellow symbols with CMS were compared to a control (open lane) condition. Since the two yellow symbols in this evaluation were over the middle and outside lanes, motorists had a shorter sight distance to the LCS because of an upstream horizontal curve. Thus, it may be that traffic did not have time to recognize and respond to the LCSs before reaching the location where lane counts were made.

However, there was a significant difference in lane distribution between the yellow diagonal arrow without CMS and the yellow diagonal with CMS when used in the middle lane. When the CMS was used, the lane distribution decreased. Since the CMS was over the inside shoulder where motorists had a longer viewing distance, traffic could respond to the signal further upstream. However, a significant difference did not occur in the outside lane, probably because the entrance ramp was directing incoming traffic into the outside lane directly under the LCS array.

The lane change movements within approximately 76 meters (250 feet) downstream of the initial LCS array were also evaluated. As shown in Figure B-5, no significant difference in lane changing frequency was detected between the yellow X with CMS and the yellow diagonal arrow with CMS. Relative to a no-CMS display, the lane percentages are smaller in the closed lane, indicating increased driver response to the lane closure.

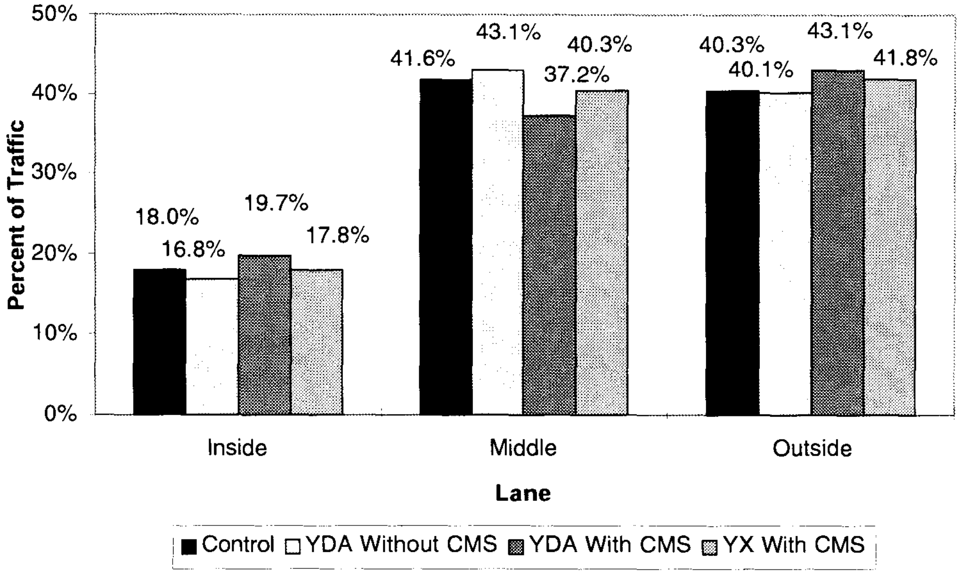


FIGURE B-4. Lane Distribution Percentages for Case Study D (Two Outside Lanes Closed)

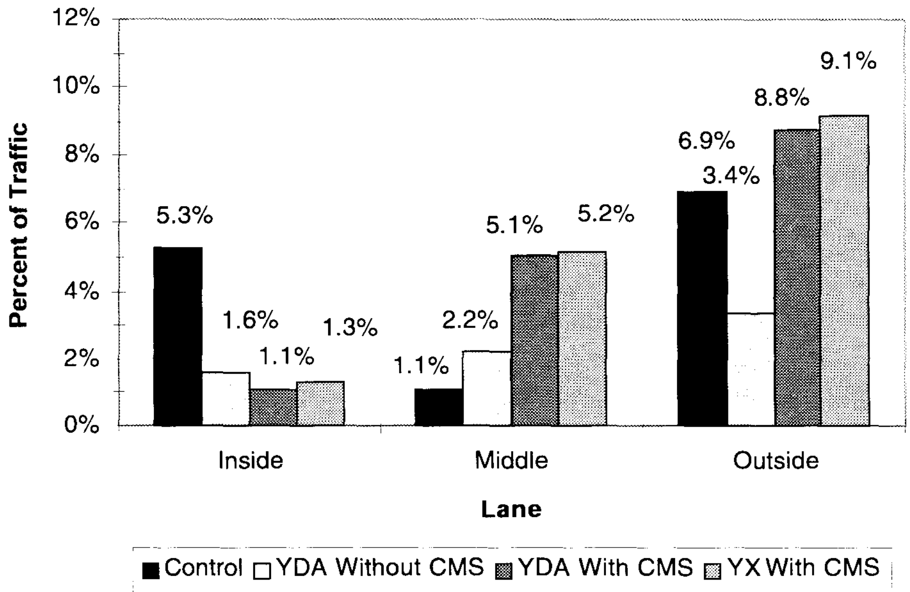


FIGURE B-5. Percentage of Traffic Leaving Lane for Case Study D (Two Outside Lanes Closed)

As shown in Figure B-6, the percent of traffic entering the open and closed lane exhibited changes consistent with the percent of traffic leaving other lanes (as depicted in Figure B-5). Specifically, there was no significant difference between the yellow X with CMS and the yellow diagonal arrow with CMS. The amount of traffic entering the inside open lane increased when the yellow diagonal arrow without CMS was displayed. There was an additional increase in the amount of traffic entering the inside lane whenever the CMS was used, regardless of the LCS symbol displayed. Researchers again detected no erratic behavior within approximately 76 meters (250 feet) upstream of the LCS array when either yellow symbol was displayed.

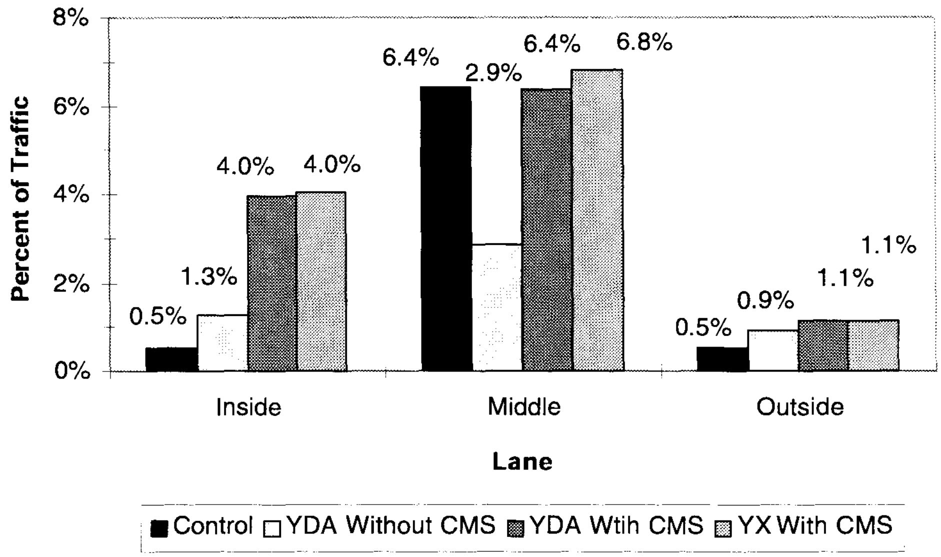


FIGURE B-6. Percentage of Traffic Entering Lane for Case Study D (Two Outside Lanes Closed)

Case Study E

The fifth and final case study in San Antonio occurred on June 5, 1996, in the southbound direction of I-35 at Pine street. CMS maintenance at this location necessitated the closure of the inside lane. The basic roadway cross-section at this location consists of four traffic lanes, full inside and outside shoulders, and a deceleration lane for an exit ramp to Pine Street. Motorists approaching the study section could not see the lane closure or the LCS until about 150 meters prior to the array because of a vertical crest curve. A CMS was located approximately 0.4 kilometers upstream of the LCS array which indicated "Road Construction Ahead, Left Lane Closed, 1 Mile --- Merge Right."

Figure B-7 indicates that traffic in the inside lane at the LCS array reduced significantly when the yellow diagonal arrow and upstream CMS were activated. As shown, the percent of traffic in that lane decreased from 20.4 percent under normal conditions to 10.3 percent during the times of the lane blockage.

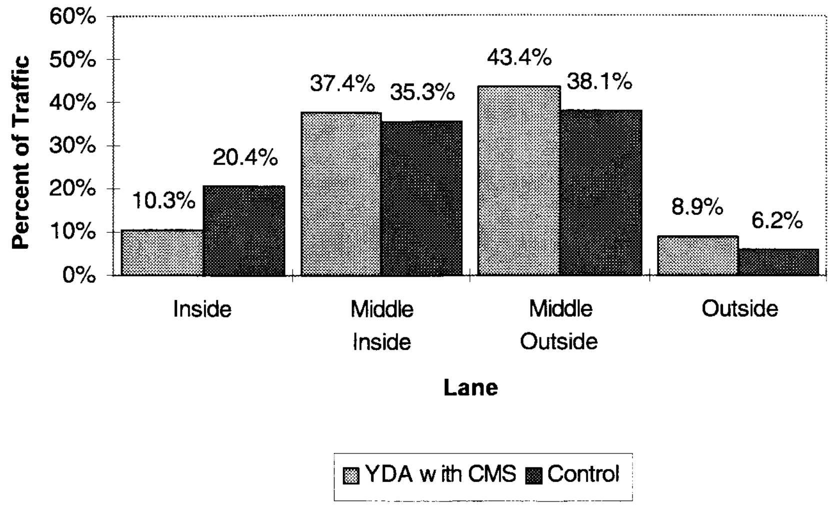


FIGURE B-7. Lane Distribution Percentages for Case Study E (Inside Lane Closed)

Figure B-8 summarizes the lane-changing frequency at this study site, indicating the percent of traffic that exited each lane. As the figure indicates, the exiting percentage from the inside lane was actually lower during the times the yellow diagonal arrow and CMS were displayed. However, given the dramatic reduction in lane distribution for that lane as reported in Figure B-7, the values in Figure B-8 more likely represent a condition whereby more motorists who normally change lanes just after reaching the LCS exited the lane farther upstream (because of the information on the CMS and/or the diagonal arrow as they came to the crest of the hill).

CONCLUSIONS

This research has indicated that there is no significant difference between the yellow X and yellow diagonal arrow symbols in terms of their effect upon driver behavior at the most upstream LCS array used at a location. However, when researchers compared the two yellow symbols with an open lane condition, they detected a decrease in the traffic volume in the lane with a yellow symbol. Depending on the site, though, this decrease in lane percentages was not always significant.

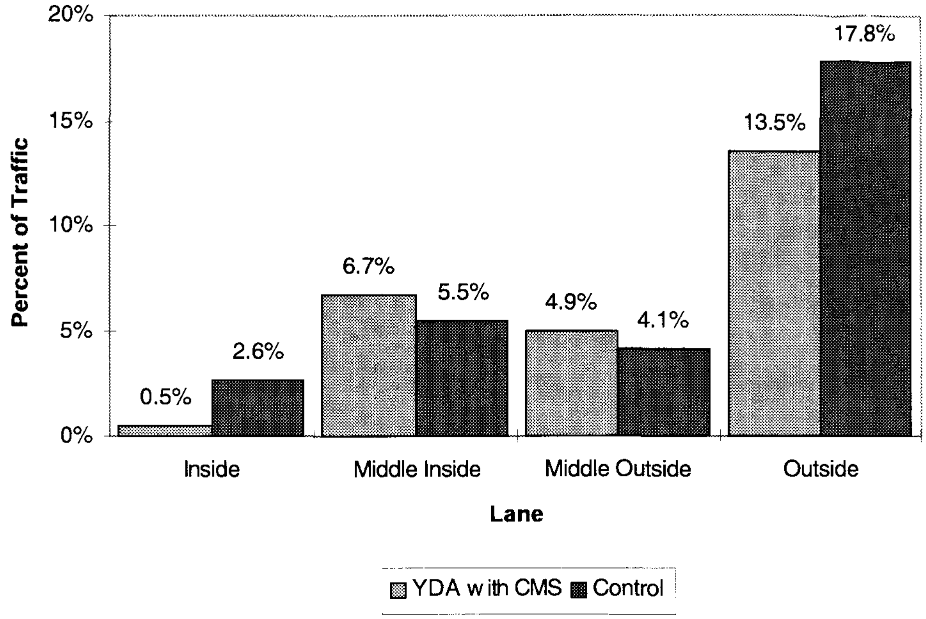


FIGURE B-8. Percentage of Traffic Exiting Each Lane for Case Study E (Inside Lane Closed)

Furthermore, when the yellow symbols were displayed, the traffic leaving the lane with a yellow symbol tended to increase, and the traffic entering the lane with a yellow symbol tended to decrease. Also, motorist responses to the yellow symbols increased with the addition of a changeable message sign. Overall, the motorist responses followed the general trends that were expected; however, there were significant site to site variations which made the comparison of data difficult. Lastly, researchers did not detect erratic behavior at the three sites to indicate a preference of one type of yellow symbol over another.

APPENDIX C: FORT WORTH STUDIES

INTRODUCTION

Lane control signals (LCSs) have been in use around the United States since the 1960s. However, they have not been widely used for freeway traffic management purposes. The Fort Worth District I-35W Freeway Traffic Management System offered an excellent opportunity to obtain data on driver responses to LCS used for freeway traffic management purposes. This appendix summarizes the results of studies conducted in Fort Worth to evaluate the effectiveness of the yellow X display and the effect of LCSs in general during both congested and uncongested operating conditions.

OBJECTIVE

The goal of this research was to evaluate how motorists respond to freeway lane control signals during lane blockage conditions on I-35W in Fort Worth, Texas. Although the focus of the evaluation was on peak-period incidents, additional off-peak lane closure data occurring during the study period are presented as well. The specific objectives of the study were as follows:

1. Determine if the percent of traffic in the closed lane(s) immediately downstream of a lane control signal array changed when a yellow or red X was displayed because of downstream incident conditions.

2. Determine if the relative frequency of lane changes to and from the closed lane(s) immediately downstream of the array was affected by the display of a yellow or red X to indicate downstream incident conditions.

STUDY DESIGN

Study Site

The 8.7 km (95.4 mi) stretch of I-35W in Fort Worth, Texas, between I-20 and I-30 was utilized for this research study. This section of the interstate is equipped with 7 sets of lane control signals spaced approximately every 1.2 km (0.8 mi) in each direction, 8 closed-circuit television (CCTV) cameras, and 2 changeable message signs (CMSs). All of this equipment is controlled by operators in the TxDOT Fort Worth District Satellite Operations Center located at the southern end of the instrumented freeway section. They are able to change the LCSs and CMSs according to what is seen on the closed-circuit televisions or by notification from other authorities.

Data Collection and Analysis

Researchers used the CCTV system monitored at the Satellite Operations Center to collect the data for this research. TTI researchers, with the cooperation of TxDOT District operations personnel, developed a quick-response data collection system that allowed data to be collected during peak-period lane-blocking incidents that lasted long enough for the LCS to be utilized. Researchers placed four VHS videocassette recorders in the satellite center and connected them to the CCTV monitors located there. Depending on the spot of an incident and the location of upstream lane control signals, the system operator would switch the appropriate CCTV camera feeds to those monitors connected to the VCR.

To facilitate data collection consistency and to avoid burdening the system operator with too many additional tasks during their incident response activities, TTI researchers established a simple step-by-step protocol to follow for each incident. As soon as an incident occurred that would require one or more LCS arrays to be changed from their normal green arrow display, the system operators began recording the queue upstream from the incident. The operators focused cameras to obtain a perspective view of the freeway showing individual vehicles to obtain traffic counts by lane at identifiable locations (gores, signs, bridges, etc.) for all lanes in the desired direction at each activated LCS array. The operators then called the TTI-Arlington office pager to notify the researchers that an incident had occurred. The researchers then responded to the incident by calling the center to determine the incident location, lanes blocked, LCS arrays used, queue patterns, and anticipated length of the incident. A researcher also went out to the center if the incident was expected to last for a significant period of time.

The operators recorded video throughout the incident and for an additional 30 minutes after the LCS returned to the normal display (this last period serving as the base data for the study). It should be noted that the operators performed their normal incident response procedures before setting up the cameras for the TTI study. Also, any of the other normal operator duties preempted the TTI study as well.

Researchers counted traffic volumes by lane from these videos to determine lane distribution volumes and lane change movements. These videos were also used to observe the condition of the traffic on the freeway during and after the accident. The lane change movements were only calculated for the adjacent lanes which had different LCS symbols above them. Also, it is important to note that only those lane change movements occurring approximately 76 m (250 ft) after motorists had passed each lane control signal array were considered in the lane changing analysis. The number of lane changes from one lane to the next within that 76 m (250 ft) was then divided by the number of vehicles in the initial lane to determine the percent of traffic making a particular lane change at that location.

For analysis purposes, the results from the videos were divided into two periods: during the accident and after the accident. Researchers considered the data collected after the accident as "normal" or "usual" conditions for which comparisons to the accident data were made. The after accident data was used as the "normal" data due to time constraints and the unavailability of historical lane volume data for the corridor studied. During this "normal" period, the lane control signals were in their green arrow mode over all lanes (except for the northbound arrays at Allen and Hattie which had a red or yellow X over the left lane due to ongoing construction activity at the I-35W/I-30 interchange).

RESULTS

Between February and June 1995, three peak period and one off peak case studies were conducted on I -35W in Fort Worth, Texas. Table C-1 summarizes the dates, locations, and normal traffic volumes at those locations for each of the case studies. Researchers determined lane distribution percentages at each location, and lane change movements at all but one location. In these case studies, some of the locations had queues present and some did not. The presence or absence of a queue did appear to influence driver response to the signals, and this influence is discussed on a case-by-case basis.

TABLE C-1. Case Study Site Characteristics

Date and Time	Location	Lanes Blocked	Normal Traffic Volumes
Case Study A: February 10, 1995 4:30-4:53 pm	Northbound near Allen	Inside	700-1200 vphpl[a]
Case Study B: March 14, 1995 5:10-6:31 pm	Southbound before Seminary and Felix	All lanes -- 5:10-5:21 pm Two inside lanes -- 5:21-6:31 pm	550-1150 vphpl
Case Study C: June 8, 1995 9:30 am-4:00 pm	Northbound between Hattie and I-30	Two inside lanes (construction phase shift)	400-1000 vphpl
Case Study D: June 12, 1995 7:45-9:35 am	Northbound between Hattie and I-30	Two inside lanes (Inside already closed because of construction)	400-1000 vphpl

[a]Volumes between 9:00 am and 4:00 pm over affected freeway section

Case Study A

On Friday, February 10, 1995, a stalled car in the northbound inside lane between Allen and Rosedale resulted in that lane being closed during part of the evening peak period (but in the off-peak direction of travel). As shown in Table C-2, the LCSs at Morningside and Allen were activated. However, due to data collection difficulties, the only location where data was available for this study was Morningside.

TABLE C-2. LCS Configuration for Case Study A (2/10/95)

Location	Normal LCS Display	Incident LCS Display
Morningside	GGGG	YGGG
Allen	YGG	RGG

G = Green ↓
Y = Yellow X
R = Red X

The first LCS activated for the incident was at Morningside, which was approximately 1.7 kilometers upstream of the accident. At this location, no queues developed in any of the freeway lanes. The lane distribution percentages computed just downstream of that LCS array show a reduction in the portion of vehicles driving in the inside lane when a yellow X was displayed (in comparison to the normal green arrow condition). As shown in Figure C-1, the percent of all freeway traffic using the left lane decreased from 17 percent under normal conditions to 13.6 percent when the yellow X was displayed. This statistically significant 3.4 percent shift in lane distribution represents a 20 percent reduction in the left lane traffic volume expected at that location, as computed by the following equation:

$$\%\ reduction = \frac{(\%LN)(TVI)\ -\ (LVN)}{LVN}$$

where,

% reduction	=	estimated percent change in lane volume
%LN	=	percent of traffic using the lane under normal conditions
TVI	=	total volume using all lanes at that location during incident
LVN	=	volume using that lane under normal conditions

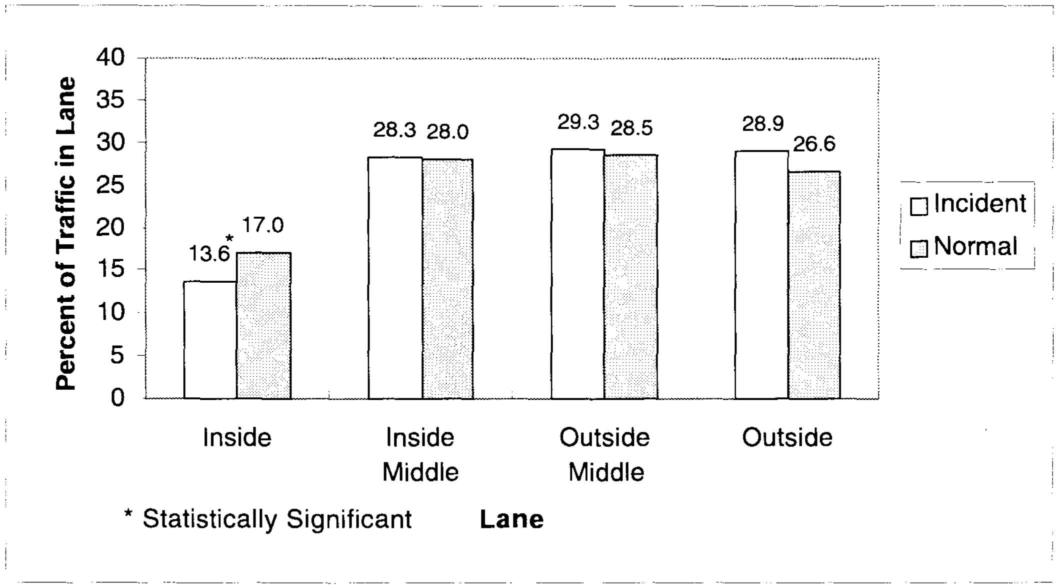


FIGURE C-1. Changes in Lane Distributions at Morningside (2/10/95)

The remaining traffic distributed fairly evenly over the remaining three lanes which had green downward arrows over them.

The lane change movements at this location (shown by Figure C-2) tripled in frequency from the left (closed) lane to the center lane just downstream of the LCS array. Normally, about 3 percent of the left lane traffic moves to the center lane in that distance. During the incident when the yellow X was displayed, this lane changing frequency increased to 9.2 percent of left-lane traffic, a statistically significant increase. The frequency of lane changes from the center lane to left lane did not increase in a similar manner.

Case Study B

The second case study was conducted during a major tractor-trailer incident that occurred in the southbound direction of I-35W between Felix and Seminary. This incident occurred during the evening peak period on Tuesday, March 14, 1995. System operators activated the LCSs at the Berry, Ripy, and Seminary overpasses. Initially, the entire freeway was closed. After about 10 minutes, operators opened the two right lanes so that traffic could bypass the incident, and it is this latter configuration that was evaluated in this case study. The configuration of the LCSs for this situation can be seen in Table C-3. In this case study, there was a queue present in the outside lane from Berry downstream to the incident location for most of the evaluation period. Queues were also present in the other lanes at locations closer to the incident.

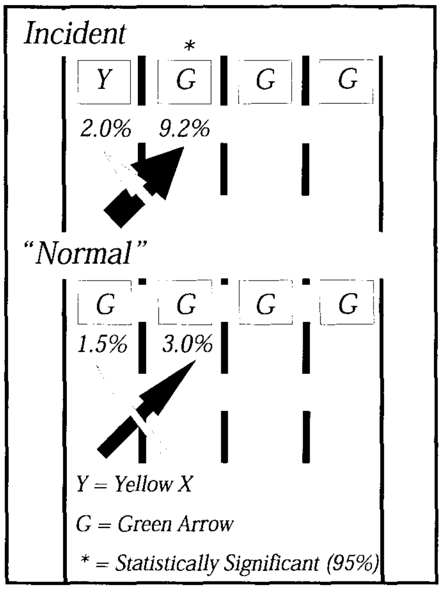


FIGURE C-2. Lane Change Movements Just Downstream of Morningside (2/10/95)

TABLE C-3. LCS Configuration for Case Study B (3/14/95)

Location	Normal LCS Display	Incident LCS Display
Berry	GGGG	YYGG
Ripy	GGGG	YYGG
Seminary	GGGG	RRGG

G = Green ↓
Y = Yellow X
R = Red X

Figure C-3 shows the distribution of traffic by lane just downstream of the Berry LCS. The influence of the LCS is again evident at this location. The percent of traffic in the two inside (closed) lanes decreased relative to normal travel conditions, and increased in the outside-middle and outside lanes. The changes in the closed lanes percentages were statistically significant. These changes represent a 15.8 and 23.6 percent reduction in traffic volumes in the inside and inside-middle lanes, respectively (an average 20.5 percent volume reduction for the two lanes). The shift in traffic to the outer lanes caused a queue in the right lane that extended to Berry.

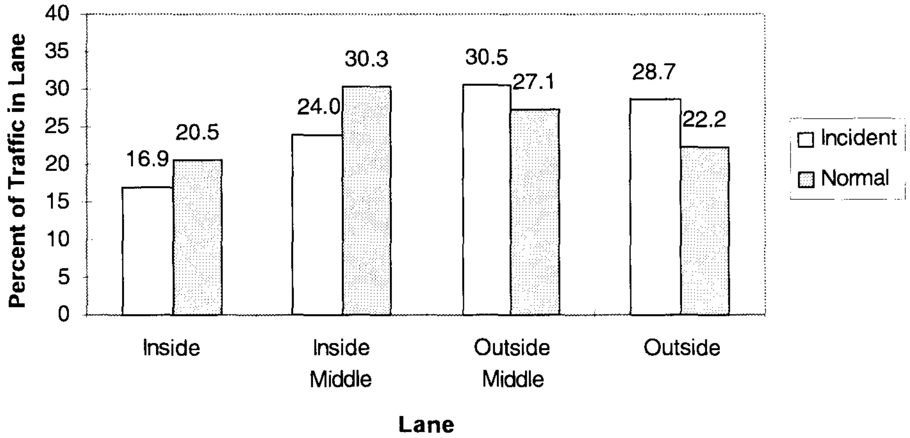


FIGURE C-3. Lane Distribution at Berry (3/14/95)

The effect of the incident and the LCS on lane-changing frequency just downstream of the Berry LCS is illustrated in Figure C-4. Only 2.1 percent of the inside-middle lane traffic normally changed lanes to the outside-middle lane just downstream of the Berry LCS, but 19.8 percent of the traffic in that lane made this maneuver during the incident. This increase was statistically significant.

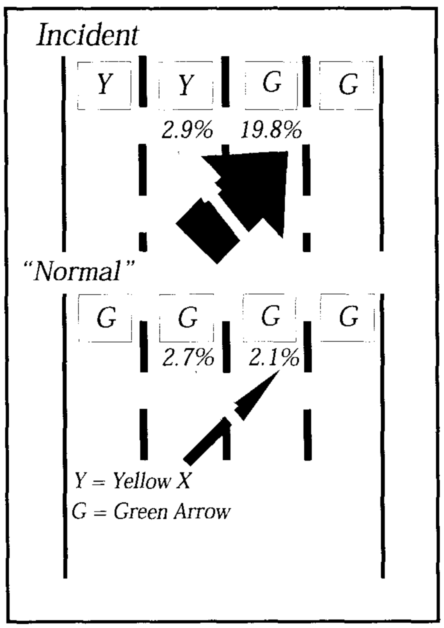


FIGURE C-4. Lane Change Movements Downstream of Berry (3/14/95)

The second location where drivers encountered an LCS used for the incident was at Ripy. At this location, a queue existed in the two outside lanes. No statistically significant change occurred in the percent of traffic using the inside lane, whereas the inside-middle lane exhibited a statistically significant 3.5 percent shift, as shown in Figure C-5. Computationally, this shift represents a 13.1 percent reduction in the amount of traffic using that lane at that point. It appears that the majority of the traffic that vacated the closed lanes stayed in the outside middle lane. During the incident, the outside lane actually experienced a decrease relative to normal operating conditions

The frequency of lane changes between the two middle lanes was also significantly greater during the incident period than during the "normal" period. These results are shown in Figure C -6. At first, the increase in lane-changing from the outside-middle (open) lane to the inside-middle (closed) lane seems to violate expected behavior. However, recall that a queue was present in both open lanes by the time motorists reached the Ripy overpass. Thus, the lane-changing behavior represents not only the influence of the LCS displays, but also the effect that the presence of the queue may have had on behavior. Review of the videotape data did show that many motorists in the outside middle lane were "queue-jumping", moving into the closed inside-middle lane to bypass congestion. Unfortunately, it is not possible to separate the influence of the LCS array at Ripy from the presence of a queue in the open travel lanes upon this lane-changing frequency.

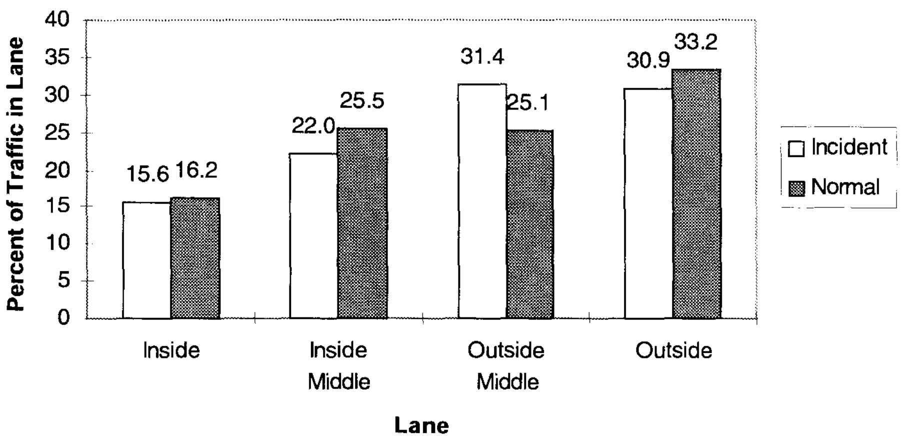


FIGURE C-5. Changes in Lane Distribution at Ripy (3/14/95)

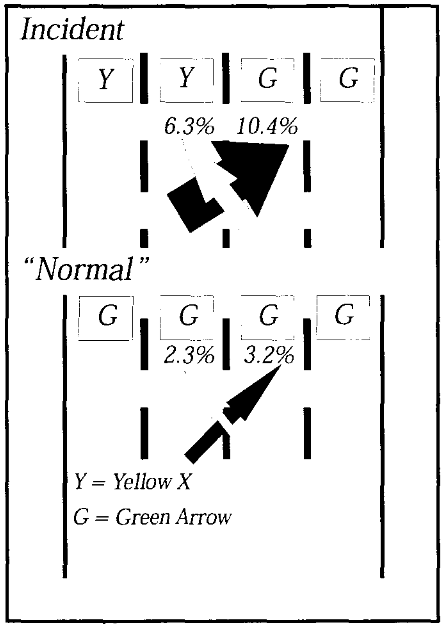


FIGURE C-6. Lane Change Movements Downstream of Ripy (3/14/95)

The third and final location which had lane control signals activated for this incident was at Seminary, which was only 0.40 km (0.25 mi) upstream from the accident. At this location, queues were present in all four lanes. In addition, the motorists were able to see the incident in front of them. Both the presence of the queues and the ability of the drivers to see the incident ahead likely affected motorist responses to the point that the LCS may have been of little use to them. As shown by Figure C-7, the inside-middle lane did experience a reduction in the percentage of traffic during the incident, serving only 14.7 percent of the traffic flow (as compared to normally serving 28.0 percent of the traffic at that location). Converting this change in lane distribution to a change in traffic volume in that lane suggests that there was a 47.2 percent reduction in lane volume.

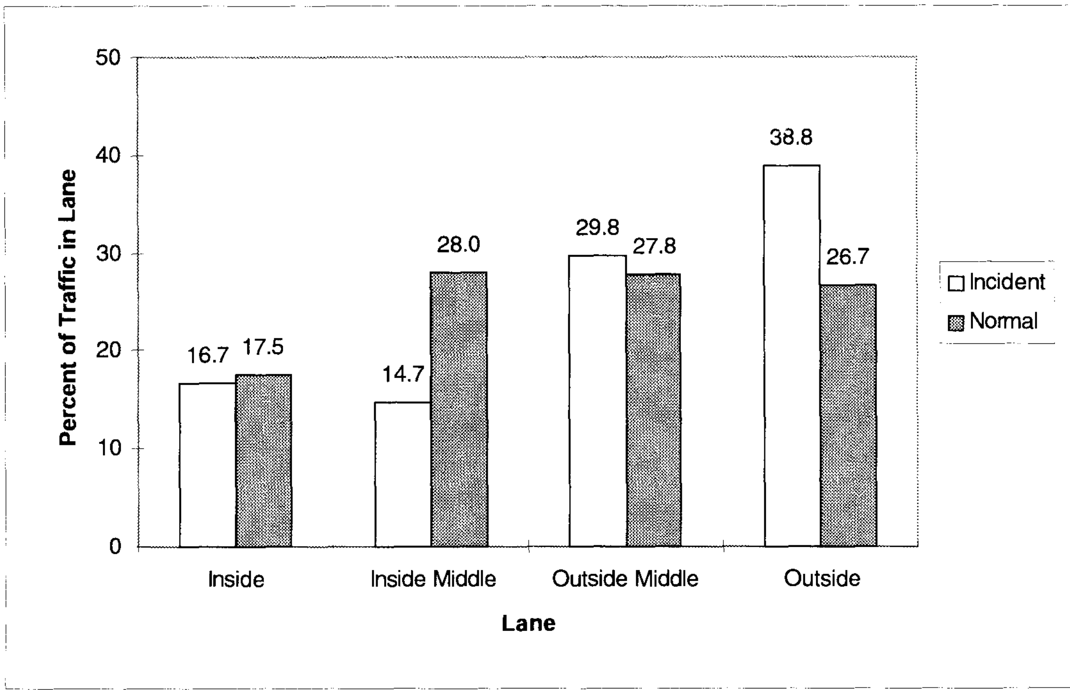


FIGURE C-7. Changes in Lane Distribution at Seminary (3/14/96)

Again, it must be emphasized that these changes represent not only the effect of the LCS but also that of the congested traffic flow conditions and the visibility of the downstream incident. Also, although the percentage of traffic using the inside lane was similar for both the normal and incident conditions, the operating conditions were vastly different. Specifically, traffic in the inside lane during normal conditions operated uncongested and at high speeds. In contrast, traffic in the inside lane during the incident at this location operated under congested conditions. Unfortunately, additional data (i.e., speed and density) were not available to help distinguish between these different operating scenarios.

Figure C-8 illustrates the lane-changing frequency from the inside-middle to the outside-middle lanes just downstream of the Seminary LCS. As researchers expected, the frequency of changes between these lanes increased significantly during the incident. Also note that lane-changing from the outside-middle to the inside-middle lanes did not increase during the incident. It is important to remember that this behavior is the result of the combined effect of the visual cues from the incident and the traffic queue, and not just the LCS indications. In fact, it is very likely that the incident and queue were the primary forces influencing lane distribution and lane-changing at this location.

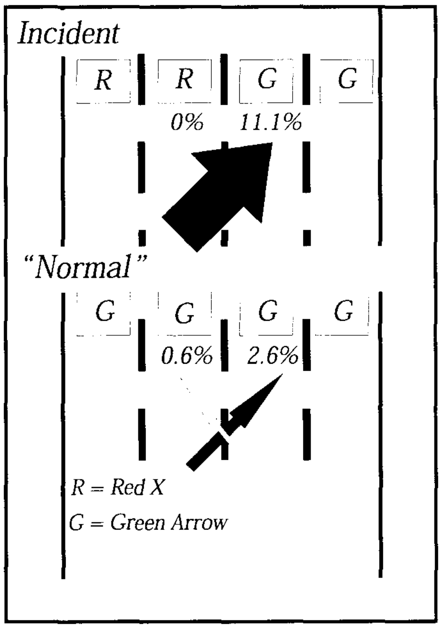


FIGURE C-8. Lane Change Movements Downstream of Seminary (3/14/95)

The previous graphs provide a "snapshot" of traffic behavior at specific points upstream of the incident. Another perspective of the impact of the incident, the queue, and the LCS can be obtained by plotting how the lane distributions change as a function of the distance to the incident. These data are shown in this manner in Figure C-9. Plotted in this manner, the data indicate a gradual shift of traffic from the closed to the open lanes.

Case Study C

The fourth case study was also an off-peak evaluation of a construction phase shift between 9:30 am and 4:00 pm affecting northbound I-35W traffic approaching the I-30/I-35W interchange. This evaluation was performed on June 8, 1995. At this location, researchers evaluated only lane distribution data (lane-changing frequencies were not examined). Table C-4 summarizes the LCS configurations that were displayed at the Hattie, Allen, Morningside, and Berry overpasses upstream of the interchange. Also, the changeable message sign at Seminary warned approaching motorists of the lane closure. Generally speaking, a queue developed and extended back to the Allen overpass, primarily in the middle and right travel lanes.

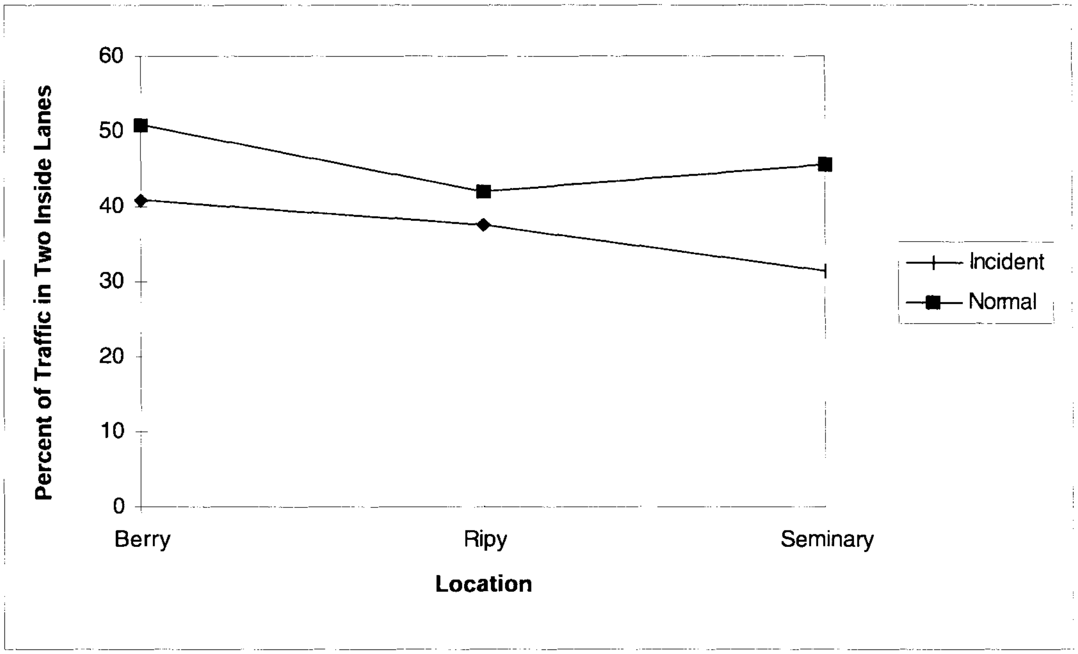


FIGURE C-9. Traffic Distribution Profiles for Case Study B

TABLE C-4. LCS Configuration for Case Study C (6/8/95)

Location	Normal LCS Display	Incident LCS Display
Berry	GGGG	YGGG
Morningside	GGGG	YYGG
Allen	YGG	YYG
Hattie	RGGY	RRGY

G = Green ↓
Y = Yellow X
R = Red X

Figure C-10 presents the lane distribution for normal and incident (lane closure) conditions at Berry. At this point, only the inside lane is denoted as closing downstream (by displaying a yellow X over that lane). Furthermore, traffic at this point is upstream of the point where the traffic queue is visible. The data in Figure C-10 show a statistically significant 6.6 percent decrease in the portion of traffic using the inside lane. This represents over a 35 percent reduction in the amount of traffic that would be expected to be using that particular lane at that time of the day. Lane changing movements were not examined just downstream of the Berry overpass in this particular evaluation. However, it is evident that the LCS did have a significant influence on traffic behavior at this point.

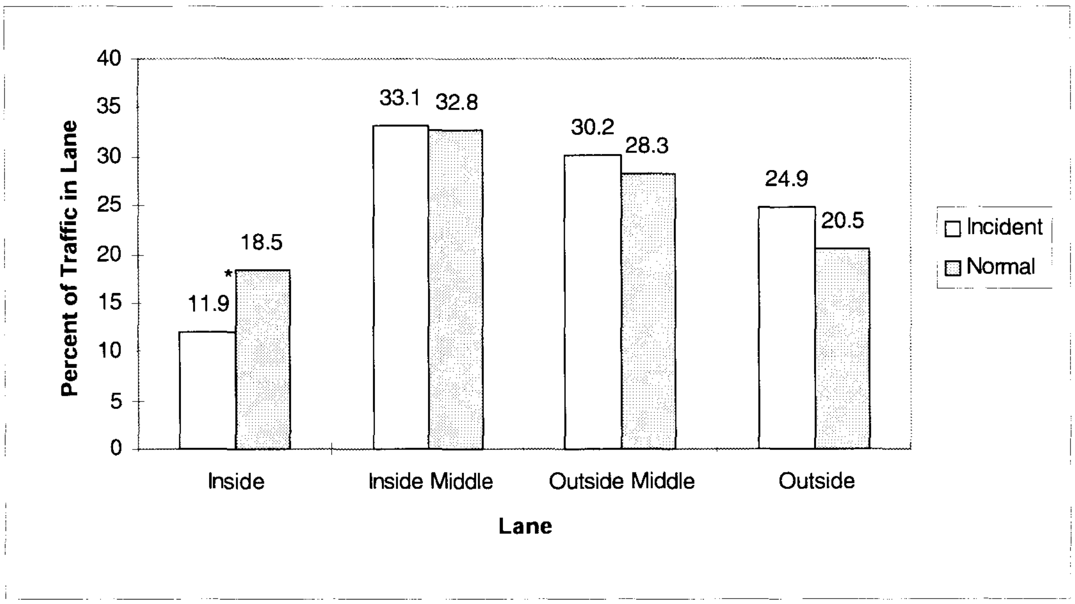


FIGURE C-10. Lane Distribution at Berry (6/8/95)

Figure C-11 documents the relative distribution of traffic at the Morningside overpass, where yellow Xs were displayed over the two inside lanes. At this location, both the inside and middle-inside lanes exhibited significant reductions in the percent of traffic using those lanes. The portion of all traffic using the inside lane decreased 7.5 percent, whereas the portion using the middle-inside lane decreased 4 percent (an 11.5 percent combined reduction for the closed lanes). From equation 1, this represents a 25.6 percent reduction in the amount of traffic expected to use those lanes.

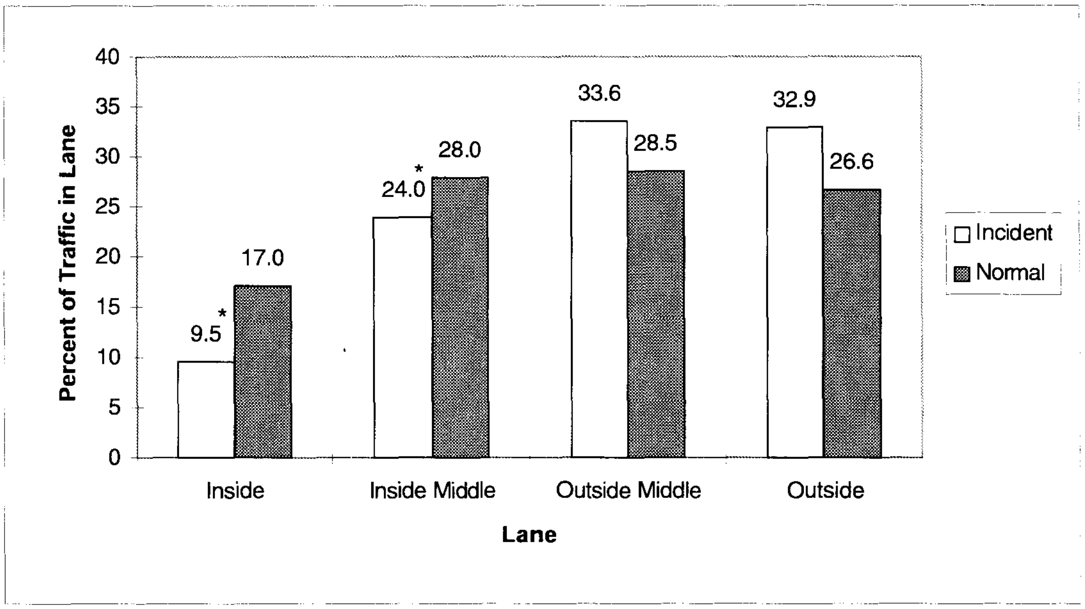


FIGURE C-11. Lane Distribution at Morningside (6/8/95)

Figure C-12 presents the lane distribution at the Allen overpass. Recall that this is the location where the queue began in the open right lane and middle lane due to the lane closures at Hattie Street. Even though the LCS indicated that the left two lanes are closed, the percent of traffic in these lanes is not statistically different than under normal conditions. However, operating conditions were quite different. Whereas, traffic flows were high speed and uncongested in all lanes under normal conditions, traffic speeds during the closure were much slower in the middle and outside lanes. In terms of the average lane volume, very little difference was evident between those still in the lane at the Morningside overpass (250 vph) and those at Allen (215 vph). Thus, the slight increase in relative lane distributions in the closed lane is more an indication of the effect of queued traffic in the middle and right lanes upon flows than an indication of driver violation of the LCS.

Figure C-13 illustrates how the traffic distributions in the inside and middle-inside lanes changed as one approached the lane closure. Specifically, one sees a rather consistent and significant shift in traffic away from the closed lanes at the first two data collection locations. Once traffic reaches the back of the queue, though, differences in flow conditions appear to mask the influence of the LCS on driver behavior.

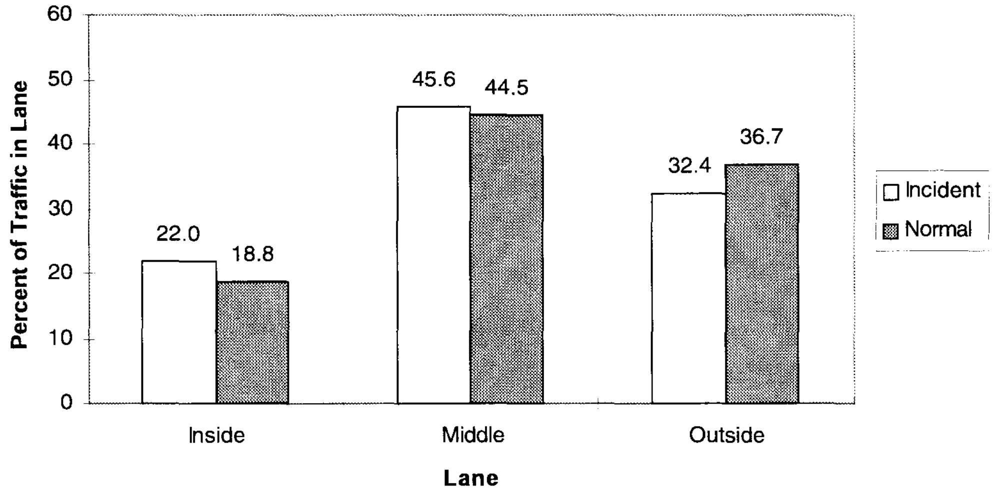


FIGURE C-12. Lane Distribution at Allen (6/8/95)

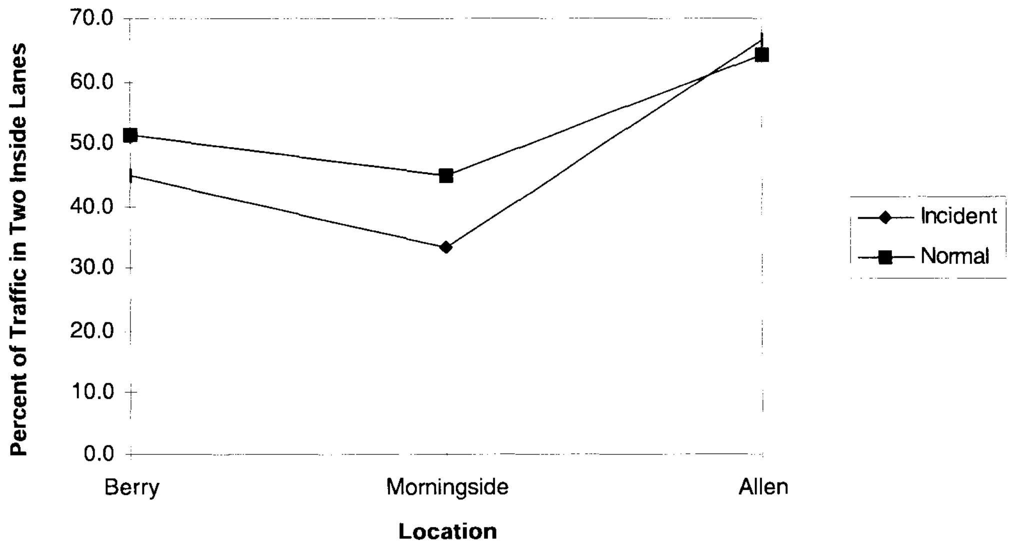


FIGURE C-13. Traffic Distribution Profile for Case Study C

Case Study D

The fourth case study involved an incident which occurred during the morning peak period in the northbound direction of I-35W between Hattie and I-30 on June 12, 1995. The incident closed two of the three lanes available at this location (one of the lanes had been previously closed with concrete barriers for construction). Table C-5 presents the configuration of the lane control signals for this case study.

TABLE C-5. LCS Configuration for Case Study D (6/12/95)

Location	Normal LCS Display	Incident LCS Display
Berry	GGGG	YGGG
Morningside	GGGG	YYGG
Allen	YGG	YYG
Hattie	RGG	RRG

G = Green ↓
Y = Yellow X
R = Red X

A queue was present in the three right lanes from Berry downstream to the accident location. As at the second case study site, it appears that the queue played an important role in how drivers responded to the incident. The most upstream location where an LCS array was changed was at Berry, where a yellow X was presented to motorists over the inside lane. However, because the incident left only one lane open downstream at Hattie, queuing developed in the three right lanes all the way upstream to Berry.

The effect of the queue at this site is quite dramatic, as evidenced in the distribution of volume across the travel lanes at this point (see Figure C-14). Although the LCS indicated that the inside lane was about to close (i.e., as per the yellow X indication), researchers observed a higher percentage of vehicles traveling in that lane during the incident as compared to normal conditions. Unlike the previous case study (where researchers hypothesized that the different flow rates in the queued lanes versus the closed but unqueued lane were responsible for the percentages computed in each lane), there is some evidence that a certain proportion of the drivers chose to utilize the inside lane to bypass congestion, or "jump the queue," rather than stay in the other lanes shown to be open on the LCS. Evidence of "queue-jumping" is presented in Figure C-15 which shows the lane changing patterns at this location. As the figure illustrates, nearly 15 percent of the traffic in the inside-middle lane changed to the inside lane just downstream of the

Berry LCS, despite the fact that the LCS displayed a yellow X over the inside lane. Under normal conditions, less than 2 percent of the traffic in that lane changed over to the inside lane in that same freeway section.

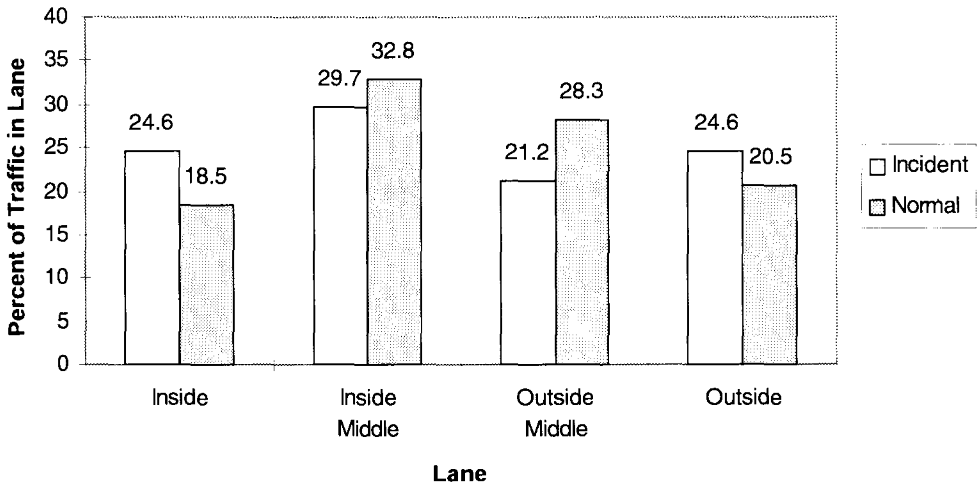


FIGURE C-14. Lane Distribution at Berry (6/12/95)

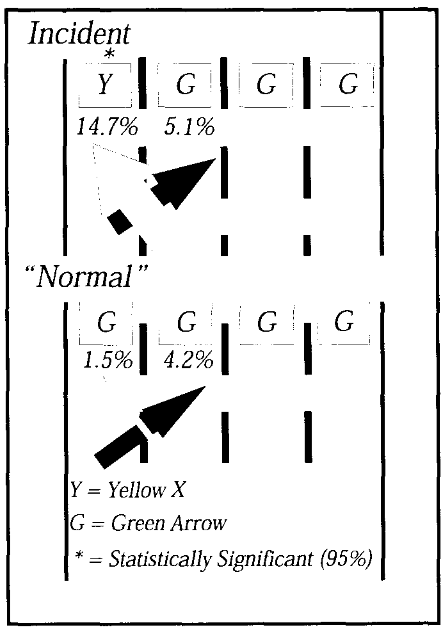


FIGURE C-15. Lane Change Movements Downstream of Berry (6/12/95)

The next location where motorists encountered LCSs displayed for this incident was at Morningside, where yellow Xs were displayed over both the inside and the inside-middle lanes. Once again, queuing existed in the three right lanes. Similar to the previous location and shown by Figure C-16, there was a higher percentage of vehicles traveling in the inside lane which had the yellow X over it during the incident condition. In addition, no significant change occurred in the percentage of traffic using the inside-middle lane, despite having a yellow X also displayed over that lane at Morningside during the incident.

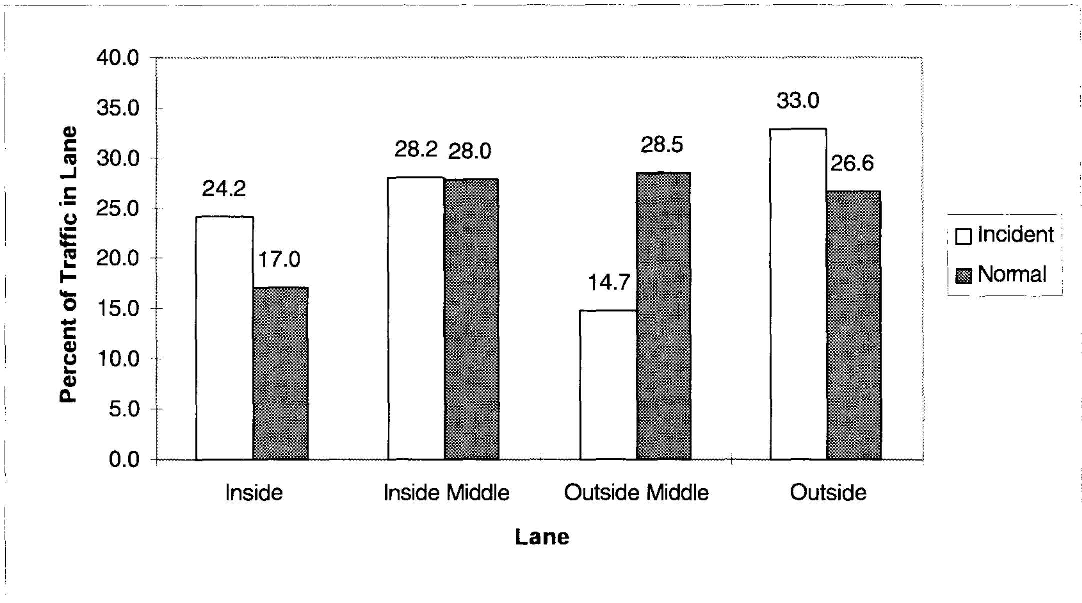


FIGURE C-16. Lane Distribution at Morningside (6/12/95)

The lane change movements of motorists at the Morningside location are shown in Figure C-17 for the inside-middle and outside-middle lanes. Although both of these lanes were queued at this location, there was a higher percentage of vehicles observed changing from the inside-middle lane to the outside-middle lane during the incident as compared to "normal" conditions. However, this fourfold increase in lane changing frequency to the open lane cannot be attributed solely to the LCS because of all the other visual cues related to the incident that were presented to motorists to help them make their lane choice decisions.

For the lane control signals at Allen, a yellow X was constantly displayed over the inside lane due to ongoing freeway reconstruction. Thus, the only change in the LCS array at Allen was the display of a yellow X over the middle lane. All lanes were queued at this location as well, although the queue appeared to be less dense in the inside lane. As shown by Figure B-19, almost half the traffic was traveling in the inside lane even though it had a yellow X over it. This is much higher than for "normal" conditions.

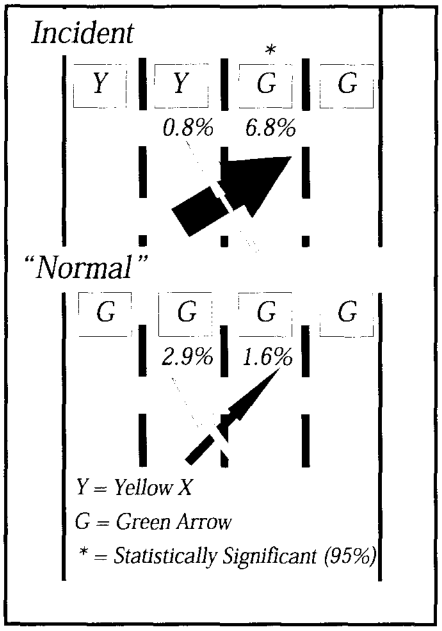


FIGURE C-17. Lane Change Movements at Morningside (6/12/95)

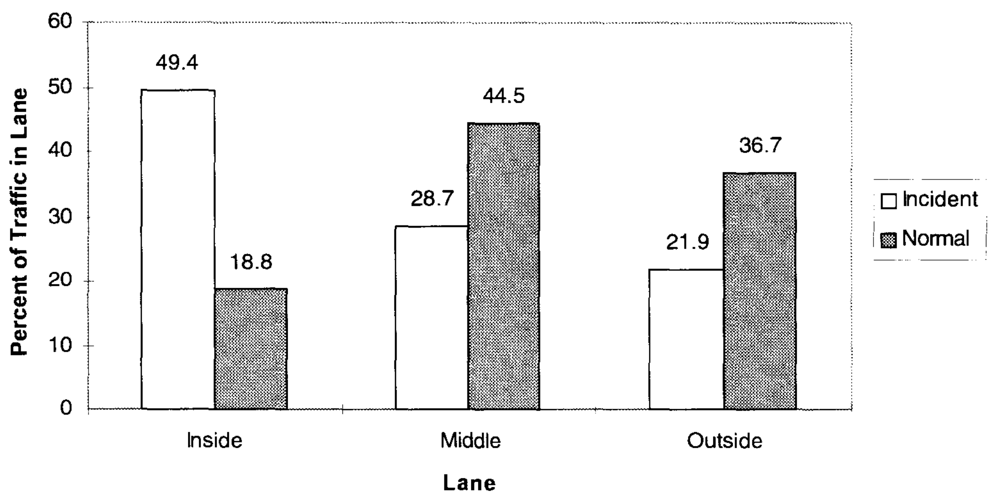


FIGURE C-18. Lane Distribution at Allen (6/12/95)

It is possible that while most driver exit this lane by the time they reach the LCSs under "normal" conditions (since motorists know the lane is closed downstream), motorists could not or would not do this under heavily queued conditions when the incident was present. As another explanation, the "queue jumpers" as described above were able to travel faster in the inside lane than the other lanes until past Allen, at which time they pushed their way back into the two right lanes. In turn, this forcing behavior into the adjacent lanes further reduced the queued flow rate in the middle and outside lanes upstream, making the inside lane even more attractive to bypass the queue and creating the imbalanced flow rates across lanes.

Figure C-19 illustrates the lane-changing frequency observed in the queue just downstream of the Allen LCS. Although the incident was not visible from the data collection location, it is evident that motorists did have some information about which lanes were blocked downstream. Lane-changing rates from the middle to the outside lane tripled during the incident, even though traffic was queued and operating in a stop-and-go fashion. Meanwhile no motorist who was in the outside lane moved to the middle lane during the incident.

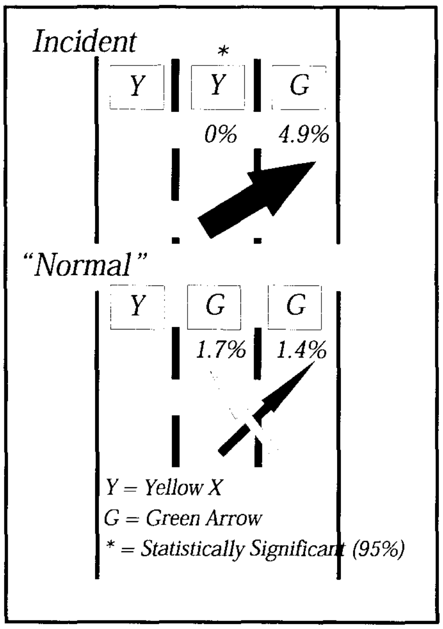


FIGURE C-19. Lane Change Movements at Allen (6/12/95)

Finally, Figure C-20 presents a location-by-location summary of traffic distributions in the closed lanes upstream of the lane closure. As already discussed, the traffic queue caused by the closure significantly affected flow rates and traffic distributions at each location examined.

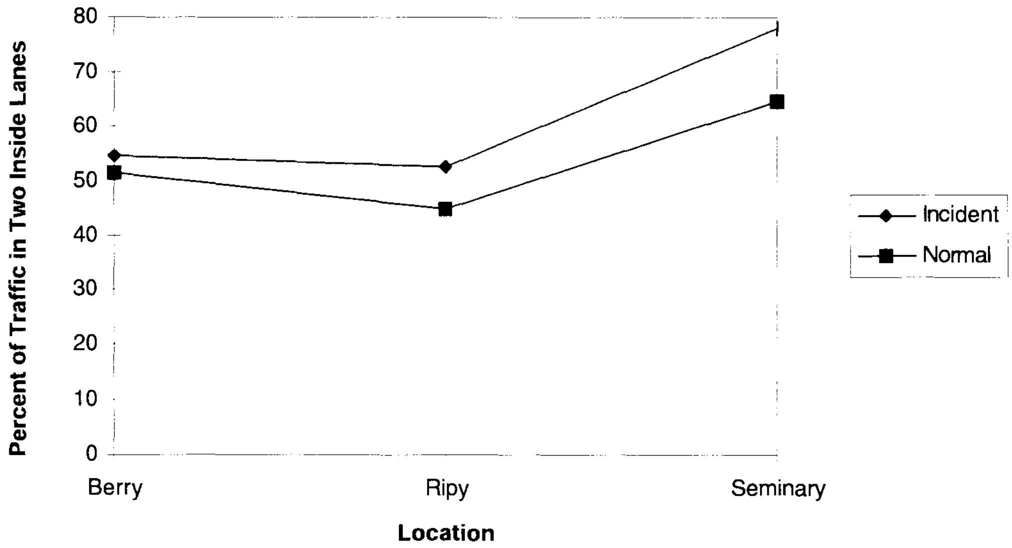


FIGURE C-20. Lane Distributions Upstream of the Closure (6/12/95)

SUMMARY

When traffic flow conditions are uncongested, it appears that the presence of LCS upstream of lane blockages does affect driver behavior to some degree. Under the conditions examined in this research, a 2 to 6 percent shift in traffic distributions from closed to open lanes can be expected, resulting in a 16 to 25 percent reduction total in traffic that would be expected to use the closed lane(s).

The effects of the LCS are less clear, though, if queuing develops upstream of the lane blockage and is visible to the motorists at the point where the LCSs are displayed. On one occasion, the combined LCS/traffic queue presence appeared to facilitate a significant shift in traffic distribution and lane volumes from the closed to the open lanes. During another study, however, traffic distributions and lane volumes indicated an increase in the closed lane, despite the LCS indications that the lane was closed downstream. The near gridlock condition in the open and adjacent lane apparently encouraged many drivers to move into the closed lane in an attempt to bypass a significant distance of the queue. The fact that the closed lane very seldom queued as far back as the other two lanes and even then did not remain that way for very long further encouraged this queue-jumping behavior. Under these types of conditions, the information on the LCS becomes secondary to many driver's individual desires to minimize their delays, even if it entails violating the LCS indications.

As a final note, it must be remembered that these evaluations also included the use of changeable message signs located on I-35W to further inform motorists of downstream traffic conditions. Consequently, this evaluation must be considered as an overall assessment of the information system available on I-35W and not solely an effect attributable to the LCS.