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16. Abstract

This project investigated the operations and safety characteristics of left exit lane drops. As generally recognized, constructing left exits is to be avoided; however, when present, suggestions on methods to improve safety and operations are valuable. One alternative for better communicating to motorists the presence of a left exit lane drop is with pavement markings. Lane drop pavement markings, pavement arrows, and raised pavement markings were evaluated at one site to determine their effectiveness during daytime and evening operations.

Erratic maneuvers were reduced by 40 percent during daylight operations, and by 34 percent during evening operations. The predominant type of erratic maneuver within 300 ft (91.5 m) of the gore was the lane change through the gore area. The most common type of erratic maneuver upstream of the gore area was the two-lane lane change.

The study site, which was 1240 ft (378 m) in length, experienced a 31 percent reduction in lane changes (64 percent for the 300 ft (91.5 m) nearest the gore) between the before and after periods during daylight operations. Examining the data by zone (which were typically 100 ft (30.5 m) in length) showed a significant reduction in lane changes per hour in the 700 ft (213.5 m) nearest to the gore, with fluctuations in the remaining zones (between 700 and 1200 ft (213.5 and 366 m) upstream of the gore) for both daylight and evening operations. The data indicated that motorists performed their lane changes, into or out of the exit-only lane, further upstream of the gore in the after period than in the before period.

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IMPROVED COMMUNICATION OF A LEFT EXIT LANE DROP USING PAVEMENT MARKINGS

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IMPLEMENTATION STATEMENT

This study demonstrated that motorists' behavior at a left exit lane drop changed when pavement markings were installed. Findings revealed that fewer lane changes and erratic maneuvers occurred after the installation of the markings. Findings also demonstrated that motorists move earlier out of a lane that is being dropped (i.e., further upstream of the exit) when lane drop markings are present. Consistent use of the standardized marking treatments provides several benefits, such as consistency in communicating lane drops on Texas freeways to drivers, and improved driver expectancy at lane drops. The improved driver expectancy encourages motorists to move out of or into a lane that is being dropped further upstream of the gore area. This behavior results in fewer erratic maneuvers.

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation (TxDOT) or the Federal Highway Administration (FHWA). This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. This report was prepared by Kay Fitzpatrick (PA-037730-E), Marty Lance, and Tom Urbanik (TX-42384).

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The TxDOT 1232 technical advisory panel chair, Gary Trietsch, is also recognized for his time in providing direction and comments for this research. This study was performed in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

The authors would also like to recognize the undergraduate students (Deanne Simmons and Stacy Wiatrek) who diligently watched several hours of video tapes to extract the necessary data for this project.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF TABLES

SUMMARY

The purpose of this project was to investigate the operations and safety characteristics of left exit lane drops. As generally recognized, constructing left exits is to be avoided; however, when present, suggestions on methods to improve safety and operations are valuable. Exit lane drops can also cause difficulties for unaware motorists. Without proper notification of the impending exit, drivers can find themselves performing erratic maneuvers in order to prevent exiting at undesirable locations. To negotiate a lane drop successfully, motorists need the following: knowledge of the lane drop, location of the lane drop, choice of an appropriate maneuver, and time to execute that maneuver. Pavement markings provide one alternative for better communicating the presence of a left exit lane drop to motorists.

Several research efforts have focused on communicating information through signing at exit lane drops. Several studies support the use of the black-on-yellow EXIT ONLY panel at exit lane drops where the through traffic continues on the freeway mainline. When route discontinuity occurs the EXIT ONLY panel is not recommended for use. Research indicates that drivers require more time to read and interpret information on diagrammatic signs in comparison with conventional signs. Despite this finding research results have indicated that diagrammatic signs will produce a benefit to motorists' performance at certain interchanges such as major forks, left exits, left exit lane drops, lane drops with an optional lane, and locations where route discontinuity occurs.

Although they provide one solution for communicating lane drops to motorists, very few studies regarding pavement markings at lane drops have been conducted. One recent study found that lane changes and erratic maneuvers decreased at right-hand lane drop exits after lane drop markings were installed. Researchers have also found that various types of pavement markings can produce a reduction in erratic maneuvers at freeway exits. These pavement markings included: color coded markings, raised pavement markings, dotted extended lines, pavement arrows, double white lines, wide solid white lines, and lane drop markings.

A before-and-after field study was designed to measure the effects of lane drop pavement markings on driver behavior at a left exit lane drop. The number and location of erratic maneuvers and lane changes upstream of the exit lane drop were the measures of effectiveness used to describe driver behavior.

A significant reduction in the number of erratic maneuvers within the study segment occurred during both daylight and evening operations. Erratic maneuvers were reduced by 40 percent during daylight operations, and by 34 percent during evening operations. The predominant type of erratic maneuver within 300 ft (91.5 m) of the gore was the lane change through the gore area. The most common type of erratic maneuver upstream of the gore area was the two-lane, lane change. A number of congestion-related erratic maneuvers were also observed.

The lane change data were examined in several ways. First, the overall reduction in number of lane changes for both the 300 ft (91.5 m) nearest to the gore and the entire study segment was determined. The study site experienced a 31 percent reduction in lane changes (64 percent for the 300 ft (91.5 m) nearest the gore) between the before- and after-periods during daylight operations. Second, the lane changes were divided into two categories: lane changes from the through lanes to the exit lane, and lane changes from the exit lane to the through lanes. During both daylight and evening operations, in both the before- and after-periods, the number of vehicles entering the exit lane was significantly more than the number of vehicles leaving the exit lane.

Lane changes, including lane changes into both the exiting and the through lanes, were also examined by location throughout the lane drop area. The results of the before-and-after study indicated an overall reduction in lane changes of approximately 19 percent for both daylight and evening operations. The plots of lane changes per hour by zone show a reduction in lane changes per hour in the 700 ft (213.5 m) nearest to the gore, with fluctuations in the remaining zones (between 700 and 1200 ft (213.5 and 366 m) upstream of the gore) for both daylight and evening operations. Therefore, the plots appear to indicate a shift in the location of lane changes between the before- and after-periods. Statistical analysis of the data was used to validate the "shift" theory. During daylight operations the first four zones had a significant reduction in lane changes, while three of the upstream zones had a significant increase in the number of lane changes. During evening operations, two of the first four zones contained a significant reduction in lane changes, while three of the upstream zones contained a significant increase in lane changes. The overall reduction in lane changes could indicate that portions of the "shift" may be occurring upstream of the study segment.

In summary, the before-and-after data indicated that the lane drop markings had a positive effect on driver behavior at the left exit lane drop. Erratic maneuvers and lane changes were both significantly reduced between the before and after periods. The data also indicated that motorists performed their lane changes, into or out of the exit-only lane, further upstream of the gore in the after period than in the before period.

CHAPTER 1
INTRODUCTION

The driving public is accustomed to an interchange design that provides an exit ramp on the right side of the freeway. Any variation of this design creates an element of surprise and confusion for the motorist. In the absence of advance warning, unfamiliar motorists desiring to exit at a downstream interchange will move to the right lane. If the exit ramp is on the left, drivers in the right lane desiring to exit may either miss their exit, or perform a hazardous late lane change to move to the left lane. Such maneuvers can result in traffic conflicts or collisions.

According to the American Association of State Highway and Transportation Officials, (AASHTO) extreme care should be taken to avoid left-hand entrances and exits in the design of interchanges (*1*). Left-hand entrances and exits are contrary to driver expectancy when intermixed with right-hand exits. Even in the case of major forks and branch connections, the less significant roadway should exit and enter on the right. Left-side exits break the uniformity of the interchange patterns and in general create hesitant operation on the through roadways. While left-hand exits are considered satisfactory for collector-distributor roads, their use on high-speed, free-flow ramp terminals is not recommended. Because left-hand entrances and exits are contrary to driver expectancy, AASHTO states that special attention should be given to signing and to providing adequate decision sight distance in order to alert the driver that an unusual situation exists.

The multiple expectancy violation of a left exit lane drop can be a far more serious problem than either of its individual components (i.e., left exit or lane drop); more drivers are affected, interaction in the traffic stream is more turbulent, and the potential for confusion and accidents is substantially greater. A left exit lane drop is recognized as a potential source of operational and safety problems.

Because previous conditions have resulted in the design and construction of left exits as well as left exit lane drops, insight into methods available to provide for smooth and safe operations at a left exit lane drop is valuable. This report reviews the current knowledge regarding left exits and left exit lane drops and reports on a field study. The field study collected data on motorists' behavior at a left exit lane drop. This behavior included frequency and location of lane changes and erratic maneuvers. Special pavement markings were installed at the site and after data were collected. The before and after data were compared to determine whether the pavement markings would result in improved operations and safety. The report finishes with conclusions and recommendations.

CHAPTER 2

SIGNING

A driver needs certain information in order to travel through an exit area smoothly, especially an exit lane drop area. To negotiate a lane drop successfully, motorists need the following: knowledge of the lane drop, location of the lane drop, choice of an appropriate maneuver, and time to execute that maneuver (*2*). The National and Texas Manuals on Uniform Traffic Control Devices (MUTCD and TxMUTCD) contain information on signs and markings available to guide and warn motorists of upcoming exits and lane drops (*3,4*).

CURRENT PROCEDURES

The following are the current procedures for signing and marking lane drops and left exits as contained in the National and Texas Manuals on Uniform Traffic Control Devices.

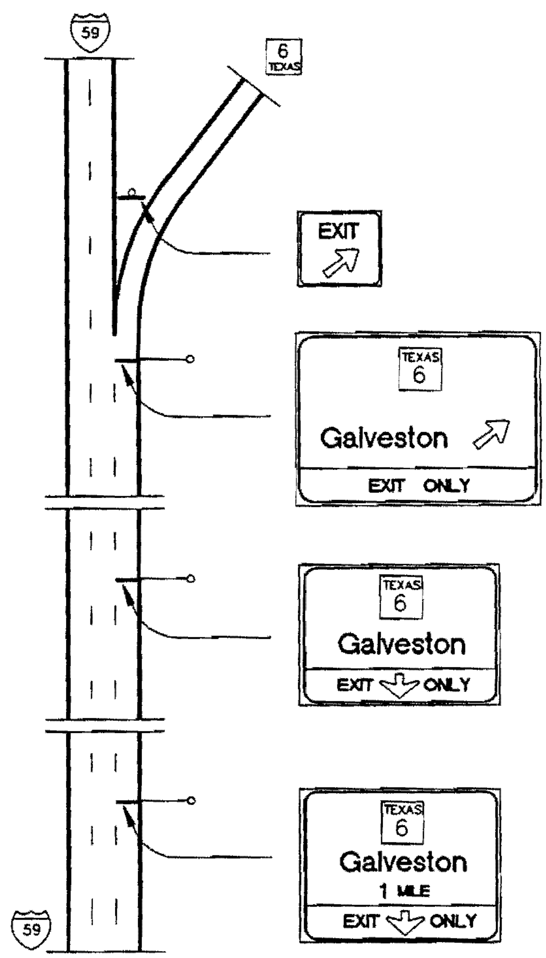
Lane Drop Exits

Exit-only signs and pavement markings are two methods used to communicate an exit lane drop to motorists. Signs are a required treatment in the MUTCD while pavement markings are an optional treatment. Sign treatments include diagrammatic signs, the modified diagrammatic signs, the use of the black on yellow EXIT ONLY panel on conventional signs, and other signs. Markings include alternative gore area treatments and special lane lines.

The TxMUTCD states that the EXIT ONLY panel shall be used on guide signs at all interchange lane drops in which the through route is carried on the mainline. Figure 2-1 illustrates the signs used at a right hand interchange lane drop. The panel has a black legend on a yellow, reflectorized background. The EXIT ONLY panel with a downward black arrow is to be used on advance guide signs for right-hand exits (see illustration in Figure 2-1).

The MUTCD and TxMUTCD contain suggested pavement markings to be used at exit lane drops. The markings are shown in Figure 2-2 (reproduced from Figure 3-11A in the

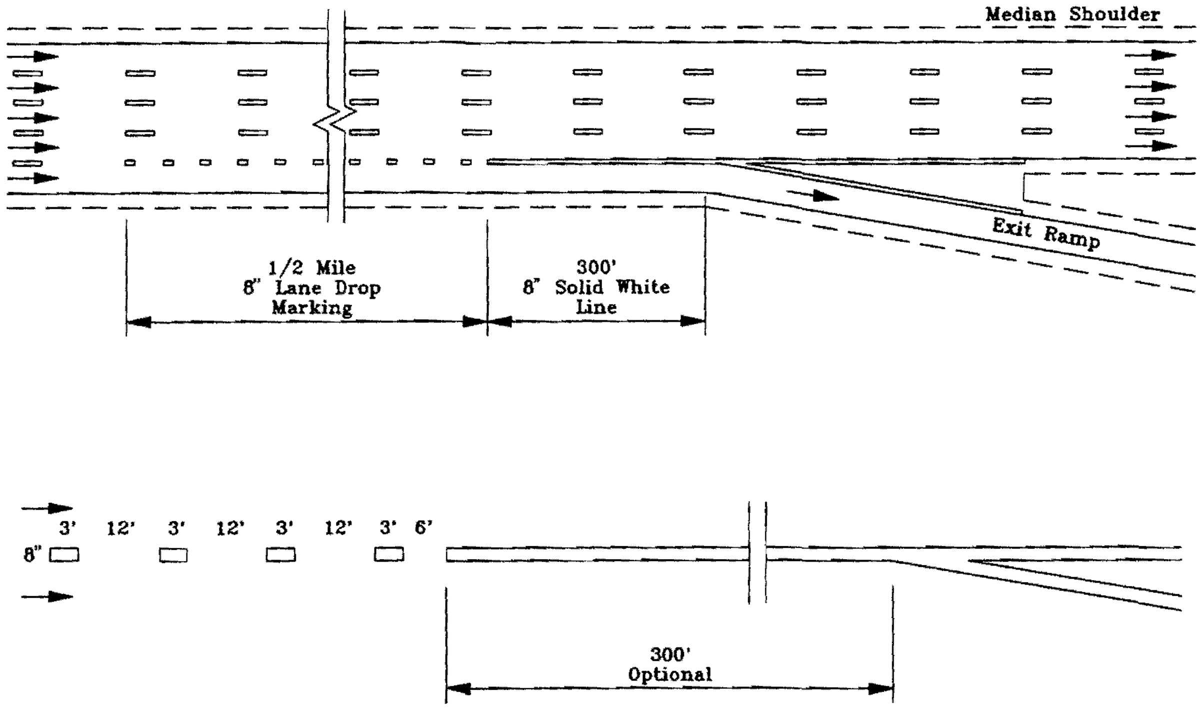
TxMUTCD). The special marking pattern, which may be used to distinguish the lane drop situation from a normal exiting ramp or an auxiliary lane, consists of special lane striping and a solid white channelizing line. The special lane striping is 8-in (203.2 mm) wide by 3-ft (0.9 m) long separated by 12-ft (3.7 m) gaps beginning ½ mile (0.8 km) in advance of the theoretical gore point. The solid white channelizing line is 8-in (203.2 mm) wide and extends approximately 300 ft (91.5 m) upstream from the theoretical gore point.



Conversion Factor: 1 mile = 1.61 km

Source: Reproduction of TxMUTCD Figure 2-25.

Figure 2-1. Exit Lane Drop on Right (3).



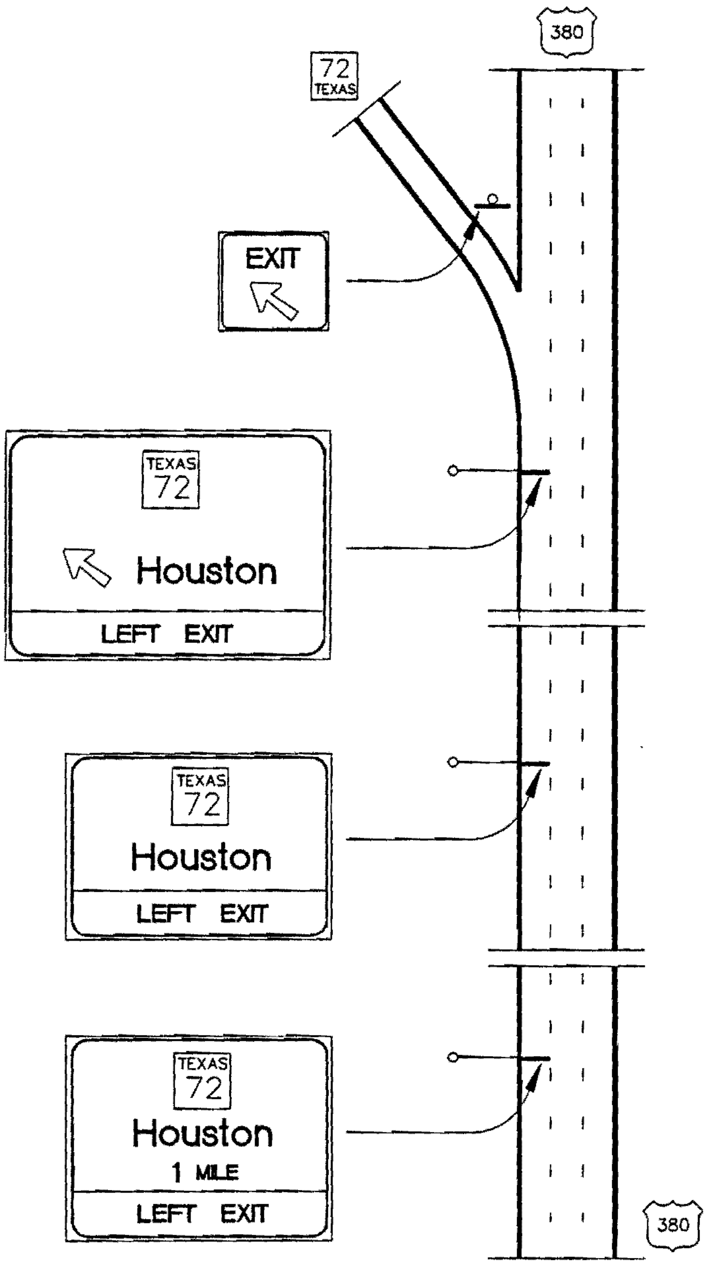
Conversion Factors: 1 mile = 1.61 km and 1 ft = 0.305 m

Source: Reproduction of TxMUTCD Figure 3-11a.

Figure 2-2. Lane Drop Markings at Exit Ramps (*3*).

Left Exits

The TxMUTCD (*3*) states that the LEFT EXIT panel is intended for use on guide signs to provide advance information for left-hand exits. The 1980 TxMUTCD, revised November 18, 1988, also states that all new signing for left-hand exits (except exit-only conditions) shall have the LEFT EXIT panel on advance guide and exit directional signs. It shall be the last line of the sign and shall extend the entire width of the sign. The panel has a black legend on a yellow, reflectorized background. A standard up arrow shall be used with the LEFT EXIT panel at the exit direction sign location (see Figure 2-3).



Conversion Factor: 1 mile = 1.61 km

Source: Reproduction of TxMUTCD Figure 2-26.8.1.

Figure 2-3. Left Exit Condition (*3*).

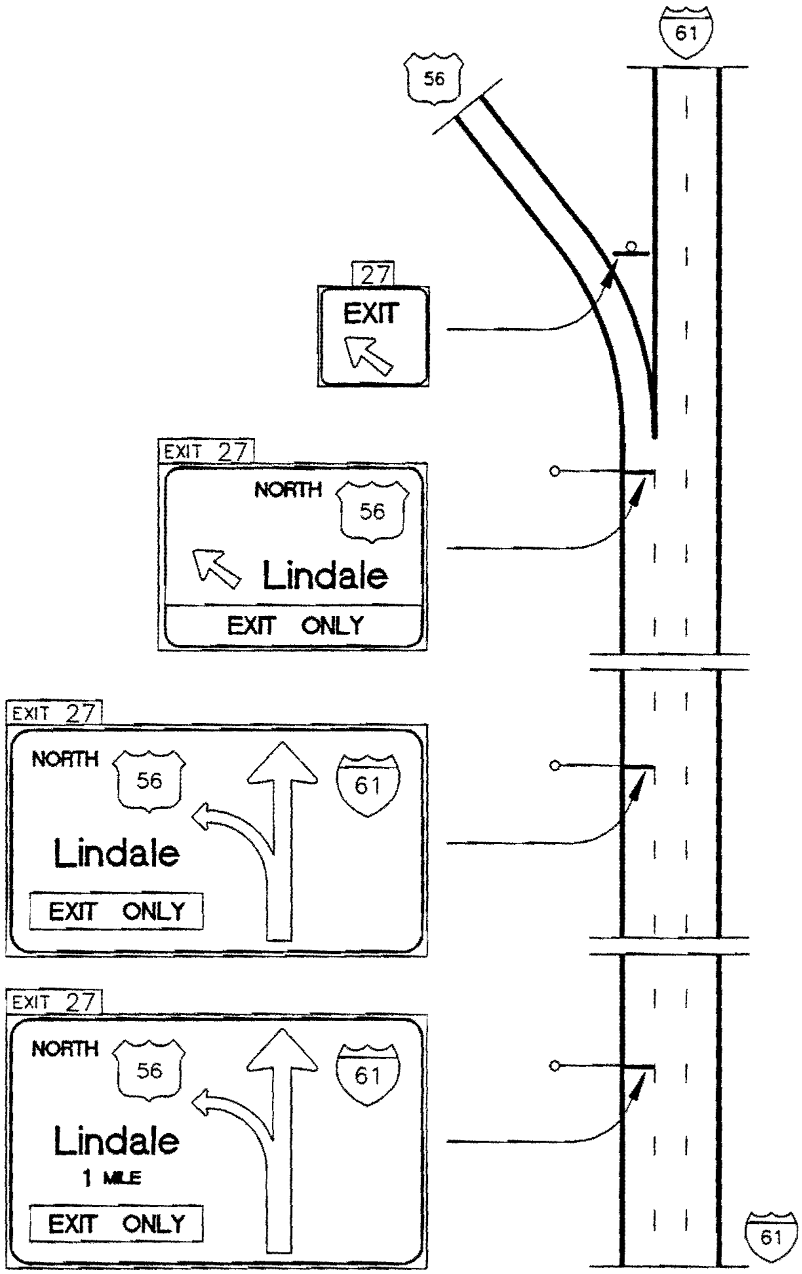
Left Exit Lane Drop Exits

For lane drops on the left side, diagrammatic signing with the EXIT ONLY panel should be used without a down arrow for advance guide signs as shown in Figure 2-4. Left-hand exit-only conditions shall retain the signing principles as stated in the previous section on signing of exit lane drops.

PLACEMENT OF ADVANCE INFORMATION AT LEFT EXITS

A study by Northwestern found that left-hand exit ramps were less efficient operationally and slightly more hazardous than similarly designed right-hand ramps (*5*). The researchers cited signing as the "single most important factor affecting left-hand exit ramp operation." Because signing is of prime importance, they recommended that directional signs be placed at points 2, 1, ½, and ¼ mile (3.2, 1.6, 0.8, and 0.4 km) upstream of the ramp nose.

The Texas Transportation Institute (TTI), in conjunction with several state highway departments, conducted a study of highway visual communication systems, using a diagnostic team approach in the late 1960s (*6*). In addition to developing the diagnostic technique, the study objectives included the identification of problem areas in visual communication and the formulation of recommendations to alleviate them. One of the team's comments regarding exiting on freeways was that driver expectancy plays a critical role in interpretation of information presented to the driver. The TTI team members identified driver expectancy as a primary factor in determining the effectiveness of highway visual communication systems. When the driver expects one situation (a right-hand exit ramp) and encounters another (a left-hand exit ramp), the associated perception reaction time is greatly increased. Therefore, in unusual situations it is particularly important to present information (e.g., presence of left-hand ramp) well in advance of the decision point.



Conversion Factor: 1 mile = 1.61 km

Source: Reproduction of TxMUTCD Figure 2-26.9.

Figure 2-4. Exit Lane Drop on Left with Diagrammatic (*3*).

In 1981, Perfater conducted a survey in Virginia to evaluate motorists' understanding of directional messages (*7*). Although the survey did not contain questions specifically addressing guide signing at left exits, respondents were provided space on the questionnaire for any comments about interstate guide signs. Of the 1,006 respondents, 762, or almost 76 percent, entered a comment of some type. Approximately 6 percent of those who commented perceived deficiencies in the signing of left exits. The time needed to change lanes and "move to the left" was seen as being insufficient. Several participants cited a need for more signs and/or for diagrammatic signs.

DIAGRAMMATIC SIGNS AT LEFT EXITS

Studies have shown that diagrammatics are effective in providing advance notice of an unexpected highway feature (*8, 9*), for example, when an off-route movement is to the left of a through-route movement.

In 1972, Roberts conducted a before-and-after study of diagrammatic signs at left exits (*8*). The research team selected erratic maneuvers as their method of evaluation for the study. Erratic maneuvers observed in the "before" films appeared to be a result of driver confusion due to inadequate signing and/or road geometry. The findings of the study showed a decrease in the number of erratic maneuvers at left exits after diagrammatic signs were installed and again after lane lines were added. The study also indicated some apparent improvements of diagrammatic signs over standard signs:

- The exit directions are more clearly communicated at more advanced locations, as well at the most advanced location, at the first sign.
- The number of lanes for a movement can be communicated at the most advanced point. This may be done through a display of different arrow stem thicknesses and lane lines.

- The destination and route number information is more meaningful because it is matched with the major diagrammatic components of the interchange on all signs. Motorists do not, therefore, have to infer the match in advance.
- The attention value of the diagrammatic signs in this study seems greater than that of the conventional sign, perhaps because the arrows add more white area.

In 1972, another diagrammatic signing study developed warrants and standards for the use of diagrammatic guide signs on controlled access highways (*9*). The findings of the project indicated that drivers require more time to read and interpret information on diagrammatic signs than on conventional signs. Moreover, as the graphic component on the sign becomes more complex, driver interpretation time increases. Despite these findings, the research results clearly indicated that diagrammatic guide signs will produce a benefit to motorist performance at interchanges where traffic must exit to the left of the through route. Such interchanges include major forks, left exits, and left exits in combination with right exits.

In 1972, Gordon also conducted a study of diagrammatic guide signs at exits with nontypical geometrics (*10*). The study sites included a freeway cloverleaf intersection, a lane drop, a multiple-split ramp, a left ramp downstream from a right, two right ramps in quick succession, and a major fork. The evaluation included a comparison of diagrammatic and conventional signs based on the speed and accuracy of the subject's lane selection. The study results indicated that the conventional signs tested were slightly more effective than the experimental diagrammatic signs. They produced fewer errors and faster response time than diagrammatic signs. Although the results would not support the use of diagrammatic signs at any of the interchanges tested, the author notes that the diagrammatic display of road geometry may have advantages in certain situations, particularly when the geometry violates drivers' expectations. Such might be the case at a left exit or an exit lane drop.

CHAPTER 3
LITERATURE

An exit ramp is usually located on the right side of the freeway; however, conditions may cause the designer to recommend a left-hand exit. The effects that these unusual exits have on traffic characteristics and safety as reported in the literature are discussed in this chapter.

OPERATIONS

Berry et al. (*11*) conducted a review of the operations on left-hand exit ramps in the early 1960s. They used time-lapse photography at four ramps (three left-hand and one right-hand) to obtain volume, speed, density, exiting paths, and hazardous maneuvers. The results were used to support their conclusion that the "left-hand exit ramps studied operate quite satisfactorily." The following are some of their findings:

- Left-hand exit ramps on level freeways do not seriously impair the capacity of the through lanes;
- Left-hand exit ramps do not adversely affect the speeds of vehicles through the exit area;
- Density of traffic upstream from left-hand exit ramps is not excessive or abnormal (as compared to similar conditions for right-hand ramps);
- Exiting truck traffic does not degrade the quality of flow on left-side exits, provided that the exit areas are level and that trucks are not required to keep right; and
- Vehicles enter left-side-exit deceleration lanes very near the beginning of the lanes, indicating good ramp operations.

A study conducted by Northwestern University (*5*) in 1969 concluded that use of left-hand exit ramps should be avoided whenever possible. The research included the study of 34 left-hand ramps and 118 right-hand ramps. The study showed that left-hand ramps tend to be more hazardous. It was also noted that lane changing occurs more frequently in the vicinity of left-hand ramps than near right-hand ramps. Deceleration in the left lane to exit may cause a decrease in the overall operating speeds in the left lane, which is usually the high-speed lane. Although in many situations left-hand ramps may be more economical with regard to construction cost, the authors concluded that the losses suffered in terms of operations and safety will often override this economic advantage.

A 1986 study on driver expectancy (*12*) tested a number of redundant information sources at left exit lane drops. The tests were to determine whether additional informational sources could minimize substantial operational problems. Tests included the following information sources: a median mounted regulatory sign, "LEFT LANE MUST TURN LEFT," a black-on-yellow "ONLY" panel on the overhead guide sign; the word "ONLY" with an arrow painted in the dropped lane; and a different color and texture on the dropped lane. The study recommended diagrammatic signs with a black-on-yellow EXIT ONLY panel in accordance with the MUTCD for left exit lane drops.

SAFETY

While the study Berry et al. (*11*) performed indicated that left exits do not cause major operational problems, left-side exits do have higher accident rates than similar right-side exits. In 1961, Fisher made this same conclusion after studying the accident records of several left- and right-side exits (*13*). Berry proposed several sound reasons why left-side exits were observed to be more accident-prone; left exits are much less common on today's system than are right exits, and are not expected by the driver. Despite good signing and delineation, the exiting driver may be in the right lane at such a time that it is difficult, if not impossible, to safely exit to the left. Rapid movement across through lanes may cause friction and result in unsafe conditions. Because of the typically higher speeds in the left lane, drivers in the left lane who slow before the deceleration lane are often more hazardous than those who slow for a right-side exit.

In 1967, Lundy evaluated the effect of ramp type and geometry on accident rates (*14*). The study involved 722 freeway ramps. In a period of about three years, over 2 billion vehicles used these ramps, and during this time 1643 accidents occurred. The study indicated that the design of left-side ramps should be avoided whenever possible. This conclusion was based on the consistently higher accident rates that left-side ramps along with scissor ramps had than their counterparts (see Table 3-1).

Table 3-1. Accident Rates by Type of Freeway Ramp (*14*).

Ramp Type	On	Off	On & Off
Diamond Ramps	0.40	0.67	0.53
Cloverleaf Ramps with Coll-Dist Roads[a]	0.45	0.62	0.61
Direct Connections	0.50	0.91	0.67
Cloverleaf Loops with Coll-Dist Roads[a]	0.38	0.40	0.69
Buttonhook Ramps	0.64	0.96	0.80
Loops with Coll-Dist Roads	0.78	0.88	0.83
Cloverleaf without Coll-Dist Roads	0.72	0.95	0.84
Trumpet Ramps	0.84	0.85	0.85
Scissors Ramps[b]	0.88	1.48	1.28
Left Side Ramps	0.93	2.19	1.91
Average	0.59	0.95	0.79

Note: Accident rates are per million vehicles.
[a] Only the On & Off rate includes the accidents occurring on the collector-distributor roads.
[b] A ramp that had opposing traffic crossing the ramp traffic under stop sign control.

In 1969, Goodge investigated three freeway interchanges with left-side entrance and exit ramps (*15*). Accident records were analyzed to determine accident rates and accident severity rates for each of the ramps within the interchanges. One interchange demonstrated that left-side ramps can be used safely when traffic volumes are low and the interchange is well designed. The other two sites demonstrated that left-side ramps on average produce accident rates that are about 1.75 times higher than right-side ramps. Also the accidents at right-hand ramps had a greater average severity than the accidents at left-hand ramps. Although left-hand ramps produced more accidents at two of the sites, the accidents were less severe. This apparent contradiction can be explained by the fact that while 29 percent of the left-side ramp accidents were sideswipes, a relatively less severe accident, only 13 percent of those attributed to the right-hand ramps were of this type.

The studies also show a large variance of results; some left-side ramps had low accident rates while some right-side entrances and exits had high accident rates. Thus there are other factors involved. One important factor immediately apparent is that the first ramp encountered by a motorist after an uninterrupted run is liable to have a high propensity for accidents and therefore needs extra attention to its design. For example, the accident rate of a "first encountered ramp" on the right side is 2.88 per 10 million vehicles, compared to an average of 1.73 for right-side ramps (*15*). One "first encountered ramp" on the left side had an accident rate of 17.0, which should be ample warning against the use of a left-side ramp for the first ramp in any future, high volume interchange.

Leisch also emphasizes that only right exits and entrances should exist on a designated freeway route (*16*). Right exits satisfy driver expectancy, keep slow-moving vehicles from the left lanes, and avoid weaving across all lanes of the freeway. Leisch also comments that the accident rates at left-side ramps is twice that at right-side ramps.

CHAPTER 4
FIELD STUDY

This chapter describes the field study that was used to collect information on driver behavior at a left exit lane drop. The following sections narrate the major activities and discuss the issues associated with each of the various tasks.

MEASURES OF EFFECTIVENESS

An objective of this study was to determine whether additional pavement markings at left exit lane drops are an effective method of informing motorists of the exit. To determine the effectiveness of the additional markings, changes in driver behavior were examined. Driver behavior in this study was measured using frequency of lane changes and erratic maneuvers, the positions of these behaviors, and the time of day that these behaviors occurred. A more detailed description of the measures of effectiveness follows.

Erratic Maneuvers and their Locations

In general, an erratic maneuver consists of any movement that involves a sudden disruption in the continuity of direction and/or speed of the vehicle, or a deviation from the traveled path intended by the design and traffic engineers responsible for the geometric configuration of the exit (*17*). Erratic maneuvers can occur when the driver is indecisive as to where to go or how to get there. This indecision may result from several factors, including misleading or inadequate information in the form of signing, delineation, and geometric design, or a deficiency in the driver decision-making process. In many cases these factors combine to cause erratic maneuvers.

In studying erratic maneuvers (rather than traffic flow variables) it was believed that a positive response to the pavement markings (i.e., a decrease in erratic maneuvers) would improve safety and operations at freeway exit lane drops. Because erratic maneuvers cause disturbances in the traffic flow of both exiting and through vehicles, any obtainable reduction in traffic flow disturbances would provide for more effective operations.

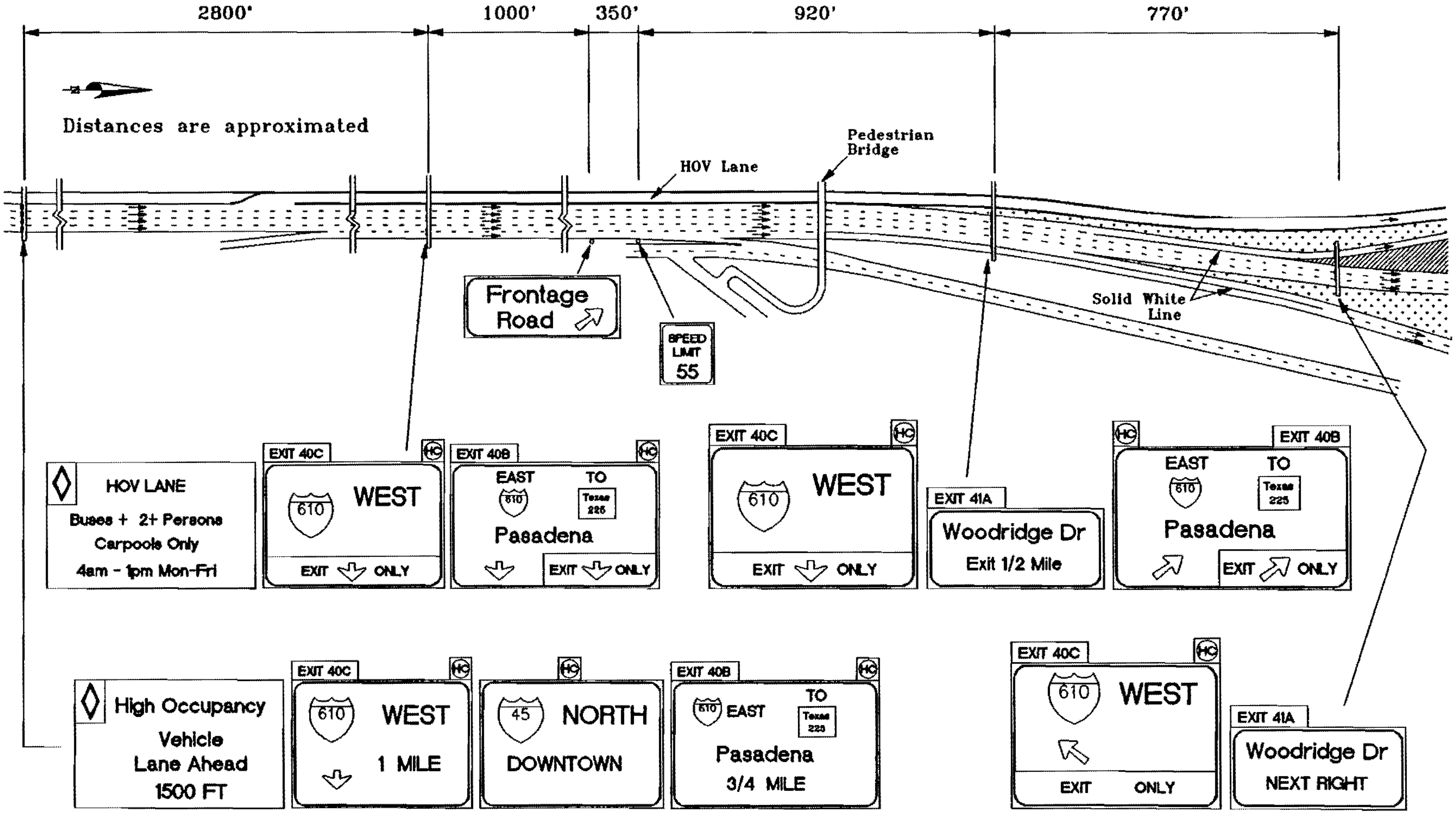
Lane Changes and their Location

The uniqueness of a lane drop at a left exit could further emphasize a changing situation to motorists and encourage those drivers who desire to either enter or leave the exit lane to do so further upstream. To examine this hypothesis, lane change behavior was recorded throughout the lane drop area. For each lane change the beginning and ending lanes were recorded along with the location of the lane change with respect to the gore of the exit. The beginning and ending lanes were recorded to distinguish the difference between vehicles moving into the exit lane and vehicles moving out of the exit lane. Based on previous observations of lane change behavior, the location where more drivers are moving into or out of the exit lane(s) is influenced by the geometry of the site and/or the level of congestion present (*18*).

SITE SELECTION

The site selection was based upon the following: geometric design, accessibility, traffic volumes, current signing, and pavement markings. The lane drop selected for this evaluation was a one-lane, left exit located in Houston, Texas. This exit is located on the I-45 Northbound freeway, at the interchange with I-610 West, south of downtown. Figure 4-1 is a schematic of the site. The length of the dropped lane is greater than 5 miles (8.05 km). Approximately 400 ft (122 m) prior to the left exit lane drop, an exit lane drop occurs on the right side of the freeway. The median contains a high-occupancy vehicle (HOV) lane.

The site has several factors that could influence driver behavior, such as the fact that it is a left exit lane drop within a high volume freeway. For 1992, the average annual daily traffic along this corridor was 202,000. This section frequently experiences low speeds and noticeable delays during the a.m. period. Although the nearest entrance or exit ramp on the left side of the freeway is the entrance ramp to the HOV lane which is located 3,800 ft (1159 m) upstream



Conversion Factors: 1 mile = 1.61 km and 1 ft = 0.305 m

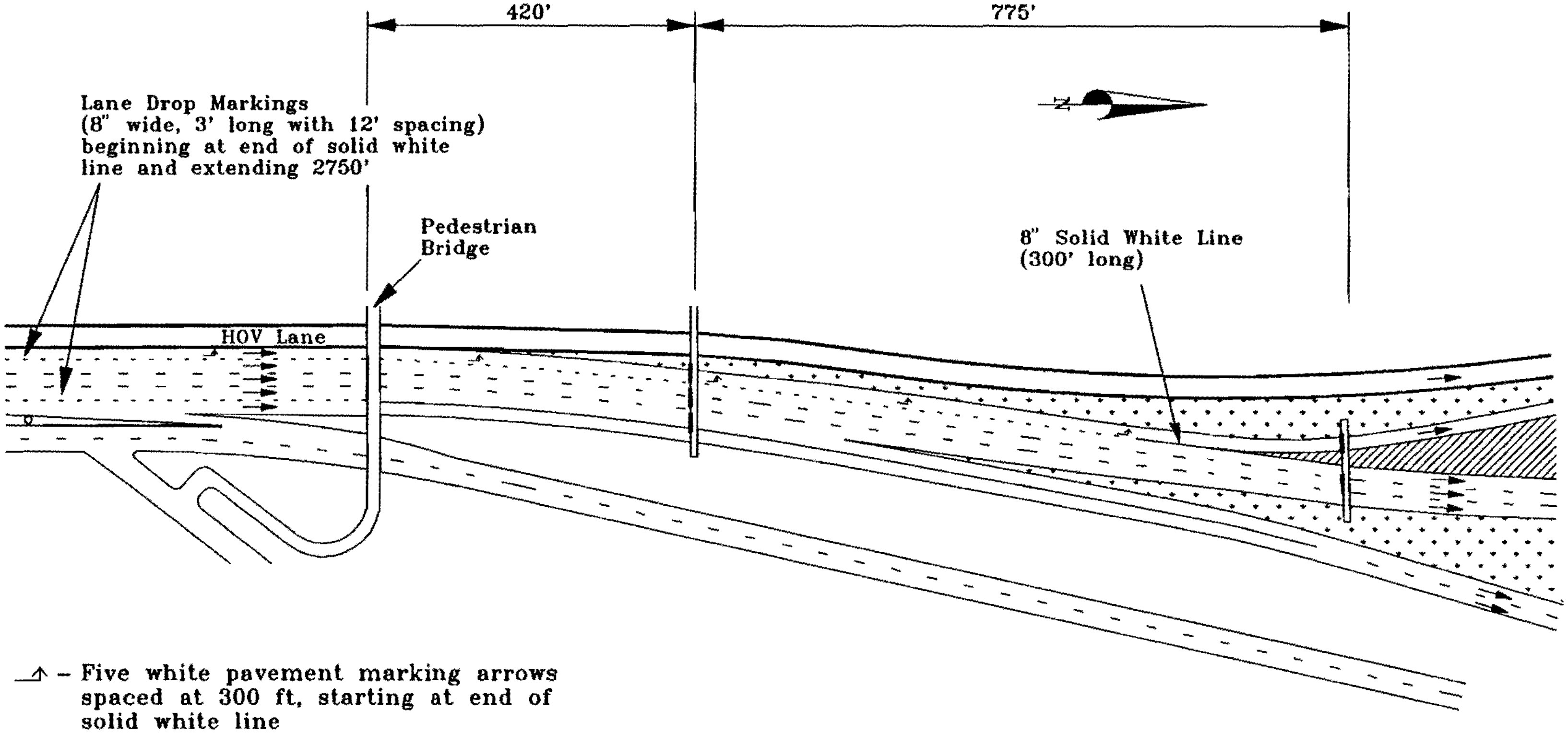
Figure 4-1. I-45 Northbound to I-610 West.

of the lane drop, motorist behavior at the site could be influenced by exit and entrance ramps on the right side of the freeway.

A two-lane, exit lane drop with an optional lane occurs on the right side of the freeway 400 ft (122 m), upstream of the exit being studied. An exit ramp to the frontage road also occurs on the right side of the freeway, 1,440 ft (439.2 m) upstream of the left exit lane drop. These right-side exit ramps should have little effect on the operations at the left exit lane drop. A more likely influence is the entrance ramp on the right side of the freeway, located 4,400 ft (1342 m) upstream of the left exit lane drop. This entrance ramp could effect traffic operations because motorists entering the freeway that desire to take the left exit would have to merge across three lanes of traffic in a relatively short distance.

Five green guide signs announcing the I-610 West exit lane drop precede the exit. The first two signs, occurring 2 miles (3.2 km) and 1 mile (1.6 km) before the exit as stated on the signs, do not contain the black-on-yellow EXIT ONLY panel; however, the second sign does contain a downward arrow over the left-most lane. The third, fourth, and fifth signs contain the black-on-yellow EXIT ONLY panels over the exit lane. Downward pointing arrows on the third and fourth sign, and an upward arrow on the fifth (last) sign are displayed over the left lane. The pavement markings existing prior to this study consisted of a solid white line between the exiting lane and the adjacent lane beginning approximately 250 ft (76.3 m) prior to the gore and typical dashed lane lines throughout the remainder of the study section. The signs and original markings at the site are illustrated in Figure 4-1.

Lane drop markings and pavement arrows, which are optional treatments, were selected for installation at the exit lane drop. In addition to the lane drop markings, raised pavement markers (RPMs) were installed. A RPM was located on each of the dashed lines; therefore, the RPMs on the lane drop markings are more closely spaced than the RPMs on the normal lane lines. Figures 4-2 and 4-3 illustrate the markings installed at the site. The white pavement arrows used at the site were similar in style to left turn arrows used at intersections.



Distances are approximated

Conversion Factor: 1 ft = 0.305 m

Figure 4-2. Lane Drop Markings Installed at the Site.

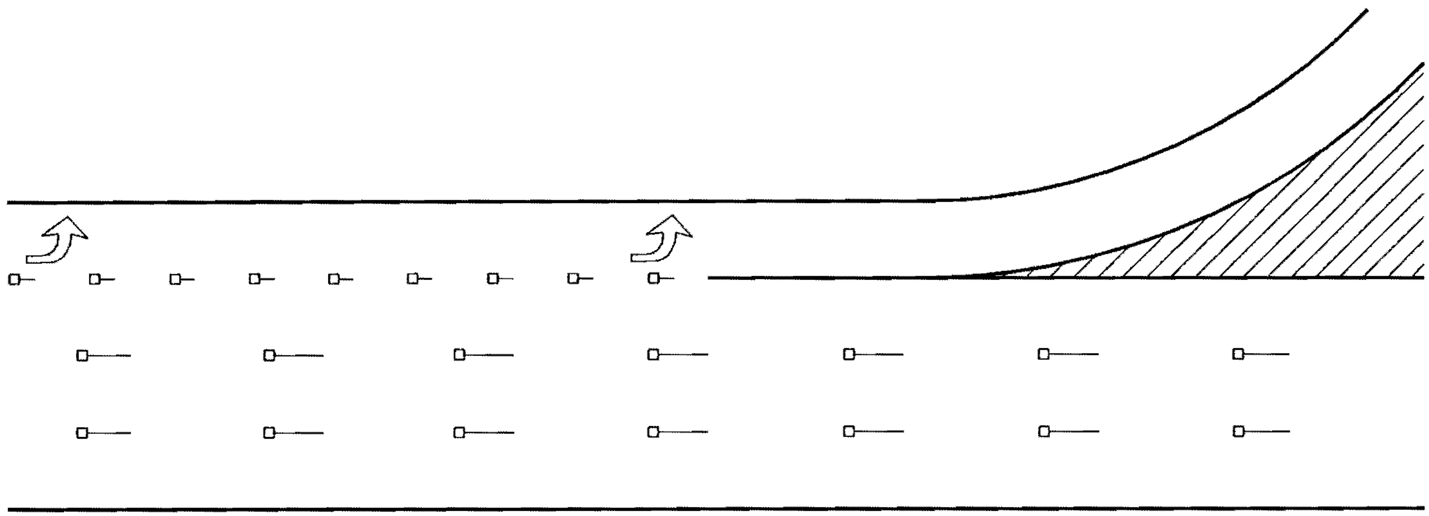


Figure 4-3. Raised Pavement Markers and Pavement Arrows at the Site.

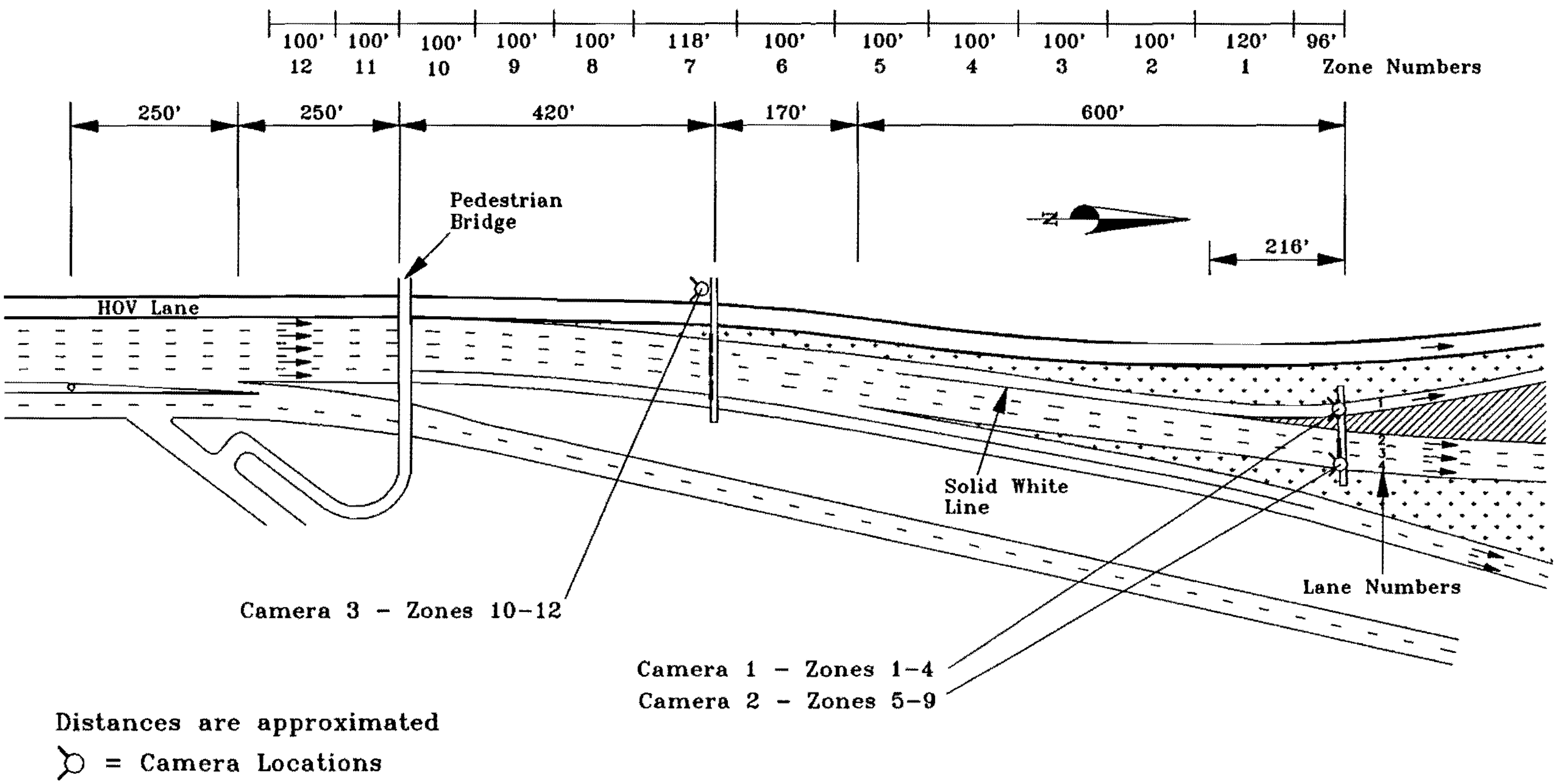
DATA COLLECTION

Data collection began with an inventory of the treatments currently being used at the site and recognition of other factors that may influence motorist behavior at the exit lane drop. Lane change and erratic maneuver data were collected for 1,500 ft (457.5 m) upstream of the lane drop gore both before and after the markings are installed. Closed circuit video cameras equipped with special wide angle and zoom lenses were used to allow optimum recording. The cameras were mounted in the field on overhead sign structures and appeared to be undetectable by passing motorists. Three cameras were installed at the site as shown in Figure 4-4. Two cameras were mounted on the overhead sign structure directly over the gore area. One of the cameras was focused near the gore area, while the other camera was focused upstream of the gore. The third camera was positioned on the overhead sign structure located 775 ft (236.4 m) upstream of the gore area. The before data was filmed during March, 1993 and the after filming occurred during the month of November, 1993.

Data were collected for approximately one full week excluding weekends. Six hour recording intervals were selected on time lapse VCRs. This recording period allowed extended recording lengths at an acceptable frame-by-frame speed. Technicians started the recording process between 6:00 and 7:00 a.m., and then returned six hours later to change VHS tapes for an additional six hours of recording. Additional tapes were used to record evening operations (from 6:00 to 10:00 p.m.) on two days during the after period.

DATA REDUCTION

The data reduction process began by subdividing the 1,500-ft (457.5 m) study length into segments of approximately uniform length. These uniform segments are called "zones." Rumble strips on the right shoulder that were generally spaced at 100-ft (30.5 m) increments were used to delineate the zones. The zones were numbered, beginning with Zone 1 at the gore and continuing upstream. All zones were 100 ft (30.5 m), except Zone 1 and 7 which were 120 ft (36.6 m) and 118 ft (36.0 m), respectively. Figure 4-4 illustrates the zone locations at the



Conversion Factor: 1 ft = 0.305 m

Figure 4-4. Locations of Cameras and Zones.

site. Each lane was also labeled, beginning with the exit only lane as Lane 1, and the adjacent lane as Lane 2. Three types of data were collected from the video tapes: lane changes, erratic maneuvers, and volume counts. The data were reduced in 15-minute intervals.

Lane Change Data

A lane change was recorded if a vehicle either entered or exited the exit-only lane. Therefore, moves from Lane 1 into Lane 2, from Lane 2 into Lane 1, from Lane 1 into Lane 3, or from Lane 3 into Lane 1 were recorded. For each lane change the beginning and ending lanes were recorded along with the zone from which the lane change originated. The zone from which the lane change originates is defined as the zone in which the vehicle's front wheel first crosses over the pavement markings separating the lanes.

Erratic Maneuver Data

The locations of erratic maneuvers were determined with the same criteria as lane changes. In addition to location, the type of erratic maneuver was designated with one of the following number codes:

(1) One-lane, lane change through the gore.
(2) Two-lane, lane change.
(3) Two-lane, lane change through the gore.
(4) Three-lane, lane change.
(5) Three-lane, lane change through the gore.
(6) Slowed/stopped (other cars passed).
(7) Slowed/stopped in gore to merge.
(8) Swerved in lane and back out / Attempted lane change.
(9) In/out of shoulder.
(10) Rode in between two lanes on solid white line.

A one-lane, lane change is not considered erratic unless the motorist drives across or into the gore. For example, a lane change from Lane 1 to Lane 2 in Zone 3 would only be recorded as a lane change, while a lane change from Lane 1 to Lane 2 in Zone 1 would also be recorded as an erratic maneuver (see Figure 4-5). All multiple-lane, lane changes were considered erratic maneuvers. For example a lane change from Lane 1 to Lane 3 in any zone was considered an erratic maneuver (also illustrated in Figure 4-5).

Data reducers were taught the different types of erratic maneuvers. The training was necessary to ensure that data reduction was consistent during the before and after periods.

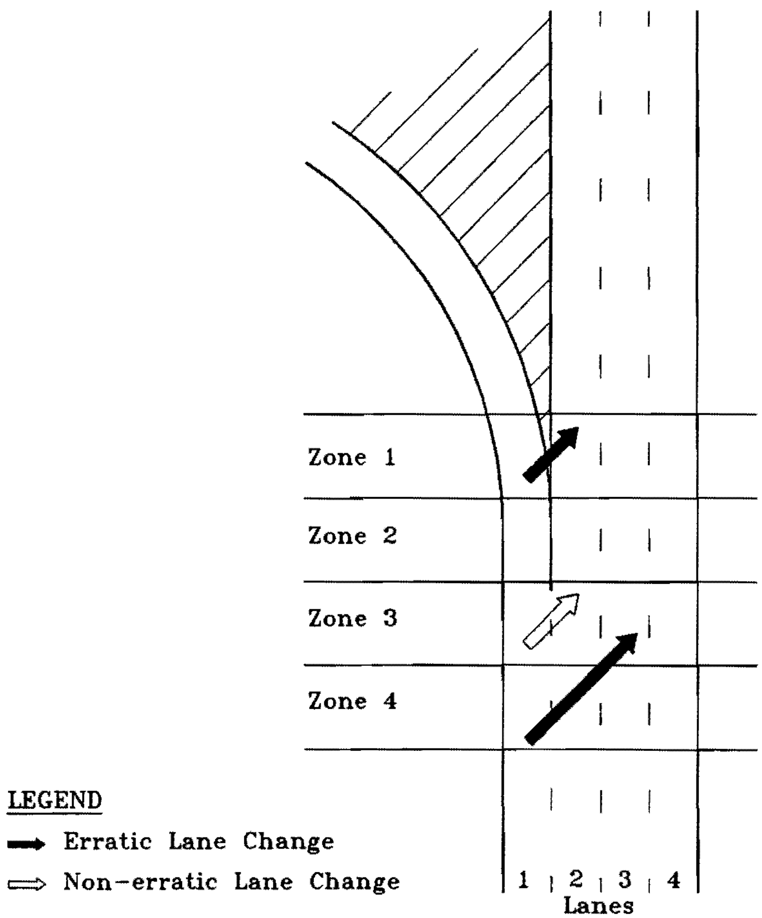


Figure 4-5. Illustration of Erratic and Non-Erratic Lane Changes.

Traffic Counts

So that lane change rates and erratic maneuver rates could be determined, exiting and through traffic volumes were obtained from the video tapes. The volumes were recorded for each freeway lane for a minimum of 15 minutes at the beginning of each hour. The vehicles were counted as they passed the point of the painted gore. All vehicle types were recorded.

Compilation of Data

Once the information was extracted from the video tapes, the data were entered into computer spreadsheets. A spreadsheet was created for each zone. The entries in the spreadsheets included the actual time interval reduced, the lane change count, and the erratic maneuver count for that particular 15-minute interval. The data were adjusted to 15-minute intervals and 100-ft (30.5 m) zone lengths with ratios if the actual time intervals reduced were less than 15 minutes or if the zone length was not 100 ft (30.5 m). The adjusted data were then averaged for each 15-minute period and summarized by total number of lane changes or erratic maneuvers for all hours, and typical number of lane changes or erratic maneuvers per hour for each zone. Once the lane change and erratic maneuver data were obtained for each zone, the next step was to combine the individual zone data into one file.

DATA ANALYSIS/EVALUATION

Observations of lane change behavior in the field, and findings from other studies indicate that the location where more drivers are moving into or out of the exit lane could be a characteristic of the geometry of the site or of the level of congestion at the site. To address this issue, the difference in the number of vehicles moving into the exit lane and the number of vehicles moving out of the exit lane were also calculated. Since the site had high volumes with noticeable levels of congestion, comparisons between peak and non-peak periods were made.

Graphs representing the calculated number of lane changes and erratic maneuvers per hour by zone were used to evaluate the findings. Initially, the findings were plotted by the 100-ft (30.5 m) increments used to reduce the data. The data were then aggregated into 300-ft (91.5 m) zone groups to reduce data variability. The data were also evaluated using appropriate statistical tests.

The concluding step of the evaluation used all available resources, such as site characteristics, plots, numeric values, and results from the statistical evaluations, to draw observations and then conclusions for the study.

RESULTS

This section presents the results of the study, including volume counts, and a summary of motorists' lane change behavior and erratic maneuver behavior throughout the lane drop area. Both before and after data are presented for daylight and evening operations. The statistical evaluations of the data are also contained in this section.

Volume Counts

The freeway hourly volumes during daylight operations (see bottom of Table 4-1) illustrate the high volume nature of the site, especially in the number of vehicles exiting. Over 1,700 vehicles in a typical hour used the left exit. The numbers of vehicles exiting per hour ranged between 1,370 and 2,100 during the before study period, and between 1,320 and 2,190 during the after study period. While the exiting volumes appear to be extremely high for a freeway lane, the exit does become a new lane on the I-610 freeway. The vehicles exiting are not required to merge for several miles with other traffic downstream of the lane drop gore.

The evening (6:00 p.m. to 9:00 p.m.) hourly volumes were about 30 percent lower than the daylight (7:00 a.m. to 5:00 p.m.) hourly volumes (see Tables 4-1 and 4-2). The average number of vehicles exiting per hour during daylight operations was approximately 1,700 for both the before and after time periods. The average number of vehicles exiting per hour during evening operations was approximately 1,050 during both the before and after time periods.

When comparing changes in driver behavior in a before-and-after study, potential influences, other than the items being studied, should be investigated to determine whether they affect the results. One way to detect other potential influences is to determine whether traffic volumes are similar from the before period to the after period. To compare the before-and-after traffic volumes during both daylight and evening operations, an analysis of variance statistical model was used with a confidence level of 0.05. The test showed that the volumes were statistically equal; therefore, there were no significant differences in the before and after traffic volumes for either the daylight or evening operations.

Table 4-1. Fifteen Minute Volume Counts—Daylight Hours.

Time	Before Volumes					After Volumes				
	L1	L2	L3	L4	Total	L1	L2	L3	L4	Total
7:00-7:15	526	445	499	402	1871	522	436	452	448	1858
8:00-8:15	525	433	479	416	1853	535	392	412	459	1798
9:00-9:15	343	388	395	351	1476	397	365	368	243	1373
10:00-:15	354	243	329	220	1146	360	365	332	234	1291
11:00-:15	350	363	359	208	1280	330	368	354	220	1272
12:00-:15	367	360	353	224	1303	368	326	342	234	1270
1:00-1:15	382	368	360	245	1354	382	352	372	237	1343
2:00-2:15	435	372	361	246	1413	392	336	348	222	1298
3:00-3:15	425	380	387	264	1455	432	334	356	236	1358
4:00-4:15	502	339	339	259	1439	463	370	384	248	1465
5:00-5:15	490	363	384	266	1502	548	341	356	273	1518
Average of counts	427	369	386	282	1463	430	362	371	278	1440
Hourly Volume	1708	1474	1543	1126	5851	1720	1449	1482	1111	5761

Note: L1 = Lane 1; represents the exit-only lane
L2 = Lane 2; represents the lane adjacent to Lane 1
L3 = Lane 3; represents the lane adjacent to Lane 2
L4 = Lane 4; represents the right-most lane

Table 4-2. Fifteen Minute Volume Counts—Evening Hours.

	Before Volumes					After Volumes				
Time	L1	L2	L3	L4	Total	L1	L2	L3	L4	Total
6:00-6:15	370	356	352	237	1315	393	342	330	215	1279
7:00-7:15	240	245	262	155	902	238	257	243	168	906
8:00-8:15	230	182	204	148	764	246	172	202	141	731
9:00-9:15	208	182	189	113	692	209	178	191	111	689
Average of counts	262	241	252	163	918	264	237	242	159	901
Hourly Volume	1048	965	1007	653	3672	1056	949	966	635	3605

Note: L1 = Lane 1; represents the exit-only lane
L2 = Lane 2; represents the lane adjacent to Lane 1
L3 = Lane 3; represents the lane adjacent to Lane 2
L4 = Lane 4; represents the right-most lane

Erratic Maneuvers

As might be expected, the majority of the erratic maneuvers near the gore were of the "cross gore" variety. The more dangerous maneuvers, such as backing or stopping in the gore area, occurred less often.

In the before data the largest number of erratic maneuvers occurred within 300 ft (91.5 m) of the gore (see Table 4-3 for daylight and Table 4-4 for evening). In the before data over half (53 percent) of the erratic maneuvers occurred in Zones 1, 2, and 3, with most occurring in Zone 1 (see Figure 4-6). A large number of erratic maneuvers also occurred within 300 ft (91.5 m) of the gore during the after period. Approximately 45 percent of the erratic maneuvers during the after period occurred in Zones 1, 2, and 3 (see Figure 4-6). The predominant type of erratic maneuvers within 300 ft (91.5 m) of the gore was the lane change through the gore area. The number of erratic maneuvers within 300 ft (91.5 m) of the gore was reduced 50 percent between the before and after periods during daylight operations (see Table 4-3), and by 42 percent during evening operations (see Table 4-4).

Table 4-3. Types of Erratic Maneuvers Observed—Daylight.

Erratic Maneuver Type[a]	Gore Area (0-320 ft)		Upstream (320-1238 ft)	
	Before	After	Before	After
One-lane, lane change through the gore	430	218	0	0
Two-lane, lane change	64	6	332	246
Two-lane, lane change through the gore	5	19	0	0
Three-lane, lane change	0	1	7	11
Three-lane, lane change through the gore	0	2	0	0
Suddenly slowed to merge (other cars passed)	2	0	32	25
Slowed or stopped to merge in gore	0	2	0	1
Rode in between two lanes on solid white line	0	0	4	0
In/out of shoulder	2	0	9	3
Swerved in lane and back out/Attempted lane change	0	4	63	30
Totals	503	252	447	316

[a] Observations during 20 daylight hours
Conversion Factor: 1 ft = 0.305 m

Table 4-4. Types of Erratic Maneuvers Observed—Evening.

Erratic Maneuver Type[a]	Gore Area (0-320 ft)		Upstream (320-1238 ft)	
	Before	After	Before	After
One-lane, lane change through the gore	87	54	0	0
Two-lane, lane change	13	3	85	68
Two-lane, lane change through the gore	9	5	0	0
Three-lane, lane change	0	1	0	1
Suddenly slowed to merge (other cars passed)	0	0	4	0
Swerved in lane and back out/Attempted lane change	0	0	7	4
Totals	109	63	96	73

[a] Observations during 6 evening hours
Conversion Factor: 1 ft = 0.305 m

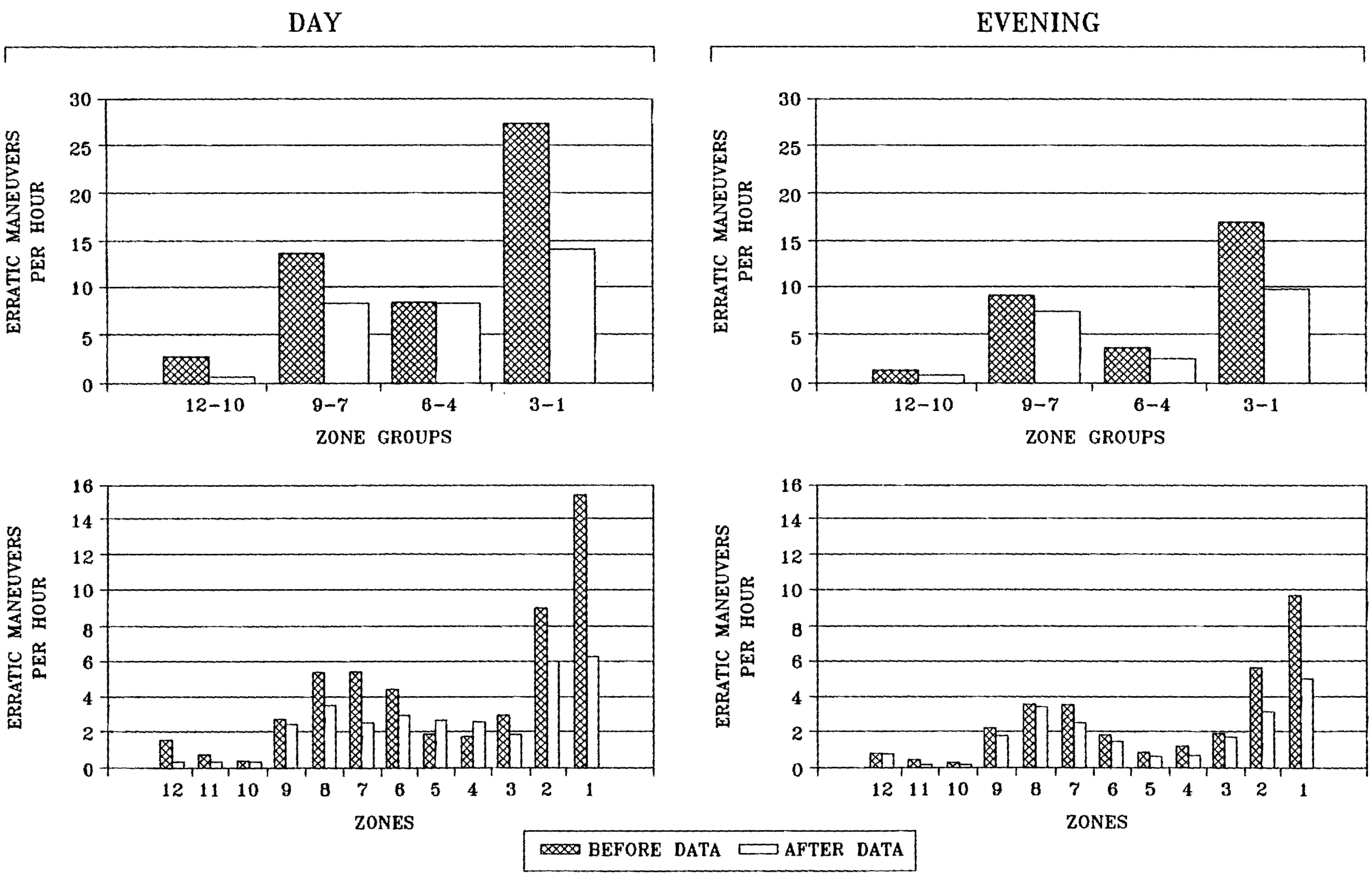


Figure 4-6. Erratic Maneuvers Per Hour Per Zone.

Although erratic maneuvers commonly occur in the vicinity of the gore area, the cause of the erratic maneuver may not be associated with the gore area. For example, a motorist might stop in the gore area because of confusion by the directional legend at the first advance exit sign. The driver's confusion and indecision did not manifest itself until the occurrence of the erratic maneuver in the gore area.

The most common type of erratic maneuver upstream of the gore area was the two-lane, lane change (see Tables 4-3 and 4-4). A number of congestion-related erratic maneuvers were also observed. Some drivers suddenly slowed in an attempt to position for a lane change, while others attempted but failed to make a lane change. Upstream of the gore the number of erratic maneuvers was reduced by 30 percent between the before and after periods during daylight operations (see Table 4-3), and by 25 percent during evening operations (see Table 4-4).

By examining the erratic maneuvers per hour by zones during daylight operations (Figure 4-5) one sees an overall reduction in erratic maneuvers throughout the lane drop area. Only Zones 4 and 5 contain a slight increase in erratic maneuvers during the after period. The evening plots appear to follow the same trends as the daylight plots except the erratic maneuvers in Zones 4 and 5 do not increase during the after period. Considering the entire lane drop area, erratic maneuvers were reduced from the before period to the after period by 40 percent during daylight operations, and by 34 percent during evening operations.

Lane Changes—Frequency

Table 4-5 summarizes the before and after counts at the site. For the 1240-ft study site, 315 lane changes occurred in the before period and 217 lane changes occurred in the after period, a reduction of 31 percent. An even greater reduction in lane changes occurred in the 300 ft (30.5 m) nearest to the gore. The decrease from 66 lane changes to 24 represents a 64 percent reduction.

Table 4-5. Comparison of Before-and-After Data.

Characteristics	I-45 Northbound to I-610 West					
Zones used in comparison	Zones 1-12					
Equil. length of study site	1240 ft					
Time used in comparison	7:15 a.m. to 6:00 p.m.			6:00 p.m. to 9:00 p.m.		
Light Condition	DAYLIGHT			EVENING		
	Before	After	Change	Before	After	Change
Freeway hourly volume[a]	5851	5761	-2%	3672	3605	-2%
Hourly volume exiting[a]	1708	1720	1%	1048	1056	1%
Total study length						
Lane Changes[b]	315.0	217.0	-31%	234.0	158.0	-32%
Erratic Maneuvers[b]	51.0	31.0	-39%	32.0	21.0	-34%
For 300-ft nearest to gore						
Lane Changes[b]	66.0	24.0	-64%	42.0	14.0	-67%
Erratic Maneuvers[b]	27.0	14.0	-48%	17.0	10.0	-41%
Rate[c] (10^{-6}/ft/veh)						
Lane Changes	43.43	30.38	-30%	51.39	35.35	-31%
Erratic Maneuvers	6.55	3.98	-39%	7.03	4.7	-33%

[a] Freeway hourly volumes were measured prior to gore and represent the average of the time periods used in the comparison.
[b] Values represent an average 60-minute period for the time periods used in the comparison.
[c] Rates were determined by dividing the number of lane changes, or erratic maneuvers, in an hour by study length and freeway hourly volume, and multiplying by 1,000,000.
Conversion factor: 1 ft = 0.305 m

Lane changes per hour were plotted by zone for both daylight and evening operations (see Figure 4-7). Because of the variability in the data for the individual zones, the data were collapsed into 300-ft (90.5 m) zone groups. The plot of lane changes per hour by zone group during daylight operations shows a reduction in lane changes for each zone group in the after period. This reduction in lane changes also appears to be greater in the first two zone groups, Zone Group 1-3 and Zone Group 4-6. The plot of lane changes per hour by individual zones

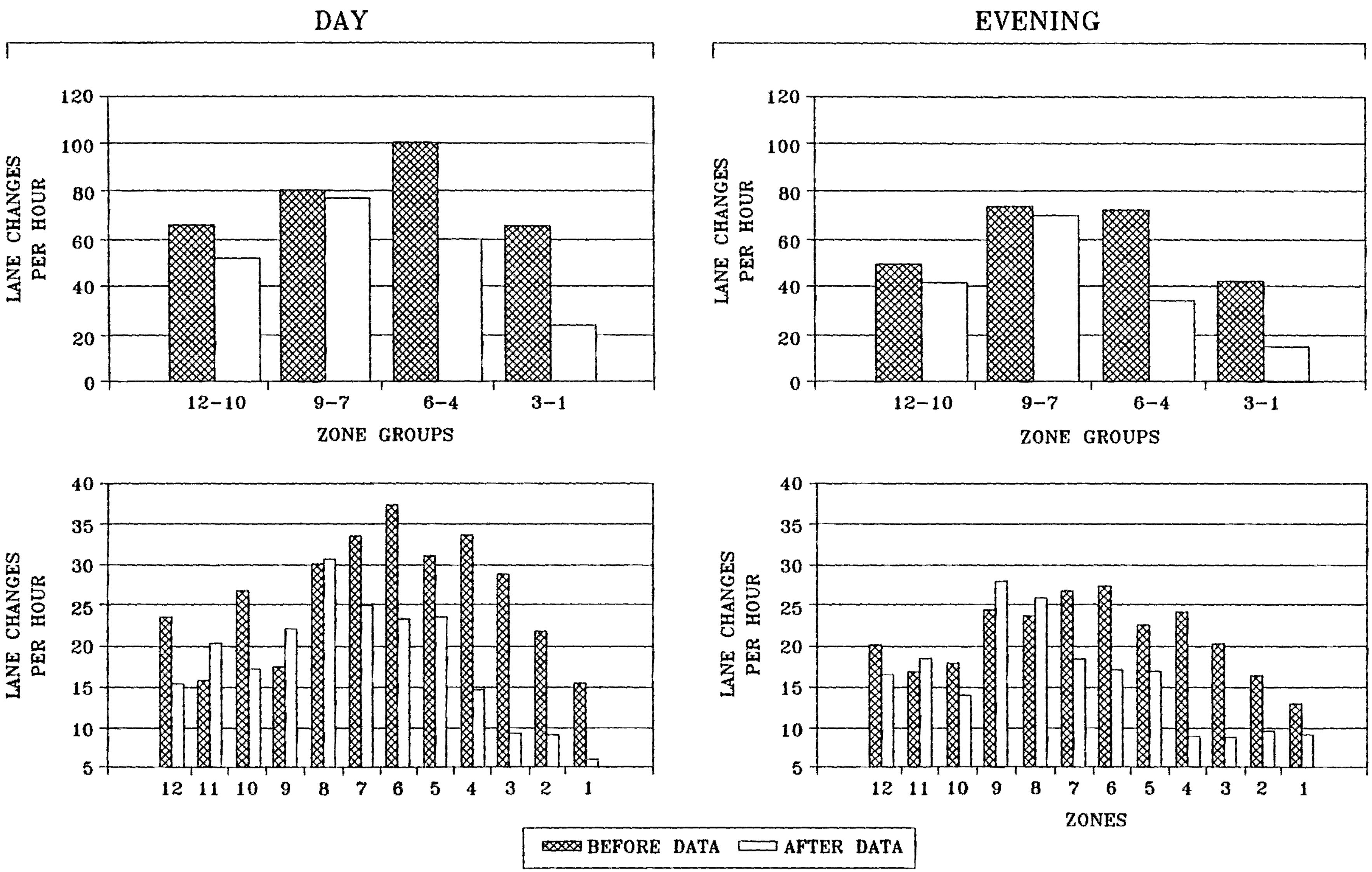


Figure 4-7. Lane Changes Per Hour Per Zone.

reveals that the lane changes per hour actually increased in Zones 8, 9, and 11, during the after period. Overall, a substantial reduction (approximately 45 percent) in lane changes per hour in Zones 1-7 occurred, with fluctuations in the remaining zones (Zones 8-12).

The evening plots yielded similar patterns (see Figure 4-7). The evening plot of lane changes per hour by zone group again indicates a reduction in lane changes per hour for each zone group during the after period, with a greater reduction occurring in the first two zone groups. The evening plot of lane changes per hour by individual zones also shows a substantial decrease (approximately 54 percent) in lane changes per hour in Zones 1-7, with fluctuation in Zones 8-12.

During both daylight and evening operations, for each zone, in both the before and after studies, the number of vehicles entering the exit lane was more than the number of vehicles leaving the exit lane (see Figure 4-8). Approximately 70 to 80 percent of the lane changes were vehicles moving into the exit lane.

Statistical Test of Measures of Effectiveness

A statistical test was performed to determine whether the decreases in erratic maneuvers and lane changes per hour from the before to the after period were statistically significant. A binomial test of proportions with a 0.05 confidence level was used to determine whether the percentages of lane changes and erratic maneuvers before the treatment were equal to the percentages after treatment. For example, during daylight operations, the percent of lane changes for the entire study segment was 59.3 percent during the before period and 40.7 percent during the after period. The statistical test compares these numbers to 50 percent. For a decrease in the percentages of lane changes or erratic maneuvers to be significant the calculated z-value must be greater than 1.645. The results of the test indicate that the reduction in percentages was significant in every case (see Table 4-6).

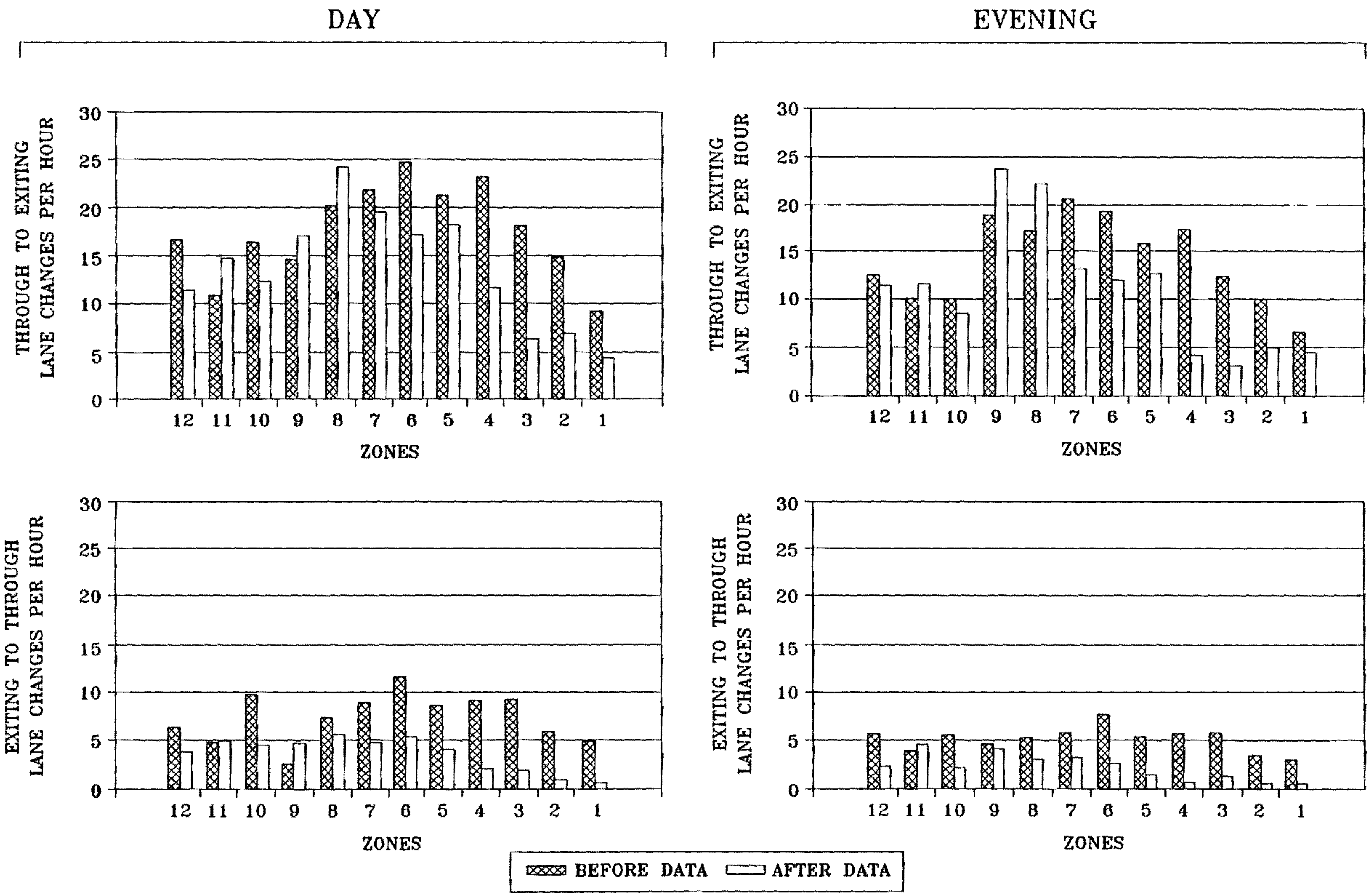


Figure 4-8. Entering and Exiting the Exit Lane Changes Per Hour Per Zone.

Table 4-6. Results of the Binomial Test of Proportions.

	Daylight Operations		Evening Operations	
	Before	After	Before	After
Lane Changes Per Hour for Study Segment	315	217	234	158
Lane Change Proportion	59.3	40.7	59.7	40.3
z-value Significant/Not Significant?	6.07 Significant		5.43 Significant	
Erratic Maneuvers Per Hour for Study Segment	51	31	32	21
Erratic Maneuver Proportion	62.5	37.5	60.4	39.6
z-value Significant/Not Significant?	3.20 Significant		2.14 Significant	
Lane Changes Per Hour for Gore Area	66	24	42	14
Lane Change Proportion	73.1	26.9	75.0	25.0
z-value Significant/Not Significant?	6.20 Significant		5.29 Significant	
Erratic Maneuvers Per Hour for Gore Area	27	14	17	10
Erratic Maneuver Proportion	66.2	33.8	63.0	37.0
z-value Significant/Not Significant?	2.93 Significant		3.38 Significant	

A more comprehensive test for before-and-after data included an examination of the data's variability rather than only testing the significance of the difference between two averages. Before-and-after hourly lane changes and erratic maneuvers were also compared using the Chi-Square test of independence. This test, which was also conducted at the 0.05 confidence level, compares the percentage distribution of hourly lane changes and erratic maneuvers before and after the treatment. It provides an appreciation for the variability of the data. The results are shown in Table 4-7.

Table 4-7. Results of Chi-Square Tests.

	χ^2_{CALC}	χ^2_{TABLE}	Significant?
Daylight Operations			
Total Lane Change Per Hour	54.88	19.7	Yes
Exiting to Through Lane Changes Per Hour	26.81	11.1	Yes
Through to Exiting Lane Changes Per Hour	28.94	18.3	Yes
Erratic Maneuvers Per Hour	11.23	9.5	Yes
Evening Operations			
Total Lane Changes Per Hour	49.16	17.0	Yes
Exiting to Through Lane Changes per Hour	24.86	7.82	Yes
Through to Exiting Lane Changes per Hour	29.69	17.0	Yes
Erratic Maneuvers per Hour	4.23	6.0	No

The results of the Chi-Square test indicate that the distributions of lane changes and erratic maneuvers in the after period were significantly different from the before period. The distribution of daylight and evening lane changes, both exiting-to-through and through-to-exiting, changed significantly between the before and after periods. Both types of lane changes were examined to determine whether the pavement markings had an effect on both exiting and through motorists.

The results of the Chi-Square tests agree with the results of the proportions test in each case except one. According to the Chi-Square test, the erratic maneuvers during the evening period were not significantly changed, while the proportions test indicates that they were significantly changed. This discrepancy could be due to the low observation rate of erratic maneuvers in each zone during evening operations; 75 percent of the zones had less than five erratic maneuvers per hour during the after period.

Lane Changes—Location

Both the daylight and evening plots appear to indicate a shift in the location of lane changes between the before and after periods. If the after data shows a decrease in the number of lane changing in one portion of the lane drop area, and an increase in the number of lane changes in another portion of the lane drop area then it can be concluded that the pavement markings created a shift in the location of lane changes. In this study, the before data contains a large number of lane changes in the first seven zones, while the after data shows approximately a 50 percent reduction in lane changes in these zones. The lane change per hour in Zones 8 to 12 show little reduction between the before and after periods—approximately 7 percent during daylight operations, and approximately 1 percent during evening operations.

Although the study segment does not contain zones with substantial increases in lane changes per hour during the after period, these increases may occur prior to the study segment. An increase in lane changes per hour during the after period in zones prior to the study segment would indicate that motorists are positioning themselves further downstream in reaction to the lane drop markings. It should be noted that the lane drop marking extended for 2,500 ft (762.5 m) prior to the gore; therefore, they appeared for approximately 1,300 ft (396.5 m) prior to the study area.

Statistical Test on Location of Lane Changes

To determine whether a "shift" in lane change locations is occurring, plots of percent of lane changes per zone were used. The plot of percent of lane changes per zone during daylight operations (see Figure 4-9) indicates a shift in where vehicles are changing lanes from the before to the after period. For the five zones closest to the gore, fewer vehicles changed lanes in the after period than in the before period, while more vehicles changed lanes in last five zones in the after period than in the before period. This "shift" in lane change location can also be seen by examining the cumulative percent of lane changes throughout the study segment (see Figure 4-10).

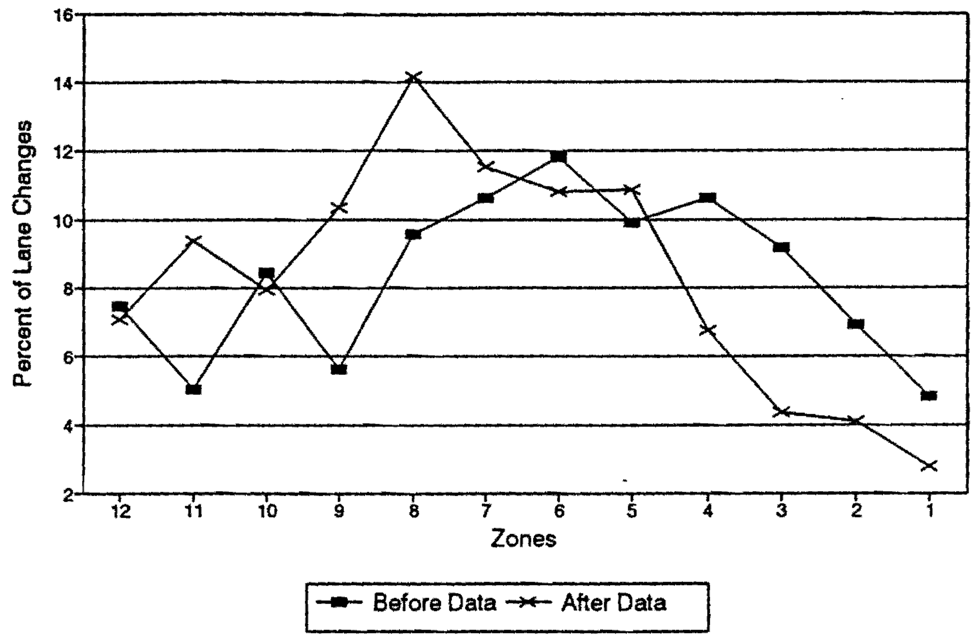


Figure 4-9. Lane Change Percentage Distribution—Daylight.

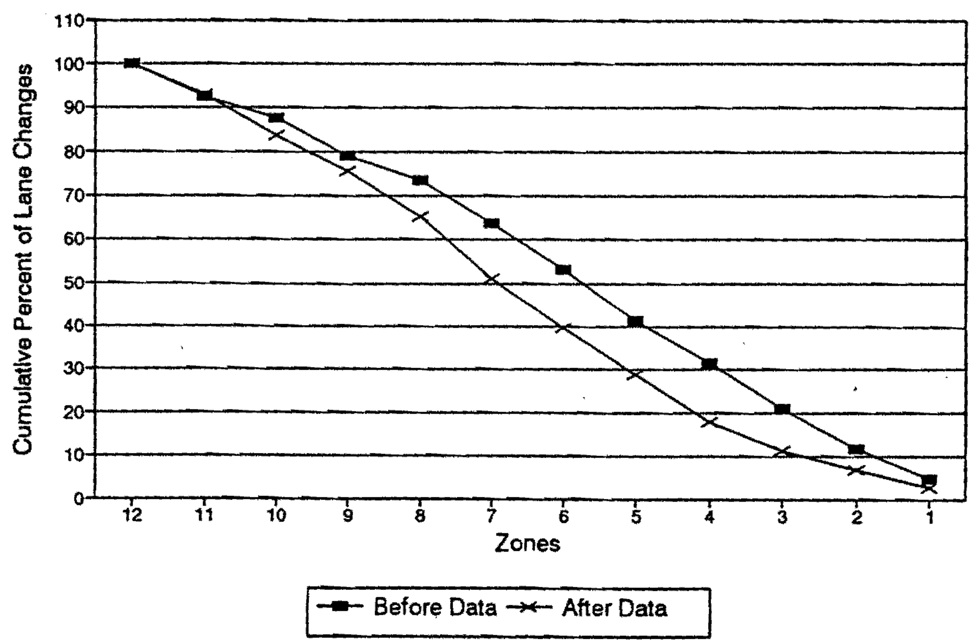


Figure 4-10. Cumulative Percentage Distribution—Daylight.

The plot of percent of lane changes during evening operations per zone follows the same trend as the plot for daylight operations (see Figure 4-11). The evening plot illustrates an even more noticeable difference between the before and after data. Again, fewer vehicles are changing lanes in the first five zones during the after period than the before period, while more vehicles are changing lanes in the last five zones during the after period than the before period. The plot of cumulative percents for the evening period, Figure 4-12, also illustrates a slightly more noticeable "shift" than the daylight plot, Figure 4-10.

The plots of the percentage distribution and cumulative percentage distributions indicate a difference in before-and-after lane change behavior depending upon the distance from the gore. To statistically validate this, a binomial proportions test was conducted on the before-and-after percentages for each zone. Thus, the zones with significantly different proportions between the before and after periods could be determined. The direction of change (i.e., whether the number of lane changes increased or decreased from before to after) was also determined. The results of the individual proportions test by zone in addition to the direction of change ("-" indicates a decrease in lane changes from before to after and "+" indicates an increase) are included in Table 4-8 (daylight operations), and Table 4-9 (evening operations). All tests were done at the 0.10 confidence level.

Lane Changes—Hour of Day

The number of lane changes per hour throughout the day was also examined. Figure 4-13 illustrates the number of lane changes per hour throughout the day, including both daylight and evening hours. The frequency plot demonstrates that the number of lane changes is higher in the afternoon peak period (4:30 p.m. to 6:30 p.m.) than in the morning peak period (7:30 a.m. to 8:30 a.m.). This finding supports the observation that the congested nature of this freeway in the morning limits the number of lane changes as well as the number of lane changing opportunities for drivers. The highest number of lane changes occurred during the middle of the day. When the plot is adjusted to reflect volume, a similar pattern is seen (see Figure 4-13). The highest lane-change rate occurs during the middle portion of the day and the

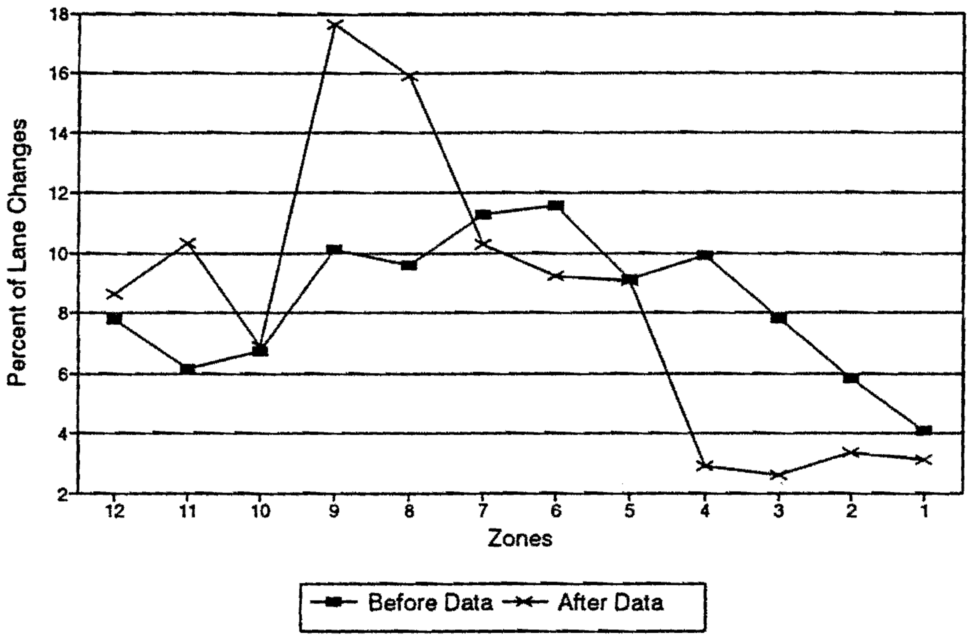


Figure 4-11. Lane Change Percentage Distribution—Evening.

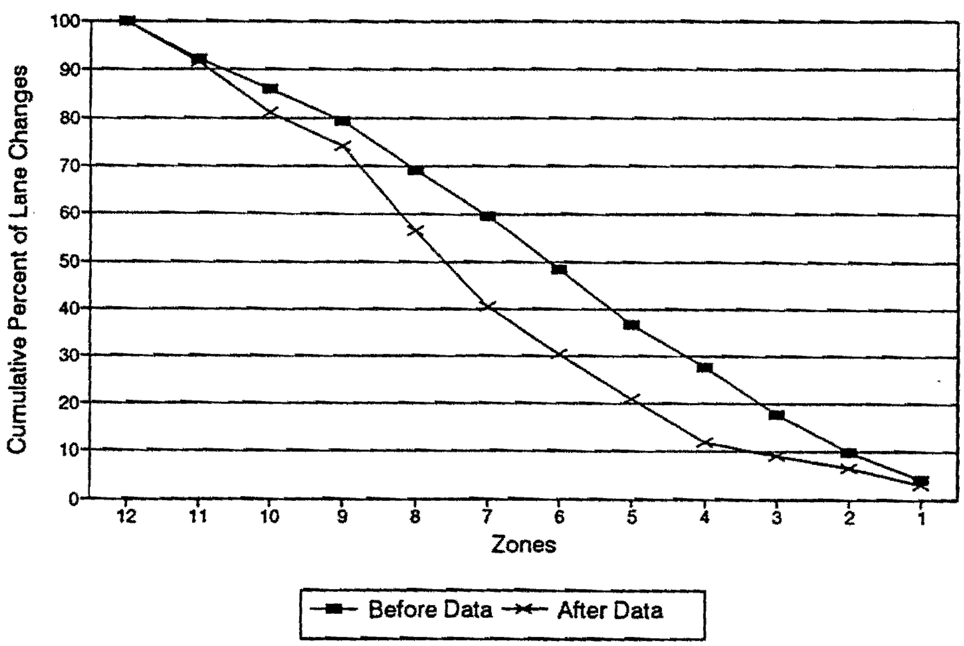


Figure 4-12. Cumulative Percentage Distribution—Evening.

lowest during the heavily congested a.m. period. A peaking trend in the rate of lane changes also occurs during the evening hours (6:00 p.m. to 10:00 p.m.) when the freeway volumes are lowest.

Table 4-8. Results of Proportions Test for Each Zone—Daylight.

Zone	Total Lane Changes			Exiting to Through Lane Changes			Through to Exiting Lane Changes		
	% Change	Sig?	Dir	%Change	Sig?	Dir	%Change	Sig?	Dir
1	2.07	Yes	–	3.34	No	•	0.95	No	•
2	2.83	Yes	–	3.89	No	•	1.52	No	•
3	4.82	Yes	–	5.56	No	•	3.12	No	•
4	3.88	Yes	–	4.73	No	•	3.89	Yes	–
5	0.96	No	•	0.03	No	•	1.07	No	•
6	1.00	No	•	0.88	No	•	1.06	No	•
7	0.88	No	•	0.75	No	•	1.55	No	•
8	4.58	Yes	+	4.23	No	•	5.15	No	•
9	4.73	Yes	+	6.97	Yes	+	3.60	No	•
10	0.49	No	•	0.57	No	•	0.33	No	•
11	4.33	Yes	+	5.55	No	•	3.94	Yes	+
12	0.40	No	•	1.54	No	•	1.14	No	•
Overall	18.60	Yes	–	32.63	Yes	–	12.53	Yes	–

Table 4-9. Results of Proportions Test for Each Zone—Evening.

Zone	Total Lane Changes			Exiting to Through Lane Changes			Through to Exiting Lane Changes		
	%Change	Sig?	Dir	%Change	Sig?	Dir	%Change	Sig?	Dir
1	0.95	No	•	3.40	No	•	0.40	No	•
2	2.47	No	•	3.93	No	•	2.24	No	•
3	5.20	Yes	–	4.74	No	•	5.04	Yes	–
4	7.29	Yes	–	7.26	No	•	7.08	Yes	–
5	0.74	No	•	2.88	No	•	0.38	No	•
6	2.33	No	•	2.45	No	•	2.17	No	•
7	0.97	No	•	2.49	No	•	1.99	No	•
8	6.30	Yes	+	2.97	No	•	6.71	Yes	+
9	7.59	Yes	+	8.91	No	•	6.87	Yes	+
10	0.16	No	•	0.24	No	•	0.64	No	•
11	4.15	Yes	+	11.16	Yes	+	2.90	No	•
12	0.86	No	•	0.68	No	•	1.36	No	•
Overall	19.46	Yes	–	42.14	Yes	–	12.90	Yes	–

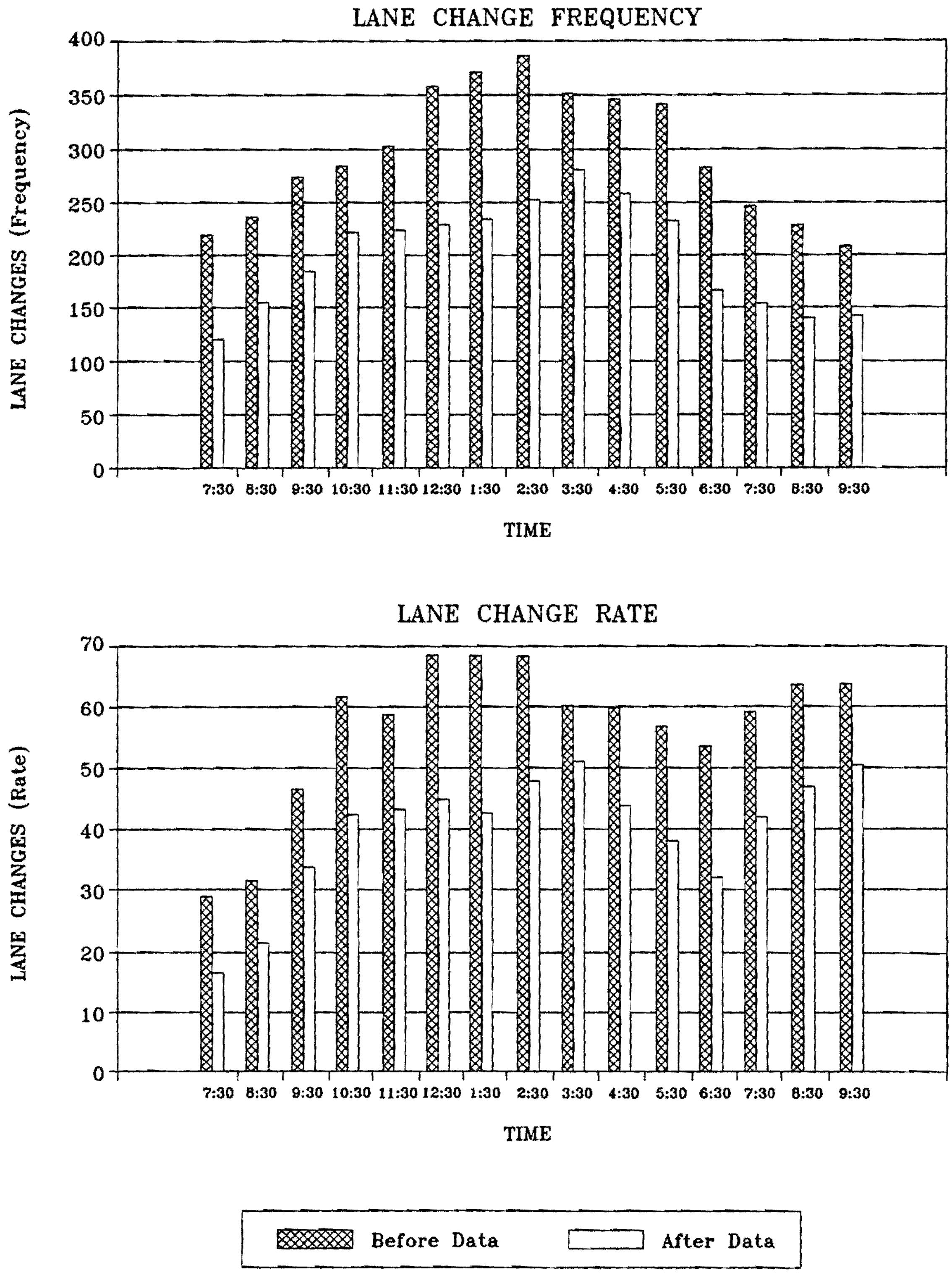


Figure 4-13. Lane Changes Per Hour of the Day.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

The purpose of this project was to investigate the operations and safety characteristics of left exit lane drops. As is generally recognized, constructing left exits is to be avoided; however, when present, suggestions on methods to improve safety and operations are valuable. One alternative for better communicating the presence of a left exit lane drop to motorists is with pavement markings. Lane drop pavement markings, pavement arrows, and raised pavement markings were evaluated in the field to determine their effectiveness during daytime and evening operations at a left exit lane drop. This chapter contains the conclusions of the evaluations of motorist behavior in response to the lane drop markings. Recommendations and suggested topics for future research are also contained in this chapter.

CONCLUSIONS

The results of the before-and-after study indicated that the lane drop markings and raised pavement markers had a positive effect on driver behavior throughout the lane drop area; therefore, they were an effective treatment at the left exit lane drop. Erratic maneuvers and lane changes were both significantly reduced between the before and after periods during both daylight and evening operations. The results also indicated that motorists performed their lane changes, into or out of the exit-only lane, further upstream of the lane drop exit after the markings were installed. This "shift" occurred during both daylight and evening operations.

Some of the reduction in the lane changes and/or erratic maneuvers may be partially attributed to the greater attention value from the uniqueness of the markings within the lane drop area since the optional lane drop markings are not consistently used at lane drop sites within the state. Because the lane drop markings were evaluated four months after their installation, however, the change in driver behavior is presumably not due to the "newness" of the markings.

RECOMMENDATIONS

The consistent use of lane drop markings and raised pavement markers at left exit lane drops is recommended. Consistent use of standardized markings treatments can provide several benefits, among them improved driver expectancy at exit lane drops. The improved driver expectancy encourages motorists to move out of or into a lane that is being dropped further upstream of the gore area. This behavior results in fewer erratic maneuvers.

SUGGESTED RESEARCH

Examine the Relationship between Erratic Maneuvers and Accidents

The study of erratic maneuvers appears to be a promising tool for evaluating problem exits. Accident rates may be too broad to detect the fine changes in driver behavior that result from different treatments at exit lane drops. Therefore, it would be worthwhile to determine if there is a quantifiable relationship between frequency of accidents and erratic maneuvers. If a definitive relationship exits, benefits in the form of reduced accidents could be estimated from erratic maneuver data.

Determine Driver Information Needs

In this study erratic maneuvers and lane changes were evaluated at an exit lane drop to determine whether motorists were confused as they traveled through the lane drop area. Some motorists traveling through the lane drop area indicated with a blinker their desire to change lanes, but were not able to change lanes. Therefore, there is reason to believe that some motorists were confused or took a wrong route, but did so without making an erratic maneuver or a lane change. Continued research is suggested to determine driver information needs at exit lane drops, and how they can be satisfied.

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