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16. Abstract

This project determines how motorists interpret or respond to various sign and pavement marking alternatives they may or may not have experienced before. Motorist interpretation of signs and markings were obtained through surveys, while field observations were used to measure actual motorist responses to pavement markings.

The results from both surveys indicate that motorists have a high level of understanding of the yellow EXIT ONLY panel. Drivers do not understand the use of the white arrow next to a yellow EXIT ONLY panel as well. Over one third of the participants incorrectly interpreted the meaning of the white arrows. Motorists prefer the use of diagrammatic signs as the first of several signs indicating an approaching exit lane drop and the use of the conventional black on yellow panel close to the exit lane drop. Texas motorists understand the meaning of the wide solid white line.

The field studies demonstrate that the installation of lane drop markings can cause a shift in motorist lane change locations in advance of a lane drop. One site's data directly reveals while the other site's data indicates that drivers move into or out of the exiting lane further upstream of the lane drop in the period after markings were installed than in the period before markings were installed. For the 800 feet (244 m) immediately upstream of the gore at one site, fewer vehicles left the exit lane in the after period than in the before period, while in the area between 1700 and 1000 ft (518 and 305 m) upstream of the gore, more vehicles left the exit lane in the after period than in the before period. The before-and-after studies also reveal that the number of erratic maneuvers within the entire study segment decrease with the installation of markings.

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FREEWAY EXIT LANE DROPS IN TEXAS

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IMPLEMENTATION STATEMENT

This study demonstrates that motorists have a good understanding of exit lane drop markings and signs, except for the white down arrow located next to the yellow EXIT ONLY panel on two-lane exits with an option lane and an exit only lane. Findings also demonstrate 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 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), Torsten Lienau, Mike Ogden (TX-77485), Marty Lance, and Tom Urbanik (TX-42384).

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This study was performed in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

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SUMMARY

Field studies measured the effects of lane drop markings on driver behavior. Number and location of lane changes and erratic maneuvers upstream of an exit only lane drop were the measures of effectiveness used to describe driver behavior. Data were collected at seven sites: four, one-lane, lane drop exits (three to the right and one to the left); and three, two-lane exits with an option lane and an exit only lane. When the lane change and erratic maneuver data were compared between sites, the uniqueness of each site became obvious. The location of entrance or exit lanes upstream of the lane drop in addition to the lane drop itself were the major influences on where lane change and erratic maneuver frequencies would peak. When examining the frequency patterns of erratic maneuvers by distance, the most notable observation was the peaking of erratic maneuvers in the gore area. Larger numbers of erratic maneuvers were observed at the two-lane exits with an option lane and an exit only lane than at the one-lane, lane drop exits.

Lane drop markings were installed at two sites. The total number of lane changes for the entire study segment at both sites showed a decrease. One site showed a statistically significant decrease of 29 percent in lane changes, while the other site showed a modest decrease. With these mixed results, a strong conclusion that lane drop markings definitely reduce the number of lane changes is not possible; however, when the number of lane changes for the 300 ft (91.5 m) nearest to the gore are examined, both sites show a statistically significant decrease from the before period to the after period.

The number of erratic maneuvers at both before-and-after sites decreased from the before period to the after period for both the entire study length and the 300 ft (91.5 m) nearest to the gore. These decreases were statistically significant at one site. Substantial decreases in the number of one-lane, lane changes through the gore, and swerving into a lane and back out (attempted lane changes) were the prime contributors to the reduction in the number of erratic maneuvers at this site, while the other site's decrease was caused by a reduction in the number of two-lane, lane changes. The pavement markings did decrease the number of erratic maneuvers within the entire study segment.

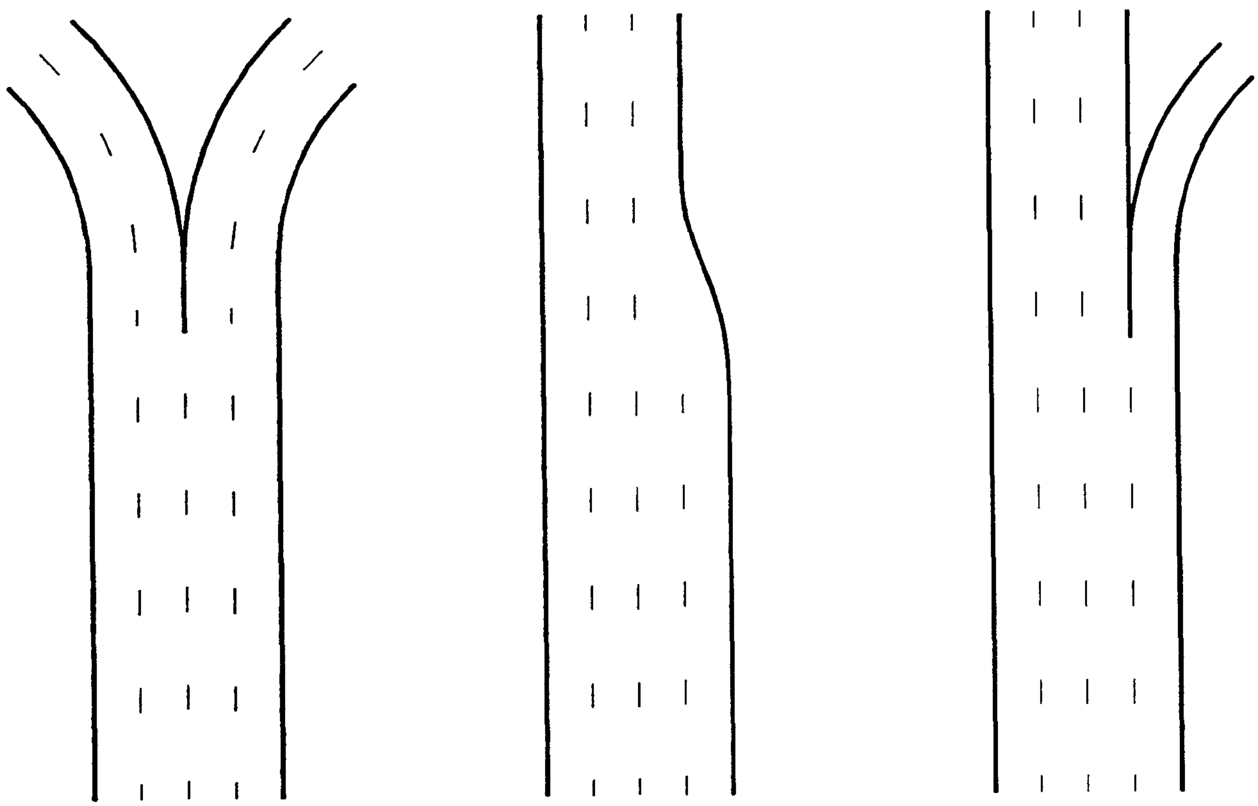
Lane drop markings also cause a "shift" in motorist lane change locations in advance of lane drops. The data from one site revealed that drivers are exiting the lane further upstream of the lane drop in the after period than they were in the before period. Similar analysis at the other before-and-after study site did not produce the same results. The data showed that a shift was not occurring *within* the study segment. Other evidence, such as the statistically significant reduction in number of lane changes, indicates that a shift may be occurring just upstream of the study segment. An entrance ramp is located upstream of the study segment and the large reduction in lane changes within the segment could be a reflection of vehicles that enter the freeway on the entrance ramp and, after seeing the lane drop markings, move through the exit lane to a through lane prior to entering the study segment.

Surveys were used to obtain motorists' interpretation of sign and pavement marking alternatives. An auto show survey which used graphics of different lane drop treatments indicates high level of understanding of exit only signs. Only the sign for the two-lane exit with an option lane and an exit only lane shows correct comprehension percentages below 80 percent. Regardless of the presence or absence of other visual clues (signs, approaching exit, etc.), the wide solid line and the double white line were almost always interpreted by participants as indicating the same needed driver action. Also, both of these pavement striping alternatives always had the highest percentage of correct responses. Motorists prefer the use of diagrammatic signs as the first of several signs indicating an approaching lane drop and the use of the conventional black on yellow panel (rather than the diagrammatic sign) close to the exit lane drop. The second survey of driver instructors indicates that students have a good comprehension of exit lane drop signs and markings.

CHAPTER 1

INTRODUCTION

Freeway traffic demand changes often, especially when traffic crosses another major freeway, or enters or exits an urban area. As traffic demand decreases, the need for existing lanes may decrease as well. Consequently, one or more lanes may be eliminated from the roadway in an effort to make the highway function more efficiently. This phenomenon is known as a lane drop. There are three basic types of lane drops: lane splits, lane terminations, and exit lane drops (see Figure 1). A lane split refers to the division of a multilane highway into two separate roadways so that the level of service provided to either roadway is approximately equal. A lane termination denotes the ending of a lane, usually by tapering it into the adjoining lane. The exit lane drop refers to the departure of one or more lanes from the through lanes on the freeway in the form of an exit. The exit lane drop is the focus of this project.



(a) Split Lane (b) Lane Termination (c) Exit Lane Drop

Figure 1. Basic Types of Lane Drops.

Several variations of exit lane drops exists. A drop can occur either on the right side of the freeway or on the left, and may involve multiple lanes rather than a single lane. Another variation involves having traffic on one lane of a multiple lane exit being able to continue on the freeway. This variation is called a two-lane exit with an option lane and an exit only lane. A lane that is added to the freeway at an entrance ramp and is then dropped at the next exit ramp is known as an auxiliary lane. An auxiliary lane is commonly less than 0.5 miles (0.8 km).

Exit lane drops can cause driver confusion when the driver does not expect the lane to exit; rather, the driver expects the lane to continue with the freeway main lanes. Without proper notification of the impending exit, drivers can find themselves performing erratic maneuvers in order to prevent exiting at undesirable locations. In order for a motorist to successfully travel through an exit lane drop area, knowledge of the existence of the lane drop and the location of the lane drop in sufficient time to perform the desired maneuver is needed. Exit-only signs and pavement markings are two treatments used to communicate an exit lane drop to the motorist. The National and Texas Manuals on Uniform Traffic Control Devices (MUTCD and TxMUTCD) contain information on the treatments available to guide and warn motorists of upcoming lane drops[1,2].

Exit-only signs are a required condition in the MUTCD, while pavement markings are an optional treatment. Sign treatments include diagrammatic signs, modified diagrammatic signs, black on yellow EXIT ONLY panels on conventional guide signs, and other signs. Pavement markings, which are generally known as lane drop markings, consist of larger width lane striping that begins approximately 0.5 miles (0.8 km) in advance of the theoretical gore point, and a solid white channelizing line 8-inches wide (203 mm) extending approximately 300 ft (91 m) upstream from the theoretical gore point. The larger lane striping is 8-inches wide by 3-ft long (203 mm wide by 0.9 m long) white stripes separated by 12-ft (3.7 m) gaps.

RESEARCH SCOPE AND OBJECTIVES

This project determines how motorists interpret or respond to various sign and pavement marking alternatives they may or may not have experienced before. An initial objective was to identify the techniques currently used in Texas to communicate lane drops to motorists. Motorist interpretation of signs and markings were obtained through surveys, while field observations were used to measure motorist responses to pavement markings. Specific objectives by study type include the following:

Survey

- Determine driver interpretation and comprehension of *existing* pavement markings and signs currently used at exit lane drops.
- Determine driver interpretation of *alternative* pavement markings that could be used at exit lane drops.

- Determine driver *preferences* of pavement markings and signs to be used at exit lane drops.

Field Observations

- Determine driver behavior at exit lane drops.
- Determine if driver behavior changes when lane drop markings are installed.
- Determine if pavement markings are an effective treatment at exit lane drops.

ORGANIZATION OF REPORT

The research findings are presented in eight chapters. A brief summary of the material in each chapter follows:

Chapter 1: **"Introduction"** contains a brief introduction into lane drops and the treatments used at exit lane drops. It also presents the research scope and objectives, and an overview of the contents of the report.

Chapter 2: **"Literature Review"** presents information from several research projects and from The National and Texas Manuals on Uniform Traffic Control Devices.

Chapter 3: **"Surveys"** discusses the two surveys conducted for this project -- the auto show survey and the driver instructor survey.

Chapter 4: **"Overview of Field Studies"** presents general information on the field studies. It reviews the site selection process, the methods used to collect, reduce, and analyze data, and the installation of the lane drop markings.

Chapter 5: **"Site Selection"** provides detailed information on how the seven sites were selected. It also includes figures showing the plan view and types of signs present at each site.

Chapter 6: **"Specific Site Information"** discusses each site in detail. It presents a description of the site, the data collection, data reduction, and marking installation information specific to the site, and a discussion on the findings and observations on the site's lane change and erratic maneuver data.

Chapter 7: **"Comparisons Between Sites"** discusses the variation in lane change and erratic maneuver behaviors between different groups of sites. It also presents the findings from the before-and-after studies.

Chapter 8: **"Summary"** presents a summary of the study results.

Chapter 9: **"Conclusions and Recommendations"** provides the conclusions from the project and recommendations for future research.

The **"References"** section lists the material referenced in the report.

The **"Appendix"** provides the following plots for each site: zones, lane changes per hour by zone; exit to through lane, lane changes per hour by zone; through to exit lane, lane changes per hour by zone; lane change difference per hour by zone; erratic maneuvers per hour by zone; lane change frequency by hour; and lane change rate by hour.

CHAPTER 2

LITERATURE REVIEW

Exit lane drops have been examined in several research projects. Some of the findings from the projects have influenced the sign and marking treatments included in the current editions of the MUTCD and the TxMUTCD. The treatments included in these reference manuals have also been influenced by the state's experiences. Following is a summary of the relevant material included in the current edition of the TxMUTCD and the MUTCD, and a brief discussion of how the material evolved into its current form. Discussions on previous research into exit lane drop issues are also provided.

EXIT LANE DROP PROCEDURES IN THE MUTCDs

Current Material on Signs

Currently, several methods are used to communicate an exit lane drop to the motorist. Sign treatments include diagrammatic signs, modified diagrammatic signs, black on yellow EXIT ONLY panels on conventional signs, and other signs. The TxMUTCD states that the EXIT ONLY yellow sign panel shall be used for all interchange lane drops where the through route is carried on the mainline. The EXIT ONLY panel should be used on advance guide signs for right-hand exits as shown in Figure 2. 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 3, or the left exit panel can be used as shown in Figure 4. Additional information is provided in the TxMUTCD regarding the required use of the EXIT ONLY panel for specific cases, and the use of the panel with or without a white up or down arrow.

While the national MUTCD provides illustrations and information about communicating an exit lane drop for a one-lane exit ramp to the motorist, information is lacking on communicating an exit lane drop for a two-lane exit ramp. The TxMUTCD provides guidance on the signing for two-lane exit only conditions, and the two-lane exit with an option lane and an exit only condition, as shown in Figures 5 and 6, respectively. While some guidance on pavement markings can be discerned from Figures 5 and 6, specific markings for two-lane exit ramps are not included in the "Markings" section of the TxMUTCD.

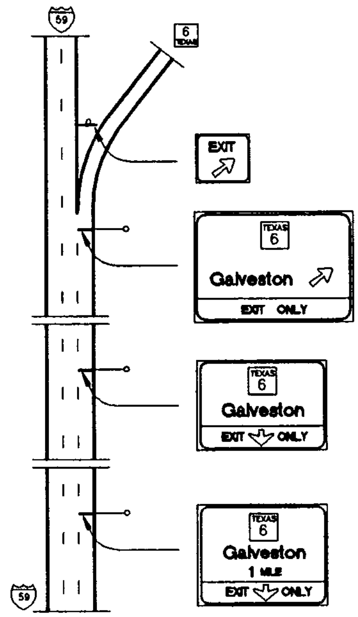


Figure 2. Exit Lane Drop on Right (Right Hand Interchange Lane Drop).[1]

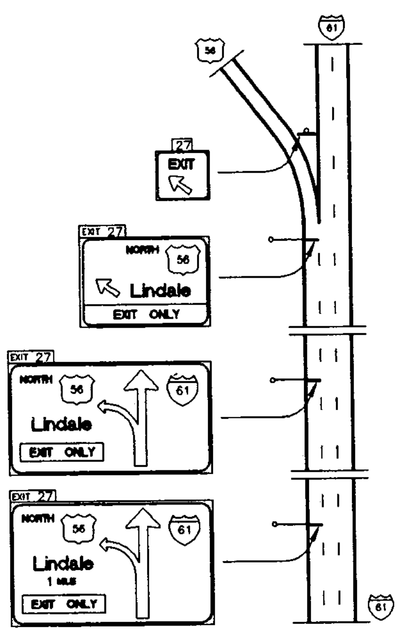


Figure 3. Exit Lane Drop on Left with Diagrammatic (Left Hand Interchange Lane Drop).[1]

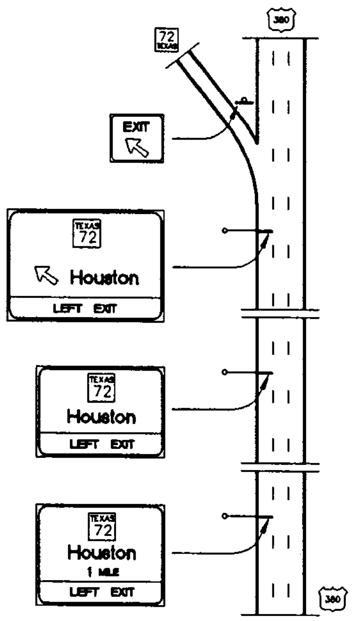


Figure 4. Left Exit Condition.[1]

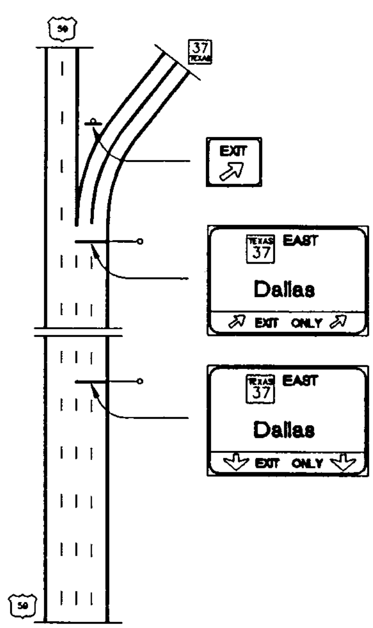


Figure 5. Two-Lane, Lane Drop Exit Condition.[1]

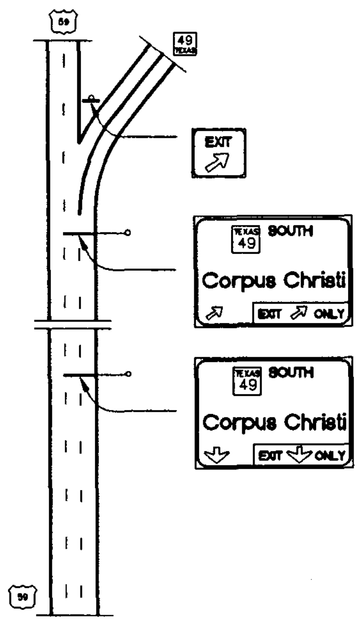


Figure 6. Two-Lane Exit with an Option Lane and an Exit Only Lane Condition.[1]

EXIT ONLY Panel Inclusion in the MUTCD

The current national MUTCD (1988 Edition) requires the use of the EXIT ONLY panel(s) at all interchange lane drops at which the through route is carried on the freeway mainline. However, the EXIT ONLY panel has not always been required for use at interchange lane drops. As recently as the 1961 Edition of the national MUTCD[3], no requirements, and in fact, no mention, of the EXIT ONLY panel were given. The next edition of the national MUTCD (1971)[4] did present some information regarding the panels in the section entitled "Miscellaneous Guide Signs". The 1971 national MUTCD states:

> A special sign reading EXIT ONLY is of value in advising drivers of an imminent lane drop situation. The sign shall have a yellow background with black legend, and may be used on the lower edge or lowest line of overhead gore, exit direction, or advance guide signs on roadways approaching an interchange where there is a reduction in the number of available lanes for through traffic.

In this singular mention of the EXIT ONLY panels, their use is only suggested, not required.

A study conducted in 1976 by Lunenfeld and Alexander[5] recommended that changes be made to the national MUTCD so that the EXIT ONLY panel would be required for use in certain lane drop situations. Beginning with the 1978 Edition of the national MUTCD[6], the

EXIT ONLY panel became a requirement at all interchange lane drops. In fact, the 1978 and 1988 editions do not differ regarding the use of the panel.

Current Material on Markings

Pavement markings for exit lane drops in the MUTCD include alternative gore area treatments and larger lane striping. The markings, shown in Figure 7 (reproduced from Figure 3-11A in the TxMUTCD), consist of 8-inch (203 mm) wide by 3-ft (0.9 m) long white stripes separated by 12-ft (3.6 m) gaps beginning approximately 1/2 mile (0.8 km) in advance of the theoretical gore point. An 8-inch (203 mm) wide solid white channelizing line extends approximately 300 ft (91.5 m) upstream from the theoretical gore point[2]. This special marking pattern is used to distinguish the lane drop situation from a normal exiting ramp or an auxiliary lane.

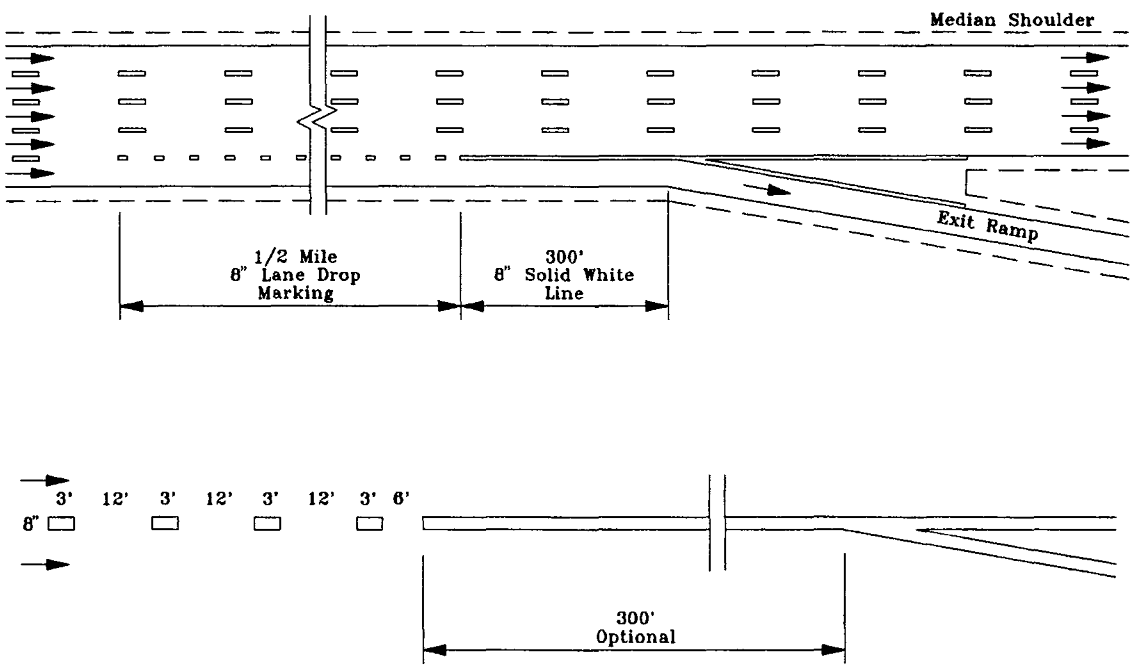


Figure 7. Lane Drop Markings at Exit Ramps.[1]

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

Special Pavement Marking at Exit Lane Drops Inclusion in the MUTCD

Between 1970 and 1972, California conducted operational reviews of its metropolitan freeways, and, as a result, identified the need for a special treatment at exit lane drops. The reviews revealed that with the use of standard lane lines at exit lane drops, many motorists would either exit involuntarily, or make a last minute lane change to avoid the exit. A statewide delineation committee made several trial installations of a proposed stripe at exit lane drops similar to those shown in Figure 7. Reflective pavement markers, and supplemental warning and guide signs were used in conjunction with these pavement markings. In 1975, the special exit lane drop striping and signing was approved by the California Traffic Control Devices Committee and included in its Traffic Manual[7].

In 1978 the Office of Traffic Engineering in the Department of Transportation in California wrote a letter to the National Advisory Committee at the Federal Highway Administration recommending the special pavement markings for inclusion in the national MUTCD[7]. The markings were adopted and included in the 1988 edition of the national MUTCD for optional use at exit lane drops.

PREVIOUS RESEARCH ON EXIT ONLY SIGNS

General Comments on Signs

The sign is a frequently used traffic control device for communicating lane drops to motorists. Consequently, many more research efforts have focused on communicating lane drop information via signing than any other form of traffic control. Brackett et al.[8], in 1991, assessed the effectiveness of the operational information currently being supplied to highway users in larger urban areas of Texas. The study concluded that improved lane assignment information and forewarning of impending geometric modifications is necessary. Adequate time is sometimes not given to the motorist to make an appropriate decision.

Wording of a sign can be very important. Oftentimes, the interpretation one driver makes of a sign is completely different from another motorist's interpretation. MacDonald and Hoffmann[9], in 1979, investigated the use of positive versus negative messages on signs. A positive sign would state, perhaps, *straight ahead only*; whereas, a negative sign would state, in the same case, *no right turn*. They found no difference between positive and negative signs with respect to the accuracy with which they were retained in short-term memory. However, negative symbolic signs were found to perform worse in terms of driver response time and error rate.

In 1987, Shapiro and associates[10] conducted a study identifying the national MUTCD standards that lacked research support or were in conflict with research findings. Four major categories within the national MUTCD were cited by Shapiro and associates as deficient in research backing. Signs, pavement markings, signals, and construction and maintenance signs were identified. Although the explanations given by Shapiro and associates did not specifically find signing treatments or pavement markings at lane drops to be deficient, serious concerns about the driving public's understanding of lane markings were expressed. In addition, the symbol versus word messages on signs seemed to lack research backing. The research conducted by Shapiro and associates critiqued the 1978 edition of the national MUTCD. Soon after the publication of their research, the national MUTCD 1988 edition was published, and whether or not their concerns were addressed is unknown.

In a socio-related experiment conducted by Laux and Mayer[11] in 1991, the possibility of sex and/or age differences in the ability to understand roadway signs, and whether these differences are associated with age related changes in sensory and cognitive functioning, was investigated. Based on participant identification of 35 road signs, it was discovered that the youngest participants performed the best, with scores of 90 percent or better. Scores declined rapidly as age increased, largely due to the fact that female scores declined steadily with each decade, while male scores did not. In addition, those that scored poorly on the road sign comprehension test were significantly correlated with those that did poorly on the tests of visual and cognitive functioning.

Exit Only Signs

Black on Yellow

The black on yellow EXIT ONLY panel (see example in Figure 2) is used at interchange lane drops where the through traffic continues on the freeway mainline. A study by Lunenfeld and Alexander[5] (1976) directed towards individuals unfamiliar with a particular area, evaluated the EXIT ONLY panel and other variations. The analysis was based on expectancy violations with limited experimental data. The study recommended the use of the EXIT ONLY panel when route continuity is maintained or, in conjunction with diagrammatic signs, at exits. In addition, conventional signing was recommended for certain splits without an optional lane. When route discontinuity occurs, the panel was not recommended for use.

Roberts and Klipple[12] (1976) conducted an exit lane drop signing experiment comparing four different exit panels with messages and one panel without a message but with directional arrows. Twenty subjects viewed eight slides depicting a three-lane interstate highway with different exit sign messages. Immediately after each slide presentation, the subject selected from a slide one to five geometric considerations expected at the exit based on the location and message content of the sign shown in the previous slide. Configuration responses and relative certainty responses were given verbally. Response time was also recorded. The experiment supported the conclusion that the MUST EXIT and EXIT ONLY panel messages were most helpful in correctly influencing driver expectations, and that the difference between these signs is so small that either one is recommended for use; however, only one should be used in the interest of improving the accuracy of driver expectations.

Diagrammatic Signs

A diagrammatic sign, as stated in the national MUTCD, is a guide sign that shows a graphic view of the exit arrangement with respect to the main highway (see Figure 3 for an example). Several studies have investigated the use of diagrammatic signs versus conventional signs, especially at lane drops.

A study by Roberts[13], in 1971, investigated the effectiveness of diagrammatic signs at one location in New Jersey, and evaluated the use of these signs by conducting a before-and-after study. Roberts used the occurrences of erratic maneuvers (stopping, crossing lane lines, or backing) in a 200-ft (61 m) zone ending at the gore to evaluate traffic characteristics before and after the installation of the signs. Roberts found that there were significantly fewer erratic maneuvers after the diagrammatic signs were installed. However after six months, Roberts found that there was a significant increase in the number of erratic maneuvers when no signing changes were made at the same site. The increase was attributed to the fact that the two data sets were collected in unlike seasons.

Roberts and Klipple,[18] in 1976, investigated the effect of current signing and variations of current signing on driver expectancy violations. The researchers asked 20 subjects to anticipate geometric configurations based on a series of 8 slides depicting different exit sign messages. The study concluded that diagrammatic signs, with or without words, influenced driver expectancy favorably. In another 1976 study, Lunenfeld and Alexander[5], investigated the use of diagrammatic signs at lane drops with different geometric characteristics, and recommended that diagrammatic signs be used at exits with route discontinuities.

Studies that investigated diagrammatic signs, while not specifically examining the lane drop scenario, can still provide insight into their use at freeway lane drops. A 1961 study[14] investigated the interpretability of diagrammatic signs, whether sign preferences existed, and whether these sign preferences are similar to typical diagrammatic signs found in Europe. In addition, the study incorporated sign preferences into the design of diagrammatic signs and tested the interpretability of these "altered" signs. The study concluded that pictorial signs were the most easily interpreted, and signs that are altered to meet preferential needs increase interpretability. MacDonald and Hoffmann[9] (1979) found that diagrammatic signs better communicate information to the driver in terms of initial perception time than do verbal signs. However, there is little to no difference in the accuracy with which drivers retain the information contained on diagrammatic or verbal signs in short term memory.

PREVIOUS RESEARCH ON PAVEMENT MARKINGS

Pavement markings can effectively communicate to the driver a change in geometric conditions. Signs act as a periodic reminder of changing conditions, but pavement markings act as a constant reminder to the driver where the vehicle should be, as well as what maneuvers the driver is permitted to perform. Therefore, when a new pavement marking appears, or the previous markings change, the driver is informed of an impending (or recent) change in conditions. Although pavement markings could be a candidate for communicating lane drops to motorists, very few studies regarding pavement markings at lane drops have been conducted.

The earliest identified study dealing with pavement markings at exit and entrance ramps was conducted in 1966 by Roth and DeRose[15]. They investigated the effectiveness of a color coded system consisting of edgemarking, delineation, and signing. Pavement markings consisted of white lines for through traffic, blue for exit ramps, and yellow for entrance ramps. The study evaluated the effectiveness of the striping by observing vehicle movements before and after the installation of the new markings. Interviews were also conducted to determine the public's reaction to the new system. The study reported a significant reduction in erratic maneuvers around two exit and two entrance ramps as a result of the new pavement markings. The reduced erratic maneuvers included two-lane lane changes within the approximate 2000-ft (610 m) study sections, and stopping, backing, and radical movements across the gore. In addition, the driver interviews revealed that 85 to 90 percent of the drivers believed the system was beneficial.

Another study related to color coding pavement markings was conducted by Cornette[16]. Cornette specifically tested a 5-inch (127 mm) wide yellow edgeline and 2-ft (0.6 m) wide yellow gore striping at various lane drop situations, including exit lane drops. In addition, Cornette tested the effectiveness of double amber reflectors on both sides of the roadway with decreased spacing approaching the gore area. Seven lane drop sites were chosen, including two single-lane *exit* lane drops. At both these sites, the combination of amber delineators and yellow striping were most effective in reducing erratic movements and brakelight applications, although this combination was not necessarily found effective at other lane drop situations.

In 1975, Pigman and Agent[17] investigated the effectiveness of raised pavement markers at lane drops. The study collected before-and-after data at five lane drop sites, including two exit lane drops, in which several different types of raised pavement markers were installed. Statistical analysis of the conflict surveys, consisting of erratic maneuver and brakelight application counts, revealed that raised pavement markers are an effective means of reducing erratic movements; however, brakelight rates at lane drops remained unchanged. The raised pavement markers, while effective during both day and nighttime conditions, were found to be much more effective in reducing erratic maneuvers during nighttime conditions.

In the late 1980s, Texas sponsored a study that investigated signing and/or pavement markings that could provide additional information to motorists at an exit lane drop[18]. A series of short white dashes followed by a double white stripe prior to the gore area and a sign stating DO NOT CROSS DOUBLE WHITE LINES were selected for investigation. The pavement markings were installed at three sites in the Houston area recommended by the Texas State Department of Highways and Public Transportation (SDHPT). All erratic maneuvers between the mandatory exit lane and the adjacent through lane from the gore to a point between 500-700 ft (152-213 m) prior to the gore were recorded before and after the markings were installed. Comparisons were made on a matched 15-minute interval basis. Due to geometric configurations at the sites, one location received both the pavement markings and the signs treatment, while the remaining sites received variations on the pavement markings only. One location showed improvement in operations during all peak periods; another location (Braeswood Exit) showed improvement in operations for all peak periods, except the p.m. period; and the last site had mixed results, with some improvements in lane changes and some increases in lane changes. In the case of the last site, most of the deteriorating operations were attributed to the difficult geometrics of the site.

Approximately one year after the special markings were installed at the Braeswood Exit, additional lane change data were collected[19]. The data from this effort were compared to the data in the preceding effort. The results are listed in Tables 1 and 2. In addition, both efforts gathered total and peak hour volumes. The volumes showed a continual growth over time (see Table 3), demonstrating that even with increased volumes, the erratic lane changes decreased as a result of the pavement striping.

Table 1. Percent of 15-Minute Intervals with a Change in Lane Movements at the Braeswood Exit in Houston[21].

	Percentage of 15-Minute Intervals	
Percentage of:	SM1*	SM2**
15-Minute Intervals with a Decrease in Lane Changes	62%	68%
15-Minute Intervals with an Increase in Lane Changes	34%	25%
15-Minute Intervals with No Change in Lane Changes	4%	7%

* A few months after special markings were installed. 530, 15-minute intervals were analyzed.
** One year after special markings were installed. 456, 15-minute intervals were analyzed.

Table 2. Percent Change in Lane Movements at the Braeswood Exit in Houston[19].

	Percentage of Lane Changes	
Change in Number of:	SM1*	SM2**
A.M. Peak Lane Changes	35% Decrease	71% Decrease
Off Peak Lane Changes	11% Decrease	70% Decrease
P.M. Peak Lane Changes	26% Increase	56% Decrease
Total Daily Lane Changes	12% Decrease	67% Decrease

* A few months after special markings were installed.
** One year after special markings were installed.

Table 3. Comparison of Average Volumes at the Braeswood Exit in Houston[19].

	Volumes		
	SM0*	SM1**	SM2***
Weekday			
Daily	56,300	62,700	64,800
A.M. Peak Exit	1000	820	810
P.M. Peak Exit	2280	2490	2560
Weekend			
Daily	55,700	58,700	59,300
A.M. Peak Exit	240	160	230
P.M. Peak Exit	960	840	1050

* Before special markings were installed.
** A few months after special markings were installed.
*** One year after special markings were installed.

OTHER RELATED STUDIES

Goodwin[20] in 1976 recommended several design principles at lane drops. One design principle was that a driver should be notified that a lane is not continuous by using contrasting pavements or special purpose lane delineations to emphasize the lane's dissimilarity. Goodwin recommended that normal lane lines should not be used to delineate two adjacent lanes (one of them being an exit lane) because they would reinforce the concept that a through lane has been permanently added (e.g. at an upstream entrance ramp).

An Institute of Transportation Engineers (ITE) technical committee[21] in 1976 reported on a survey of highway agency practices for the installation of traffic control devices at freeway lane drops. Of the 45 states responding, less than one third used specialized pavement markings to communicate lane drops on freeways to motorists. Some of the state agencies made recommendations for certain pavement markings at lane drops, including rumble strips, contrasting color and/or texture, and diagonal arrows. The number of states in 1976 using special markings follows:

- 3 states used pavement arrows 200 to 1000 ft (61-305 m) in advance of the theoretical gore.

- 5 states used a solid white line up to 1000 ft (305 m) in advance of the theoretical gore.
- 2 states used a dotted line for 1000 ft (305 m) or more in advance of the theoretical gore.
- 1 state terminated lane lines and used no marking for 1000 ft (305 m) in advance of the gore.
- 2 states used "V" or "zebra" markings within the gore area.

Dotted extended lines (2 ft (0.6 m) long, 27 ft (8.2 m) on center), while not required for use at exit lane drops, could be used near an exit lane drop. The motivation for their use is similar to the reasons for using specialized markings at exit lane drops. In a 1978 study by Keck and Roberts,[22] the uses of dotted extended lines after the solid white line at right hand freeway exits and parallel single deceleration lanes were investigated. Twelve sites in New Jersey were selected to conduct before-and-after studies in which the dotted extended lines were installed. Statistical tests of significance were conducted on exiting maneuver counts at all sites before and after the dashed lines were installed. Although the study did not involve exit lane drops, it is important to note that the tests revealed that a dotted extension of a right edge line was more effective than no dotted line for orienting exiting traffic into the deceleration lanes sooner.

OTHER STUDIES ON LANE DROPS

Other aspects of lane drops studied include geometric considerations, operational effects, and safety. The following is a summary of the studies relating to these aspects of exit lane drops.

Geometric Considerations

Cornette[16] conducted a study in 1972 comparing the operational characteristics of four different types of lane drops (single lane exit with a refuge area after the drop, single lane exit without a refuge area, a lane termination, and a single-lane split). Conflict surveys (erratic movements and brake light applications), spot speed measurements, and lane volume counts were collected at the four sites before and after various traffic control devices were implemented at the sites. The devices used in this study consisted of: a) 5-inch (127 mm) wide, yellow edge line and 2-ft (0.6 m) wide yellow gore striping; b) double amber reflectors on both sides of the roadway with decreased spacing approaching the gore area; and c) black on yellow EXIT ONLY panels. Of the four lane drop types, Cornette found that the single lane exit without a refuge area had the lowest conflict rates. In addition, the study concluded that lane drops associated with poor geometrics, i.e. high rates of curvature, and sight distance restrictions, had higher conflict rates than those with more optimal geometric features. As a result, he concluded that traffic control devices are not as effective in reducing conflicts as are proper site geometrics.

Goodwin and Goodwin[23], in 1972, and Goodwin[20] in 1976, developed a set of principles on which lane drops should be designed, most of which are also applicable to *exit* lane drops. Their research approach consisted of a telephone interview of traffic engineers to determine the number of lane drops and associated problems of lane drops in many areas of the country, and a collection of information concerning lane drops by interviewing traffic engineers and observing lane drop sites. The information collected included data on the geometrics, accident experience, and operational characteristics of selected sites, lane drop problems, and solutions and design standards currently in use. Over twenty different metropolitan areas were surveyed and several hundred lane drop sites were observed from which 65 were selected for more detailed information. The survey findings were analyzed to determine whether patterns exist in lane drop design. The following is the set of principles developed as a result of this research:

- The lane drop should be placed where the surface of the roadway remains continuously visible for a significant amount of time.
- The lane drop should be placed away from attention-dividing conditions, such as ramps or complicated directional signing.
- The lane drop taper should provide adequate visual cues that inform the driver that the lane is ending and should allow a smooth lane change transition in the taper area.
- The lane drop should be placed on the side of the freeway that is better with respect to given traffic and geometric conditions.
- When a lane is added at an on-ramp and dropped at a nearby off-ramp, the entering drivers should be notified that the lane in which they are traveling is not a continuous lane for through travel.
- Consistent and appropriate traffic control devices should be used in advance of a lane drop.
- An "escape" lane should be provided if a lane is trapped onto an off-ramp; the escape lane should appear to be just that, and not an optional lane for through drivers.

Operational Effects

In 1971, Goodwin and Lawrence[24] conducted a study in which they determined from field data the effectiveness of existing freeway mainline lane drops with regard to traffic operations. Information concerning the locations, configurations, traffic conditions, and accident experience at all lane-drop sites on the California freeway system was obtained from the California Division of Highways. Three sites were chosen for intensive study, of which two were lane terminations and one was an exit lane drop. At these sites, aerial data was collected to produce trajectories of the distance, lane position, and velocity of all vehicles traveling through the freeway segment containing the lane drop. Data were collected for periods up to 15 minutes.

For the exit lane drop, the results of data analysis showed that only 10 percent of the vehicles on the freeway were traveling in the exit only lane at the beginning of the test section (approximately 1000 ft (305 m) before the gore). Most of these vehicles not wishing to exit performed the lane change well before the end of the lane. However, a small proportion of vehicles did make their maneuver in the last 50 ft (15 m) before the gore. The speed of the vehicles at the exit lane drop were also investigated. Analysis revealed a gradual decrease in speeds as flow increases. At moderate flow levels, speeds in the two adjacent lanes to the exit lane drop lane decreased slightly, but recovered downstream of the exit. The median lane experienced no speed fluctuations. As flow increased, however, speed decreased in the lane adjacent to the exit lane drop, and the recovery of speeds in the two adjacent lanes was delayed. Again, no decrease in speeds was observed in the median lane until the highest flow level was analyzed, and then only a slight decrease in speeds was observed. At this flow level, no recovery was witnessed in the lanes adjacent to the lane drop within the area studied[24].

Safety

Few studies have dealt with the issue of safety at lane drops. Cornette[16] in 1972 investigated conflicts at four lane drop sites -- one lane termination, one lane split, and two exit lane drops. By investigating brakelight counts and erratic movements (conflicts), Cornette concluded that there was no distinct relationship between the traffic volumes and conflict rates, nor conflict and accident rates at the lane drop sites investigated. Goodwin and Lawrence[24] calculated hazard and severity ratios of car-following pairs using aerial photography. The ratios were calculated as a function of vehicle speeds and distance between the two vehicles. One of the hazard ratios calculated was expected to take into account the possibility of a vehicle merging ahead too close to a following vehicle, a maneuver highly expected at exit lane drops. The analysis concluded that there was no indication of significant differences in the safety effectiveness of the three different configurations studied. An analysis of California accident data for the three sites supported these findings.

A study conducted in 1968 by Tye[25] analyzed the accident records of 1965 and 1966 for 167 different lane drop sites in California. Eight lane drop categories were created, two of which were exit lane drops with one providing an escape lane. An escape lane is a lane provided after the gore for last minute lane changes. The lane is not striped for use by other vehicles. Accident rates were calculated from accident reports and compared with related situations. The comparisons were examined for statistical significance. The exit lane drop with the escape lane, although having slightly lower accident rates, was not significantly different from the exit lane drop without an escape lane. The accident rate for either of these situations was found to be at least twice as great as that where the lane was dropped in the form of a lane termination away from the influence of the interchange ramp. Based on this analysis, Tye recommended locating capacity dictated lane drops for multilane facilities on tangents away from ramp transitions. Although not specifically tested, Tye states that, "generally speaking, lane drop situations present more of a hazard to the motorist than do highways of constant cross-section."

CHAPTER 3

SURVEYS

The traffic engineer can communicate to motorists an approaching exit lane drop in many ways. Some of the options, such as the yellow panel on the green guide sign, have been used for several years. Other options, such as pavement markings, are reasonable; however, they have not been used on a consistent basis. To test the effectiveness of several different types of pavement markings in the field would require a significant outlay of personnel efforts and funds. Using a survey technique can obtain drivers' reactions to different types of pavement markings without the sizable monetary commitment.

This project used a survey during an auto show to identify drivers' responses to different types of signs and pavement markings. A mailout survey gathered driver instructors' views on their students' comprehension of exit lane drops.

DRIVER SURVEY -- AUTO SHOW

Development of Survey

Initial efforts to develop the auto show survey included several meetings of the research team to determine the survey's goals and to develop appropriate questions. Two goals were selected for the survey:

- Determine driver interpretation of alternative marking and sign techniques.
- Determine driver preference of exit-only signs.

Because one of the emphases of the survey was on drivers' reactions to new markings, the initial questions were posed in this way, "If you saw this sign (or marking) what would you do?" To satisfy the second goal, questions concerning the participants' sign preference were developed. The survey concluded with standard demographic-type questions.

The type of participant was also considered during the survey preparation efforts. Because these participants were attending a recreational event and were unpaid volunteers, simplicity and shortness were important qualities for questions. A survey length of ten to twelve minutes was estimated as the maximum time that a participant would be willing to contribute. When developing the survey, trade-offs between using photographs of existing conditions and using computer generated art work were evaluated. Because this survey was testing alternative markings that may (or may not) be in current use, computer generated art work was used. Color graphics were produced for use in the survey because of the need to show *yellow* EXIT ONLY panels on *green* guide signs and different styles of *white* lane lines between lanes.

Once the questions were selected and the research team was satisfied with the contents, the questionnaire was pre-tested. Pre-testing a survey identifies situations where the answer may be obvious to those who developed the questionnaire, but is confusing to those not familiar with the material. Over 30 respondents representing different sex/age groups were used to evaluate the understandability of the questions. The pre-test effort resulted in only minor changes.

A laptop computer system stored the results from the survey into a data base. The participants vocalized their answers (typically multi-choice answers of A, B, C, or D), and the individual conducting the survey typed the answers into the data base. If the laptop computer was unavailable or malfunctioning, answer sheets were used to record the participants' responses. Additional comments were also recorded for later reference.

Experimental Plan

If the survey presented all the different pavement markings to each participant, the answer to questions on markings shown in the latter portion of the survey may be answered differently because of knowledge gained from the initial questions. To overcome this "learning curve," the research team asked participants questions on only one type of marking. Four versions (or alternatives) of the questionnaire were used, with each alternative containing the same questions but with different pavement markings.

The four pavement marking alternatives selected for testing were:

- I -- typical white lane lines (10-ft long, 4-inch wide stripe with 30-ft gaps) (3.1 m long, 101.6 mm wide stripe with 9.2 m gaps).
- II -- double white lines (each 4 inches wide, set 4 inches apart) (101.6 mm wide, set 101.6 mm apart).
- III -- lane drop markings (3-ft long, 8-inch wide stripe with 12-ft gaps) (0.92 m long, 203.2 mm wide stripe with 3.66 m gaps).
- IV -- wide solid white line (8 to 12 inches wide) (203.2 to 304.8 mm wide).

The typical white lane lines (Alternative I) were tested as a "base-line" for comparison. The questions for each of the four alternatives were assembled into a separate 3-ring binder for use during the auto show. A participant would be asked questions from only one of the four 3-ring binders. The use of each 3-ring binder would be rotated so that a similar number of participants would answer the questions for each alternative.

Several types of questions were asked within each alternative. For example, the initial questions dealt with driver actions when only the markings were visible, while later questions covered driver actions when both markings and signs with an EXIT ONLY panel were visible. The questions were grouped by the type of view presented to the participant. The questions did not change between alternatives, only the visual presented to the participant (i.e., the type of pavement markings) did. The following questions were asked within each alternative:

- Questions 1 to 3 dealt with *markings only* (see Figure 8 for an example).

- Questions 4 and 5 dealt with markings and the appropriate sign for a *one-lane, lane drop exit* (see Figure 2 for an example of the sign).

- Questions 6 and 7 dealt with markings and the appropriate sign for a *two-lane exit with an option lane and an exit only lane* (see Figure 6 for an example of the sign).

- Questions 8 to 10 dealt with markings and the appropriate sign for a *two-lane, lane drop exit* (see Figure 5 for an example of the sign) where the alternative markings were placed between *one set of lanes* (lanes 2 and 3).

- Questions 11 to 13 dealt with markings and the appropriate sign for a *two-lane, lane drop exit* (see Figure 5 for an example of the sign) where the alternative markings were placed between *two sets of lanes* (lanes 2 and 3 and lanes 3 and 4).

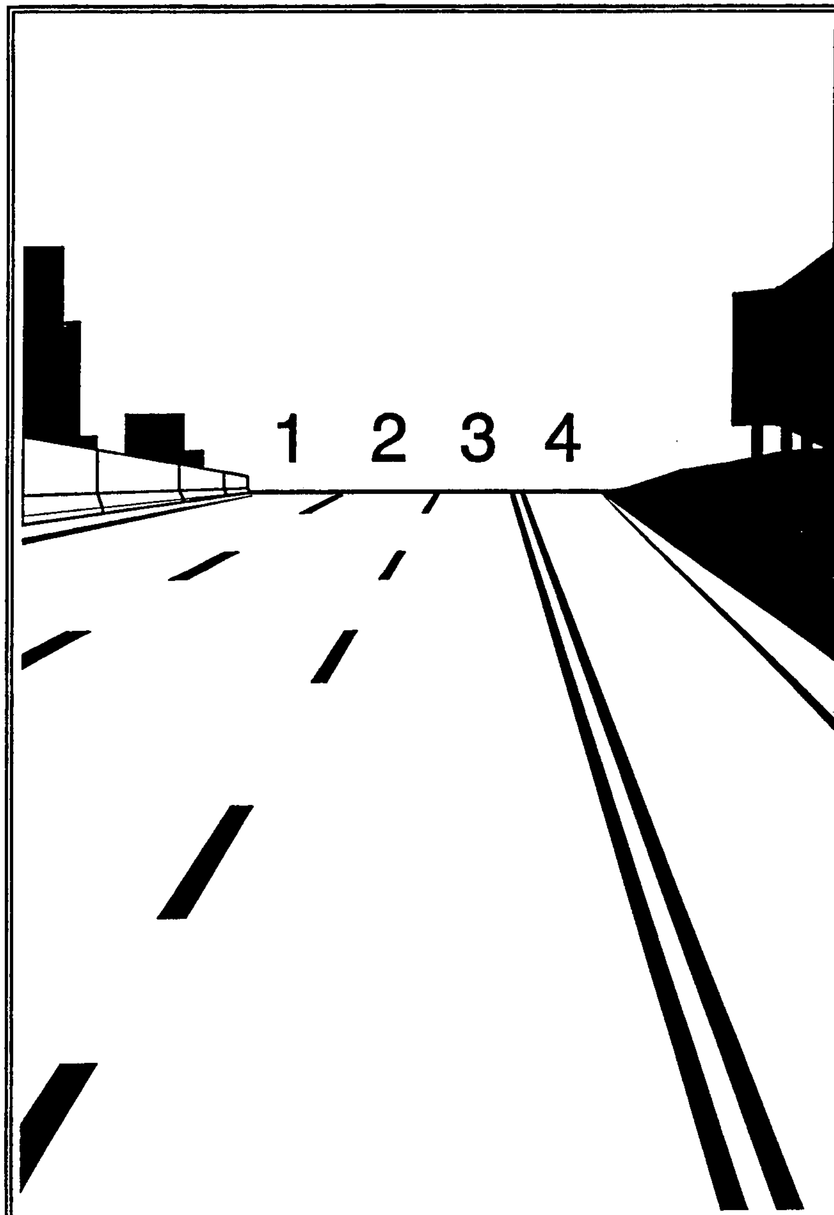
The initial set of questions (Questions 1 to 3) was critical, because it relayed the driver understanding of the pavement markings without any additional visual clue of the approaching mandatory exit (see Figure 8 for an example of these questions for Alternative II). The next set of questions (Questions 4 and 5) used the same markings and added a green guide sign with a yellow EXIT ONLY panel (see Figure 9 for an example). The difference between the first and second sets of questions should illustrate the better understanding of the exit lane drop situation when both the pavement markings and the yellow EXIT ONLY panel are present. The remaining questions dealt with the participants' understanding of other types of exit only situations.

In addition to investigating driver opinion on alternative pavement markings, the survey contained questions regarding driver preference concerning the different types and locations of exit only signs. The signs tested included:

- the conventional green guide sign with a yellow EXIT ONLY panel (with a black down arrow on the panel or a white arrow on the green guide sign).

- a diagrammatic sign.

- a green guide sign with a yellow EXIT ONLY panel and a black upward-sloping arrow.



You are looking at four lanes on a freeway and are approaching a right-hand exit.

1. **Traffic in Lane 4...**

   A. Must continue on the freeway
   B. Must exit
   C. May either exit or continue on the freeway
   D. Not sure

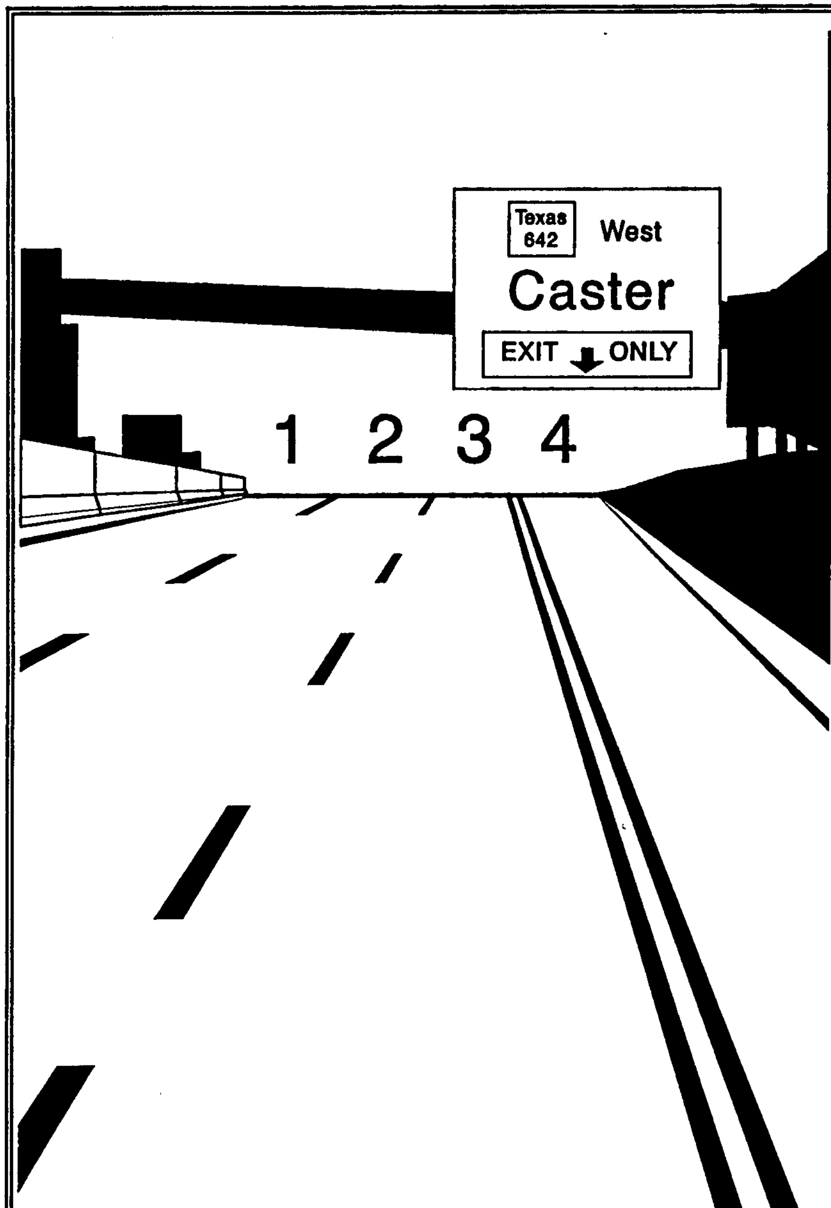
2. **Traffic in Lane 3...**

   A. Must continue on the freeway
   B. Must exit
   C. May either exit or continue on the freeway
   D. Not sure

3. **What do the pavement markings between Lanes 3 and 4 mean (you may choose more than one answer)?**

   A. Traffic in Lane 4 must exit from the freeway
   B. Traffic in Lane 3 may either exit or continue on the freeway
   C. You may not cross the pavement marking line in either direction
   D. Not sure

Figure 8. Example of Visual Aid Used During the Auto Show Survey (Questions 1 to 3, Alternative II).



You are approaching the exit to Caster (Texas 642 West).

4. Traffic in Lane 4...

A. Must continue on the freeway
B. Must exit to Caster (Texas 642 West)
C. May either exit or continue on the freeway
D. Not sure

5. Traffic in Lane 3...

A. Must continue on the freeway
B. Must exit to Caster (Texas 642 West)
C. May either exit or continue on the freeway
D. Not sure

Figure 9. Example of Visual Aid Used During the Auto Show Survey (Questions 4 to 5, Alternative II).

Conduct Survey

The survey was conducted during the 1992 Houston Auto Show within the Traffic Safety sections. A total of 528 individuals participated in the exit only survey, or an average of 130 per alternative. The participants of the survey were provided state and local maps as well as other literature from the Texas Department of Transportation in appreciation for participating in the survey. No unusual conditions occurred while administering the survey that would affect the survey results. Note that while the illustrations presented in this report were modified to black-and-white for reproduction purposes, the actual drawings viewed by the participants were in color.

Findings

Demographics

Table 4 compares the distribution of survey participants with the distribution of licensed drivers in the United States. The survey captured higher percentages of younger drivers than represented in national demographics. This indicates that the participants do not have as much driving experience as a representative group would have.

Table 5 lists the results from the demographic questions for each alternative. As experienced in past auto shows, most of the survey participants were white males. Over 80 percent of the respondents were under 40 years old with roughly half of these respondents being 25 and younger and the other half being 25 to 39 years old. The majority of the respondents had a high school degree, or its equivalent, and approximately one-third of the participants had a college degree. The majority of the participants drive less than 15,000 miles (24,150 km) per year.

Table 4. Survey and National Demographics.

Category	Survey (all alternatives)	Licensed Drivers in the United States[26]
Gender		
Male	67	52
Female	33	48
Age		
Under 25 yrs	40	17
25-39 yrs	41	36
40-54 yrs	17	22
55 or over	2	24

Table 5. Results from Demographics Questions.

	Percent of Respondents (%)			
	Alternative I	Alternative II	Alternative III	Alternative IV
Gender				
Male	66	63	64	75
Female	34	37	36	25
Age				
Under 25 yrs	39	44	38	36
25-39 yrs	42	35	45	43
40-54 yrs	16	18	16	19
55 or over	3	3	1	2
Education				
Less Than High School	10	11	9	6
High School or Equiv.	22	21	26	17
Some College	40	36	39	42
College Degree(s)	28	32	26	35
Family Background				
White	75	83	83	87
Black	8	5	6	3
Hispanic	13	8	9	7
Asian	2	4	2	2
American Indian	2	0	0	1
English as the primary language? Yes	94	96	96	97
No	6	4	4	3
Driving a major part of your job? Yes	33	25	34	27
No	67	75	66	73
Average annual miles driven				
Less than 10,000	13	18	18	20
10,000-15,000	40	32	32	26
15,001-20,000	19	21	22	25
20,001-30,000	17	21	13	17
over 30,000	11	8	15	12
Most of your driving time is...				
Within the Houston city limits	43	35	28	36
Outside the Houston city limits	21	29	30	30
About half & half	36	36	42	34
Number of Responses	132	148	124	124

Conversion factor: 1 mile = 1.61 km

Markings Only Questions

The objective for the initial set of questions was to determine driver's interpretation of the following pavement markings (without any other visual clues):

- Alternative I -- typical white lane lines (10-ft long, 4-inch wide stripe with 30-ft gaps) (3.1 m long, 101.6 mm wide stripe with 9.2 m gaps).

- Alternative II -- double white lines (each 4 inches wide, set 4 inches apart) (101.6 mm wide, set 101.6 mm apart).

- Alternative III -- lane drop markings (3-ft long, 8-inch wide stripe with 12-ft gap) (0.92 m long, 203.2 mm wide stripe with 3.66 m gaps).

- Alternative IV -- wide solid white line (8 inches wide) (203.2 mm wide).

Figure 10 shows a summary of the responses from the four alternatives. Figure 8 shows the actual questions concerning pavement markings only (Questions 1 to 3) for Alternative II.

For Alternative I, 8 percent of the participants stated that if they were driving in Lane 4, they must exit from the freeway. Responses from Alternative III revealed 52 percent of the participants stated they must exit if they are in Lane 4. The other two alternatives pertaining to the wide solid white line markings resulted in approximately 72 percent of the participants stating that they must exit if in Lane 4. The *solid* white lines, even without any additional visual clues such as seeing the exit approaching or seeing a yellow panel sign, indicated most clearly to the motorists that they will be required to exit if they continue in the lane.

Question 3 of the survey was similar to Question 1, except it was presented in a manner which would obtain additional understanding of motorists' interpretations of the markings. In Alternative II, participants indicated that the two solid white lines cannot be crossed. This understanding may be a reflection of the Houston district using two solid white lines on some freeway exit ramps merging with a frontage road in conjunction with the sign that says DO NOT CROSS DOUBLE WHITE LINES. The results of Question 3 in Alternative III indicated that participants interpreted the lane drop markings as being permissible in nature. A higher percentage of respondents in Alternative III than in Alternatives II or IV indicated that the vehicles in Lane 4 may either exit or continue.

Comments received from participants were informative, with some indicating that they had never seen some of the markings being tested (i.e., the double white lines or the lane drop markings). One participant asked the meaning of the short dashed lines because they were unfamiliar. When answering Questions 1 to 3, several participants stated that they wanted a sign to provide the information on whether to exit rather than just basing their decisions on the pavement markings present. These comments serve as a reminder of the need to provide a secondary source of information until drivers are familiar with the new markings.

QUESTION LANE RESPONSE	Alternative I	Alternative II	Alternative III	Alternative IV
1 4 Must continue on freeway	2%	7%	8%	4%
1 4 Must exit	8%	73%	52%	72%
1 4 May either exit or continue	82%	13%	31%	19%
1 4 Not sure	8%	7%	9%	5%
2 3 Must continue on freeway	NA	67%	61%	55%
2 3 Must exit		3%	1%	3%
2 3 May either exit or continue		27%	37%	37%
2 3 Not sure		3%	1%	5%
3 L-4 must exit	NA	27%	42%	41%
3 L-3 may exit or continue		14%	35%	16%
3 May not cross marking		57%	9%	37%
3 Not sure		2%	14%	6%
Number of Respondents	132	148	124	124
Number of Responses for Question 3		175	153	157

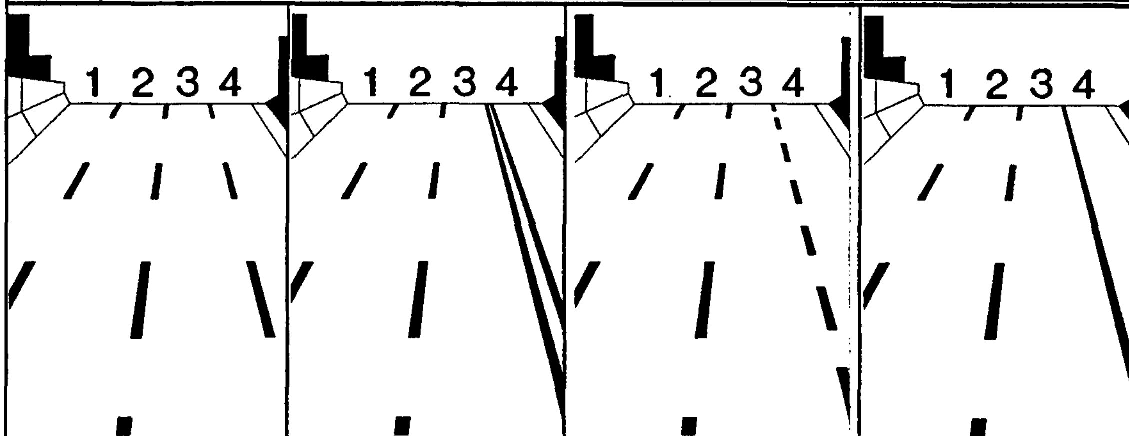
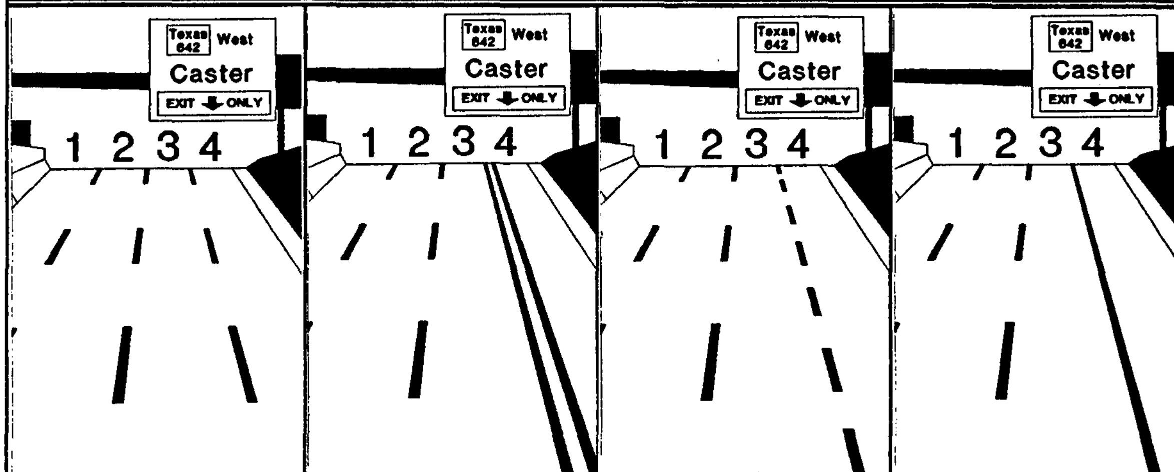


Figure 10. Summary of Responses to Marking Only Questions.

One-Lane, Lane Drop Exit Questions

The objective for the one-lane, lane drop exit questions was to determine if the combination of signs and markings improves driver understanding of the approaching mandatory exit. Figure 11 illustrates the graphics as well as the findings from the survey. Driver comprehension of the markings increased noticeably with the addition of the Exit Only sign. Over 91 percent of the respondents for each alternative indicated that Lane 4 must exit to Caster. For Alternative I, when no sign was used with the standard lane markings, 8 percent of the participants indicated that they must exit. However, when the sign was added, the *must exit* response increased to 92 percent.

While the percentage of respondents choosing *must exit to Caster* for Lane 4 in the four alternatives was fairly consistent (91 to 98 percent), the respondents choosing *must continue on freeway* for Lane 3 was not as uniform. The lane drop markings alternative (Alternative III) had the lowest number of participants selecting the *must continue* option (60 percent). The majority of the remaining participants selected the *may either exit or continue* selection. Over 80 percent of the participants of Alternative II selected the *must continue* option. This high percentage may be a reflection of the use of double solid white lines in some areas of Houston when freeway exit ramps meet the frontage road.



QUESTION LANE RESPONSE	Alternative I	Alternative II	Alternative III	Alternative IV
4 4 Must continue on freeway	2%	1%	2%	0%
4 4 Must exit to Caster	92%	95%	91%	98%
4 4 May either exit or continue	6%	3%	5%	2%
4 4 Not sure	0%	1%	2%	0%
5 3 Must continue on freeway	NA	82%	60%	72%
5 3 Must exit to Caster		2%	2%	2%
5 3 May either exit or continue		15%	35%	23%
5 3 Not sure		1%	3%	3%
Number of Respondents	132	148	124	124

Figure 11. Responses to One-Lane, Lane Drop Exit Questions.

Two-Lane Exit with an Option Lane and an Exit Only Lane Questions

The objective for these questions was to determine if the combination of signs and markings improves driver understanding that the approaching exit is a two-lane exit with an option lane and an exit only lane (see Figure 12). Over 90 percent of the participants recognized that Lane 4 must exit. Between 67 and 79 percent of the participants selected the *may exit or continue on the freeway* option for Lane 3, which is the correct answer. A noticeable number of the respondents, between 17 and 30 percent, selected the *must continue on freeway* answer when travelling in Lane 3. This indicates that several participants did not recognize the white down arrow (that is outside the yellow EXIT ONLY panel) as meaning that the drivers in the third lane have a choice; they can either exit or stay on the freeway. Few participants (less than 5 participants out of the 130 per alternative) selected the *must exit* answer.

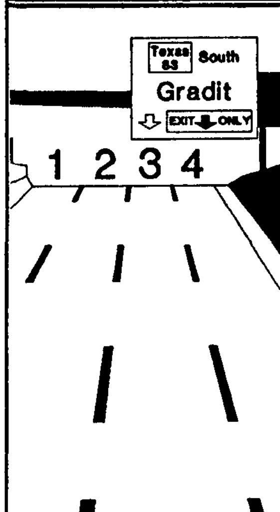
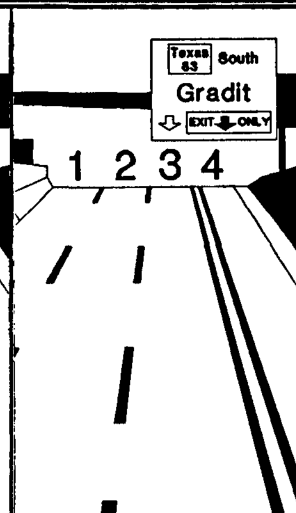
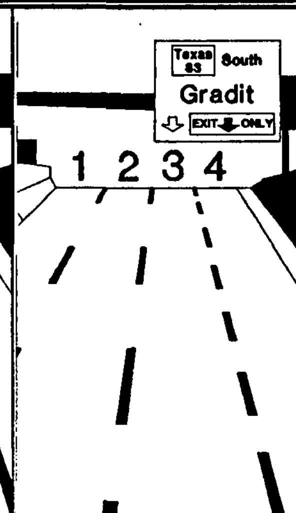
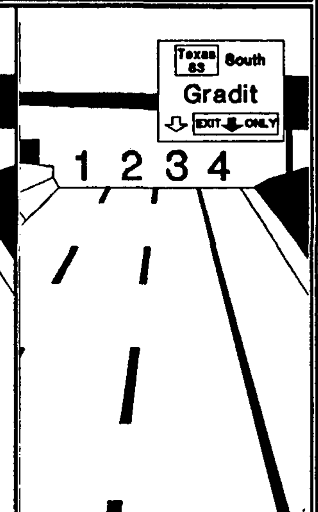
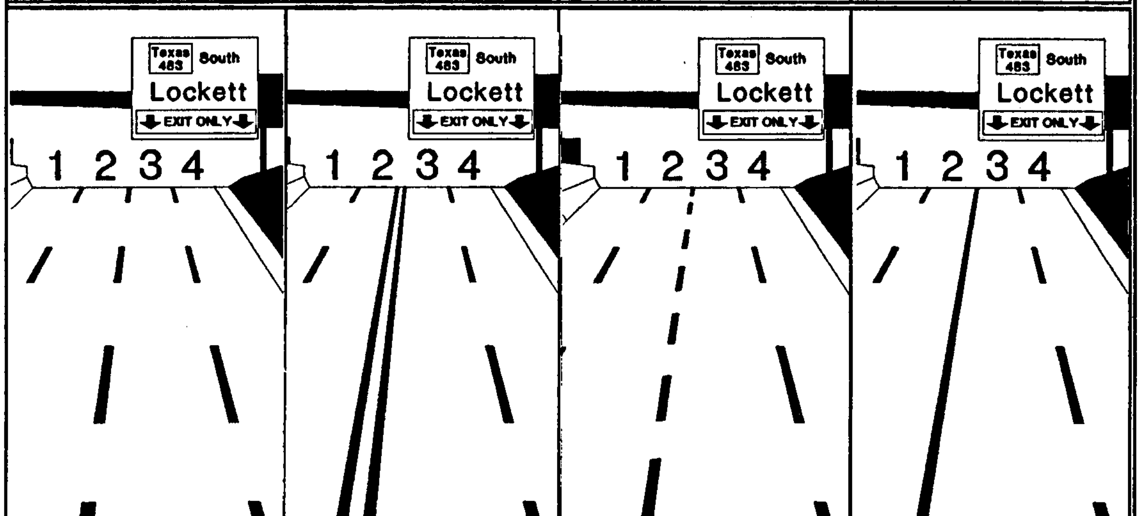
QUESTION LANE RESPONSE	Alternative I	Alternative II	Alternative III	Alternative IV
				
6 4 Must continue on freeway	1%	5%	5%	5%
6 4 Must exit to Gradit	92%	90%	89%	91%
6 4 May either exit or continue	7%	5%	4%	4%
6 4 Not sure	0%	0%	2%	0%
7 3 Must continue on freeway	28%	30%	18%	21%
7 3 Must exit to Gradit	4%	3%	2%	2%
7 3 May either exit or continue	67%	66%	79%	76%
7 3 Not sure	1%	1%	1%	1%
Number of Respondents	132	148	124	124

Figure 12. Responses to Two-Lane Exit with an Option Lane and an Exit Only Lane Questions.

Two-Lane, Lane Drop Exit with Markings Between One Set of Lanes Questions

The objective for these questions was to determine if the combination of signs and markings improves driver knowledge of an approaching two-lane mandatory exit. Over 94 percent of the participants correctly selected the *must exit* answer for Lane 4, while only 82 to 90 percent of the participants correctly selected the *must exit* answer for Lane 3 (see Figure 13). Between 80 and 91 percent correctly selected the *must continue* option for Lane 2. Alternative III (lane drop markings), offered the highest number of incorrect answers and those individuals selected the *may either exit or continue on the freeway* answer. Respondents felt that the permissive nature of the broken lane lines allows them to change lanes, and this possibly encouraged them to select the *either exit* or *continue on freeway* option.

QUESTION LANE RESPONSE	Alternative I	Alternative II	Alternative III	Alternative IV



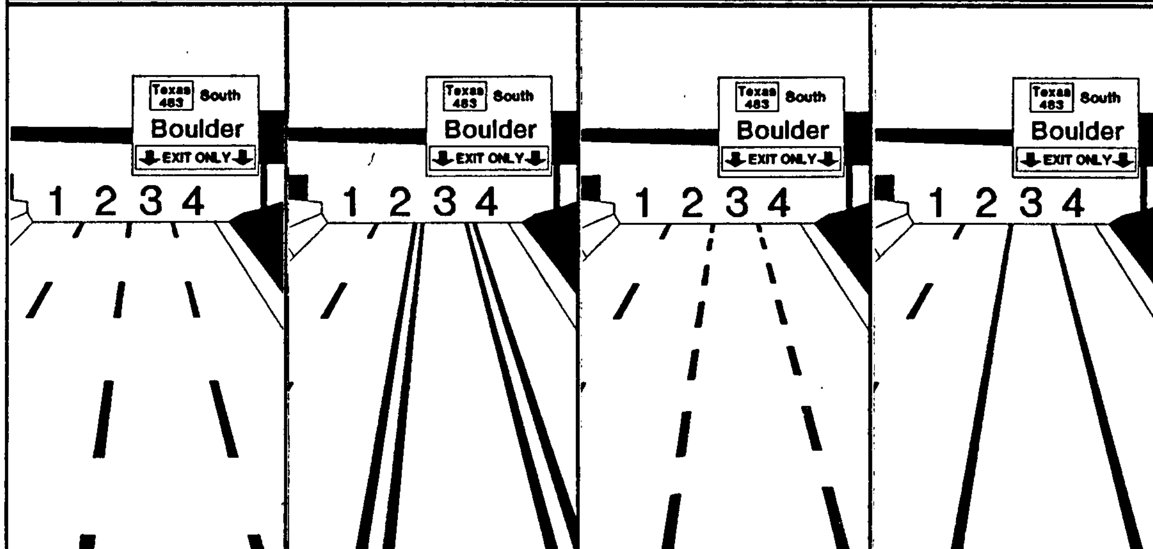
QUESTION LANE RESPONSE	Alternative I	Alternative II	Alternative III	Alternative IV
8 4 Must continue on freeway	0%	2%	2%	2%
8 4 Must exit to Lockett	94%	96%	94%	94%
8 4 May either exit or continue	5%	1%	4%	4%
8 4 Not sure	1%	1%	0%	0%
9 3 Must continue on freeway	4%	4%	3%	2%
9 3 Must exit to Lockett	84%	89%	83%	90%
9 3 May either exit or continue	11%	7%	14%	8%
9 3 Not sure	1%	0%	0%	0%
10 2 Must continue on freeway	87%	91%	80%	88%
10 2 Must exit to Lockett	3%	2%	2%	1%
10 2 May either exit or continue	9%	6%	18%	9%
10 2 Not sure	1%	1%	0%	2%
Number of Respondents	132	148	124	124

Figure 13. Responses to Two-Lane, Lane Drop Exit with Markings Between One Set of Lanes Question.

Two-Lane, Lane Drop Exit with Markings Between Two Sets of Lanes Questions

Figure 14 shows the results from these questions which determine if the change in markings alters driver knowledge of the approaching two-lane mandatory exit. The findings for this group of questions was similar to the previous group of questions. Between 93 and 99 percent (compared to 94 and 96) of the participants correctly selected the *must exit* answer for Lane 4, while 81 to 90 percent (compared to 82 and 90) of the participants correctly selected the *must exit* answer for Lane 3. Between 71 and 92 percent (compared to 81 and 91) correctly selected the *must continue* answer for Lane 2. Alternative III (lane drop markings), again offered the highest number of incorrect answers, with those individuals selecting the *may either exit or continue* answer.

Several participants were surprised when viewing the graphics for Alternatives II to IV on this group of questions. They had never seen a situation where the markings are used between two sets of lanes. Several individuals stated that Lane 3 should continue somewhere other than in the direction of Lane 4, and that the sign is misleading because both lanes are going to Boulder. They felt that these pavement markings denoted one lane going to one place and the other lane going to another place.



QUESTION LANE RESPONSE	Alternative I	Alternative II	Alternative III	Alternative IV
11 4 Must continue on freeway		2%	2%	0%
11 4 Must exit to Boulder	NA	96%	93%	99%
11 4 May either exit or continue		1%	3%	4%
11 4 Not sure		1%	2%	1%
12 3 Must continue on freeway		5%	5%	2%
12 3 Must exit to Boulder	NA	86%	80%	91%
12 3 May either exit or continue		7%	14%	6%
12 3 Not sure		2%	1%	1%
13 2 Must continue on freeway		89%	72%	92%
13 2 Must exit to Boulder	NA	3%	2%	0%
13 2 May either exit or continue		8%	25%	6%
13 2 Not sure		0%	1%	2%
Number of Respondents	132	148	124	124

Figure 14. Responses to Two-Lane, Lane Drop Exit with Markings Between Two Sets of Lanes Questions.

Driver Preference Questions

Two objectives were selected for the driver preference questions. They were: 1) to determine if drivers understand the difference between an advanced guide sign and an exit direction sign, and 2) to determine driver preference between different exit only signs. Figures 15 to 17 summarize the findings from the survey. The two primary findings are that diagrammatic signs were chosen most often for the first sign but less often for later usage, and that drivers prefer the down arrow for the first sign usage. One participant commented that specific distances should be included on the signs.

Interpretation of Findings

The driver survey indicated a high level of understanding of the exit only signs. In most Exit Only sign comprehension cases the correct response was selected by over 90 percent of the participants. Only the Exit Only sign for the two-lane exit with one lane mandatory and one lane optional had correct comprehension percentages below 80 percent. The correct interpretation of the white down arrow next to the yellow EXIT ONLY panel ranged between 66 and 79 percent, depending upon the type of markings shown on the figure (see Figure 12).

The visuals only represented a specific location along a freeway. When on a freeway, drivers may encounter other visual clues, such as the approaching geometrics and/or other signs, to aid them in their driving decisions. The scenarios presented to each participant in this survey, however, could represent those cases where a preceding sign was not observed or the driver entered the freeway after preceding signs. With such a scenario, the results of the survey indicated that the majority of the drivers correctly selected the appropriate response.

A noticeable difference occurred between the lane drop markings and the solid lane line markings. Drivers are correctly interpreting the broken line markings as being permissive in nature while the solid lines are restrictive in nature. For example, when only the markings (no signs) are shown, over 70 percent of the respondents indicated that the right most lane must exit while only 52 percent of the respondents selected the *must exit* choice for the lane drop markings alternative (see Figure 10).

This survey indicates that improved comprehension of appropriate driver actions can be expected when the lane markings supplement current exit only signs. The survey also indicates that many motorists already correctly interpret the meaning of a solid white line or the lane drop markings when present on a freeway. When a sequence of three exit only related signs are present, the participants preferred the diagrammatic sign as the initial sign.

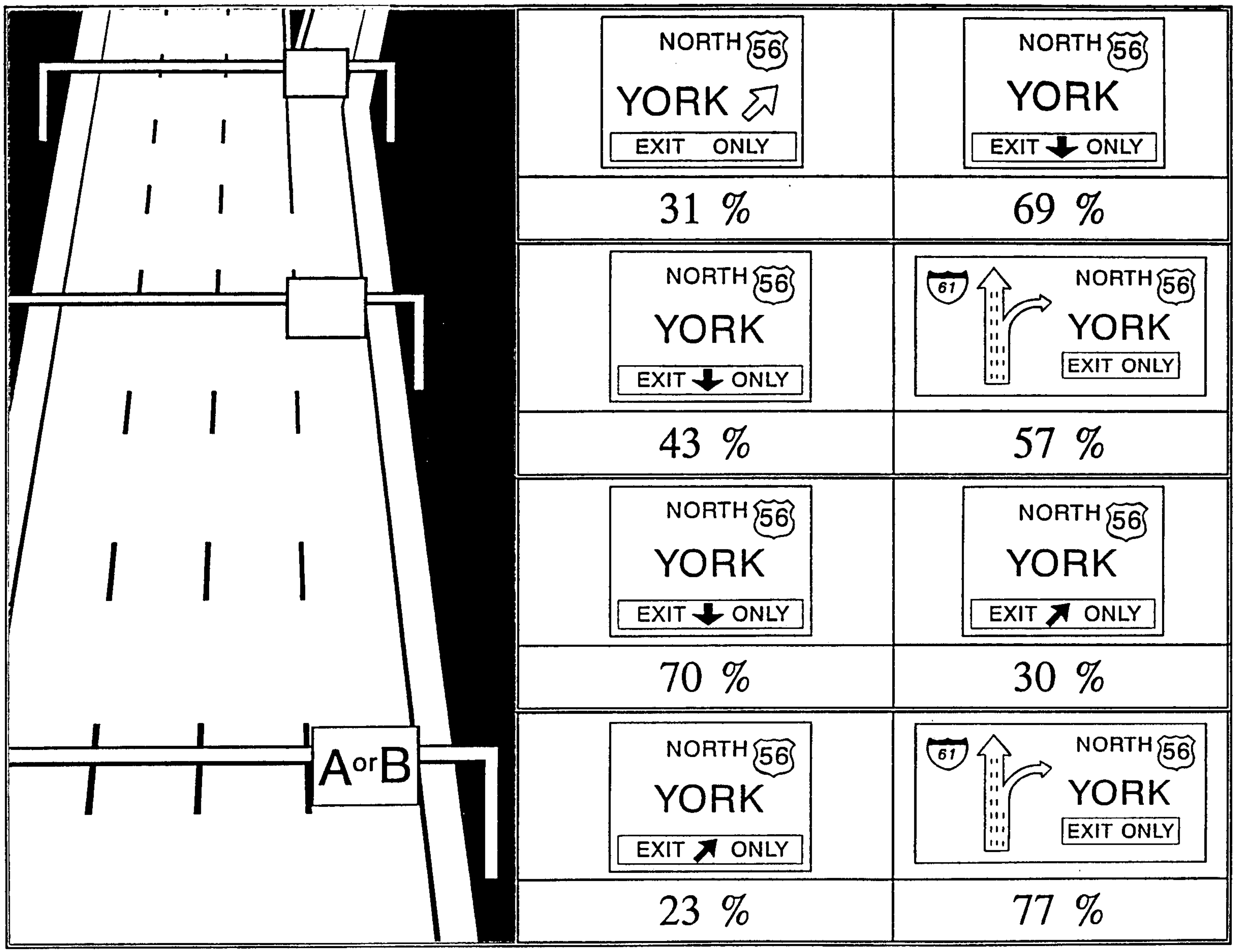


Figure 15. Participants' Preferences for the Initial Exit Only Sign.

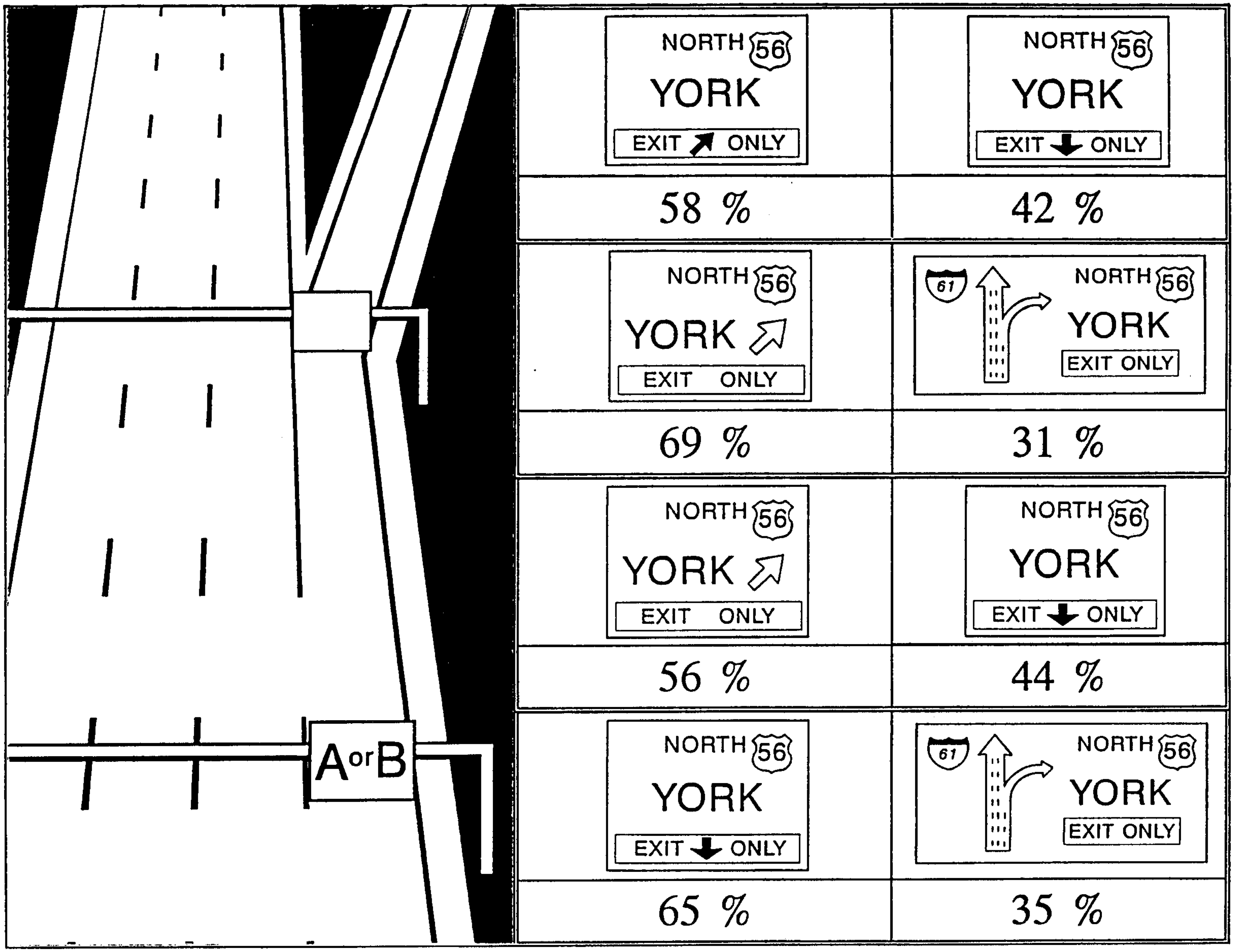


Figure 16. Participants' Preferences for the Second Exit Only Sign.

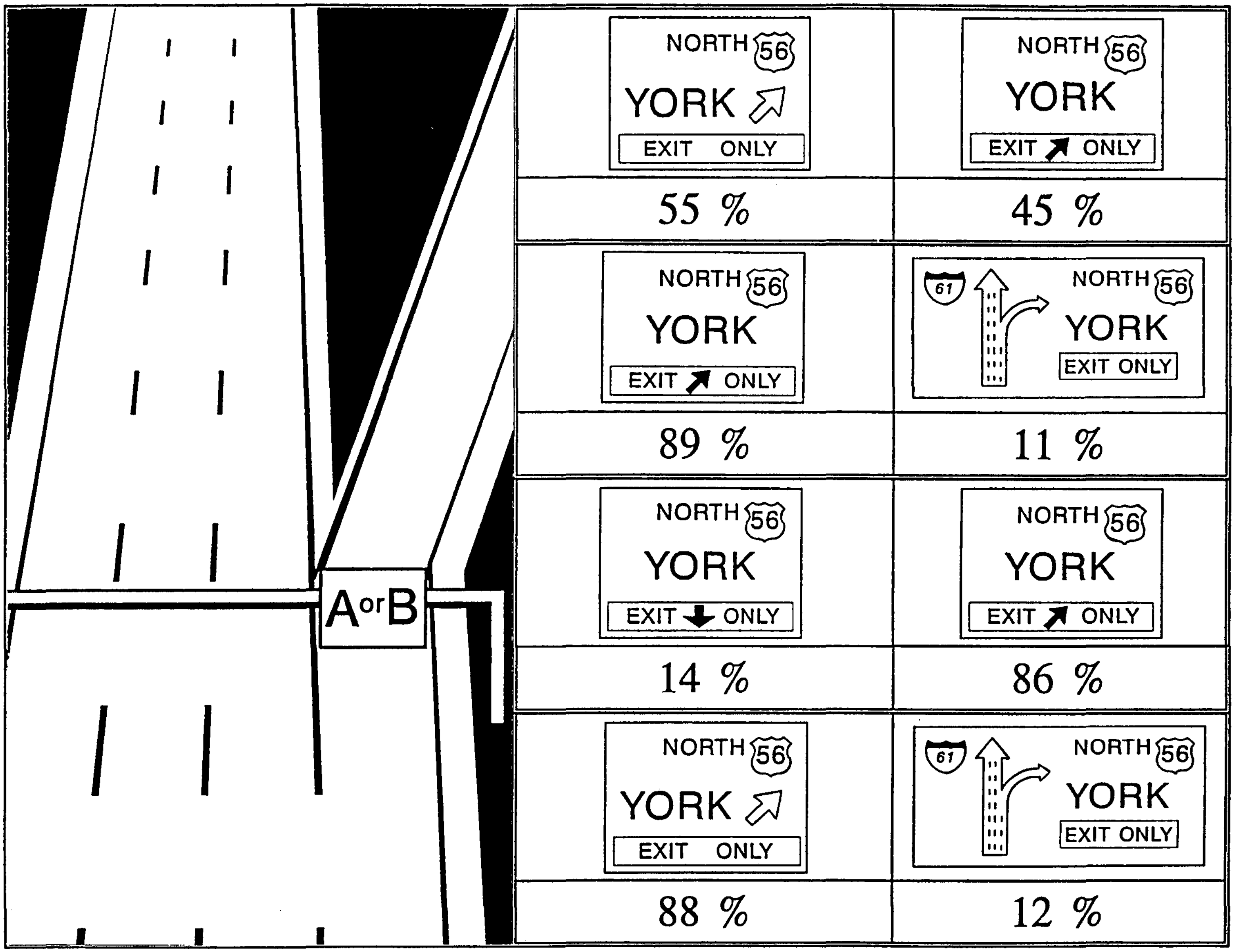


Figure 17. Participants' Preferences for the Final Exit Only Sign.

DRIVING INSTRUCTOR SURVEY -- MAILOUT SURVEY

Development of Survey

The goal of the mailout survey was to obtain information on instructors' perceptions of their students' understanding of signs and pavement markings for freeway exit only lanes. Because of the inherent characteristics of a mailout survey, certain limitations were observed during its development. For example, the questionnaire was limited to one page, and it primarily contained questions needing one word responses. The questionnaire also contained an introduction that explained the source of the survey and its purpose.

In addition to obtaining names and addresses of driving instructors, driving instruction and defensive driving course notes were also acquired. Examination of these course notes and discussions with instructors revealed that exit only signs and pavement markings receive little to no coverage during these courses. As a result, obtaining students' comprehension of these devices through actual tests was not possible. Instead, a survey was developed to obtain instructors' opinions of their students' comprehension of signs and pavement markings for freeway exit only lanes. The responses also reflect comprehension of devices that individuals have seen as passengers in vehicles rather than as the drivers.

Selection of Questions

The questions selected for inclusion in the survey covered a range of issues relating to exit only signs and markings. The selected issues included signs, solid white lines, and lane drop markings. Figure 18 is a reproduction of the survey. The first question covered the comprehension of current signing and pavement markings for freeway exit only lanes. This question served as a base line for comparing the results from the other questions. The respondents were also given the opportunity to provide comments on the current exit only lane signs and markings.

Recent debates on the appropriate use of up and down arrows on guide signs indicate the need to determine if students perceive a difference. According to the MUTCD, the down arrow is used as a lane assignment arrow to specifically point to the lane in which one must be to go to the destination indicated. An upward pointing arrow indicates that the destination indicated is ahead. A question on the comprehension of the difference between the up and down arrow was included in the survey. Questions on the yellow panel and the preference of the diagrammatic sign over the yellow EXIT ONLY panel were also selected for the questionnaire.

The Texas Department of Transportation is sponsoring a research study with the Texas Transportation Institute on improvements to the signing and pavement markings used for freeway exit-only lanes. We would appreciate your assistance in evaluating how well your students understand the signing and pavement markings for freeway exit-only lanes. Because you are a Texas driving instructor, we would like to have your opinions on the following questions.

Please rate your students' comprehension of the following issues on a scale of 1 to 5 by circling your response on the numbers provided. The value 5 indicates excellent comprehension, 3 indicates average comprehension, and 1 represents poor comprehension.

Your students' comprehension....	POOR		AVERAGE		EXCELLENT
of the current signing and pavement markings for freeway exit-only lanes...........	1	2	3	4	5
Why?______________________________					
of the difference between an up arrow (↑) and a down arrow (↓) on an exit guide sign........	1	2	3	4	5
that a yellow panel on a guide sign indicates that a lane must exit or that the approaching exit is to the left........	1	2	3	4	5
that a solid white line prior to an exit communicates that the lane will exit from the freeway........	1	2	3	4	5
that motorists can legally cross a solid white line prior to an exit........	1	2	3	4	5
that short dashed lane striping (shown between Lanes 3 and 4 in Figure 1) indicates that Lane 4 will exit from the freeway........	1	2	3	4	5
that motorists can legally cross the short dashed lane striping prior to an exit (shown between Lanes 3 and 4 in Figure 1)........	1	2	3	4	5

Please also answer the following questions:

Yes/No Does a diagrammatic sign (example shown in Figure 2) better communicate that the right-most lane must exit instead of the yellow EXIT ONLY panel?

Do you have any additional comments on how to better communicate exit-only lanes to motorists?

____

____

____

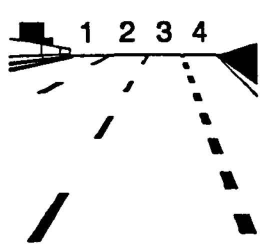


Figure 1

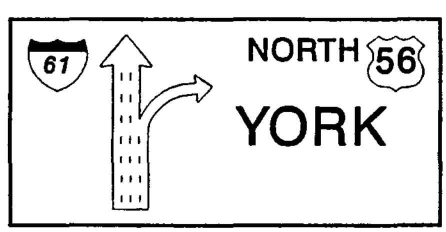


Figure 2

Thank you for your cooperation.

Please return this form at your earliest convenience in the postage paid envelope provided.

Figure 18. Driving Instructor Survey.

A solid white line preceding an exit lane drop gore is an optional pavement marking as presented in the MUTCD. The solid line, when used prior to an exit, communicates to the motorist that the lane will exit from the freeway. However, the solid white line is not always used due to its optional placement as indicated in the MUTCD. As a result, potentially confusing interpretations by motorists may arise regarding the meaning of the marking. The lane drop markings that consist of short dashes and short gaps are also recommended (by the MUTCD), but not required, for use at exit lane drops. The short dashed lines communicate to the motorists that the isolated lane will be exiting from the freeway. This marking, because it is not widely used, may also cause confusion. As a result, questions on the ability of the solid white line and the lane drop markings to communicate an impending exit were selected for inclusion in the survey as well as questions which tested whether students comprehend that they can "legally" cross the different types of lines. The questionnaire closed with a request to provide additional comments on communicating exit only lanes to motorists.

Conduct Survey

Because exit only lanes are more predominant in urban areas than in rural areas, the survey was only distributed to individuals in large metropolitan areas. The survey was sent to members of the Texas Driver and Safety Education Association in Austin, Houston, Dallas/Fort Worth, and San Antonio. A total of 164 surveys were mailed during the summer of 1992. Each survey was accompanied by a postage-paid envelope to encourage participation.

The number of surveys sent to each city, received from each city, and deemed undeliverable, as well as the response rate are given in Table 6. For all cities, the response rate was nearly 30 percent. In addition to receiving surveys from driving instructors, an instructor in the Dallas/Fort Worth area distributed the survey to her students. Therefore, an unexpected 271 surveys completed by students were received. Because actual student responses were also collected, comparisons between the instructors' opinions of their students' comprehension, and the students' comprehension of the survey questions, were able to be made, with some reservations due to the method in which the student surveys were obtained.

Table 6. Texas Instructor Survey Response Results.

Metropolitan Area	Number of Surveys...			Response Rate
	Sent	Received	Undeliverable	
Austin	22	9	1	43%
Dallas/Fort Worth (DFW)	37	11	2	31%
Houston	91	17	5	20%
San Antonio	14	7	1	54%
Total	164	44	9	28%

Findings

Instructor Responses

The way an exit lane drop is striped or marked with signs can differ from site to site. Although some guidance is given, neither the Texas MUTCD nor the national MUTCD requires specific lane drop markings or signs to be used for all exit lane drop situations. Because of the flexibility provided to the TxDOT districts, each metropolitan area surveyed in this study may have developed their own signing and pavement marking procedures. Consequently, the comprehension of various markings and signs may depend on the region in which a driver lives. Therefore, survey data for each city was compiled separately in order to investigate the possibility of students having better understanding of current signing and pavement markings due to their geographic location or the extent of instruction each student received. In addition, all the data from each metropolitan area was compiled together to obtain an overall idea of students' comprehension of traffic control regarding exit lane drops.

Following is a discussion of the findings for each question on the survey. The results have been tabulated in tables. Percentages shown in these tables may not add to 100 percent due to the fact that some respondents did not answer all the questions. Rounding errors may also cause percentages to be less than 100 percent.

The purpose of the first question on the survey was to obtain an overall view of students' comprehension of current signing and pavement markings regarding freeway exit lane drops. The results from this general question are compared to the results of the remaining more specific questions on the survey to test the reliability of the responses. The responses to the first question are given in Table 7. San Antonio had both the lowest mean response and a below average comprehension of current signing and pavement markings. Overall, however, the comprehension of current signing and pavement markings was average or better.

Table 7. Comprehension of Current Signing and Pavement Markings.

	Austin	DFW	Houston	San Antonio	All Cities
Number of Responses	9	11	17	7	44
Responses (%)					
Poor	0%	0%	0%	14%	2%
Below Average	11%	0%	12%	14%	9%
Average	22%	55%	77%	57%	57%
Above Average	56%	46%	12%	0%	27%
Excellent	11%	0%	0%	14%	5%
Mean Response (1=poor, 5=excellent)	3.67	3.45	3.00	2.86	3.23

The second question on the survey concerned students' comprehension of the difference between an up and a down arrow on an exit guide sign. The responses to this question are shown in Table 8. The surveys from San Antonio once again had the lowest mean response (below average), and no San Antonio instructors responded that their students have *above average* comprehension or better. When the responses from all the cities were tallied, the mean response was below average, indicating a strong misunderstanding of the up and down arrows on exit guide signs.

Table 8. Comprehension of the Difference Between an Up Arrow and a Down Arrow.

	Austin	DFW	Houston	San Antonio	All Cities
Number of Responses	9	11	17	7	44
Responses (%)					
Poor	22%	9%	24%	29%	21%
Below Average	0%	18%	6%	43%	14%
Average	22%	18%	65%	29%	39%
Above Average	44%	18%	6%	0%	16%
Excellent	11%	36%	0%	0%	11%
Mean Response (1=poor, 5=excellent)	3.22	3.54	2.53	2.00	2.84

The third question intended to determine student comprehension of a yellow panel on a guide sign indicating that a lane must exit or that the approaching exit is to the left. The results to this question are shown in Table 9. As indicated by the results, the Dallas/Fort Worth area responses were quite positive, showing only *average* and above responses, with more *excellent* comprehension replies than any other response. When responses from all the cities were totalled, the mean response was higher than average, with 77 percent of the responses revealing an *average* or better comprehension. This indicates a generally positive comprehension of the yellow panels on guide signs.

Table 9. Yellow Panel Comprehension.

	Austin	DFW	Houston	San Antonio	All Cities
Number of Responses	9	11	17	7	44
Responses (%)					
Poor	0%	0%	18%	29%	11%
Below Average	11%	0%	12%	14%	9%
Average	33%	27%	47%	14%	34%
Above Average	44%	27%	12%	29%	25%
Excellent	11%	46%	6%	14%	18%
Mean Response (1=poor, 5=excellent)	3.56	4.18	2.59	2.86	3.23

Instructor responses about their students' comprehension of the solid white line prior to an exit lane drop are shown in Table 10. Three out of the four urban areas surveyed indicated none of the students had a *poor* comprehension of the meaning of a solid white line. In addition, the mean response in all urban areas taken separately and together indicated an above average comprehension of this pavement marking. In fact, responses from the Dallas/Fort Worth area showed that 82 percent of the responses were *above average* or better. When all cities were totalled, 86 percent of the responses were *average* or better, indicating that students have a very good understanding of the solid white line. Surprisingly, this mean response is higher than that of the understanding of the yellow panel.

Table 10. Solid White Line Comprehension.

	Austin	DFW	Houston	San Antonio	All Cities
Number of Responses	9	11	17	7	44
Responses (%)					
Poor	0%	0%	0%	14%	2%
Below Average	22%	9%	12%	0%	11%
Average	0%	9%	53%	57%	32%
Above Average	56%	46%	29%	0%	34%
Excellent	22%	36%	6%	29%	21%
Mean Response (1=poor, 5=excellent)	3.78	4.09	3.29	3.29	3.59

The fifth question on the survey dealt with the legality of crossing or not crossing over the solid white line preceding an exit lane drop. Results of instructor responses are given in Table 11. The results may indicate poor comprehension because of the wording of the question.

Table 11. Legal Crossing of Solid White Line.

	Austin	DFW	Houston	San Antonio	All Cities
Number of Responses	9	11	17	7	44
Responses (%)					
Poor	11%	18%	0%	29%	11%
Below Average	22%	18%	18%	29%	221%
Average	33%	18%	53%	43%	39%
Above Average	22%	36%	18%	0%	21%
Excellent	11%	9%	6%	0%	7%
Mean Response (1=poor, 5=excellent)	3.00	3.00	2.94	2.14	2.84

Table 12 lists instructor responses to their students' comprehension of the short dashed lane striping. Only one urban area's (Dallas/Fort Worth) mean response was above average, and Houston displayed the lowest mean comprehension of all other cities. This mean response also happened to be the lowest on the survey. When the results for all the cities were totalled the mean response was well below average, indicating a general misunderstanding of these short dashed lines. The general public understands both the yellow panel and the solid white line better than the short dashed lines.

Table 12. Short Dashed Lane Striping Comprehension.

	Austin	DFW	Houston	San Antonio	All Cities
Number of Responses	9	11	17	7	44
Responses (%)					
Poor	22%	0%	41%	29%	25%
Below Average	22%	36%	24%	14%	25%
Average	33%	18%	24%	43%	27%
Above Average	11%	36%	0%	14%	14%
Excellent	11%	9%	6%	0%	7%
Mean Response (1=poor, 5=excellent)	2.67	3.18	1.88	2.43	2.45

The seventh question on the survey investigated the legality of crossing the short dashed lines. The short dashed striping allows crossing either into or out of the exit lane. Table 13 reveals the instructor responses regarding their students' comprehension of the short dashed lines. The mean response for each of the cities displayed approximately *average* comprehension. Therefore, based on this survey, approximately half of the driving public is aware that crossing the short dashed line is legal.

Table 13. Legal Crossing of Short Dashed Lane Striping.

	Austin	DFW	Houston	San Antonio	All Cities
Number of Responses	9	11	17	7	44
Responses (%)					
Poor	11%	0%	12%	29%	11%
Below Average	33%	9%	6%	14%	14%
Average	22%	9%	35%	29%	25%
Above Average	22%	73%	35%	14%	39%
Excellent	11%	9%	6%	14%	9%
Mean Response (1=poor, 5=excellent)	2.89	3.09	3.00	2.71	3.14

The final question on the survey dealt with diagrammatic signs. The question asked whether the instructor thought a diagrammatic sign (shown in Figure 18 as Figure 2) would better communicate that a lane must exit than the yellow EXIT ONLY panel. As can be seen in Table 14, the response was overwhelmingly in favor of a diagrammatic sign.

Table 14. Preference in Communicating a Lane Drop.

	Austin	DFW	Houston	San Antonio	All Cities
Number of Responses	9	11	17	7	44
Responses (%)					
Diagrammatic	78%	64%	65%	86%	71%
Yellow Panel	11%	27%	35%	0%	23%

In conclusion, the instructors were asked to make any additional comments regarding communication of lane drops to motorists. Several suggestions were made including some obvious solutions such as erecting additional signs, placing the signs farther from the gore (more advanced warning), and providing longer exit lanes than are typically used, such as auxiliary lanes. Other suggestions involved adding pavement markings such as arrows, EXIT ONLY phrases, and beginning the solid white line at the first exit only sign and then adding a second solid stripe closer to the gore. Some suggestions for signs included using diagrammatic signs in conjunction with the yellow panel, changing the coloring of the signs, and adding RIGHT LANE or LEFT LANE to the EXIT ONLY panel. Some other more interesting concepts consisted of enhancing law enforcement, using rough buttons on the pavement to slow traffic, and placing lane drops on both sides of the road, especially on freeways with 3 or more lanes.

Student Responses

One instructor in the Dallas/Fort Worth area distributed the survey to her students in addition to completing the survey herself. As a result, 271 student responses were obtained. This data was collected from only one driving school in one urban area of Texas. Responses can vary from each region, as well as from each school within that region. The results are listed in Table 15 in the order in which questions appeared on the survey.

A notable number of students (19 percent) responded with a poor understanding of the difference between an up and a down arrow (question 2). In addition, when comparing the students' understanding of the solid white line indicating an impending exit (question 4) to that of the short dashed lines indicating an impending exit (question 6), a significantly larger percentage of students had a better understanding of the solid white line (87 percent responded *average* or better) as opposed to those of the short dashed line (68 percent responded *average* or better). Even when comparing the student responses concerning the yellow panel and the solid white line, the mean answer for students' comprehension of the solid white line (question 4) was much higher than the mean answer for the yellow EXIT ONLY panel (question 3). Few students (6 percent) did not know that motorists can legally cross the short dashed line prior to an exit (question 7), indicating a good understanding of the permissive nature of the dashed line.

Some of the suggestions for better communicating lane drops to motorists made by the students included: a) more signs should be erected farther from the gore, b) EXIT ONLY should be placed on the pavement, c) a different color pavement should be used for exit lane drops, d) exit lane drop markings should be a different color, and e) lane dividers (bumps) at exit only lanes should be provided to prevent erratic lane changes.

Table 15. Arlington Student Responses to All Questions on the Survey

Question	Mean Response (1=poor, 5=excell-ent)	Number of Responses	Percentage of Responses				
			Poor	Below Average	Average	Above Average	Excellent
1	3.54	271	4%	6%	39%	26%	20%
2	3.23	271	19%	8%	30%	18%	25%
3	3.22	271	11%	13%	35%	24%	16%
4	3.83	271	4%	9%	23%	28%	36%
5	2.71	271	27%	14%	26%	17%	14%
6	3.12	271	13%	18%	31%	19%	18%
7	3.65	271	6%	8%	34%	20%	32%
8	n/a	271	66% in favor of diagrammatic sign			25% in favor of yellow panel	

Instructor Responses Versus Student Responses

In every case except two (questions 3 and 5) the students' mean responses were higher than the instructors' estimations of their comprehension. In the case of question 5, the wording of the question was poor, so analysis was difficult. Having the instructors' mean responses lower than the students' indicates that the instructors' responses may have been a more conservative estimation of their students' comprehension of signing and pavement markings related to freeway exit lane drops.

Interpretation of Findings

The answers given by the instructors are appraisals of their students' knowledge of the subject; however, this project assumes that these answers are an accurate appraisal. Even the data collected from actual students in drivers' education classes must be interpreted with caution, as this data was collected from only one driver's education class in one city of Texas. Therefore, the student data may not be an accurate representation of statewide driver's education students.

The use of the solid white line and the yellow EXIT ONLY panel prior to an exit gore area are good devices to communicate an impending lane drop, with the solid white line having the best understanding according to this survey. This fact also indicates the importance of pavement markings for communicating vital information to motorists. Both the students' responses and the driver instructors' responses indicated that the short dashed lines used prior to an exit are not widely understood by drivers. Although these dashes are intended to warn the driver of the impending exit, they are not widely utilized, and this may be the reason for the low comprehension displayed by drivers.

Lane drop markings (short dashed lines) are intended to warn drivers of the impending exit, and to give drivers the opportunity to change lanes prior to the gore. As indicated by the responses on the surveys, the permissive nature of the short dashed lines is understood. On the other hand, the up and down arrows as used on guide signs, such as Exit Only signs, are not.

The San Antonio area more consistently uses pavement markings prior to an exit lane drop than any other area observed within Texas. However, the responses from the survey show that San Antonio has a below average mean response for every question on the survey except the question concerning the meaning of the solid white line. San Antonio responses also displayed the lowest mean responses for the different cities to the questions concerning comprehension of general exit lane drop traffic control devices, up and down arrows, crossing the dashed line, and meaning of the solid white line. The low understanding of common lane drop traffic control devices may be attributed to region bias. Another explanation may be that the markings in San Antonio are frequently ignored or misused; therefore, the driving instructors felt that their students did not have an adequate understanding of the lane drop devices.

CHAPTER 4

OVERVIEW OF FIELD STUDIES

Field studies were conducted in addition to the surveys of motorists and driver instructors. An overview of the steps used in the field studies follows. Specific site information and additional details are included in the following chapters.

IDENTIFICATION OF CANDIDATE SITES

Areas explored to identify candidate sites include district personnel, research team's experiences, and responses during motorist interviews. While these methods produced some possible sites, a more comprehensive approach was needed to identify sites that would satisfy the project's criteria. Specific freeways in major urban areas in Texas were filmed using a Super 8-mm video camera. Data obtained from the video tapes were entered into a computer data base which was used to create lists of sites with similar characteristics. For example, the data base was used to list all one-lane, lane drop exits with similar characteristics such as location of upstream entrance or exit ramps or type of markings associated with the lane drop.

SELECTION OF SITES

The field studies were designed so that a before-and-after analysis of new lane drop markings could be done. Lane change and erratic maneuver behavior was collected for several hundred feet upstream of the lane drop gore both before markings were installed and after the markings were installed. The initial intent of the field study was to couple the before-and-after studies with control sites. Two one-lane, lane drop exits, and two, two-lane exits with an option lane and an exit only lane were selected as part of Phase I of the field studies. The original plan was to install new markings at only one of the two, one-lane, lane drop exit sites and one of the two, two-lane exit with an option lane and an exit only lane sites. This plan was revised during the course of the study with more emphasis being given to other elements of the field studies. The emphasis of the second part of the field studies, known as Phase II, was to locate sites with unusual qualities or with known or suspected high lane change behavior.

INSTALLATION OF MARKINGS

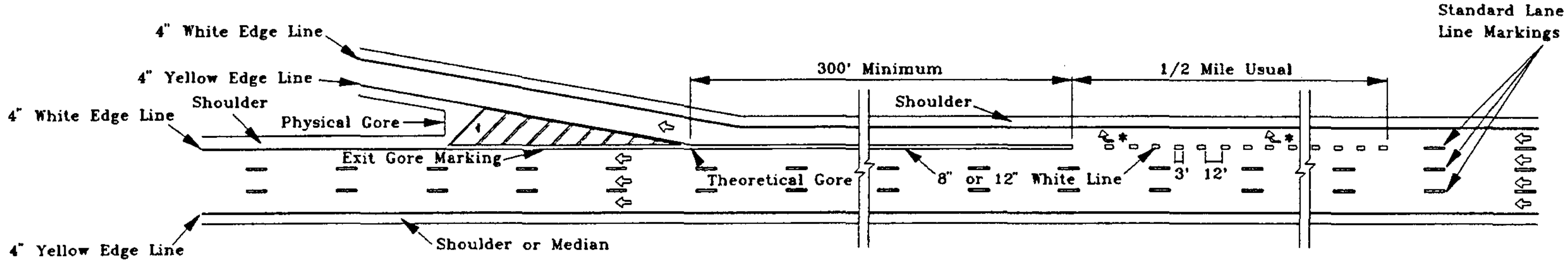
Specific exit lane drop treatments were selected based upon the results of the motorist survey given at the 1992 Houston Auto Show (see Chapter 3) and discussions with the TxDOT advisory panel. The results of the motorist survey indicated a high level of understanding of the EXIT ONLY panels; however, motorist comprehension of lane drop markings (short wide lines with short gaps) was lower. Because there exists little documented research on motorist understanding of these markings, the advisory panel and the research staff selected the lane drop markings as shown in Figure 19 for the field studies of this research project. The pavement arrows, while an optional treatment in the drawings, were used at each site. Also, EXIT ONLY words on the pavement, which are not shown on the drawings, were chosen for testing at a selected site. The markings installed at specific sites are shown in Chapter 6.

Schematics of the study site were delivered when appropriate to each district representative with type and placement dimensions of the study markings. Meetings were held with each district to discuss the details of marking placement and research requirements. Due to difficulties with contracting in the Houston area, the markings were not installed during the project period (September 1991 to August 1993). The Houston district maintenance representatives did work diligently to install the markings. Unfortunately, they were not installed within the project period, and were not able to be tested in the Houston area. Subsequently, there is no after data with which to compare the before data for several sites.

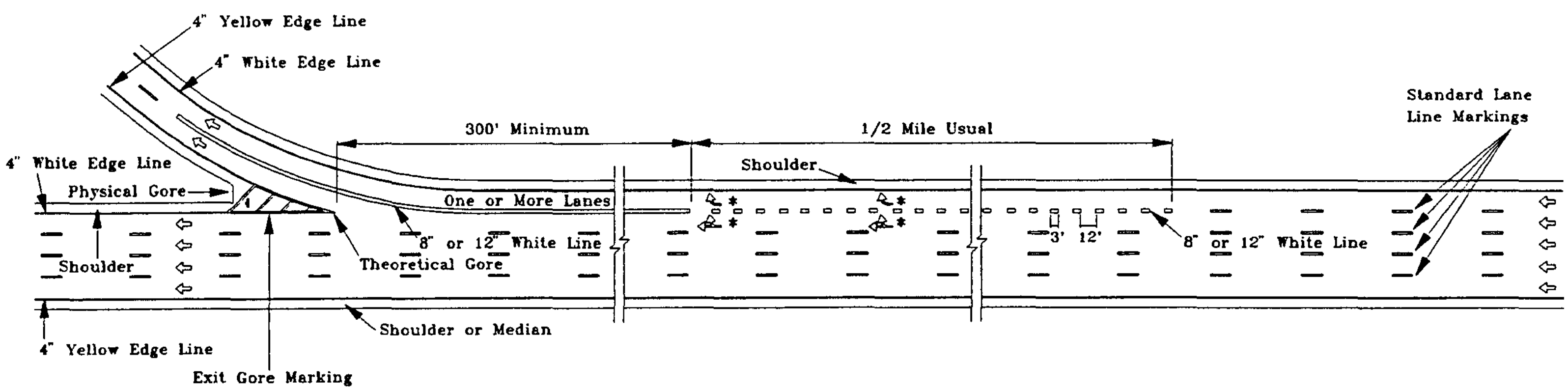
DATA COLLECTION

Once sites were selected and necessary study criteria refined, the specification of how to collect the information was required. The feasibility of collecting lane change and erratic maneuver data is directly dependant upon the location of these maneuvers. To be able to collect accurate information the vantage point at which these maneuvers are viewed is critical. The visibility of manual data collection efforts may influence traffic and a good viewing location at all sites for the data collectors was not available. Based on previous work done with video surveillance cameras and VCRs, this technique was selected to collect the information.

Closed circuit video cameras equipped with special wide angle and zoom lenses allowed optimum recording performance. The cameras were mounted in the field on overhead sign structures and were mostly undetectable by passing motorists. See Figure 20 for an example of the largest camera and housing unit used in the project. A VCR housing unit was mounted at ground level on the overhead sign structures to provide power, and weather and theft protection. This position allowed easy access to the VCR for multiple days of recording information so that VHS tapes could be switched in and out of the machines. A time lapse VCR was utilized to extend the recording time on the VHS tapes, and to generate both the time and date information on the videotape. This data collection process also provided a permanent record of the data for continual viewing during the data reduction process.



Single Lane Exit – Lane Drop or Exit Only



Multiple Lane Exit – Exit Only with Option Lane

LEGEND

- OM-2HR, OM-2HP or surface mount object marker (K-Marker) installed 2 to 20 feet from Physical Gore. Mounting height is approximateley 18 inches. K-Marker may be Carsonite, Safe-Hit or equal.
- Denotes direction of traffic.
- Pavement marking arrows (white).
- * – Optional

Figure 19. Typical Lane Drop Markings.

Figure 20. Mounted Camera on Sign Structure.

Coordination with Districts

Due to the extensive nature of planning and mounting the video surveillance systems in the field, a coordinated effort with the TxDOT local districts was required to complete the work. Each TxDOT district with a study site received a letter outlining the study objectives and methodology, as well as an assistance request for personnel and equipment. The district received a phone call a few weeks after the letter. The appropriate contact person was identified (usually within the district maintenance section) and details of the district assistance need was discussed. Each district provided housing units for the surveillance systems and secured them at ground level to each of the study site sign structures. These housing units were typically old controller cabinets that were emptied and not being used. The districts also provided an a/c receptacle in the housing unit that was wired from the sign structure luminaries. The research staff met with each district contact person to inspect the site and discuss the assistance required. Schedules were coordinated with each TxDOT district to allow maintenance crews to provide access to electrical power at each site, and to provide the bucket (crane) truck and manual assistance to place the video cameras. Arrangements were then made to schedule the installation of the video surveillance cameras using district manpower and access equipment.

Installation of Equipment

The placement of the video cameras required the use of a utility bucket (crane) truck. The bucket truck allowed access to the top of the overhead sign structures where the cameras were mounted (see Figures 21 and 22). The cameras were placed inside an all-weather housing unit to prevent direct exposure to extreme temperatures and moisture (see Figure 23). The housing units were then mounted to the top of the sign structures using c-clamps. Both power and video coaxial cables were run along the sign structures to the side support columns and down to ground level where the controller cabinet with the a/c receptacle and VCR (see Figure 24). A small TV monitor was connected to the VCR to allow proper positioning of the surveillance cameras. This positioning was critical due to the substantial area covered by the cameras during the data collection process. Approximate time to set up per site ranged between two and four hours depending upon the number of cameras used.

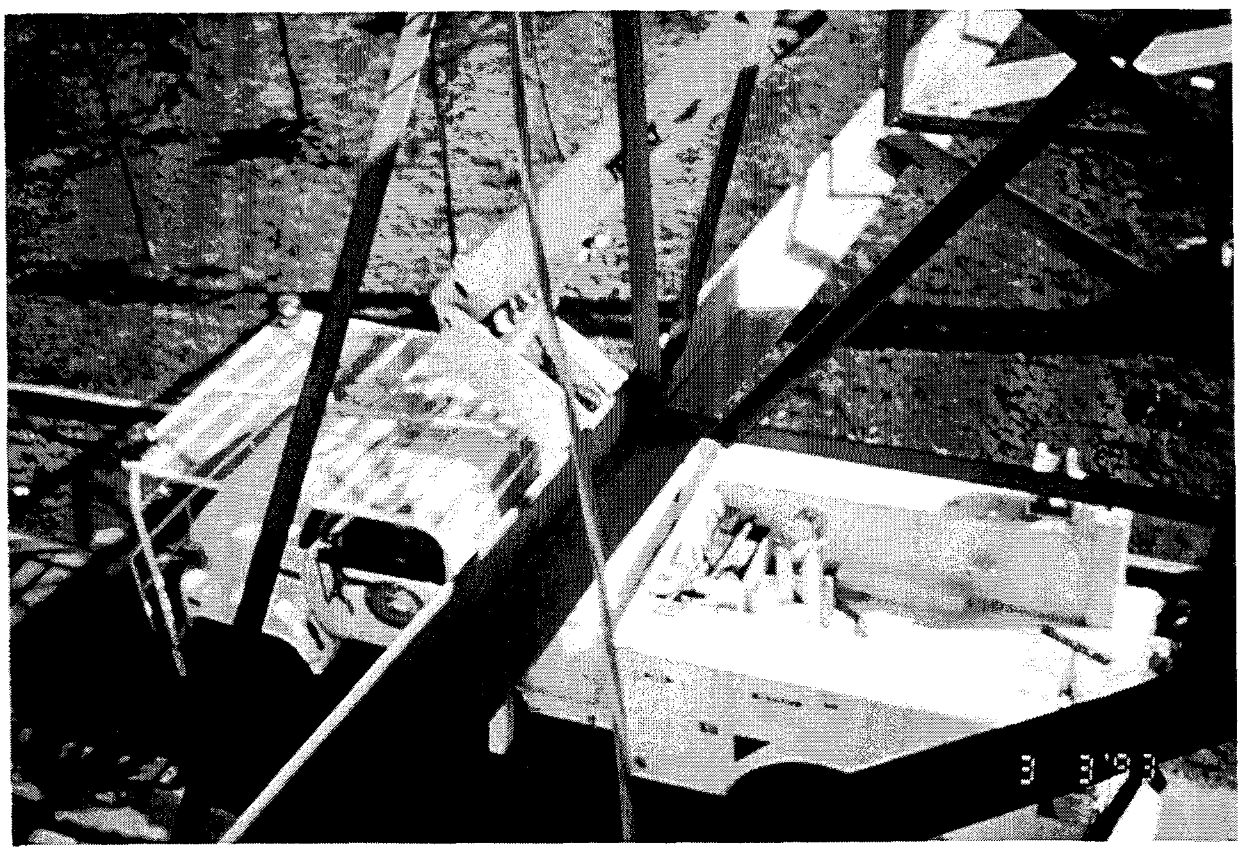


Figure 21. Bucket Truck Used to Install Video Equipment.

Figure 22. Installation of Video Equipment on Sign Structure.

Figure 23. All-Weather Housing Unit.

Figure 24. VCR in Controller Cabinet.

Recording of Data

The data collection process recorded between 1,000 and 2,000 ft (305 and 610 m) upstream of the lane drop gore depending upon the number of cameras used and the spacing of the sign structures. To begin the process, the study length was subdivided into segments. These segments could reflect the field of view of the camera and/or they could vary from the before to the after condition. Dividing the segments into uniform increment lengths would produce a more desirable set of data. These uniform increment lengths were called "zones." Because rumble strips (or jiggle bars) were frequently present at the study location, and were visible on the monitor, they were used to determine the zone locations. Also, due to rumble strips being typically spaced at 100-ft (30.5-m) increments, the zone spacing at each of the study sites was selected to be 100 ft (30.5 m). The entire study length upstream of the gore area was sectioned into these measured increments and marked along the shoulder.

Zone increments and zone location were visually recorded on the videos. This procedure involved driving a study vehicle along the shoulder of the freeway starting at the farthest upstream zone marking. The study vehicle stopped at each marking, and a technician stood next to or in front of the vehicle and waved a flag for 10 seconds. This step was repeated at each zone marking until the gore area was reached. The recorded procedure allowed the research staff to design a template for the viewing monitor that would show the actual location upstream where lane changes and erratic maneuvers were occurring. Determining overlapping area recorded by two different cameras was also made easier.

Data were collected for approximately one full week excluding weekends. Six hour recording intervals were selected on the time lapse VCRs. This recording period allowed extended recording lengths at an acceptable frame-by-frame speed. Technicians would start the recording process between 6:00 and 7:00 a.m., and then return six hours later to change VHS tapes for an additional six hours of recording. Videos were rewound and spot checked in the office for accuracy and recording efficiency. Once the video data was collected, the district was contacted to arrange for the removal of the video equipment.

DATA REDUCTION

Identification of Zones and Lanes

The initial step in reducing the data from the video tapes involved identifying the zones on the video tapes. Rumble strips that typically appeared every 100 ft (30.5 m) on the right shoulder were used to delineate the zones and/or the "flagging" process, described in the previous section, was used to identify the zone locations. The zones were numbered, beginning with Zone 1 at the gore and continuing upstream. Each lane was also labeled, beginning with the exit only lane as Lane 1, and the adjacent lane as Lane 2. Therefore, for a single lane exit, Lane 1 was the exit only lane, and Lanes 2, 3, etc., were through lanes. For a two-lane exit with an option lane and an exit only lane, Lane 1 was the exit only lane, Lane 2 was the option lane, and Lanes 3, 4, etc. were the through lanes. However, approximately 300 ft (91.5 m) from the gore, the option lane in a two-lane exit becomes wide enough to contain two vehicles. Distinguishing between the exiting portion (2E) and the through portion (2T) of the option lane for this area was necessary.

Creation of Templates

Once the zones and lanes were located and identified, they were marked on a template. A clear mylar, which was taped over the video monitor, was used as the base of the template. Thin black tape was placed on the mylar separating the video image into the 100-ft (30.5 m) zones. Other video images were traced on the mylar to identify the lanes and to allow for the removal and replacement of the templates without requiring the zones to be relocated. Because more than one video monitor could be used for the data reduction process, and the location of the zones is sensitive to the size of the monitor, the monitor used to create the template was also recorded on each template. The date and videotape number were recorded.

Selection of Video Tapes to be Viewed

The process of data reduction generally involved viewing approximately 24 hours of video tape per site per camera. Typically three cameras were used to record the data and for each camera view, two 12-hour days were reduced. These days usually began at 6:30 a.m. and continued until 6:30 p.m. For consistency, data collected on Tuesdays, Wednesdays, and Thursdays were used when available. When possible, the same days were selected for the before-and-after periods for each camera view at a site. In some cases, data collected on a Monday or Friday was reduced; although, data collected on Saturdays and Sundays was never used. Poor weather conditions, camera and/or videotape malfunctions, or power outages account for the discrepancies in day and time intervals reduced for each camera view.

Lane Change Data

Three types of data were collected from the video tapes: lane changes, erratic maneuvers, and volume counts. A lane change was recorded if a vehicle either entered or exited an option or exit only lane. For a one-lane exit, a lane change was recorded only if a motorist moved into or out of 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 finally from Lane 3 into Lane 1 were recorded. Table 16 illustrates a typical raw data entry table for a one-lane exit. The erratic maneuvers were recorded below the lane changes at the base of the table. Type, zone of origination, and video times were recorded for each erratic maneuver in these spaces.

Table 16. Typical Raw Data Entry Form for a One-Lane Exit.

ZONE	1 to 2	2 to 1	1 to 3	3 to 1
1				
2				
3				
4				
5				

Erratic Maneuvers:	1.	2.	3.	4.	5.
type (zone)	6.	7.	8.	9.	10.

For a two-lane exit with an option lane, the lane change possibilities increased greatly. With the two-lane exit, lane changes in and out of the exit only lane had to be recorded, along with lane changes involving the optional exit lane. Table 17 represents a typical raw data entry form for upstream zones of a two-lane exit with an option lane and an exit only lane.

Table 17. Typical Raw Data Entry Form for a Two-Lane Exit with an Option Lane.

Zone	1 to 2	2 to 1	3 to 2	2 to 3	1 to 3	3 to 1
5						
6						
7						
8						

Erratic Maneuvers: 1. 2. 3. 4. 5.
type (zone) 6. 7. 8. 9. 10.

Zones within 300 ft (91.5 m) of the gore on a two-lane exit with an option lane and an exit only lane required another type of entry form. This additional version was necessary because of the distinction between the exiting portion (2E) and the through portion (2T) of the option lane in this area. The raw data entry table shown in Table 18 contains the possible lane changes to be recorded for this portion of a two-lane exit with an option lane.

Table 18. Typical Raw Data Entry Form for Zones near the Gore of a Two-Lane Exit with an Option Lane and an Exit Only Lane.

Zone	1-2E	2E-1	2E-2T	2T-2E	3-2T	2T-3	1-2T	2T-1	2E-3	3-2E
1										
2										
3										

Erratic Maneuvers: 1. 2. 3. 4. 5.
type (zone) 6. 7. 8. 9. 10.

Lane change data were reduced in 15-minute intervals. A separate data entry table was used for each 15-minute interval and that time was recorded with each table. The person viewing the video tapes recorded a lane change and the zone from which it originated by entering a tally into the correct block on the data entry table. The zone from which the lane change originated was defined as the zone in which the vehicle's first wheel crosses over the pavement markings separating the lanes.

A single lane change occurred when a motorist moved out of one lane and into an adjacent lane. For example, a maneuver from Lane 1 into Lane 2 was considered a single lane change. An erratic lane change involved a motorist moving out of a lane, across an adjacent lane, and into a third lane. An example of an erratic lane change was a maneuver out of Lane 1, across Lane 2, and into Lane 3. The portion of Lane 2 (the optional lane) within 300 ft of the gore contained additional types of erratic lane changes because the exiting and through portions of the optional lane were considered separate lanes. For example, a lane change from Lane 1, across Lane 2E, and into Lane 2T, was considered a two-lane, lane change (or erratic maneuver). By noting the beginning and the ending lanes for each lane change, a determination of whether or not the movements were erratic was made.

Erratic Maneuver Data

Erratic maneuvers were also recorded for all fifteen minute intervals in the spaces provided under the lane change tables (see Tables 16 to 18). The locations of erratic maneuvers were determined with the same criteria as lane changes. In addition to location, the type of erratic maneuver was also designated with one of the following number codes:

(1) One-lane, lane change through the gore.
(2) Two-lane, lane change not recorded in raw data entry form.
(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) Swerving in lane and back out / Attempted lane change.
(9) In/out of shoulder.
(10) Rode in between two lanes on solid white line.
(11) Rode through grass.

A one-lane, lane change was not considered erratic unless the vehicle drove across or into the gore. All two-lane, lane changes were considered erratic maneuvers, but only two-lane lane changes that were not recorded in the lane change data tables were noted below in the erratic maneuvers portion of the data form.

Traffic Counts

Traffic volumes were also obtained from the video tapes. The volumes were recorded for each freeway lane and were made for a minimum of fifteen minutes at the beginning of each hour. The vehicles were counted as they passed the point of the painted gore. If a site contained other exits upstream of the lane drop, volume counts were performed at those exits.

Equipment

To extract the information from the video tapes, a VCR with an editor was utilized. The VCR editor allowed the video tapes to be viewed at twice normal speed, half normal speed, or in a frame-by-frame fashion. When a lane change or erratic maneuver occurred, rewinding the video tape and viewing the maneuver at a slower speed was necessary to determine the zone in which the maneuver originated or to define the maneuver.

Compilation of Data

Once the information was extracted from the video tapes, the data were entered into computerized spreadsheets, as illustrated in Figure 25. A spreadsheet was created for each zone of each site. The entries in the spreadsheets included the actual time interval reduced and the lane change count, or the erratic maneuver count for the particular 15-minute time interval. The data were adjusted to a 15-minute interval and a 100-ft (30.5 m) zone length 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 (see bottom portion of Figure 25 for an example).

DATA ANALYSIS

Once the lane change and erratic maneuver data were obtained for each zone within a site, the next step combined the individual zone data into one file for a site. To calculate the number of lane changes or erratic maneuvers required that the time periods used within each zone be consistent. For example, the zones recorded by the camera which always had its VHS tape changed last could lag 15-minutes behind the other recordings because of the time required to physically move from one controller cabinet to another. In this situation, only the time periods available for all zones would be used. Generally, data were available for each zone between the hours of 7:00 a.m. and 6:00 p.m. Exceptions were those sites filmed during the winter months. They generally had fewer time periods reduced due to available light. The lane change and erratic maneuver data were then summarized for the time periods available for all zones.

Site number Day 1 = date, day of week; Day 2 = date, day of week

Start Time	End Time	Actual Time Reduced		Lane Changes from Lane 1 to Lane 2: Raw Data		Time Adj		Len Adj		Average
		day 1	day 2	day 1	day 2	day 1	day 2	day 1	day 2	
6:45	7:00	15	15	0	0	0	0	0	0	0
7:00	7:15	15	15	0	0	0	0	0	0	0
7:15	7:30	15	15	1	0	1	0	1	0	0.5
7:30	7:45	15	15	0	0	0	0	0	0	0
7:45	8:00	15	15	0	0	0	0	0	0	0
8:00	8:15	15	15	0	0	0	0	0	0	0
8:15	8:30	15	15	0	0	0	0	0	0	0
8:30	8:45	15	15	0	0	0	0	0	0	0
8:45	9:00	15	15	0	0	0	0	0	0	0
9:00	9:15	15	15	0	0	0	0	0	0	0
9:15	9:30	15	15	0	0	1	0	1	0	0.5
9:30	9:45	15	15	0	0	0	0	0	0	0
9:45	10:00	15	15	0	0	0	0	0	0	0
10:00	10:15	15	15	0	0	0	0	0	0	0
10:15	10:30	15	15	0	0	0	0	0	0	0
10:30	10:45	15	15	0	0	0	0	0	0	0
10:45	11:00	15	15	1	0	1	0	1	0	0.5
11:00	11:15	15	15	1	0	1	0	1	0	0.5
11:15	11:30	15	15	1	1	1	1	1	1	1.0
11:30	11:45	15	15	0	0	0	0	0	0	0
11:45	12:00	15	15	0	0	0	0	0	0	0
12:00	12:15	10	11	0	0	0	0	0	0	0
12:15	12:30	15	15	0	0	0	0	0	0	0
12:30	12:45	15	15	0	4	0	4	0	4	2.0
12:45	1:00	15	15	0	0	0	0	0	0	0
1:00	1:15	15	15	0	0	0	0	0	0	0
1:15	1:30	15	15	0	1	0	1	0	1	0.5
1:30	1:45	15	15	0	0	0	0	0	0	0
1:45	2:00	15	15	0	0	0	0	0	0	0
2:00	2:15	15	15	0	0	0	0	0	0	0
2:15	2:30	15	15	0	0	0	0	0	0	0
2:30	2:45	15	15	0	1	0	1	0	1	0.5
2:45	3:00	15	15	0	0	0	0	0	0	0
3:00	3:15	15	15	0	0	0	0	0	0	0
3:15	3:30	15	15	0	0	0	0	0	0	0
3:30	3:45	15	15	1	0	1	0	1	0	0.5
3:45	4:00	15	15	0	0	0	0	0	0	0
4:00	4:15	15	15	1	0	1	0	1	0	0.5
4:15	4:30	15	15	1	0	1	0	1	0	0.5
4:30	4:45	15	15	0	0	0	0	0	0	0
4:45	5:00	15	15	0	0	0	0	0	0	0
5:00	5:15	15	15	1	1	1	1	1	1	1.0
5:15	5:30	15	15	0	0	0	0	0	0	0
5:30	5:45	15	15	0	1	0	1	0	1	0.5
5:45	6:00	15	15	0	0	0	0	0	0	0
6:00	6:15	15		0		0		0		0
									Total for the day	9
									Typical hour (average of all 15-minute periods * 4)	0.77

Figure 25. Sample Data Extracted for a Particular Lane Change and Zone.

Another consideration for the before-and-after studies was the length of the study segment. For example, if differing amounts of zones were visible on the monitor in the before period and in the after period, only those zones common to both periods could be used in comparisons. The number of lane changes or erratic maneuvers was calculated across those zones common to both the before-and-after period, and also across time periods common to both periods.

Generally, four hourly values were sought for each site: the number of lane changes and erratic maneuvers for the entire study length, and the number of lane changes and erratic maneuvers for the 300 ft (91.5 m) nearest to the gore. The hourly values for the entire study length provided an appreciation of the quantity of lane changes (or erratic maneuvers) occurring at the site. Because of concern with inappropriate driving behavior near gore areas, the 300 ft (91.5 m) nearest to gore value was also determined. Constant length and constant time value also permitted general comparisons between sites. Accounting for volume, geometric configuration, and other factors was required for direct comparisons. The hourly volumes were calculated by dividing the total number of lane changes for a zone, or for all zones, by the number of 15-minute intervals reduced and then multiplying by 4 to obtain an hourly value.

Observations of lane change behavior in the field, and findings from other studies indicated that the location where more drivers are moving into or out of the exit lane(s) 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 was also calculated. For the sites with high volume and noticeable levels of congestions, comparisons between peak and non-peak periods were developed.

Graphical representatives of the values calculated were valuable tools in evaluating the findings. Initially, the findings were plotted by the 100-ft (30.5 m) increments used to reduce the data. These plots, while revealing the trends in the data, also showed the variability that exists between such short increments -- a driver can cover the 100-ft (30.5 m) increment in 1.2 seconds when driving 55 mph (89 km/h). The data were then grouped into 300-ft (91.5 m) zone groups so that the trends would still be present; however, the distracting data variability was minimized. When only two 100-ft (30.5 m) zones were available to create a zone group, the data were adjusted to reflect a 300-ft (91.5) length so that reasonable comparisons could be made between zone groups within a site. Both the 300-ft (91.5 m) and 100-ft (30.5 m) plots are included in this report -- the 300-ft (91.5 m) plots were used in the main portion of the report while the 100-ft (30.5 m) plots are included in the appendix. Necessary plots were then generated for each site. The data were also evaluated using appropriate statistical tests.

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

CHAPTER 5

SITE SELECTION

SITE IDENTIFICATION

Identifying and selecting study sites is critical in a field study. A comprehensive approach to identifying exit lane drop situations was desired in order to have the best possible range of potential sites for the data collection efforts. In developing a comprehensive list of potential data collection sites, the characteristics of a site most needed to make a decision regarding site selection need to be identified. The list of characteristics for this project included type of exit configuration, type of pavement markings, number of signs and phrasing on each, length of exit lane, number of through lanes, and others. Because no known database currently exists with this information regarding exit lane drops in Texas, other methods for obtaining the information were examined.

Exit lane drop sites were identified by video taping freeways in major Texas cities. Video taping allowed the research team to view the tape in-house and record necessary observations. A video log of specific freeways was produced in eight major cities within Texas, as listed in Table 19. The freeways were recorded by placing a video camera on the passenger side of a vehicle and filming as the vehicle drove along the freeway. In this way, signs, pavement markings, lengths of the exits, and other characteristics were captured on video, and could be referred to at any time in-house.

Table 19. Cities and Freeways Contained in Video Log.

City	Freeway
Amarillo	I-40, I-27
Austin	US 290, Loop 1, US 183, I-35
Beaumont	I-10, US 69
Dallas	I-635, I-20, I-35E, I-45, US 75
Fort Worth	I-820, I-35W
Houston	I-610, I-10, I-45, US 225, US 290, US 59, US 288
San Antonio	I-10, I-35, I-37, I-410, US 281, US 90
Waco	I-35

Once a video record of freeways in the specified cities was obtained, the videos were viewed and a sketch of each exit lane drop was drawn. The diagram showed the number of lanes on the freeway, the number of signs related to the exit, phrasing on the signs and pavement, pavement markings, entrances, other exits, and the exit lane drop configuration.

In addition to drawing diagrams of each exit lane drop in the cities, a database was created in which characteristics of each lane drop were entered. The database included a total of 190 exit lane drops for seven of the eight cities. The data entered for each lane drop is shown in Table 20. San Antonio was excluded from the database because the majority of the city's sites have pavement arrows and EXIT ONLY phrasing in advance of the lane drop gore. These markings eliminated the sites from use as a field study location.

Most of the data entered into the database was obtained from the video or the diagrams drawn of each site. Some of the entries, such as the exit lane length and the distance to the nearest upstream ramp, were difficult to obtain from the video unless distances on signs were given, or mile markers could be seen. In most cases, exit lane lengths were estimated from distances given on signs not necessarily pertaining to the exit. Lane lengths were often recorded as "less than" or "greater than" an estimated length. In some cases, an exit lane drop site was revisited by the research team, and lane lengths were measured in order to confirm estimates from the video, or to update the database.

The database allowed easy manipulation of the exit lane drop inventory. For instance, if one-lane exit lane drops with "typical" geometry needed to be investigated (i.e., sites without left exits, lane splits of the exit lane after the lane dropped, auxiliary lanes, or two exit lane drops within 1/4 mile (0.4 km) of each other), they could easily be extracted from the database. An example of the database from which one-lane exit lane drops with no geometric modifications (i.e., "typical" exits) were extracted is shown in Figure 26. Although some of the entries, such as sign phrasing, seem to be truncated, their column widths were reduced in order to position the figure in this report. The database contains the entire entry. Table 20 includes the descriptions of the database codes used in Figure 26.

SITE SELECTION

A very important step in collecting quality data for any study is to select sites most appropriate for the type of data required. In this study, erratic movements and lane changes at exit lane drops were the data required for collection. Consequently, sites needed to be chosen where other influences around the exit lane drop that may cause erratic movements or lane changes are limited. In addition, the sites had to be accessible for data collection. They had to provide relatively easy and safe video camera mounting around the exit lane drop so that approximately 1500 ft (457 m) upstream of the gore could be captured on video.

Table 20. List of Database Entries.

Database Entry	Database Abbrev.	Database Coded Entry Explanations
City	CIT	1 = Amarillo, 2 = Austin, 3 = Beaumont, 4 = Dallas, 5 = Fort Worth, 6 = Houston, 7 = San Antonio, 8 = Waco
Freeway	RTE	Route number of freeway from which a vehicle would exit
Direction of Freeway	DIR	N = North, S = South, E = East, W = West, B = Both
Exit Street	EXIT	Route number or street name of road to which a vehicle would exit
Direction of Exit Street	DIR	N = North, S = South, E = East, W = West, B = Both
Number of Exit Lanes	EL	1 = One-lane, lane drop exit; 1.5 = Two-lane exit with an option lane and an exit only lane; 2 = Two-lane, lane drop exit; 2.5 = Three-lane exit with an option lane and two exit only lanes
Geometric Modification of Exit Lane Drop	MOD	1 = Left exit, 2 = Auxiliary lane, 3 = Lane split of exit lane, 4 = Two-lane drops occurring within 1/4 mile (0.4 km) of each other on the same side of the road, 5 = Geometric modification 4 except on opposite sides of the road
Number of Through Lanes	LN	1-9 = Actual number of lanes, including exit lane(s), prior to gore, in one direction, 0 = Not known
Existence of Solid White Line	S	S = Solid white line exists, [blank] = No solid white line before exit
Existence of Pavement Arrows	AR	A = Pavement arrows are on the pavement, [blank] = No pavement arrows on the pavement
Existence of Special Markings	EP	E = Special lane drop markings are used at the exit, [blank] = No lane drop markings used at the exit
Existence of Pavement Phrasing	VR	V = EXIT ONLY is written on the pavement, [blank] = No phrasing on the pavement
Number of Signs	SN	0-10 = Actual number of signs pertaining to exit lane drop
Phrasing on Sign	SIGN[#]	Actual sign phrasing of each sign
Existence of "EXIT ONLY" Panel	YP[#]	Y = Yellow EXIT ONLY panel is on exit sign, N = Yellow EXIT ONLY panel is not used
How Each Sign is Mounted	O/R	O = Sign is mounted overhead, R = Sign is mounted on a pole on either side of the road

Table 20 Con't. List of Database Entries.

Database Entry	Database Abbrev.	Database Coded Entry Explanations
Estimated Length of Lane Drop	EST1, LEN	0-10 = Length of exit lane in tenths of a mile, ">" = Length is the minimum, "<" = Length is the maximum, "=" = Length is the actual length
Reason for Lane Drop	R	1 = Decreased demand, near limits of city; 2 = High demand exit to another freeway; 3 = High demand exit to a street
Type of Nearest Upstream Ramp	U	1 = Entrance ramp, 2 = Exit ramp
Estimated Distance to Upstream Ramp	EST2, RAM	0-10 = Distance to nearest ramp in tenths of a mile, ">" = Length is the minimum, "<" = Length is the maximum, "=" = Length is the actual length
Reason for Eliminating Site	PROB	1 = Exit lane too short, not well established; 2 = Construction in vicinity; 3 = Filming traffic would be difficult 4 = Presence of lane drop markings
General Comments Regarding Site	CO	1 = Lanes are narrow, 2 = Construction in the vicinity, 3 = Filming traffic would be difficult, 4 = Raised pavement markers present, 5 = Heavy weaving caused by other entrance/exit, 6 = Very high volumes, 7 = Lane drop created by upstream entrance ramp

Conversion Factor: 1 mile = 1.61 km

* SINGLE LANE EXIT LANE DROPS, NO GEOMETRIC MODIFICATIONS

CIT	RTE	DIR	EXIT	DIR	EL	MOD	LN	S	AR	EP	VR	SN	SIGN1	YP1	O/R	SIGN2	YP2	O/R	SIGN3	YP3	O/R	SIGN4	YP4	O/R	EST1	LEN	R	U	EST2	RAM	PROB	CO
2	I35	N	US183	B	1		4	S				2	183 LAMPA	N	O	183 LAMPA	Y	O							=	4.8	2	1	<	0.75		
4	I45	N	WASHIN	W	1		4					3	WASHINGT	Y	O	WASHINGT	Y	O	WASHINGT	Y	O				>	2.8	3	2	=	0.5		
6	I610S	E	I45/US7	S	1		4	S				5	SOUTH 45 7	N	O	SOUTH 45	N	O	RIGHT LAN	N	R	SOUTH 45 7	Y	O	>	2.3	2	2	=	0.25		5
4	I35E	S	I20	W	1		3					4	20 SHREVE	N	O	20 WEST FT	N	O	20 WEST FT	Y	O	20 WEST FT	Y	O	>	1.7	2	2	=	0.25		
5	I35W	S	I30W	W	1		3					2	I30 I80 WES	Y	O	I30 I80 WES	Y	O								1.7						
4	I635	S	I175	E	1		5					4	175 KAUFM	N	O	175 EAST K	Y	O	175 EAST K	Y	O	175 EAST K	Y	O	>	1.5	2	1	=	0.25		
6	US59	S	I45	B	1		4	S				4	45 GALVES	N	O	45 GALVES	Y	O	RIGHT LAN	N	R	45 GALVES	Y	O	>	1.5	2					
6	US290	W	W 43RD	B	1		4	S				4	W 43RD ST	Y	O	W 43RD ST	Y	O	RIGHT LAN	N	R	W 43RD ST	Y	O	>	1.5	3					
4	I635	W	TX121	N	1		3	S				3	TEXAS 121	N	O	TEXAS 121	Y	O	TEXAS 121	Y	O				>	1.5	3	1	<	0.75		
6	I610N	E	HARDY	B	1		5	S				3	HARDY TOL	Y	R	HARDY TOL	Y	O	HARDY TOL	Y	O				=	1.3	3					
6	I10	W	WIRT R	B	1		4	S				3	WIRT RD EX	Y	R	WIRT RD EX	Y	O	WIRT RD 1	N	O				=	1.2	3					
2	LOOP1	S	US183	S	1		3					3	SOUTH 183	N	O	183 SOUTH	N	R	SOUTH 183	Y	O				>	1.2	2	2	<	1.2		
5	I820	E	TX199 F	B	1		4					3	TEXAS 199	N	O	TEXAS 199	Y	O	TEXAS 199	Y	O				>	1.2	3	2	=	0.75		
6	I45	N	AIRLINE	B	1		5	S				3	AIRLINE DR	Y	O	RIGHT LAN	N	R	AIRLINE DR	N	O				>	1.1	3					
4	US75	S	YALE BL	W	1		3	S				3	YALE BLVD	Y	O	YALE BLVD	Y	O	YALE BLVD	Y	O				>	1.1	3	2	=	0.25		
1	I27	S	HILLSID	W	1		3	S				2	WEST HILLS	Y	O	HILLSIDE R	Y	O							>	1.1	3	2	=	0.25		
6	I45	S	HOWAR	B	1		4	S				4	HOWARD D	Y	O	HOWARD D	Y	O	RIGHT LAN	N	R	HOWARD D	Y	O	>	1.1	3					4
6	SH225	E	ALLEN-	B	1		4	S				2	ALLEN GEN	Y	O	ALLEN GEN	Y	O							>	1.1	3					
5	I820	E	CAMPU	B	1		5					3	CAMPUS D	Y	O	CAMPUS D	Y	O	CAMPUS D	Y	O				>	1.1	3	1	<	1.1		
2	LOOP1	N	ENFIEL	B	1		3	S				2	ENFIELD R	Y	O	ENFIELD R	Y	O							=	1.02	3					
5	I820	S	I30	W	1		4					4	30 1 1/2 MIL	N	O	30 FT WOR	N	O	30 WEST W	N	O	30 WEST W	Y	O	=	1	2	2	<	0.5		
6	I10	E	WASHIN	B	1		6	S				3	WESTCOTT	N	O	RIGHT LAN	N	R	WASHINGT	Y	O				>	1	3					
5	I820	N	WHITE	B	1		4					3	WHITE SET	N	O	WHITE SET	Y	O	WHITE SET	Y	O				=	1	3	1	>	0.5		
6	I610S	W	N. BRAE	B	1		4					4	S. BRAESW	Y	R	RIGHT LAN	N	R	S. BRAESW	Y	O	S. BRAESW	N	O	>	1	3					4
6	I610N	E	HARDY	B	1		6	S				2	HARDY ST.	Y	O	HARDY ST.	Y	O							=	1	3					
5	I820	S	US80 F	B	1		3					3	80 FM303 L	Y	O	80 FM303 L	Y	O	80 FM303 L	Y	O				>	0.9	3	2	<	0.9		
5	I820	E	HULEN	B	1		3					3	HULEN ST S	N	O	HULEN ST S	Y	O	HULEN ST S	Y	O				>	0.8	3	2	=	0.75		
5	I820	S	LAS VE	B	1		4					2	LAS VEGAS	Y	O	LAS VEGAS	Y	O							>	0.8	3					
6	I45	S	PARK P	B	1		5	S				3	PARK PLAC	Y	O	RIGHT LAN	N	R	PARK PLAC	Y	O				>	0.7	3					
5	I820	W	OLD DE	B	1		4					3	OLD DECAT	N	O	OLD DECAT	Y	O	OLD DECAT	Y	O				=	0.6	3					
5	I35W	N	FELIX S	E	1		4					2	FELIX ST EX	Y	O	FELIX ST EX	Y	O							>	0.6	3	2	<	0.6		
3	I10	W	11TH ST	B	1		4					3	11TH ST 1/2	Y	O	11TH ST EXI	Y	O	11TH ST EXI	Y	O				>	0.5	3					
4	I635	E	I75	S	1		4	S				2	75 SOUTH	Y	O	75 SOUTH	Y	O							>	0.5	2	2	=	0.4		
6	I45	S	CAVALC	B	1		5	S				3	CAVALCAD	N	R	RIGHT LAN	N	R	CAVALCAD	Y	O				>	0.2	3					

* See Table 20 for explanations of the abbreviations.

Figure 26. Sample of Data in the Exit Lane Drop Database.

Conversion Factor: 1 mile = 1.61 km

The field studies were designed to be before-and-after studies. The initial intent of the field study was to couple the before-and-after studies with control site studies. New pavement markings would then be installed at only one site of each pair of sites. This plan was revised during the course of the study. While some pairs appeared to be comparable, additional information gathered during data collection indicated that the sites were not as similar as initially suspected. Extensive statistical adjustments of the data may have permitted direct comparison of findings for each pair of sites, but the decision was made to emphasize other elements of the field studies rather than the control site requirement. The emphasis of the second part of the field studies, known as Phase II, was to locate sites with unusual qualities or sites with known or suspected high levels of lane change behavior.

Phase I Site Selection

Phase I site selection efforts concentrated on selecting exit lane drops for data collection with minimal influences on driver behavior other than the lane drop. The process started by determining what characteristics an optimum site should or should not have. The following is a list of conditions or criteria by which an identified exit lane drop was *excluded* from further consideration as a data collection site:

- presence of "atypical" geometrics (e.g., left exit, two exit only lane drops occurring with 0.25 miles (0.4 km), etc.).
- road construction in the vicinity.
- exit lane drops less than 0.5 mile (0.8 km) (later revised to 1 mile or 1.61 km).
- more than two other upstream exit or entrance lanes in a 1500-ft (457 m) study section.

Because of the desire to test the effects of special markings, a site was also excluded from consideration if the following type of pavement markings were present:

- any lane drop markings.
- EXIT ONLY phrasing on pavement.
- any thermoplastic or painted pavement arrow(s).

The above criteria eliminated all San Antonio sites from consideration. As a result, the San Antonio lane drop data were not entered into the database. Other considerations used to eliminate sites included:

- difficult filming due to inaccessibility of sign structures, or security of camera equipment.
- guide signs not containing yellow EXIT ONLY panel.

Of the 190 entries in the database, 104 potential sites met Phase I requirements ("typical" geometry). The first attempt at selecting sites in the Phase I effort included any exit lane drops with lane lengths that could have been greater than 0.5 miles (0.8 km). After eliminating sites with lengths less than 0.5 miles (0.8 km), approximately 76 percent of the identified lane drops remained in the database. Next, sites with the above criteria were eliminated. Because Amarillo, Waco, and Austin consistently use either pavement arrows, special markings, or EXIT ONLY phrasing on the pavement, most of their sites were eliminated. Table 21 presents the number of lane drops in the database that were rejected or accepted based on the criteria listed above for Phase I type lane drops.

Table 21. Frequency of Lane Drops with No Geometric Modification as Sorted in the Database Based on Specific Criteria.

Sorting Criteria	Number of Exiting Lanes					Total
	One	Two, With One Optional	Two	Three, With One Optional	Three	
All Sites	66	25	11	1	1	104
Exit Lane Lengths < 0.5 miles	9	3	1	0	0	13
All Other Rejection Criteria*	10	0	2	0	0	12
Total Remaining Sites	**47**	**22**	**8**	**1**	**1**	**79**

* Road construction, any lane drop markings, EXIT ONLY phrasing on pavement, etc.
Conversion Factor: 1 mile = 1.61 km

Originally, the research team desired to identify "pairs" of sites in order to implement a control site analysis. In this way, changes in conditions because of influences other than the lane drop markings could be monitored. Criteria used to identify potential pairs included:

- two sites in the same city and preferably near each other so that the drivers using the exits are similar.
- similar traffic volumes and geometrics (i.e., number of freeway lanes, etc.).
- similar types of signs.

As shown in Table 21, few sites (10) were available with two or more exiting lanes; therefore, emphasis was placed on selecting sites from the one-lane, lane drop exit and the two-lane exit with an option lane and an exit only lane categories. Using the above-mentioned criteria, two pairs of sites were selected. The first set of lane drop sites selected for data collection are located in the Houston District, and are two-lane exits with an option lane and an exit only lane. These two sites are illustrated in Figures 27 and 28, and are:

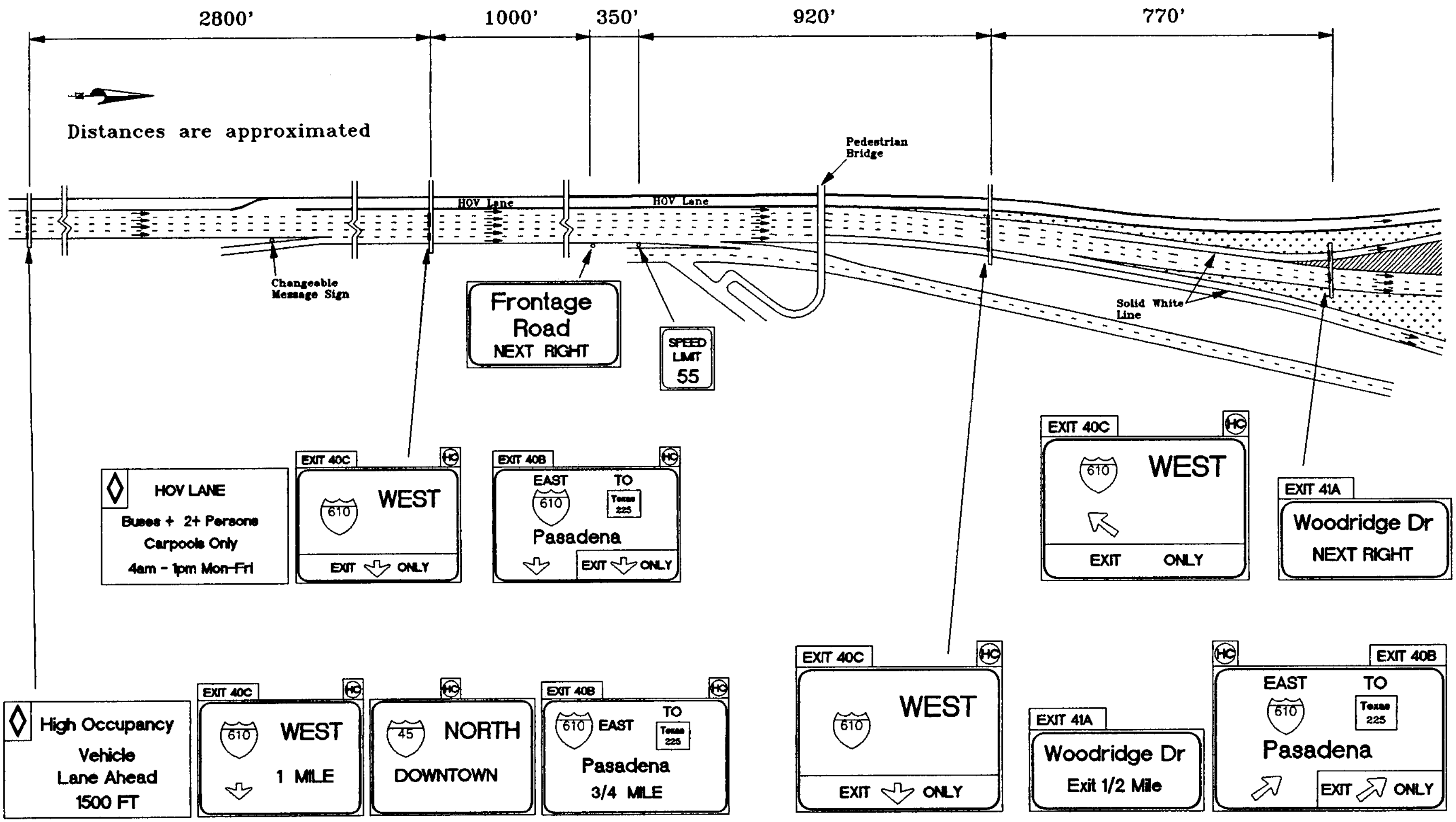


Figure 27. Site 1: Interstate 45 Northbound at Interstate 610 Westbound and Eastbound and Texas 225.

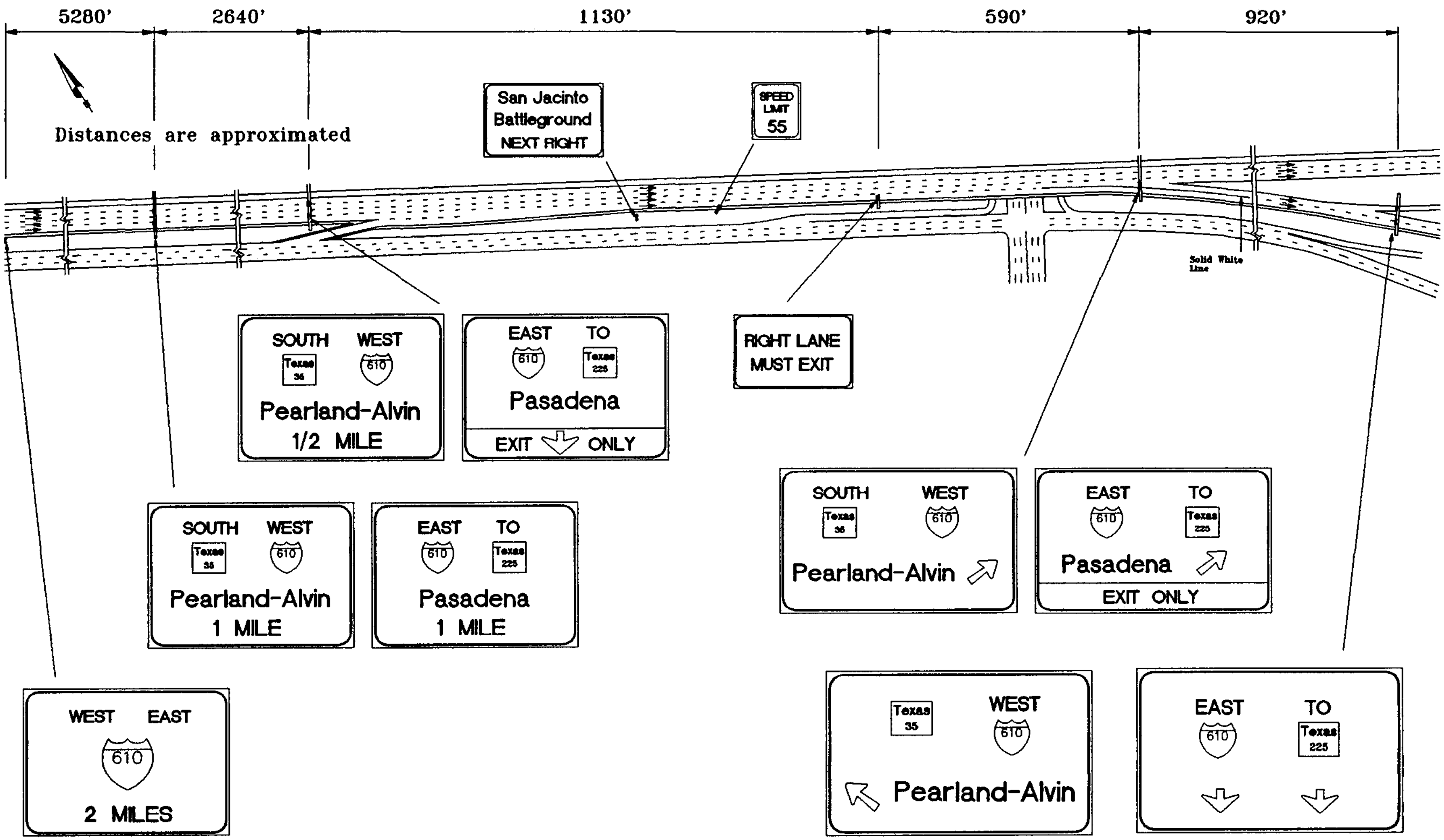


Figure 28. Site 2: Interstate 45 Southbound at Interstate 610 Eastbound and Westbound, Texas 225, and Texas 35.

- I-45 northbound to I-610 East and Texas 225.
- I-45 southbound to I-610 East and West, Texas 225, and Texas 35.

The second pair of lane drop sites are located in the Fort Worth District, and are one-lane, lane drop exits. The two sites are listed below and are illustrated in Figures 29 and 30, respectively.

- I-820 northbound to White Settlement Road.
- I-820 southbound to Old Decatur Road.

After data collection efforts began on the four Phase I sites, and additional detailed information was obtained on each site, the length of the exiting lane at the I-820 SB to Old Decatur Road site was determined to be slightly less than 0.5 miles (0.8 km). This project is concerned with how drivers, who believe they are on a continuous freeway lane, behave when their travel lane is forced to exit, so an exit lane drop of less than a half mile (0.8 km) was deemed as being too short. Using one mile (1.61 km) as the new exit lane length criteria, an additional 13 one-lane, lane drop exits, 3 two-lane exits with an option lane and an exit only lane, and 1 two-lane, lane drop exit were excluded from further consideration, leaving approximately 60 percent of the original Phase I database from which to choose an additional site. Another one-lane, lane drop site was selected from the database using a one-mile (1.6 km) minimum constraint. The site selected had a lane drop length of over seven miles (11.3 km) and is located in Dallas at I-35E southbound to I-20 westbound. The site is shown in Figure 31.

Because before data was collected at the Old Decatur site, it was retained in the field study plan. This site provides insight into the operations of a short exit only lane (or auxiliary lane), and it is a control site for the other Fort Worth site.

Phase II Site Selection

The Phase II site selection efforts concentrated on "atypical" exit lane drops. The database was a good source for identifying these lane drops because one of the entries in the database offered descriptions of atypical lane drops. Districts also offered suggestions on lane drops with atypical geometric designs and/or high numbers of lane changes. Table 22 presents the number of lane drops in the database that were rejected or accepted based on the same criteria listed in the *Phase I Site Selection* section, except that "typical" exits were excluded from Phase II selections, and the exit lane length criteria was based on one mile or 1.6 km.

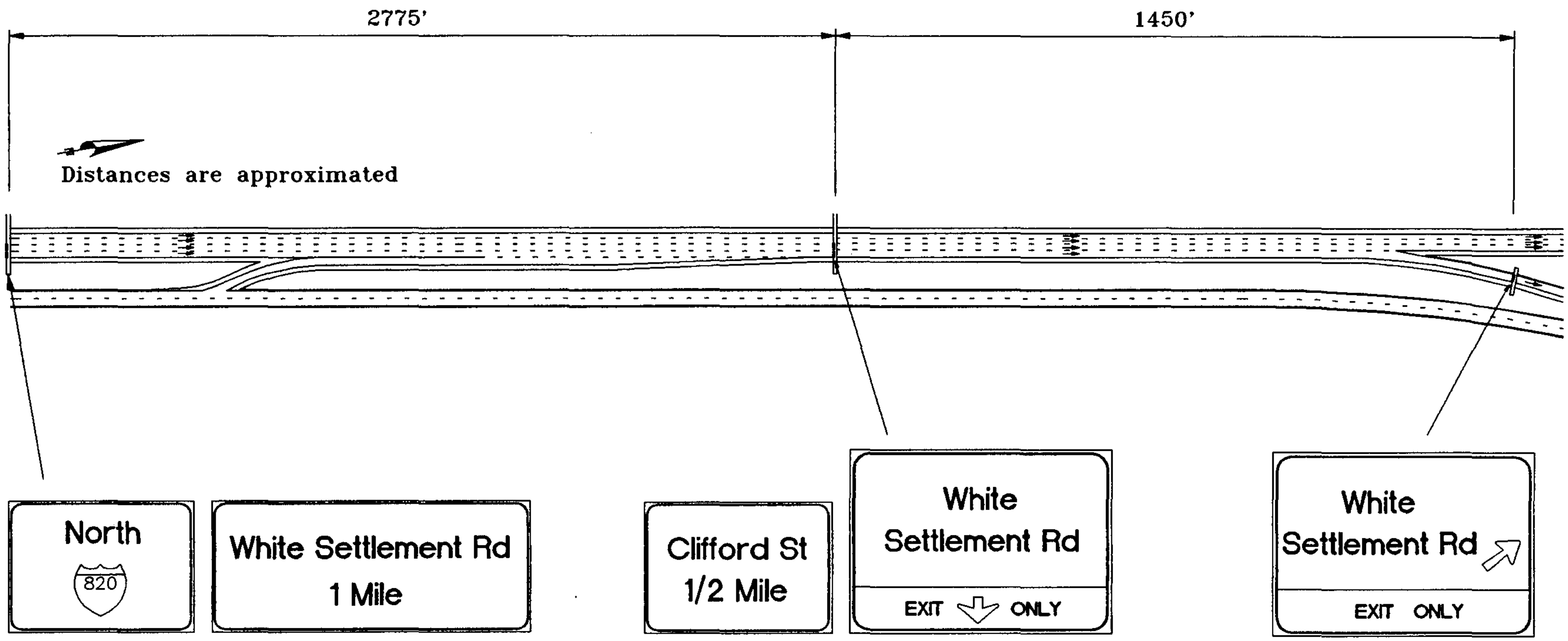
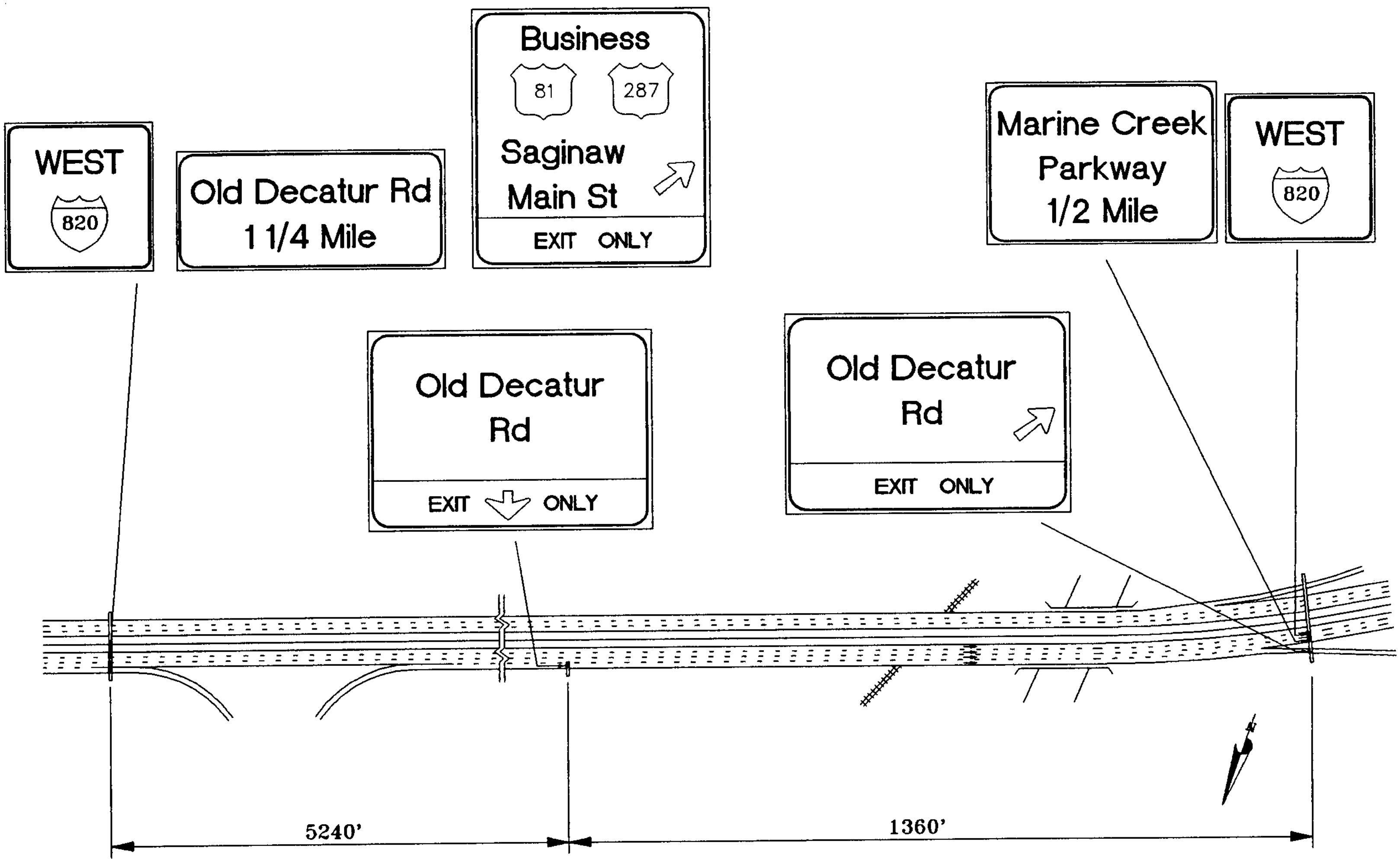


Figure 29. Site 3: Interstate 820 Northbound at White Settlement Road.

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



Distances are approximated

Figure 30. Site 4: Interstate 820 Southbound at Old Decatur Road.

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

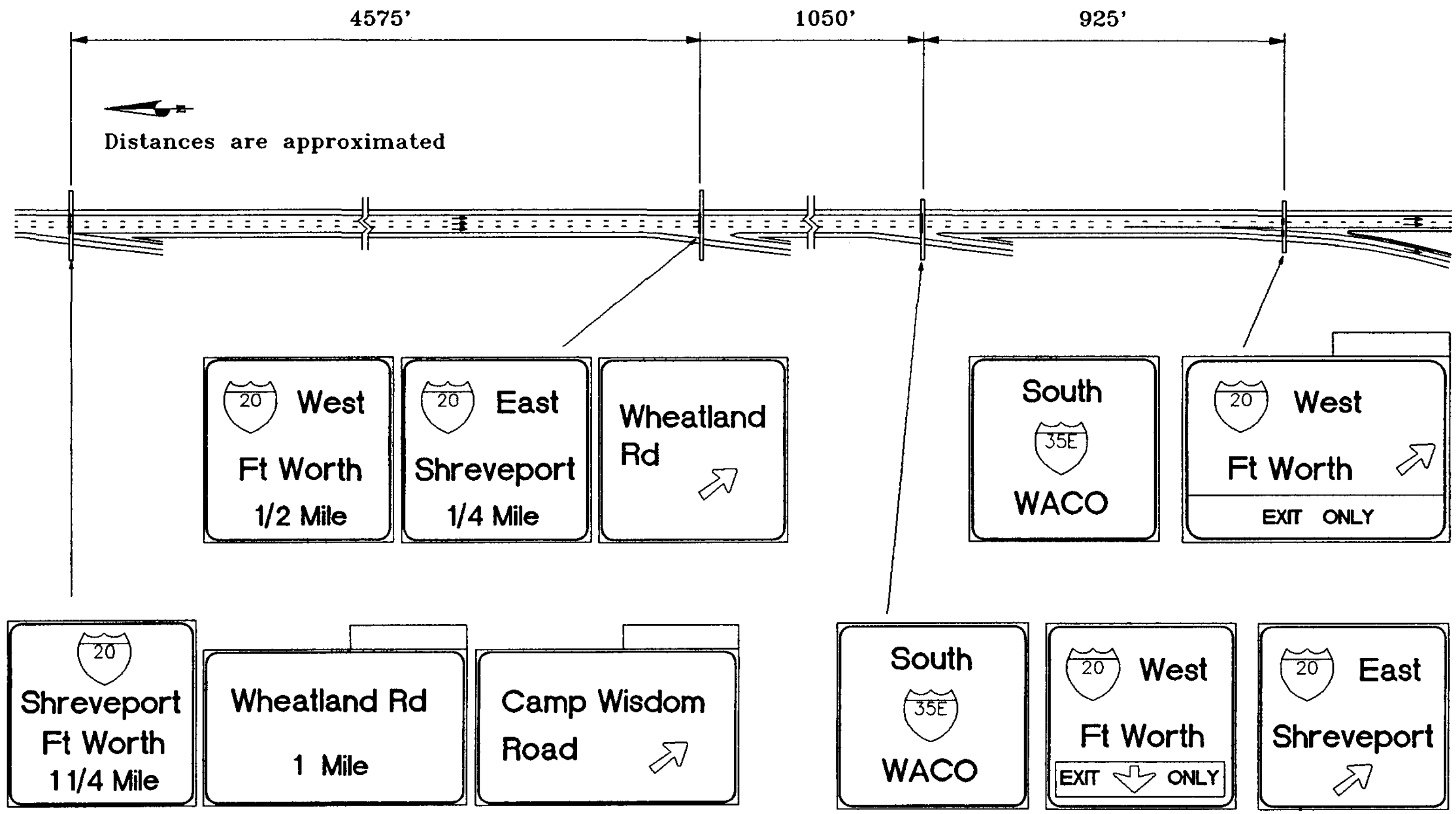


Figure 31. Site 7: Interstate 35E Southbound at Interstate 20 Westbound.

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

Table 22. Frequency of Lane Drops with Geometric Modifications as Sorted in the Database Based on Specific Criteria.

Sorting Criteria	Number of Exiting Lanes					Total
	One	Two, With One Optional	Two	Three, With One Optional	Three	
All Sites	51	29	5	0	1	86
Exit Lane Lengths < 1 mile	36	8	2	0	0	46
All Other Rejection Criteria*	4	2	2	0	0	8
Total Remaining Sites	**11**	**19**	**1**	**0**	**1**	**32**

* Road construction, any lane drop markings, EXIT ONLY phrasing on pavement, etc.
Conversion Factor: 1 mile = 1.61 km

Thirty-two of the 86 "atypical" sites (37 percent) remained in the database after eliminations were made. Of the remaining sites, two sites were selected for the Phase II effort. They are:

- I-45 Northbound to I-610 West.
- I-610W Southbound to South Post Oak.

These sites are shown in Figures 27 and 32, respectively. The I-45 northbound to I-610 West site is a one-lane exit to the left and is located just downstream of a Phase I site. The other site is a two-lane exit with an option lane and an exit only lane on the right side of the road. This second site was recommended by the Houston District because the exit lanes are straight, while the mainlanes curve to the left.

Sites Selected

Table 23 lists the seven sites selected and used in the field studies. The table also lists the districts responsible for the sites, the exit lane configurations, and the exit lane lengths.

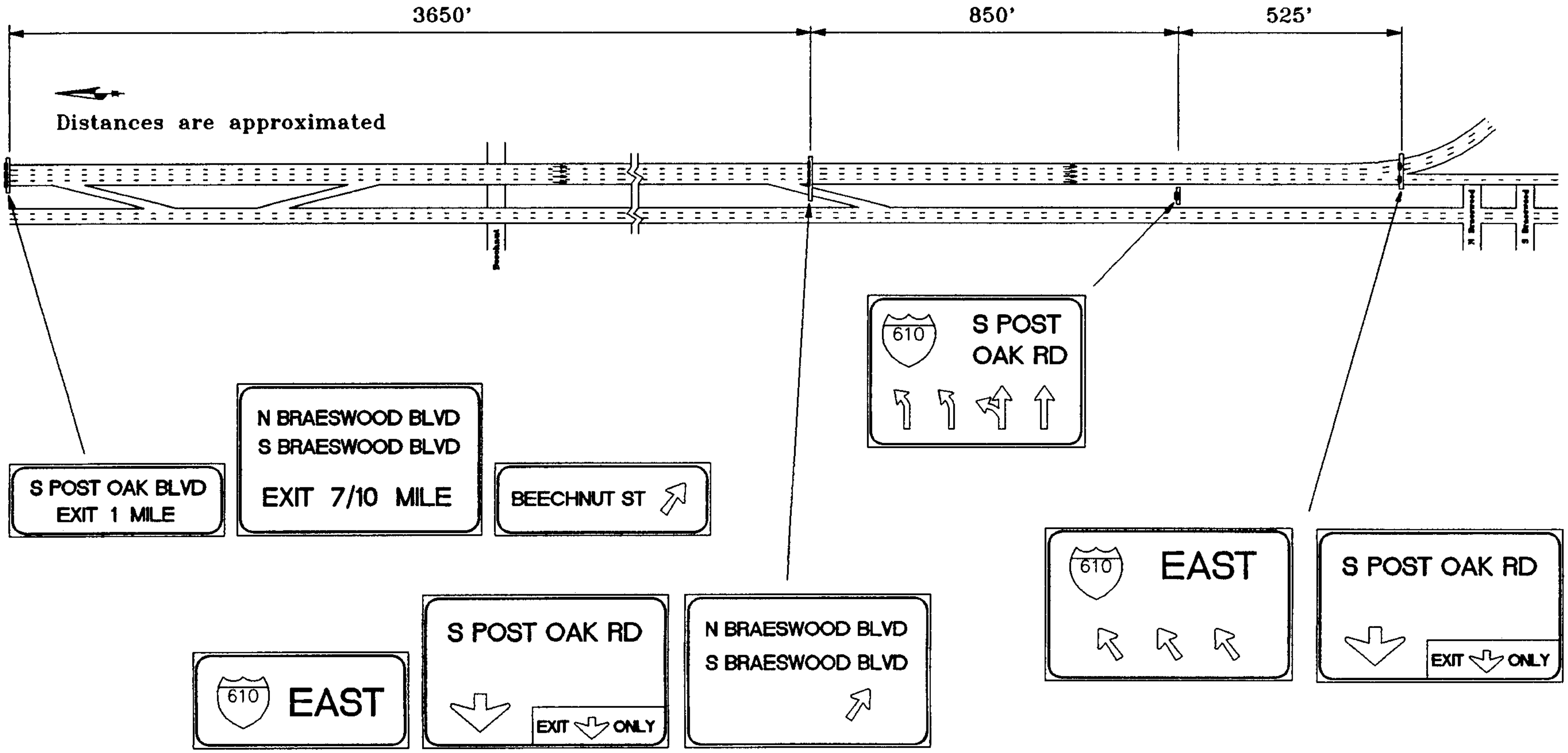


Figure 32. Site 6: Interstate 610 Southbound at South Post Oak Road.

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

Table 23. List of Sites.

Phase	Site Number	Site Name	District	Exit Configuration	Exit Length (mi)
I	1	I-45 Northbound to I-610 East and Texas 225	Houston	Two-lane exit with an option lane and an exit only lane	0.65
I	2	I-45 Southbound to I-610 East and West, Texas 225, and Texas 35	Houston	Two-lane exit with an option lane and an exit only lane	> 2.0
I	3	I-820 Northbound to White Settlement Road	Fort Worth	One-lane, lane drop exit	0.8
I	4	I-820 Southbound to Old Decatur Road	Fort Worth	One-lane, lane drop exit	0.6
II	5	I-45 Northbound to I-610 West	Houston	One-lane, lane drop exit Exit is to the left	> 5.0
II	6	I-610W Southbound to South Post Oak	Houston	Two-lane exit with an option lane and an exit only lane; Exit lanes are straight while mainlanes curve to the left	> 1.25
I	7	I-35E Southbound to I-20 Westbound	Dallas	One-lane, lane drop exit	> 7.0

Conversion Factor: 1 mile = 1.61 km

CHAPTER 6

SPECIFIC SITE INFORMATION

SITE 1: I-45 NORTHBOUND TO I-610 EAST AND TEXAS 225

Description

Site 1 is a two-lane exit with an option lane and an exit only lane. It is located in southeast Houston just south of the southern I-610/I-45 interchange, which is commonly known as the Gulfgate interchange. The lane drop exit is located on northbound I-45 for traffic exiting to I-610 East and to Texas 225. Figure 27 contains an illustration of the plan view of the site and the existing signs and pavement markings.

The right-most northbound lane on I-45, which is the lane that is dropped at the exit, was created by an entrance ramp approximately 0.65 miles (1.05 km) upstream of the exit. The neighboring lane, which is the option lane, exists for several miles upstream of the site. Prior to the exit, the freeway has five lanes. After the lane drop, the freeway has four lanes for approximately 400 ft (122 m) when another lane is dropped on the left side of the freeway. (This left-exit lane drop was selected as Site 5 for this study, for additional information on Site 5 see the appropriate section.) After the left exit, the freeway has three through lanes. An exit ramp is located approximately 1,000 ft (305 m) upstream of the right exit lane drop.

Four green guide signs announcing the I-610 East/Texas 225 exit lane drop precede the exit. The first two signs, occurring 1.75 and 0.75 miles (2.82 and 1.21 km) before the exit as stated on the sign, do not contain a yellow EXIT ONLY panel. The third and fourth sign both contain yellow EXIT ONLY panels over the mandatory exit lane. Both the optional and mandatory exit lanes have downward pointing arrows on the third sign and upward slanting arrows on the fourth (last) sign. The original pavement markings consisted of typical dashed lane lines between lanes throughout the section analyzed, with the exception of a wide solid white line between the two right-most lanes beginning approximately 600 ft (183 m) prior to the gore. The wide solid white line continues past the gore, separating the two exiting lanes for an additional 500 ft (152 m).

I-45 in this area of Houston is characterized by high volumes of traffic. For 1992, the average annual daily traffic in this area was 202,000. A high-occupancy vehicle lane is present in the median area within this section of I-45. This section frequently witnesses low speeds and noticeable delays during the a.m. period. Several periods of the day have heavy traffic volumes with substantial congestion during the a.m. peak period. Travel time studies performed for the department have shown that queuing and delays are experienced along the I-45 corridor, specifically near the I-610 interchange.

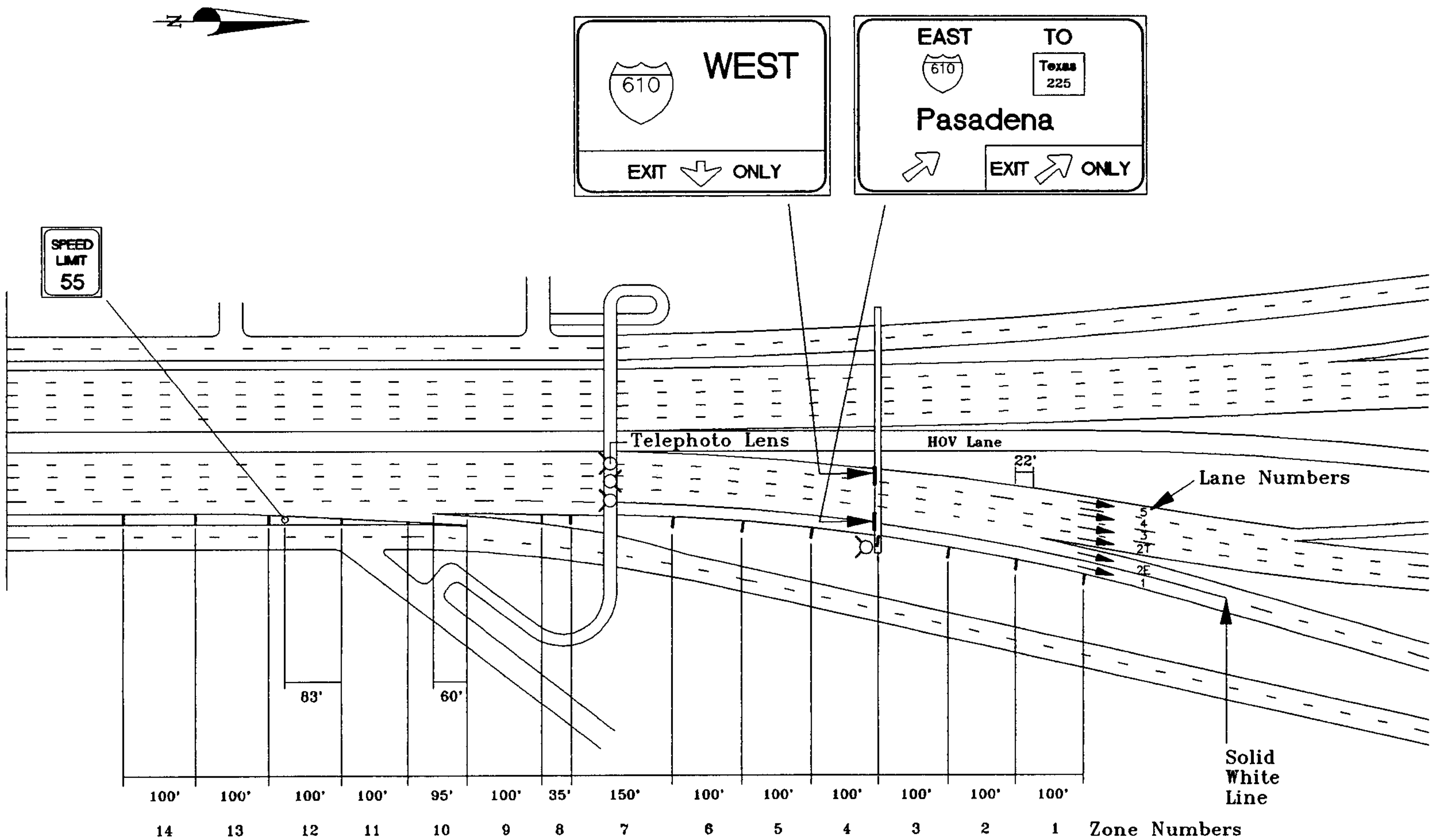
Data Collection and Data Reduction

During early stages of the data collection efforts, different techniques were tested. The method used to collect data at Site 1 varied from that used at the other sites in that Site 1's method used Super 8-mm cameras on tripods rather than surveillance cameras on sign structures. A pedestrian cross walk located approximately 600 ft (183 m) upstream of the gore was an optimal location to record driving behavior associated with the lane drop. Three cameras were located on the bridge -- one to film the area north of the bridge and two to film the area south of the bridge. As shown in Figure 33, one camera filmed the gore area and the zones nearest to the gore, another camera, which was set at a normal focal length, filmed the area immediately south of the bridge, and another camera, which made use of the telephoto capability of the lens, filmed the area upstream of what the previous camera recorded. A fourth camera was attached to a sign post. This camera filmed the area under the bridge, which the three other cameras missed. Unfortunately, the combination of the low height of the camera and the horizontal curve of the freeway lanes in the immediate area of the pedestrian bridge prevented obtaining useable data from the fourth camera. Approximately 150 ft (46 m) of lane changes were missed.

Filming at Site 1 occurred over three days, June 30 to July 2 of 1992, on a Tuesday, Wednesday, and Thursday. Filming was performed between the hours of 7:00 a.m. and 6:00 p.m. The behavior of the traffic during those days appeared typical, e.g., no accidents or other non-recurrent incidents occurred during the filming period. The locations of the zones were set using the rumble strips present on the right shoulder. These strips were generally spaced at 100-ft (30.5 m) increments and were clearly visible on the monitor. During data collection efforts, the distances between the rumble strips were measured using a measuring wheel. Figure 33 shows the zones used for this site and the lane numbers assigned to each lane near the lane drop gore. The entire study length for Site 1 is approximately 1300 ft (396 m) and is divided into 14 zones. A total of 68, 15-minute periods (or 17 hours) of data were reduced for each zone. Because the markings were not installed at this site during the project period, after data is not available. All evaluations were performed on the before data findings.

Findings and Observations

Table 24 lists the findings from the before data collection efforts. The average freeway hourly volumes (total and per lane) for the 7:00 a.m. to 6:00 p.m. time period, as shown in Table 24, demonstrate the high traffic volume nature of the freeway and the exit lane drop. The volume of exiting traffic in Lane 1 ranged from 475 to 1,100 during the hours studied. Traffic exiting from Lane 2 ranged between 230 and 650. At Site 1, Lane 2 is predominately used by vehicles continuing on the freeway. Table 24 also provides a summary of the lane changes and erratic maneuvers for the study site. For the entire study length of 1300 ft (396 m), 665.9 lane changes occurred in a typical hour; 92.2 of those changes (approximately 13 percent) occurred within 300 ft (91.5 m) of the lane drop gore. The 300-ft (91.5 m) distance represents close to 23 percent of the study length. Most of the lane changes in the study area occurred at distances greater than 300 ft (91.5 m) of the gore.



Distances are approximated

= Camera Locations

Figure 33. Site 1 Zones.

Conversion Factor: 1 ft = 0.305 m

Table 24. Site 1 Findings.

	June/July 1992
Freeway hourly volume[a]	
Lane 1 (lane drop)	656
Lane 2	1570
Exiting	409
Through	1161
Lane 3	1482
Lane 4	1384
Lane 5	1665
Freeway	6757
Total study length (1300 ft)	
Lane Changes[b]	665.9
Erratic Maneuvers[b]	24.4
For 300 ft nearest gore	
Lane Changes[b]	92.2
Erratic Maneuvers[b]	13.2
Rate[c] (10^{-6}/ft/veh)	
Lane Changes	75.8
Erratic Maneuvers	2.8

[a] Freeway hourly volumes were measured just prior to the gore and represent the average of the time periods used in the comparison (7:00 a.m. to 6:00 p.m.).

[b] Values represent an average 60-minute period for the time periods used in the comparison (7:00 a.m. to 6:00 p.m.).

[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

Figure 34 shows the number of lane changes for a typical 60-minute period for the 300-ft (91.5 m) zone groups. The plot for the 100-ft (30.5 m) zones is included in the Appendix as Figure A-2. Most of the lane changes within the study area occurred in the 10-8 Zone Group. This value is heavily influenced by the exit ramp that is located in Zone 10 (see Figure 33). The number of lane changes for Zone Group 10-8 includes not only the vehicles leaving the freeway, but also those vehicles moving into the gaps created by the vehicles leaving the freeway. This finding is also supported when the number of lane changes is divided into the number of vehicles leaving the exit lanes and vehicles moving into the exit lanes. Figure 35 illustrates the difference in those vehicles entering the exit lanes and those vehicles leaving the exit lanes. In the 13-11 and 10-8 Zone Groups (which represent the area that is 700 to 1300 ft, or 213 to 396 meters, upstream of the gore), more vehicles are entering the exit lane than are leaving. In the area within 600 ft (183 m) of the gore, approximately equal numbers of vehicles are leaving and entering the exit lanes.

The distribution of erratic maneuvers is very different from the distribution of lane changes. While the majority of the lane changes occurred upstream of the gore, the majority of the erratic maneuvers were within 300 ft (91.5 m) of the gore (see Figure 36). Approximately 24 erratic maneuvers occurred in a typical hour within the entire study area; close to 54 percent of these maneuvers occurred in the 300 ft (91.5 m) nearest to the gore (which is only 23 percent of the study area). The predominant types of erratic maneuvers (see Table 25) are the two-lane, lane changes and lane changes through the gore.

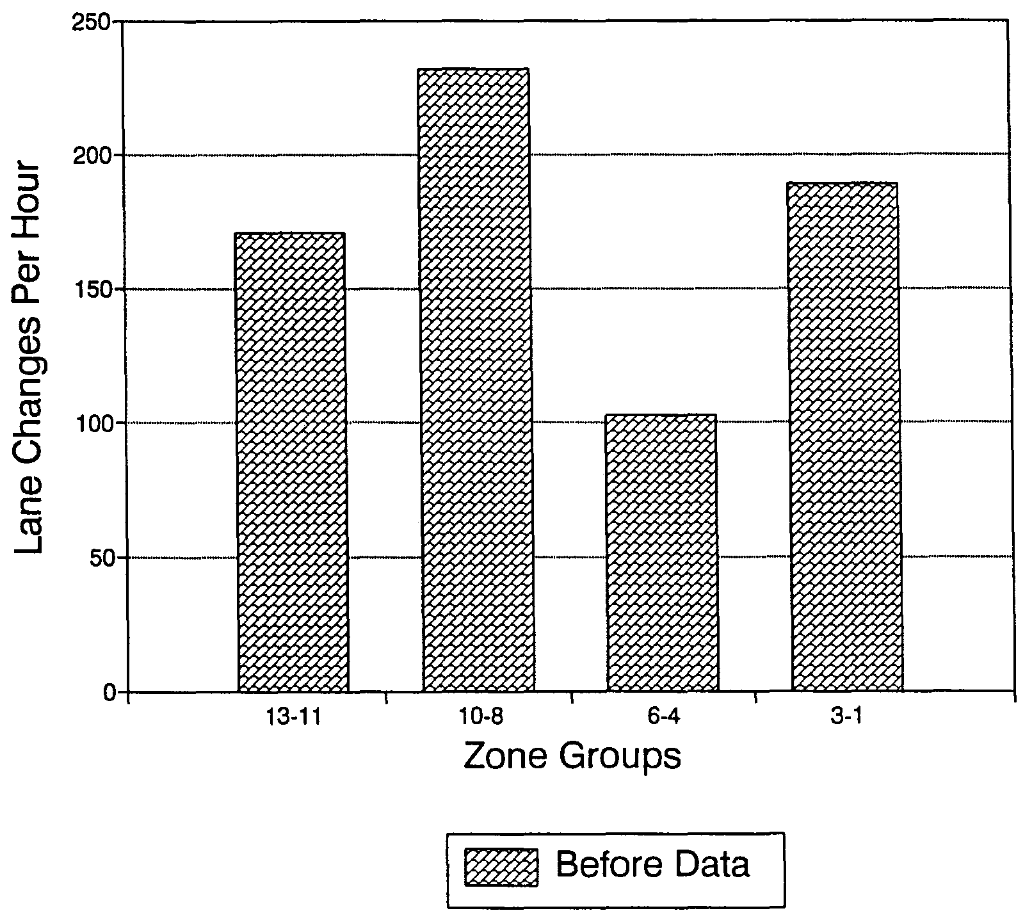


Figure 34. Site 1 Lane Changes Per Hour by Zone Group.

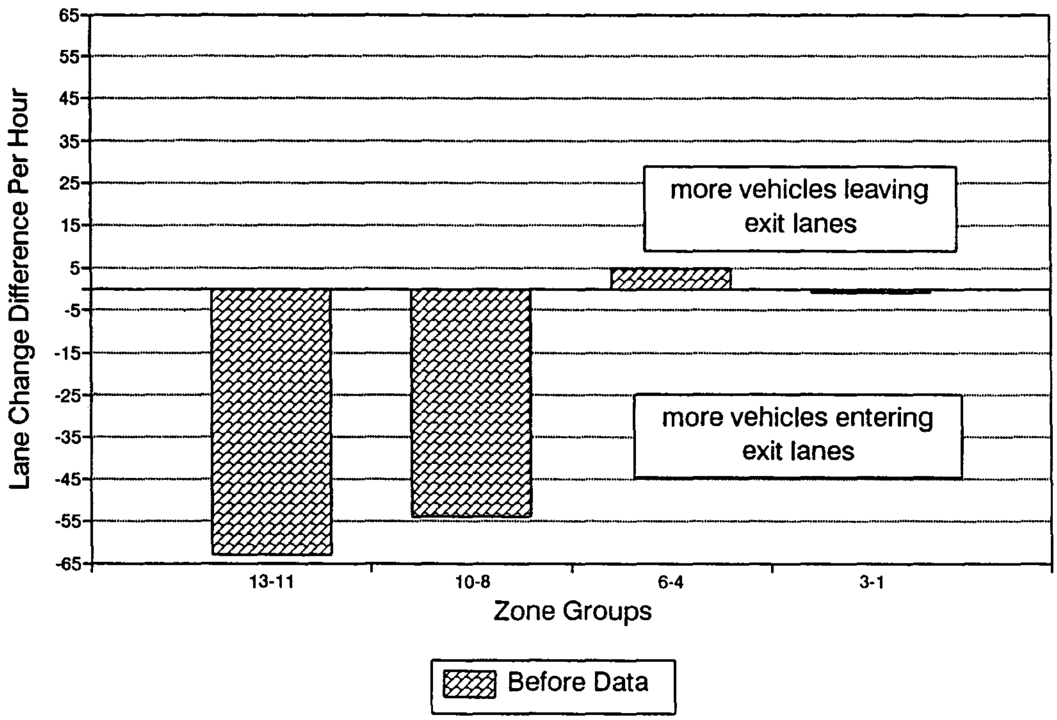


Figure 35. Site 1 Difference in Lane Changes Per Hour by Zone Group.

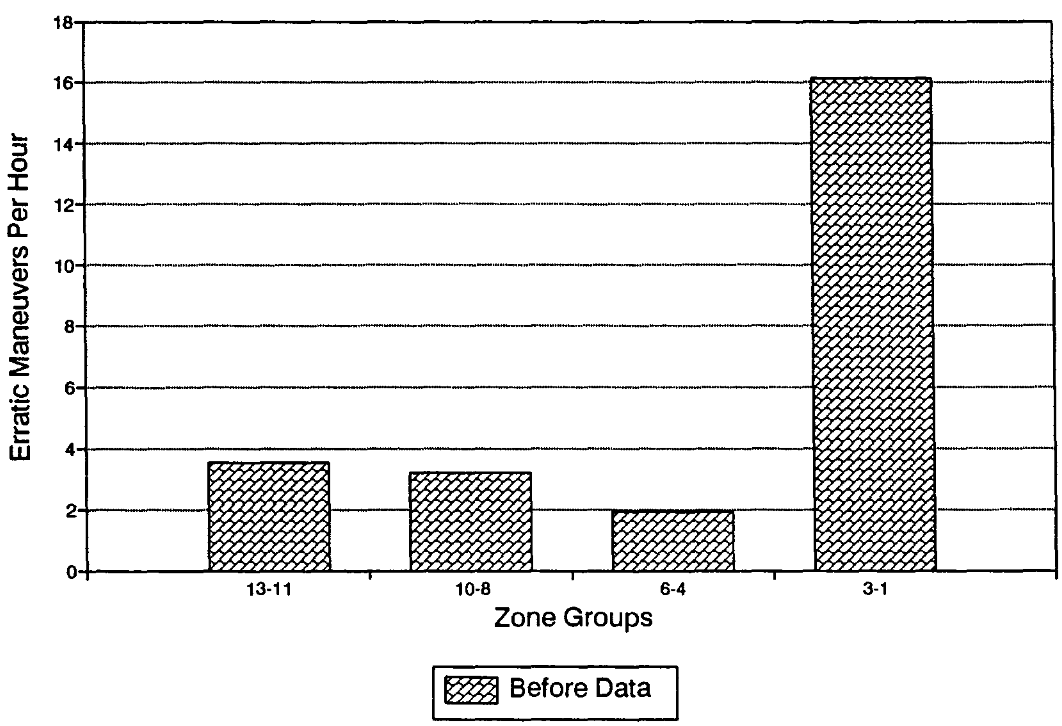


Figure 36. Site 1 Erratic Maneuvers Per Hour by Zone Group.

Table 25. Erratic Maneuver Types for Site 1.

Erratic Maneuver Type	Gore Area (0-322 ft)	Upstream of Gore Area (322-880 ft)
One-lane, lane change through the gore	25	1
Two-lane, lane change	133	101
Two-lane, lane change through the gore	33	0
Three-lane, lane change	3	1
Three-lane, lane change through the gore	2	0
Suddenly slowed (other cars passed)	2	1
Slowed or stopped to merge in gore	5	0
Swerving in lane and back out / Attempted lane change	0	22
In/out of shoulder	3	6
Rode in between two lanes on solid white line	1	0
Through grass	1	0
Totals	**208**	**132**

Conversion factor: 1 ft = 0.305 m

SITE 2: I-45 SOUTHBOUND TO I-610 EAST AND WEST, TEXAS 225, AND TEXAS 35

Description

Site 2 is a two-lane exit with an option lane and an exit only lane. When originally selected, Site 2 was to serve as a control site for Site 1; therefore, it was near Site 1. It is located just north of the southern I-610/I-45 interchange (Gulfgate interchange) in southeast Houston. The lane drop exit is for southbound I-45 traffic exiting to I-610, Texas 225, and Texas 35. The plan view of the site along with the existing signs and markings at the site are shown in Figure 28.

The dropped lane at this site begins over 2 miles (3.2 km) upstream of the lane drop gore. After the lane drop, the freeway has three through lanes. A vertical curve over an arterial street crests at approximately 400 ft (122 m) prior to the lane drop gore. The wide solid white line preceding the lane drop begins near the crest of the vertical curve. Signs informing motorists of the impending drop include two green guide signs with yellow EXIT ONLY panels that also display distances located at one mile (1.6 km) and two miles (3.2 km) prior to the exit. A black on white RIGHT LANE MUST EXIT sign is located 850 ft (259 m) prior to the gore and at the gore is a green guide sign with a yellow EXIT ONLY panel and a white upward sloping arrow.

As with Site 1, I-45 in this area of Houston is characterized by high volumes of traffic. The 1992 average annual daily traffic is between 183,000 and 202,000 according to the Department traffic map. The peak period for the southbound 45 lanes is in the p.m. period. Congestion is prevalent during the evening period with more severe queuing occurring just downstream of this exit ramp. Traffic operations during the other periods flow relatively freely.

Data Collection and Data Reduction

With the experience gained during the recording of Site 1 data, the data collection procedure was refined. Instead of collecting data with tripod mounted cameras that required constant monitoring by a data collection team, surveillance cameras were mounted on sign structures and connected with a remote video cassette recorder located in a temporary traffic controller cabinet.

Three cameras were located at this site as shown in Figure 37. One camera was mounted on the overhead sign structure located over the crest vertical curve, and it filmed the area upstream of the gore. Another camera was located downstream of the gore and it filmed the area surrounding the gore. The third camera was located at the sign structure 850 ft (259 m) from the gore and it recorded lane changes that occurred upstream of its location.

Cameras were positioned to record data for as much of the study length as possible. However, due to sign structure locations and camera limits, at some locations portions of the freeway cannot be adequately filmed. The three cameras captured approximately 1,500 ft (457 m) upstream of the gore. The area between Zones 8 and 9 [approximately 100 ft (30.5 m)] was not captured on film. The filming at this site occurred during the month of September in 1992.

The 1,500 ft (457 m) filmed was divided into the 12 zones as shown in Figure 37. All zones were 100 ft (30.5 m) except Zones 8 and 10 which were 200 ft (61 m) each. The zones coincided with rumble strips located on the right shoulders. The distance between rumble strips were measured using a measuring wheel during the installation of the cameras. For most of the zones, over 140, 15-minute periods (35 hours) of data were reduced. The data represent lane changes and erratic maneuvers occurring between 7:00 a.m. and 6:45 p.m.

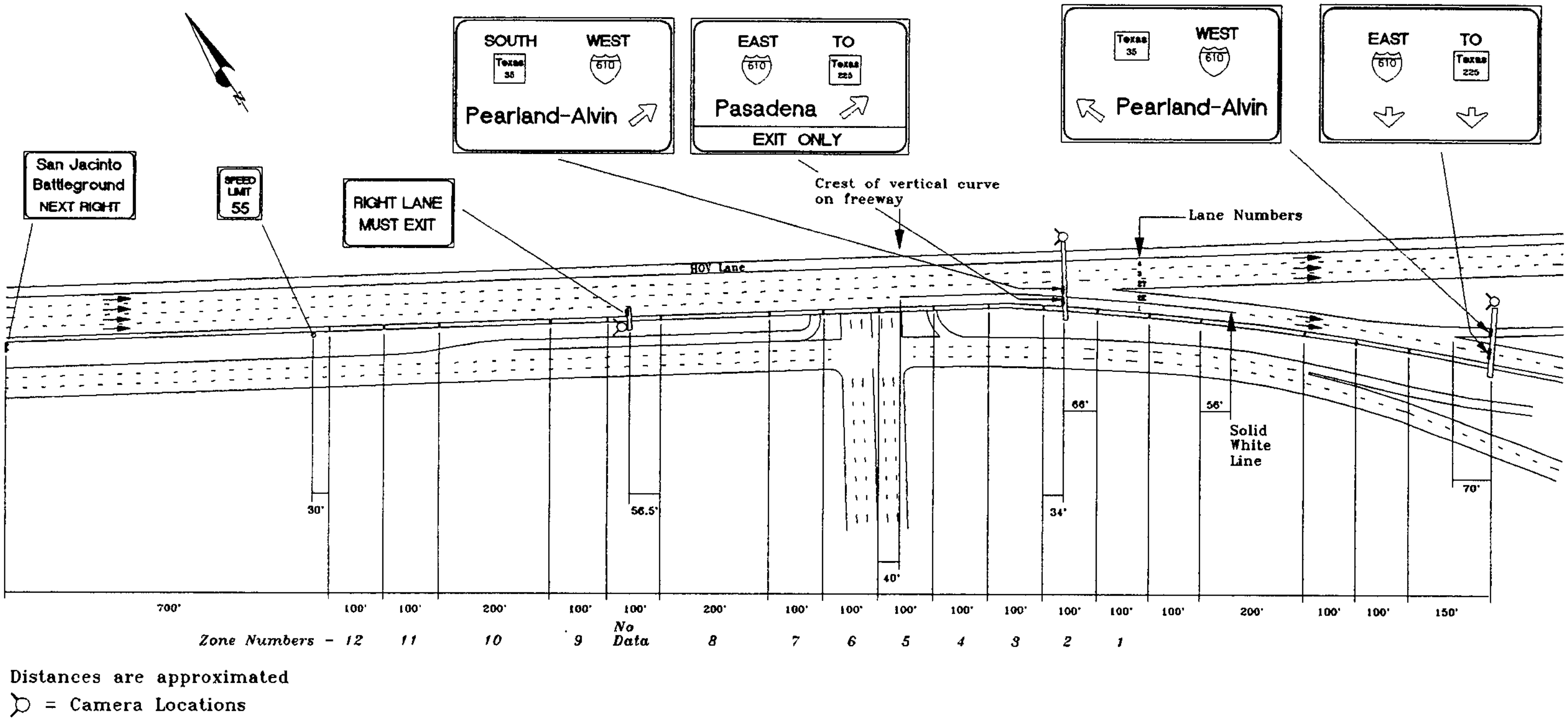


Figure 37. Site 2 Zones.

Conversion Factor: 1 ft = 0.305 m

Findings and Observations

The average hourly volumes for each lane, and the freeway total for all lanes, demonstrate that Site 2 has high volumes (see Table 26). For example, the average hourly volume (between 7:00 a.m. and 6:45 p.m.) ranged between 1,000 and 1,500 vehicles per hour per lane. Review of the hourly volumes and observations made during data reduction indicate that the peak period was during the evening, with congestion influencing the lane change behavior of some motorists during that period. The volume of exiting traffic is especially high; Lane 1 hourly volume ranged between 550 and 2200 during the study period (7:00 a.m. to 6:45 p.m.), and the lane 2 *exiting* hourly volume ranged between 425 and 1825. At the gore, Lane 2 witnessed approximately equal numbers of through and exiting vehicles during the hours between 7:00 a.m. and 4:00 p.m. From 5:00 p.m. to 7:00 p.m., between 72 and 78 percent of the volume in Lane 2 is exiting.

Table 26 also presents the number of lane changes and erratic maneuvers for both the entire study length and for the 300 ft (91.5 m) nearest the gore. Almost 600 lane changes occurred during a typical hour in the 1200-ft (366 m) study area. Approximately 23 percent of those lane changes occurred in the 300 ft (91.5 m) nearest to the gore (which represents 25 percent of the study area). Figure A-10 in the Appendix contains the plot of the lane changes per hour for each 100-ft (30.5 m) zone. Figure 38 shows the same material grouped into 300-ft (91.5 m) increments. As shown in Figure 38, the number of lane changes are fairly well distributed between the zone groups except for the zone group that represents Zones 7 to 9.

Figure 39 shows the difference in the number of vehicles entering the exit lanes from the number of vehicles leaving the exit lanes. For most zone groups, equal numbers of vehicles leave and enter the exit lanes (e.g., less than a 5 vehicle difference in a hour). Zone Group 6-4, however, had 14 more vehicles leaving the exit lanes than entering in a typical hour. These findings indicate that the highest percentage of vehicles moving away from the exit lanes occurred 350 to 450 ft (107 to 137 m) prior to the gore. This location is just after the crest of the vertical curve and the start of the wide solid white line.

When the data is separated into peak and non-peak times, the difference in lane changes follows a very different pattern. During the peak periods, more vehicles enter the exiting lanes than leave the exit lanes for every zone. During the non-peak time, the opposite occurs; more vehicles leave the exit lanes than enter in all except one zone.

The number of erratic maneuvers per zone displayed a very different distribution than the number of lane changes per zone (see Figure 40). While lane changes were generally equal for the different zone groups, the erratic maneuvers were concentrated within the 200 ft (61 m) nearest the gore. Over 90 percent of all the erratic maneuvers recorded for the study area occurred within 200 ft (61 m) of the gore.

Table 27 lists the types of erratic maneuvers for the 300 ft (91.5 m) nearest the gore and for the 900 ft (274 m) upstream of the previous 300 ft (91.5 m). Two-lane, lane changes and lane changes through the gore were the predominate types of erratic maneuvers. These maneuvers indicate that drivers are making "last minute" lane changes in an attempt to exit or avoid exiting the freeway. Two-lane, lane changes where motorists moved into the exit lanes were more common in Zone 1, while two-lane, lane changes where motorists moved out of the exit lanes were more common in Zones 2 to 6.

Table 26. Site 2 Findings.

	September 1992
Freeway hourly volume[a]	
Lane 1 (lane drop)	1009
Lane 2	1510
Exiting	782
Through	728
Lane 3	1213
Lane 4	1159
Freeway (all lanes)	4891
Total study length (1200 ft)	
Lane Changes[b]	580.3
Erratic Maneuvers[b]	74.5
For 300 ft nearest gore	
Lane Changes[b]	130.9
Erratic Maneuvers[b]	69.1
Rate[c] (10^{-6}/ft/veh)	
Lane Changes	98.9
Erratic Maneuvers	12.7

[a] Freeway hourly volumes were measured just prior to the gore and represent the average of the time period used in the comparison (7:00 a.m. to 6:45 p.m.).

[b] Values represent an average 60-minute period for the time periods used in the comparison (7:00 a.m. to 6:45 p.m.).

[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

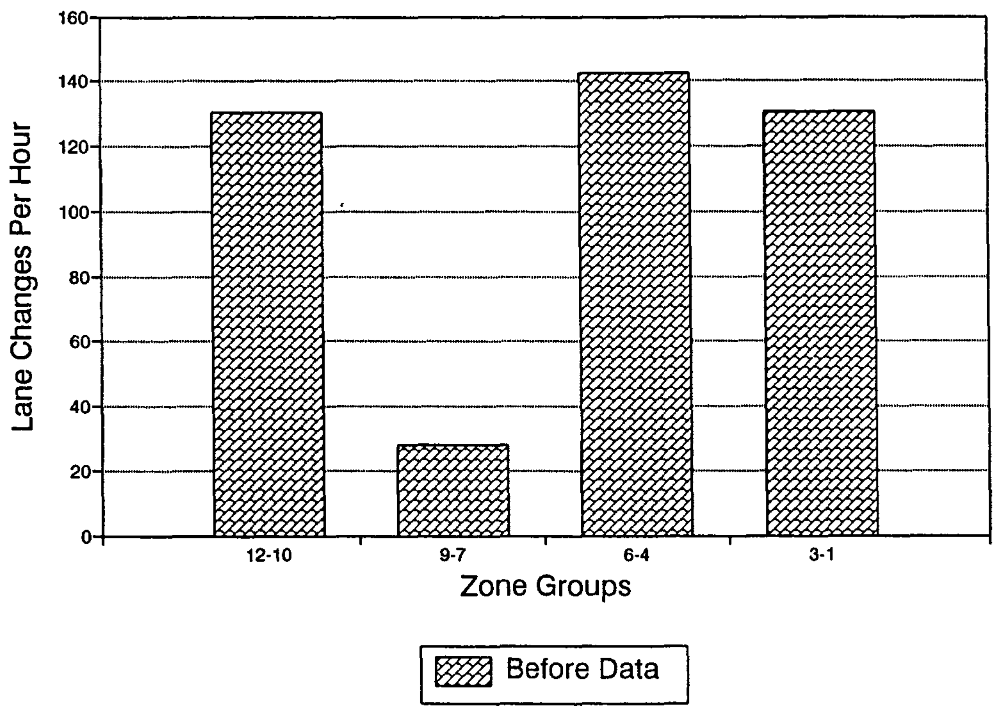


Figure 38. Site 2 Lane Changes Per Hour by Zone Group.

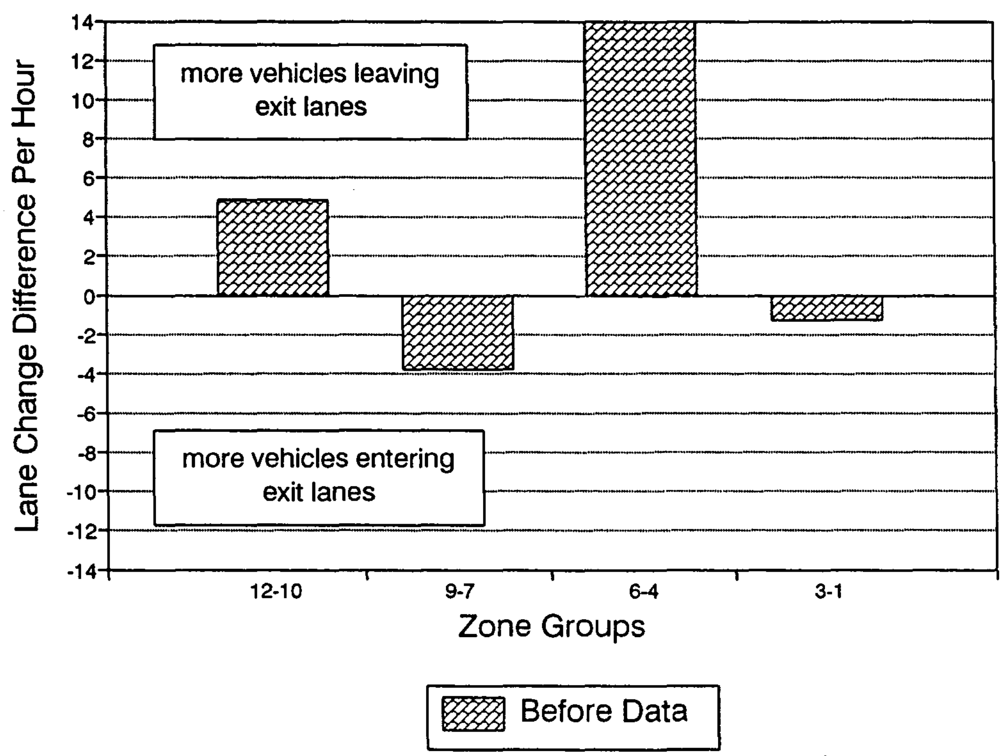


Figure 39. Site 2 Difference in Lane Changes Per Hour by Zone Group.

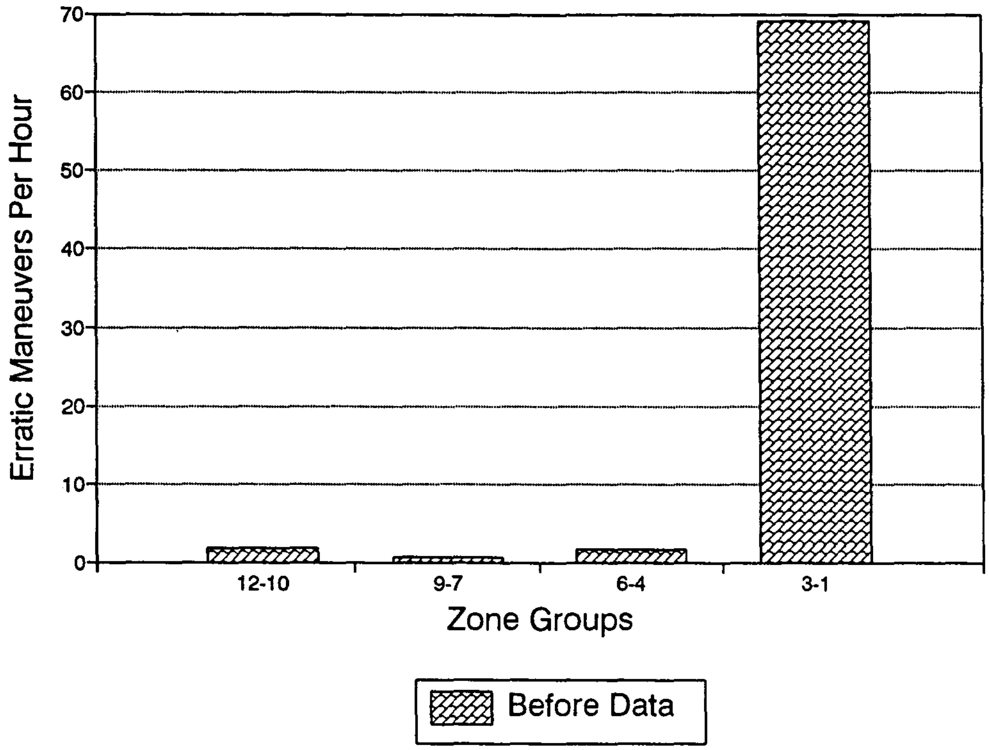


Figure 40. Site 2 Erratic Maneuvers Per Hour by Zone Group.

The type of exit explains the high number of erratic maneuvers and lane changes so close to the gore. As shown in Figure 37, the lane drop splits into two exits (I-610 West and Texas 35 versus I-610 East and Texas 225) 600 ft (183 m) after the lane drop's gore. Another potential contributor to the lane change behavior is the vertical curve that crests within Zone 5. Upstream of the vertical curve, the roadway is relatively flat and the crest vertical curve limits the visibility of the exit gore configuration. Once drivers crest the vertical curve, they have approximately 400 ft (122 m) to the painted gore area. This short distance, combined with high speeds and volumes, contributes to the high number of lane changes in Zones 3 to 5.

The types of signs present at Site 2, in addition to the exit geometry and the crest vertical curve, may also influence the lane change and erratic maneuver behavior at the site. None of the signs at Site 2 (see Figures 28 and 37) indicate that the second lane is an optional exit lane. Each sign with a yellow EXIT ONLY panel includes only one white arrow (as opposed to the sign generally used at two-lane exits with an option lane and an exit only lane, see Figure 6 for an example). Also, information for the Pearland-Alvin exit and the Pasadena exit is contained on *two* different signs even though the driver must *first* use the same lane drop exit prior to using two separate exits to reach the two different destinations. Information is not communicated to the motorists that the most efficient method (i.e., least number of lane changes) for reaching the Pearland-Alvin exit is to be in Lane 2; in fact, no information, by way of signs, is provided to the motorists that they can exit while in Lane 2. With the complex geometric and exit configurations, the existing signs may be justifiable for this area -- this research study is not evaluating the appropriateness of particular signs at a site. The types of signs and how they are placed, however, are important observations on how lane change and erratic maneuver behavior is influenced at a site. Site 2's large number of lane changes and erratic maneuvers, especially within the zones closest to the gore, appear to be influenced by the signs used at the site.

Table 27. Erratic Maneuver Types for Site 2.

Erratic Maneuver Type	**Gore Area** (0-300 ft)	**Upstream** (300-1300 ft)
One-lane, lane change through the gore	304	0
Two-lane, lane change	1043	278
Two-lane, lane change through the gore	206	0
Three-lane, lane change	6	6
Three-lane, lane change through the gore	9	0
Suddenly slowed (other cars passed)	6	0
Slowed or stopped to merge in gore	21	0
Swerving in lane and back out / Attempted lane change	44	25
In/out of shoulder	1	7
Rode in between two lanes on solid white line	83	3
Through grass	1	0
Totals	**1724**	**319**

Conversion factor: 1 ft = 0.305 m

SITE 3: I-820 NORTHBOUND TO WHITE SETTLEMENT ROAD

Description

Site 3 is the I-820 northbound to White Settlement Road exit located in west Fort Worth. This site is a one-lane, lane drop exit and is created by an entrance ramp from I-30 westbound approximately 1 mile (1.6 km) upstream of the lane drop. Three through lanes continue on I-820 after the lane drop. The site is characterized by very flat, level terrain, and uncongested flow. The Average Annual Daily Traffic (AADT) from the 1992 traffic maps for I-820 in this area is 47,000.

Existing signs at the White Settlement site consist of three white on green guide signs prior to the gore. The first sign announces the exit and the distance (1 mile or 1.6 km) to the exit. The remaining two signs, located approximately 1,200 ft (366 m) prior to the gore and 150 ft (46 m) past the gore, contain yellow EXIT ONLY panels. The sign located 1200 ft (366 m) prior to the gore has a downward pointing arrow over the exit lane, whereas the sign 150 ft (46 m) past the gore has an upward sloping arrow. The original pavement markings consisted of typical dashed lane lines separating the lanes. A wide solid white line separating the exit lane from the adjacent through lane prior to the gore was not present. Figure 29 illustrates the signs and the before pavement markings at White Settlement.

Data Collection and Data Reduction

Four cameras in the before period and three cameras in the after period were used to record the operations at this site. Figure 41 shows the location of the cameras. For the before-and-after data, two cameras were placed on the sign structure 150 ft (46 m) downstream of the gore. One camera had a 12X telephoto lens, allowing the video equipment to record 200 to 1,400 ft (61 to 427 m) upstream of the gore. The other camera captured from 500 ft (152 m) prior to the gore to 100 ft (30.5 m) downstream of the gore. Both cameras on this sign structure captured the front of vehicles.

For the before data, two cameras were placed on the sign structure located 1,200 ft (366 m) upstream of the gore. For the after data, only one camera was placed on the sign structure. One camera was placed similarly for both study periods, capturing the fronts of vehicles 1,300 to 1,900 ft (396 to 579 m) prior to the gore. The second camera used in the before data collection recaptured 500 to 1,000 ft (152 to 305 m) prior to the gore. This camera taped the backs of vehicles and was not used in the before data reduction as all zones were visible in the other views. As a result, the camera set-up was slightly modified in the after period from the set-up used in the before period.

The study segment was divided into 100-ft (30.5 m) zones. Figure 41 shows the location and numbers of the zones. The before period had data for Zones 1 to 19, while the after period had data for Zones 1 to 20. Therefore, all comparisons were made using Zones 1 to 19 data. Because each zone was 100-ft (30.5 m) long, no distance adjustment was required for any of the data, and the equivalent study site length was 1900 ft (579 m). The same number of 15-minute intervals were reduced in both the before-and-after periods. The findings reflect the operations at the site for two 12-hour days or 96, 15-minute intervals.

The installed markings are shown in Figure 42. Figure 43 shows a photograph of the lane drop markings at the site with a noticeable difference between these markings and the regular lane markings. Actual field installation of the pavement arrows is shown in Figure 44. A curved type of arrow template similar to those used for intersection markings was used at the site.

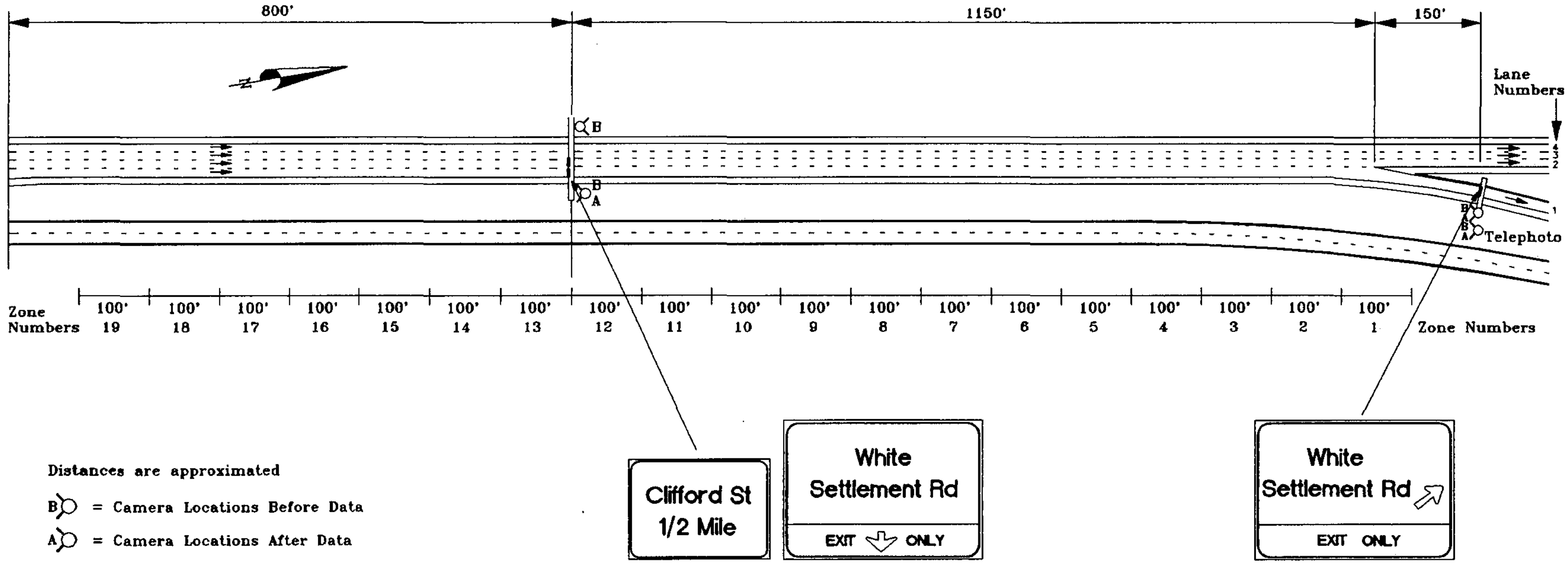
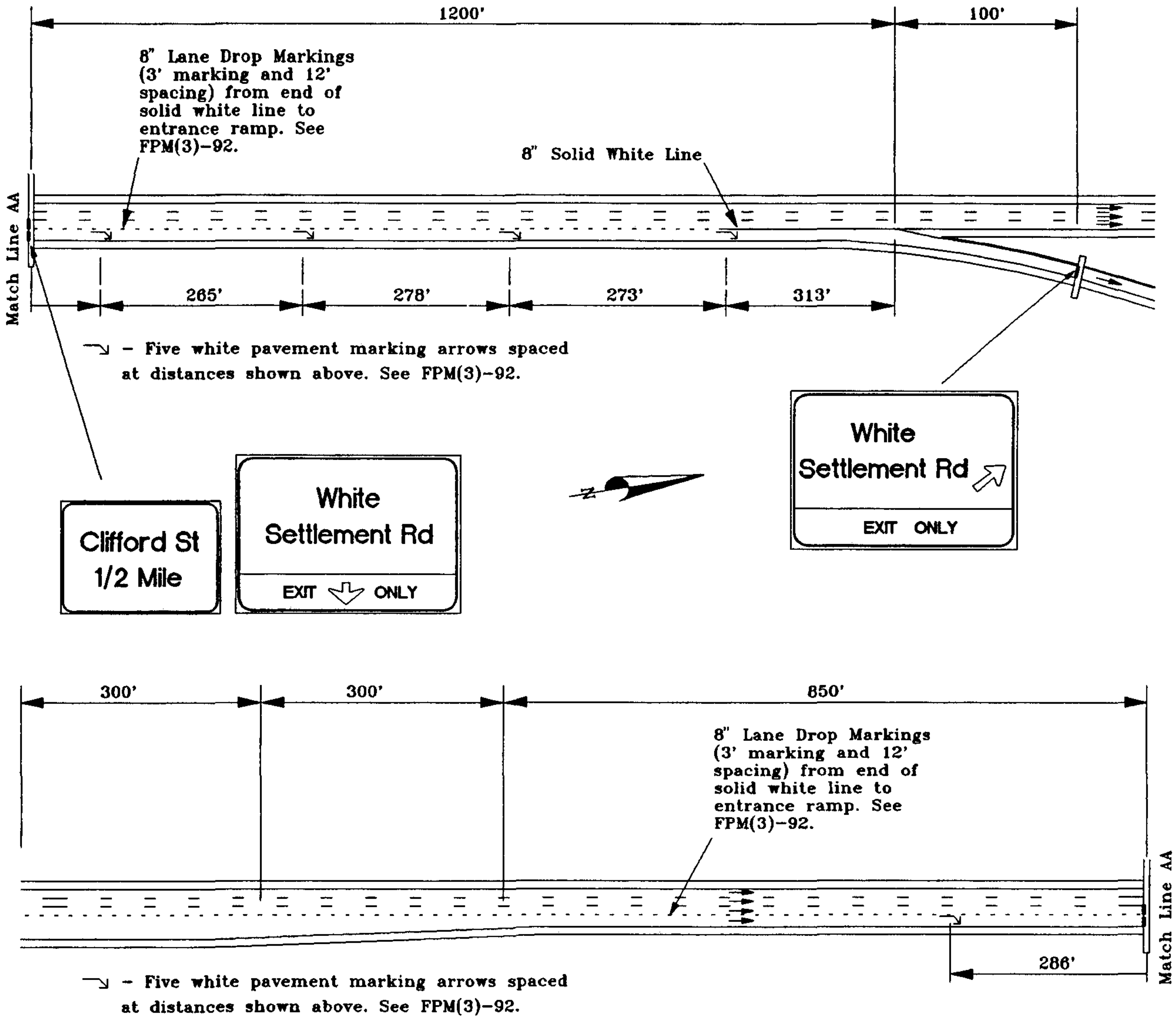


Figure 41. Site 3 Zones.

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



Distances are approximated

Figure 42. Markings Installed at Site 3.

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

Figure 43. Lane Drop Markings at Site 3.

Figure 44. Pavement Arrow at Site 3.

Findings and Observations

Table 28 lists the lane change and erratic maneuver findings for the total study length and the 300 ft (91.5 m) nearest the gore for both the before-and-after marking installation conditions at Site 3. The time period used was from 7:30 a.m. to 5:45 p.m. In the before period, approximately 95 vehicles changed lanes in a typical hour in the 1,900-ft (579 m) study section. That value decreased almost 30 percent to 68 vehicles changing lanes in a typical hour in the after period. Figure 45 shows the number of lane changes in a typical hour for the 300-ft (91.5 m) zone groups. (Figure A-18 in the Appendix shows the findings for the 100-ft or 30.5 meter zones.) The reduction in lane changes was fairly consistent (between 2 and 10 lane changes) for each zone group except for Zone Group 6-4. There exists a slight (less than 1 vehicle per hour) increase in lane changes from the before period to the after period.

Table 28. Site 3 Findings.

	Before Period January 1993	After Period June 1993	Change (%)
Freeway hourly volume[a]			
Lane 1 (lane drop)	280	231	
Lane 2	619	648	
Lane 3	462	479	
Lane 4	74	95	
Freeway	1436	1453	1
Total study length (1900 ft)			
Lane Changes[b]	95.2	67.8	-29
Erratic Maneuvers[b]	5.1	4.2	-18
For 300 ft nearest gore			
Lane Changes[b]	5.3	3.1	-42
Erratic Maneuvers[b]	0.7	0.5	-29
Rate[c] (10^{-6}/ft/veh)			
Lane Changes	34.9	24.6	-30
Erratic Maneuvers	1.9	1.5	-19

[a] Freeway hourly volume were measured prior to gore and represent the average of the time period used in the comparison (7:30 a.m. to 5:45 p.m.).

[b] Values represent an average 60-minute period for the time periods used in the comparison (7:30 a.m. to 5:45 p.m.).

[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

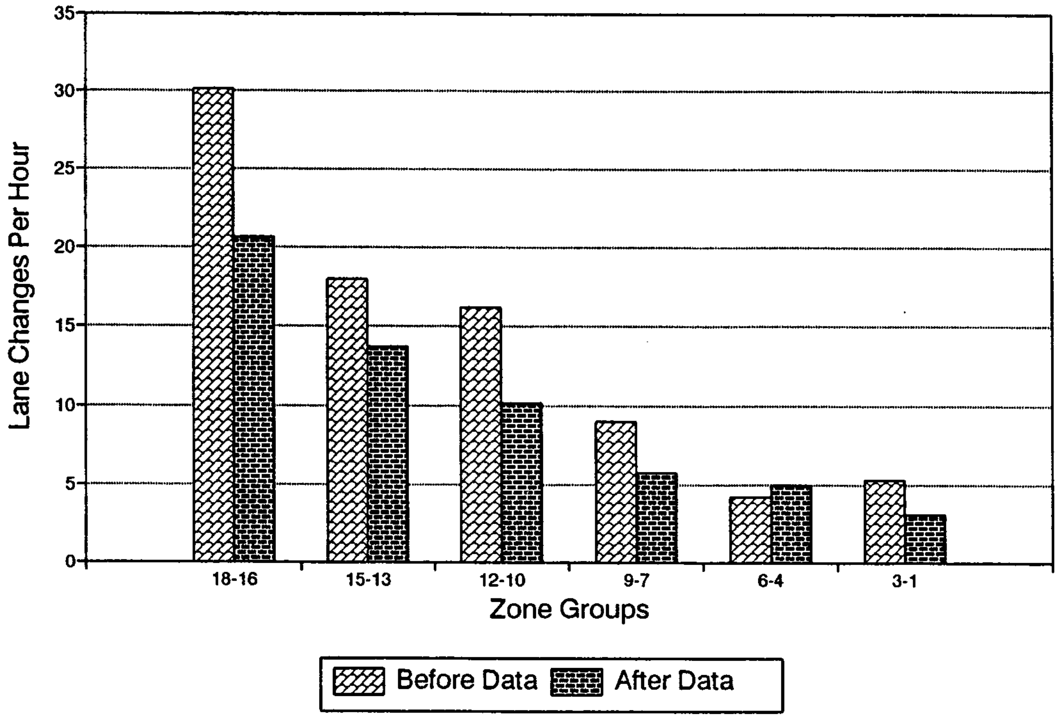


Figure 45. Site 3 Lane Changes Per Hour by Zone Group.

For the 300 ft (91.5 m) nearest to the gore, the number of lane changes decreased by 42 percent from the before to the after period. The number of lane changes occurring within the 300-ft (91.5 m) distance represents 5 to 6 percent (before-and-after periods) of all lane changes in the study area while the 300 ft (91.5 m) represent 16 percent of the distance studied. This finding emphasizes that few lane changes are occurring close to the gore in either period, which is a desirable situation.

Providing motorists with a traffic control device that presents continuous information of an impending lane drop could result in drivers making a lane change prior to the location where they were performing the maneuver previously. An inspection of all lane change per distance plots (i.e., total lane changes, lane changes from the exiting lane to the through lanes, lane changes from the through lanes to the exiting lane, and the difference in exiting to through and through to exiting data) could reveal if drivers have "shifted" where they are entering or leaving the exit lane. The overall decrease in number of lane changes, however, could mask the shift. If the number of lane changes is transformed to percent of lane changes that occur within a zone, then the effects of the overall decrease would be minimized.

The plot of percent lane changes per zone for Site 3 (see Figure 46) indicates that the distribution of lane changes in the before period is similar to the distribution of lane changes in the after period. In other words, no shifting of lane changes from one area of the study segment to another occurred. Plots of vehicles entering the exit lane and vehicles leaving the exit lane showed similar distributions as the total lane change plot.

Figure 47, which shows the difference in lane changes into the exit lane and out of the exit lane for the 300-ft (91.5 m) zone groups (the 100-ft or 30.5-meter zone data is shown in the Appendix in Figure A-21), can also demonstrate if drivers are changing lanes earlier, later, or in the same place as a result of the new markings. In the before period, more vehicles left the exit lane than entered the exit lane in the area located 1300 to 1900 ft (396 to 579 m) upstream of the gore. The same trend (with slightly smaller differences) is shown in the after period. While the installation of the pavement markings decreased the total number of lane changes in almost every zone, it did not change the distribution of lane changes from one zone to another within the 1900-ft (579 m) study section. This finding indicates that more lane changes are occurring more than 1,900 ft (579 m) upstream of the gore or that the markings are discouraging lane changes. For example, a specific driver may have been moving into the exit lane, not realizing that the lane will be dropped at the exit, and then later moving out of the lane within the study segment in the before situation. The same driver may not make the two-lane changes in the after condition.

Careful attention must be given when interpreting results from Figure 47. Although the graph indicates more vehicles (1 vehicle) entered the exit lane than left the exit lane in the 300 ft (91.5 m) closest to the gore in the after period, this does not mean the number of vehicles entering the exit lane increased in the after period. Instead, it is likely that the number of lane changes entering the lane remained unchanged while the number of vehicles leaving the exit lane decreased enough between the before and after periods to make it the less dominant lane change.

The 29 percent reduction in lane changes was evenly distributed between a reduction in the number of vehicles moving into and vehicles moving out of the exit lane. In the before period, approximately 54 percent of the recorded lane changes were for drivers moving from the exit lane to the through lane. This percentage only changed to 55 percent in the after period. The decrease in lane changes was essentially equal from lane changes into and out of the exit lane for the entire study area.

The same is not true for the 300 ft (91.5 m) just prior to the gore. A larger decrease in lane changes occurred within 300 ft (91.5 m) of the gore. In the before period, 5.3 vehicles changed lanes in a typical hour. In the after period, only 3.1 vehicles changed lanes -- a 42 percent decrease in lane changes. Most of this decrease was a reduction in the number of vehicles leaving the exit lane. In the before period, almost as many vehicles entered the exit as left the exit lane. In the after period, 70 percent of the lane changes were vehicles moving into the exit lane. While the proportions and number of lane changes varied from the before to the after period, keeping the findings in perspective is important. The 42 percent decrease in lane changes for the 300 ft (91.5 m) nearest to the gore represents a decrease of only 2 lane changes in an hour.

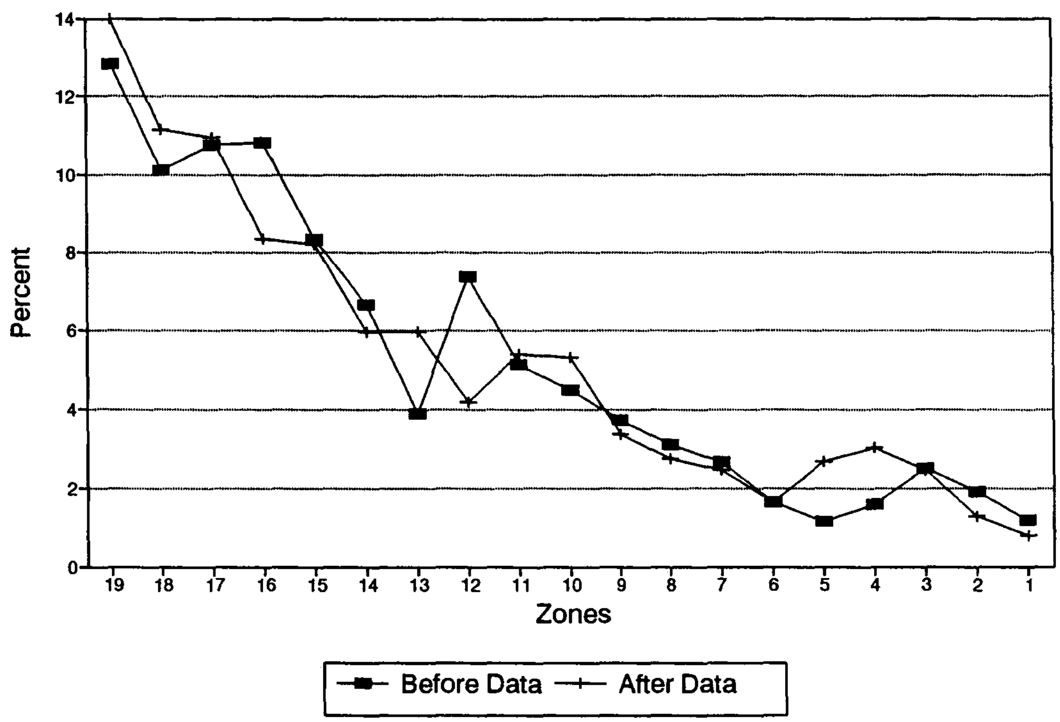


Figure 46. Site 3 Percent of Lane Changes Per Hour by Zone.

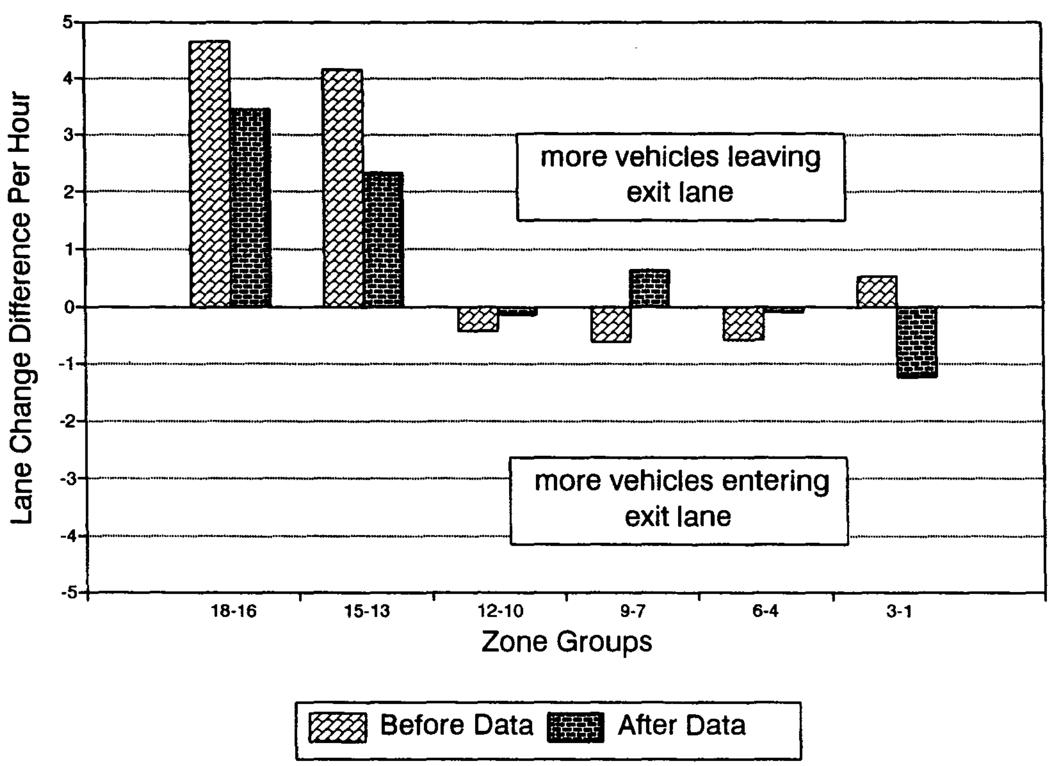


Figure 47. Site 3 Difference in Lane Changes Per Hour by Zone Group.

The number of erratic maneuvers also decreased from the before period to the after period. For the entire study length a decrease of 18 percent was observed, and a decrease of 29 percent occurred for the 300 ft (91.5 m) nearest the gore. The largest decrease was in the 12-10 Zone Group -- 2 erratic maneuvers occurred in the before period and 0.8 erratic maneuvers occurred in the after period (see Figure 48). Most of the decreases were in the two-lane, lane change erratic maneuvers (see Table 29).

Other characteristics of the site that influenced the findings include the absence of congestion and the entrance ramp located upstream of the study segment. The hourly traffic volumes on I-820 near White Settlement ranged between 800 and 2200 for *all* four lanes during the study times in both the before-and-after periods. Congestion-related behavior (e.g., noticeable slowing of traffic, etc.) was not observed during the data reduction efforts. The entrance ramp located upstream of the study site could have had a significant influence on the findings for this site. The ramp is a parallel design which allows for lane changes to occur for over 500 ft (152 m) prior to the beginning of the ramp's taper. Because the lane drop markings extended well past the taper portion of the entrance ramp, the markings could have encouraged drivers to change lanes prior to the start of the study section.

SITE 4: I-820 SOUTHBOUND TO OLD DECATUR ROAD

Description

Similar to Site 3, Site 4 is a one-lane, lane drop exit located in northwest Ft. Worth. It was originally selected as the control site for Site 3. The exit only lane is created by an on ramp located 2,250 ft (686 m) upstream of the gore. The AADT near the site is 60,000 and three through lanes exist on the freeway after the lane drop.

The Old Decatur site contains three green guide signs informing drivers of the impending exit. The first sign reveals that Old Decatur road exits in 1.25 miles (2.01 km). The remaining signs display yellow EXIT ONLY panels without identifying distances. The first yellow EXIT ONLY panel appears approximately 1,150 ft (351 m) prior to the gore and contains a downward pointing arrow over the exit lane. The other sign containing the yellow EXIT ONLY panel contains an upward sloping arrow. Markings include typical dashed lane lines separating all lanes and a solid 8-inch (203 mm) white line extending 160 ft (49 m) upstream of the gore. Pavement markings and signs for Site 4 are shown in Figure 30.

Data Collection and Data Reduction

The research team encountered several difficulties during the filming of the before condition at this site. During January 1993, several days of thunderstorms occurred during the filming, and at one point, the high winds rotated the camera so that the roadway was no longer filming horizontally across the screen. The camera also began to malfunction during the filming

Table 29. Erratic Maneuver Types for Site 3.

Erratic Maneuver Type	Gore Area (0-300 ft)		Upstream (300-2000 ft)	
	Before Data	After Data	Before Data	After Data
One-lane, lane change through the gore	2	8	0	0
Two-lane, lane change	6	3	74	48
Three-lane, lane change	1	0	0	4
Swerving in lane and back out / Attempted lane change	2	0	8	6
In/out of shoulder	1	0	12	12
Rode in between two lanes on solid white line	2	0	0	0
Totals	**14**	**11**	**94**	**70**

Conversion factor: 1 ft = 0.305 m

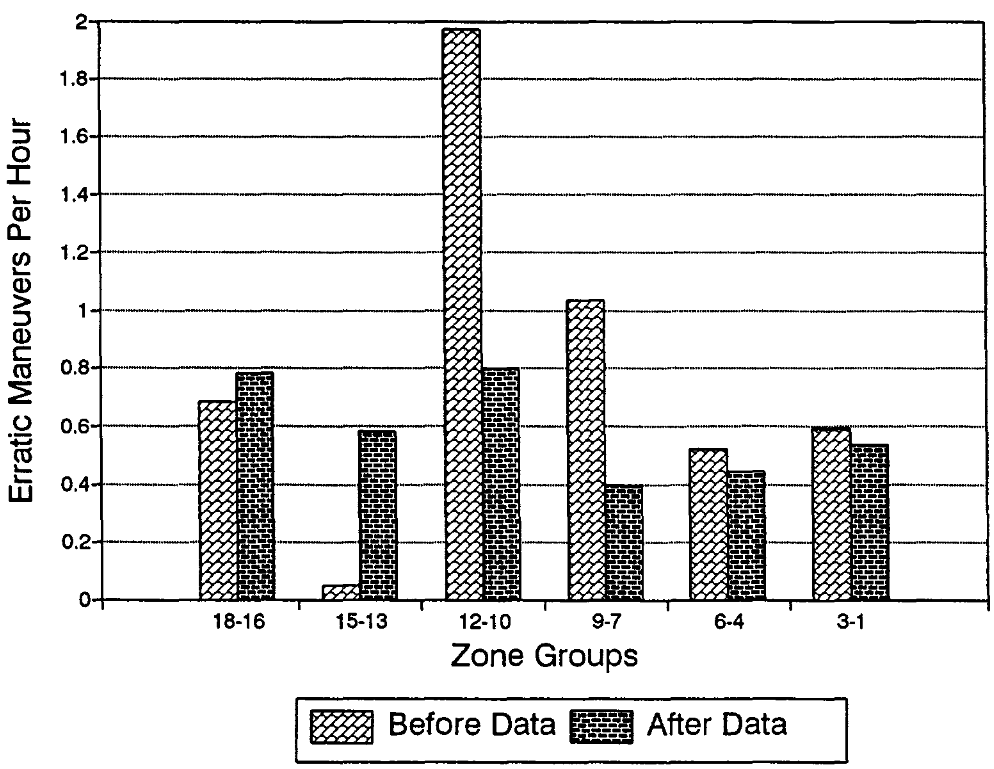


Figure 48. Site 3 Erratic Maneuvers Per Hour by Zone Group.

of the site, with the quality of the video degenerating over the study period. If this location had been a site of high interest, the before period would have been refilmed. However, due to considerations discussed previously (e.g., the desire to have a long exit only lane), the data from this site was only used on a limited basis.

The Old Decatur after data was filmed during June of 1993 simultaneously with the filming at White Settlement. No change in pavement markings occurred at Old Decatur. The camera used during the after period was placed in the same location as the camera used in the before period -- on the sign structure located just downstream of the gore. No difficulties were experienced during the taping of the after data.

Because of the quality of the before data film, the research team reduced data for only 370 ft (113 m). This distance was divided between two zones as shown in Figure 49. Both the before-and-after periods used zones of similar lengths. Because only two zones were filmed, neither zone's data were adjusted to a 100-ft (30.5 m) length. The data shown in Figures 50 to 52 reflect the actual lengths of the zones. A total of 90, 15-minute periods (22.5 hours) were reduced in the before period, and 96 periods (24 hours) were reduced in the after period.

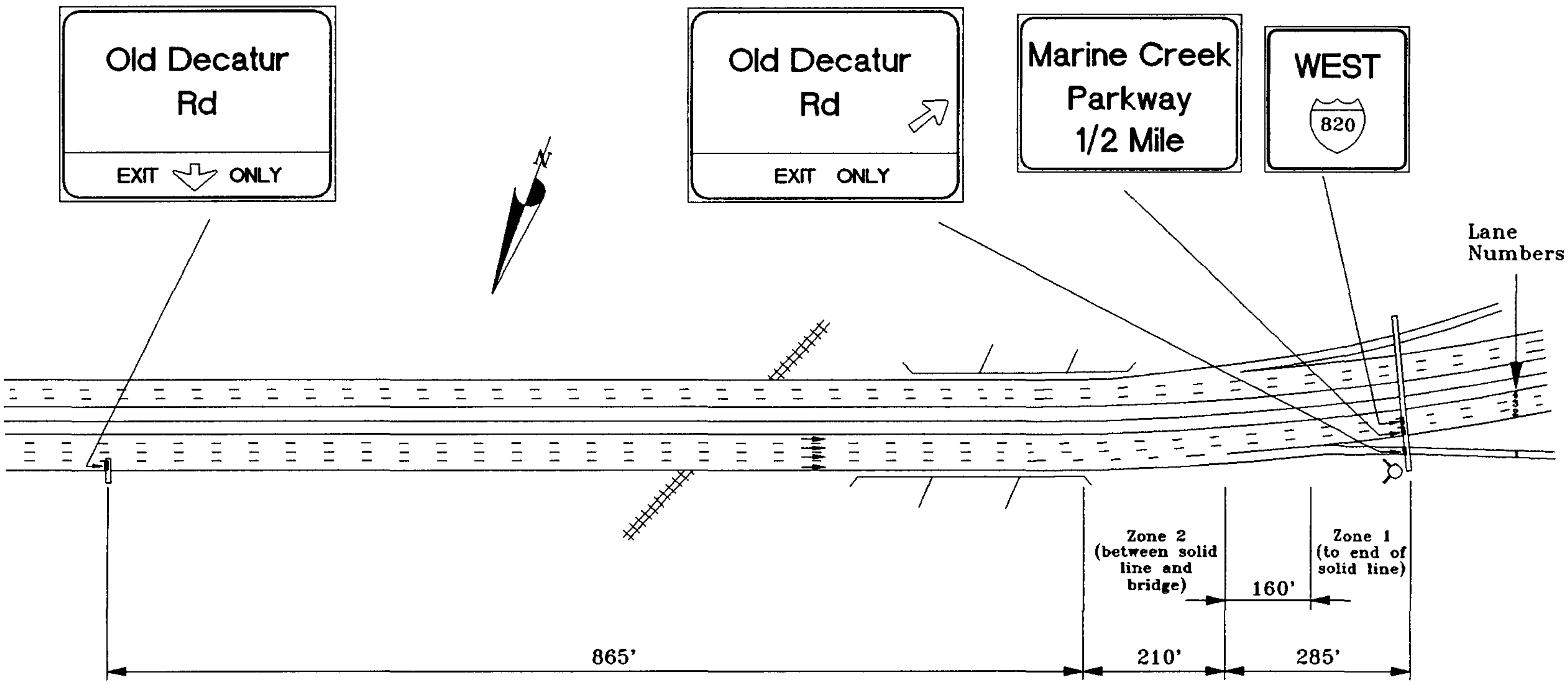
Findings and Observations

Table 30 lists the findings from the before-and-after data collection efforts. The freeway hourly volume values indicate that congestion-related behavior is not a major influence at this site. The total freeway hourly volume (average of data between 7:00 a.m. and 5:30 p.m.) was 1,769 in the before period and 1,822 in the after period. The number of vehicles exiting the site in both the before-and-after periods ranged between 30 and 210 vehicles per hour. Table 30 also lists the number of lane changes and erratic maneuvers for both the before period and the after period. A total of 6.5 lane changes occurred in the 370-ft (113 m) study section in the before period while 7.7 occurred in the after period -- an increase of 18 percent.

Figure 50 shows the number of lane changes per hour for each zone. Both zones had a slight increase in the number of lane changes from the before period to the after period. Figure 51 illustrates the difference in vehicles moving into the exit only lane and vehicles moving out of the exit only lane. While an equal number of vehicles move into and out of the exit only lane in Zone 1 (which represents the 160 ft (49 m) immediately upstream of the gore), Zone 2 has slightly more vehicles entering than leaving the exit lane.

The number of erratic maneuvers also increased from 2.2 to 2.8 erratic maneuvers per hour. Figure 52 shows that the increase was due to more erratic maneuvers recorded in Zone 1 in the after period. These maneuvers included more lane changes through the gore and more attempted lane changes than were observed in the before period.

While the percentage of increases appears noteworthy for both the lane changes and erratic maneuvers (see Table 31), it only reflects the recording of 9 additional erratic maneuvers



Distances are approximated
= Camera Locations

Figure 49. Site 4 Zones.

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

Table 30. Site 4 Findings.

	Before Period January 1993	After Period June 1993	Change (%)
Freeway hourly volume[a]			
Lane 1 (lane drop)	92	91	
Lane 2	680	695	
Lane 3	698	721	
Lane 4	300	315	
Freeway	1769	1822	3
Total study length (370 ft)			
Lane Changes[b]	6.5	7.7	18
Erratic Maneuvers[b]	2.2	2.8	27
Rate[c] (10^{-6}/ft/veh)			
Lane Changes	9.9	11.4	15
Erratic Maneuvers	3.4	4.2	24

[a] Freeway hourly volumes were measured just prior to the gore and represent the average of the time period used in the comparison (7:00 a.m. to 5:30 p.m.).
[b] Values represent an average 60-minute period for the time periods used in the comparison (7:00 a.m. to 5:30 p.m.).
[c] Rates were determined by dividing the number of lane changes, or erratic maneuvers, in an hour by study length and freeway hourly volumes, and multiplying by 1,000,000.
Conversion factor: 1 ft = 0.305 m

Table 31. Erratic Maneuver Types for Site 4.

Erratic Maneuver Type	Gore Area (0-370 ft)	
	Before Data	After Data
One-lane, lane change through the gore	28	31
Two-lane, lane change	7	8
Three-lane, lane change	0	1
Three-lane, lane change through the gore	0	0
Swerving in lane and back out / Attempted lane change	0	4
In/out of shoulder	0	2
Totals	**35**	**46**

Conversion factor: 1 ft = 0.305 m

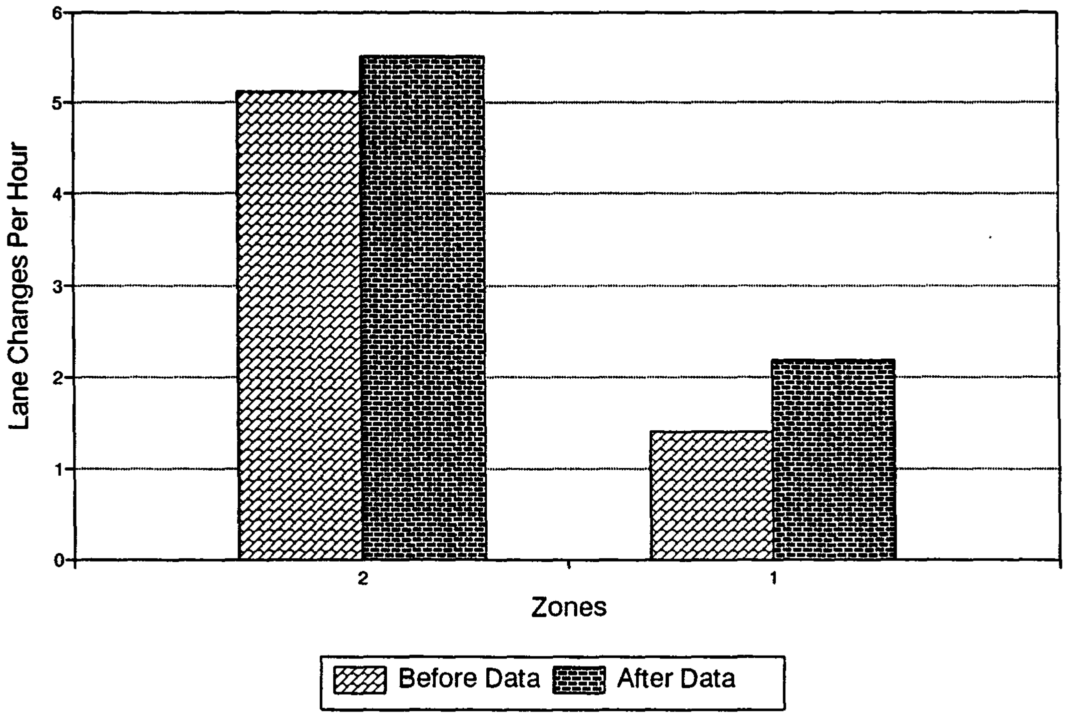


Figure 50. Site 4 Lane Changes Per Hour by Zone.

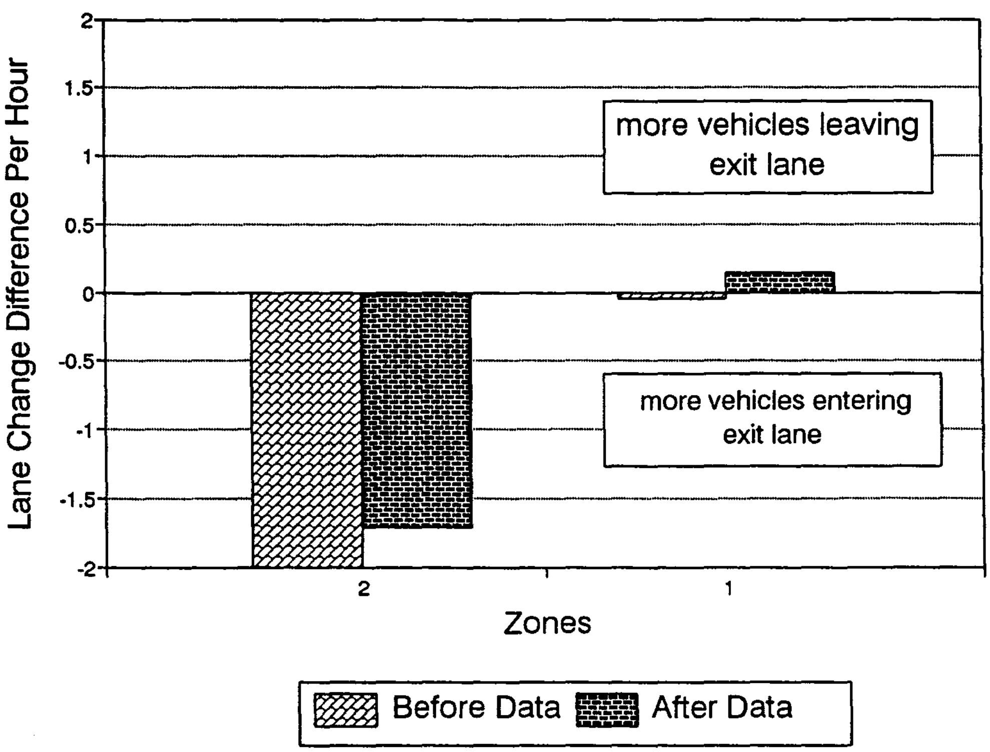


Figure 51. Site 4 Difference in Lane Changes Per Hour by Zone.

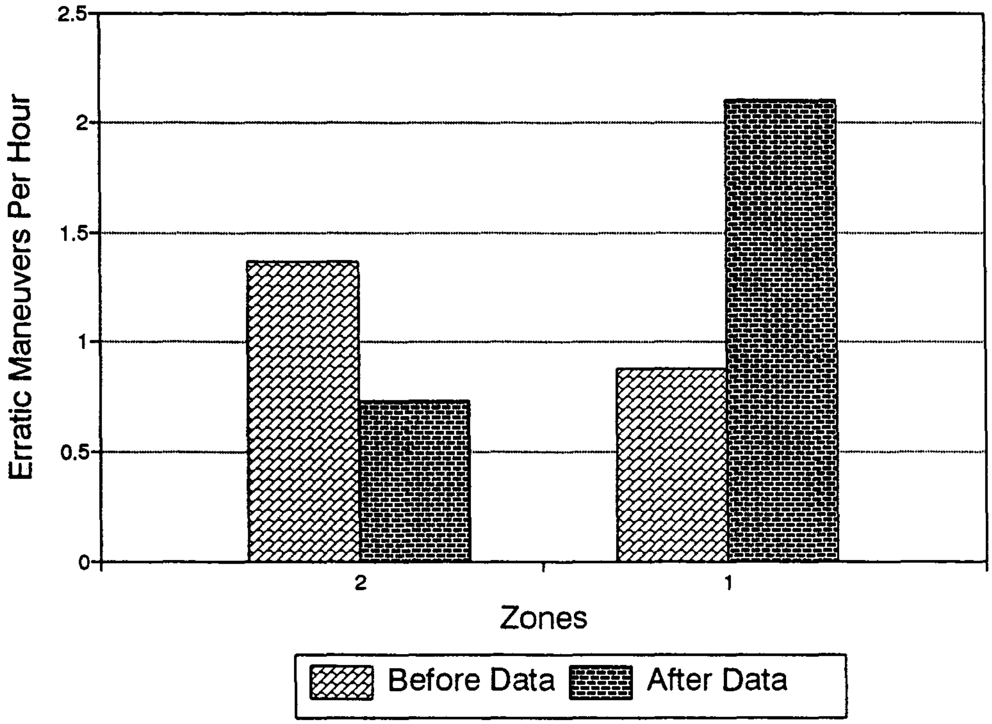


Figure 52. Site 4 Erratic Maneuvers Per Hour by Zone.

over the 24 hours of reduced data and 1 additional lane change per hour for the 370 ft (113 m) of study area. Also, while the same level of quality control was used to reduce Site 4 data as was used with the other sites, the poor quality of video for the before data could have caused some lane changes to be missed.

SITE 5: I-45 NORTHBOUND TO I-610 WEST

Description

Site 5 is a one-lane, lane drop exit to the left from I-45 northbound to I-610 westbound located just downstream from Site 1. The length of the dropped lane is greater than 5 miles (8.1 km). I-45 has four lanes for 400 ft (122 m) prior to the left exit lane drop. At 400 ft (122 m), Site 1's exit lane drop occurs on the right side of the freeway. The median contains a high-occupancy vehicle lane. The average annual daily traffic for 1992 along this corridor was 202,000. As with Site 1, Site 5 is congested during all periods of the day with the most congestion occurring during the a.m. peak period.

Site 5 uses generally the same signs and pavement markings as Site 1. Five green guide signs inform drivers of the I-610 West 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 a yellow EXIT ONLY panel; however, the second sign does contain a downward pointing arrow over the left-most lane. The third, fourth, and fifth signs contain yellow EXIT ONLY panels over the exit lane. Downward pointing arrows on the third and fourth sign, and an upward slanting arrow on the fifth (last) sign are displayed over the left lane. The before pavement markings consisted of typical dashed lane lines between lanes throughout the section analyzed, with the exception of a wide solid white line between the exiting lane and the adjacent lane and beginning approximately 250 ft (76 m) prior to the gore. Pictorial representations of the signs and markings at Site 5 are illustrated in Figure 27.

Data Collection and Data Reduction

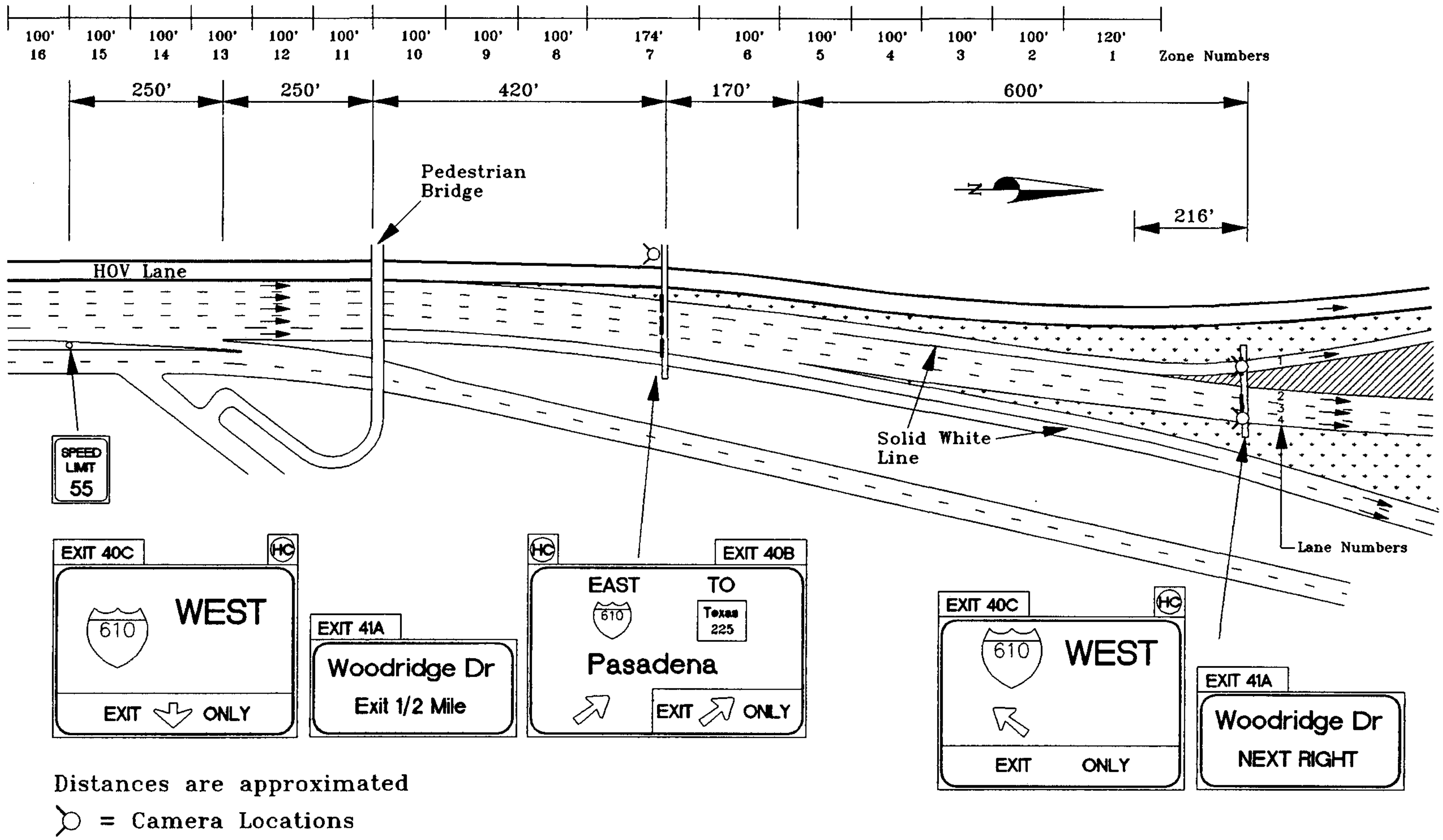
Surveillance cameras were mounted on overhead sign structures and connected to a remote video cassette recorder within a traffic controller cabinet mounted at ground level. Three cameras were installed at this site as shown in Figure 53. Two cameras were mounted on the overhead sign structure directly over the gore area. One of the cameras was focused near the gore area (Zones 1-5), while the other camera was focused upstream of the gore (Zones 6-11). The third camera was positioned on the overhead sign structure at Zone 7. This camera filmed upstream to Zones 12-16. The filming at this site occurred during the month of March, 1993.

Approximately 1700 ft (518 m) were filmed and divided into 16 separate zones as shown in Figure 53. All zones were 100 ft (30.5 m), except Zones 1 and 7 which were 120 ft (37 m) and 174 ft (53 m), respectively. The distances matched the location of the rumble strips (or jiggle bars) along the inside shoulder. An average of 74, 15-minute periods (18.5 hours) of data were reduced. The data represent lane changes and erratic maneuvers occurring between 7:15 a.m. and 6:00 p.m. Because new markings were not installed at this site during the project period, after data are not available. All evaluations were performed on the before data findings.

Findings and Observations

The freeway hourly volume values for Site 5 (see Table 32) illustrate the high volume nature of the Site, especially in the number of vehicles exiting. Over 1,700 vehicles in a typical hour use the left exit. The number of vehicles exiting ranged between 1,525 and 2,100 during the study period. The higher exiting volumes occurred during the a.m. period. While the exiting volumes appear to be extremely high for a freeway lane (i.e., 2,100 vehicles in a hour), the exit lane 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.

Site 5 influences driver behavior very little except that it is a left exit lane drop. 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 of the lane drop. Inspection of the lane changes per zone plot (see Figure A-34 in the Appendix), or the lane changes per 300-ft (91.5 m) zone group plot (shown in Figure 54) illustrates that the number of lane changes increased



Distances are approximated

= Camera Locations

Figure 53. Site 5 Zones.

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

Table 32. Site 5 Findings.

	March 1993
Freeway hourly volume[a]	
Lane 1 (lane drop)	1726
Lane 2	1510
Lane 3	1542
Lane 4	1103
Freeway	5881
Total study length (1500 ft)	
Lane Changes[b]	371.6
Erratic Maneuvers[b]	58.5
For 300 ft nearest gore	
Lane Changes[b]	62.9
Erratic Maneuvers[b]	26.1
Rate[c] (10^{-6}/ft/veh)	
Lane Changes	42.1
Erratic Maneuvers	6.6

[a] Freeway hourly volumes were measured just prior to the gore and represent the average of the time period used in the comparison (7:15 a.m. to 6:00 p.m.).
[b] Values represent an average 60-minute period for the time periods used in the comparison (7:15 a.m. to 6:00 p.m.).
[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

until about 600 ft (183 m) from the gore. The 300 ft (91.5 m) nearest to the gore represent 20 percent of the observed area, and possess 17 percent of the lane changes for the study area.

For each zone, the number of vehicles which entered the exit lane was more than the number of vehicles which left the exit lane. This finding was also true when the data was subdivided into peak and offpeak periods. Figure A-37 in the Appendix shows the data for the 100-ft (30.5 m) zones, and Figure 55 shows the data for the 300-ft (91.5 m) zone groups. For the entire study length, 70 percent of the vehicles changing lanes moved into the exit lane.

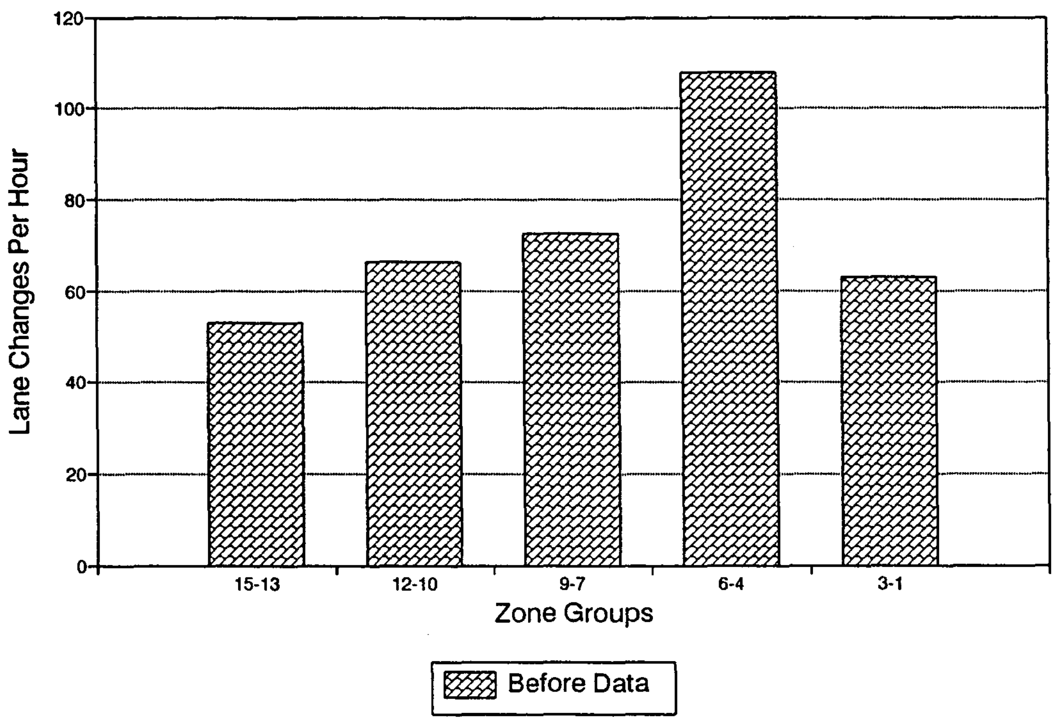


Figure 54. Site 5 Lane Changes Per Hour by Zone Group.

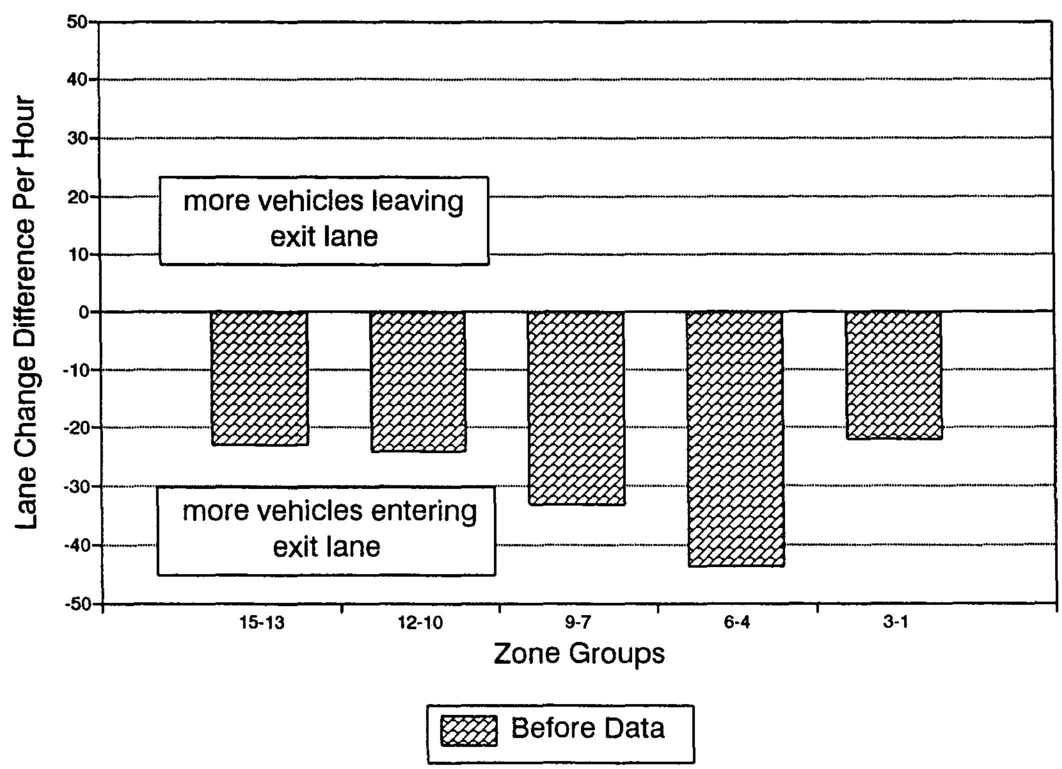


Figure 55. Site 5 Difference in Lane Change Per Hour by Zone Group.

The largest number of erratic maneuvers occurred within 300 ft (91.5 m) of the gore (see Table 33). Almost half (45 percent) of the erratic maneuvers occurred in Zones 1, 2 and 3, with most occurring in Zone 1 (see Figure A-38 in the Appendix for the 100-ft (30.5 m) zones or Figure 56 for the 300-ft (91.5 m) zone groups). The predominant type of erratic maneuvers in the area near the gore was the lane change through the gore area. These erratic maneuvers are a reflection of the high traffic volumes present at the site. The most common type of erratic maneuvers upstream of the gore area was the two-lane, lane change. Congestion-related erratic maneuvers were also high at Site 5. A large number of drivers either suddenly slowed in an attempt to position for a lane change, or attempted but failed to make a lane change.

The number of lane changes per hour for the entire study length is included in the Appendix as Figure A-39. The frequency plot demonstrates that the number of lane changes is higher in the afternoon peak period than in the morning peak period. 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 A-40 in the Appendix). The highest lane change rate occurs during the middle portion of the day and the lowest is during the heavily congested a.m. period.

Table 33. Erratic Maneuver Types for Site 5.

Erratic Maneuver Type	**Gore Area** (0-320 ft)	**Upstream** (320-1800 ft)
One-lane, lane change through the gore	342	0
Two-lane, lane change	39	313
Three-lane, lane change	0	8
Suddenly slowed (other cars passed)	0	32
Swerving in lane and back out / Attempted lane change	4	55
In/out of shoulder	0	6
Rode in between two lanes on solid white line	0	7
Totals	**385**	**421**

Conversion factor: 1 ft = 0.305 m

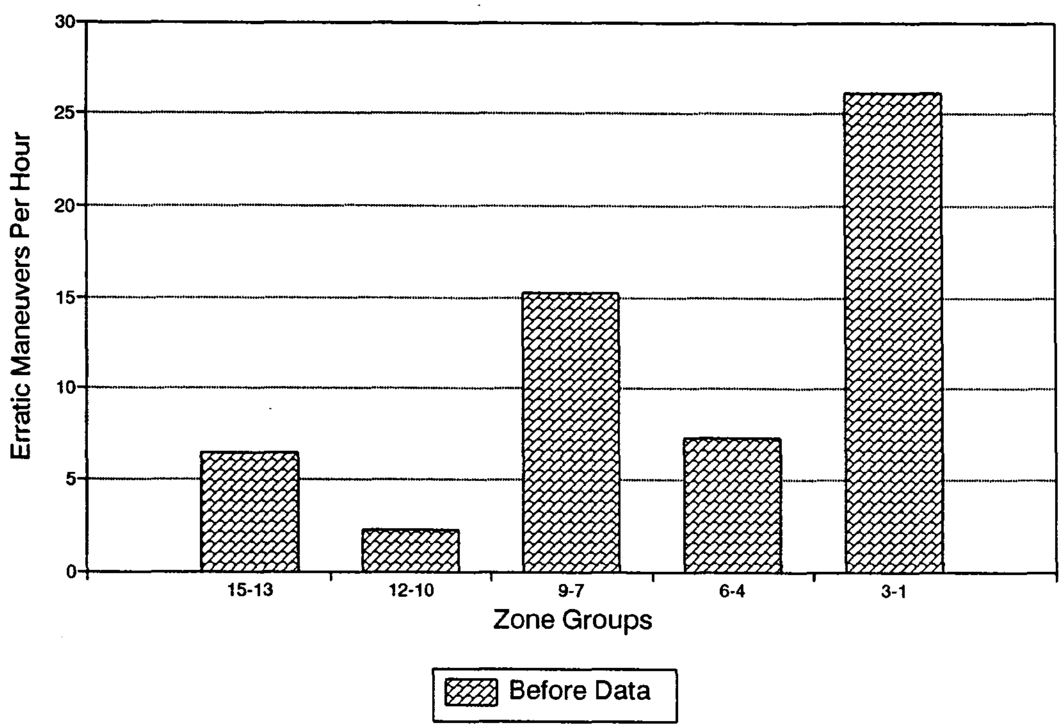


Figure 56. Site 5 Erratic Maneuvers Per Hour by Zone Group.

SITE 6: I-610W SOUTHBOUND TO SOUTH POST OAK

Description

Site 6 exits southbound traffic from I-610W to South Post Oak. The site is located in west Houston where the circular interstate curves from having a north-south orientation to an east-west orientation. The site was selected based upon the Department's experience of high volume, numerous erratic lane changes, and high number of incidents associated with the location. The geometry of the site, as can be seen in Figure 32, influences the lane changing behavior. The mainlanes sharply curve to the left while the exiting lanes proceed on a straight alignment.

The lane that is dropped was created at an entrance ramp located more than 1.25 miles (2.0 km) upstream of the gore. Three through lanes remain on the freeway after the lane drop, and an exit ramp to Braeswood Boulevard is located approximately 1300 ft (396 m) upstream of the gore. The AADT for I-610 near South Post Oak is 139,000, and traffic operations through the area are generally at free-flow conditions. However, during the p.m. peak period, traffic queues upstream and downstream of this exit due to heavy commuting patterns.

Figure 32 illustrates the signs and pavement markings prior to the South Post Oak exit. Four green guide signs pertaining to the exit begin one mile (1.6 km) prior to the lane drop. The first sign simply indicates the South Post Oak exit is one mile (1.6 km) ahead. The second and fourth sign both contain yellow EXIT ONLY panels over the exit only lane with downward pointing arrows over both the option lane and exit only lane. The third sign is a modified diagrammatic sign. It depicts Lanes 3 and 4 with upward slanting, left arrows, while Lane 2's direction is illustrated by a straight arrow and an upward slanting left arrow. The direction of Lane 1 is shown with a straight upward arrow. The sign has the I-610 shield over the left-pointing arrows and the words S POST OAK RD over the straight arrows. The original lane markings at Site 5 consist of typical dashed lane lines between all lanes. No wide solid white line separates the exit lane from the through lanes.

Data Collection and Data Reduction

Three surveillance cameras were mounted on overhead sign structures and connected to a remote video cassette recorder within a traffic controller cabinet mounted at ground level. The first camera was mounted on the overhead sign structure just upstream of the gore area as shown in Figure 57 and it filmed Zones 4-7. The second camera was mounted on the cantilever sign structure in Zone 6, and it filmed downstream of that location and recorded Zones 1-3. The third camera was mounted on the overhead sign structure just upstream of Zone 11, and it also filmed downstream of that position and recorded Zones 8-11. The filming at this site occurred during the month of April,1993.

Approximately 1200 ft (366 m) were filmed and divided into 11 separate zones as shown in Figure 57. Each zone varied in length and was set according to the rumble strips (jiggle bars) along the outside shoulder. An average of 96, 15-minute periods (24 hours) of data were reduced. The data represent lane changes and erratic maneuvers occurring between 7:00 a.m. and 6:30 p.m. Because the markings were not installed at this site during the project period, after data are not available. All evaluations were performed on the before data collection findings.

Findings and Observations

Table 34 lists the volumes, lane changes, and erratic maneuvers for a typical hour. The volumes indicate that congestion-related behavior could be an influence on the number of lane changes and on the types of erratic maneuvers. The Lane 1 volume averaged 733 vehicles per hour over the 7:00 a.m. to 6:30 p.m. study period. As many as 1,300 vehicles exited in the 5:00 to 6:00 p.m. hour. The neighboring exit lane averaged 548 vehicles exiting per hour; however, during the 5:00 to 6:00 p.m. hour it peaked at 1225 exiting vehicles. The hour between 5:00 and 6:00 p.m. contained the largest number of lane changes, and the two hours preceding and following it witnessed the next highest numbers. Figure A-47 in the Appendix illustrates these findings.

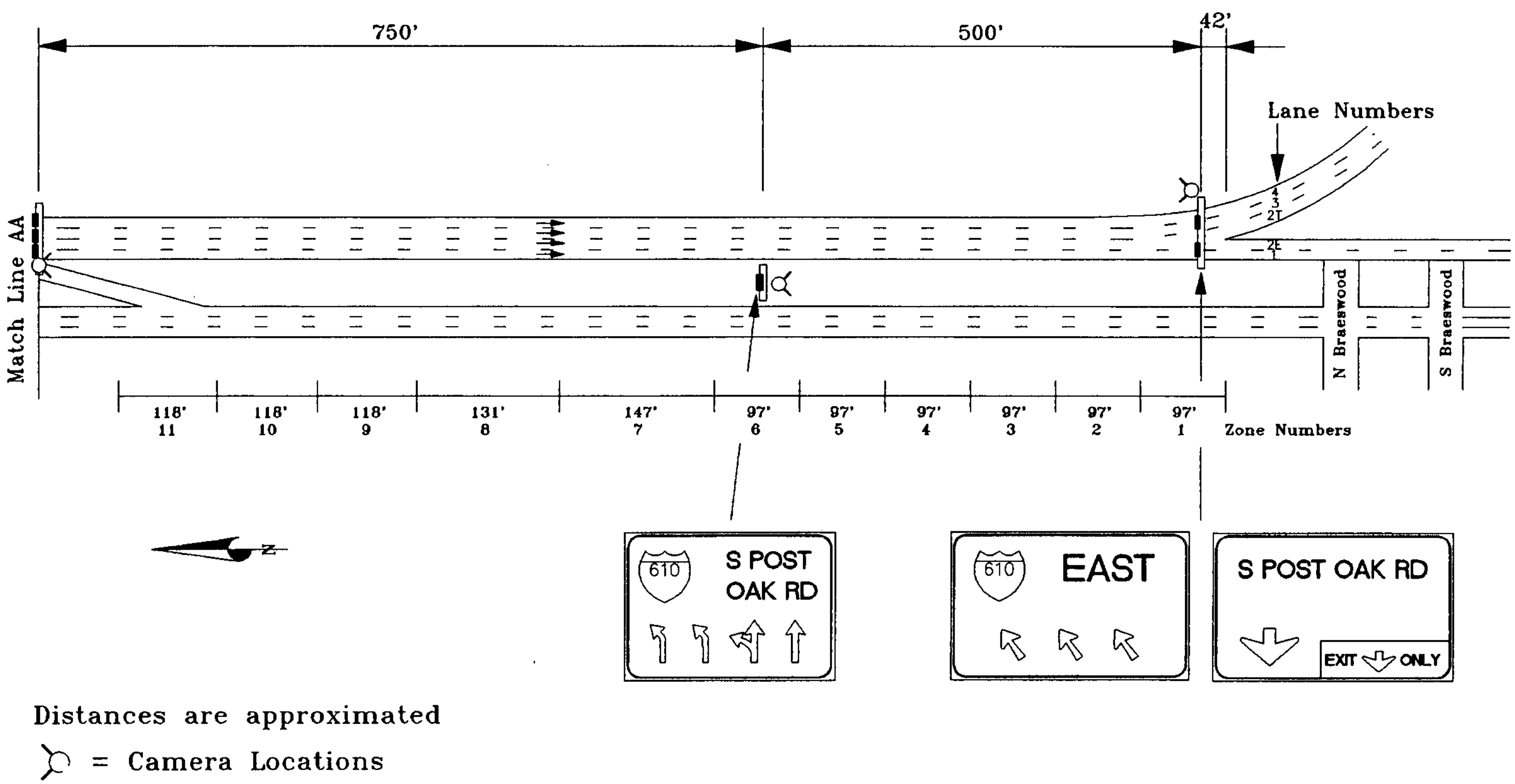


Figure 57. Site 6 Zones.

Conversion Factor: 1 ft = 0.305 m

When the number of lane changes is adjusted to reflect volume (i.e., the lane change rates are determined for each hour), the peaks observed during the 3:00 to 6:00 p.m. period are not present (see Figure A-48 in the Appendix). The rates of lane changes per hour for the time periods studied are relatively equal except for low rates in the 8:00 to 9:00 and 9:00 to 10:00 a.m. periods. The largest rate of lane changes occurs in the 7:00 to 8:00 a.m. period.

Table 34. Site 6 Findings.

	April 1993
Freeway hourly volume[a]	
Lane 1 (lane drop)	733
Lane 2	1192
Exiting	548
Through	644
Lane 3	1221
Lane 4	1335
Freeway	4481
Total study length (1,100 ft)	
Lane Changes[b]	591.5
Erratic Maneuvers[b]	23.0
For 300 ft nearest gore	
Lane Changes[b]	71.9
Erratic Maneuvers[b]	9.9
Rate[c] (10^{-6}/ft/veh)	
Lane Changes	120.0
Erratic Maneuvers	4.7

[a] Freeway hourly volumes were measured just prior to the gore and represent the average of the time period used in the comparison (7:00 a.m. to 6:30 p.m.).
[b] Values represent an average 60-minute period for the time periods used in the comparison (7:00 a.m. to 6:30 p.m.).
[c] Rates were determined by dividing the number of lane changes, or erratic maneuvers, in an hour, by study length and freeway hourly volumes, and multiplying by 1,000,000.

Conversion factor: 1 ft = 0.305 m

Approximately 600 lane changes per hour occurred within the entire study length for the 11.5 hours observed. Approximately 12 percent of these lane changes occurred within the 300 ft (91.5 m) nearest to the gore (which represents 27 percent of the study segment). The largest number of lane changes occurred in Zone 11 (see Figure A-42 in Appendix or Figure 58); many of these lane changes were a reflection of the effects of the upstream exit ramp (located 1,300 ft (396 m) from the gore). Vehicles leaving the freeway on the exit ramp created gaps which other vehicles filled. Over 65 percent of the lane changes in Zone 11 were vehicles moving into the exit lanes. Figure 59 illustrates the difference in lane changes for the vehicles entering and exiting the exit lanes for each zone group. For all zone groups except the 300 ft (91.5 m) prior to the gore, more vehicles entered the exit lanes than left the exit lanes.

Another peak in the number of lane changes per zone occurred in Zones 7 and 6. This peak indicates where the majority of the drivers within the study area changed lanes in anticipation of the lane drop.

The erratic maneuver plots illustrate a slightly different behavior than the lane change plots. The majority of the erratic maneuvers occurred in the zones closest to the gore (Zone Group 3-1) or in the zones closest to the upstream exit ramp (Zone Group 11-10adj) as shown in Figure 60. The predominate type of erratic maneuver was the two-lane, lane change (see Table 35).

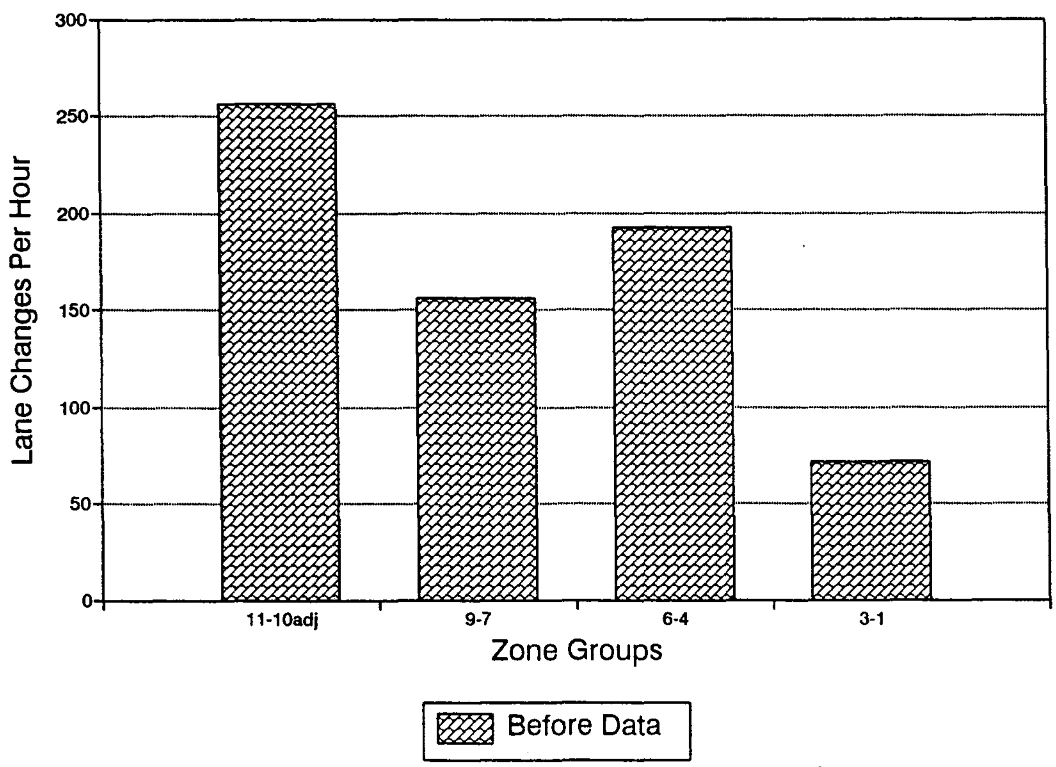


Figure 58. Site 6 Lane Changes Per Hour by Zone Group.

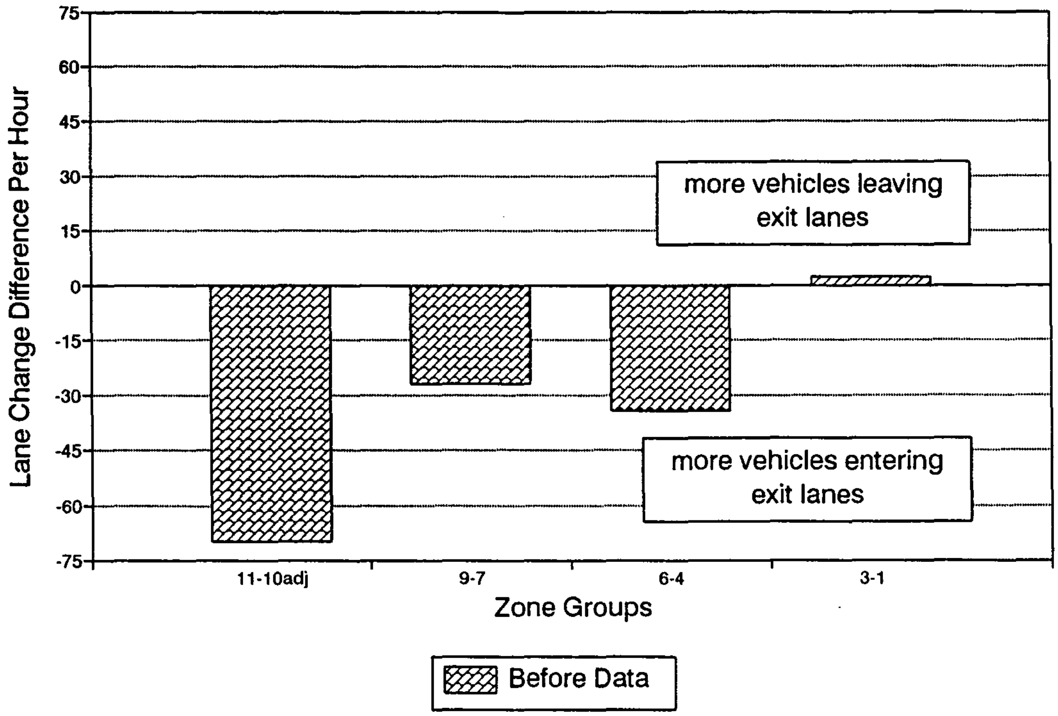


Figure 59. Site 6 Difference in Lane Changes Per Hour by Zone Group.

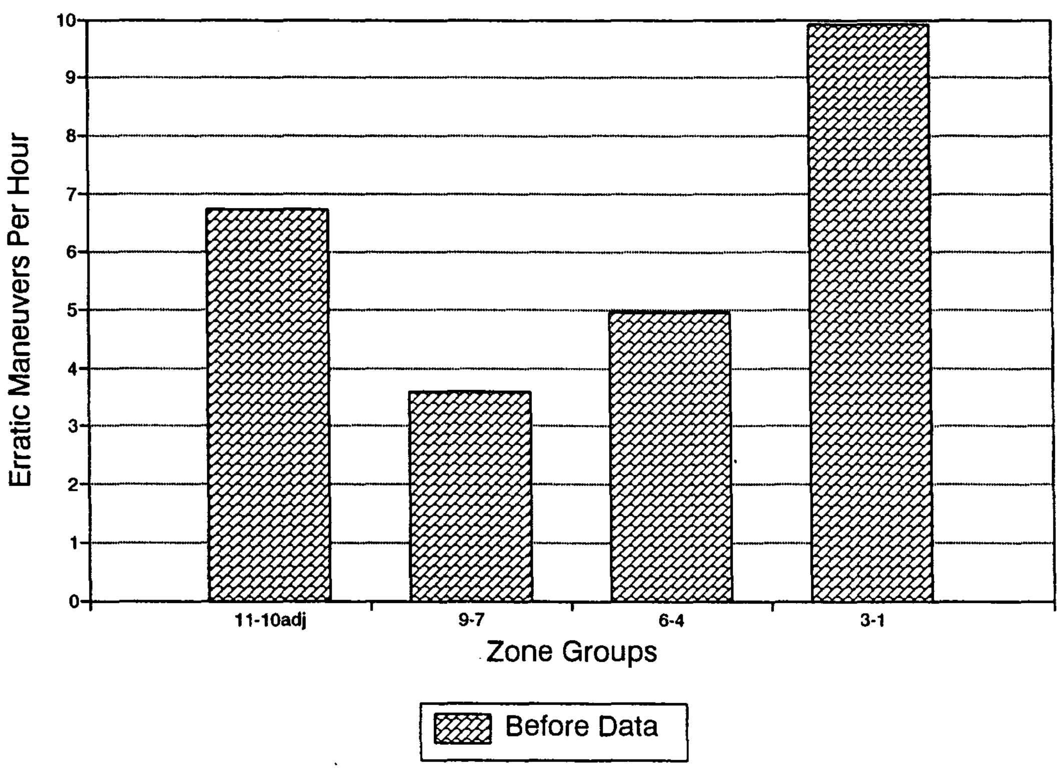


Figure 60. Site 6 Erratic Maneuvers Per Hour by Zone Group.

Table 35. Erratic Maneuver Types for Site 6.

Erratic Maneuver Type	**Gore Area** (0-291 ft)	**Upstream** (291-1214 ft)
One-lane, lane change through the gore	21	0
Two-lane, lane change	166	287
Two-lane, lane change through the gore	2	0
Three-lane, lane change	5	9
Three-lane, lane change through the gore	0	2
Suddenly slowed (other cars passed)	5	18
Slowed or stopped to merge in gore	3	0
Swerving in lane and back out / Attempted lane change	6	17
In/out of shoulder	1	4
Through grass	0	1
Totals	**209**	**338**

Conversion factor: 1 ft = 0.305 m

SITE 7: I-35E SOUTHBOUND TO I-20 WEST

Description

Site 7 was located in south Dallas. I-35E south of Dallas contains two high volume exits to I-20. The first exit, which has a conventional taper exit design, is to I-20 East. The second exit from southbound I-35E is to I-20 West (Ft. Worth) and is a one-lane, lane drop exit. The I-35E lane exists for over seven miles (11 km) before being dropped to I-20 West. Two exit ramps occur within 1800 ft (549 m) of the lane drop -- one located 900 ft (274 m) upstream of the lane drop which exits to I-20 East (Shreveport), and an exit to Wheatland Road. Two through lanes remain on I-35 after the lane drop. The AADT for I-35E prior to the I-20 exits is 75,000.

Four green guide signs precede the Site 7 lane drop. The first two signs, placed 1.25 miles (2.0 km) and 0.5 miles (0.8 km) prior to the lane drop, indicate the distances to both I-20 exits. The last two signs contain yellow EXIT ONLY panels, the third with a downward pointing arrow, and the last (which is over the gore) having an upward sloping arrow. The original pavement markings at this site consisted of typical dashed lane lines with a 180-ft (55

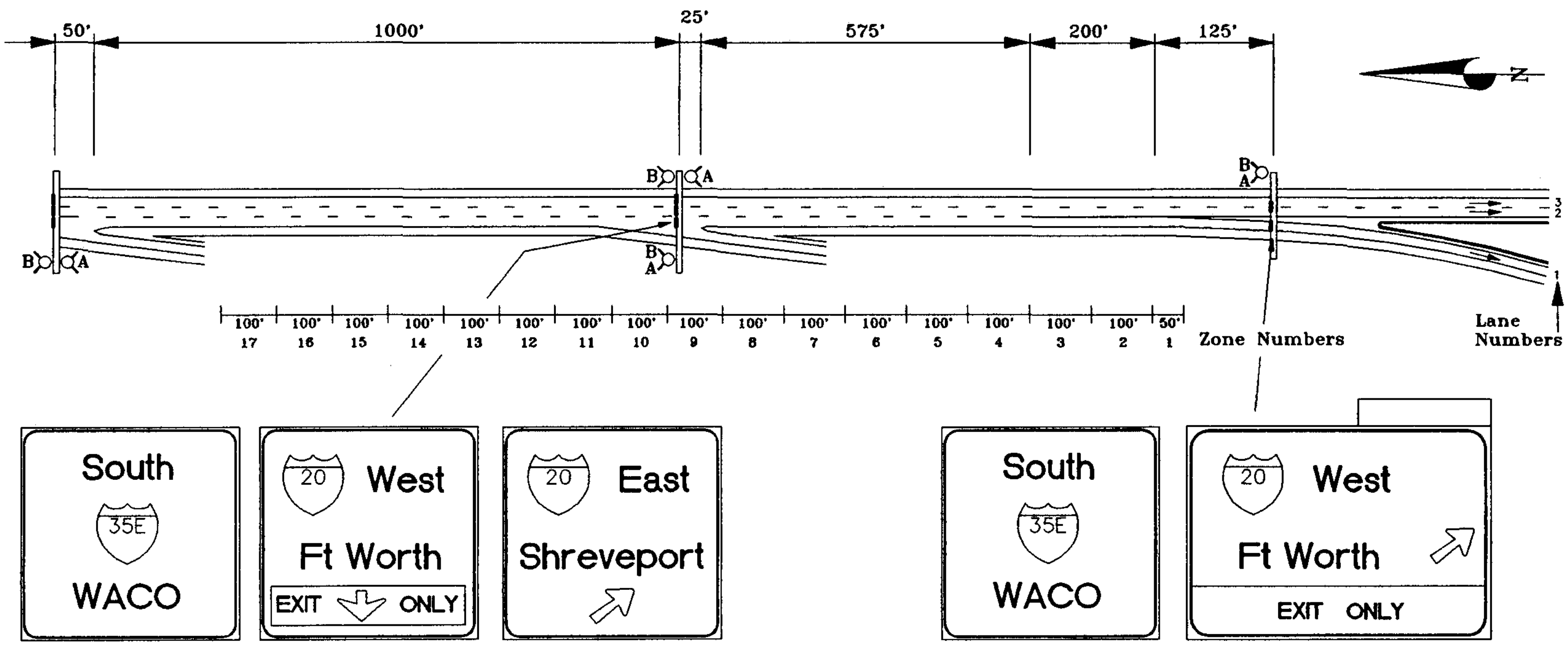
m) wide solid white line preceding the gore. Figure 31 illustrates the signs and original pavement markings at Site 7.

Data Collection and Data Reduction

Four cameras were placed at the I-20 site for both the before-and-after study periods, as shown in Figure 61. The second (1770 ft (540 m) from gore) and third (750 ft (229 m) from gore) sign structures were spaced at greater distances than the typical filming range of the cameras; therefore, cameras were positioned on each sign facing each other so that as much as possible of the area between the signs could be captured on video. The camera on the third sign faced traffic so the fronts of vehicles were captured on film, and the camera on the second sign recorded the backs of vehicles. A third camera was placed on the fourth sign (over the gore) for both the before-and-after period. This camera had a 12X telephoto lens, making it possible to capture the 750 plus ft (229 m) between it and the camera upstream. Unfortunately, data reduction of the before data revealed that Zones 6 to 8 were small on the video screen, making reduction more difficult. In addition, a crest vertical curve peaks at the third sign structure making Zones 9 and 10 undiscernible on the video. As a result a fourth camera was placed on the third sign structure for the after data to aid the telephoto camera in capturing the data for those zones. Although the fourth camera solved the problems related to Zones 6 to 8, data for Zones 9 and part of 10 were still not captured on video for either study period.

The approximately 1,900-ft (579 m) study section was divided into 17 zones for data reduction, as shown in Figure 61. All zones, with the following exceptions, were 100 ft (30.5 m): Zone 1 was 50 ft (15 m), Zone 10 was 40 ft (12 m), Zone 17 was 60 ft (18 m), and Zones 7 and 8 were reduced as one, 200-ft (61 m) zone for the before period. The data for each of these zones were adjusted to a 100-ft (30.5 m) zone length. No data was available for Zone 9.

Before data at Site 7 were collected from June 3 to 9, 1993, and after data were collected June 23 to 30, 1993. A total of 96 periods (24 hours) of data were reduced in both the before period and the after period. The installed markings are shown in Figure 62. Actual placement of the markings varied slightly from the standard drawings (see Figure 19) so that three arrows could be placed between the lane drop gore and the upstream exit ramp. Dotted extension markings were installed at the upstream exit ramps. Figure 63 shows a photograph of the lane drop markings at the site. Field installation of the slanted type of pavement arrows is shown in Figure 64.



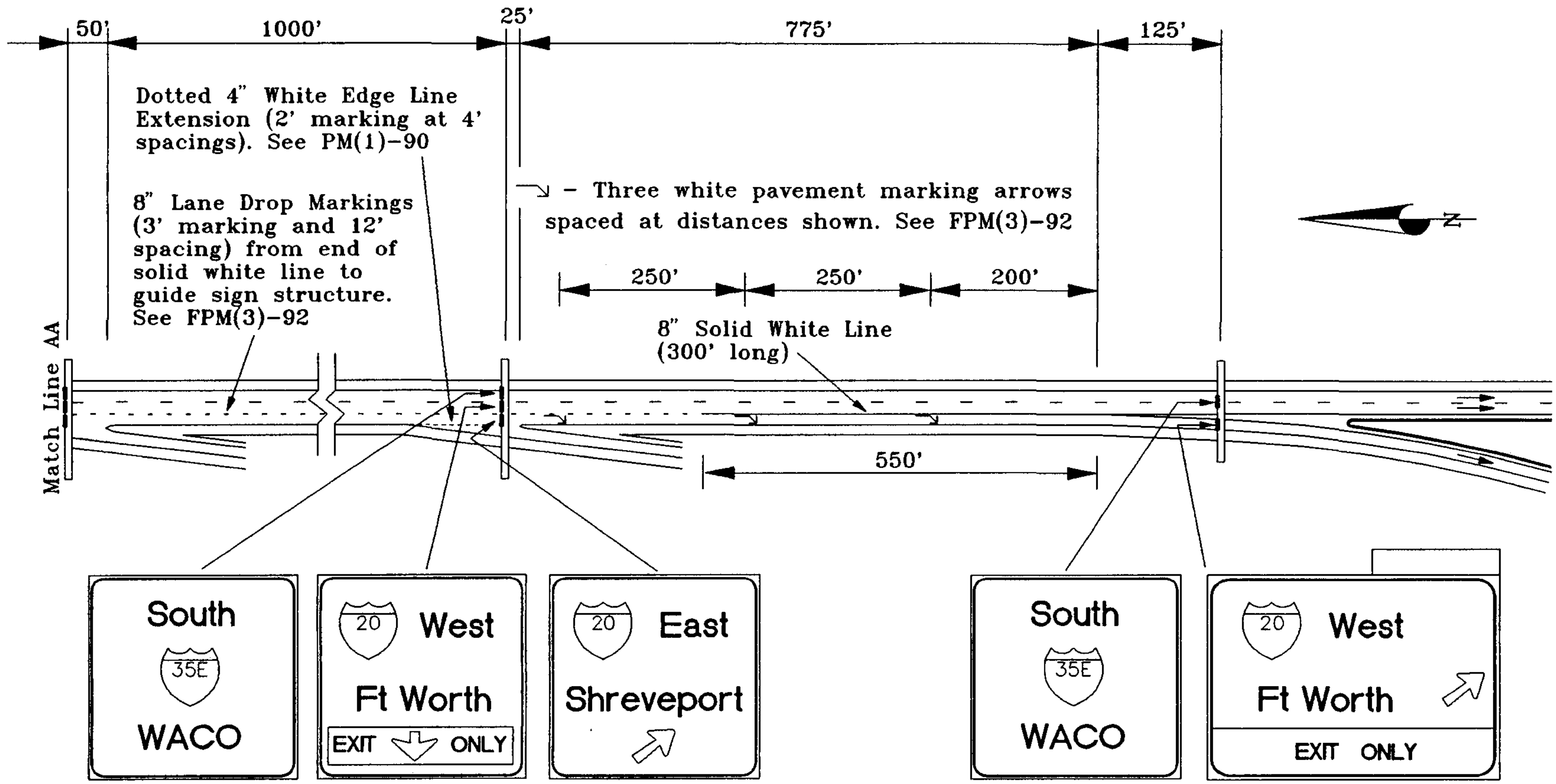
Distances are approximated

B = Camera location for before study

A = Camera location for after study

Figure 61. Site 7 Zones.

Conversion Factor: 1 ft = 0.305 m



Distances are approximated

Figure 62. Markings Installed at Site 7.

Conversion Factor: 1 ft = 0.305 m

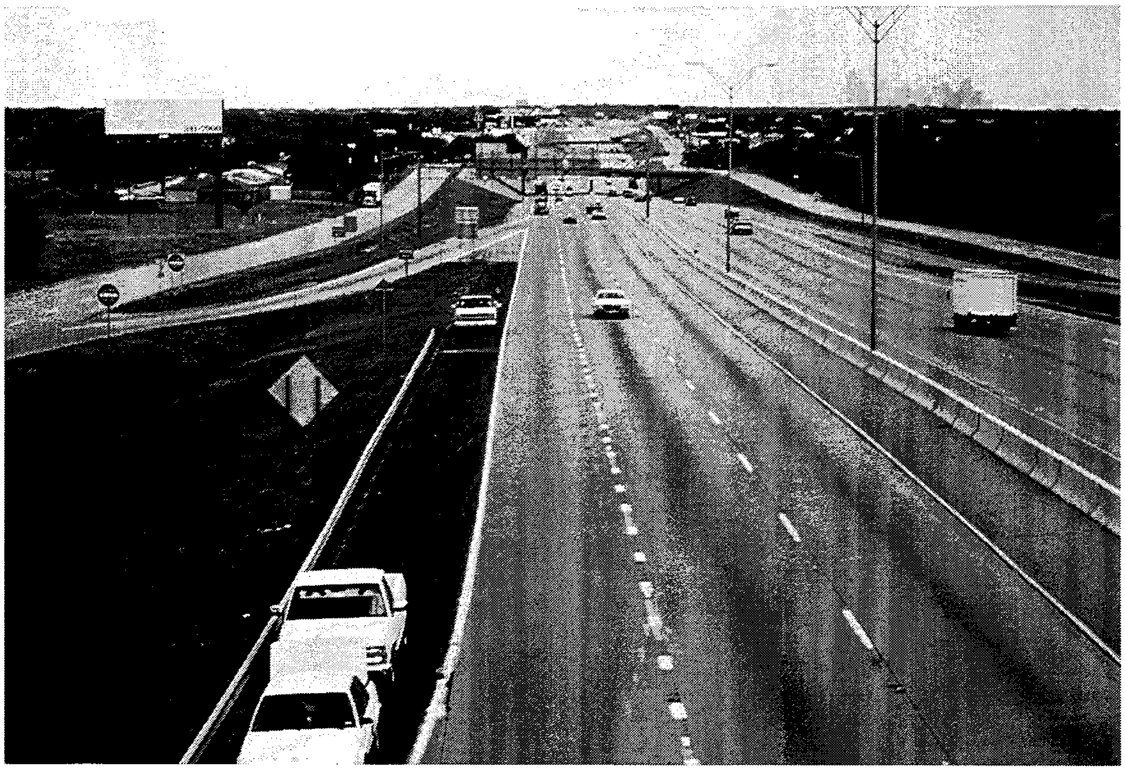


Figure 63. Lane Drop Markings at Site 7.

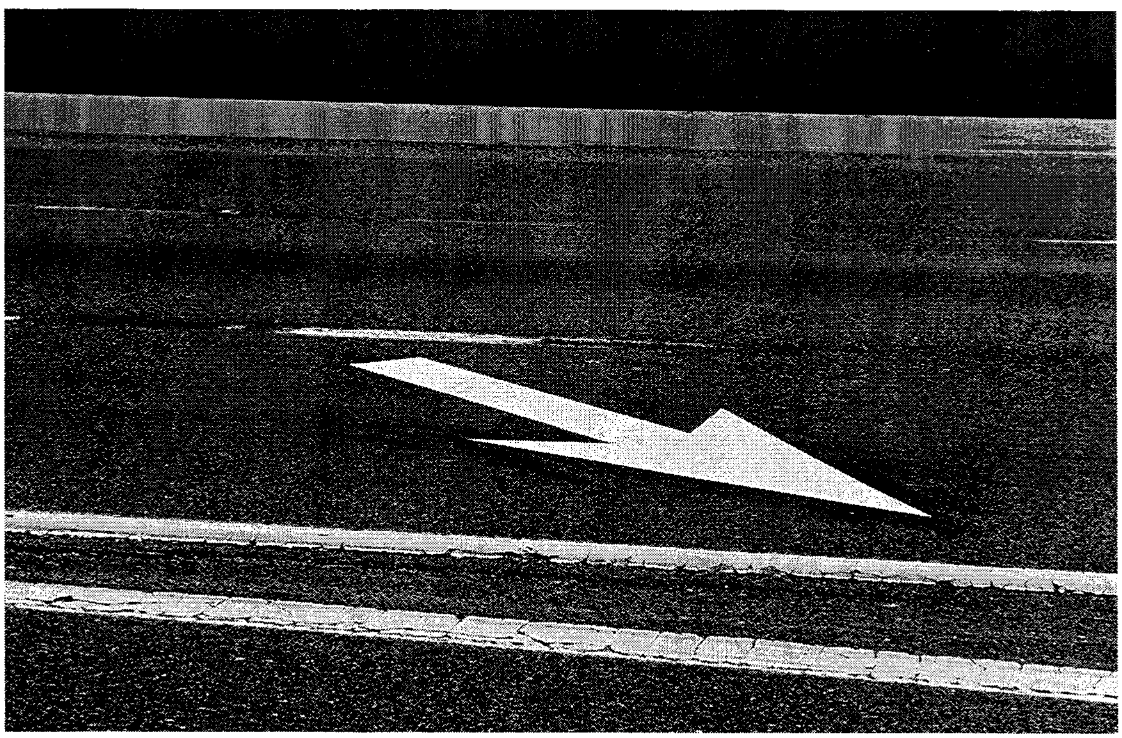


Figure 64. Pavement Arrow at Site 7.

Findings and Observations

Table 36 lists Site 7 findings for both before markings and after markings. The freeway hourly volumes indicate that high traffic flow, or congestion, is not a significant concern in the lane drop operations. Approximately 160 vehicles exit the freeway in a typical hour at this site. A small decrease in total lane changes from the before period to the after period was observed for the entire study length. The before period witnessed approximately 150 lane changes in a typical hour, while the after period showed approximately 140 per hour. This observation reflects a 6 percent decrease in lane changes. With such a relatively small change in the number of lane changes, inspection of the distribution of lane changes over distance can demonstrate if the location of lane changing activities shifted from the before period to the after period. For the area downstream of the I-20 East exit, Figure 65 shows decreases in lane changes in Zone Groups 3-1 and 6-4, and an increase in lane changes in the Zone Group 8-7adj. (Group 8-7 was adjusted to reflect 300 ft (91.5 m), the same length used in the other zone groups.) More lane changes in the after period occurred in the 15-13 Zone Group. In summary, the location of lane changing activity at Site 7 did shift from the 700 ft (213 m) nearest the gore to areas upstream.

Lane changes decreased even more for the 300 ft (91.5 m) nearest the gore, where the number of lane changes decreased by over 40 percent from the before period to the after period. The number of lane changes in the 300-ft (91.5 m) section, over 19 percent of the study length, represents 3 to 5 percent of all lane changes within the study area. The majority of the lane changes within the study section in both the before-and-after periods occurred at distances greater than 300 ft (91.5 m) from the gore.

The two upstream entrance ramps influence driver behavior in relation to the exit only ramp. The ramp at Zone 9 (900 ft (274 m) upstream of the lane drop gore) leads to I-20 East and has almost as many vehicles exiting as the lane drop exit (130 vehicles exiting in a typical hour as compared to the 160 vehicles exiting to I-20 West). Another exit ramp is located 1800 ft (549 m) upstream of the gore. The plots of lane changes per distance (see Figure A-50 in the Appendix for 100-ft (30.5 m) increments and Figure 65 for the 300-ft (91.5 m) increments) demonstrate the influences of the exit ramps. The before data showed peaks in the typical lane change values immediately after the exit ramps (see Zone Groups 16-17adj and 8-7adj) with the number of lane changes decreasing until the next gore. These peaks reflect the lane changes occurring in response to the gaps created by vehicles leaving the freeway. After the markings were installed, the lane change pattern still showed the peak in the 8-7adj Zone Group; however, a higher number of lane changes occurred in the 15-13 Zone Group than in the 16-17adj Zone Group. The greatest drop occurred in vehicles moving into the exit only lane within those zones.

Table 36. Site 7 Findings.

	Before Period June 1993	After Period June 1993	Change (%)
Freeway hourly volume[a]			
Lane 1 (lane drop)	158	165	
Lane 2	684	643	
Lane 3	563	566	
Freeway	1405	1375	-2
Total study length (1600 ft)			
Lane Changes[b]	149.6	141.1	-6
Erratic Maneuvers[b]	12.9	8.6	-33
For 300 ft nearest gore			
Lane Changes[b]	7.8	4.4	-44
Erratic Maneuvers[b]	5.6	2.0	-64
Rate[c] (10^{-6}/ft/veh)			
Lane Changes	66.5	64.2	-4
Erratic Maneuvers	5.7	3.9	-32

[a] Freeway hourly volumes were measured just prior to the gore and represent the average of the time period used in the comparison (7:00 a.m. to 5:30 p.m.).

[b] Values represent an average 60-minute period for the time periods used in the comparison (7:00 a.m. to 5:30 p.m.).

[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

A plot showing the percent of lane changes per zone for the after period and the before period can indicate if a shift in lane change location occurred. A figure showing the numeric difference in lane changes could also indicate that information; however, if the total number of lane changes decreased, as it did for Site 7, then the decrease could hide a shift in where lane changes occurred. Figures 66 and 67 show the difference in lane changes for a typical hour by zone group and the percent of lane changes per zone, respectively. (The plot of difference in lane changes per zone is included in the Appendix as Figure A-53.) Before the markings were installed, more vehicles were leaving the exit lane than entering the exit lane within 800 ft (244 m) of the gore. After the markings were installed, more vehicles were entering the lane than leaving within 800 ft (244 m) of the gore. These observations indicate that a shift occurred where drivers entered and left the exit lane. After the markings were installed, drivers changed lanes further from the gore and left the exit lane further upstream than they had previously.

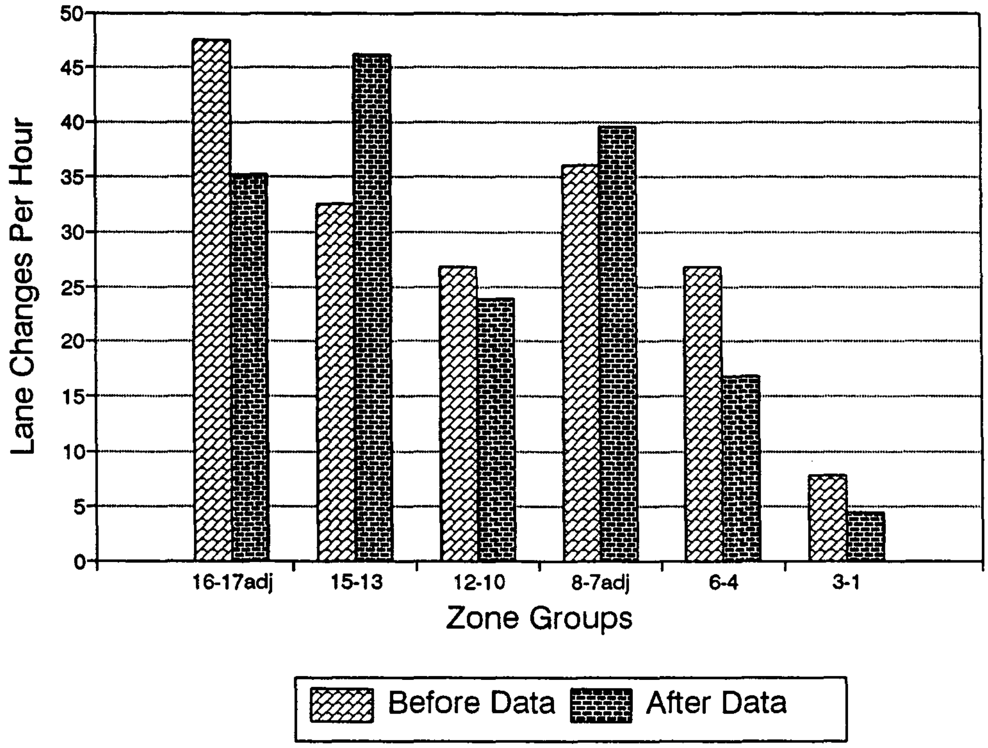


Figure 65. Site 7 Lane Changes Per Hour by Zone Group.

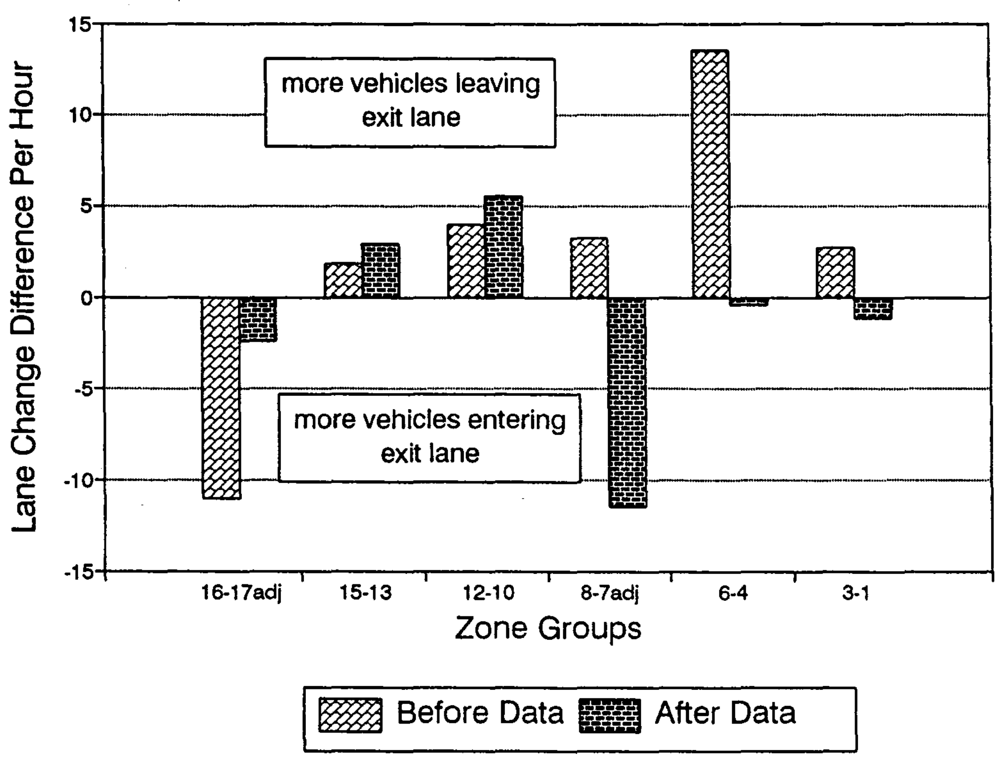


Figure 66. Site 7 Difference in Lane Changes Per Hour by Zone Group.

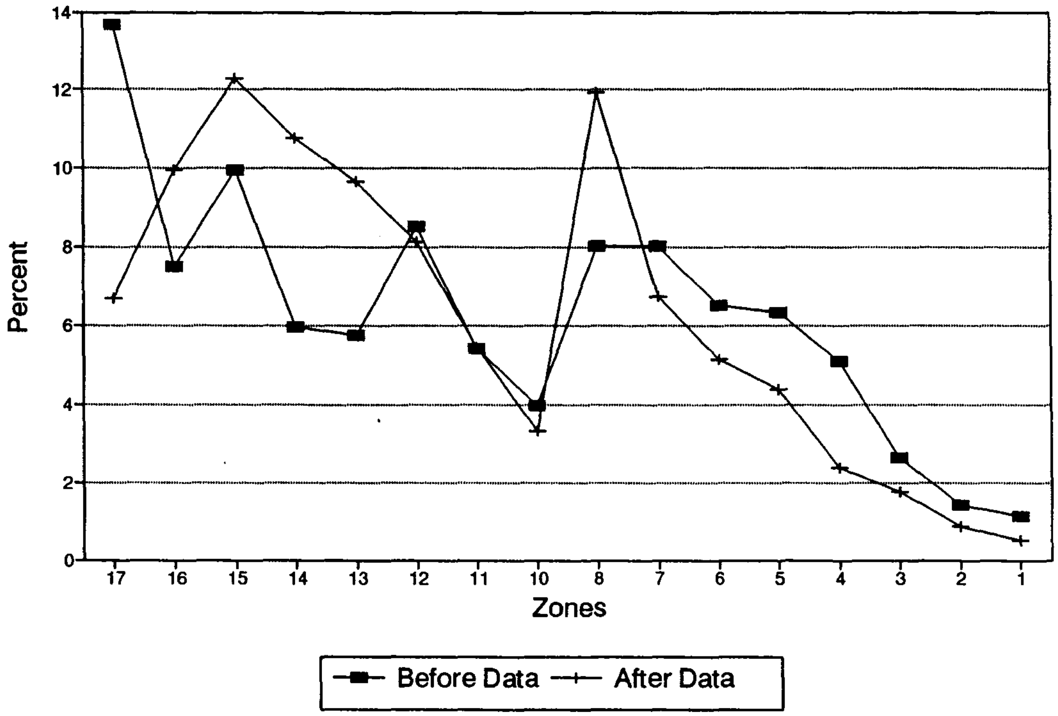


Figure 67. Site 7 Percent of Lane Changes Per Hour by Zone.

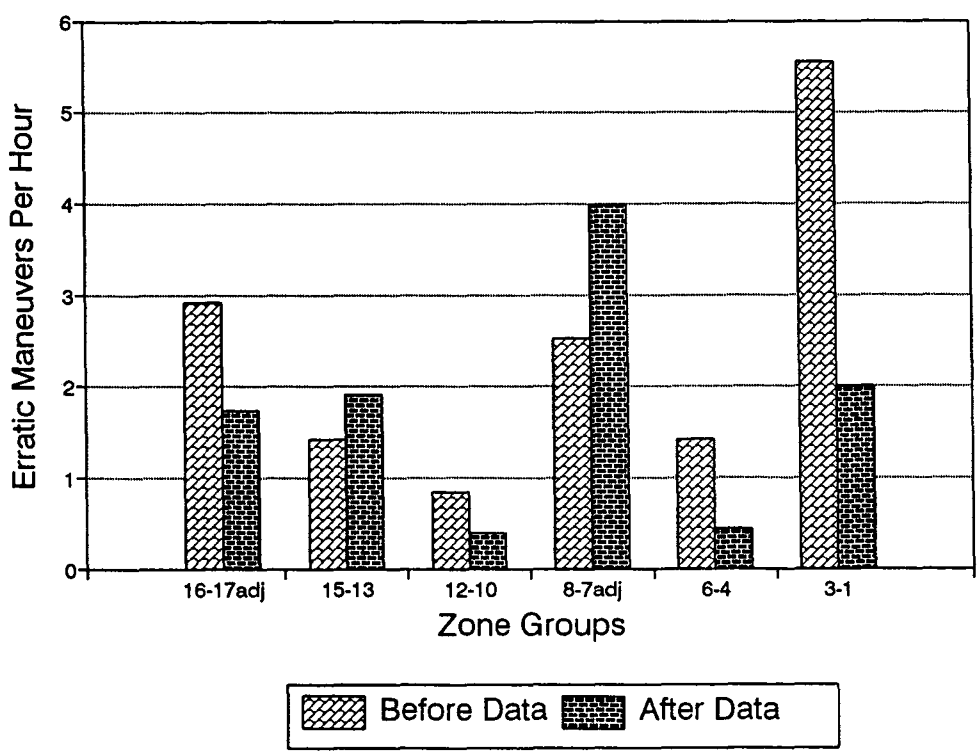


Figure 68. Site 7 Erratic Maneuvers Per Hour by Zone Group.

As with lane changes, the number of erratic maneuvers also decreased; however, it did so at a much higher rate. For the entire study segment, a 33 percent decrease was observed. For the 300 ft (91.5 m) nearest the gore, a 64 percent reduction was observed. In the before period, the erratic maneuvers that occurred in the 300-ft (91.5 m) area nearest to the gore represented almost half of all the erratic maneuvers that were recorded for the entire study. Figure 68 shows the distribution of erratic maneuvers for the different zone groups. The largest decrease in erratic maneuvers was the one-lane, lane change through the gore (see Table 37). With motorists changing lanes further upstream, the lane changes across the gore area also decreased.

Table 37. Erratic Maneuver Types for Site 7.

Erratic Maneuver Type	Gore Area (0-300 ft)		Upstream (300-1700 ft)	
	Before Data	After Data	Before Data	After Data
One-lane, lane change through the gore	68	31	7*	31*
Two-lane, lane change	1	1	91	87
Three-lane, lane change	0	0	4	0
Three-lane, lane change through the gore	0	0	2	2
Suddenly slowed (other cars passed)	0	0	2	2
Slowed or stopped to merge in gore	3	1	3	3
Swerving in lane and back out / Attempted lane change	2	0	26	3
In/out of shoulder	1	0	8	6
Rode in between two lanes on solid white line	1	0	4	1
Through grass	0	0	2	1
Totals	**76**	**33**	**149**	**136**

* These erratic maneuvers occurred at the gore for the exit ramp located 900 ft upstream of the lane drop.

Conversion factor: 1 ft = 0.305 m

CHAPTER 7

COMPARISONS BETWEEN SITES

Chapter 6 presented information on each individual study site, including a description of the characteristics for each site and a discussion on how those characteristics influenced the motorists' lane changing and erratic maneuver behavior. The next step compares the lane change and erratic maneuver findings between sites. The sites can be grouped into several similar categories, for example, one-lane, lane drop exits, two-lane exits with an option lane and an exit only lane, sites with congestion, sites with right exits as opposed to the site with the left exit, and others. The findings for each of these groups are generally in one of three areas; therefore, the discussions are grouped into the following three areas: lane change behavior, erratic maneuver behavior, and the influence of markings on lane changes and erratic maneuvers. The section on the influences of markings, called Before-and-After Studies, includes discussions on the statistical validity of the findings.

Tables 38 and 39 present a summary of the findings for the seven sites. Table 38 contains the information on the sites with before-and-after data, which included all three one-lane, right exits:

Site 3: I-820 NB to White Settlement Road.
Site 7: I-35E SB to I-20 West.
Site 4: I-820 SB to Old Decatur Road.

Table 39 presents the information on the remaining sites which included the three two-lane exits with an option lane and an exit only lane, and the site with the one-lane left exit:

Site 1: I-45 NB to I-610 East and Texas 225.
Site 2: I-45 SB to I-610 East and West, Texas 225, and Texas 35.
Site 6: I-610W SB to South Post Oak.
Site 5: I-45 NB to I-610 West.

Table 38. Comparison of Before-and-After Data for Sites 3, 7, and 4.

Characteristics	Site 3	Site 7	Site 4
Exit Name	I-820 NB to White Settlement Road	I-35E SB to I-20 West	I-820 SB to Old Decatur Road
Location	west Ft. Worth	south Dallas	northwest Ft. Worth
Description	One-lane exit	One-lane exit	One-lane exit
Length of lane drop	approximately 1.0 miles	over 7 miles	2250 ft
Dates of filming	Before: Jan 1993 After: June 1993	Before: June 1993 After: June 1993	Before: Jan 1993 After: June 1993
Markings installed	May 1993	June 1993	NA
Num. of lanes after exit	three	two	three
Potential Influences (distance upstream from gore)	Entrance ramp (2000 ft)	Exit ramp--I-20 E (900 ft) Exit ramp (1800 ft)	Poor film quality for before data Auxiliary lane
AADT on freeway (1992 AADT Maps)	47,000	75,000	60,000

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

Table 38 (continued). Comparison of Before-and-After Data for Sites 3, 7, and 4.

Characteristics	Site 3			Site 7			Site 4		
Exit Name	I-820 NB to White Settlement Road			I-35E SB to I-20 West			I-820 SB to Old Decatur Road		
Time used in comparison	7:30 a.m. to 5:45 p.m.			6:45 a.m. to 6:00 p.m.			7:00 a.m. to 5:30 p.m.		
Zones used in comparison	Zones 1 to 19			Zones 1 to 17 (except 9)			Zones 1 to 2		
Equil. length of study site	1900 ft			1600 ft			370 ft		
	Before	After	Change	Before	After	Change	Before	After	Change
Freeway hourly volume[a]	1436	1453	1%	1405	1374	-2%	1769	1822	3%
Hourly volume exiting[a]	280	231	-18%	158	165	4%	92	91	-1%
Total study length									
Lane Changes[b]	95.2	67.8	-29%	149.6	141.1	-6%	6.5	7.7	18%
Erratic Maneuvers[b]	5.1	4.2	-18%	12.9	8.6	-33%	2.2	2.8	27%
For 300-ft nearest to gore									
Lane Changes[b]	5.4	3.1	-42%	7.8	4.4	-44%	5.3	6.2	18%
Erratic Maneuvers[b]	0.7	0.5	-29%	5.6	2.0	-64%	1.8	2.3	27%
Rate[c] (10^{-6}/ft/veh)									
Lane Changes	34.9	24.6	-30%	66.5	64.2	-4%	9.9	11.4	15%
Erratic Maneuvers	1.9	1.5	-19%	5.7	3.9	-32%	3.4	4.2	24%

[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

Table 39. Comparison of Before Data for Sites 1, 2, 6, and 5.

Characteristics	Site 1	Site 2	Site 6	Site 5
Exit Name	I-45 NB to I-610 East and Texas 225	I-45 SB to I-610 East and West, Texas 225, and Texas 35	I-610W SB to South Post Oak	I-45 NB to I-610 West
Location	southeast Houston	southeast Houston	west Houston	southeast Houston
Description	Two-lane exit with an option lane and an exit only lane	Two-lane exit with an option lane and an exit only lane	Two-lane exit with an option lane and an exit only lane	One-lane, left exit
Length of lane drop	0.65 miles	greater than 2 miles	greater than 1.25 miles	greater than 5 miles
Dates of filming	June/July 1992	September 1992	April 1993	March 1993
Num. of lanes after exit	four	three	three	three
Potential Influences (distance upstream from gore)	Exit ramp (1,000 ft) High volumes	Exit lanes split to two destinations approx. 600 ft beyond the exit lane drop gore Vertical curve that crests at 500 ft prior to the gore	Exit ramp (1,300) Main lanes curve while exit lanes are straight	Two-lane with optional lane lane drop (see Site 1) (600 ft)
AADT on freeway (1992 AADT Maps)	202,000	183,000 to 202,000	139,000	202,000

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

Table 39 (continued). Comparison of Before Data for Sites 1, 2, 6, and 5.

Characteristics	Site 1	Site 2	Site 6	Site 5
Exit Name	I-45 NB to I-610 East and Texas 225	I-45 SB to I-610 East and West, Texas 225, and Texas 35	I-610W SB to South Post Oak	I-45 NB to I-610 West
Time used in comparison	7 a.m. to 6 p.m.	7 a.m. to 6:45 p.m.	7 a.m. to 6:30 p.m.	7:15 a.m. to 6 p.m.
Freeway hourly volume[a]	6757	4891	4481	5881
Hourly volume exiting[a]				
Lane 1	656	1009	733	1726
Lane 2	409	782	548	NA
Zones used in comparison	Zones 1 to 14 (except 7)	Zones 1 to 12	Zones 1 to 11	Zones 1 to 16
Equil. length of study site	1300 ft	1200 ft	1100 ft	1500 ft
Total study length				
Lane Changes[b]	665.9	580.3	591.5	371.6
Erratic Maneuvers[b]	24.4	74.5	23.0	58.5
For 300-ft nearest to gore				
Lane Changes[b]	92.2	130.9	71.9	62.9
Erratic Maneuvers[b]	13.2	69.1	9.9	26.1
Rate[c] (10^{-6}/ft/veh)				
Lane Changes	75.8	98.9	120.0	42.1
Erratic Maneuvers	2.8	12.7	4.7	6.6

[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 CHANGE BEHAVIOR

Comparisons in lane change behavior were investigated between all sites. The sites are inherently different; therefore, some comparisons are difficult to make. Some of the differences between sites can be accounted for, such as the lane change rates shown in Tables 38 and 39. These rates, which accounted for different study section lengths and volumes of traffic, were calculated so that lane changes could be compared from site to site. Some other influences that were not accounted for are geometry of sites, influences of other exits, and congestion. Following is a comparison of sites with similar geometry, different geometry, and different volumes, based on data collected before any pavement marking changes were made at the sites.

One-Lane, Lane Drop Exits

Sites 3, 4, 5, and 7 are all one-lane, lane drop exits. Tables 38 and 39 reveal that Sites 3, 7, and 4 all have comparably low volumes (1400-1800 vph), whereas Site 5 has a much higher volume (5881 vph). Even when inspecting the hourly volume ranges, Sites 3, 7, and 4 volumes (800-2900 vph) are noticeably below Site 5 (5000-7400 vph).

Sites 3 and 7 have generally the same lane change distribution over the whole study section length as seen in Figure 69, except that Site 7 has two peaks and Site 3 has one peak. The peaks occurred at the zones farthest from the gore (and closest to an upstream entrance/exit ramp) with lane changes decreasing non-linearly to the zones closest to the gore. The peaks in lane changes seen in the lane change plots of Site 3 and 7 are due to other ramps. Site 3 has an entrance ramp at the beginning of the study section. This entrance ramp causes the high number of lane changes in the zones farthest from the gore. Similarly, two peaks are seen in Site 7 lane changes -- one in Zone 17 and one in Zone 8. Both these zones contain an exit ramp, with the one in Zone 8 having very high exit volumes. Again, these peaks are a result of the lane change activity related to the two exit ramps.

Interesting, when investigating the type of lane changes occurring at one-lane, lane drop exits, approximately the same amount of vehicles entering the exit lane are leaving the exit lane over the whole study section for Sites 3, 4, and 7 (maximum difference equals 5 lane changes/hour/100 ft (30.5 m) as seen in Figures A-21, A-29, and A-53 of the appendix). Site 5, however, has up to 15 lane changes/hour/100 ft (30.5 m) more entering the exit lane than leaving over the whole study section (see Figure A-37 in the appendix). Closer analysis reveals that this finding is true in off-peak as well as peak time periods.

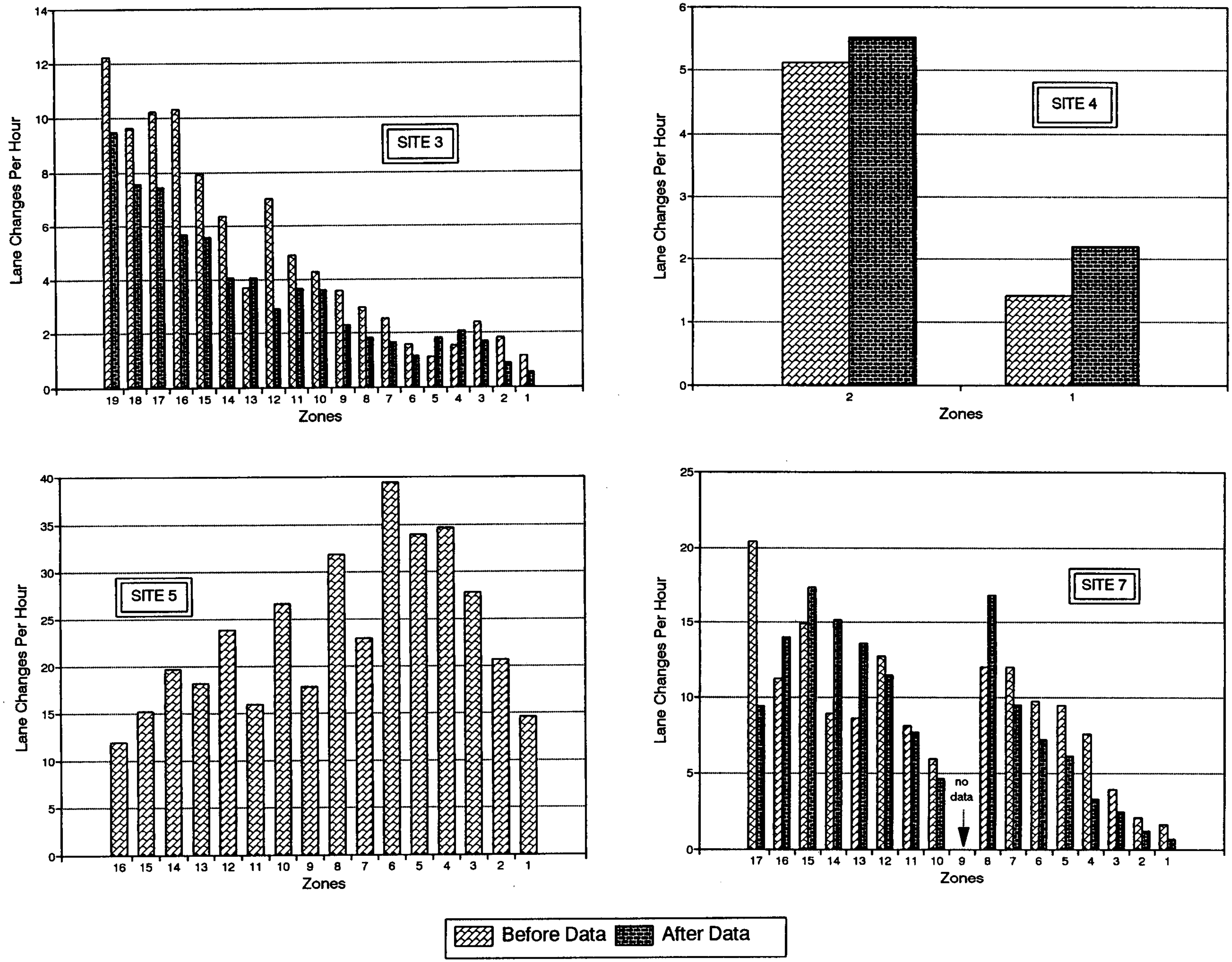


Figure 69. Lane Change Distributions at One-Lane, Lane Drop Exits.

Two-Lane Exit With An Option Lane and an Exit Only Lane

Sites 1, 2, and 6 are all two-lane exits with an option lane and an exit only lane. The three sites exit on the right, and all have generally high volumes. Site 2 has an average hourly volume of 4900 vph, with an hourly volume ranging between 3200 and 7400 vph. Similarly, Site 6 has an average hourly volume of 4450 vph, with hourly volumes ranging between 3100 and 7300. Site 1 has an average hourly volume of 6750 vph, and its hourly volumes range from 5700 to 8100 vph.

Although all three sites are comparable in that they have the same type of exits and volumes, their lane change plots are different as seen in Figure 70. The most significant finding from the analysis of two-lane exits is that the three exits investigated are different and direct comparisons are limited. Site 1 lane change behavior is heavily influenced by the exit lane at Zone 10. Site 2 contains a vertical curve that crests in Zone 5, which is believed to influence lane change behavior greatly. The vertical curve obstructs the view of the configuration of the exit ahead. Drivers may not be aware that the lane drop really contains two exits until they crest the curve and see the configuration of the exit. Site 6 differs from the other two sites in that its exit lanes proceed straight, while the mainlanes curve to the right. These differences lead to the conclusion that the three two-lane exit sites cannot be adequately compared. This conclusion is supported by the differences in the plots of lane changes witnessed at each site.

One-Lane, Lane Drop Exits vs. Two-Lane with Optional Lane Exits

Sites 3, 4, 5, and 7 are one-lane, lane drop exits, whereas Sites 1, 2, and 6 are two-lane exits with an option lane and an exit only lane. Comparison of these sites reveals that lane change rates for one-lane, lane drop exits range between 9.9 and 66.5 ($x10^{-6}$) lane changes/ft/vehicle, whereas lane change rates for two-lane exits range between 75.8 and 120 ($x10^{-6}$) lane changes/ft/vehicle. In summary, two-lane exits with an option lane and an exit only lane have much higher lane change rates than one-lane exits.

ERRATIC MANEUVER BEHAVIOR

The pattern of erratic maneuvers varies depending on the site. The most notable observation of erratic maneuver behavior is the peaking of erratic maneuvers in the gore area, especially at Sites 1, 2, 5, and 6 (see Figures 36, 40, 56, and 60). Several factors contribute to this peaking. First, certain erratic maneuver types can only occur in the gore area, for example, one-lane, lane changes through the gore, two-lane, lane changes through the gore, and stopping to merge in the gore. These types of erratic maneuvers did not occur upstream of the gore area (defined in this study as being greater than 300 ft (91.5 m) from the painted gore), unless other exit/entrance ramps existed within the study section.

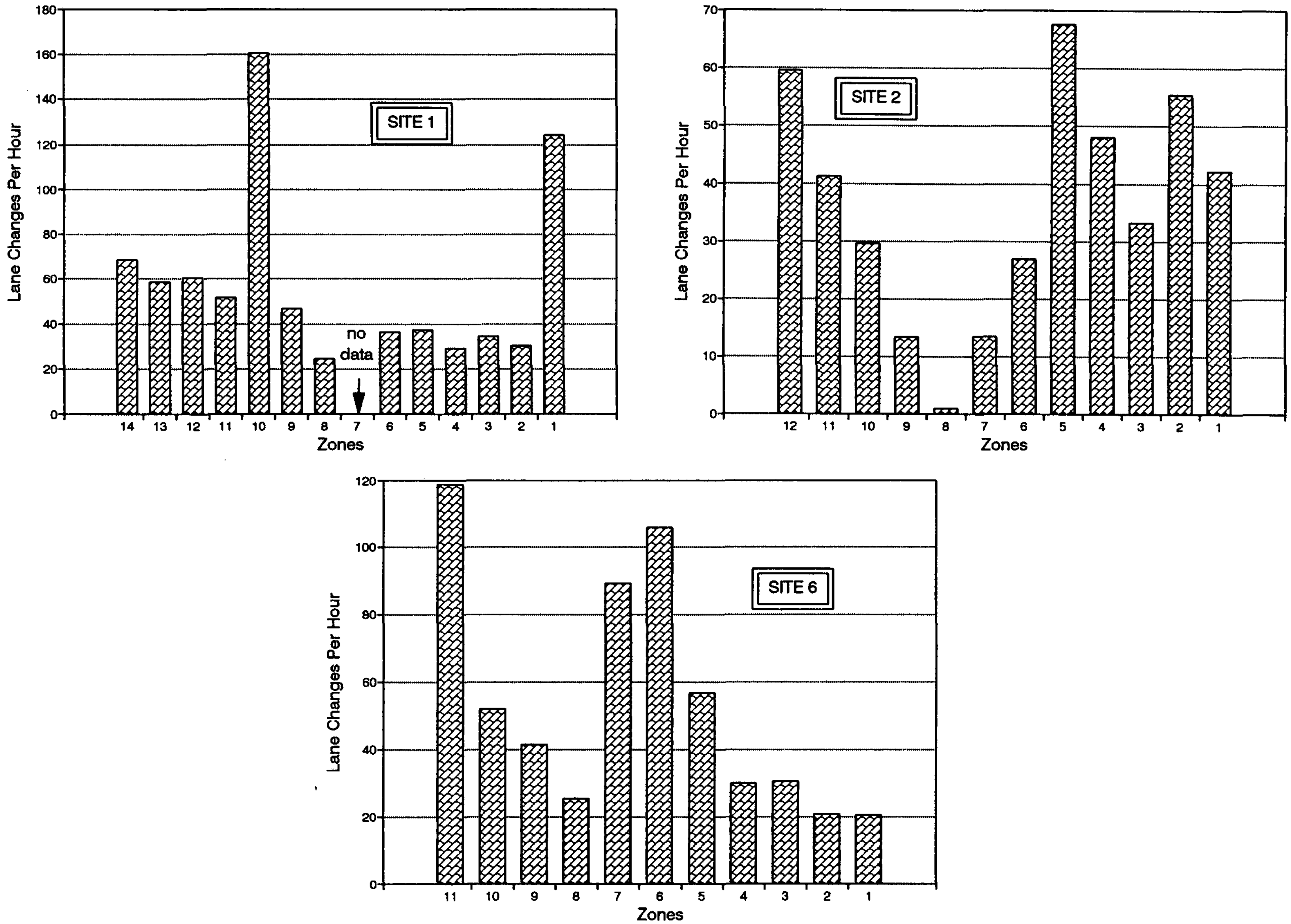


Figure 70. Lane Change Distributions at Two-Lane Exits with an Option Lane and an Exit Only Lane.

Second, the number of possible types of erratic lane changes increases in the gore area at two-lane exits with an option lane and an exit only lane. At approximately 300 ft (91.5 m) from the painted gore the option lane of a two-lane exit becomes wide enough to contain two vehicles; therefore, at this location, a distinction was made between the exiting and through portions of the lane. This distinction increased the opportunity for two-lane, lane changes. Upstream of the lane drop area there are only two possible types of two-lane, lane changes -- a lane change from lane one (the right-most lane) to lane three, and a lane change from lane three to lane one. In the gore area, the number of possible two-lane, lane changes doubles and includes: a lane change from lane one to the through portion of lane two, a lane change from the exiting portion of lane two to lane three, a lane change from lane three into the exiting portion of lane two, and finally a lane change from the through portion of lane two to lane one. The possible types of three-lane, lane changes also increased in the gore area for the same reasons.

In addition to the two factors discussed above, the high traffic volumes and the geometrics at each site also contribute to the number of erratic maneuvers observed at the two-lane exits with an option lane and an exit only lane. Motorists in the study drove more erratically at locations with additional entrance or exit ramps. Erratic maneuvers were also high at sites where the lane drop geometrics violated driver expectancy. Motorists expect through lanes to continue straight ahead, exit lanes to curve away from the through lanes, and exit ramps to be on the right side of the freeway. Even when erratic maneuver rates are examined (see Tables 38 and 39), the two-lane exits generally have higher *rates* of erratic maneuvers than the single lane exits, with the exception of the single lane, left exit (Site 5).

Site 5, the one-lane, left exit, had an erratic maneuver pattern that followed those of the two-lane exits rather than the one-lane exits. For example, a peak occurred near the gore rather than being more uniformly distributed across the study area. This trend could be due to the high volumes at both the two-lane exits and the left exit, as opposed to the lower volumes at the one-lane exits. The left exit also violates driver expectancy; therefore, drivers may drive more erratically at this site. A high proportion of the erratic maneuvers that occur at Site 5 are gore-related. Large numbers of multiple lane changes do not occur in the gore area of this site because it does not contain an optional lane, and because traffic volumes limit or restrict the opportunities for multiple lane changes.

Table 40 lists the percent of erratic maneuver types recorded for Sites 1, 2, 6, and 5. The data demonstrate the high percentages of two-lane, lane changes that occurred at the two-lane exits (Sites 1, 2, and 6) both at the gore and upstream of the gore. The majority of the erratic maneuvers near the gore at the left exit were the one-lane, lane changes through the gore. Tables 41 and 42 list the percent of erratic maneuvers by type for the gore area and upstream of the gore area, respectively, for Sites 3, 7, and 4. In most cases for the gore area, the largest percent of erratic maneuvers were the one-lane, lane changes through the gore (see Table 41). This finding was constant regardless of the time period (before or after) and the site (Site 3, 7, or 4). Similarly, the area upstream of the gore was also dominated by a particular erratic maneuver -- the two-lane, lane change (see Table 42).

Table 40. Erratic Maneuver Types for Sites 1, 2, 6, and 5.

Type	Percent of Erratic Maneuver Type*							
	At Gore Area				Upstream of Gore Area			
	Site 1	Site 2	Site 6	Site 5	Site 1	Site 2	Site 6	Site 5
One-lane, lane change through the gore	12	17	10	89	1	0	0	0
Two-lane, lane change	64	60	79	10	77	87	85	74
Two-lane, lane change through the gore	16	12	1	0	0	0	0	0
Three-lane, lane change	1	1	2	0	1	2	3	2
Three-lane, lane change through the gore	1	1	0	0	0	0	1	0
Suddenly slowed (other cars passed)	1	1	2	0	1	0	5	8
Slowed or stopped to merge in gore	2	1	2	0	0	0	0	0
Swerving in and out/Attempted lane change	0	3	3	1	17	8	5	13
In/out of shoulder	1	0	1	0	5	2	1	2
Rode in between two lanes on wide solid white line	1	5	0	0	0	1	0	2
Through grass	1	1	0	0	0	0	1	0

* Percents may not total to 100 due to round-off error.
Note: shading represents the erratic maneuver with the highest percent.

Table 41. Erratic Maneuver Types for Sites 3, 7, and 4 Near the Gore.

Type	Percent of Erratic Maneuver Type*					
	Site 3		Site 7		Site 4	
	Before	After	Before	After	Before	After
One-lane, lane change through the gore	14	73	90	94	80	67
Two-lane, lane change	43	27	1	3	20	17
Two-lane, lane change through the gore	0	0	0	0	0	0
Three-lane, lane change	7	0	0	0	0	2
Three-lane, lane change through the gore	0	0	0	0	0	0
Suddenly slowed (other cars passed)	0	0	0	0	0	0
Slowed or stopped to merge in gore	0	0	4	3	0	0
Swerving in and out/Attempted lane change	14	0	3	0	0	9
In/out of shoulder	7	0	1	0	0	4
Rode in between two lanes on wide solid white line	14	0	1	0	0	0
Through grass	0	0	0	0	0	0

* Percents may not total to 100 due to round-off error.
Note: shading represents the erratic maneuver with the highest percent.

Table 42. Erratic Maneuver Types for Sites 3 and 7 Upstream of Gore Area.

Type	Percent of Erratic Maneuver Type*			
	Site 3		Site 7	
	Before	After	Before	After
One-lane, lane change through the gore	0	0	5	23
Two-lane, lane change	79	68	61	64
Two-lane, lane change through the gore	0	0	0	0
Three-lane, lane change	0	6	3	0
Three-lane, lane change through the gore	0	0	1	2
Suddenly slowed (other cars passed)	0	0	1	2
Slowed or stopped to merge in gore	0	0	2	2
Swerving in and out/Attempted lane change	9	9	17	2
In/out of shoulder	13	17	6	4
Rode in between two lanes on wide solid white line	0	0	3	1
Through grass	0	0	1	1

* Percents may not total to 100 due to round-off error.
Note: shading represents the erratic maneuver with the highest percent.

BEFORE-AND-AFTER STUDIES

Because of difficulties in having the lane drop markings installed at several sites during the contract period, only two of the six sites scheduled for markings had them installed. (The seventh site was selected to serve as a control site so no markings were installed.) This section discusses the findings from two sites where markings were installed -- Site 3: I-820 NB to White Settlement Road and Site 7: I-35E SB to I-20 West. In addition to comparing the findings between those sites, this section presents a comparison with the before-and-after data from the site without new markings -- Site 4: I-820 SB to Old Decatur Road. Table 38 presents a summary of the information for the three sites.

One of the objectives of the field study was to determine if driver behavior changes when lane drop markings are installed. Driver behavior in this study was measured using frequency of lane changes and erratic maneuvers, and the positions of those behaviors. The number of lane changes was also subdivided into lane changes into the exiting lane, lane changes out of the exiting lane, and lane changes by time of day. Therefore, the influence of the markings may be seen in the number of lane changes (or erratic maneuvers), the position of those changes, and the time of day that the changes are occurring.

Traffic Volume Comparisons

When comparing changes in driver behavior in a before-and-after study, potential influences, other than the item being studied (which in this project is the lane drop markings), should be investigated to determine if they affect the results. From observations and information from the districts, construction or non-recurrent congestion did not influence the data. Another item to check is whether traffic volumes are similar from the before period to the after period. To compare the before-and-after traffic volumes for Sites 3, 4, and 7, an analysis of variance statistical model was used. This method compares average volumes for each of the three sites from before to after. The analysis of variance assumes that the variances of the volumes are equal among the sites. The test showed that the variances were statistically equal, i.e., there were no differences in before-and-after traffic volumes for any given site. There was a significant difference among the site traffic volumes, with Site 4 having significantly greater average volume than Sites 3 and 7.

Equality of Proportions Tests

The next statistical test performed determined if the lane change per hour values (as shown in Table 38) were statistically different from the before period to the after period. A test of equality of proportions (also known as the comparison of two binomial parameters test) was used to determine if the overall percentage of total lane changes or erratic maneuvers before was equal to the percentage after treatment. For example, for Site 3, the percent of the total lane changes was 58.3 before and 41.6 after. The statistical test compares these numbers to 50 percent; the calculations also consider the sample size of the data. Results are shown in Table 43. None of the observed differences at Site 4 were significant. Only the erratic maneuvers at Site 3 did not have a statistically significant difference between the before-and-after period.

Table 43. Results of the Equality of Proportions Tests.

	Site 3		Site 7		Site 4	
	Before	After	Before	After	Before	After
Total Number of Lane Changes for Study Segment	975.9	695.8	1684.4	1586.9	67.0	79.0
Lane Change Proportion	58.3	41.6	51.5	48.5	45.9	54.4
Z statistic* Significant/Not Significant?	9.69 Significant		2.41 Significant		1.41 Not Significant	
Total Number of Erratic Maneuvers for Study Segment	52.9	41.8	146.0	96.9	23.3	29.0
Erratic Maneuvers Proportion	55.9	44.1	60.11	39.9	44.2	55.8
Z statistic* Significant/Not Significant?	1.61 Not Significant		4.46 Significant		1.18 Not Significant	
Total Number of Lane Changes for Gore Area	55.0	31.5	87.5	50.0	67.0	79.0
Lane Change Proportion	63.6	36.3	63.6	36.4	45.9	54.1
Z statistic* Significant/Not Significant?	3.57 Significant		4.52 Significant		1.40 Not Significant	
Total Number of Erratic Maneuvers for Gore Area	7.0	5.5	62.5	22.5	23.0	29.0
Erratic Maneuvers Proportion	56.0	44.0	73.5	26.5	44.2	55.8
Z statistic* Significant/Not Significant?	0.60 Not Significant		6.14 Significant		1.18 Not Significant	

* If the calculated Z statistic is greater than 1.645, then one can conclude that the difference is significant.

These findings present a different interpretation of the data than the percent change in Table 38. For example, the differences at Site 4 appear noteworthy (e.g., the percent difference is a positive 18 or 27 percent); however, the statistical test indicates that they are not significant. The erratic maneuver change at Site 3 within 300 ft (91.5 m) of the gore is a similar example (i.e., 29 percent reduction yet not statistically significant). A key reason for the not significant finding is the low number of erratic maneuvers observed.

The number of erratic maneuvers at both sites decreased from the before period to the after period for both the entire study length and the 300 ft (91.5 m) nearest to the gore. The decrease was more substantial at the south Dallas site (Site 7) with more than a 60 percent reduction for the 300 ft (91.5 m) nearest the gore and a 33 percent reduction for the entire study length. Substantial decreases in the number of one-lane, lane changes through the gore and swerving into a lane and back out (attempted lane change) were the prime contributors to the reduction in number of erratic maneuvers at Site 7. The largest decrease in the erratic maneuver type at Site 3 was the two-lane, lane change.

Shift in Lane Change Locations

To determine if a "shift" in lane change locations were occurring, plots of percent of lane changes per zone were used. The plot of percent of lane changes per zone for Site 3 (see Figure 46) indicates that the distribution of lane changes in the before period is similar to the distribution of lane changes in the after period. In other words, no shifting of lane changes from one area of the study segment to another occurred. Plots of vehicles entering the exit lane and vehicles leaving the exit lane for Site 3 showed similar distributions as the total lane change plot. Site 7 plots, however, did show a shift in where vehicles were changing lanes. The plot of vehicles leaving the exit lane and the total lane changes plot (see Figure 67) were similar; they both had different distributions for the before data and the after data. The plot of vehicles entering the exit lane showed similar trends for both the before-and-after data. This indicates that a shift occurred in where vehicles were leaving the exit lane. For the eight zones closest to the gore (representing approximately 800 ft (244 m) upstream of the gore), fewer vehicles left the exit lane in the after period than in the before period, while for Zones 10 to 17 more vehicles left the exit lane in the after period than in the before period. In summary, Site 7 drivers were leaving the exit lane further upstream of the gore in the after period.

The plots of the percentage distribution indicate that in some cases there was a before-and-after difference in the lane change behavior depending upon the distance from the gore. To statistically validate this, the following procedure was used. The percentage distribution of counts by zone and before-and-after time periods were tested for equality using the Chi-Square test for independence. The Chi-Square test is considered significant when one of the before/after percentages is different in at least one zone. The question becomes which zones have proportions that are significantly different. To test this, the individual standardized cell Chi-Squares were computed. These values represent the relative contribution of each zone to the overall difference found, much like the multiple comparison tests in the analysis of variance indicate which means are contributing to the overall difference.

The overall Chi-Square value for Site 3 was not significant indicating that there was no significant variability in the lane change percentage distribution before and after treatment for any zones. For Site 7, the overall Chi-Square was significant which indicates that there was a difference among at least one zone. To determine the zones which were different, the individual standardized cell Chi-Squares were tested. The direction of change (i.e., whether the number of changes increased or decreased from before to after) was also determined. Table 44 lists the results of the individual Chi-Square tests by zone in addition to the direction of the change (- indicates a decrease in cell change from before to after and + indicates an increase) for Site 7. All tests were done at the 0.05 level of significance with p-values given only when the change was statistically significant. The same analysis was done for lane changes from exit to through and through to exit, with Table 44 listing the individual conclusions of tests by zone and direction of change.

Figures 71 to 73 illustrate the findings from the above statistical tests. The zones that showed a significant difference in percentage distribution of lane change before and after treatment are highlighted. The statistical tests confirmed that the lane drop markings did cause a shift in where lane changes are occurring.

Other Observations

Another observation on the reduction and shifting of lane changes is appropriate. While the lane drop markings have caused a shift in where motorists are leaving the exit lane in Site 7 but not in Site 3, this finding may be a function of the length of the study segment and the presence of other entrance and exit ramps. For example, Site 3 could have experienced a shift in where lane changes occurred, with the shift occurring upstream of the study segment. An entrance ramp is located approximately 2500 ft (762 m) upstream of the gore. The large reduction in lane changes at Site 3 could be a reflection that when vehicles enter the freeway on the entrance ramp and see the lane drop markings (see Figure 41), they are moving from the entrance ramp through the exit lane to a through lane prior to entering the study segment. If so, then a shift in where motorists are changing lanes at Site 3 could also be occurring. The large reduction in lane changes supports this theory.

The third site with before-and-after data was Site 4 (I-820 SB to Old Decatur Road). Site 4 was initially to serve as a control site for Site 3, and was considered for elimination based on the request for a site with a longer exit only lane (the lane at Site 4 is only 2,250 ft (686 m) long -- Site 7 was selected to replace Site 4). Site 4 was later retained in the study to serve as a limited control site for the other single lane exits. Another important contribution that Site 4 makes to the before-and-after field study is to emphasize the importance of appreciating the magnitude of the lane change or erratic maneuver difference rather than the percent difference between the before-and-after period. While the percent increase of lane changes was 18 percent at this site (which was not statistically significant), it only represents an increase of 1.2 lane changes in an hour for the 370 ft (113 m) of study length. If the number of lane changes went from 5 in the before period to, say, 15 in the after period, then the magnitude indicates that something is influencing driving behavior. Only having slightly more than one driver per hour making a different decision within a 370-ft distance (or 3.7 seconds at 55 mph (89 km/h)) is not as meaningful.

Table 44. Chi-Square Results for Site 7 by Zone.

Zone	Total Lane Changes		Exit to Through Lane Changes		Through to Exit Lane Changes	
	Sig. Diff, P-value	Dir	Sig. Diff, P-value	Dir	Sig. Diff, P-value	Dir
1	no	0	no	0	no	0
2	no	0	no	0	no	0
3	no	0	no	0	no	0
4	yes, 0.003	-	yes, 0.004	-	no	0
5	yes, 0.049	-	yes, 0.009	-	no	0
6	no	0	yes, 0.019	-	no	0
7	no	0	no	0	no	0
8	yes, 0.007	+	no	0	yes, 0.001	+
10	no	0	no	0	no	0
11	no	0	no	0	no	0
12	no	0	no	0	no	0
13	yes, 0.003	+	yes, 0.001	+	no	0
14	yes, 0.001	+	yes, 0.001	+	no	0
15	no	0	yes, 0.001	+	no	0
16	no	0	yes, 0.001	+	no	0
17	no	0	no	0	yes, 0.001	-
overall	yes, 0.001	-	yes, 0.001	-	yes, 0.001	-

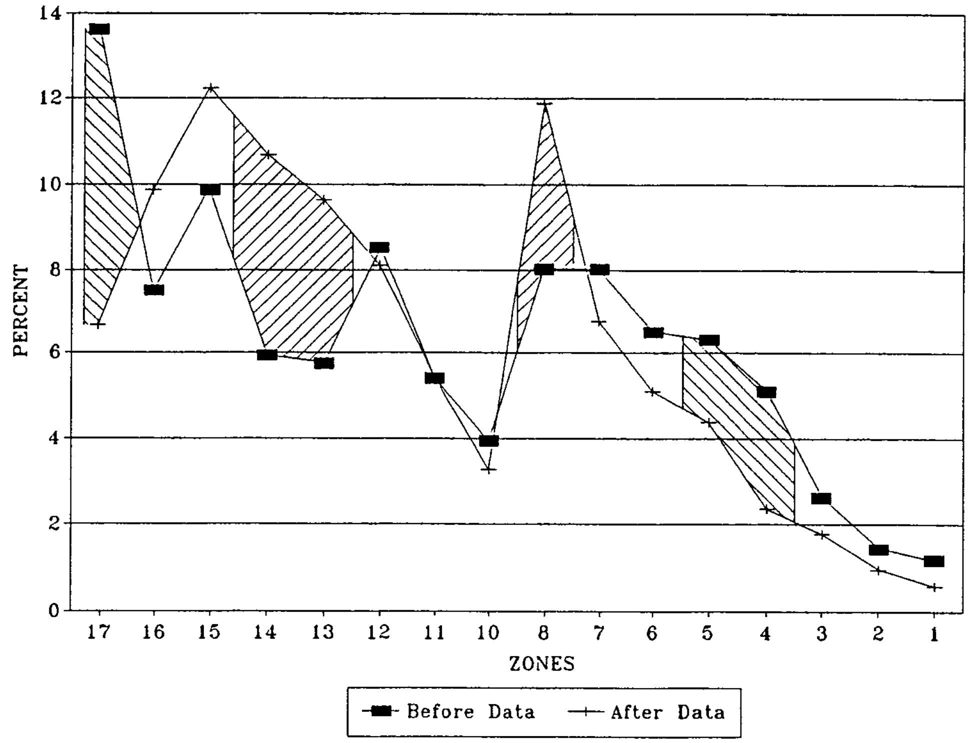


Figure 71. Total Lane Change Percentage Distribution for Site 7.

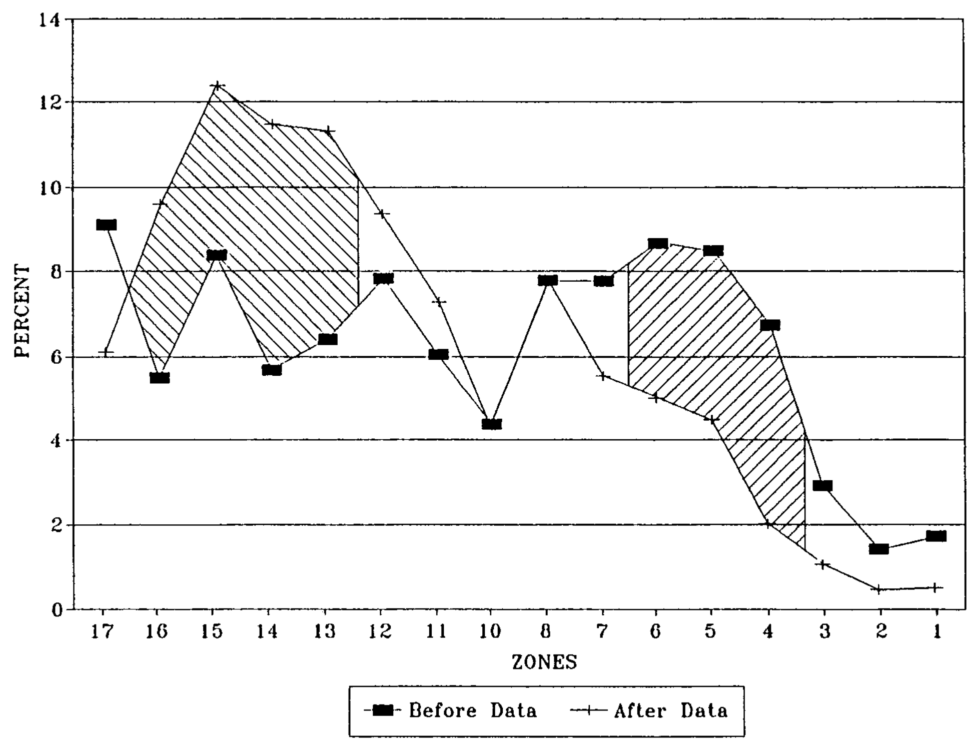


Figure 72. Exit to Through Lane Change Percentage Distribution for Site 7.

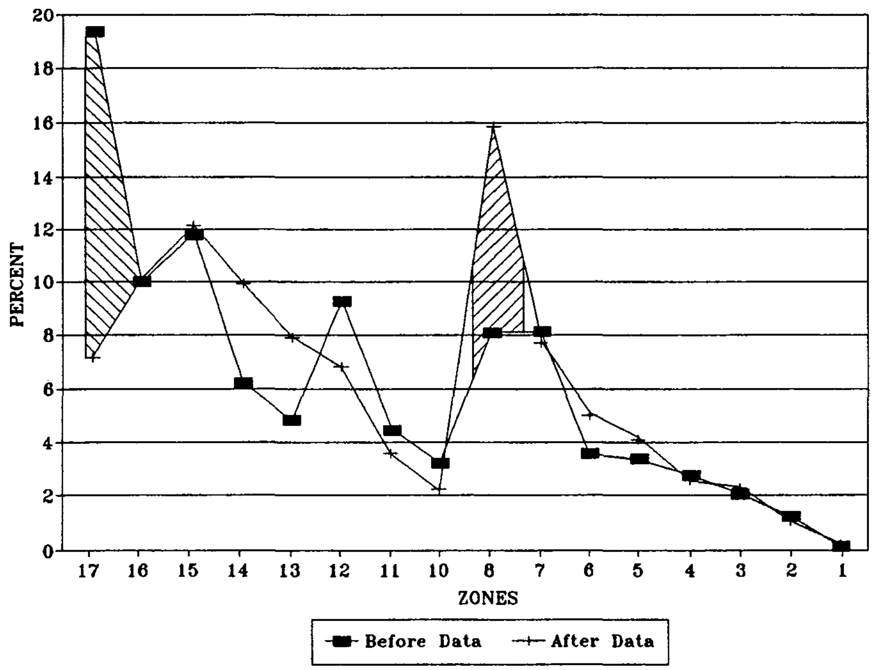


Figure 73. Through to Exit Lane Change Percentage Distribution for Site 7.

CHAPTER 8

SUMMARY

The intent of this project was to determine how motorists interpret or respond to various sign and pavement marking alternatives they may or may not have experienced before. An initial objective of the project was to identify the techniques currently used in Texas to communicate lane drops to motorists. Motorist interpretations of signs and markings were obtained through surveys, while field observations were used to measure actual motorists' responses to pavement markings.

STUDY RESULTS

Literature

Early studies conducted in the 1970s on the black on yellow panels supported the use of the panels. The panels were required at interchange lane drops beginning with the 1978 edition of the MUTCD. Early and recent studies on diagrammatic signs also support the use of diagrammatic signs at exit lane drops. Pavement markings for exit only lane drops were first included in the MUTCD in 1984 at California's suggestion. California had witnessed several years of positive experience with the markings when they made the recommendation. Several of the previous research studies on pavement markings examined the use of markings at lane drops rather than at exit only lane drops. A study in the late 1980s examined the effectiveness of markings at exit only lane drops. The study found mixed results -- at one location, improvement in operations occurred during all peak periods; at the second location, improvement occurred except during the p.m. peak, and the third location had some decrease and some increase in lane changes during the times observed.

Lane Drop Treatments Used in Texas

Several lane drop treatments are used in Texas. In most cases, a yellow EXIT ONLY panel is used at exit lane drops in Texas. Pavement markings usually consist of at least one of the following: a wide solid white line just prior to the gore, pavement arrows, EXIT ONLY phrasing on the pavement, and lane drop markings. The San Antonio District consistently uses the EXIT ONLY phrasing on the pavement at exit lane drops.

Surveys

The auto show survey which used graphics of different lane drop treatments indicated a high level of understanding of the exit only signs. Only the sign for the two-lane exit with an option lane and an exit only lane had correct comprehension percentages below 80 percent. The white down arrow next to the yellow EXIT ONLY panel was only correctly interpretated between 66 and 79 percent, depending upon the type of markings shown on the figure. While visuals used in the survey only represent a specific location along a freeway, drivers can encounter other visual clues, such as the approaching geometrics and other signs, to aid them in their driving decisions. In those cases where a preceding sign was not observed or the driver entered the freeway after preceding signs, the survey indicated that the majority of the drivers correctly selected the appropriate response.

A noticeable difference occurred between the lane drop markings (short lines/short gap treatment) and the solid lane line markings. Drivers correctly interpret the broken line markings as being permissive in nature while the solid lines are restrictive in nature. For example, when only the markings (no signs) were shown, over 70 percent of the respondents indicated that the right most lane must exit, while only 52 percent of the respondents selected the *must exit* choice for the special markings alternative. The use of a wide solid white line prior to an exit only lane drop is more prevalent than the use of the broken line. The survey also indicated that drivers have equal comprehension of the meaning of a wide solid white line and double white lines.

The goal of the second survey was to obtain an indication of the comprehension of signs and pavement markings for freeway exit only lanes by inexperienced or "new" drivers. Driver instructors were requested to provide an assessment of their students' understanding of signs and pavement markings used at freeway exit only lanes. Instructors indicated that their students have an above average comprehension of current signing and pavement markings and a below average comprehension of the difference between an up and a down arrow on an exit guide sign. Instructors' responses revealed that students had a good understanding of the meaning of the wide solid white line and a poor understanding of the meaning of the dashed white line (lane drop markings). Responses were overwhelmingly in favor of a diagrammatic sign to communicate exiting lanes. The survey indicated that both the wide solid white line and the yellow EXIT ONLY panel are devices well understood by inexperienced drivers in Texas. This finding indicates the value of using pavement markings with signs to communicate information to motorists.

Field Studies

The field studies were designed to measure the effects of lane drop markings on driver behavior. Number and location of lane changes and erratic maneuvers upstream of an exit only lane drop were the measures of effectiveness used to describe driver behavior. Data were collected at seven sites:

- 3 - one-lane, lane drop exits.
- 2 - two-lane exits with an option lane and an exit only lane.
- 2 - exit lane drops with atypical geometry.

- 1 - two-lane exit with an option lane and an exit only lane where the exit lanes are straight and the freeway mainlanes curves at a 90 degree angle to the left.
- 1 - one-lane, lane drop to the left.

The initial intent of the field study was to couple the before-and-after studies with control site studies. Four sites were selected as part of Phase I of the field studies. This plan was revised during the course of the study, with more emphasis being given to other elements of the field studies rather than the control site requirement. With this decision, the emphasis of the second part of the field studies, known as Phase II, was to locate sites with unusual qualities or with known or suspected high lane change behavior.

Video cameras equipped with special wide angle and zoom lenses were used in this study. The cameras were mounted in the field on overhead sign structures while the VCRs were located at ground level in temporarily mounted traffic controller cabinet. Each TxDOT district provided maintenance crews to install access to electrical power at each site and to provide the bucket (crane) truck and manual assistance in the placement of the video cameras. The data collection process recorded between 1,000 ft (305 m) and 2,000 ft (610 m) upstream of the lane drop gore depending upon the number of cameras used and the spacing of the sign structures. Each study site was subdivided into segments or "zones" with each zone generally being 100 ft (30.5 m) in length (which was typically the spacing between the rumble strips located on the shoulder).

The initial step in reducing the data from the video tapes involved identifying the zones and then creating a template (clear sheet of mylar placed on the video monitor) that separates the video image into the 100-ft (30.5 m) zones. Generally, data from 24 hours of video tapes for each camera at a site were reduced. For consistency, data collected on Tuesdays, Wednesdays, and Thursdays were used when available. Three types of data were collected from the video tapes: lane changes, erratic maneuvers, and volume counts, and data were reduced in 15-minute intervals. The zone from which the lane change (or erratic maneuver) originated was defined as the zone in which the vehicle's first wheel crossed over the pavement markings separating the lanes. In addition to the location, the type of erratic maneuver was also recorded.

The calculation of number of lane changes or erratic maneuvers for a site required that the time periods used within each zone be consistent. The lane change and erratic maneuver data were summarized for the time period available for all zones. When needed for the before-and-after studies, the number of lane changes or erratic maneuvers was calculated across only those zones that were common to both the before-and-after period, and also across those time periods that were common to both periods.

Lane drop markings were to be installed at six of the seven sites. Several difficulties and set backs were experienced during the project that resulted in markings being installed at only two of the six sites. After data were collected at those two sites.

Site Specific Observations

Tables 38 and 39 provide summaries of each site's characteristics and the findings for the site. Following is a brief discussion on each site.

Site 1 (I-45 Northbound to I-610 East and Texas 225) is a two-lane exit with an option lane and an exit only lane. The site has high traffic volumes with congestion present along this corridor during several periods of the day. The length of the lane drop lane is 0.65 miles (1.05 km). The two major influences on the lane change and erratic maneuver data are the high volumes in the area and an exit ramp located 1000 ft (305 m) upstream of the lane drop. The average number of vehicles exiting at the exit lane drop during the study period was approximately 1050 vehicles. For the entire study length of 1,300 ft (396 m), 665.9 lane changes occurred in a typical hour; 92.2 of those changes (approximately 13 percent) occurred within 300 ft (91.5 m) of the lane drop gore (which represents close to 23 percent of the study length). Most of the lane changes within the study area occurred either in the zone at the lane drop gore or in the zone at the upstream exit ramp. Close to 54 percent of all erratic maneuvers occurred within 300 ft (91.5 m) of the gore (which is only 23 percent of the study area). The predominate types of erratic maneuvers were the two-lane, lane changes and lane changes through the gore.

Site 2 (I-45 Southbound to I-610 East and West, Texas 225, and Texas 35) is a two-lane exit with an option lane and an exit only lane. The site is located near Site 1 (north of the I-45/I-610 interchange while Site 1 is south of the interchange), and has several similar characteristics such as high traffic volumes. The length of the lane drop lane is over 2 miles (3.2 km). Potential influences on the lane change and erratic maneuver data include the left exit from the exiting lanes that occurs 600 ft (183 m) downstream of the lane drop and the vertical curve that crests at 500 ft (152 m) prior to the exit lane drop gore. High volumes (e.g., the number of vehicles exiting during an average hour on the two lanes is 1800) also contribute to the lane change and erratic maneuver behavior. For the 1200-ft (366 m) study length, almost 600 lane changes occurred during a typical hour. Approximately 23 percent of those lane changes occurred in the 300 ft (91.5 m) nearest the gore (which represents 25 percent of the study area). While lane changes were generally equal along the study segment, the erratic maneuvers were concentrated within the 200 ft (61 m) nearest the gore. Over 90 percent occurred within 200 ft (61 m) of the gore. Two-lane, lane changes where motorists moved into the exit lanes were more common in Zone 1, while two-lane, lane changes where motorists moved out of the exit lanes were more common in the upstream zones.

Site 3 (I-820 Northbound to White Settlement Road) is a one-lane, lane drop exit created by an entrance ramp approximately one mile (1.6 km) upstream of the lane drop. A potential influence on driver behavior is the entrance ramp located 2,000 ft (610 m) upstream of the lane drop. Before-and-after data were collected at this site; therefore, discussion on those findings are presented in the following section.

Site 4 (I-820 Southbound to Old Decatur Road) is a one-lane, lane drop exit also located in west Ft. Worth. It was originally selected as the control site for Site 3. The exit only lane is created by an on ramp located 2,250 ft (686 m) upstream of the gore. The length of the dropped lane influences the lane change behavior of motorists. For the 300 ft (91.5 m) upstream of the gore, approximately 6 lane changes and 2 erratic maneuvers occurred in an average hour.

Site 5 (I-45 Northbound to I-610 West) is a one-lane, lane drop exit to the left from I-45. It is located just downstream from Site 1. The length of the dropped lane is greater than 5 miles (8 km). Over 1,700 vehicles in a typical hour use the left exit, and the number of vehicles exiting ranged between 1,525 and 2,100 during the study period. Site 5 has few influences on driver behavior other than being a left exit lane drop and within a high volume freeway segment. 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 (1,158 m) upstream of the lane drop. Also, the exit lane becomes a new lane on I-610, therefore, exiting traffic does not have to merge for several miles after leaving I-45. The number of lane changes increases until about 600 ft (183 m) from the gore. The 300 ft (91.5 m) nearest to the gore represent 20 percent of the observed area and display 17 percent of the lane changes for the study area. The largest number of erratic maneuvers occurred within 300 ft (91.5) of the gore. The predominate type of erratic maneuver in the gore area was the lane change through the gore area while upstream of the gore the most common type was the two-lane, lane change. Congestion-related erratic maneuvers were also high; a large number of drivers either suddenly slowed in an attempt to position for a lane change or attempted but failed to make a lane change.

Site 6 (I-610W Southbound to South Post Oak) is a two-lane exit with an option lane and an exit only lane. The geometry of the site influences the lane changing behavior. The mainlanes sharply curve to the left while the exiting lanes proceed on a straight alignment. The lane that is dropped is created by an entrance ramp located more than 1.25 miles (2.0 km) upstream of the gore. Another influence is an exit ramp located 1,300 ft (396 m) upstream of the gore. Approximately 600 lane changes per hour occurred within the entire study length for the 11.5 hours observed. Approximately 12 percent of these lane changes occurred within the 300 ft (91.5 m) nearest to the gore (which represent 27 percent of the study segment). The largest number of lane changes occurred in the furthest upstream zone, and this reflects the effects of the upstream exit ramp. Vehicles leaving the freeway on the exit ramp created gaps which other vehicles filled. The majority of the erratic maneuvers occurred in the zones closest to the gore or in the zones closest to the upstream exit ramp. The predominate type of erratic maneuver was the two-lane, lane change.

Site 7 (I-35E Southbound to I-20 West) is a one-lane exit lane drop. The length of the exiting lane is over 7 miles (11 km). Influences on driver behavior at this exit lane drop are the exit ramps located 900 ft (274 m) and 1800 ft (549 m) upstream of the lane drop. The ramp at 900 ft (274 m) is to I-20 East and has comparable exiting volumes as I-20 West (130 vehicles to 160 vehicles per hour). Before-and-after data were collected at this site; discussion on those findings are presented in the following section.

Before-and-After Comparisons

Both sites with new markings showed a decrease in total number of lane changes for the entire study segment. One site (Site 3) showed a statistically significant decrease in lane changes of 29 percent, while the other site (Site 7) showed a statistically significant but modest decrease of 6 percent. With these mixed results, a strong conclusion that lane drop markings definitely reduce the number of lane changes is not possible; however, when the number of lane changes for the 300 ft (91.5 m) nearest to the gore are examined, both sites showed a statistically significant decrease from the before period to the after period. Site 3 decreased by 42 percent while Site 7 decreased by 44 percent. The pavement markings did decrease the number of lane changes within 300 ft (91.5 m) of the gore.

The number of erratic maneuvers at both before-and-after sites decreased from the before period to the after period for both the entire study length and the 300 ft (91.5 m) nearest to the gore. The decreases for the entire study length and for the area near the gore at Site 7 were statistically significant. Substantial decreases in the number of one-lane, lane changes through the gore and swerving into a lane and back out (attempted lane change) were the prime contributors to the reduction in the number of erratic maneuvers at Site 7, while the Site 3 decrease was caused by a reduction in the number of two-lane, lane changes. The pavement markings did decrease the number of erratic maneuvers within the entire study segment.

Another possible effect of the lane drop markings is in causing a "shift" in where motorists are making lane changes in advance of a lane drop. For example, the markings could encourage drivers to leave the lane further upstream of the drop. The data from Site 7 revealed that drivers are exiting the lane further upstream of the lane drop in the after period than in the before period. For the 800 ft (244 m) immediately upstream of the gore, fewer vehicles left the exit lane in the after period than in the before period, while for the area between 1700 (518 m) and 1000 ft (305 m) upstream of the gore more vehicles left the exit lane in the after period than in the before period. Similar analysis at the other before-and-after study site (Site 3) did not produce the same results. The data showed that a shift was not occurring *within* the study segment (which was approximately 1600 ft (488 m) long). Other evidence, such as the statistically significant reduction in number of lane changes, indicates that a shift may be occurring upstream of the limit of the study segment. An entrance ramp is located approximately 2,500 ft (762 m) upstream of the gore, and the large reduction in lane changes within the study segment could be a reflection that vehicles entering the freeway on the entrance ramp might be seeing the lane drop markings and moving from the entrance ramp through the exit lane to a through lane prior to entering the study segment.

Site to Site Comparisons

When the lane change and erratic maneuver data were compared between sites, the uniqueness of each site became obvious. Some general observations were possible; however, detailed comparisons of how certain features influence lane change or erratic maneuver data was limited. The location of entrance or exit lanes upstream of the lane drop in addition to the location of the lane drop were the major influences on where lane change and erratic maneuver frequencies would peak. The site selection process used during this study minimized the number of upstream exit and entrance ramps (and selected sites with the largest distance between a ramp and the lane drop); however, the available pool of sites dictated that the study sites selected have an exit or entrance ramp within the study segment. Only one site, the left exit site, had results that appeared unaffected by an upstream entrance or exit ramp (the closest ramp on the same side as the exit was 3,800 ft (1158 m) upstream of the lane drop). However, traffic entering from an entrance ramp on the right side of the freeway that wanted to exit at the lane drop may not have been able to move into the left lane until a few hundred feet prior to the actual drop. This example illustrates that while general comments can be made between the difference of, say, a one-lane, lane drop exit and a two-lane exit with an option lane and an exit only lane, these differences must frequently be qualified with comments on where upstream entrance and exit ramps are located.

For this project's seven sites, the distribution of lane changes at one-lane, lane drops had the largest number of lane changes occurring at the area furthest from the gore and decreased non-linearly approaching the gore. At Site 7, which has three exits (one lane drop and two with conventional designs), a similar type of distribution was observed between each pair of exits. Comparisons of the two-lane exits with an option lane and an exit only lane did not reveal a similar finding. Each two-lane exit had a unique pattern.

When examining the patterns of erratic maneuvers by distance, the most notable observation was the peaking of erratic maneuvers in the gore area. Several factors contributed to the peaking, such as certain erratic maneuvers could only occur within the gore area and the potential for erratic maneuvers of a certain type was greater when the option lane for a two-lane exit widens to hold two vehicles simultaneously. Larger numbers of erratic maneuvers were observed at the two-lane exit with an option lane and an exit only lane than at the one-lane, lane drop exits. This finding held constant when examining frequencies or rates. The factors that contributed to the peaking of erratic maneuvers at the gore and the high volumes at each of the two-lane sites contributed to the higher numbers of erratic maneuvers at the two-lane sites.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The results from both surveys conducted during this research indicate that motorists have a high level of understanding of the yellow EXIT ONLY panel. Drivers do not understand the use of the white arrow next to a yellow EXIT ONLY panel -- over a third of the participants incorrectly interpreted the meaning of the white arrows. Motorists preferred the use of diagrammatic signs as the first of several signs indicating an approaching lane drop, and the use of the conventional black on yellow panel (rather than the diagrammatic sign) close to the exit lane drop. The surveys also revealed that Texas motorists have a good understanding of the meaning of the wide solid white line.

The field studies demonstrated that the installation of lane drop markings can cause a shift in where motorists are making lane changes in advance of a lane drop. One site's data directly revealed, while the other site's data indicated, that drivers are moving into or out of the exiting lane further upstream of the lane drop in the after period than in the before period. For the 800 ft (244 m) immediately upstream of the gore at one site, fewer vehicles left the exit lane in the after period than in the before period, while in the area between 1700 (518 m) and 1000 ft (305 m) upstream of the gore more vehicles left the exit lane in the after period than in the before period.

The before-and-after studies also revealed that the number of erratic maneuvers within the entire study segment decreased with the installation of the markings. The largest decrease was in the number of one-lane, lane changes through the gore.

RECOMMENDATIONS FOR FUTURE RESEARCH

Several studies, including this project, found that the meaning of the white arrow next to a yellow EXIT ONLY panel is not well understood by motorists. Research into alternative signs for two-lane exits with an option lane and an exit only lane would identify better techniques for communicating to motorists the downstream geometric exit configuration. The research could also examine if different types of signs used at different locations would improve driver comprehension. For example, in this project, motorists indicated that they prefer to use a diagrammatic sign as the first of several signs and the use of the EXIT ONLY panel close to the exit lane drop.

Collecting after data at the two-lane exits with an option lane and an exit only lane and the left exit would provide valuable insight into the effects of lane drop markings at other than conventional one-lane, lane drop exit sites. Increasing the pool of results from two sites to six sites would also add more strength to the current conclusions of this project, mainly that the lane drop markings do cause drivers to enter the exiting lane further upstream when the markings are present and that the markings cause a decrease in erratic maneuvers.

Driver behavior may change after a significant period of time has passed and drivers are more familiar with the lane drop markings. Collecting additional after data after the markings have been in place for over a year would provide information on the long term effects of the markings on driver behavior. The two one-lane, lane drop sites could be used for this purpose. Before, after, and long-term after data would be available for comparison.

Additional research could also investigate the need for uniformity between signs and markings used for lane drops on freeways and on arterial streets (e.g., the use of the words EXIT ONLY on freeways and MUST EXIT on arterial streets). The research should include an appraisal of whether the status quo, while non-consistent, is better than modifying signs that have been used successfully for several decades.

REFERENCES

1. State Department of Highways and Public Transportation. "Texas Manual on Uniform Traffic Control Devices", Austin, 1980.

2. U.S. Department of Transportation. Federal Highway Administration, "Manual on Uniform Traffic Control Devices", Washington D.C., 1988.

3. U.S. Department of Transportation. Federal Highway Administration, "Manual on Uniform Traffic Control Devices", Washington D.C., 1961.

4. U.S. Department of Transportation. Federal Highway Administration, "Manual on Uniform Traffic Control Devices", Washington D.C., 1971.

5. Lunenfeld, H., and G.J. Alexander. "Signing Treatments for Interchange Lane Drops." Federal Highway Administration, Final Report HS-019 119, June 1976.

6. U.S. Department of Transportation. Federal Highway Administration, "Manual on Uniform Traffic Control Devices", Washington D.C., 1978.

7. Office of Traffic Engineering, State of California. In support of the special marking at lane drops inclusion in the MUTCD, Letter to Connor, Robert E., Executive Director. National Advisory Committee, Federal Highway Administration, 1978.

8. Brackett, Quinn, R. Dale Huchingson, Nada D. Trout, and Katie N. Womack. "Highway User Operational Information." Final Report 957-1 for SDHPT, February 1991.

9. MacDonald, W.A., and E.R. Hoffmann. "Information Coding on Turn Restriction Signs." Australian Road Research Board Conference Proceedings, Vol. 9, No. 5, pp 371-382, 1979.

10. Shapiro, Phillip S., J.E. Upchurch, J. Loewen, and V. Siaurusaitis. "Identification of Needed Traffic Control Device Research." *TRR 1114*, pp 11-20, 1987.

11. Laux, Lila F., and David L. Mayer. "Road Sign Comprehension: Age and Sex Effects." Presented at TRB 70th Annual Meeting, Jan 1991.

12. Roberts, K.M., and A.G. Klipple. "Driver Expectations at Freeway Lane Drops." *Public Roads*, Vol. 40, No. 1, pp 32-35, June 1976.

13. Roberts, A.W. "Diagrammatic Sign Study Final Report." New Jersey Department of Transportation, Division of Research and Development, 1971.

14. Brainard, Robert W., Richard J. Campbell, and Edwin Elkin. "Design and Interpretability of Road Signs." *Journal of Applied Psychology*, Vol. 45, No. 2, pp 130-136, 1961.

15. Roth, W.J., and F. DeRose, Jr. "Interchange Ramp Color Delineation and Marking Study." HRB, *HRR 105*, pp 113-125, 1966.

16. Cornette, D. "Operational Characteristics of Lane Drops." Kentucky Dept. of Highways, Frankfort, Final Report KYHPR-70-63, HPR-1(8), Part 2, Aug. 1972.

17. Pigman, J.G., and K.R. Agent. "Raised Pavement Markers as a Traffic Control Measure at Lane Drops." *Public Roads*, Vol 39, No. 1, pp 1-6, June 1975.

18. Ogden, Michael A., and Stephen Albert. "Analysis of California Striping to be Utilized in Texas, Exit Lane Striping Proposal." Technical Memorandum, Texas SDHPT, May 1989.

19. Ogden, Michael A. "Analysis of California Striping to be Utilized in Texas, Exit Lane Striping Proposal, Braeswood Exit - I-610 South Loop Westbound." Technical Memorandum, Texas SDHPT, August 1990.

20. Goodwin, D. N. "Freeway Lane Drops." *NCHRP 175*, Project 3-16, Final Report, 1976.

21. Nemeth, Z.A., W.J. Diewald, B.C. Goodwin, D.N. Goodwin, A.A. Lukas, H.W. McGee, Sr., T.D. Sullivan, and J.I. Taylor. "Current Practice of Application of Traffic Control Devices at Freeway Lane Drops." *Traffic Engineering*, Vol. 46, No. 11, pp 42-49, Nov 1976.

22. Keck, W.D., and A.W. Roberts. "The Effect of Dotted Extended Lane Lines on Right, Single Deceleration Lane Use." New Jersey Department of Transportation, Division of Research and Development, 1978.

23. Goodwin, D.N., and B.C. Goodwin. "Investigation of Freeway Lane Drops." Proceedings of American Association of State Highway and Transportation Officials, Nov 1972.

24. Goodwin, D.N., and R.L. Lawrence. "Investigation of Lane Drops." Highway Research Board, HRR N388, pp 45-61, 1972.

25. Tye, E.J., "The Lane Drop Study (Relating Roadway Elements to Accidents)." California Division of Highways, Sacramento, Report HPR 1(5), B-1-11, Oct. 1968.

26. Pline, J. L., Ed. *Traffic Engineering Handbook.* Institute of Transportation Engineers, Washington, D.C., pp 2, 1992.

APPENDIX

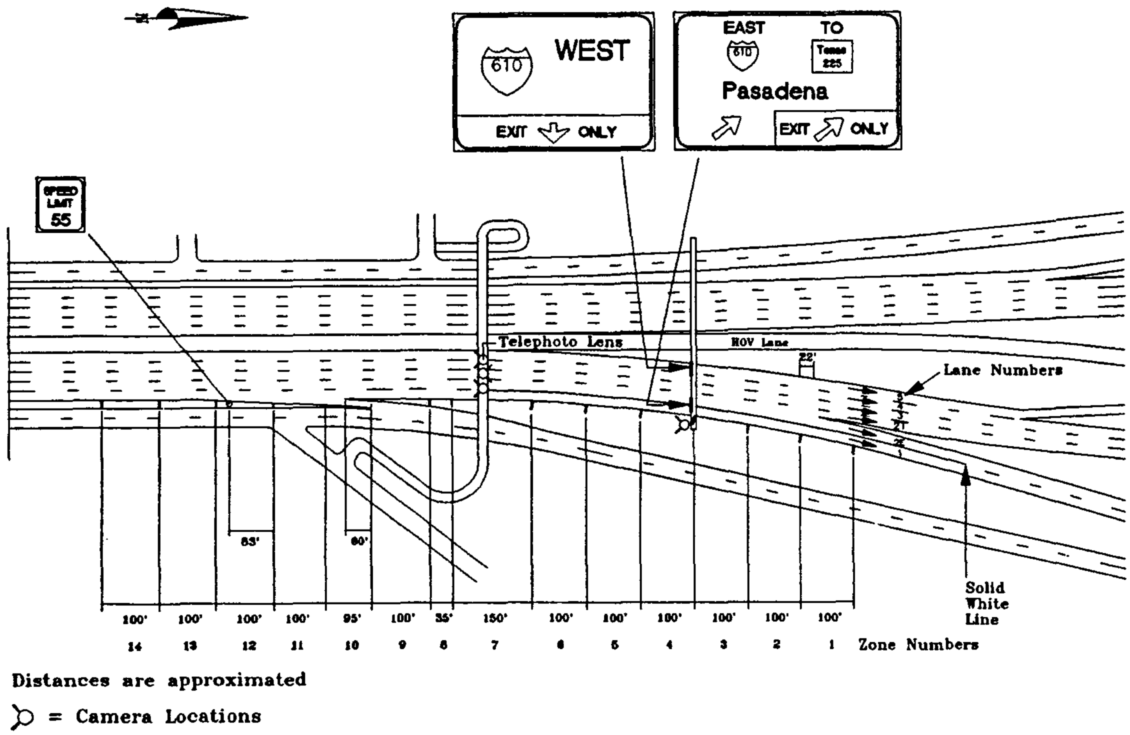


Figure A-1. Site 1 Zones.

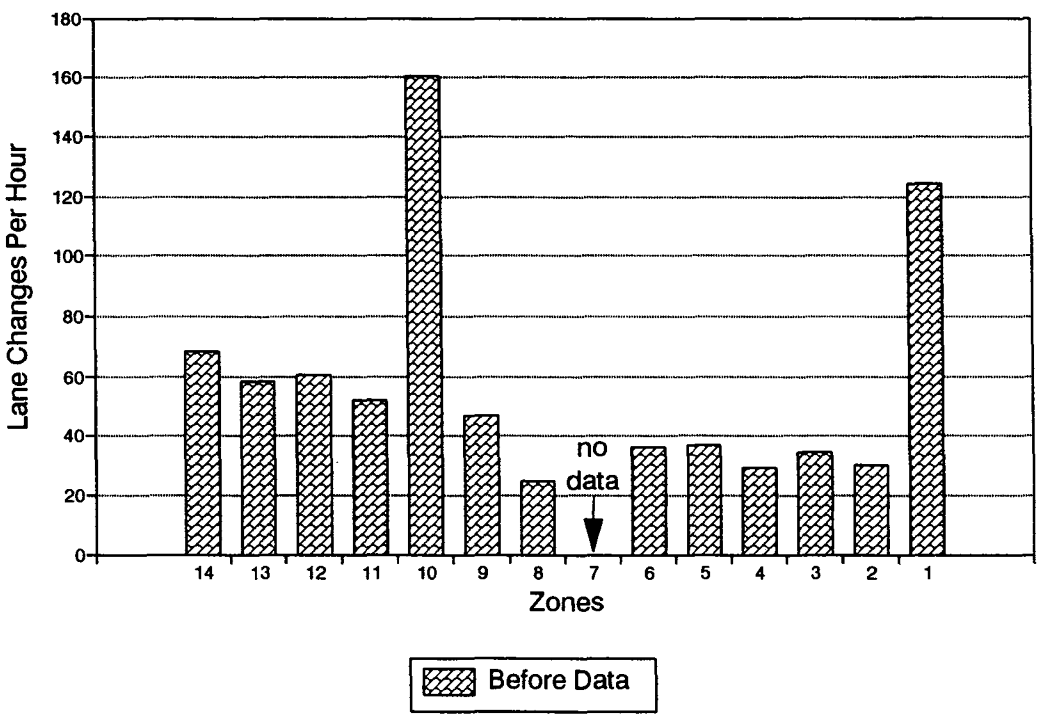


Figure A-2. Site 1 Lane Changes Per Hour by Zone.

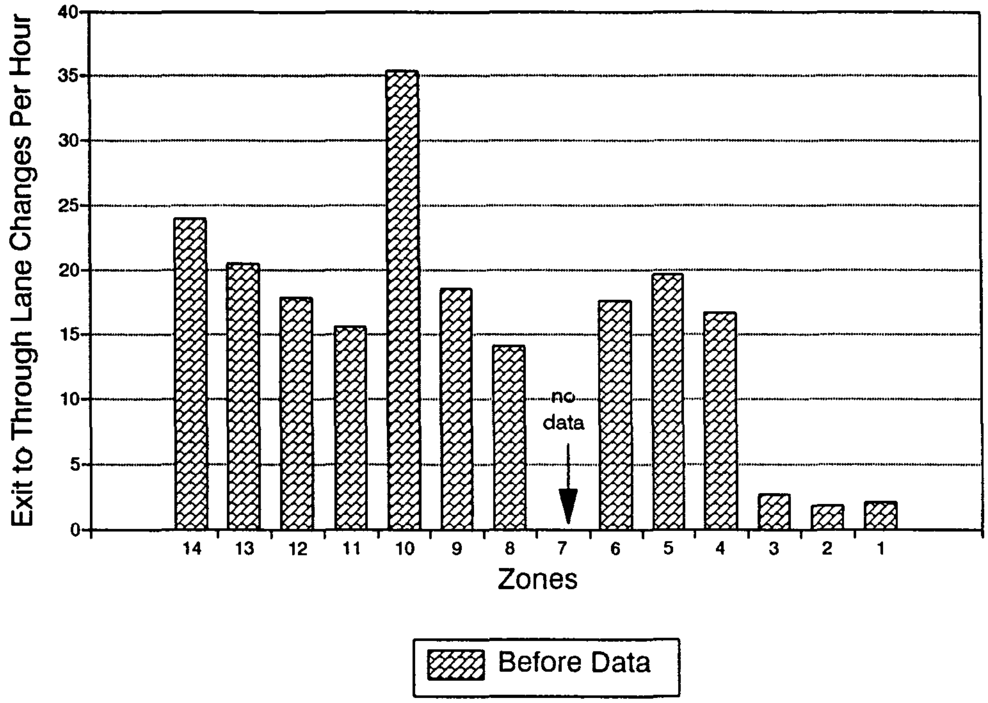


Figure A-3. Site 1 Exit to Through Lane Lane Changes Per Hour by Zone.

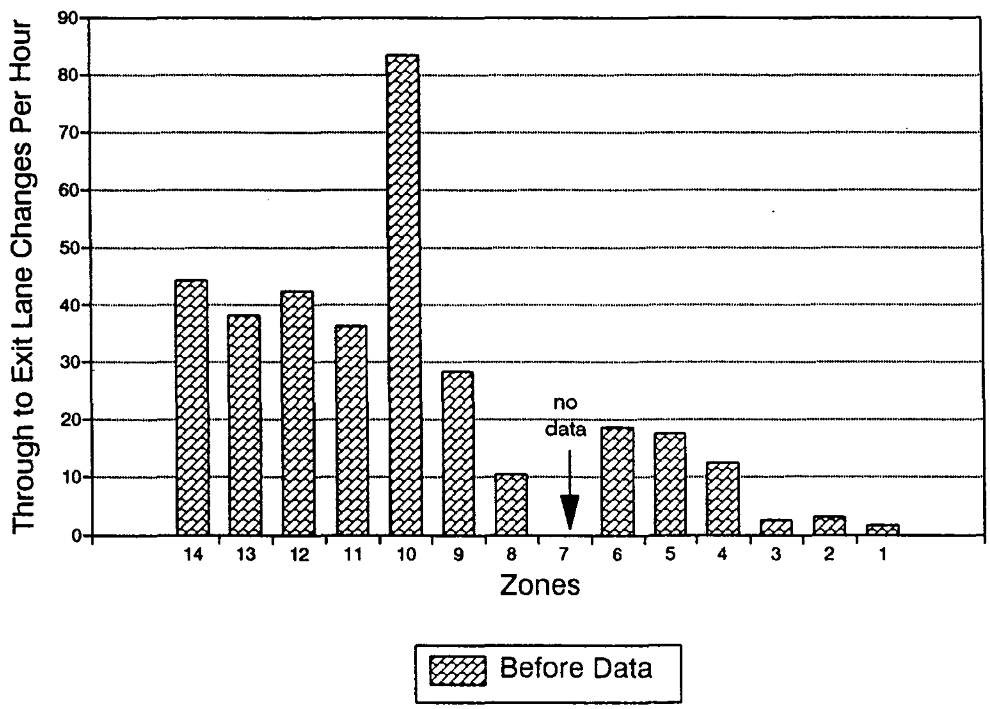


Figure A-4. Site 1 Through to Exit Lane Lane Changes Per Hour by Zone.

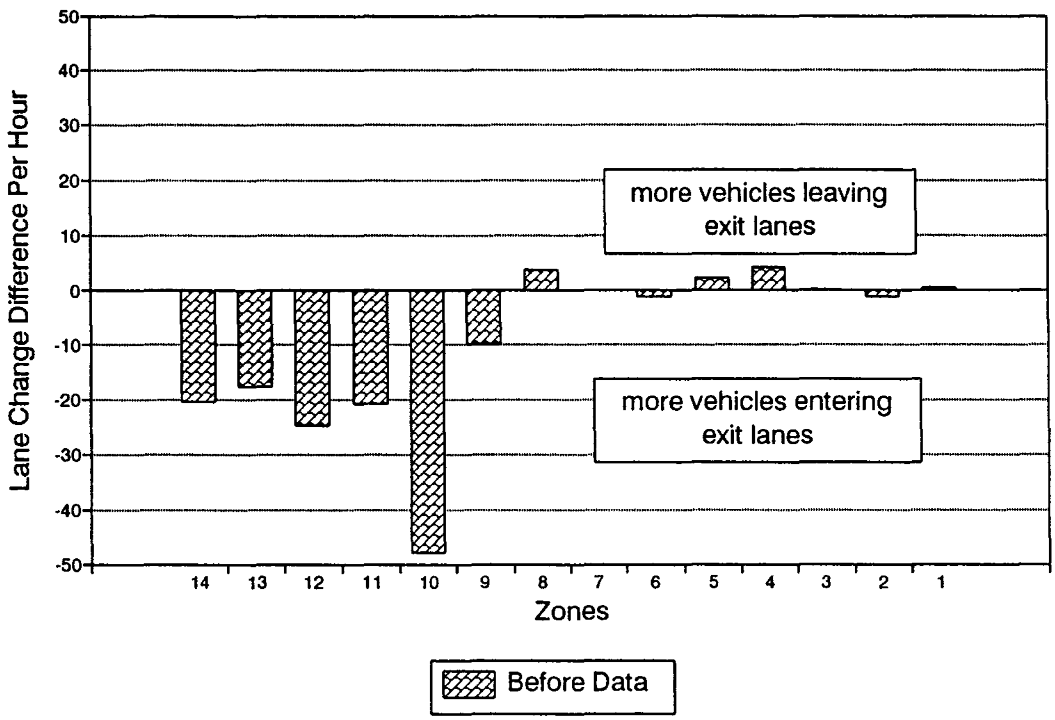


Figure A-5. Site 1 Lane Change Difference Per Hour by Zone.

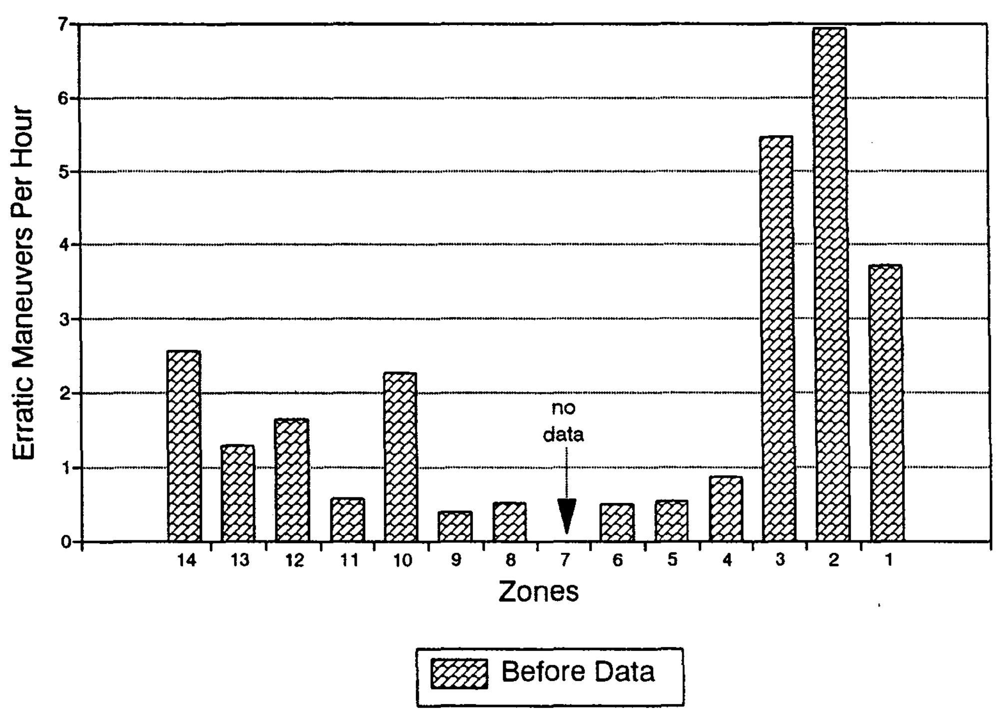


Figure A-6. Site 1 Erratic Maneuvers Per Hour by Zone.

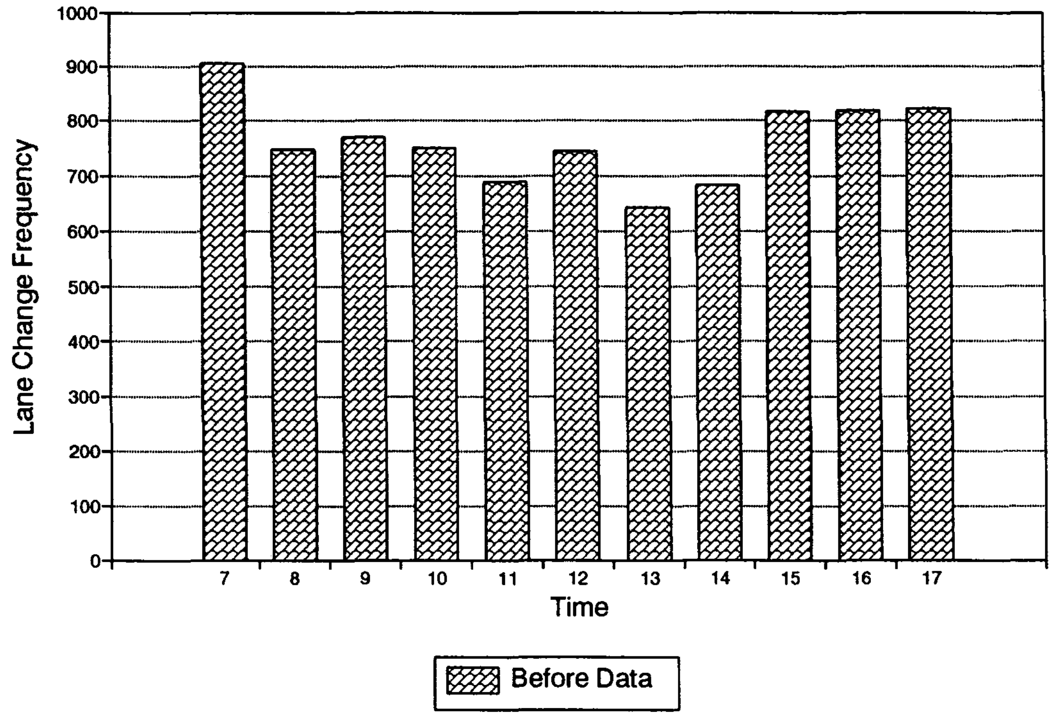


Figure A-7. Site 1 Lane Change Frequency by Hour.

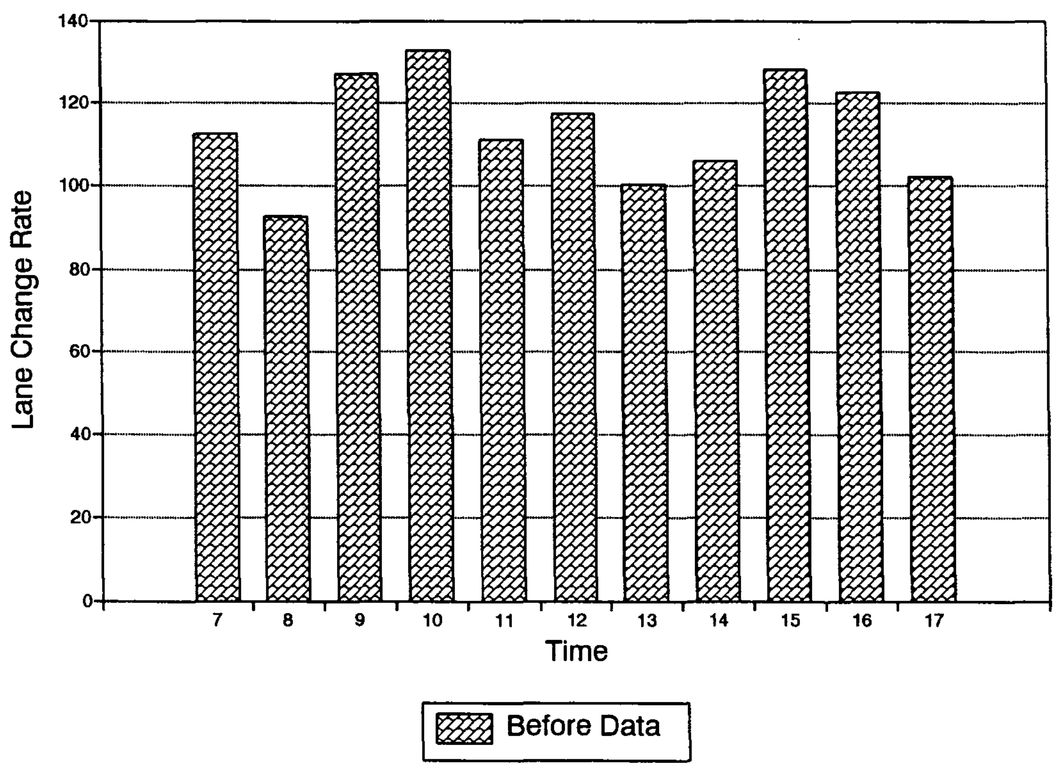


Figure A-8. Site 1 Lane Change Rate by Hour.

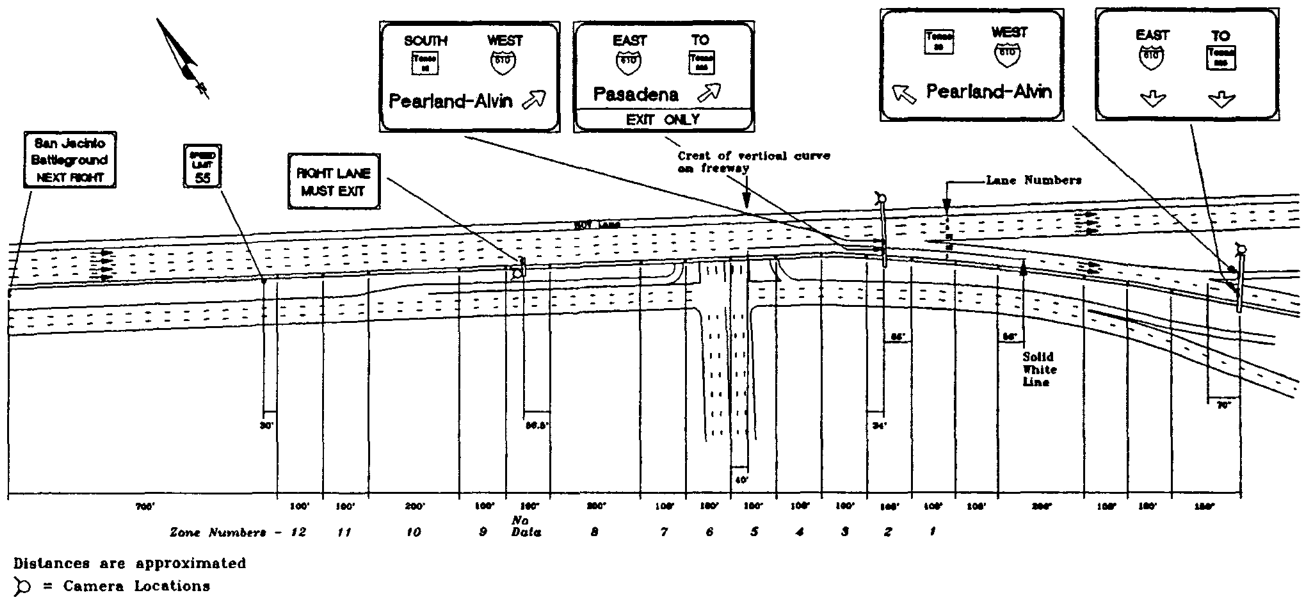


Figure A-9. Site 2 Zones.

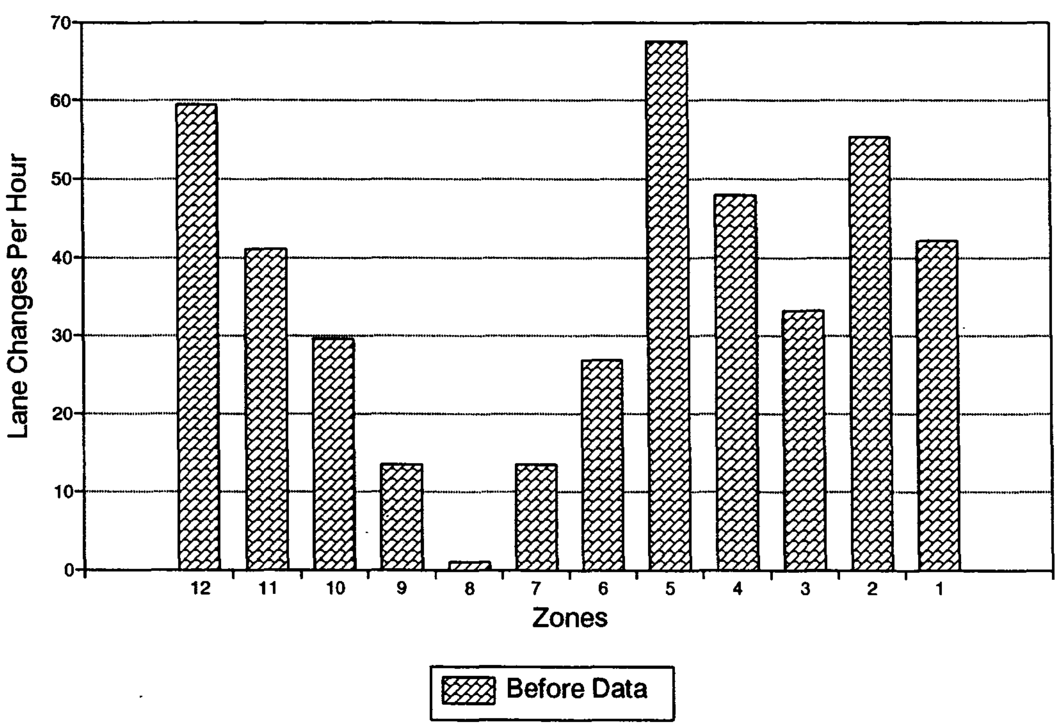


Figure A-10. Site 2 Lane Changes Per Hour by Zone.

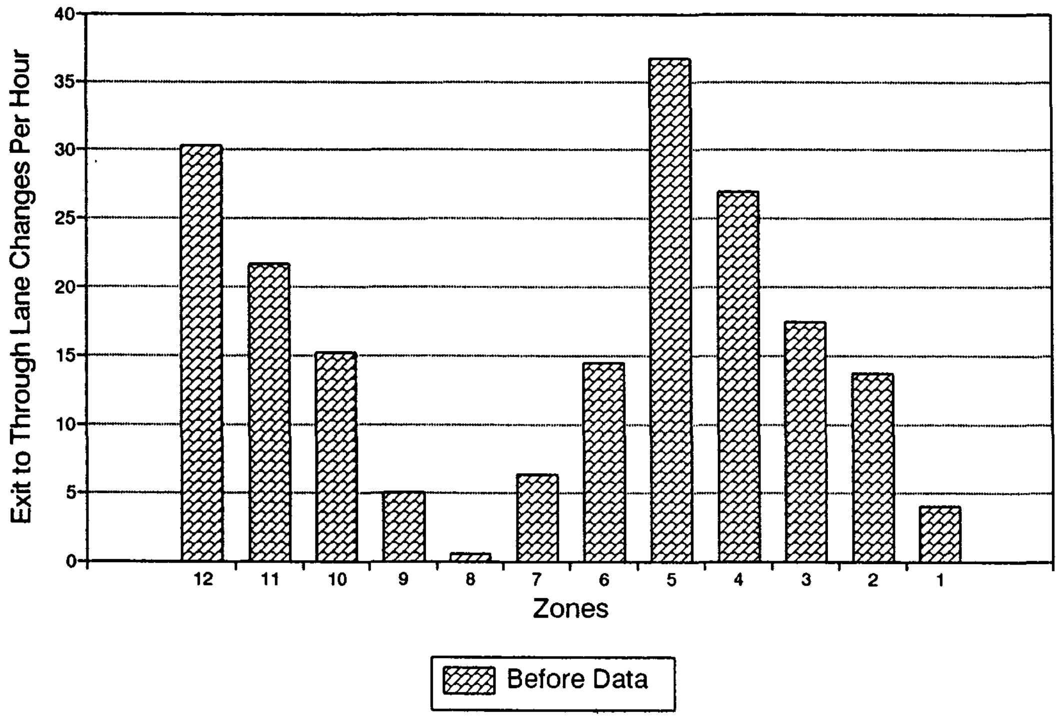


Figure A-11. Site 2 Exit to Through Lane Lane Changes Per Hour by Zone.

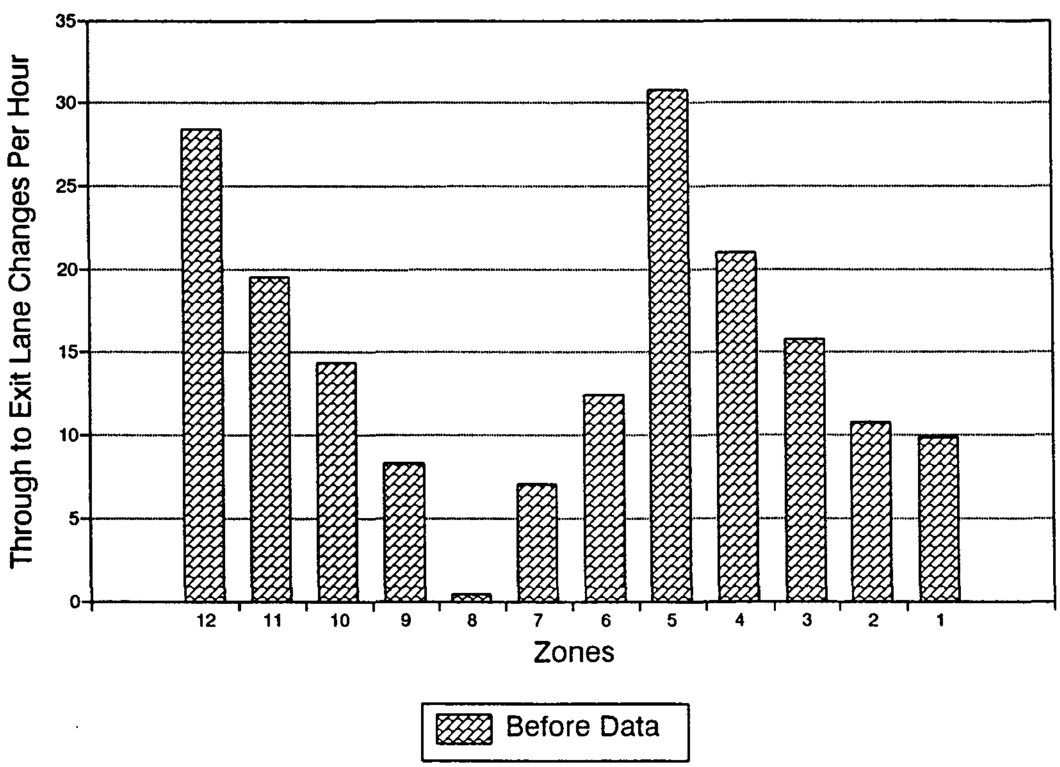


Figure A-12. Site 2 Through to Exit Lane Lane Changes Per Hour by Zone.

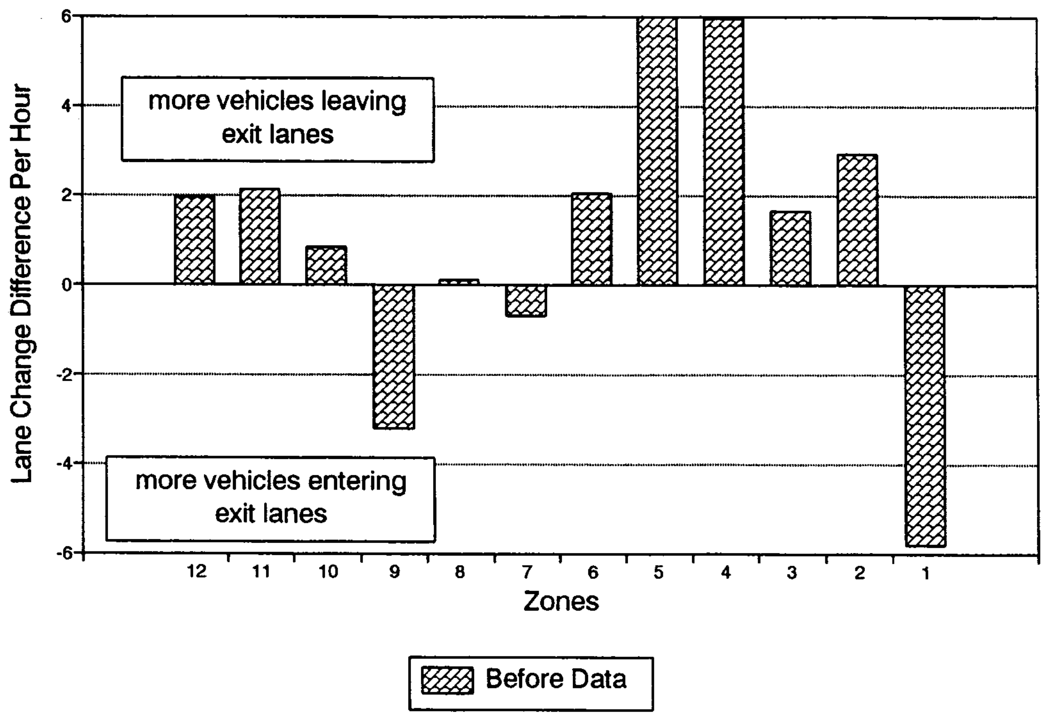


Figure A-13. Site 2 Lane Change Difference Per Hour by Zone.

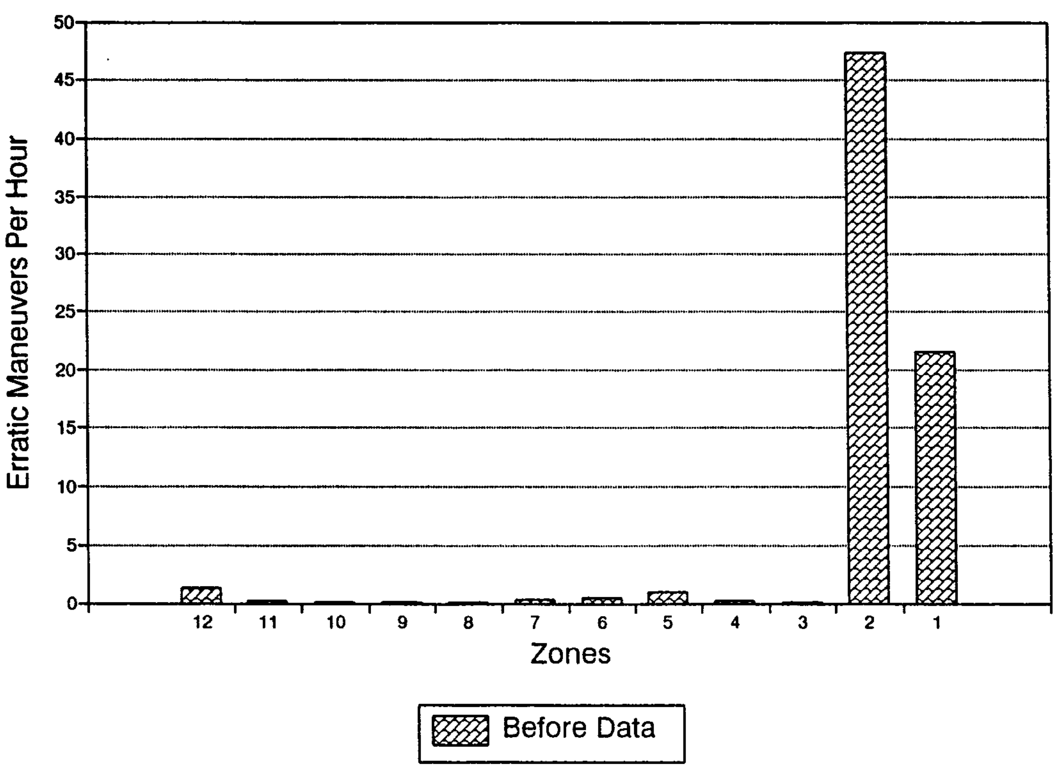


Figure A-14. Site 2 Erratic Maneuvers Per Hour by Zone.

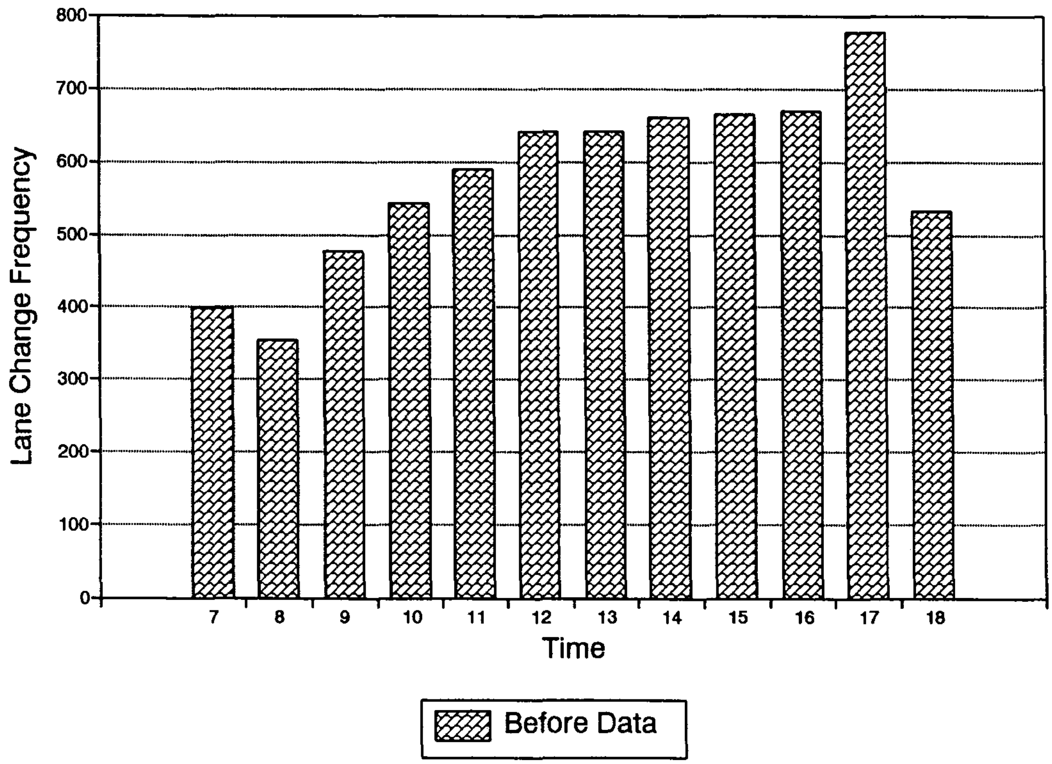


Figure A-15. Site 2 Lane Change Frequency by Hour.

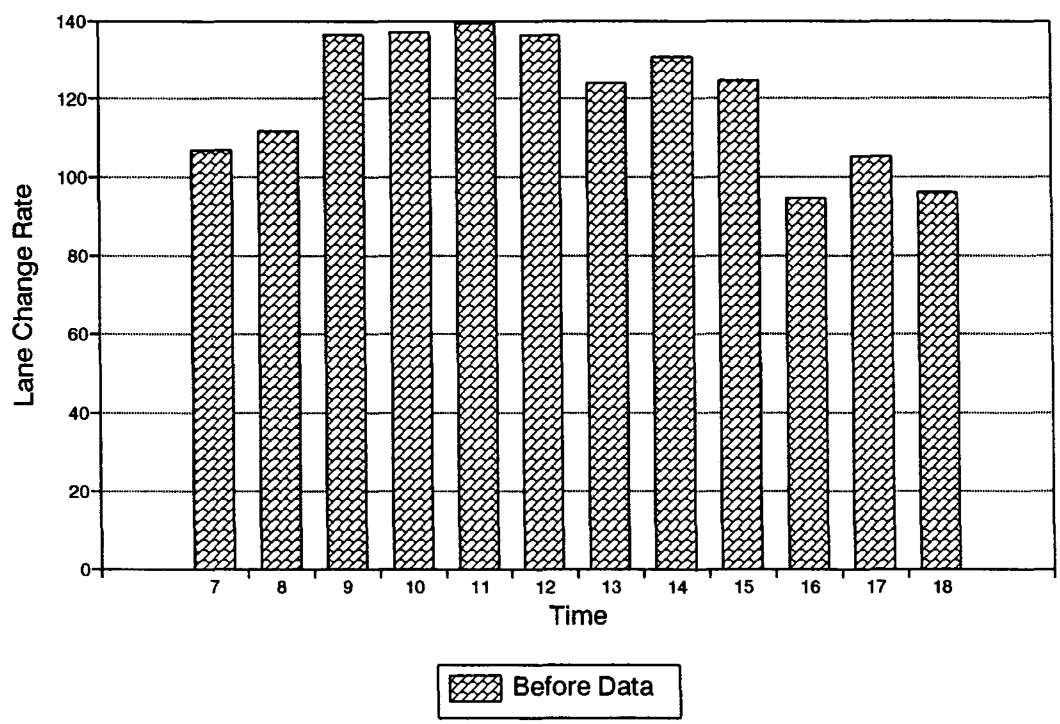


Figure A-16. Site 2 Lane Change Rate by Hour.

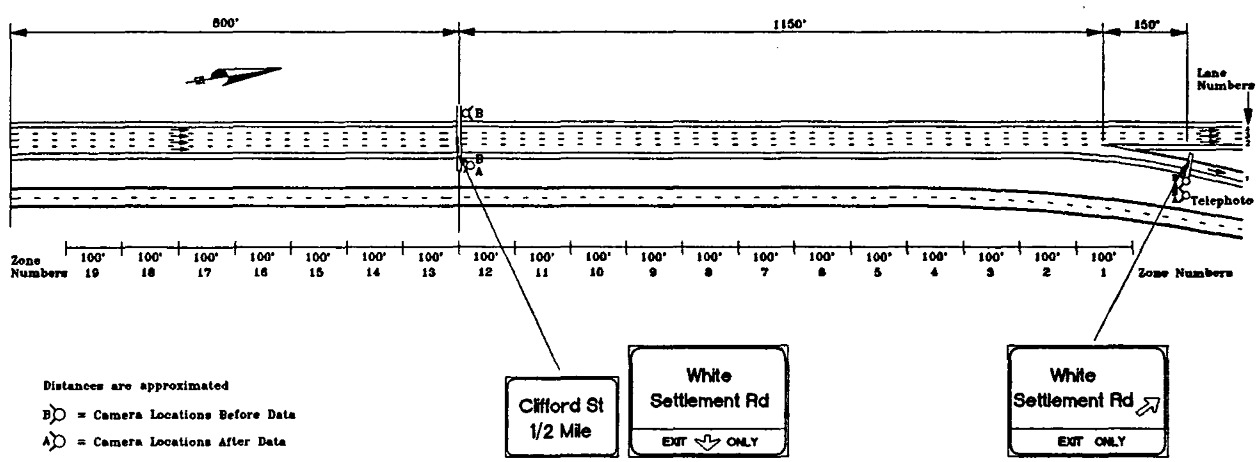


Figure A-17. Site 3 Zones.

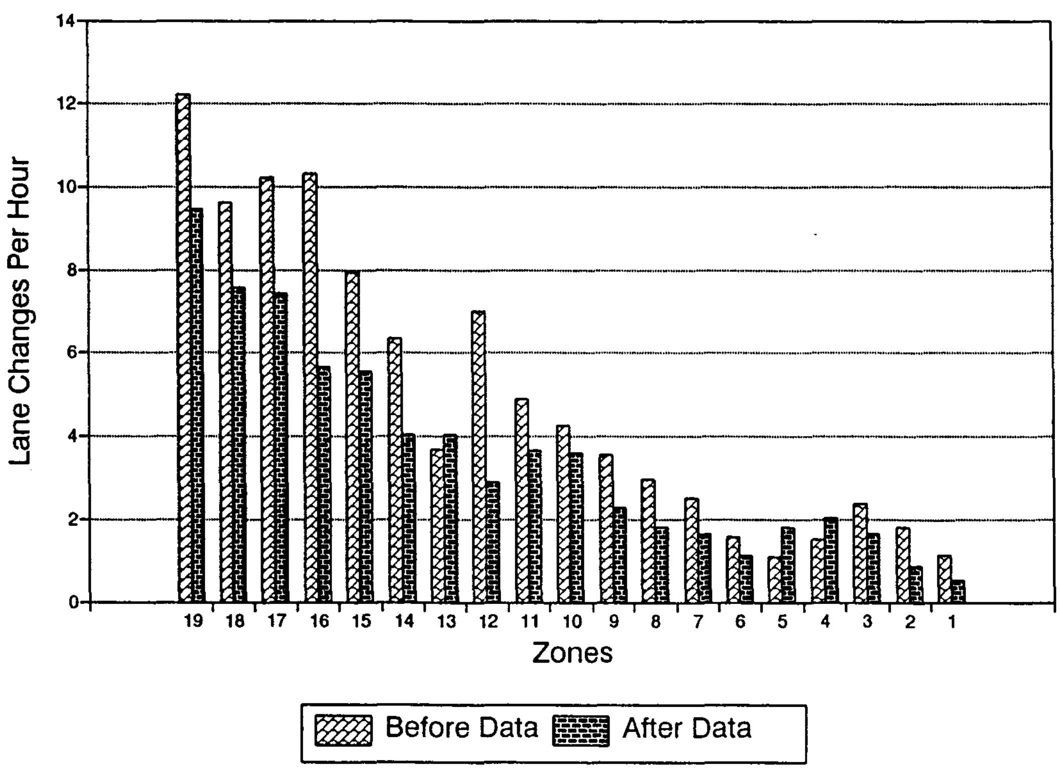


Figure A-18. Site 3 Lane Changes Per Hour by Zone.

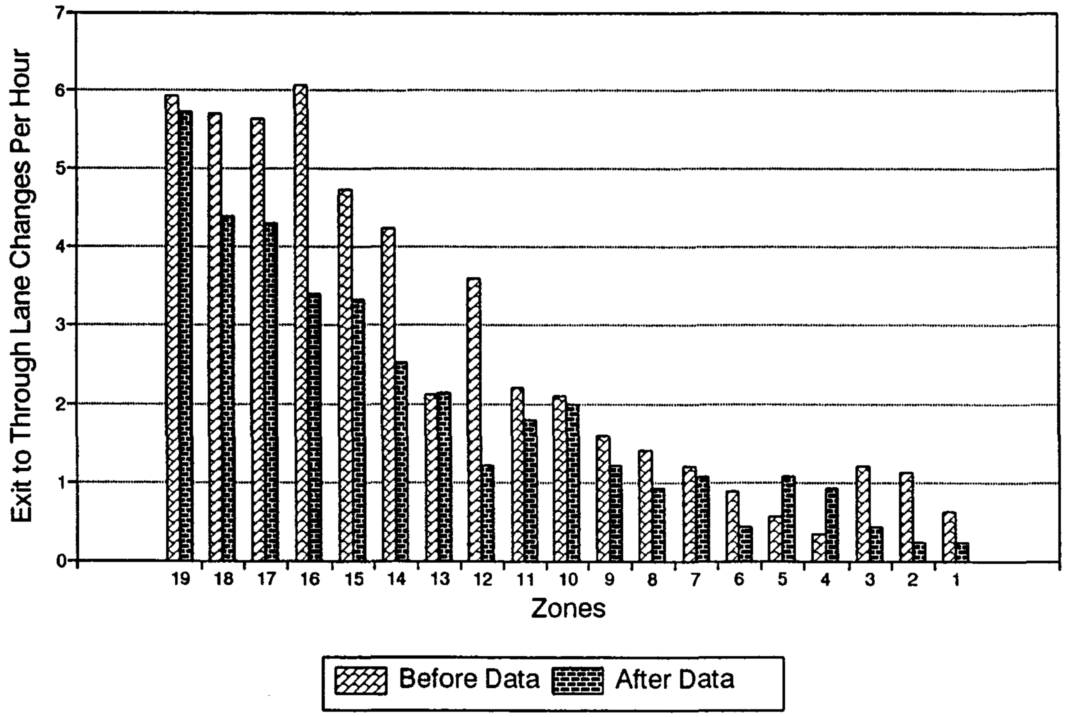


Figure A-19. Site 3 Exit to Through Lane Lane Changes Per Hour by Zone.

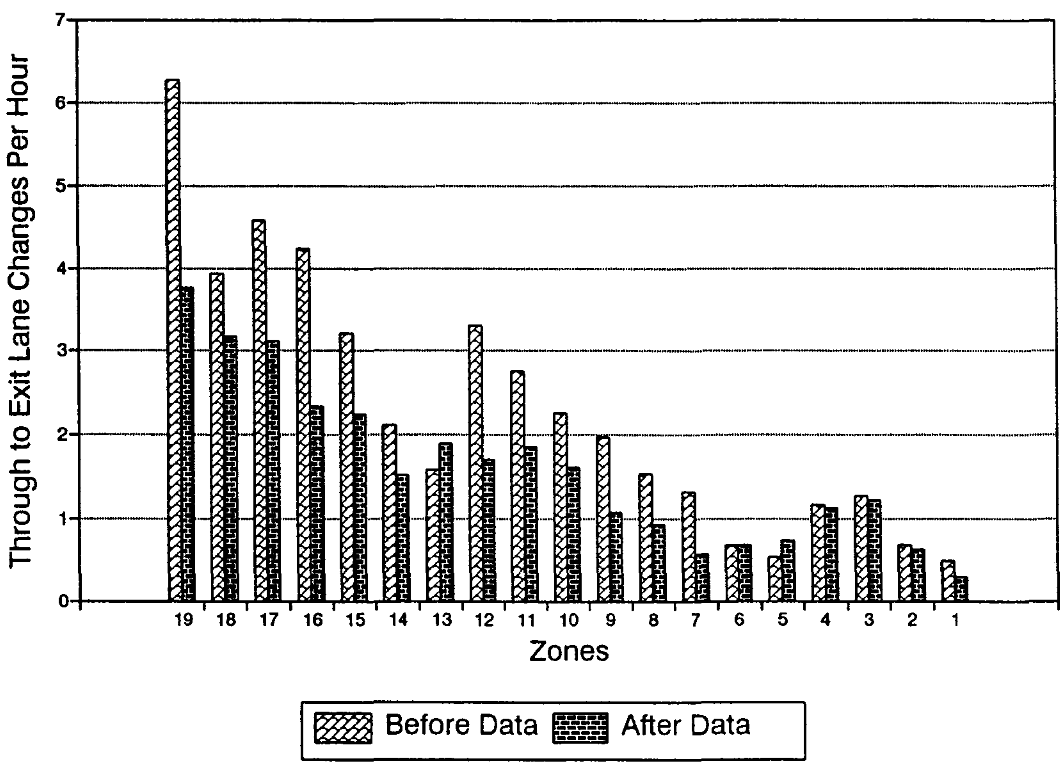


Figure A-20. Site 3 Through to Exit Lane Lane Changes Per Hour by Zone.

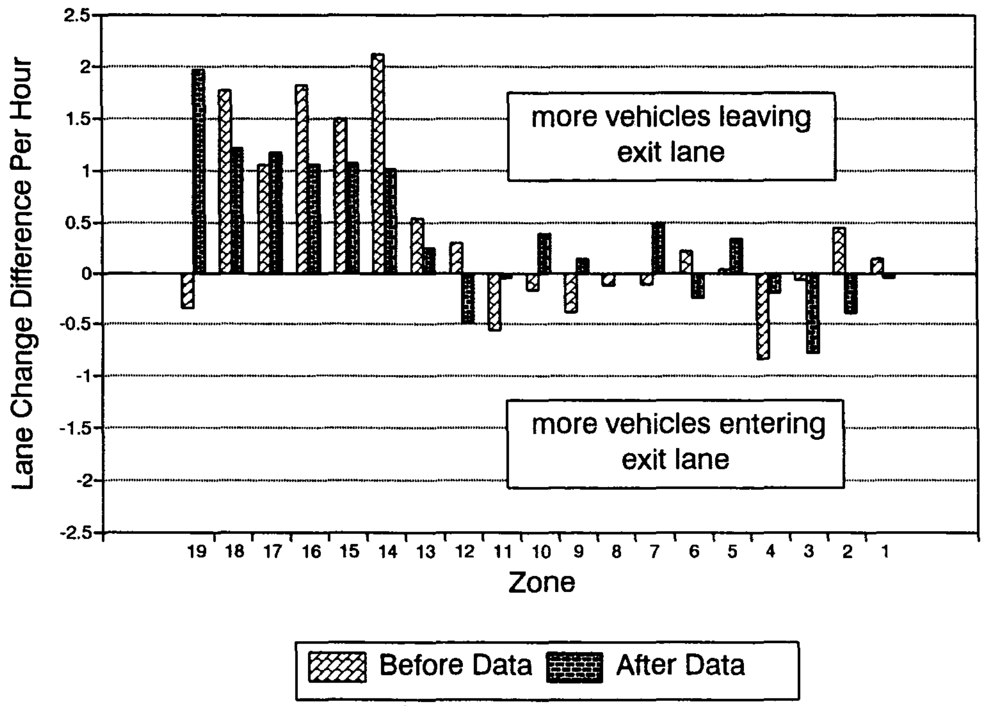


Figure A-21. Site 3 Lane Change Difference Per Hour by Zone.

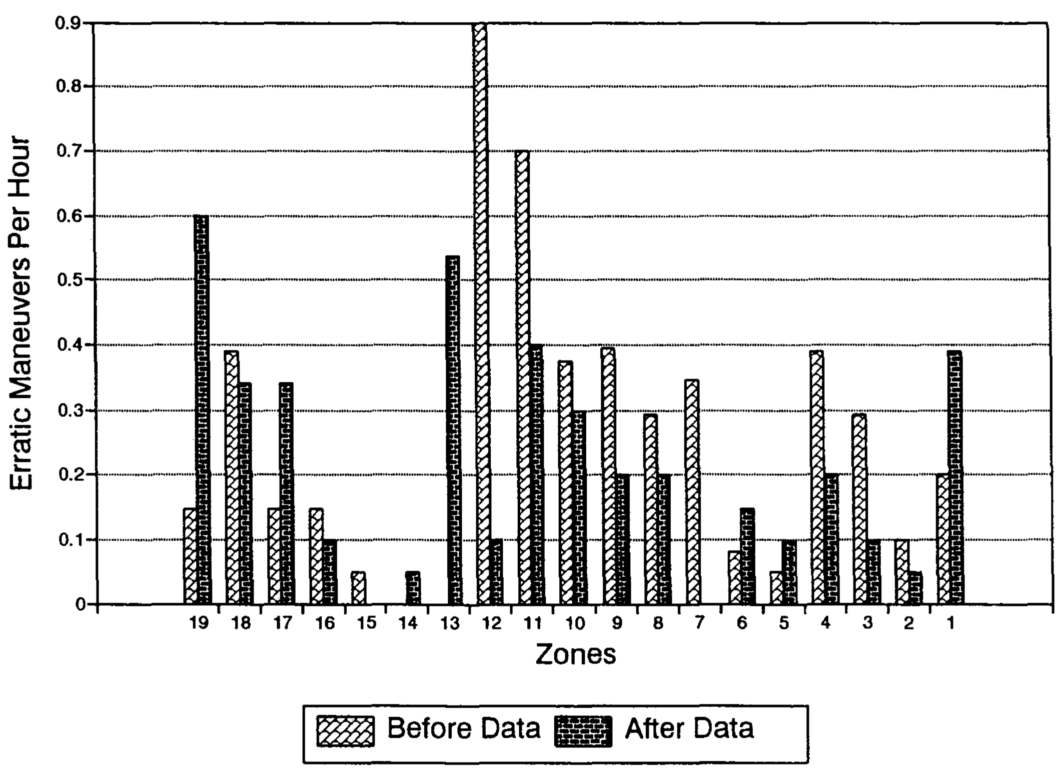


Figure A-22. Site 3 Erratic Maneuvers Per Hour by Zone.

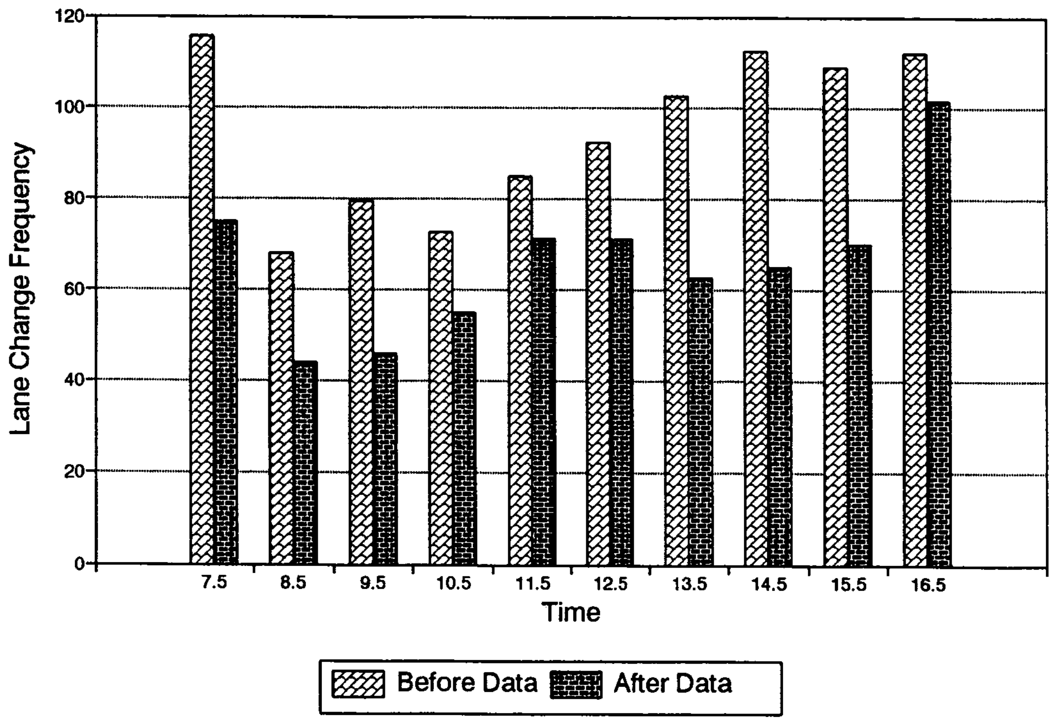


Figure A-23. Site 3 Lane Change Frequency by Hour.

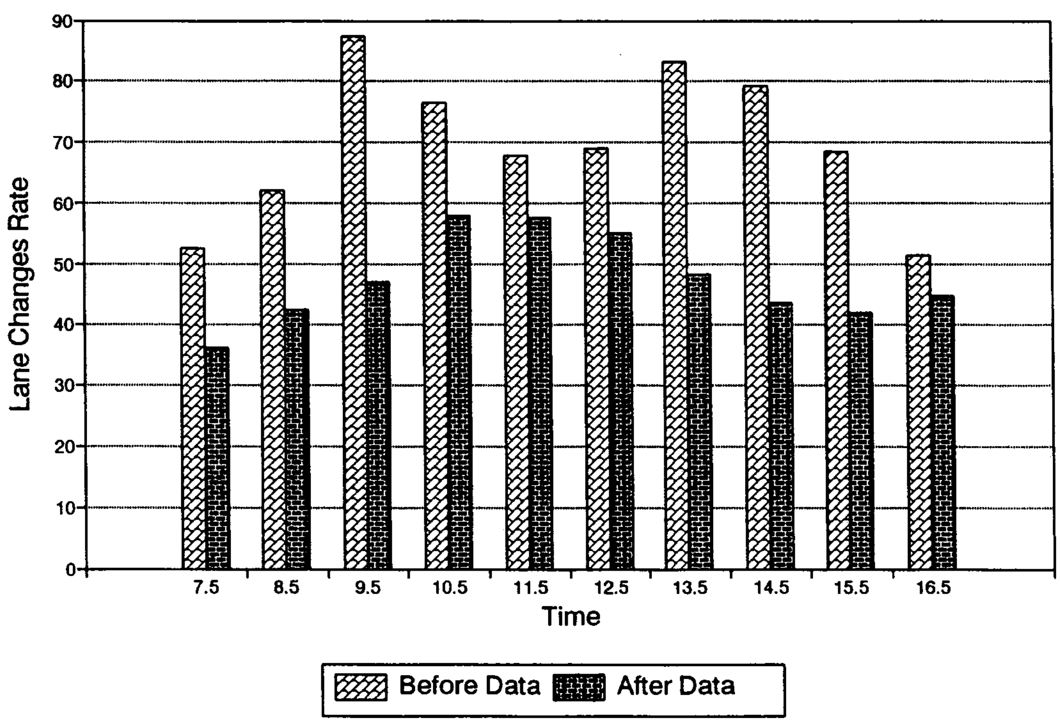
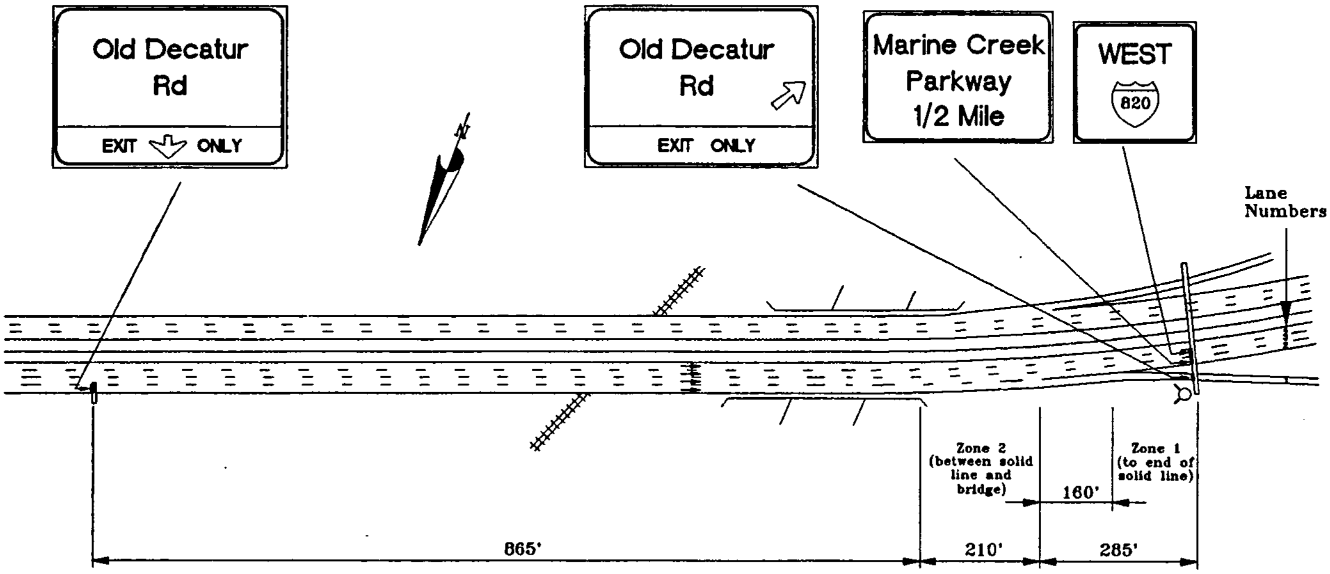


Figure A-24. Site 3 Lane Change Rate by Hour.



Distances are approximated

= Camera Locations

Figure A-25. Site 4 Zones.

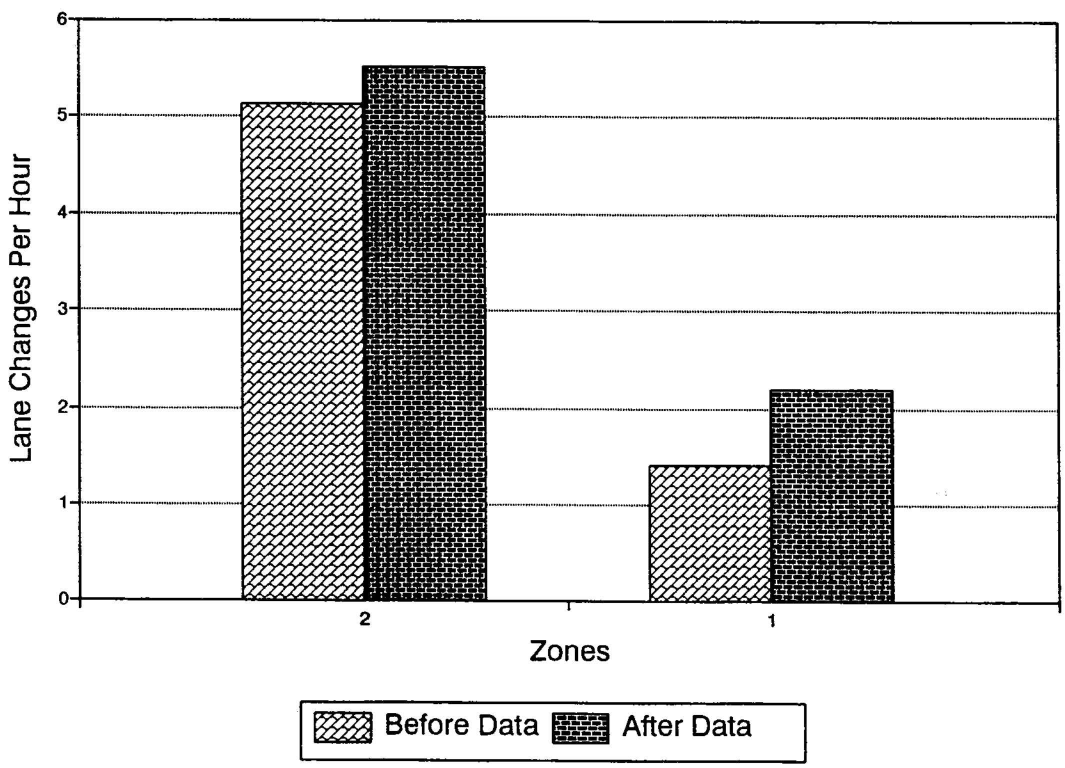


Figure A-26. Site 4 Lane Changes Per Hour by Zone.

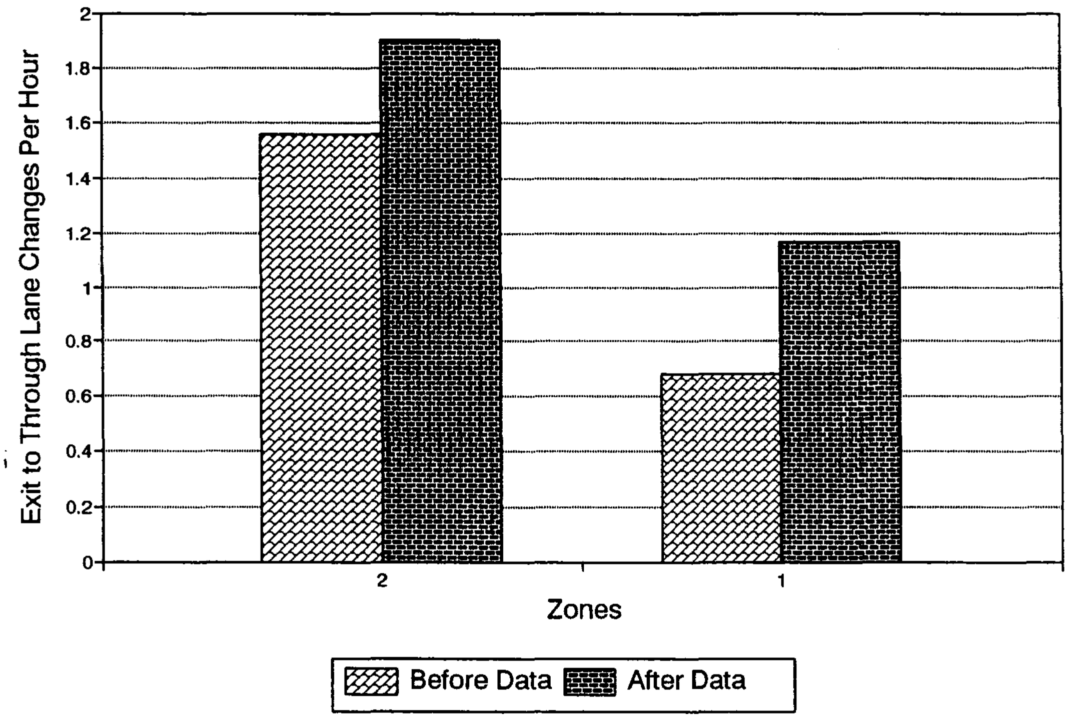


Figure A-27. Site 4 Exit to Through Lane Lane Changes Per Hour by Zone.

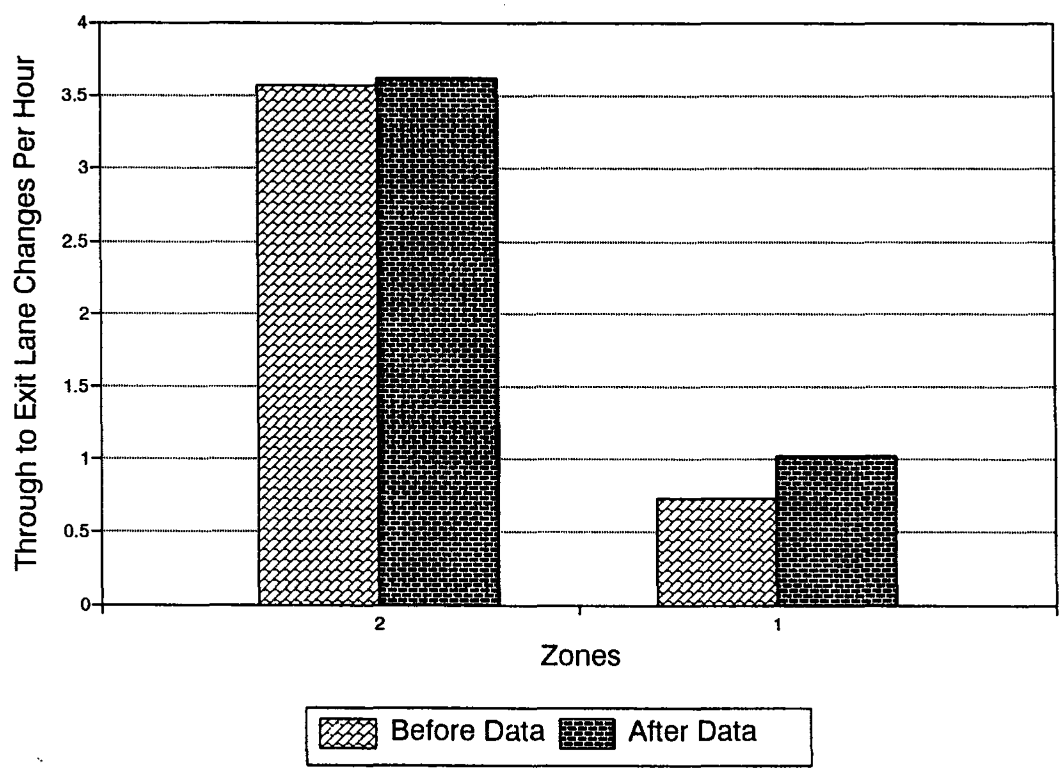


Figure A-28. Site 4 Through to Exit Lane Lane Changes Per Hour by Zone.

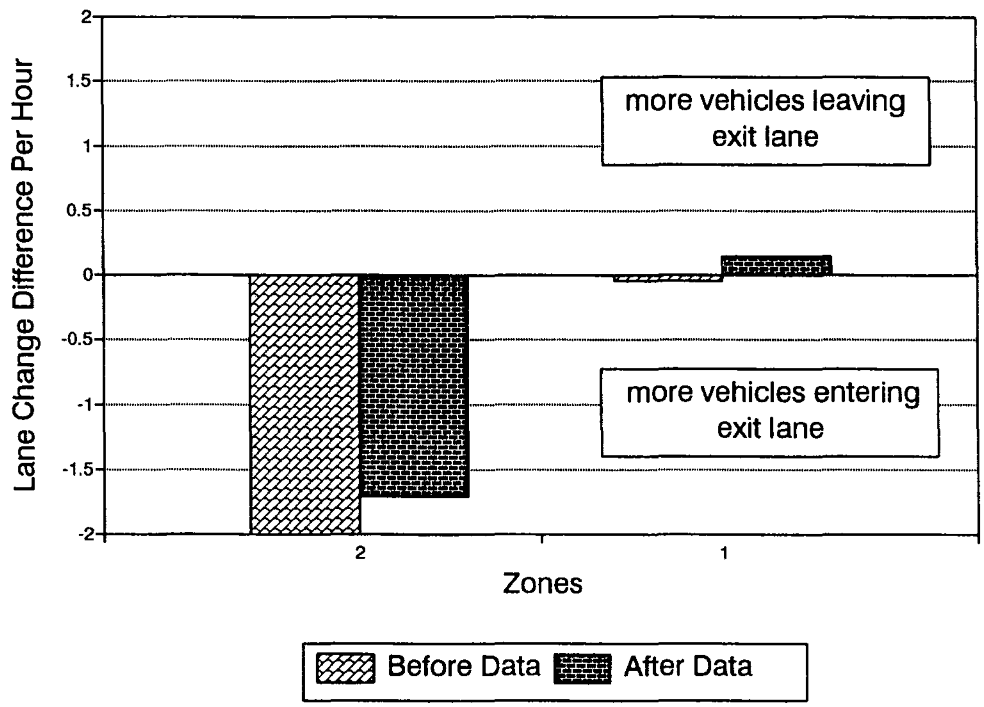


Figure A-29. Site 4 Lane Change Difference Per Hour by Zone.

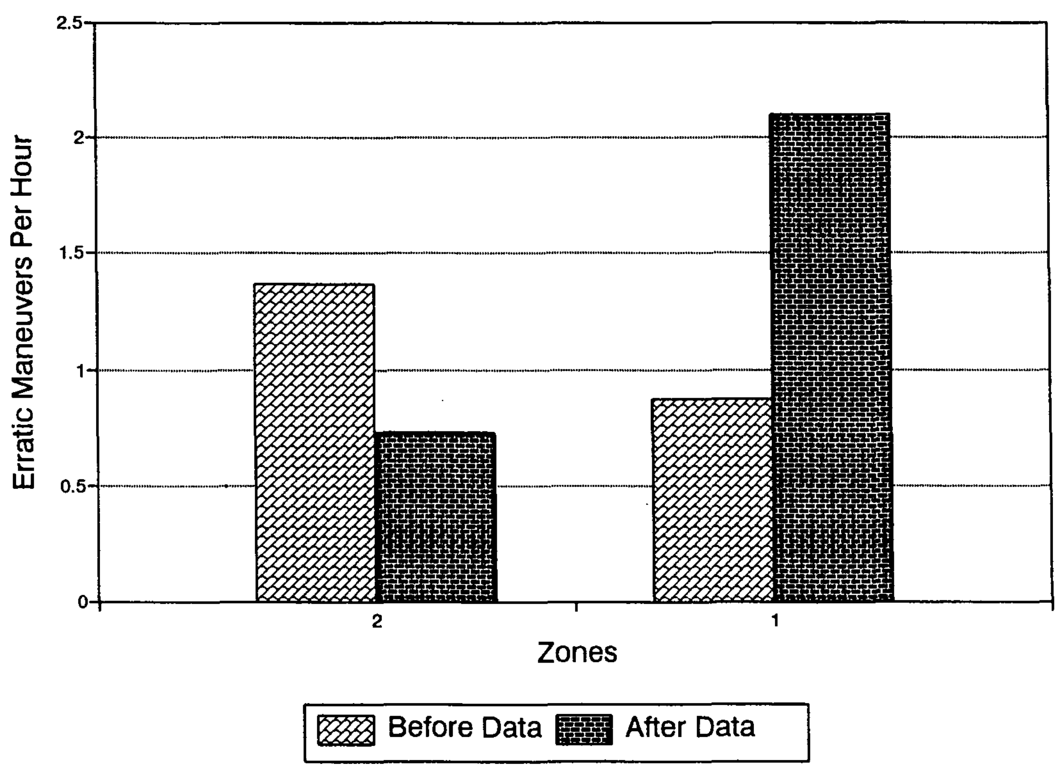


Figure A-30. Site 4 Erratic Maneuvers Per Hour by Zone.

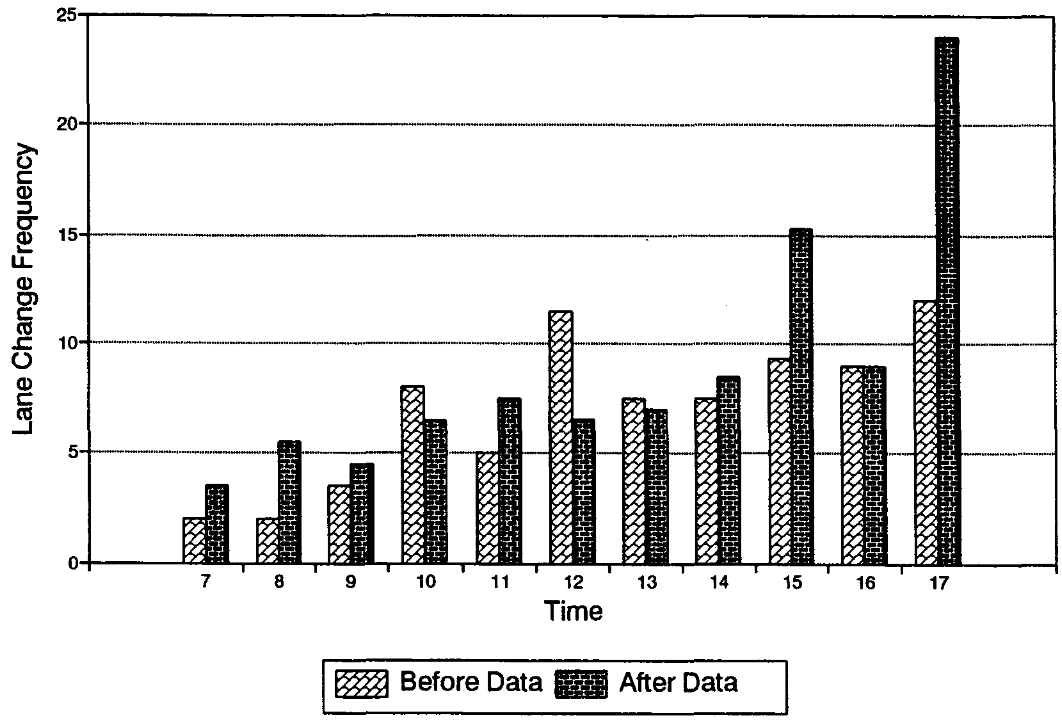
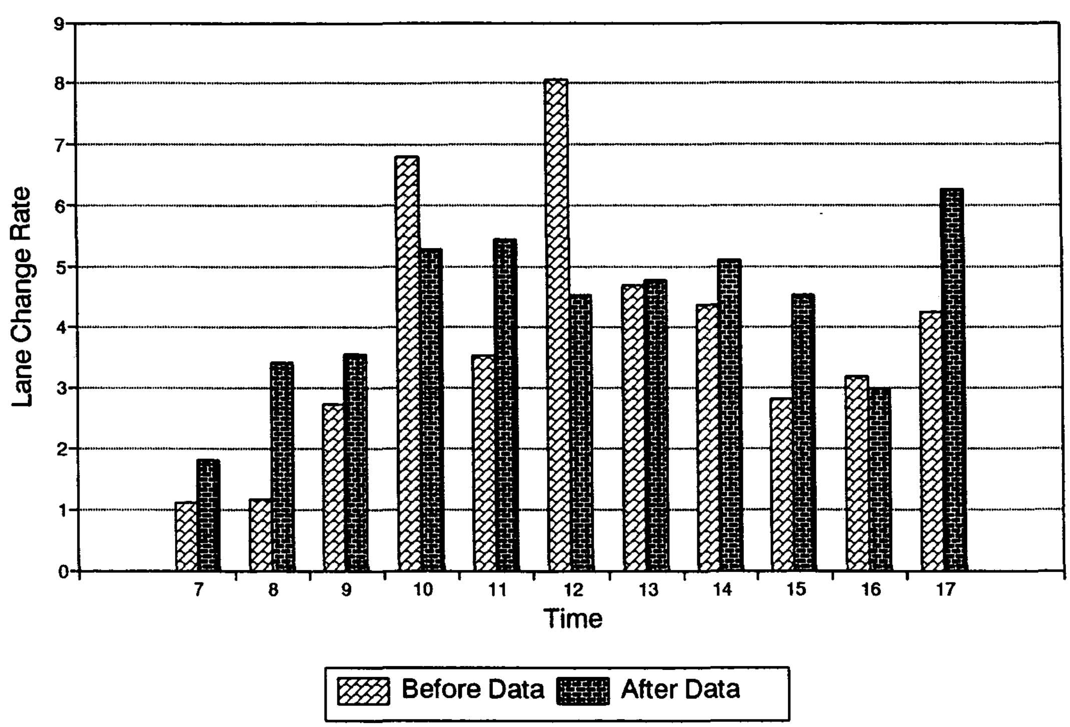


Figure A-31. Site 4 Lane Change Frequency by Hour.



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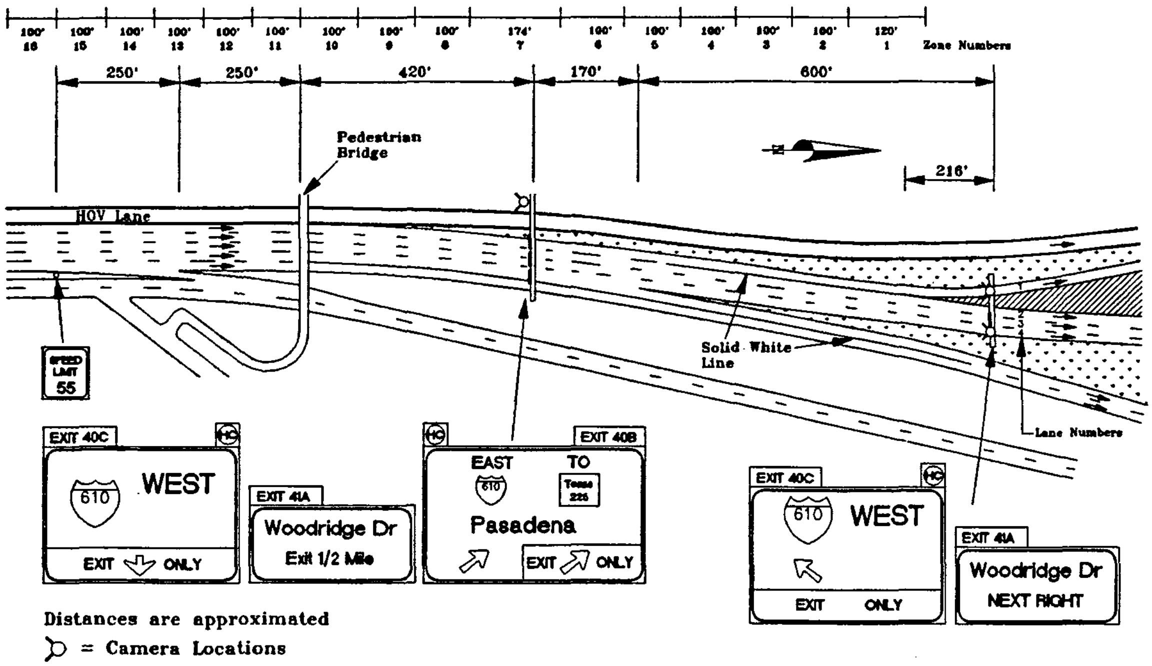

Figure A-33. Site 5 Zones.

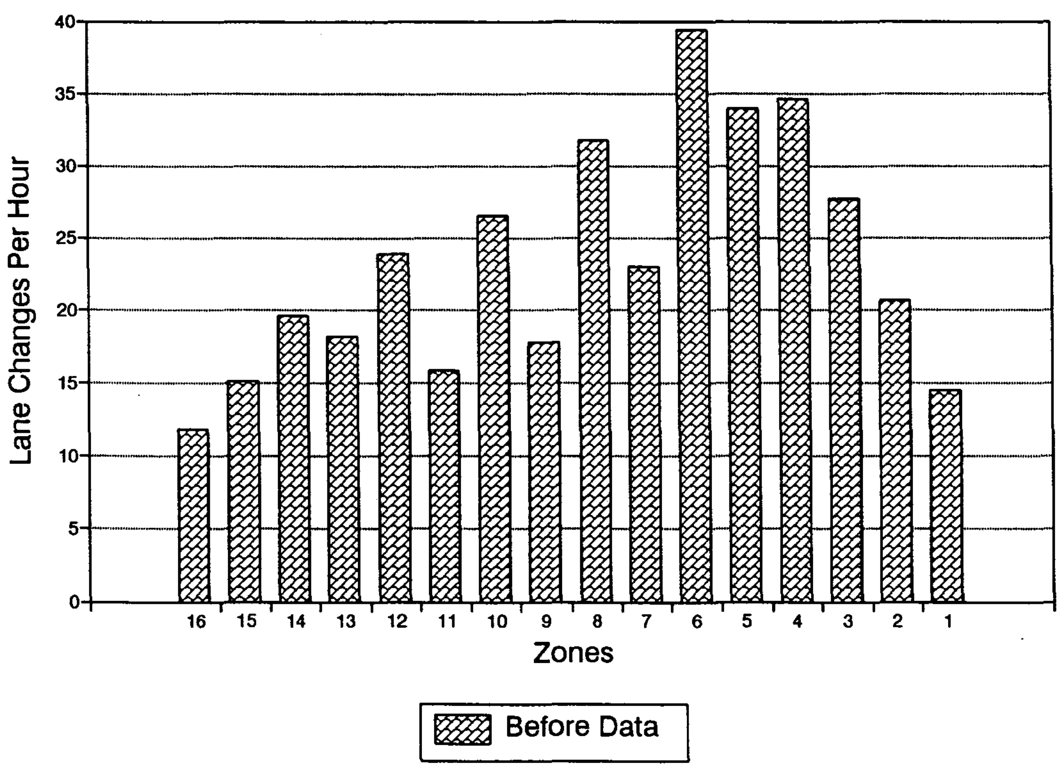

Figure A-34. Site 5 Lane Changes Per Hour by Zone.

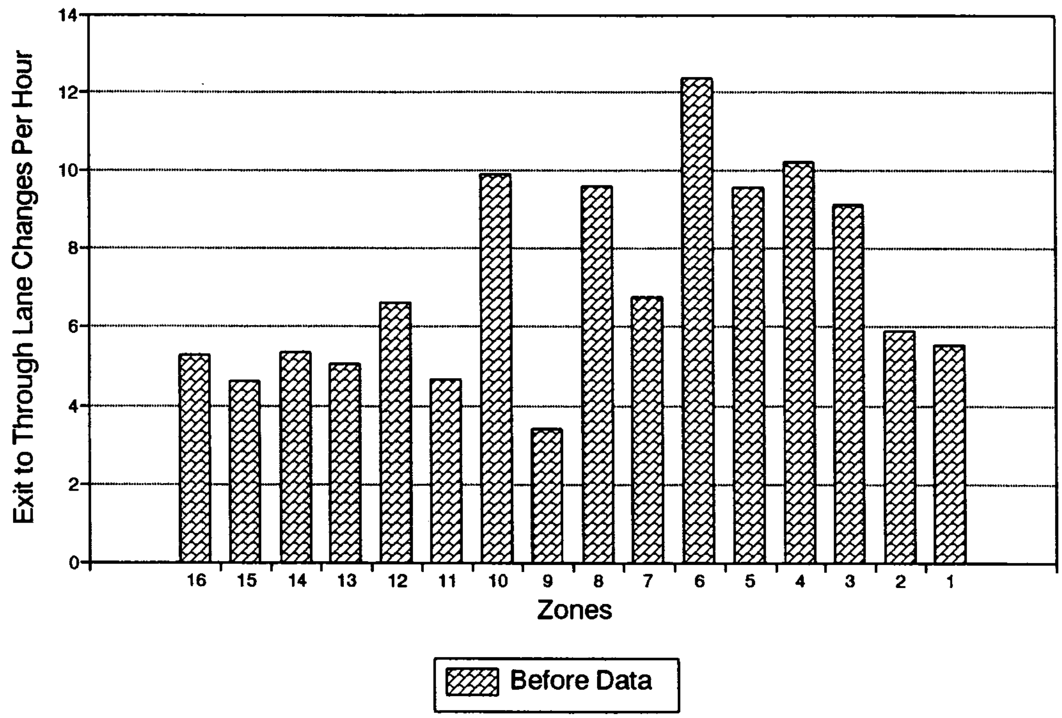

Figure A-35. Site 5 Exit to Through Lane Lane Changes Per Hour by Zone.

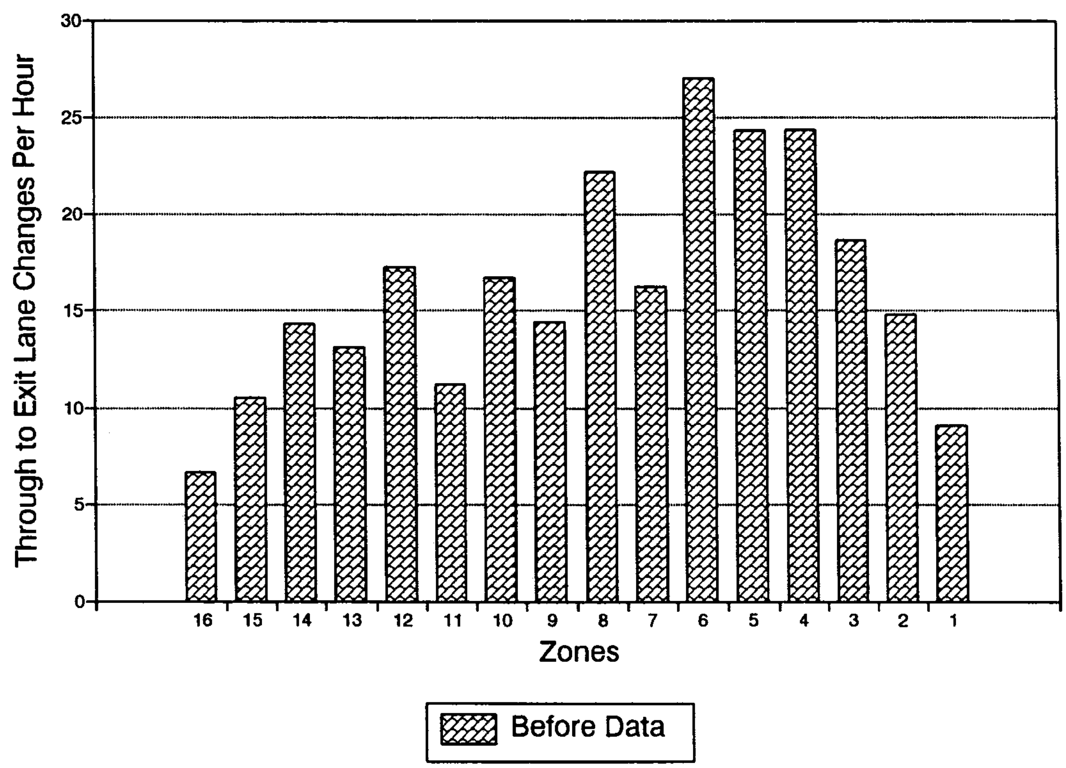

Figure A-36. Site 5 Through to Exit Lane Lane Changes Per Hour by Zone.

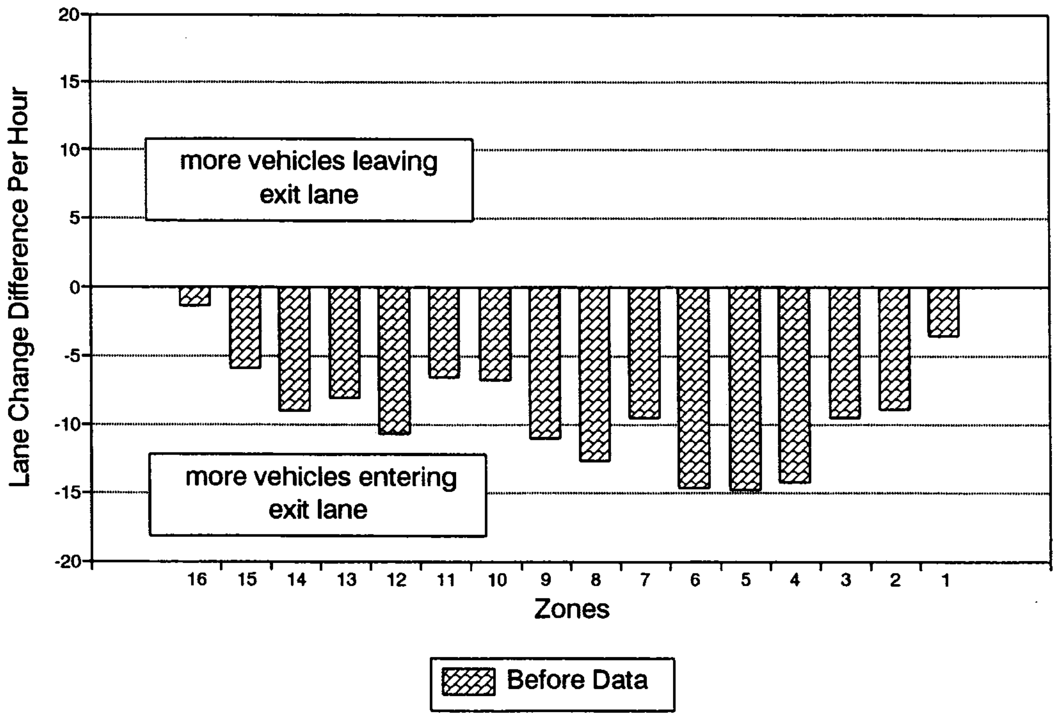

Figure A-37. Site 5 Lane Change Difference Per Hour by Zone.

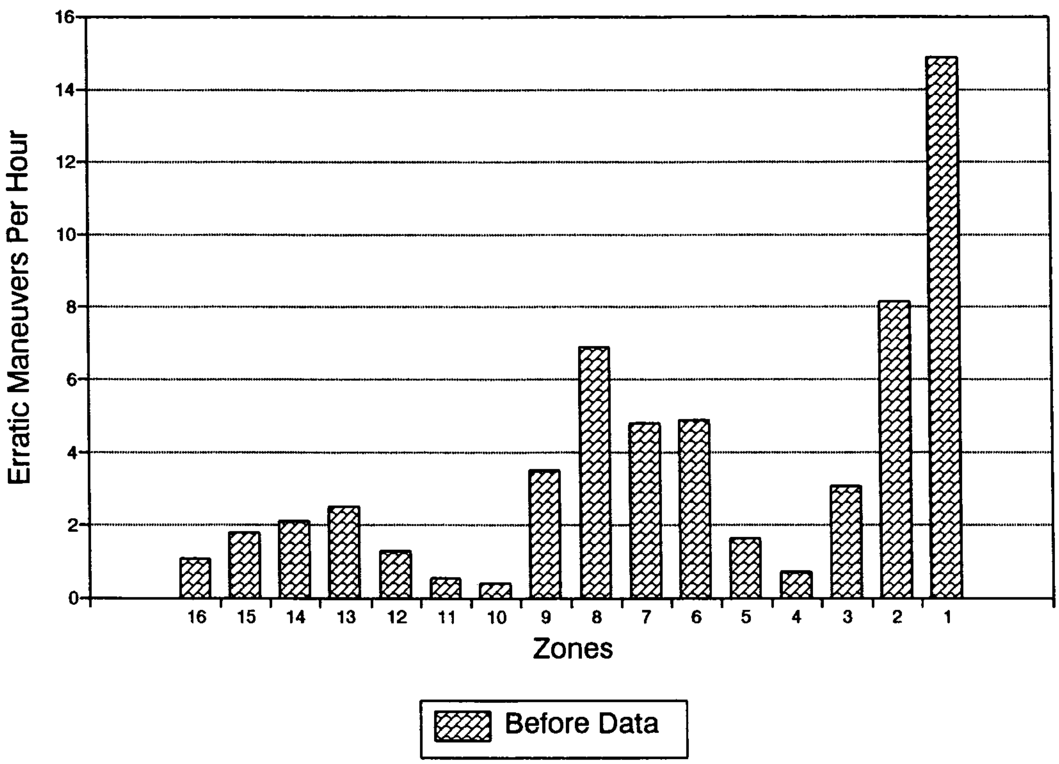

Figure A-38. Site 5 Erratic Maneuvers Per Hour by Zone.

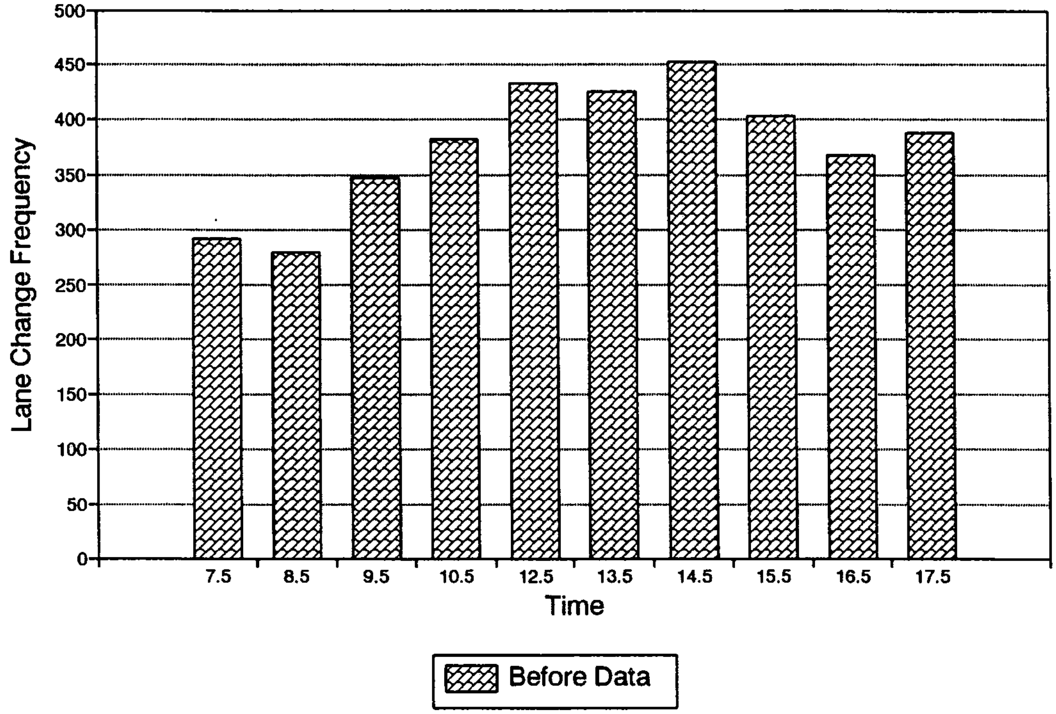

Figure A-39. Site 5 Lane Change Frequency by Hour.

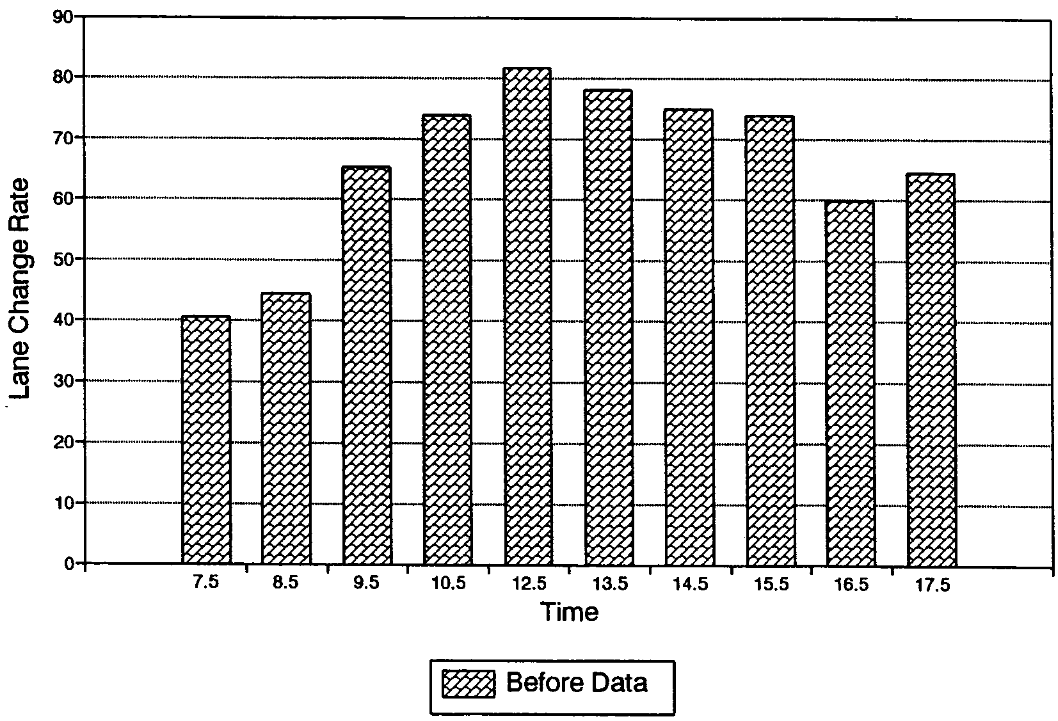

Figure A-40. Site 5 Lane Change Rate by Hour.

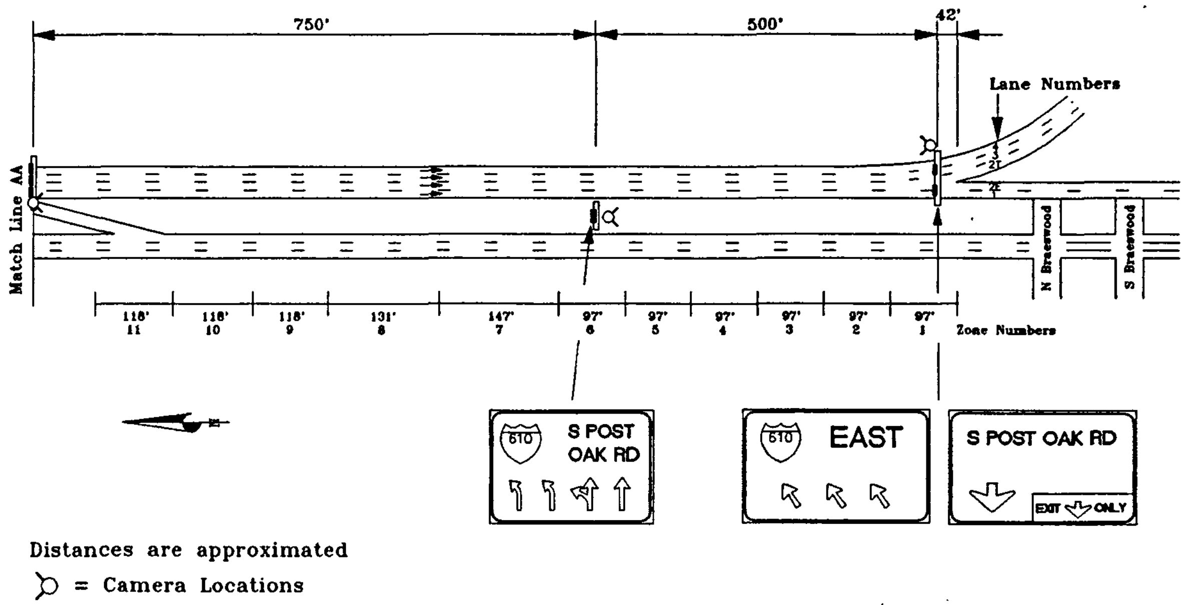

Figure A-41. Site 6 Zones.

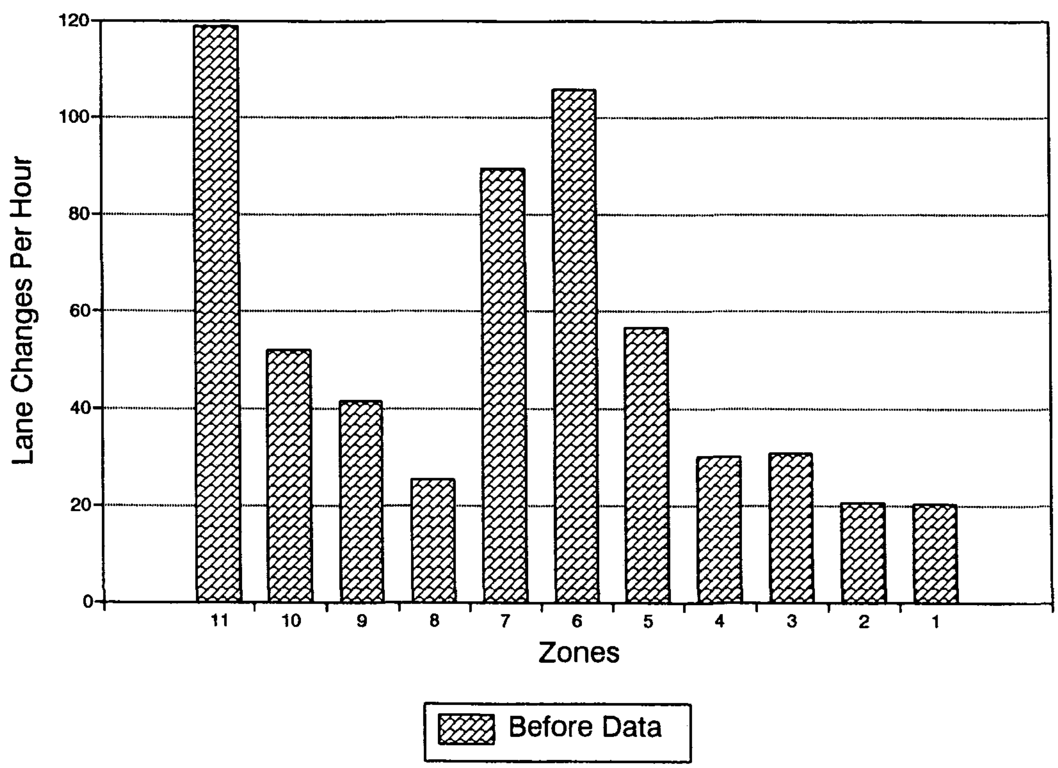

Figure A-42. Site 6 Lane Changes Per Hour by Zone.

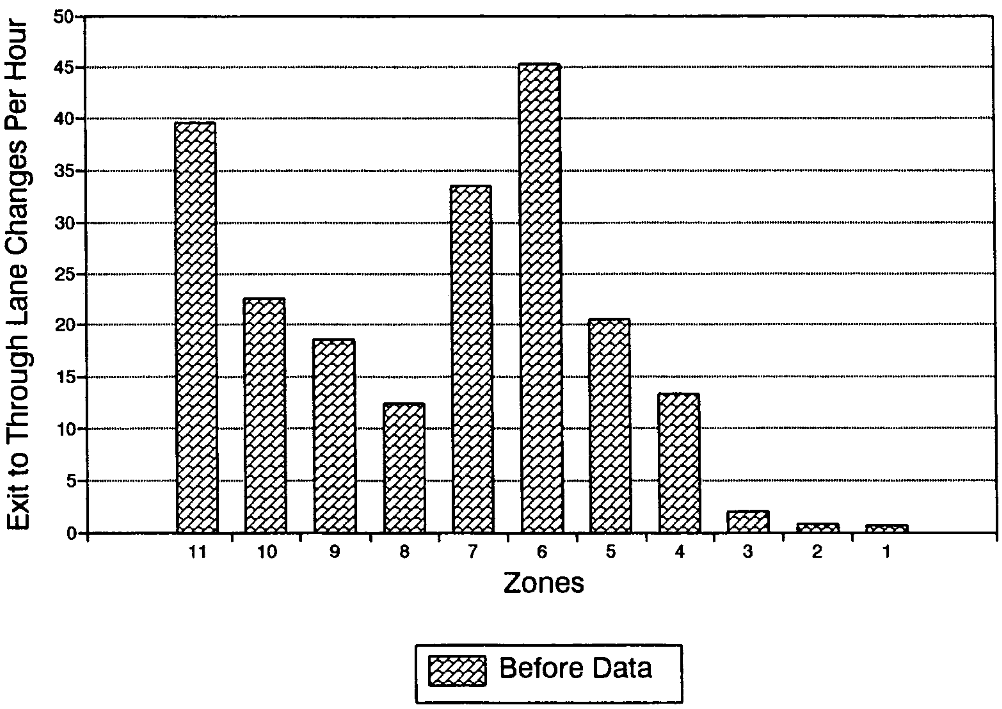

Figure A-43. Site 6 Exit to Through Lane Lane Changes Per Hour by Zone.

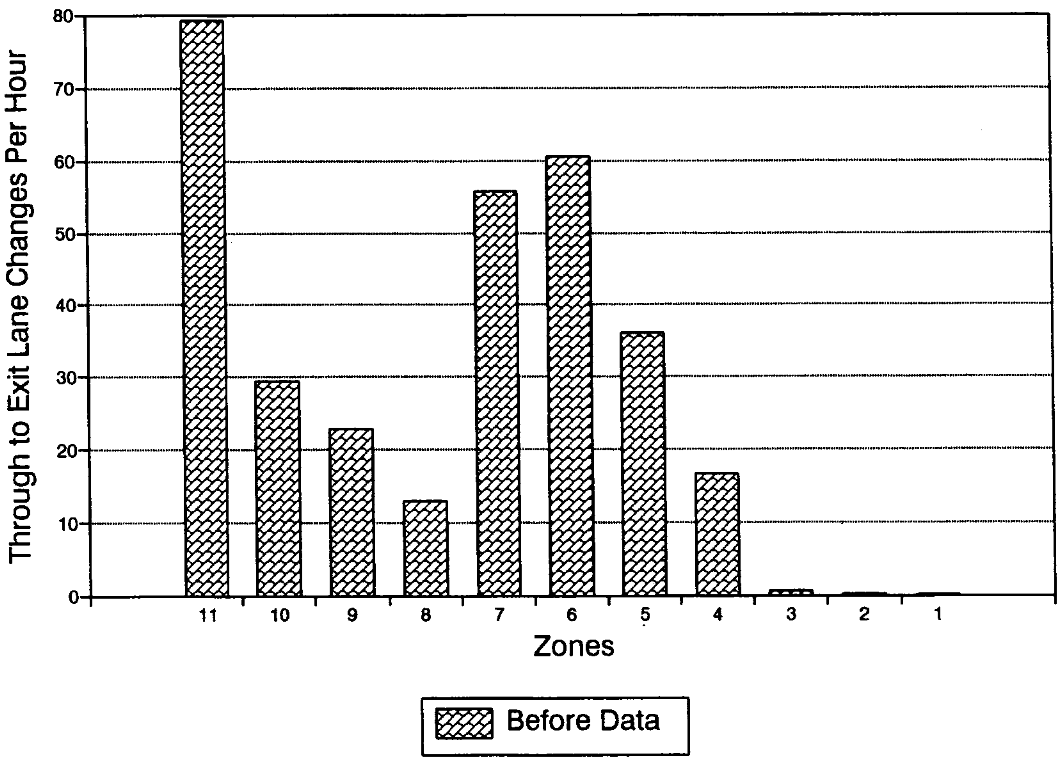

Figure A-44. Site 6 Through to Exit Lane Lane Changes Per Hour by Zone.

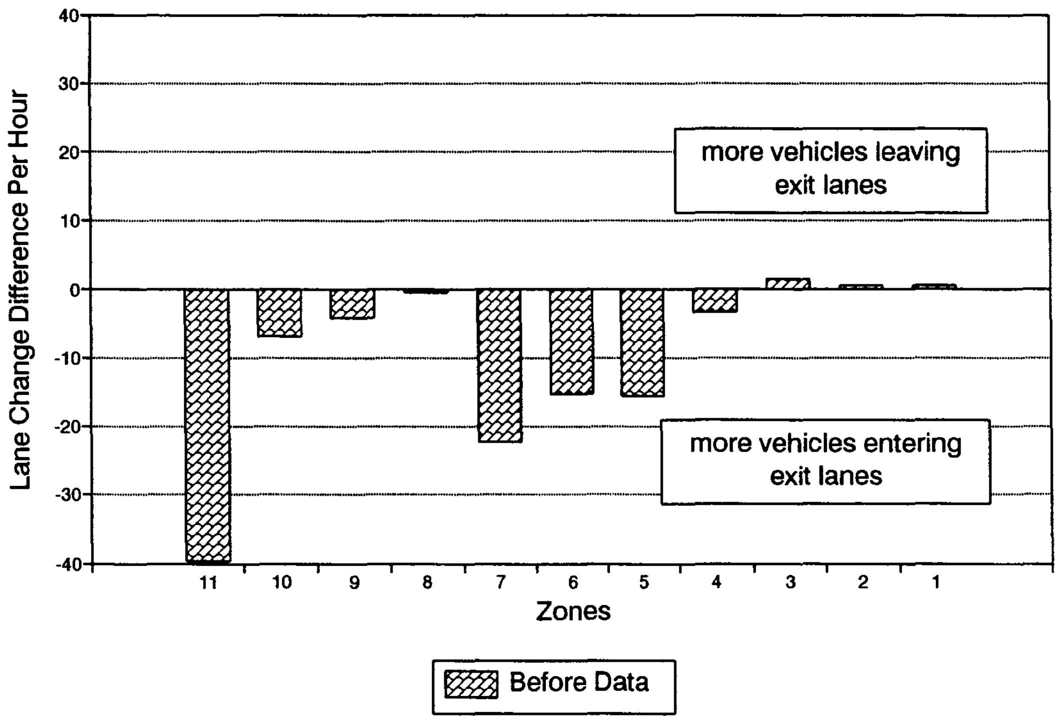

Figure A-45. Site 6 Lane Change Difference Per Hour by Zone.

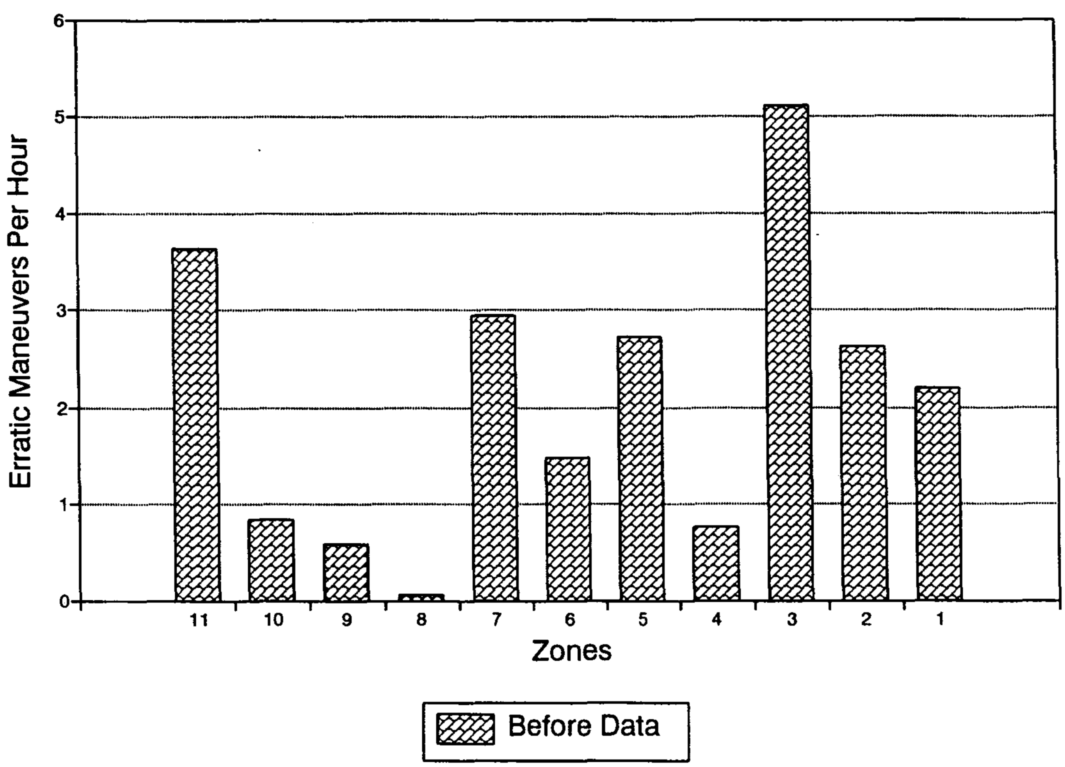

Figure A-46. Site 6 Erratic Maneuvers Per Hour by Zone.

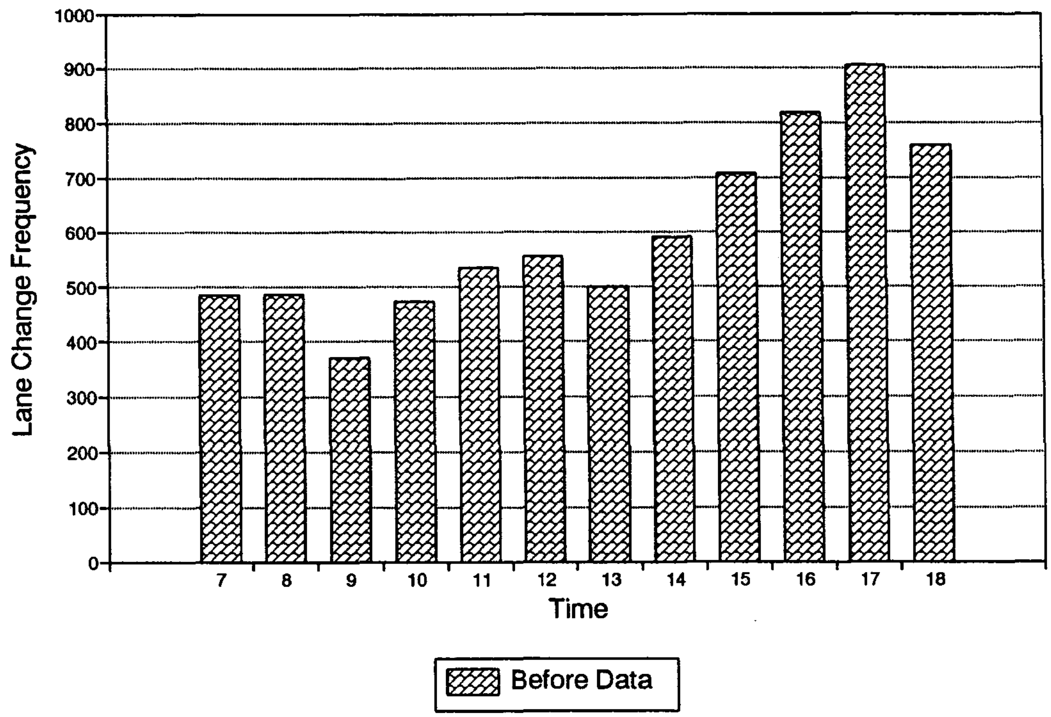

Figure A-47. Site 6 Lane Change Frequency by Hour.

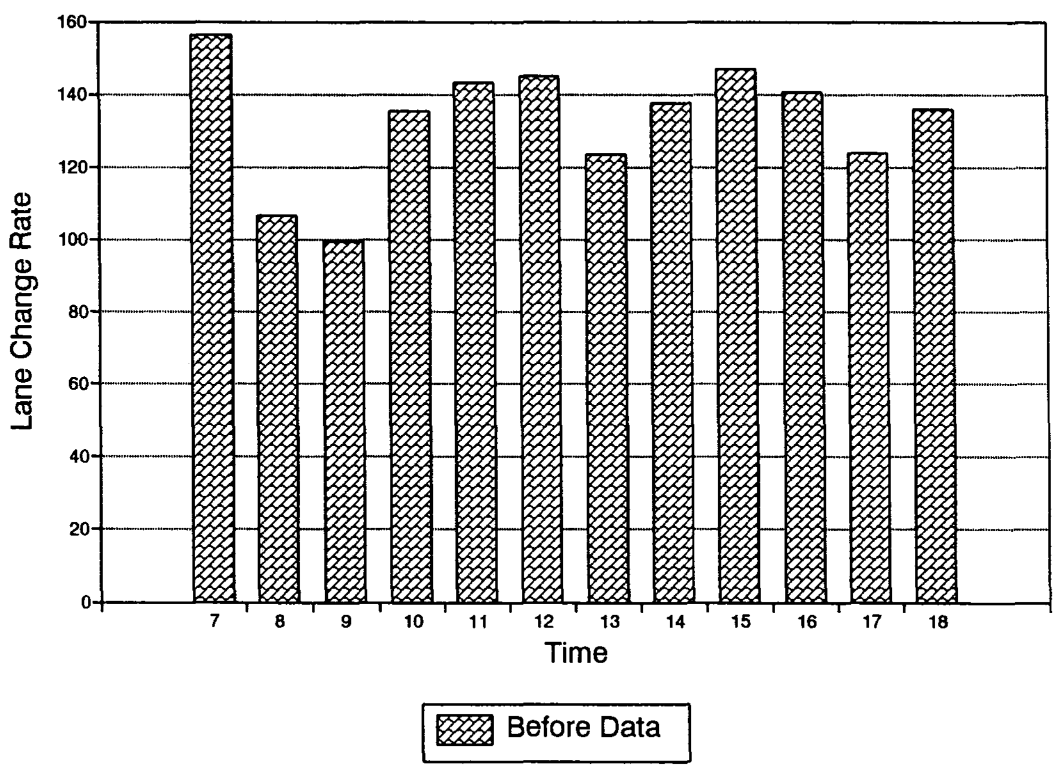

Figure A-48. Site 6 Lane Change Rate by Hour.

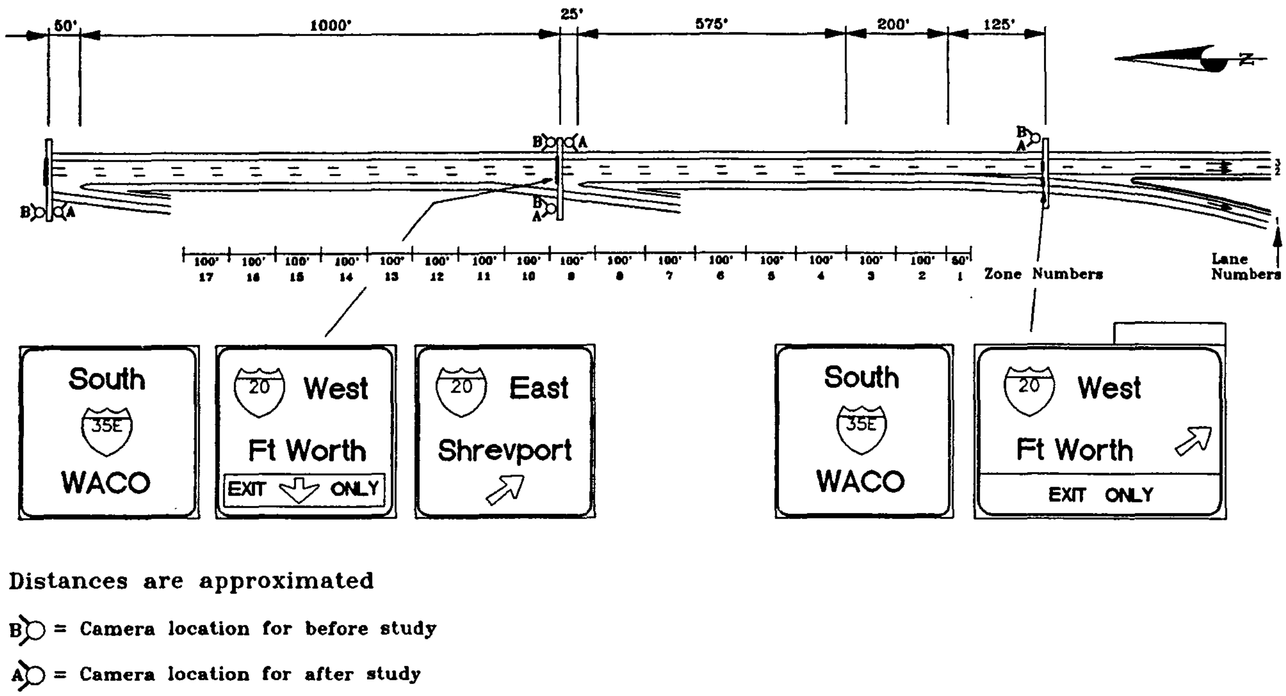

Figure A-49. Site 7 Zones.

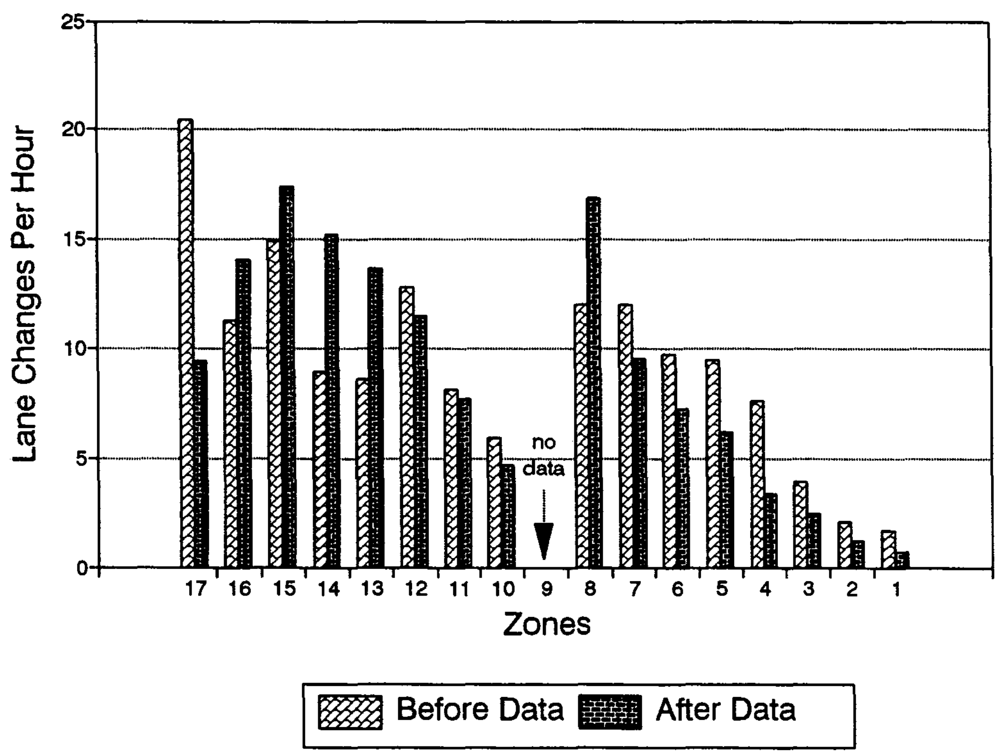

Figure A-50. Site 7 Lane Changes Per Hour by Zone.

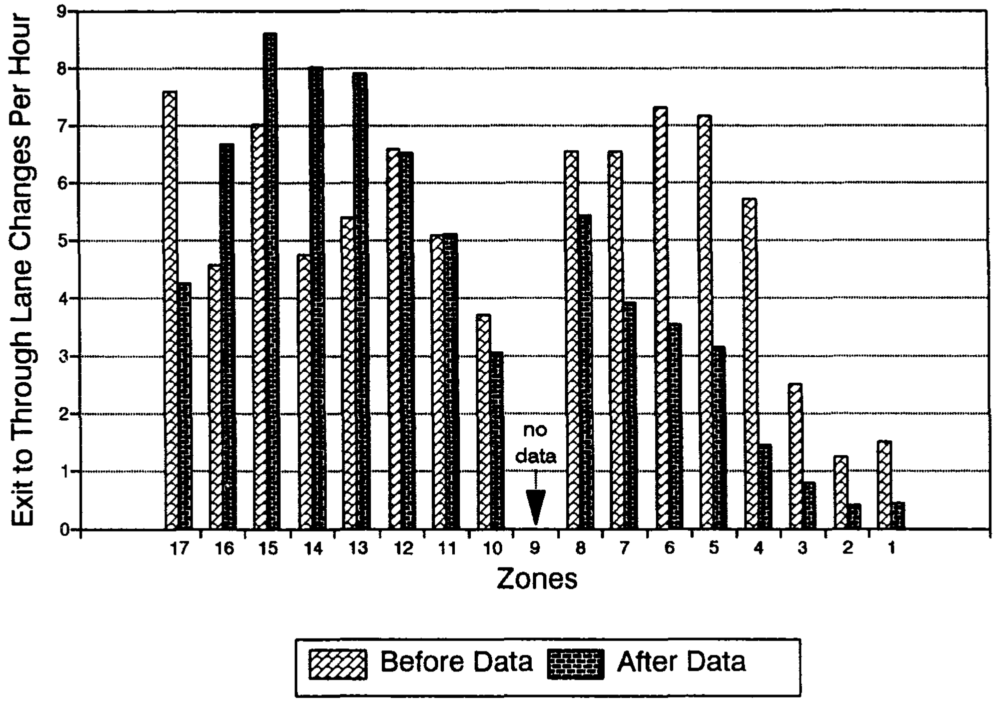

Figure A-51. Site 7 Exit to Through Lane Lane Changes Per Hour by Zone.

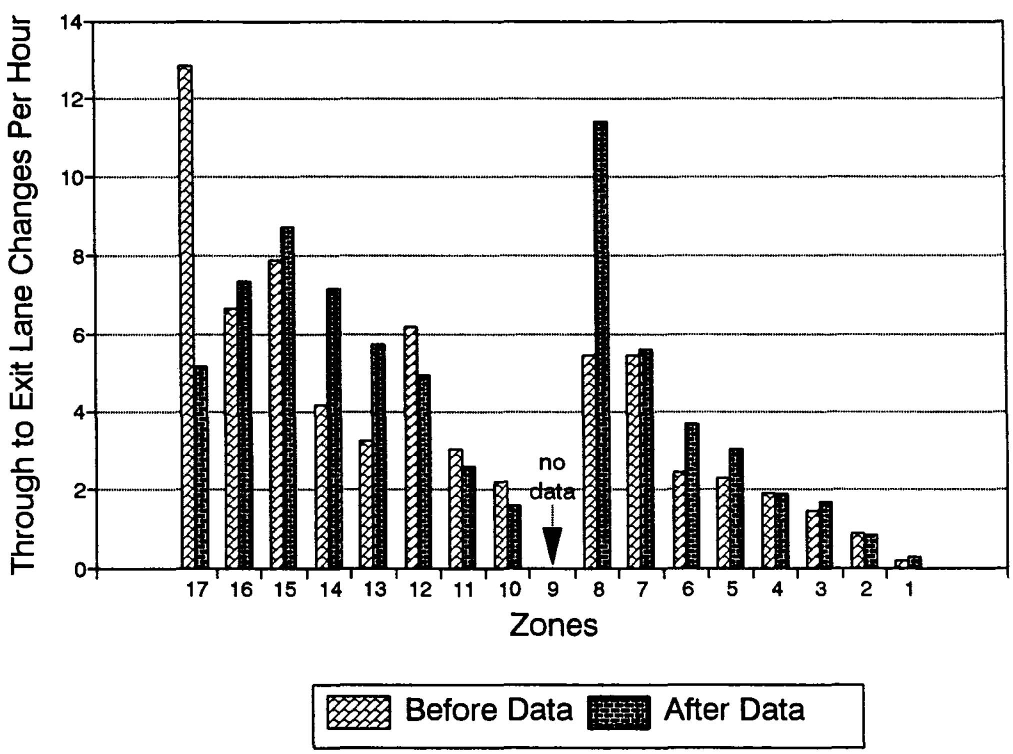

Figure A-52. Site 7 Through to Exit Lane Lane Changes Per Hour by Zone.

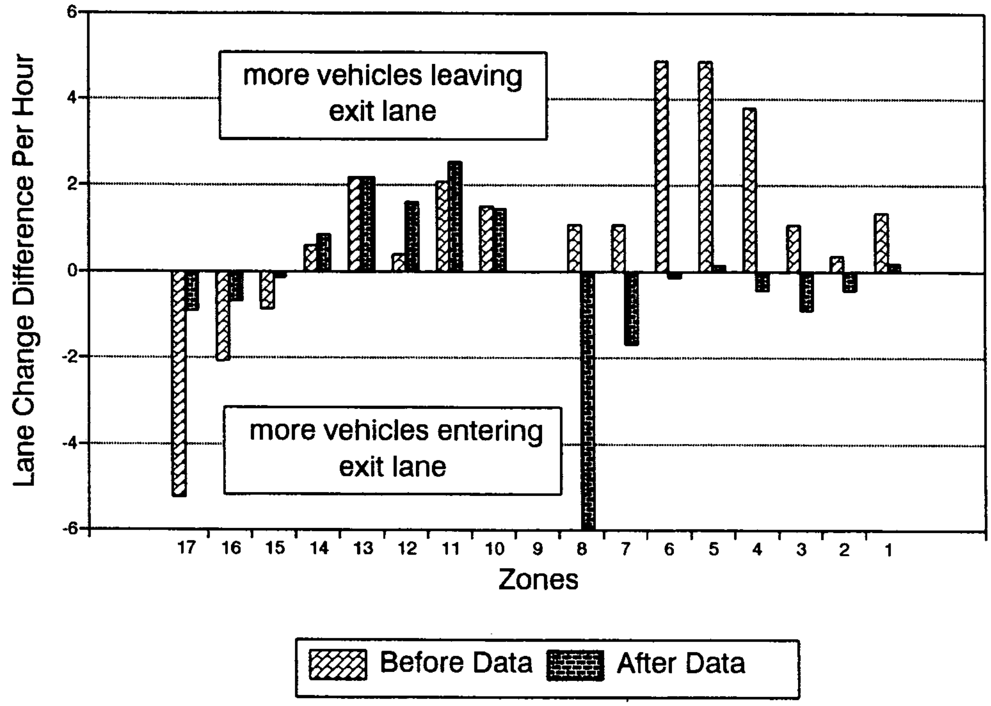

Figure A-53. Site 7 Lane Change Difference Per Hour by Zone.

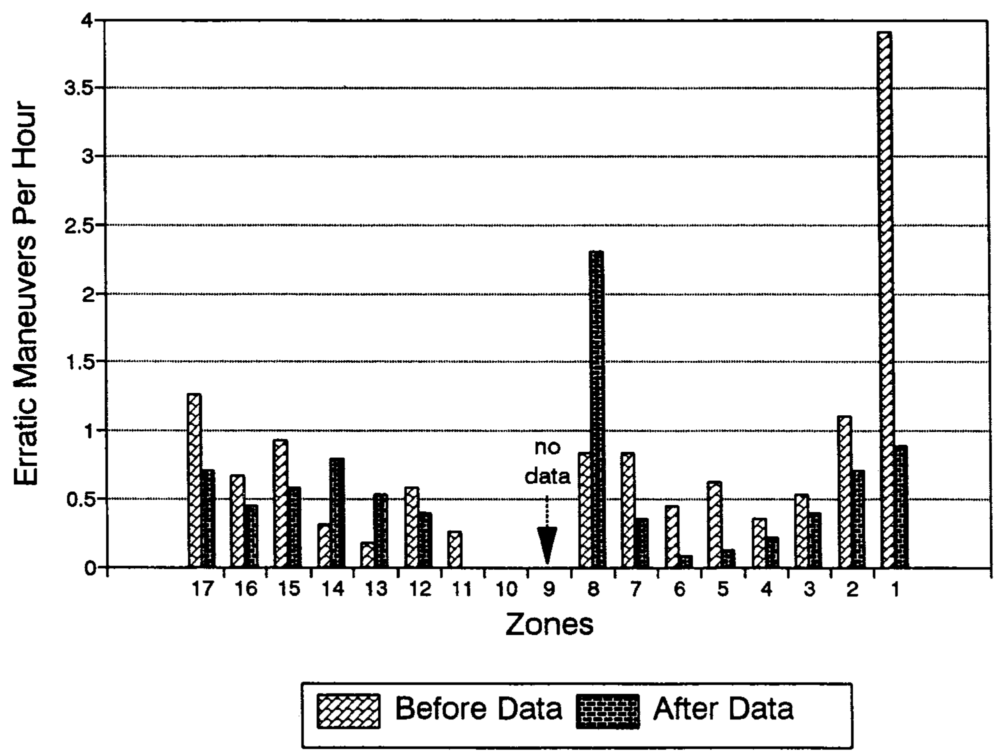

Figure A-54. Site 7 Erratic Maneuvers Per Hour by Zone.

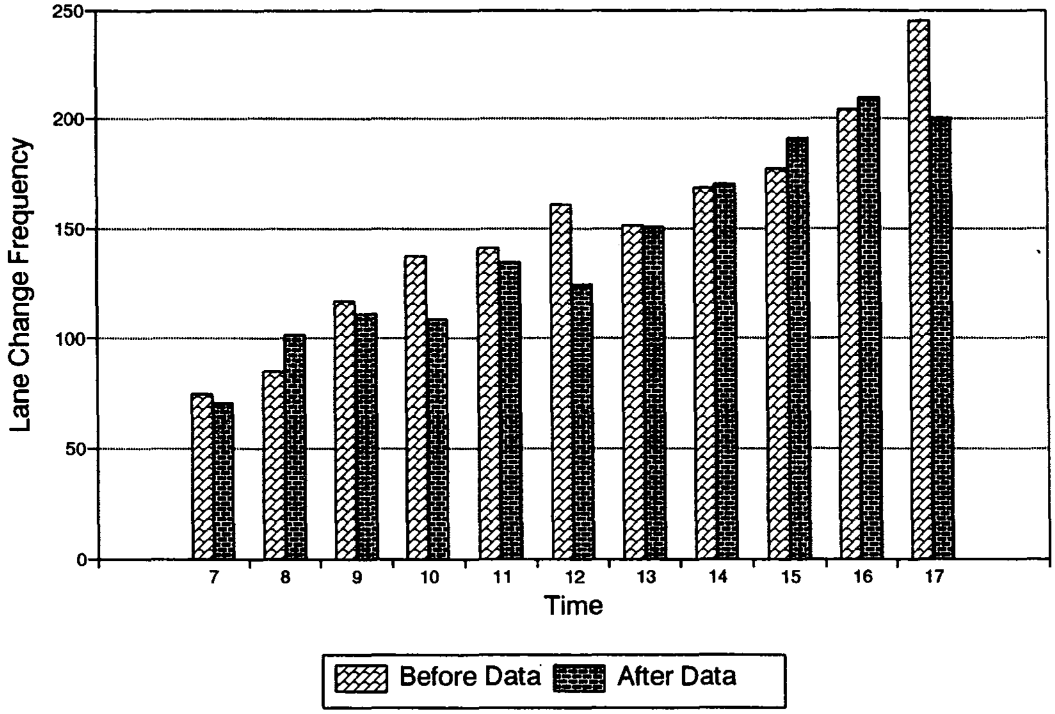

Figure A-55. Site 7 Lane Change Frequency by Hour.

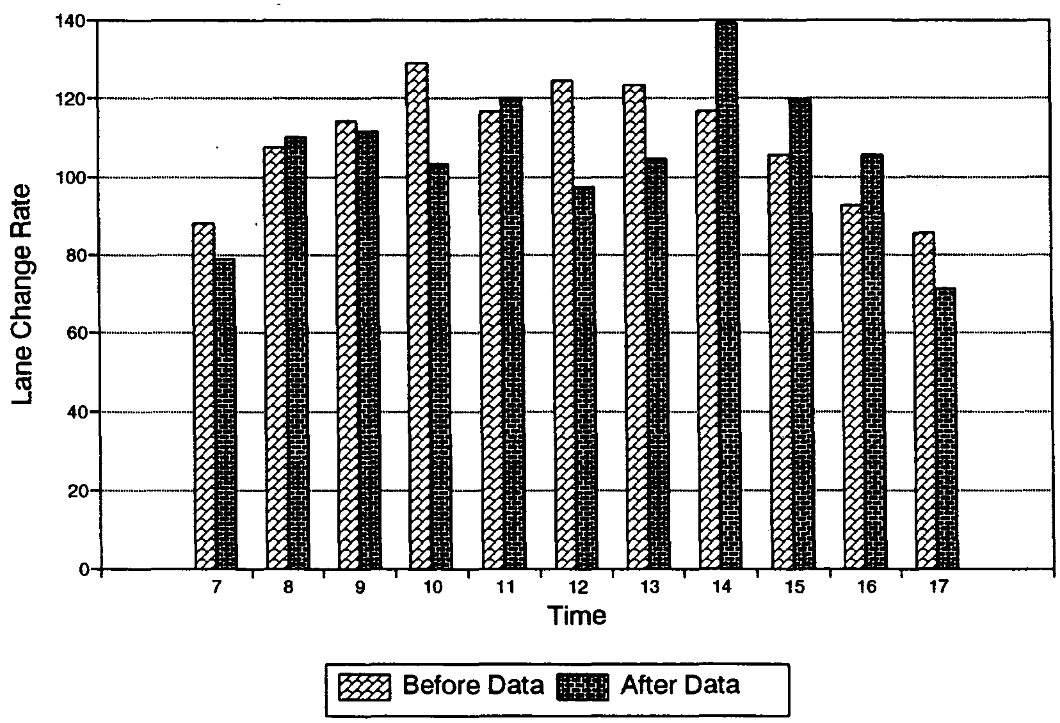

Figure A-56. Site 7 Lane Change Rate by Hour.