Effects of Pavement Markings on Driver Behavior at Freeway Lane Drop Exits

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Field studies were designed to measure the effects of pavement markings on driver behavior at freeway lane drop exits. Number and location of lane changes and erratic maneuvers upstream of three lane drop exits were the measures of effectiveness used to describe driver behavior. The data from two sites directly revealed—and the data from a third site indicated—that drivers are moving into or out of the exiting lane further upstream of the lane drop gore 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.

A lane drop exit occurs when one or more lanes are eliminated from a freeway at an exit. This treatment is used when traffic demand decreases or when high volumes are exiting to another facility. Lane drop exits 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 to prevent exiting at undesirable locations. Exit-only signs are the predominant type of traffic control device used to communicate the existence of a lane drop exit. A pavement marking treatment is included in the national and Texas Manual on Uniform Traffic Control Device (*1,2*) as an optional MUTCD treatment.

Because of interest in determining more effective methods of communicating lane drop exits to motorists, the Texas Department of Transportation (TxDOT) commissioned a study (*3*) to determine the effects of pavement markings on motorists. The pavement markings, which are generally known as lane drop markings, consist of larger-width lane striping that begins approximately 0.8 km (0.5 mi) in advance of the theoretical gore point and a solid white channelizing line 203 mm wide (8 in.) extending approximately 91.5 m (300 ft) upstream from the theoretical gore point. The larger-width lane striping is 203 mm wide by 0.9 m long (8 in. wide by 3 ft long) separated by 3.7-m (12-ft) gaps. White pavement marking arrows can also be included as part of a pavement marking treatment.

Previous studies on pavement markings at exit and entrance ramps focused on the effectiveness of different color markings and on raised pavement markers. One study (*4*) specifically investigated signing and pavement markings at lane drop exit locations. The study compared the lane changes and erratic maneuvers occurring within 152.5 to 213.5 m (500 to 700 ft) of the gore on a matched 15-min interval basis. The results were mixed; one site showed improvements in all times studied, whereas the other two sites showed decreases in lane changes only during certain times. Because the study focused only on the section 152.5 to 213.5 m (500 to 700 ft) immediately upstream of the gore, researchers designed this TxDOT study to gather data (a) for a longer distance upstream of the gore, (b) in smaller increments [say every 30.5 m (100 ft)], and (c) to separate the lane changes into those vehicles moving into the exit lane and those vehicles moving out of the exit lane.

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FIELD STUDIES

Field studies were designed to measure the effects of lane drop markings on driver behavior at three freeway lane drop exits. Number and location of lane changes and erratic maneuvers upstream of a lane drop exit were the measures of effectiveness (MOEs) used to describe driver behavior. With these MOEs the influence of the markings could be seen in the number of lane changes (or erratic maneuvers) and in the position in which those changes are occurring.

Before-and-after data were collected at the following sites: Site A, I-820 northbound (NB) to White Settlement Road; Site B, I-35E southbound (SB) to I-20 west; and Site C, I-45NB to I-610 west. Table 1 provides a summary of the characteristics for each site, whereas Figures 1 through 3 show the signs and markings present at the sites during the before-data collection. These sites were selected because the exiting lane existed for a mile or more before being dropped, and they had minimal potential influences, such as entrance ramps or poor geometry, which could affect the quantity and location of lane changes and erratic maneuvers. Figures 4 through 6 illustrate the markings installed at each site.

Video cameras recorded several days of operations at each site. Three to four cameras were installed at each site on overhead sign structures. Videotapes in videocassette recorders located in ground-VCR level controller cabinets mounted specifically for this project were replaced every 6 hr during daylight conditions. The videotapes provided the following information: number and location of lane changes; number, location, and type of erratic maneuvers; and volumes. The roadway sections studied were divided into 30.5-m (100-ft) zones. The location of an event was defined as the zone in which a vehicle's front wheel first crossed a lane line. Erratic maneuvers included one-lane lane changes through the gore; two-lane lane changes; swerving in and out of a lane or the shoulder; riding between two lanes on the solid white line; and others.

Once the lane change and erratic maneuver data were obtained, the data were then summarized in 15-min increments by zone for the time periods available for all zones. Graphic representations of the values calculated were valuable tools in evaluating the findings. The findings were plotted by the 30.5-m (100-ft) increments used to reduce the data. These plots, while revealing the trends in the data, also showed the variability that exists between such short

TABLE 1 Study Site Characteristics

Characteristics	Site A	Site B	Site C
Exit Name	I-820 NB to White Settlement Road	I-35E SB to I-20 West	I-45 Northbound to I-610 West
Location	west Ft. Worth	south Dallas	south Houston
Description	One-lane exit	One-lane exit	One-lane, left exit
Length of lane drop	approximately 1.6 km	over 11.3 km	greater than 8.1 km
Dates of filming	Before: Jan 1993 After: June 1993	Before: June 1993 After: June 1993	Before: March 1993 After: November 1993
Markings installed	May 1993	June 1993	August 1993
Number of lanes after exit	three	two	three
Potential Influences (distance upstream from gore)	Entrance ramp (610 m)	Exit ramp--I-20 E (275 m) Exit ramp (550 m)	Two-lane with optional lane lane drop exit (183 m)
AADT on freeway (1992 AADT Maps)	47,000	75,000	202,000

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

increments—a driver can traverse the 30.5-m (100-ft) increment in 1.2 sec when driving 89 kph (55 mph). Figures 7 through 9 illustrate the number of lane changes by zone location for Sites A, B, and C, respectively.

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 91.5-m (300-ft) segment closest to the gore. The hourly values for the entire study length reflected the quantity of lane changes (or erratic maneuvers) occurring at the site. Because of concern with inappropriate driving behavior near gore areas, the 91.5-m (300-ft) segment closest to gore value was also determined. The hourly values were calculated by dividing the total number of lane changes for a zone, or for all zones, by the number of 15-min intervals reduced and then multiplying by 4 to obtain an hourly value. Table 2 lists the findings for each site.

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

BEFORE-AND-AFTER FINDINGS

Volumes

When comparing changes in driver behavior in a before-and-after study, potential influences, other than the item studied (which in this

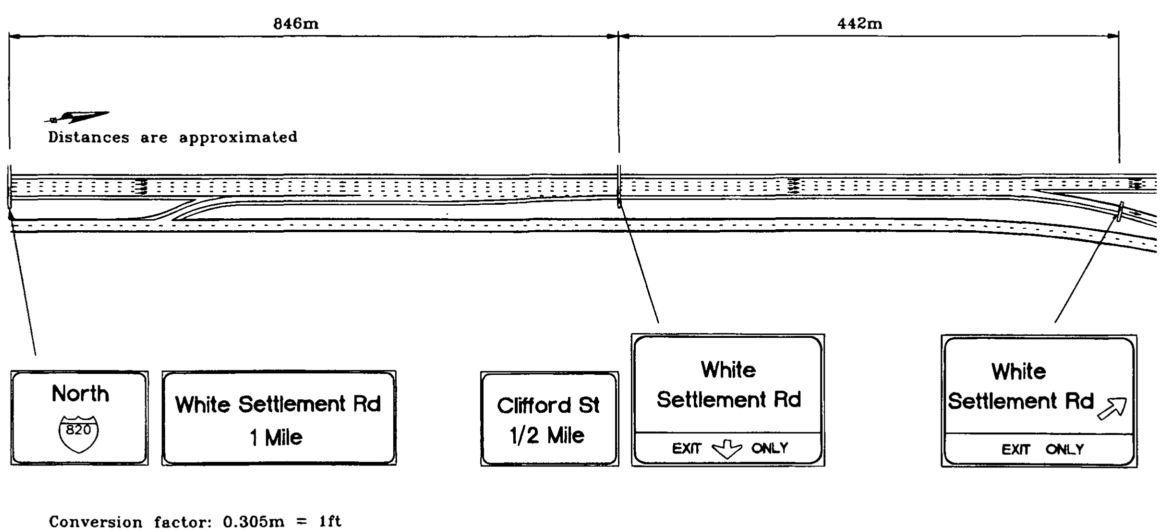
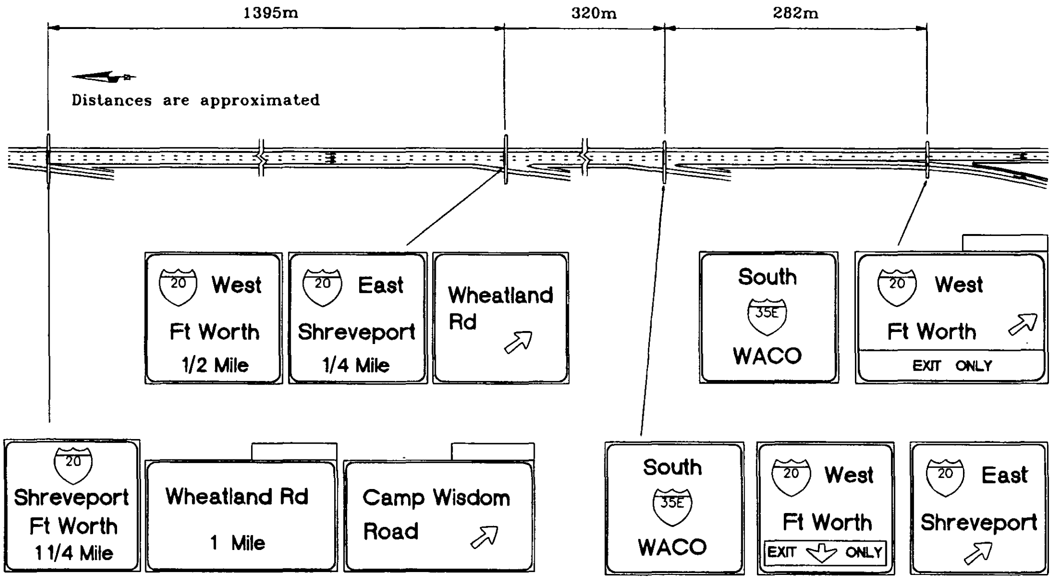


FIGURE 1 Site A before condition.



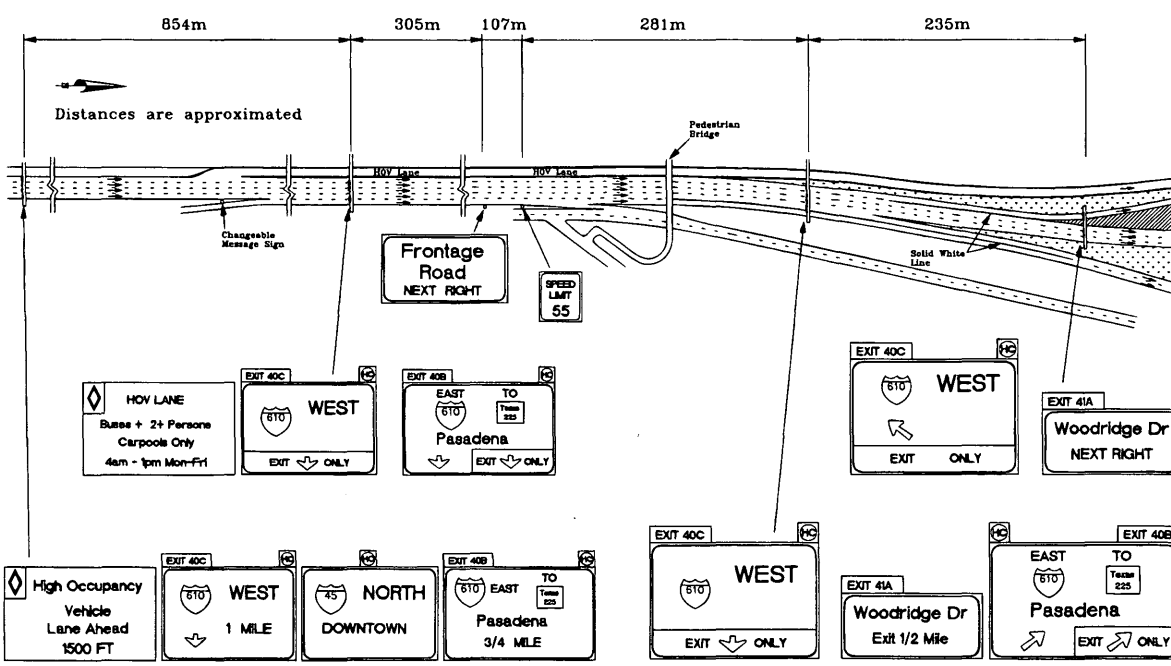
Conversion factor: 0.305m = 1ft

FIGURE 2 Site B before condition.

project is the lane drop markings), should be investigated to determine whether they affect the results. From observations and information from the TxDOT, nonrecurrent congestion or construction did not influence the data. Another item to investigate is whether traffic volumes are similar from the before period to the after period. To compare the before-and-after traffic volumes, an analysis of variance statistical model was used. The test showed that there were no differences in before-and-after traffic volumes for any given site.

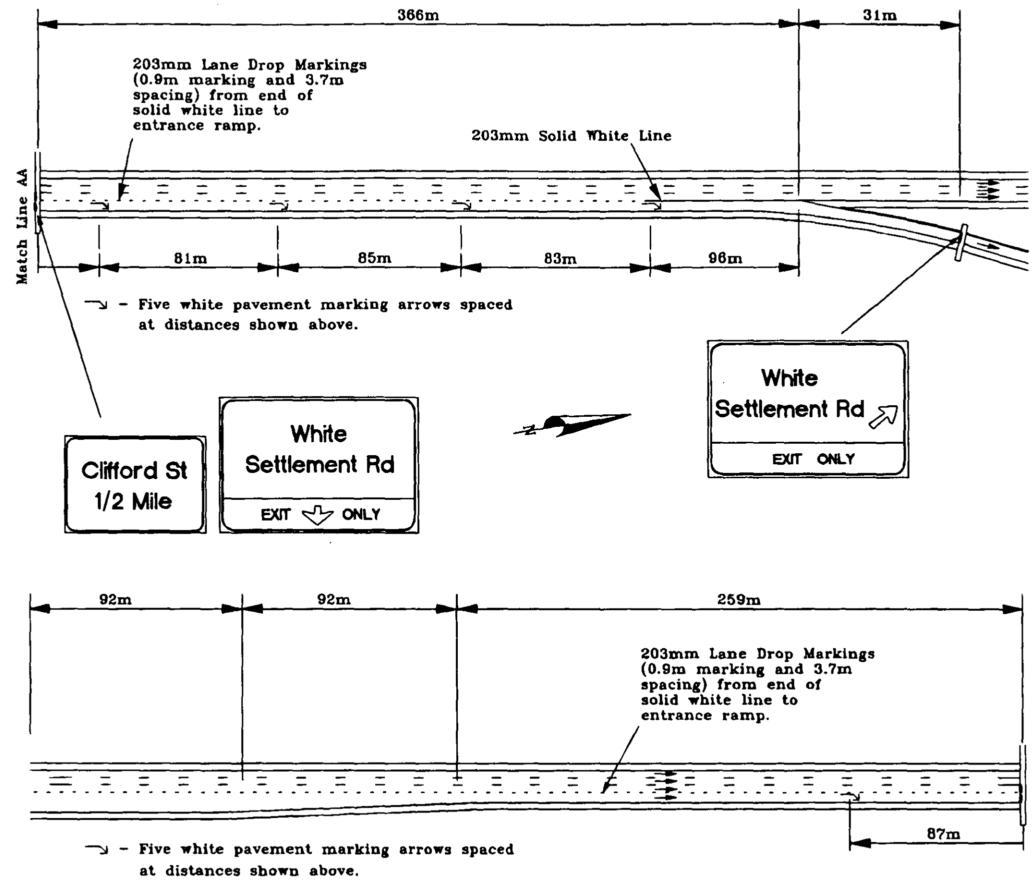
Lane Changes

The next statistical test determined if the values of lane changes per hour (as listed in Table 2) were statistically different from the changes from the before to the after period. A test of equality of proportions (also known as the comparison of two binomial parameters test) determined whether the overall percentage of total lane changes or erratic maneuvers before the treatment was equal to the



Conversion factor: 0.305m = 1ft

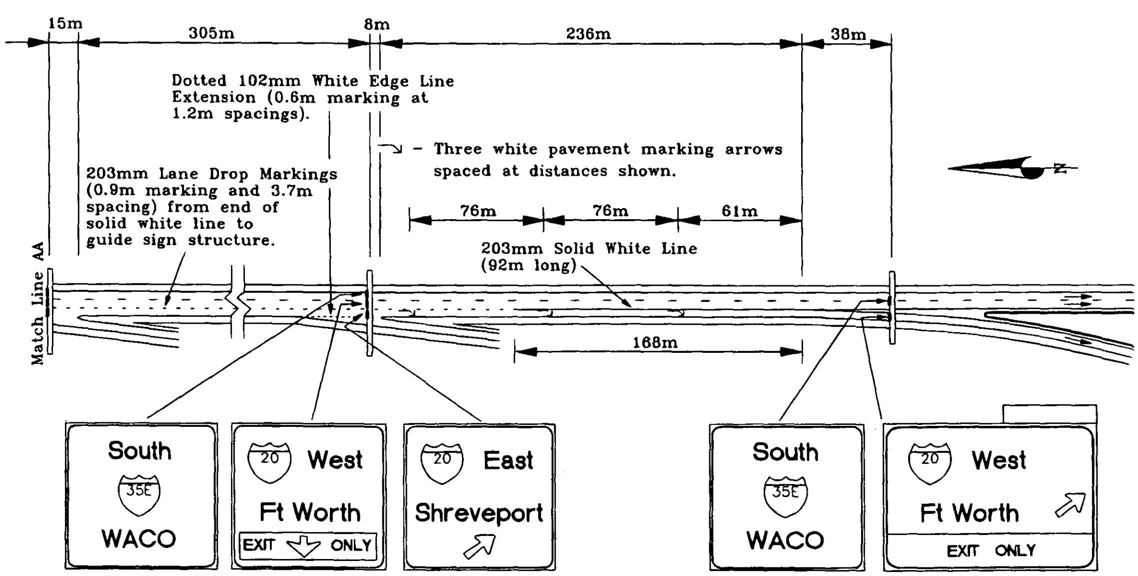
FIGURE 3 Site C before condition.



Distances are approximated

Conversion factor: 0.305m = 1ft and 25.4mm = 1in

FIGURE 4 Pavement markings installed at Site A.



Distances are approximated

Conversion factor: 0.305m = 1ft and 25.4mm = 1in

FIGURE 5 Pavement markings installed at Site B.

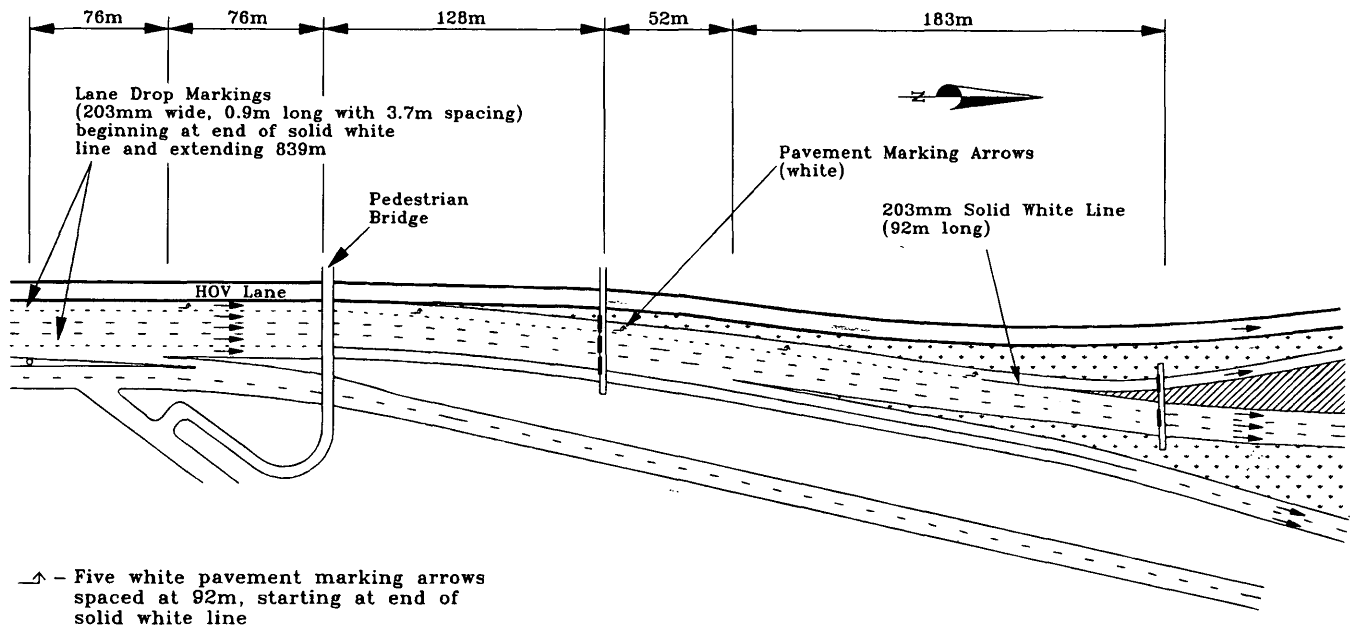


FIGURE 6 Pavement markings installed at Site C.

percentage after treatment. For example, for Site A, the percent of the total lane changes was 58.3 before and 41.6 after. The statistical test compares these numbers to 50 percent. Table 3 shows the results. In each case, the decrease in the number of lane changes at a site was statistically significant.

Erratic Maneuvers

The number of erratic maneuvers at all sites decreased from the before period to the after period for both the entire study length and the 91.5-m (300-ft) segment closest to the gore and over 33 percent for the entire study length. Substantial decreases in the number of one-lane lane changes through the gore and swerves into a lane and backout (attempted lane change) were the prime contributors to the reduction in number of erratic maneuvers at Sites B and C. The largest decrease in the erratic maneuver type at Site A was the two-lane lane change. The statistical test revealed that only the erratic maneuvers at Site A (see Table 3) did not have a statistically significant difference between the before-and-after periods.

Location of Lane Changes

To determine whether a "shift" in lane change locations is occurring, plots of percent of lane changes per zone were used. Percent lane change demonstrates where lane changes are occurring within the study site. If lane changes are uniform and the study site has ten zones, one would expect each zone to experience approximately 10 percent of the lane changes. If in the after period of the hypothetical situation the five zones furthest from the gore now each have 20 percent of the lane changes and the five zones closest to the gore now have no lane changes, a conclusion that the markings created a "shift" in where the lane changes occurred could be made, that is, one would conclude that drivers change lanes further upstream of the gore.

Because of the variations present when the data were distributed in the 30.5-m (100-ft) increments, the data were collapsed into 61-m (200-ft) zones to better illustrate the findings. When these plots were reviewed, a shift in where lane changes occurred was revealed for certain situations. The plot of percent of lane changes per zone for Site A 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 (see Figure 10).

Site B and C plots, however, did show a shift in where vehicles were changing lanes, with the most noticeable shift occurring for vehicles moving out of the exit lane. Figure 11 illustrates the percent lane changes by zone for the vehicles moving from the exit lane into the through lane for Site B. For the eight zones closest to the gore [representing approximately 244 m (800 ft) upstream of the gore], fewer vehicles left the exit lane in the after period than in the before period, whereas for Zones 10 through 17 more vehicles left the exit lane in the after period than in the before period. In summary, Site B drivers are leaving the exit lane further upstream of the gore after the lane drop markings were installed. Site C also showed a similar trend. As indicated in Figure 12, fewer vehicles in the after period than in the before period left the exiting lane in the 183 m (600 ft) closest to the gore.

To statistically validate the suspected shift, the percentage distribution for the before-and-after time periods were tested for equality using the chi-square test for independence. The overall chi-square value for total lane changes at Site A was not significant, indicating that there was no significant variability in the lane change percentage distribution before-and-after treatment for any zones. For Sites B and C, the overall chi square was significant, which indi-

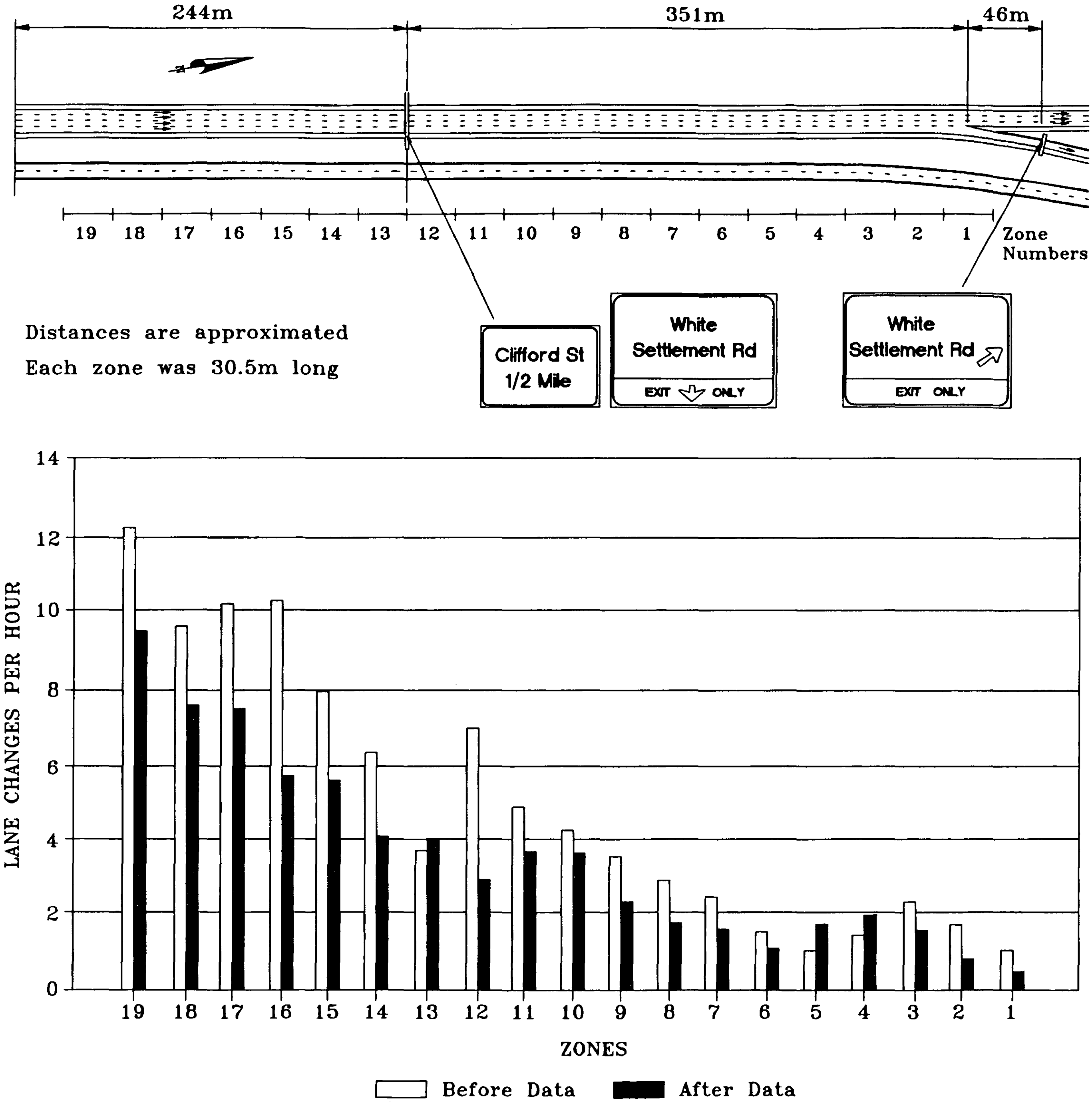


FIGURE 7 Site A layout and lane changes per hour per zone.

cates that there was a difference in at least one zone. All three sites had a statistically significant difference for the exit-to-through maneuver.

To determine the zones that were statistically different, the individual standardized cell chi squares were tested. All tests were completed at the 0.05 level of significance. Figures 11 and 12 illustrate the findings from the statistical test for the exit-to-through lane changes. 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 caused a shift in where lane changes occurred at Sites B and C.

Combining Findings

Another observation on the reduction and shifting of lane changes is appropriate. Although the lane drop markings have caused a shift in where motorists are leaving the exit lane in Sites B and C but not

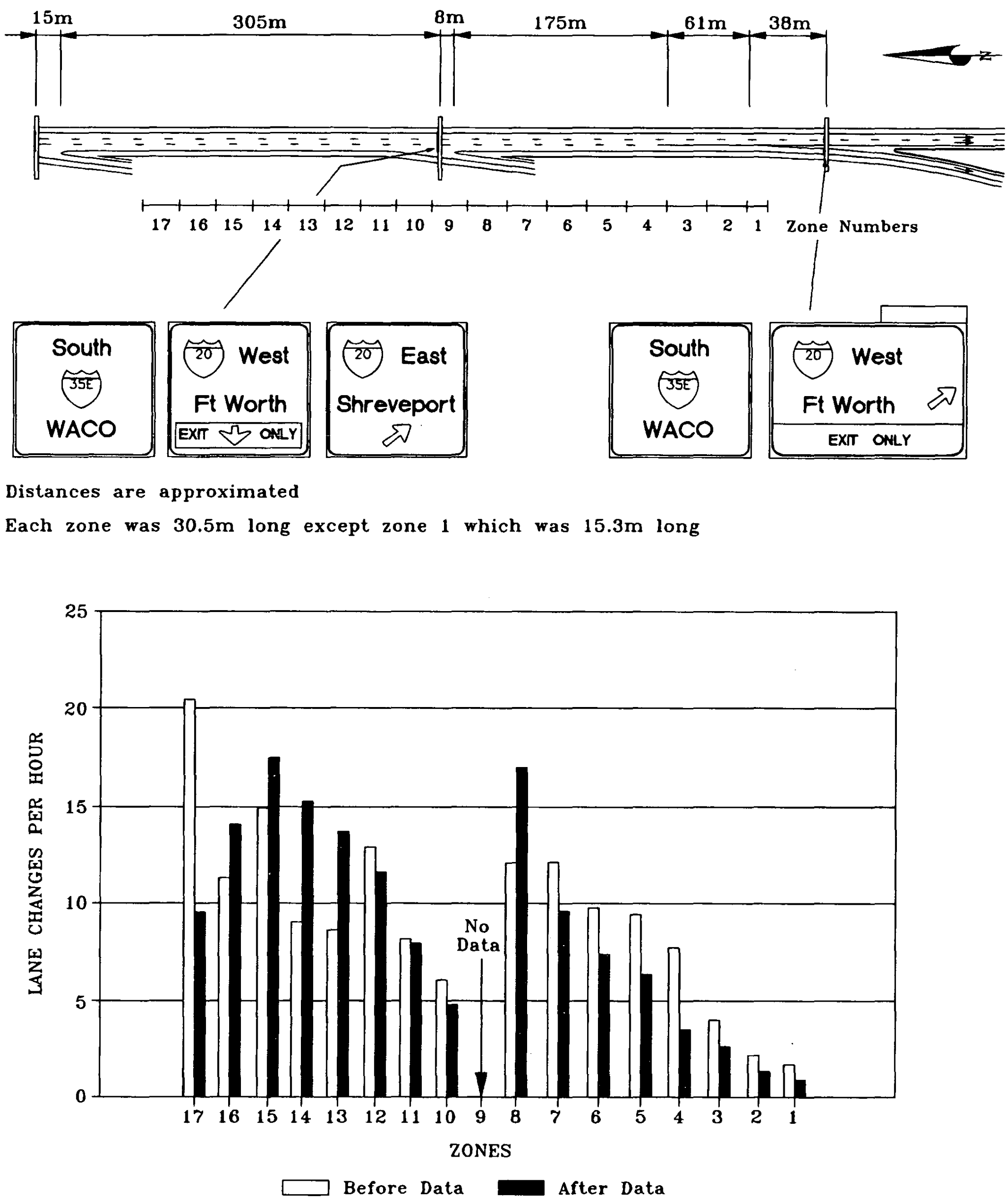


FIGURE 8 Site B layout and lane changes per hour per zone.

in Site A, this finding may be a function of the length of the study segment and the presence of upstream entrance and exit ramps. For example, Site A 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 762 m (2,500 ft) upstream of the gore. The large reduction in lane changes at Site A (29 percent drop) could be a reflection that when vehicles enter the freeway on the entrance ramp and see the lane drop markings, they are moving from the entrance ramp through the exit lane to a through lane before entering the study segment. If so, then a shift in where motorists are changing lanes at Site A could also be occurring. However this region was beyond the study sections and therefore could not be tested.

SUMMARY AND CONCLUSIONS

The field studies demonstrated that the installation of lane drop markings can cause a shift in where motorists make lane changes in advance of a lane drop. The distribution data from Sites B and C (see Figures 11 and 12) revealed that drivers are exiting the lane further upstream of the lane drop in the after period than in the before period. For the area immediately upstream of the gore [e.g., the 183 to 244 m (600 to 800 ft) closest to the gore], fewer vehicles left the exit lane in the after period than in the before period (both interns of percentages and absolute values). For the area upstream of the gore, more vehicles left the exit lane in the after period than in the before period [between 241 and 366 m (700 and 1,200 ft) or 305 to

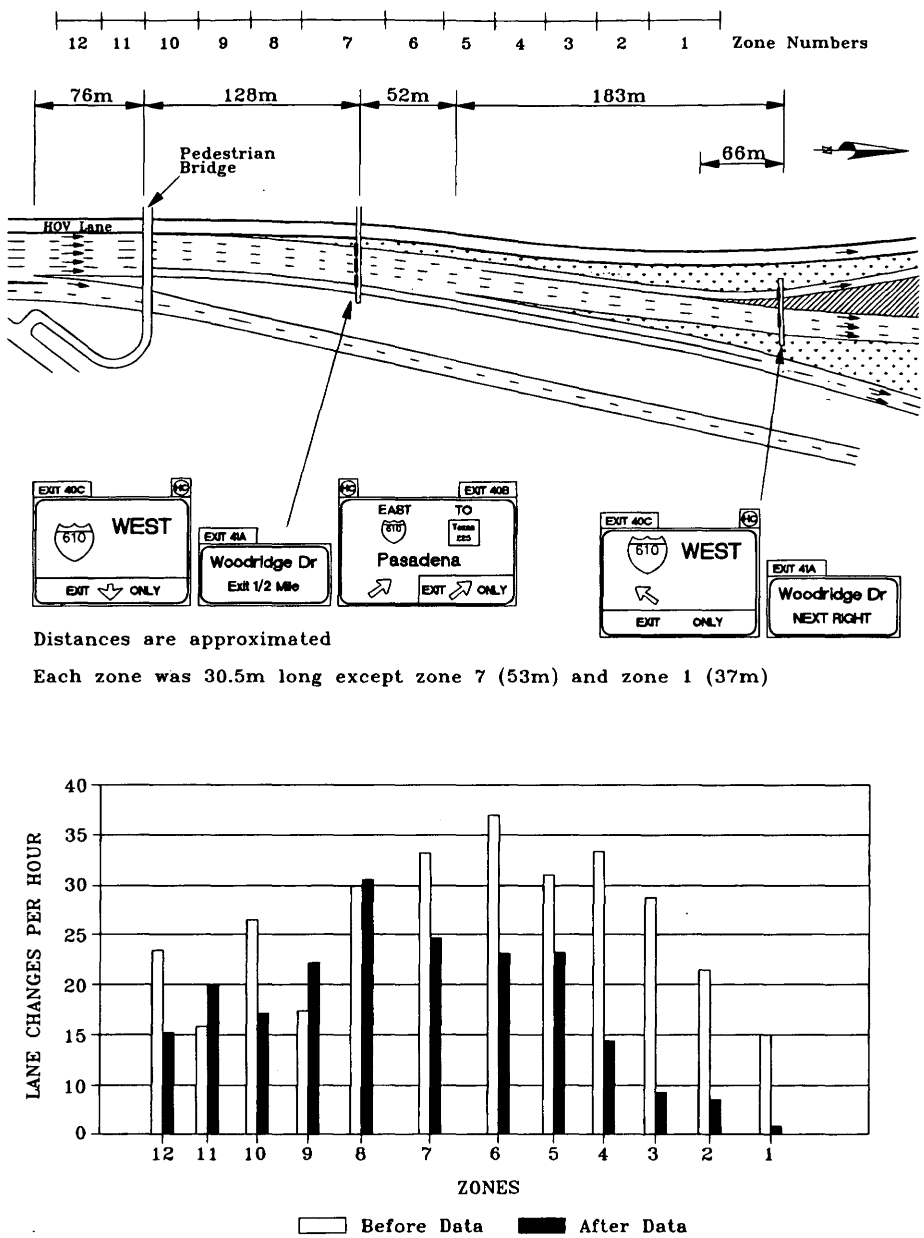


FIGURE 9 Site C layout and lane changes per hour per zone.

519 m (1,000 and 1,700 ft) upstream of the gore, depending on the site].

Similar analysis at the other before-and-after study site (Site A) did not produce the same results. The distribution data (see Figure 10) showed that a shift was not occurring within the study segment [which was approximately 488 m (1,600 ft) long]. Other evidence, such as the statistically significant reduction in the number of lane changes, indicates that a shift may be occurring upstream of the study segment limit. An entrance ramp is located approximately 762 m (2,500 ft) 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 and seeing the lane drop markings are moving from the entrance ramp through the exit lane to a through lane before entering the study segment.

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. Decreases over 50 percent were observed at two of the three sites for the area within 91.5 m (300 ft) of the gore. The largest decrease was in the number of one-lane changes through the gore.

RECOMMENDATIONS

Government agencies should use lane drop markings and arrows at exit lane drops for the following reasons: (a) the field studies demonstrated that the installation of the lane drop markings caused a shift in where motorists are making lane changes in advance of a

TABLE 2 Comparison of Before-and-After Data

Characteristics	Site A			Site B			Site C		
Exit Name	I-820 NB to White Settlement			I-35E SB to I-20 West			I-45 Northbound to I-610 West		
Time used in comparison	7:30 a.m. to 5:45 p.m.			6:45 a.m. to 6:00 p.m.			7:15 a.m. to 6:00 p.m.		
Zones used in comparison	Zones 1 to 19			Zones 1 to 17 (except 9)			Zones 1-12		
Equil. length of study site	580 m			488 m			378 m		
	Before	After	Change	Before	After	Change	Before	After	Change
Freeway hourly volume[a]	1436	1453	1%	1405	1374	-2%	5851	5761	-2%
Hourly volume exiting[a]	280	231	-18%	158	165	4%	1708	1720	1%
Total study length									
Lane Changes[b]	95.2	67.8	-29%	149.6	141.1	-6%	315.0	217.0	-31%
Erratic Maneuvers[b]	5.1	4.2	-18%	12.9	8.6	-33%	47.5	28.4	-40%
For 91.5 m nearest to gore									
Lane Changes[b]	5.4	3.1	-42%	7.8	4.4	-44%	66.0	24.0	-64%
Erratic Maneuvers[b]	0.7	0.5	-29%	5.6	2.0	-64%	25.2	12.6	-50%
Rate[c] (10^{-6}/ft/veh)									
Lane Changes	114.3	80.7	-30%	218.0	210.5	-4%	142.4	99.68	-30%
Erratic Maneuvers	6.2	4.9	-19%	18.7	12.8	-32%	21.5	13.0	-39%

[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: 0.305 m = 1 ft

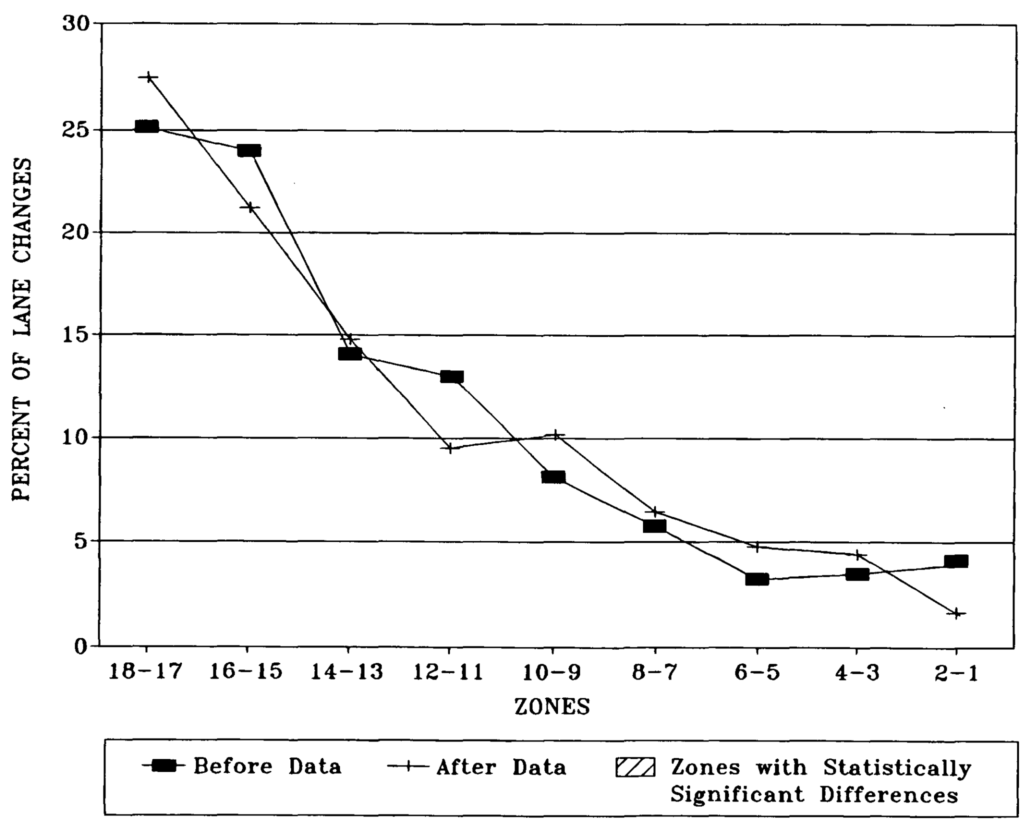


FIGURE 10 Site A exit-to-through lane changes.

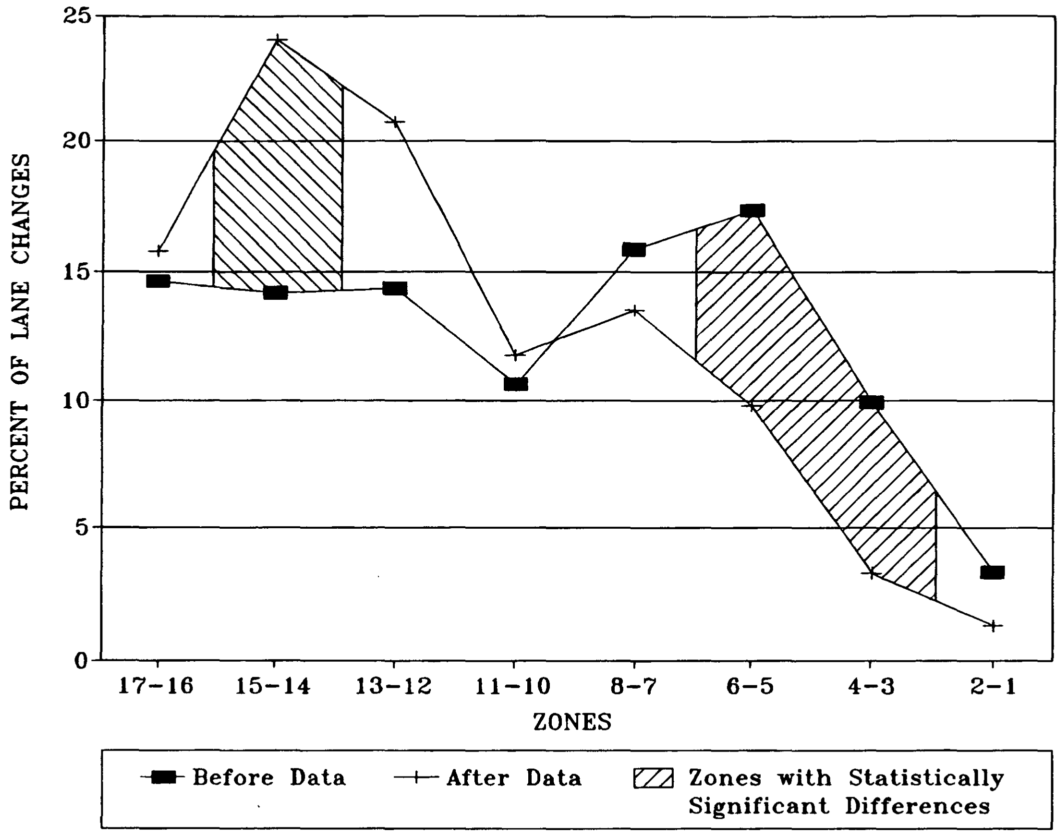


FIGURE 11 Site B exit-to-through lane changes.

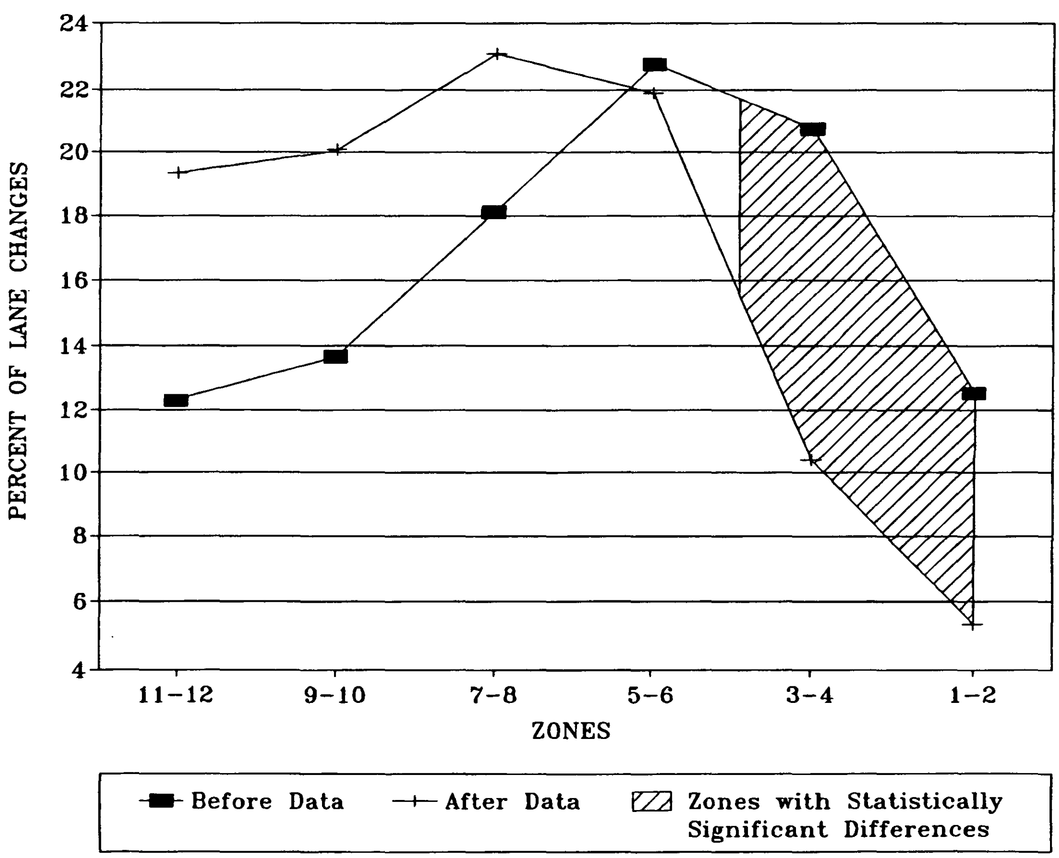


FIGURE 12 Site C exit-to-through lane changes.

TABLE 3 Results of the Equality of Proportions Tests

	Site A		Site B		Site C	
	Before	After	Before	After	Before	After
Number of Lane Changes for Study Segment[a]	976	696	1683	1587	3386	2333
Lane Change Proportion	.58	.42	.51	.49	.59	.41
Z statistic[b] Significant/Not Significant?	9.72 Significant		2.36 Significant		19.70 Significant	
Number of Erratic Maneuvers for Study Segment[a]	52	43	145	97	511	305
Erratic Maneuvers Proportion	.55	.45	.60	.40	.63	.37
Z statistic[b] Significant/Not Significant?	1.34 Not Significant		4.40 Significant		10.17 Significant	
Number of Lane Changes for Gore Area[a]	55	32	88	50	710	258
Lane Change Proportion	.64	.36	.64	.36	.73	.27
Z statistic[b] Significant/Not Significant?	3.57 Significant		4.62 Significant		20.53 Significant	
Number of Erratic Maneuvers for Gore Area[a]	7	5	63	23	271	135
Erratic Maneuvers Proportion	.58	.42	.74	.26	.67	.33
Z statistic[b] Significant/Not Significant?	0.83 Not Significant		6.19 Significant		9.50 Significant	

[a] for an average day of observations
[b] If the calculated Z statistic is greater than 1.645, then one can conclude that the difference is significant.

lane drop and (b) erratic maneuvers decreased. The consistent use of the marking treatments can provide other benefits, such as consistency in communicating lane drops to motorists and improved driver expectancy at exit lane drops.

This research studied the effects of the markings on one-lane drop exits. Additional research is needed to determine the effects of lane drop markings on motorist behavior at two-lane exits with an option lane and an exit-only lane.

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