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Accident Migration Associated with Lane-Addition Projects on Urban Freeways

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1. INTRODUCTION

Increased urban freeway capacity has been provided in many instances by the addition of a lane through reductions in shoulder width and/or restripings to reduce lane width. The need to evaluate the safety impacts of such projects has been recognized, and safety studies have been conducted on individual projects (e.g., Dunnet, 1977; Dunnet and Chow, 1977; and Endo and Anderson, 1976) and as overviews of several projects (e.g., Newman, 1985; Urbanik and Bonilla, 1987). In general, these studies have concluded that the projects have resulted in a decrease in accident rates along the affected roadway.

The vast majority of the safety studies concerning added freeway lanes are based on pre-project versus post-project comparisons of accident rates for the project area only. There are two potential problems with such an approach: First, accurate traffic volume data are required for both the pre-project and post-project periods in order to provide exposure measures in the calculation of accident rates. Experience has shown that the accuracy of traffic volume data is often suspect, particularly in the period prior to reconstruction of a roadway section; repairs to induction-loop counting devices are often delayed to coincide with the construction involving the lane addition. Consequently, in many cases traffic counts in the pre-project period, and sometimes counts in both the pre- and post-project periods, are based on projections from actual counts taken years before. Because added capacity can induce latent demand for travel on the affected section of freeway, the pre-project and post-project periods can be substantially different than predicted by ordinary projection methods. Inaccuracies in the denominators of aggregate accident rate statistics can lead to false

conclusions regarding project safety. Comparisons with "control" sections of roadway can be used in the absence of good exposure data.

The second problem with aggregate comparisons of accident rates in the project section for pre-project versus post-project periods is that the additional capacity might affect accident risks in adjacent sections of roadway. If this occurs, it is potentially misleading to define the roadway only within the project area as the spatial unit of analysis in the accident rate comparisons. This precludes the ability to analyze possible spatial redistributions of accident locations due to the changes in the characteristics of traffic congestion from the pre-project to post-project periods. Moreover, the selection of the specific area of roadway for project location might be related to its accident history. The treated section of roadway might be a "blackspot" for a number of reasons, but the random nature of accident occurrence is a component in the historical process. It has been shown that a form of selectivity bias called "regression to the mean" (Hauer, 1980a, 1980b) can lead to overestimation of the reductions in accident rates resulting from safety-improvement projects. Such bias can also lead to overestimation of accident migration from treated (project) to non-treated (adjacent) roadway sections (Stein, 1984; McGuigan, 1985).

Particularly with regard to added freeway lanes, there might be a migration of accidents from the project area and from upstream of the project area to bottlenecks downstream of the project area, due to the partial relief of congestion in one area and increased traffic flow to another area of congestion. Similarly, there might be a relief of congestion in areas upstream of the project area. Previous studies have recognized the need for "influence" areas (e.g., Urbanik and Bonilla, 1987), but it is difficult to assess the nature of any accident "migration" in terms of aggregate accident

rate statistics. The present study attempts to characterize influences through a disaggregate spatial analysis of accident locations.

2. TWO CASE STUDIES

Two case studies were undertaken to assess the safety effects of restriping and reconstruction projects that have added a non-standard mixed-flow lane to a freeway by elimination of an interior shoulder. These case studies, drawn from freeways in the Los Angeles and Orange County areas in Southern California, are not intended as comprehensive evaluations of the projects, but rather as tests of accident migrations associated with safety evaluations of freeway expansion projects.

The two restriping projects were selected for study on the basis of two criteria to minimize potential regression-to-the-mean effects: (1) the project must have been implemented in the period 1982 through late 1984 to allow at least two years of accident data in both the before and after situations, not including the construction period; (2) the additional lanes should be of sufficient length to have a measurable effect. Furthermore, (3) there should be no confounding effects due to the other projects in the same spatial and temporal sphere.

The two lane-addition projects selected were located on I-405 northbound and southbound between SR-90 and I-10 in Los Angeles County (implemented in July 1984) and I-405 northbound in Orange County between Brookhurst and Harbor Boulevards (implemented in May 1983). As is often the case, for both the Los Angeles County I-405 and the Orange County I-405 sections there were no reliable traffic volume estimates that could be used to compute the accident rate statistics before and after implementation of the additional lanes. Data

from the California Department of Transportation (Caltrans) Volume books indicate that the annual average daily traffic (AADT) on both the sections of I-405 has remained fairly constant since 1980. If this is actually the case, then standardization of the accident data is unnecessary. However, it was not possible to verify that the AADT had in fact remained constant from 1979 to 1986 for the areas under study because only partial traffic count data are available from the Caltrans control stations for the time periods of interest.

Because of the above limitations it is not possible to simply compare the difference in the pre- and post-restriping accident rates in the project area. To determine whether the restriping had an effect on the accident rate it is necessary to employ a control section of the freeway. The purpose of the control section is to provide an estimate of the change in the number of accidents that would be expected if the restriping had not occurred. The longer the control section of the freeway, the more stable the estimate.

In addition to control sections, the areas upstream and downstream of each restriping project were included to investigate the possibility that, while the operation in the project area remained unchanged or was improved, there could be a simultaneous amelioration or degeneration of the operational safety in the adjacent areas. Thus, this portion of the investigation focuses on the changes in the operational safety in two study areas that include the actual restriped roadway for each project, and the associated downstream and upstream areas of roadway.

2.1 Case Study 1: I-405 in Los Angeles County

The study areas for the northbound and southbound I-405 are from postmile 20 (south of El Segundo Boulevard) to postmile 36 (one mile south of Mulholland Drive). Shown in Figures 1 and 2 are the average number of

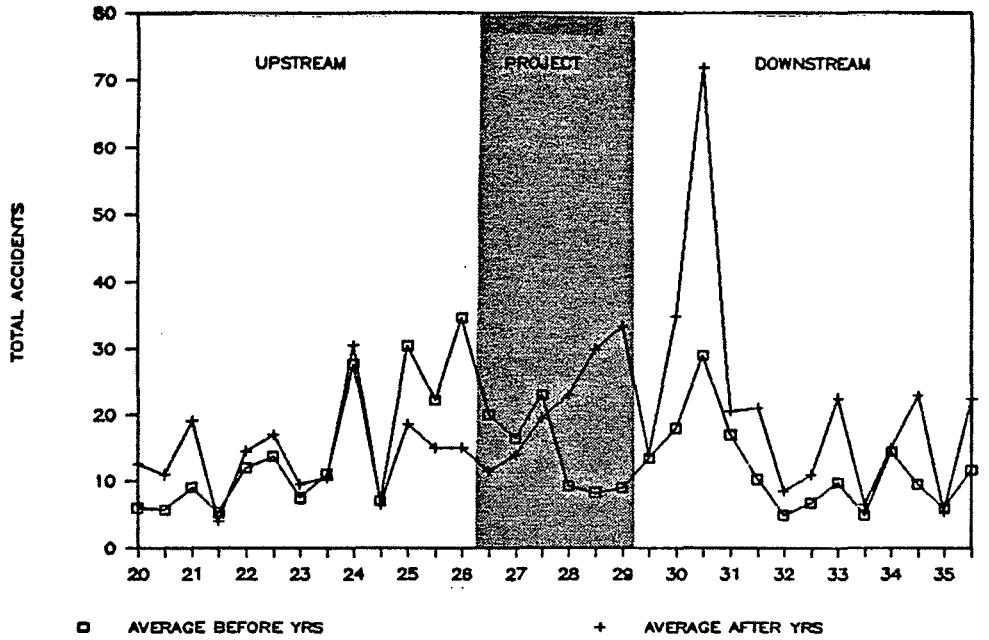

FIGURE 1

TOTAL ACCIDENTS BY .5 POSTMILE (NORTHBOUND I-405, L.A.)

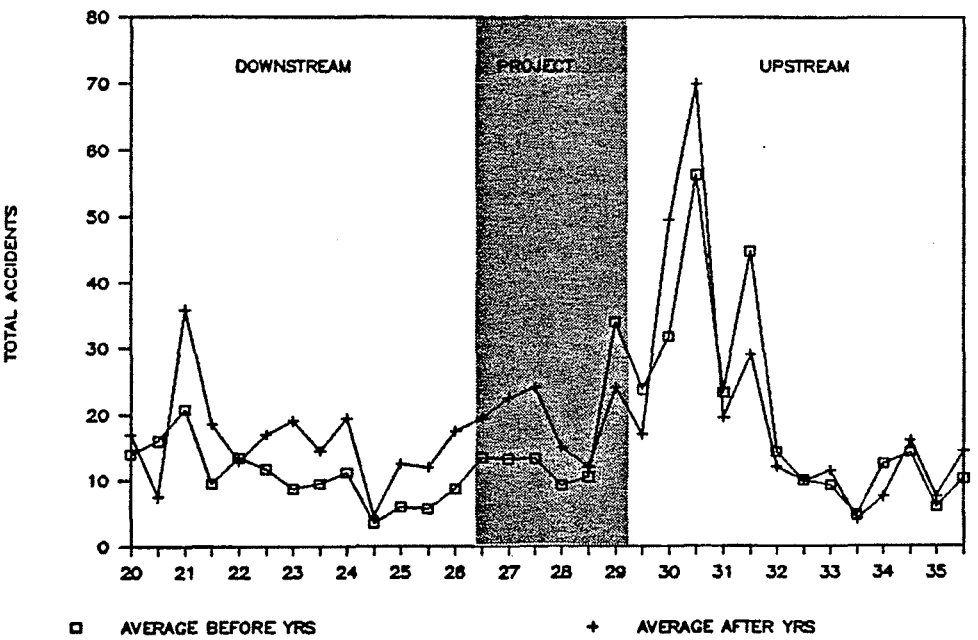

FIGURE 2

TOTAL ACCIDENTS BY .5 POSTMILE (SOUTHBOUND I-405, L.A.)

accidents in the four years preceding the restriping and the average number of accidents in the two years following the restriping. (The year encompassing the construction period is excluded from all analyses, although inclusion of this period does not change the results.) The project area is shaded in both figures. In Figure 1 (northbound) the downstream area is to the right of the project area (i.e., higher postmiles), while in Figure 2 (southbound) the downstream area is to the left of the shaded area.

The figures reveal that there is a tendency for fewer accidents to occur upstream and in the beginning portion of the project area in the years following the restriping. Conversely, there is an increase in the observed accidents in the latter portion of the project area and the downstream area. These trends are demonstrated more clearly in Figures 3, 4, and 5 which show the cumulative frequency distribution of accidents by postmile. (Note that the postmiles are reversed on Figure 4 so that the accidents could be accumulated in the direction of flow).

The pre- and post-restriping frequency distributions are very similar for the upstream and project areas. There is, however, a marked increase in the downstream area. For the total study area, there is an average yearly pre-post increase of approximately 260 accidents. There are two questions to consider in evaluating this observed difference. First, is the increase attributable to the restriping project or to a general trend of increases in the number of accidents over time (due, perhaps, to increased traffic). Second, did the restriping project cause the movement (or, migration) of accidents from the project area to a downstream section of the freeway? The issue is to ascertain whether the observed changes can be attributed to the restriping or to other factors.

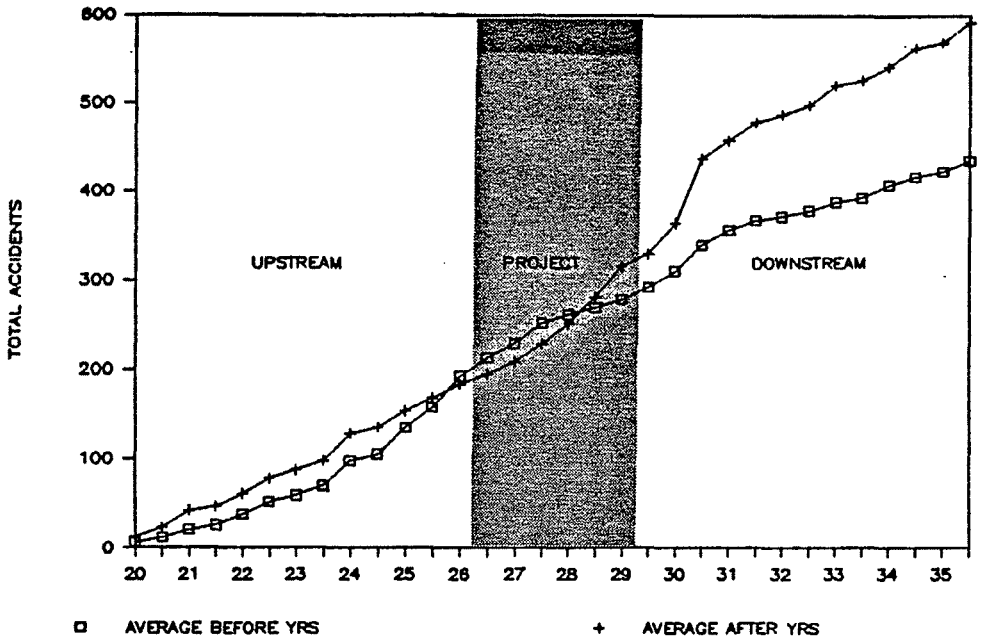

FIGURE 3

CUMULATIVE DISTRIBUTION OF ACCIDENTS (NORTHBOUND I-405, L.A.)

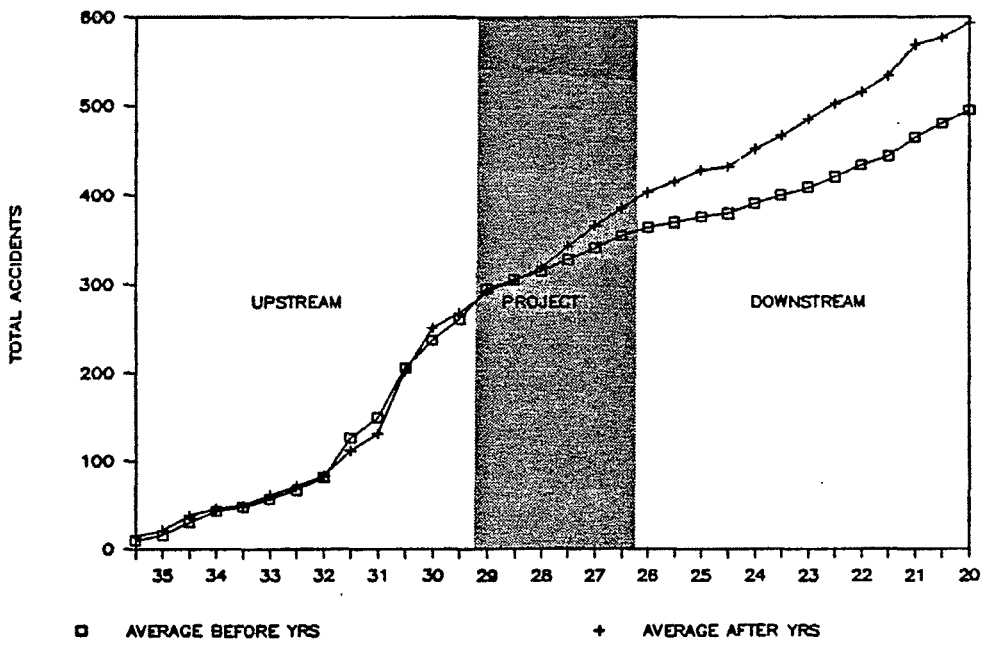

FIGURE 4

CUMULATIVE DISTRIBUTION OF ACCIDENTS (SOUTHBOUND I-405, L.A.)

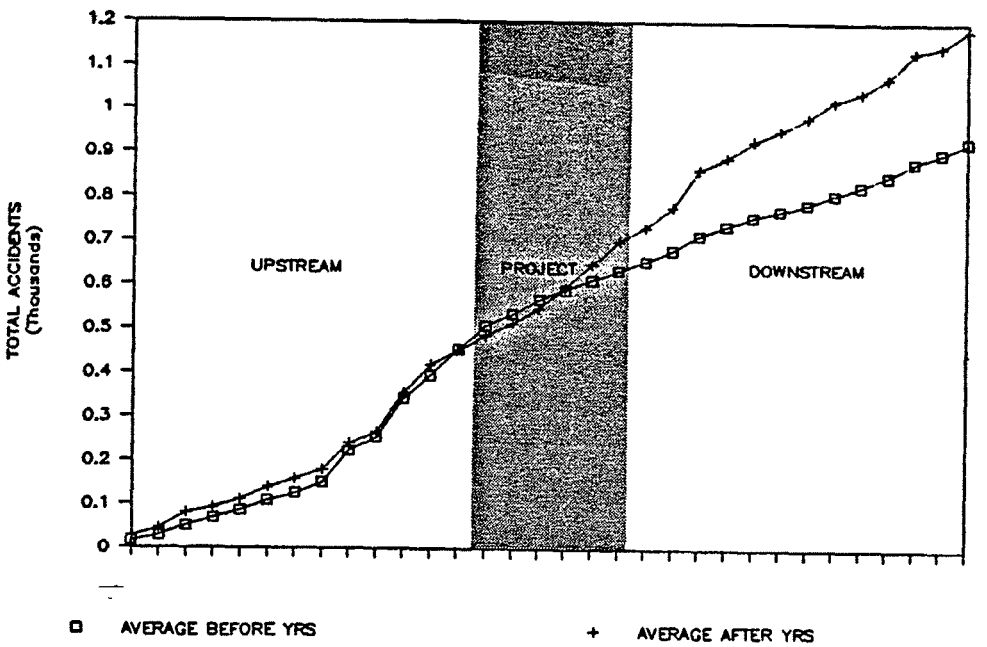

FIGURE 5

CUMULATIVE DISTRIBUTION OF ACCIDENTS (TOTAL NB+SB, I-405, L.A.)

In order to answer these questions, the study area was compared with a control area. For this case study, the control area was designated as the complete length of the Los Angeles County I-405 in both directions, with the exception of the study area. Thus, the accidents in the study area before and after the restriping were compared to the accidents in the rest of the freeway for the same two time periods. Separate comparisons were made for the northbound, southbound and the total of both directions. As these analyses yielded similar results only the totals are reported.

Four comparisons were made in order to answer the above two questions. The first comparison addressed the question of whether the increase in the average yearly number of accidents in the study area is different than that which would be expected had the area not been restriped. This was tested by comparing two ratios: (a) the total number of accidents in the study area after the restriping to the total number of accidents in the study area before and after restriping (2,371/6,084 = 0.390); (b) the number of accidents in the control area in the time period since the restriping to the total number of accidents in the control section before and after restriping (0.393). The difference between these proportions was not statistically significant at the 95 percent confidence level. This indicates that the overall increase observed in the study area was not greater than that which would be expected had the restriping not occurred.

Although the observed increase in the number of accidents in the study area is not greater than observed on the rest of the freeway, Figures 1 through 5 indicate that the spatial distribution of these accidents has changed such that the accidents have migrated downstream of the project area. This possibility was addressed in the remaining comparisons. Each of these comparisons corresponded to one section of the study area. Each comparison was conducted in the same way as the analysis for the overall study area above. That is, two ratios are compared, one representing a section of the study area and the other representing the control section. For example, the upstream study area proportion is 903/2,571 = .351, while the control area proportion is .393 as above. Table 1 presents the number of accidents for each of these areas.

TABLE 1

TOTAL NUMBER OF ACCIDENTS IN STUDY AREA AND CONTROL AREA, L.A. I-405

	STUDY AREA SECTIONS				
	Upstream	Project	Downstream	Total Study Area	Control Area
Before (4 Years)	1,814	719	1,180	3,713	4,541
After (2 Years)	903	497	971	2,371	2,944

Upstream Area. This comparison was aimed at evaluating the effect of the new lane on the upstream area. The proportion of upstream accidents after restriping (0.332) was compared with the control ratio (.393). The result of this comparison was significant at the 95 percent confidence level ($\chi^2 = 31.55$, $df = 1$). This analysis indicates that the decrease in the number of upstream accidents is not attributable to chance. The change in operational safety of the study area relative to the control area can be expressed by comparing the proportion of "after" to "before" accidents in the upstream area to the proportion of "after" to "before" accidents in the control area. That is,

$$\omega = \left(\frac{\text{accidents in upstream after}}{\text{accidents in upstream before}} \right) \Big/ \left(\frac{\text{accidents in control after}}{\text{accidents in control before}} \right)$$

This ratio is called the relative odds ratio (Bishop, Fienberg, and Holland, 1975). If the restriping has improved safety, that is, if the conditional odds of having an accident in the study area after restriping are less than the conditional odds of having an accident in the control area after restriping, then $\omega < 1$. If there has been no change in relative safety, $\omega = 1$; and if safety has deteriorated in the project area, $\omega > 1$. In this case, $\omega = .77$, indicating a relative decrease in accidents in the upstream area.

Project Area. This comparison investigated the effect of the restriping on the project area. That is, the project proportion (0.409) was compared to the control ratio. The difference between these proportions was not statistically significant at the 95 percent confidence level, indicating that the observed differences in the study area were not greater than that which would be expected had the restriping not occurred.

Downstream Area. The final comparison examined the possible downstream migration of accidents. As above, the control ratio was compared to the proportion of downstream accidents (0.451). This analysis yielded a result that is not attributable to chance. The comparison was significant at the 95 percent confidence level ($\chi^2 = 23.38$, $\underline{df} = 1$). The odds ratio, $\omega = 1.27$, indicates that the odds of an accident in the downstream area after restriping are 1.27 times the odds of an accident in the control area. This indicates a relative increase in accidents in the downstream area. This result, taken with the other analyses above, reveals that although the number of accidents in the study area was not elevated relative to the control area, the restriping shifted accidents to the downstream area. The apparent cause of

this shift is a relocation of areas of traffic congestion (i.e., the bottleneck has been shifted downstream).

Examining Accident Type Within The Study Area

The analyses were further extended by disaggregating total accidents into five categories of accident types (Andreassen, 1987). As shown in Table 2, these categories were: rear-end collisions, sideswipe collisions, accidents involving injury, accidents in which an object other than another vehicle was hit, and "other" types of accidents including broadsides and overturns. Table 2 presents the chi-square statistics for the results of the pre- and post-project comparisons of the study area sections with the control area. Table 3 presents the odds ratio for those comparisons in which the chi-square statistic was significant at the 95 percent confidence level (Fleiss, 1981). The restriping significantly reduced rear-end accidents in the upstream area. The odds of a rear-end accident in the upstream area after restriping are .64 times of the odds of a rear-end accident in the control area. Injury accidents showed a similar trend, with the upstream area becoming safer after restriping. However, the number of sideswipes in the upstream area were not reduced by the restriping. Instead, this type of accident increased in the project area after restriping. It is possible that this increase is a result of merging that occurs near the end of the project area.

The increase in accidents in the downstream area after restriping is mainly attributable to rear-end collisions; these are presumably related to congestion. Accidents involving injuries also increased in the downstream area after restriping. Examining Table 2 reveals that the "other" accidents were not affected by the restriping. This is not surprising considering that

TABLE 2

CHI-SQUARE STATISTICS
FOR THE COMPARISON OF THE CONTROL AREA
WITH THE STUDY AREA SECTIONS
BY COLLISION TYPE, L.A. I-405

Collision Type	Total Study Area	STUDY AREA SECTIONS		
		Upstream	Project	Downstream
Rear-End	4.48 *	54.06 *	2.06	23.13 *
Sideswipe	0.07	2.64	5.77 *	0.29
Injury	0.04	7.61 *	0.72	8.75 *
Hit Object	6.35 *	4.84 *	6.58 *	0.81
Other	0.55	0.02	0.09	1.20

* $p < .05$

these accidents (e.g., broadsides or overturns) are probably unrelated to congestion and to measures designed to alleviate congestion. It is not clear, however, why hit-object accidents should increase in the upstream and project areas and not in the downstream area. Overall, the results suggest that the shift in accidents is related to a downstream relocation of areas of traffic congestion.

TABLE 3

ODDS RATIOS FOR THE SIGNIFICANT COMPARISONS
OF THE CONTROL AREA
WITH THE STUDY AREA SECTIONS
BY COLLISION TYPE

Collision Type	Total Study Area	STUDY AREA SECTIONS		
		Upstream	Project	Downstream
Rear-End	0.89	0.64	---	1.37
Sideswipe	---	---	1.40	---
Injury	---	0.82	---	1.25
Hit Object	1.28	1.32	1.60	---

2.2 I-405 in Orange County

Unlike the case of I-405 in Los Angeles County, the northbound and southbound sides of the restriped area on I-405 in Orange County were not opened at the same time. The northbound side was opened almost three years earlier than the southbound side. Because there are insufficient data available in the period following the opening of the southbound side, the effect of the project on this section was not investigated. The differential opening dates did, however, allow the southbound side to serve as the control section for the northbound project. Thus, the study area was located only on the northbound side, while the control area was on the southbound side.

Figures 6 and 7 show the average number of accidents by half-mile section in the three years preceding the restriping, and the average number of accidents in the two years following the opening of the northbound lane, for both the study and the control areas. As with the previous case study, none of the analyses included the year encompassing the construction period. Also, data for the period following the opening of the added lane in the southbound direction were not included because the southbound section was employed as the control. Again, as with the previous case study, none of these omissions changed the results.

An examination of Figure 6 reveals that following the opening of the lane there are, on the average, fewer accidents near the end of the upstream and the beginning of the project area. There is also a general increase of accidents in the beginning portion of the upstream area. The effect on the downstream area noted in the Los Angeles County I-405 case study is not readily apparent in this case. These trends are also illustrated in the cumulative distribution of accidents in Figures 8 and 9.

In order to investigate whether the restriping affected the operational safety of the study area (consisting of the upstream, project, and downstream areas), analyses of the type conducted for the first case study are repeated here. That is, (a) the proportion of accidents in the study area after opening to the total study area accidents (513/1,261 = .407) is compared to (b) the proportion of accidents in the control area after the restriping to the total number of accidents in the control area (663/1,632 = .406). This control proportion is also compared to the proportion for the upstream, downstream, and project subsections of the study area. Table 4 presents the totals for these areas.

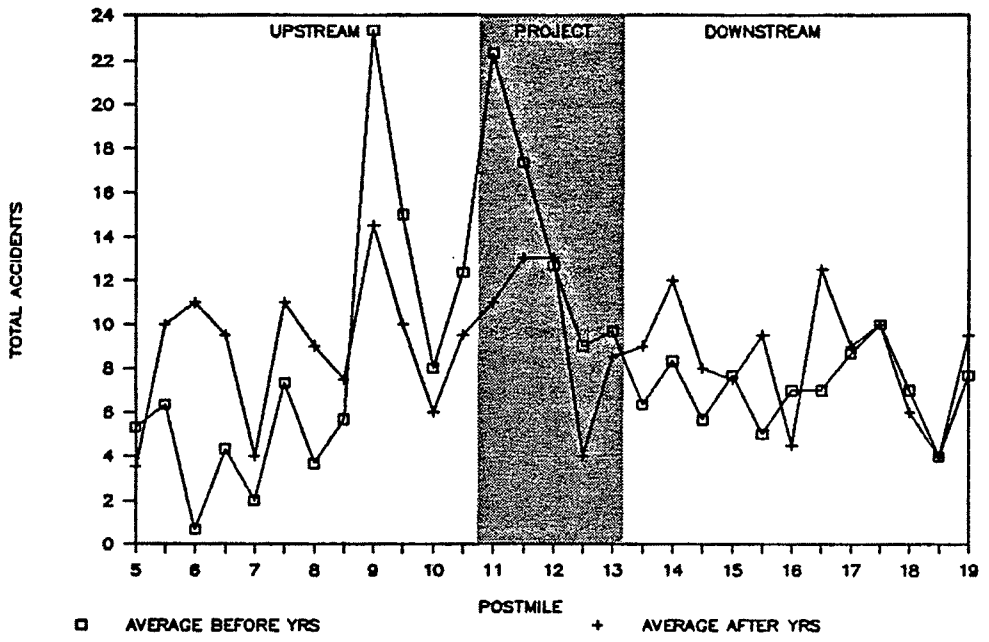

FIGURE 6

TOTAL ACCIDENTS BY .5 POSTMILE (NORTHBOUND I-405, O.C.)

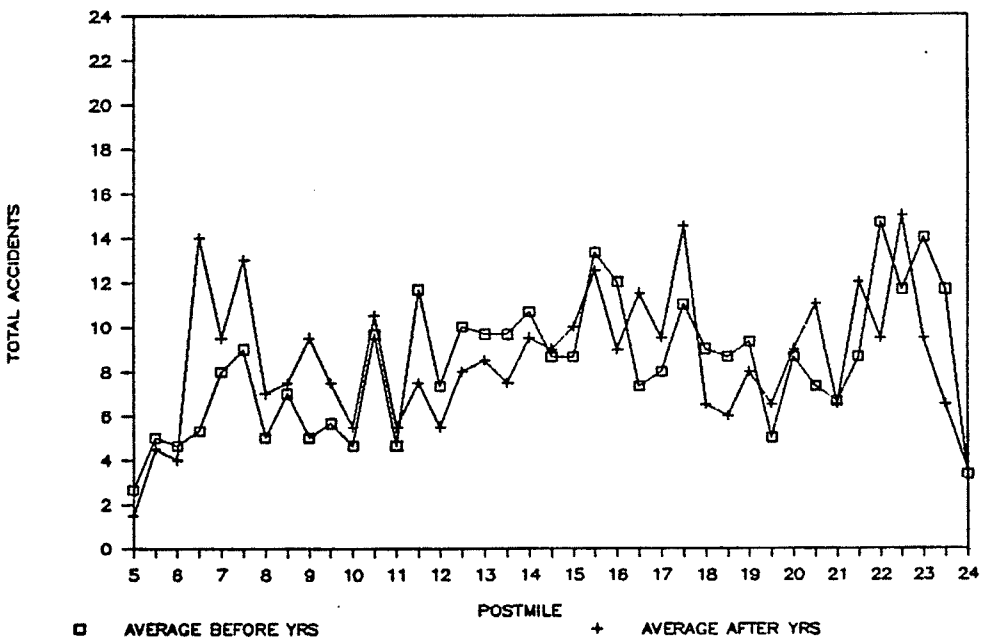

FIGURE 7

TOTAL ACCIDENTS BY .5 POSTMILE (SOUTHBOUND I-405, O.C.)

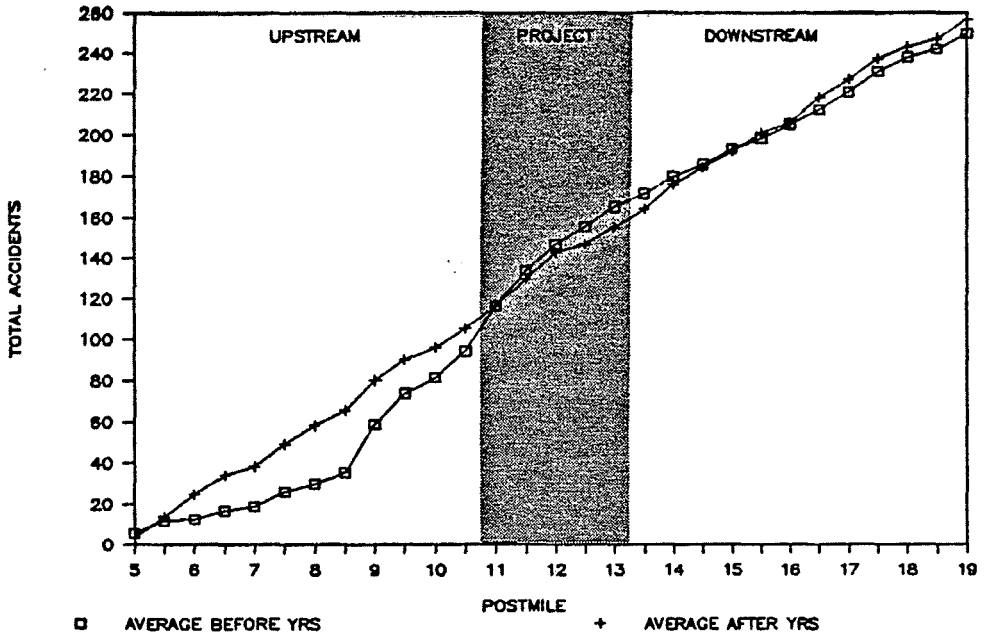

FIGURE 8

CUMULATIVE DISTRIBUTION OF ACCIDENTS IN STUDY AREA (NORTHBOUND I-405, O.C.)

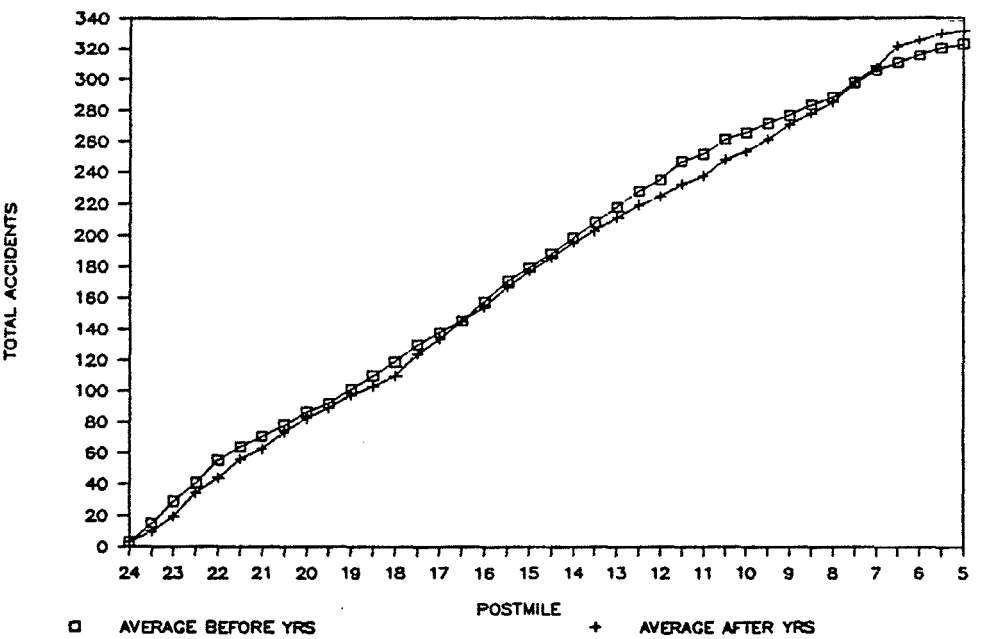

FIGURE 9

CUMULATIVE DISTRIBUTION OF ACCIDENTS IN CONTROL AREA (SOUTHBOUND I-405, O.C.)

TABLE 4

TOTAL NUMBER OF ACCIDENTS IN STUDY AREA AND CONTROL AREA
O.C., I-405

	STUDY AREA SECTIONS				
	Upstream	Project	Downstream	Total Study Area	Control Area
Before (3 Years)	282	213	253	748	969
After (2 Years)	211	99	203	513	663

The first comparison addresses the question of whether the restriping had an effect on the overall study area. The control proportion was therefore compared to the proportion for the study area (0.407). The difference between these proportions was not statistically significant at the 95 percent confidence level. This indicates that any differences observed in the study area are attributable to chance and not to the restriping.

The second comparison investigated the effect of the restriping on the upstream area. The proportion for the upstream area accidents after restriping (0.428) was not significantly different than the control proportion. Thus, although there has been a general increase in the level of accidents in the upstream area since the introduction of the new lane, this increase is not attributable to the restriping.

The third comparison evaluated the effect of the restriping on the project area. The proportion for the project area (0.317) was significantly different than the control proportion at a 95 percent level of confidence

(χ^2 = 8.69, df = 1). This analysis indicates that the odds of an accident occurring in the project area after restriping are .68 times the odds of an accident in the control area. This indicates that the restriping has increased the relative safety of the project area.

The final comparison examined the effect on the downstream area. The proportion for the downstream area (0.445) was not significantly different than the control proportion. This result indicates that, unlike the Los Angeles County Section of the I-405 case study, there has not been a migration of accidents into the downstream area. It should be noted that if the downstream area studied is only extended to postmile 17, rather than to postmile 19.5, a significant increase in downstream accidents is obtained (χ^2 = 4.07, df = 1). This implies that there may be a slight effect of the project on the downstream area but this effect is not of the magnitude observed on the Los Angeles County section of the I-405.

As with the Los Angeles County section of the I-405 analyses, the total accidents were disaggregated into the same five categories of accident types. The results of this analysis are presented in Table 5. There is an almost complete lack of effects other than the reduction in rear-end collisions after restriping. The odds of a rear-end accident in the project area after restriping are .54 times of the odds of a rear-end accident in the control area. This indicates that the relative safety in regards to rear-end accidents after restriping has dramatically improved. The only other significant result is the increase in observed "hit object" accidents in the downstream area. Although it might be tempting to attribute this effect to downstream congestion, this interpretation would be tenuous given the results of the Los Angeles County section of the I-405 restriping. It is best, then,

TABLE 5

CHI-SQUARE STATISTICS
FOR THE COMPARISON OF THE CONTROL AREA
WITH THE STUDY AREA SECTIONS
BY COLLISION TYPE, O.C., I-405

Collision Type	Total Study Area	STUDY AREA SECTION		
		Upstream	Project	Downstream
Rear-End	1.43	0.63	11.21*	1.51
Sideswipe	0.18	0.45	0.33	1.15
Injury	0.17	0.77	1.88	2.75
Hit Object	3.76	3.37	0.15	5.36*
Other	0.01	0.01	0.20	0.00

* $p < .05$

to leave the hit-object results unexplained and focus on the other very interpretable results. In this case, the problem area was targeted very well; restriping apparently reduced the large number of accidents occurring at postmiles 9 and 11 (see Figure 6) without also creating a downstream bottleneck.

2.3 Summary of Results

Case studies were undertaken to assess the safety effects of restriping and reconstruction projects that have added a non-standard mixed-flow lane to a freeway in Los Angeles or Orange County by elimination of an interior shoulder. The most pronounced safety effect of the introduction of the additional lanes studied was the shift or migration of accidents from one location (postmile range) to another. Congestion relief in the range of the added lanes (with the exception of the downstream end of the lanes) and in an area upstream of the lanes led to a reduction in accident rates in those areas. Whether or not there was a significant net decrease in accident rates over the entire area of the added lane and its influence areas depended upon the individual circumstances of each of the case studies.

It is clear from these results that the safety aspects of added lanes cannot be assessed by comparing accident statistics only for the postmile range covered by the added lane. Accident statistics for portions of roadway influenced by the lane must be included. The extent of this influence area depends upon the relative locations of traffic bottlenecks and other traffic conditions unique to each project. Evaluation studies citing accident statistics restricted to the immediate area of an added lane should be viewed as dealing only with partial (and potentially misleading) effects.

ACKNOWLEDGMENTS

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