Title
Safety Impacts Associated with Installation of HOV (High Occupancy Vehicle) Lanes

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The views expressed in this report are those of the authors and do not necessarily reflect the views of the sponsoring agencies.

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INTRODUCTION

The objective of this study was to evaluate the traffic safety of freeway High Occupancy Vehicle (HOV) lanes that are not separated by physical barriers from adjacent, general-purpose traffic lanes. The purpose of the HOV lanes is to offer an incentive to motorists to form carpools, thereby providing some relief to congestion attributable to the relatively high number of single-occupancy vehicles utilizing urban freeways. The research was aimed at determining the causes of any changes in safety conditions due to the operation of such lanes, and identifying possible actions to mitigate any adverse safety impacts.

The study focused on two HOV lane operations in the greater Los Angeles area: One is located on State Route 91 (SR-91, the Riverside Freeway) in Los Angeles County; the other is on State Route 55 (SR-55, the Costa Mesa/Newport Freeway) in Orange County. Both of these facilities have been implemented through partial removal of the left median shoulder and restriping of the lanes.

SUMMARY AND CONCLUSIONS

It is concluded that the HOV lane operation on SR-91 has had no adverse effect on safety conditions on that route. The HOV lane on SR-91 exhibits safety effects that are similar to those found to be associated with the addition of a general-purpose lane on freeways in the greater Los Angeles area (Levine, et al., 1988): There is no overall change in the exposure to accidents, but there is a significant migration of accident locations. This is due to the severe traffic bottlenecks downstream of both projects. In situations where the downstream bottlenecks are less severe, overall safety improvements can be expected.

Patterns of traffic congestion on SR-91 have changed due to the additional roadway capacity provided by the HOV lane. In summary, the worst traffic congestion eastbound during the afternoon peak period has moved downstream to the end of the HOV lane and beyond the project. Accident concentrations have been similarly relocated, and this migration of accidents is consistent with effects found in case studies of added mixed-flow lanes (Levine, et al., 1988). All of the changes in the patterns of reported accidents on SR-91 can be attributed to changes in the location and timing of traffic congestion.

While the HOV lane on SR-91 has not degraded safety, it has also not alleviated conditions. Due to traffic bottlenecks at the end of the HOV lane and downstream of the project, there has been a migration of accidents, but no reduction in their number, controlling for traffic level increases.

It is estimated that the HOV lane on SR-55 has contributed to an increase in accidents on that route of no greater than 2 percent over and above the level that would be expected from mixed-flow operation of the lane. That is, there are up to approximately 2 percent more accidents on SR-55 resulting from HOV operation of the added lane, as opposed to mixed-flow operation. This 2 percent estimate is an upper bound. It is entirely possible that there are no additional accidents due to the HOV lane, but it is impossible to confirm the no-effect hypothesis with existing data.

Congestion plays a major role in the occurrence of accidents on SR-55. The increases in accident rates since 1982 are due largely to increases in congestion levels. Congestion is centered on the SR-55/I-5 interchange area, but eight or nine miles of the route are typically severely congested. The additional lane, while serving more demand, aids in delivering more vehicles to congested situations. If the HOV lane were in mixed-flow operation, most of the congestion-related effects would still be present.

ACCIDENT FREQUENCIES

Because accurate traffic volume counts prior to the opening of the HOV lanes on the two case study sites were unavailable, it was not possible to compute accident rates per vehicle mile of travel before and after implementations of the HOV lanes. Thus, analyses of changes in accident frequencies potentially attributable to the respective HOV operations relied on comparisons to control situations.

In the case of the SR-91 freeway, the HOV lanes is unidirectional (eastbound only) and is operated only between 2:00 and 7:00 PM on weekdays. This provides contrasts for controlling for traffic level increases in comparisons of accident rates. One such comparison involved the numbers of raw accidents over time on two sections of eastbound SR-91: The 8.6-mile segment corresponding to the HOV lane location and a 13.4-mile downstream segment from the end of the HOV lane eastbound to the SR-57 connector. This comparison was limited to accidents that occurred on the eastbound highway between 2:00 and 7:59 PM on weekdays.

The proportion of total accidents in the project and downstream sections that were located in the HOV section is plotted by month in Figure 1. The last fourteen months correspond to HOV operation in this section, and the month of project initiation (June 1985) is deleted from the plot. The mean proportion in the upstream section prior to the HOV lane (January 1979 through May 1985) was 0.470; during HOV operation it was 0.475. The difference between these mean proportions is not statistically significant.

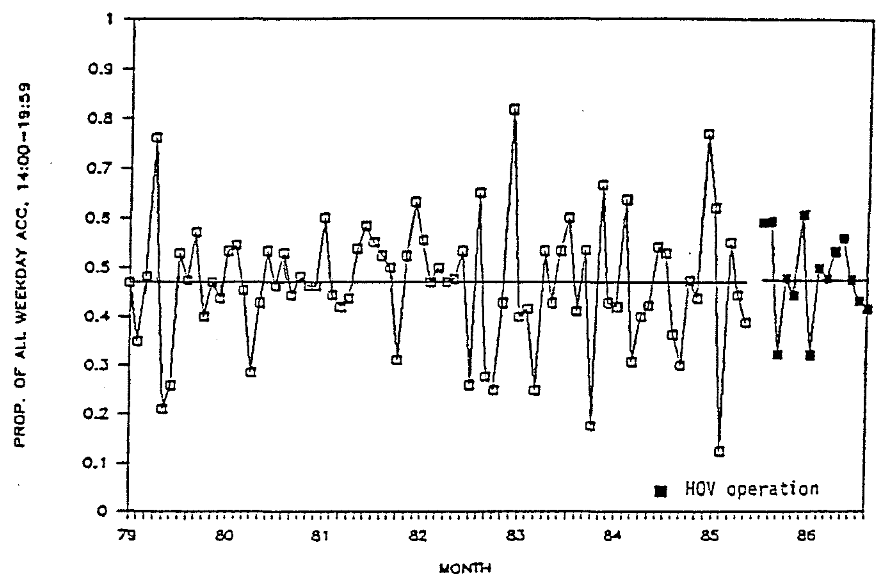

FIGURE 1

PROPORTION OF TOTAL EASTBOUND SR-91 ACCIDENTS
IN THE HOV AND DOWNSTREAM AREAS THAT ARE IN HOV AREA

A second analysis involved the relative share of all SR-91 accidents in the HOV section that occurred on weekdays on the eastbound highway between 2:00 and 7:59 PM, versus the same section of the westbound highway between 5:00 and 10:50 AM. SR-91 is known to be characterized by directional peaking, and this comparison is relative to the extent that peak-interval traffic volume changes over time are similar in the peak eastbound and westbound directions. The section of SR-91 downstream from the HOV area (from the end of the HOV lane to the SR-57 connector in Orange County) is defined to be the influence area for the project; this area provides a control sample for the comparison within the HOV area. Shown in Figure 2 are the eastbound afternoon versus the westbound morning proportions by month for the HOV area, and shown in Figure 3 are similar comparisons for the downstream area (from the end of the HOV lane to the SR-57 connection). The results reveal no significant accident increases relative to the HOV operation: The difference in the proportion of accidents eastbound afternoon versus westbound morning in the HOV area (Figure 2) is 0.669 in the pre-HOV period and 0.696 in the post-HOV period; this difference is not statistically significant. Moreover, the slight shift to more eastbound afternoon accidents for the final fourteen months is the same for both the HOV and the control sections. This indicates a relatively greater increase in traffic volume and potential congestion effects in the eastbound direction versus the westbound direction over both the project and downstream areas.

The conclusions from these analyses of total numbers of accidents are: (1) any effects of the HOV lane operation are too subtle to be identified in time series analyses of accident frequencies; and (2) changes in accident frequencies before and after project introduction are similar for the area of the HOV lane and the downstream influence area.

In contrast to SR-91, the HOV lane operation on SR-55 effectively spans the length of the Costa Mesa/Newport Freeway (approximately 10 miles) in both the northbound and southbound directions. It has been in operation since November 1985. As in the case of the SR-91 HOV Project, the lane was created from the median shoulder, with multiple access and egress areas along the HOV facility.

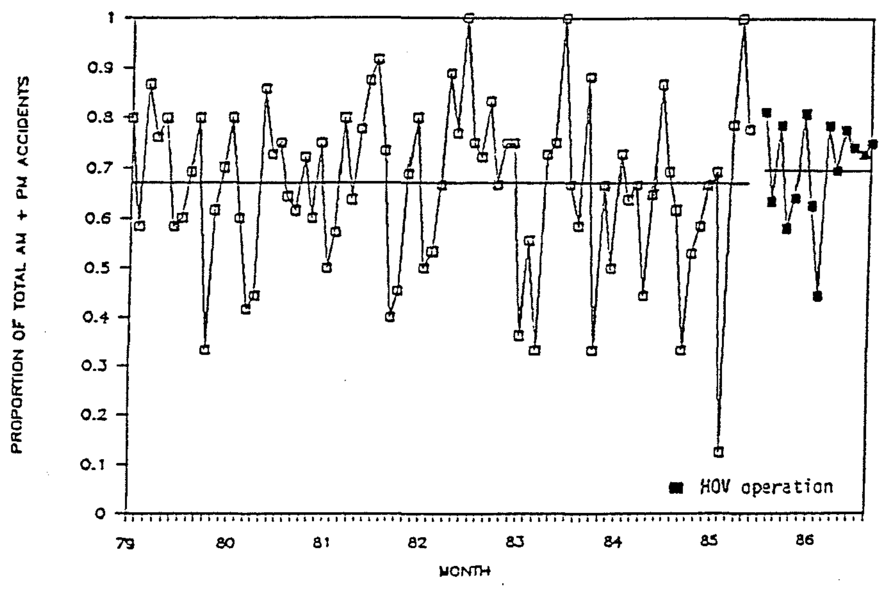

FIGURE 2

SR-91 HOV AREA: PROPORTION OF ACCIDENTS EASTBOUND PM VS. WESTBOUND AM

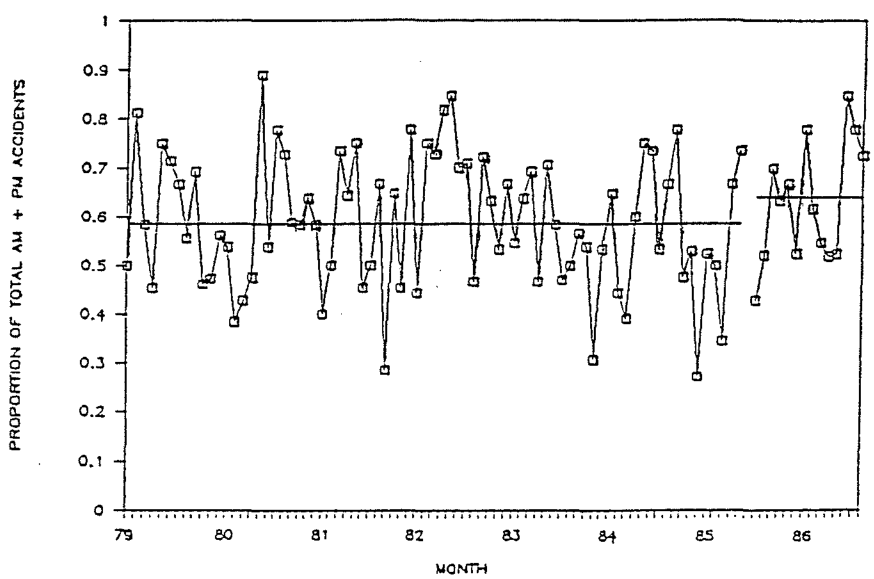

FIGURE 3

SR-91 DOWNSTREAM INFLUENCE AREA:
PROPORTION OF ACCIDENTS EASTBOUND PM VS. WESTBOUND AM

Results from a time series analysis of accident frequencies showed that the average number of accidents on the dry weekday in a particular month was the most effective measure of changes over time in safety levels on SR-55. This series, shown in Figure 4, accounts for differences in weather conditions and the number of weekend days and holidays in a month. (Accident frequencies on weekends and holidays were shown to be constant from 1979 through 1986.) Nevertheless, the month-to-month variations in the accidents per dry weekday series were still so great as to make conclusions regarding the effect of the HOV lane impossible; although the months of HOV operation were found to be

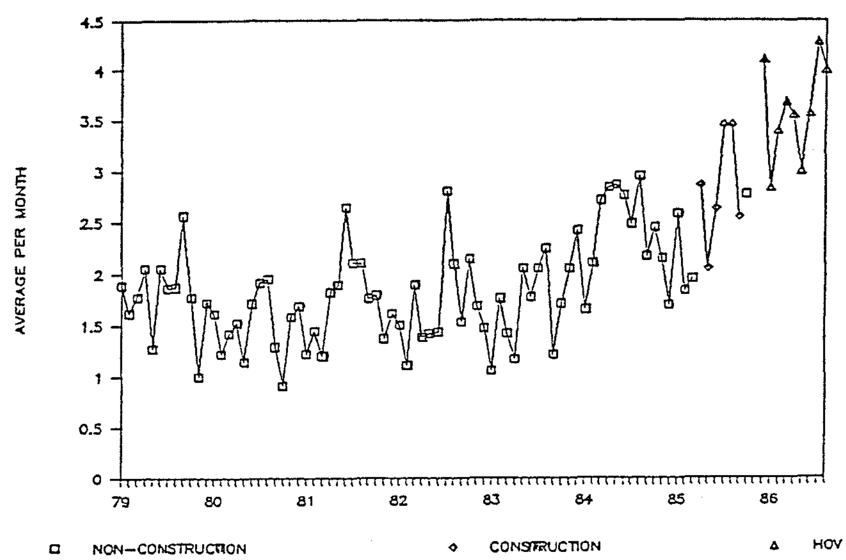

FIGURE 4

SR-55: HIGHWAY ACCIDENT HISTORY
(DRY WEEKDAYS ONLY)

within confidence intervals established by variations in the prior years for the case of all weekday data, no reasonable statistical model could be estimated for the preferred dry weekday data.

Results from the backward projections of annual average daily traffic (AADT) from known counts in the HOV period to counts in the previous years also yielded indeterminant results. For some months, and particularly for comparisons to 1985, the implied annual increases in accident rate per AADT were noticeably higher. However, for other months, and particularly for comparisons back to 1984, accident rates appear to be consistent with an AADT growth rate of between 6 and 10 percent.

It is important in all time series analyses to standardize for changes in vehicle exposure due to changes in travel volumes. Standardization should be in terms of vehicle miles of travel (VMT), but such data requires both traffic volume and trip length data (or traffic volumes on all key points along a route) and is unavailable for SR-55. The only alternative was to use AADT (annual average daily traffic) at one central cross section of SR-55 as a proxy measure of travel changes over time.

The AADT's at that location were computed based on data collected from the Caltrans microfiche records of traffic volumes for the years 1979, 1981, and 1984. Volumes for 1986 were estimated as the average of either the actual mixed-flow lane volumes or the total SR-55 volumes observed during the first nine months of the HOV projects (published in the Caltrans HOV lane nine-month operational report, November 5, 1986). The first estimate assumes that if the HOV lane were not present the 1986 AADT would be that which is observed in the mixed-flow lanes; the volume observed in the HOV lane is due to latent demand generated by the additional lane. The second estimate assumes that there has been no latent demand whatsoever on SR-55 due to the additional capacity introduced by the HOV lane. Neither is a completely realistic assumption, and both are included to test the sensitivity of the results to AADT assumptions. These AADT estimates (December 1981-October 1985) are shown in Figure 5, together with the observed AADT's during the HOV period (Caltrans, November 5, 1986).

The estimated AADT series was used to standardize the monthly series of average accidents per dry weekday for the period since late 1981. The resultant series, graphed in Figure 6, is measured in terms of accidents per dry weekday/AADT at Santa Clara Avenue x 10^{-6}. In this figure the monthly observations are divided into three ranges: (1) observations for the nine-month period of December through August of each year, (2) observations for the three months of September through November of each year, and (3) the nine-month HOV period of December 1985 through August 1986. Because of systematic seasonal variations not accounted for in the AADT estimates (e.g., summer months generally have higher traffic volumes and consequently more accidents), only the observations in the first range (December through August of each year) can be directly compared to the HOV period.

The effect of the HOV lane construction period (April-September 1985) on traffic safety on SR-55 is unknown. Consequently, two analyses of the standardized time series were performed: one deleting the 1985 observations to eliminate any bias due to construction effects, and a secondary analysis using all of the first range observations to test the consequences of ignoring the 1985 information. The estimation of trends in the standardized accident series was restricted to a linear analysis because of the well-known dangers of extrapolating non-linear functions beyond the range on which they are calibrated.

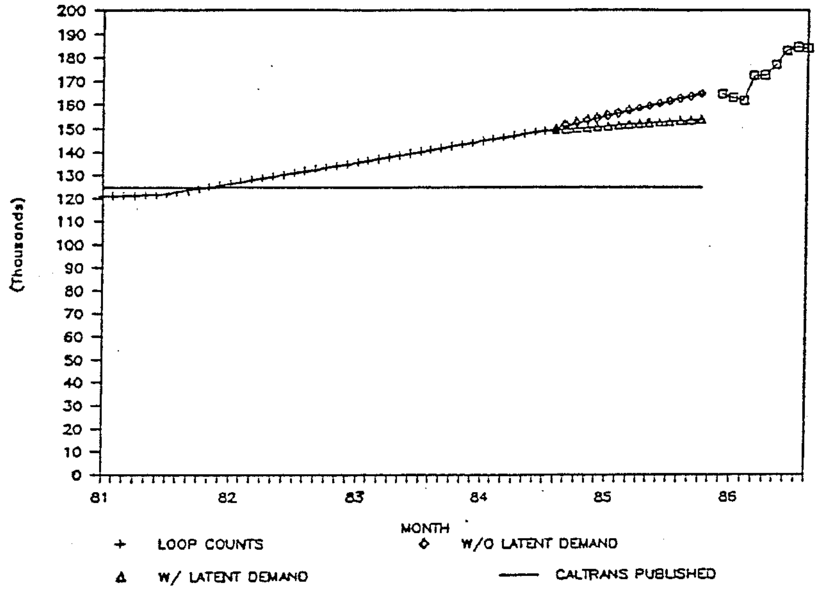

FIGURE 5

SR-55: AADT ESTIMATIONS AND OBSERVATIONS

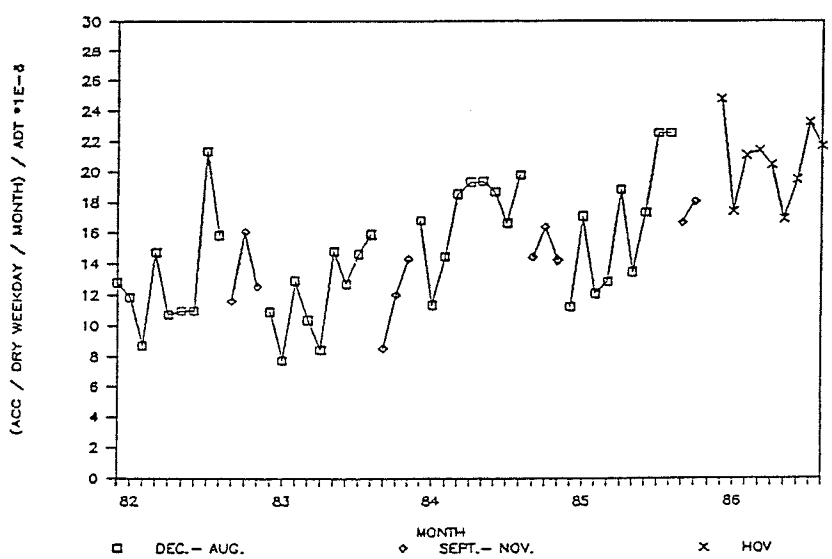

FIGURE 6

SR-55: ACCIDENTS PER DRY WEEKDAY PER MONTH
STANDARDIZED BY AADT * 1E-6

Shown in Figure 7 are the best linear regressions for the two series (with and without the construction period). Both series use the AADT estimates that are based on the assumption that latent demand is present in the HOV period. The regression for the series excluding the construction period has an intercept of 10.44 at December 1981, and the slope represents an increase of 0.241 accidents/dry weekday/AADT x 10^{-6} per month. The slope is statistically significant, indicating that there was a degradation in SR-55 safety during the entire 1982-84 period. The proportion of variance accounted for (R^2) is 0.38. The regression for the series including the construction year 1985 has an intercept of 11.11 at December 1981, and the slope is 0.175

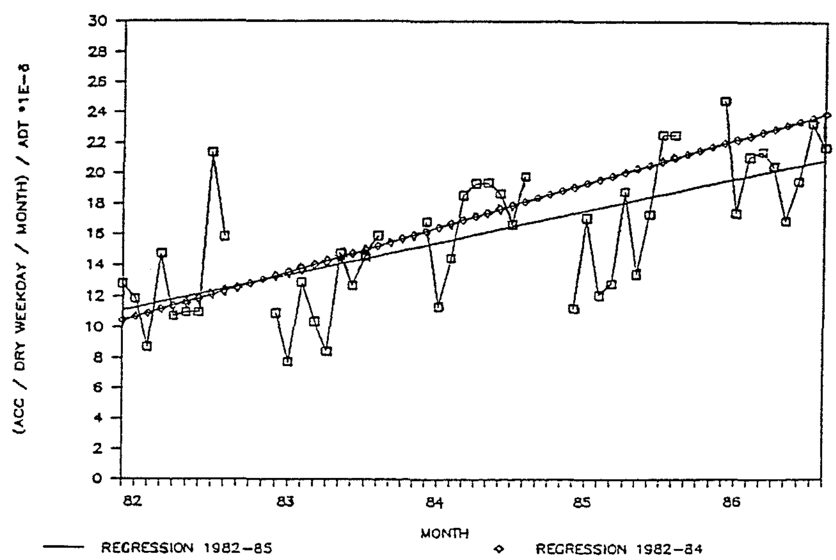

FIGURE 7

SR-55: REGRESSION ANALYSES ACCIDENTS PER DRY WEEKDAY PER MONTH
STANDARDIZED BY AADT * 1E-6
WITH PROJECTIONS TO HOV PERIOD

accidents per dry weekday per AADT x 10^{-6} per month. This slope is also significantly different from zero, but is less than the slope of the previous regression, because the 1985 observations are lower than the trend established by the 1982-84 observations.

The HOV period observations are also shown in Figure 7. Applying the trend regression that avoids the construction period (the line designated by diamonds in Figure 7), all HOV period observations are less than predicted with the exception of the first full month of HOV operation, December 1985. Applying the regression using the construction year over-predicts standardized accidents for three of the HOV months and under-predicts standardized accidents for six HOV months.

As a comparison, the best linear regression using the AADT estimates that are based on the assumption that there is no latent demand on SR-55 present in the HOV period, is shown in Figure 8. Regressions are shown in Figure 8 with and without the construction year. The HOV period observations are again generally bracketed by the two regressions.

The results of all the time series analyses are inconclusive regarding whether or not HOV operations on SR-55 contribute to a decline in safety on that route. Changes over time in the accident characteristics, specifically, changes before and after the introduction of the HOV lane can be identified in the time series analyses. However, the determination of accident causes, and the role of HOV versus mixed-flow operation of the added lane require more detailed investigation than can be provided by aggregate time series analyses.

Trends in the degradation in safety on SR-55 from 1982 through 1985 mask any potential HOV effects. Alternative assumptions regarding AADT estimates, periods over which to estimate trends, and choices of the mathematical functions to represent such trends arbitrarily determine any calculations of

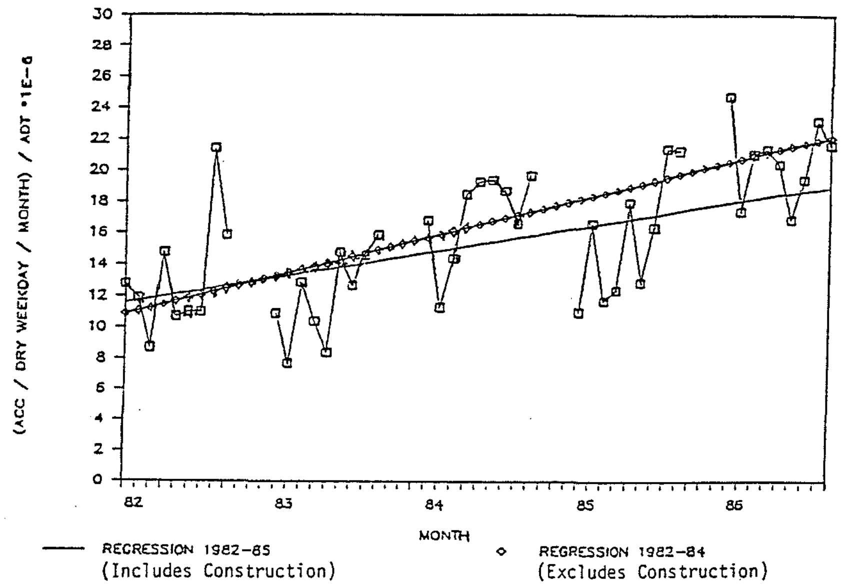

FIGURE 8

SR-55: ACCIDENTS PER DRY WEEKDAY PER MONTH
STANDARDIZED BY AADT * 1E-6
(NO LATENT DEMAND IN 1986)

HOV effects on such an aggregate basis. This is not to conclude that the HOV lane has no effect on safety. Rather, it is not possible to estimate such an effect using aggregate time series.

PATTERNS OF ACCIDENT CHARACTERISTICS

To determine if operation of the HOV lane on SR-91 has changed patterns of accident characteristics, comparisons were made among the characteristics of multi-vehicle accidents that occurred during the afternoon (2:00-7:59 PM) in the eastbound direction and those that occurred during the morning (5:00-10:59 AM) in the westbound direction for each of four fourteen-month periods: July 1985-August 1986 (HOV operation in the eastbound direction) and non-overlapping periods corresponding July to August periods in 1983-84, 1981-82, and 1979-80. The eastbound afternoon 1985-86 statistic corresponds to the operation of the HOV lane. The comparison over time since 1979 facilitates identification of long-term temporal trends that might be independent of influences that are unique to the 1985-86 period.

All characteristics available in the TASAS data were investigated as to differences eastbound AM versus westbound PM over the four fourteen-month periods. Two of the tests for differences in accident characteristics represented tests of hypotheses concerning effects of the HOV lane: (1) It was hypothesized that HOV lane operations without physical barrier separations of HOV and mixed-flow lanes would result in an increased incidence of sideswipe collisions. (2) It was hypothesized that unsafe HOV operation would lead to an increase in the incidence of lane-change accidents.

Both hypotheses were rejected on the basis of all available data. There is only a very slight increase in percentage sideswipes for the eastbound afternoon interval, 1985-86 versus 1983-84, and no differences or a decrease compared to earlier years. In any case, neither the difference for eastbound afternoon over the four time intervals nor the difference between eastbound afternoon and westbound morning intervals in 1985-86 is statistically significant.

Secondly, there has been only a slight (statistically insignificant) increase for the eastbound PM interval in the percentage of multi-vehicle collisions in which at least one vehicle's movement prior to the collision was changing lanes.

All other accident characteristics that represent direct tests of hypotheses related to the safety of HOV operation were found to be invariant over the 1979-1986 period and in the eastbound afternoon versus westbound morning comparison. However, significant patterns of change were found for two characteristics, and these provide evidence concerning causes of SR-91 accidents. The first of these characteristics was the percent of multiple-vehicle collisions that involved at least one stopped vehicle. The breakdown for this variable is shown in Figure 9. The difference between eastbound afternoon and westbound morning is statistically significant for the

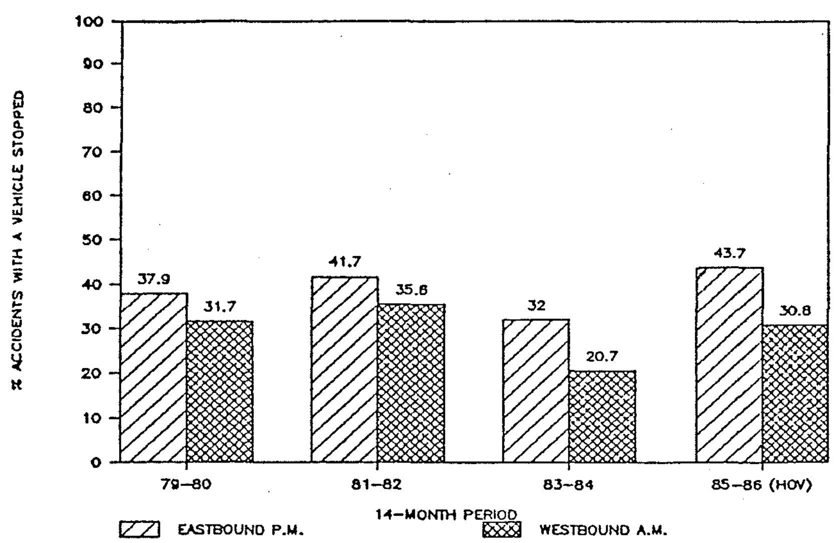

FIGURE 9

SR-91: MULTIPLE-VEHICLE ACCIDENTS WITH VEHICLE STOPPED
(WEEKDAYS, MILEPOSTS R8.2-R16.8, LOS ANGELES COUNTY)
BY EASTBOUND PM VERSUS WESTBOUND AM

1985-86 (HOV) period, but not for previous time periods. This indicates that congestion-related accidents were particularly high during the period of HOV operation, compared to the control westbound morning segment of SR-91.

The second accident characteristic with a significant trend was the percent of multiple-vehicle collisions that involved a light truck (pick-up or van). The pattern of statistically significant differences over time indicates that the variable is not simply a reflection of the proportion of light trucks in the vehicle fleet as this proportion has not varied over time in a similar pattern. The relatively high proportion of accidents involving light trucks during the fourteen-month HOV period corresponds to the pattern of stopped-vehicle accidents. The variable is an indicator of congestion effects, reflecting the effect of trucks in reducing sight distances in heavy traffic conditions.

Because of the lack of an appropriate control situation, a similar analysis of possible changes in accident patterns on SR-55 was not possible. The conclusion from the analysis of accident characteristics is that operation of the HOV lane has not altered the pattern of accident characteristics on SR-91. The only significant changes involved the relative increase in the percentage of accidents involving "stopped" vehicles and those involving light trucks, indicating increased congestion effects.

ACCIDENT LOCATIONS

The distribution of accident locations is critical to determining any influence of the operation of the HOV lane. The distribution of weekday afternoon accidents over the length of eastbound SR-91 has changed significantly over time. It is important to investigate accident locations relative to access/egress and buffer locations of the HOV lane and to lane drops and ramps that are potentially related to congestion, such as queue buildups.

The percentage distributions by mile of total weekday accidents from 2:00 to 7:59 PM over the 24-mile section of SR-91 for each of the four non-overlapping fourteen-month periods are graphed in Figure 10. Focusing on the spatial distribution for 1985-86 compared to the previous periods, the most outstanding feature in Figure 10 is the increase in accidents in the mile between postmiles 4.62 and 5.619 in Orange County. In this mile, SR-91 crosses over State College Boulevard with on- and off-ramps, and the connector off to the SR-57 Freeway is downstream (0.23 to 1.23 miles) at postmile 5.85. This could indicate queue build-ups from the SR-91/SR-57 interchange and sight distance problems at the State College overpass. This represents a migration of accident locations to a traffic bottleneck downstream of the project.

There are also differences among the spatial distributions in the area of the HOV lane (postmiles R8.22 to R16.77), with a significant shift of locations of accidents in 1985-86 to the miles beginning at R14 and R16, in the general vicinity of the egress of the HOV lane, and away from the postmile ranges beginning at R11 and R12, compared to previous periods. These changes were investigated more in detail by focusing on congestion in the area of the HOV lane.

Congestion diagrams are available for SR-91 in the periods before and after installation of the HOV lane. Such diagrams provide information on the speed of travel at each postmile location and time interval on the day on which the data are collected. Data are obtained by driving a fleet of cars along the road and recording speeds at postmile and time of day intervals. This operation was performed on eastbound SR-91 on June 5, 1985 (before the HOV lane) between approximately postmiles R7 and R18 between 2:45 and 7:00 PM.

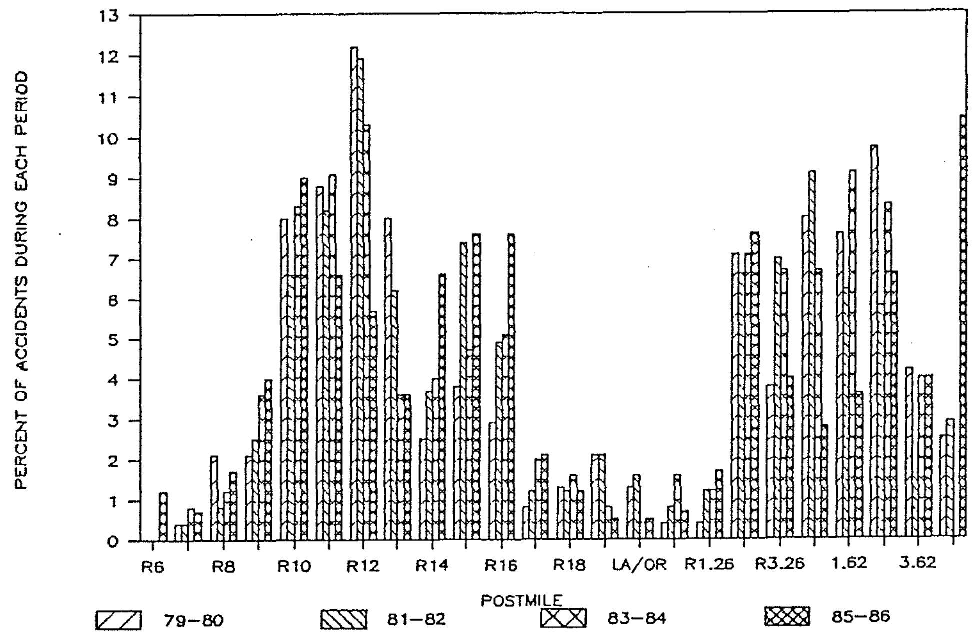

FIGURE 10

SR-91: WEEKDAY ACCIDENTS 2:00-8:00 PM:
PERCENT PER MILE OVER 24 MILES
BY FOURTEEN-MONTH PERIOD

The hard-copy congestion diagrams provided by Caltrans have been computerized for use in the present study and are reproduced in Figures 11 and 12. It can be seen from a comparison of Figures 11 and 12 that the pattern of congestion on SR-91 has changed over time.

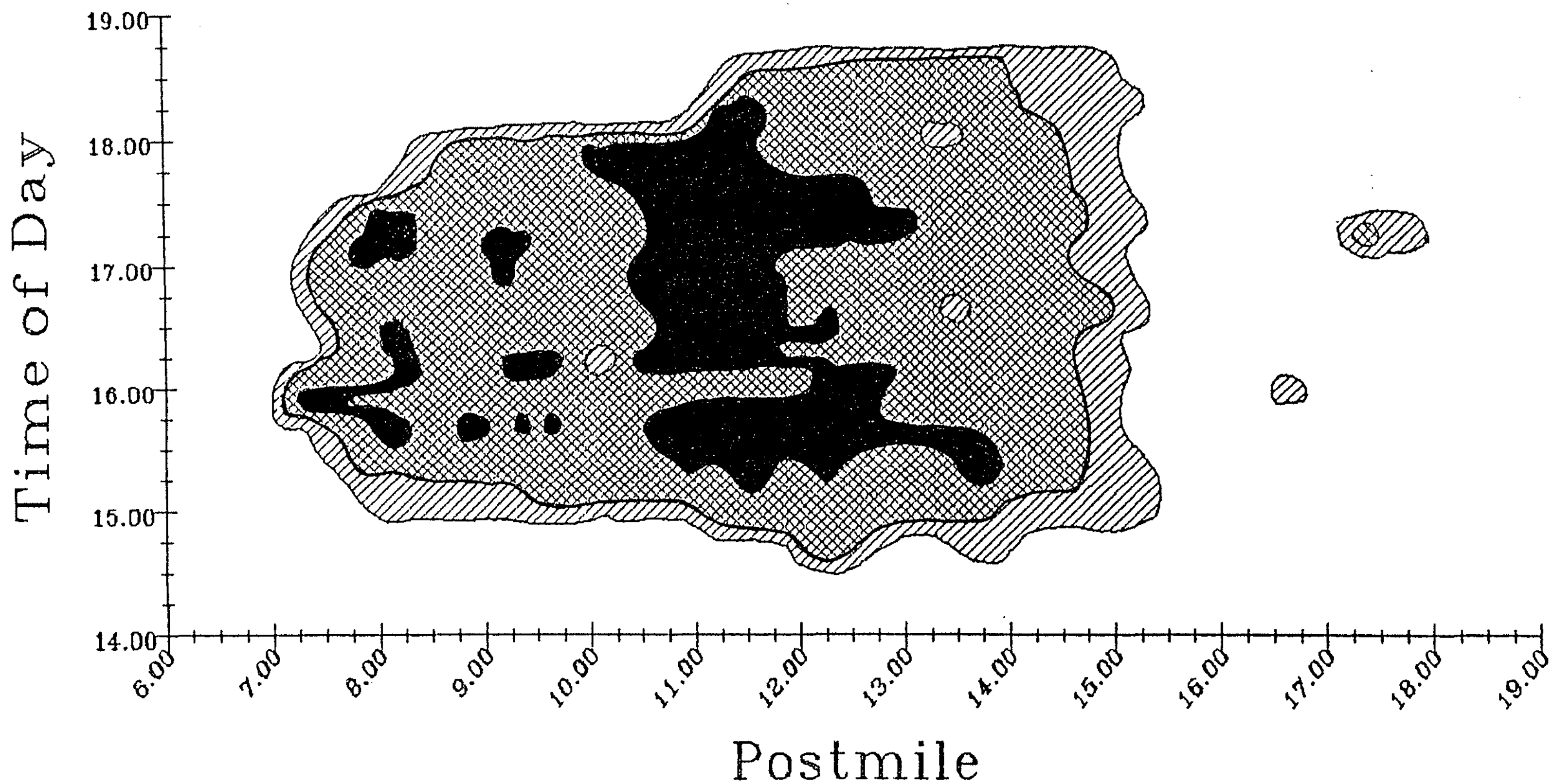

FIGURE 11

CONGESTION DIAGRAM FOR SR-91 ON JUNE 5, 1985 (BEFORE)

OVER 50 MPH | 35-50 MPH | 20-35 MPH | 0-20 MPH

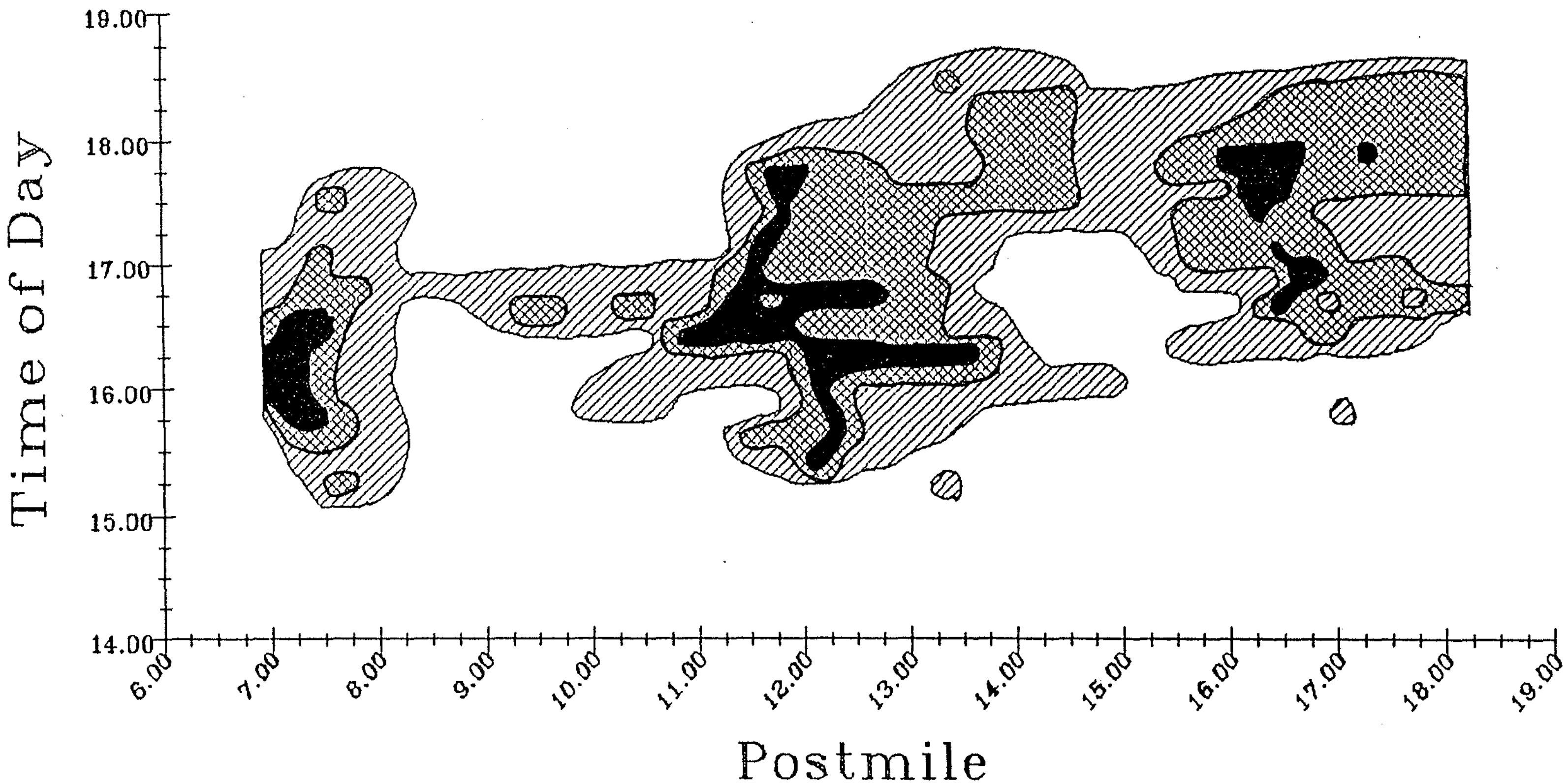

FIGURE 12

CONGESTION DIAGRAM FOR SR-91 ON JANUARY 23, 1986 (AFTER)

OVER 50 MPH 35-50 MPH 20-35 MPH 0-20 MPH

Spatial distributions on a half-mile basis for the nine-mile area encompassing the present HOV lane are shown in Figure 13. There are new peaks for the 1985-86 period of HOV operation at the half miles beginning at postmiles R10, R14.5, R15.5, and R16.5, while relative concentrations are down in the range of postmiles 10.5 to 13. The range of postmile 10.0-10.5 is in the vicinity of a lane drop. Comparing the HOV period to previous periods, there has been a shift in the relative location of accidents from the area of postmile R10.5 to R12.5 upstream to the area R10.0 to R10.5. The area encompasses two off-ramps and is upstream from another off-ramp to Long Beach Boulevard and the major off-ramp to southbound I-710. SR-91 bridges three

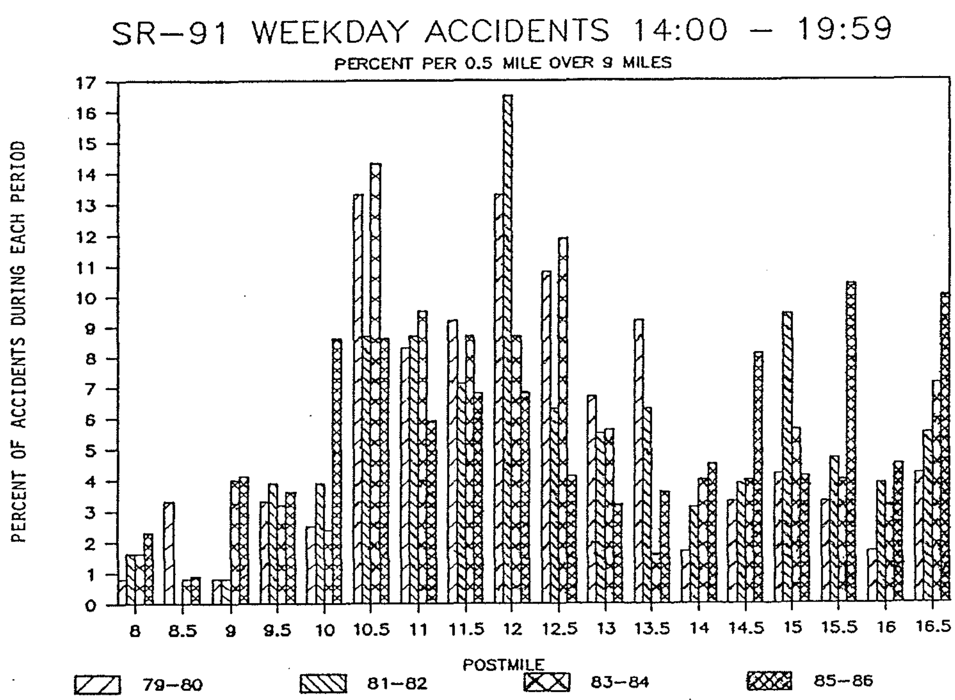

FIGURE 13

SR-91: WEEKDAY ACCIDENTS 2:00-8:59 PM
PERCENT PER .05 MILE OVER NINE MILES
BY FOURTEEN-MONTH PERIOD

major arterials and a rail line in the R10.0 to R10.5 section. Increasing queue build-ups, indicated by the onset of heavy congestion at about postmile 10.5 (Figure 12), and restricted sight distances accounts for this upstream shifting of accident locations.

The range of postmile 14.5-15.0 is in the vicinity of a lane drop. The area is also immediately preceding an HOV access/egress area; on-ramps may pose potential weaving problems associated with the HOV egress. In the period before implementation of the HOV lane, levels were relatively low in the range of postmile 14.5-15.0 during the entire PM period, indicating the break-up of queues and resumption of free speed (Figure 11). However, after implementation of the HOV lane, this decrease in congestion was not generally present (Figure 12). This change in the patterns of congestion could contribute to the concentration of accidents in the postmile 14.5-15.0 range.

The new concentration of accidents from R15.5 to R16.0 is in the area of another lane drop. It is in the general area immediately downstream of the HOV egress. However, a comparison of the congestion diagrams of Figures 11 and 12 shows that there are substantial levels of congestion in the range postmile 15.5 to 16.0 after implementation of the HOV lane (Figure 12) that were not present in that range before implementation (Figure 11). This represents a migration of congestion downstream due to the partial elimination of traffic bottlenecks in the project area. The concentration is greatest in the R15.5 to R15.8 area: Prior to 1985-86 less than 4 percent of all accidents in the R8.0 to R17.0 area occurred there; currently about 9 percent of the accidents occur in this 0.3-mile area. The area is 0.9 to 1.2 miles upstream of the off-ramp to I-605 and the end of the HOV lane. Congestion effects with reduced sight distances are expected here and may be affecting merging traffic from the HOV lane. Postmile 16.5 corresponds to an area slightly upstream of the end of the HOV lane and roughly coincident with the location of the off-ramp to the I-605 freeway.

The locational distribution of accidents depicted in Figure 13 can be simplified by considering three locations: (1) postmiles 10.5-13.5, the area of the highest levels of congestion immediately before implementation of the HOV lane (Figure 11), (2) postmiles 14.5-17.0, the area of high congestion after implementation of the lane (Figure 12), but low congestion before implementation (Figure 11), and (3) all other locations. The breakdown of accidents according to these three locations (Figure 14) shows a dramatic

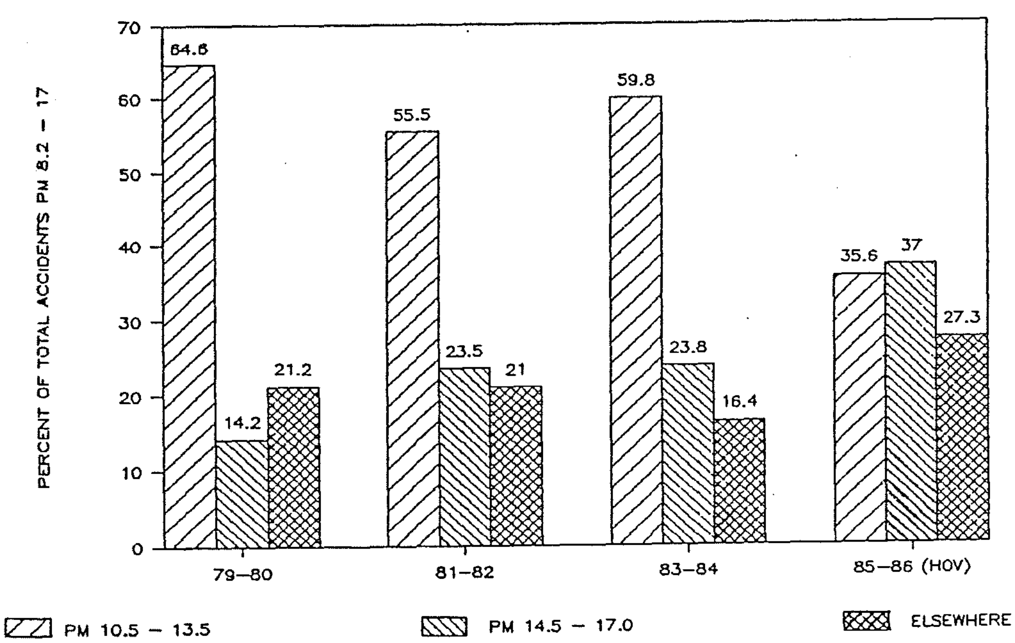

FIGURE 14

BREAKDOWN OF WEEKDAY ACCIDENTS (14:00-19:15 HOURS) BY THREE LOCATIONS shift in accidents from location category (1) to categories (2) and (3), pre-HOV versus post-HOV. This shift is statistically significant. The shift between categories (1) and (2) represents a downstream migration of accidents.

Further assessment of the role of HOV operations in these new accident locations requires establishing location and time-of-day interactions and investigating accident characteristics.

The temporal distribution of weekday eastbound SR-91 accidents for an area encompassing the present HOV lane, postmile R8.2 to R16.8, for the 2:00-7:59 PM interval is shown in Figure 15 for the four fourteen-month periods. The histograms are for half-hour intervals. The distribution for 1985-86 (the period of HOV operation) is flatter than the distributions for the previous periods, and this difference among hourly distributions is

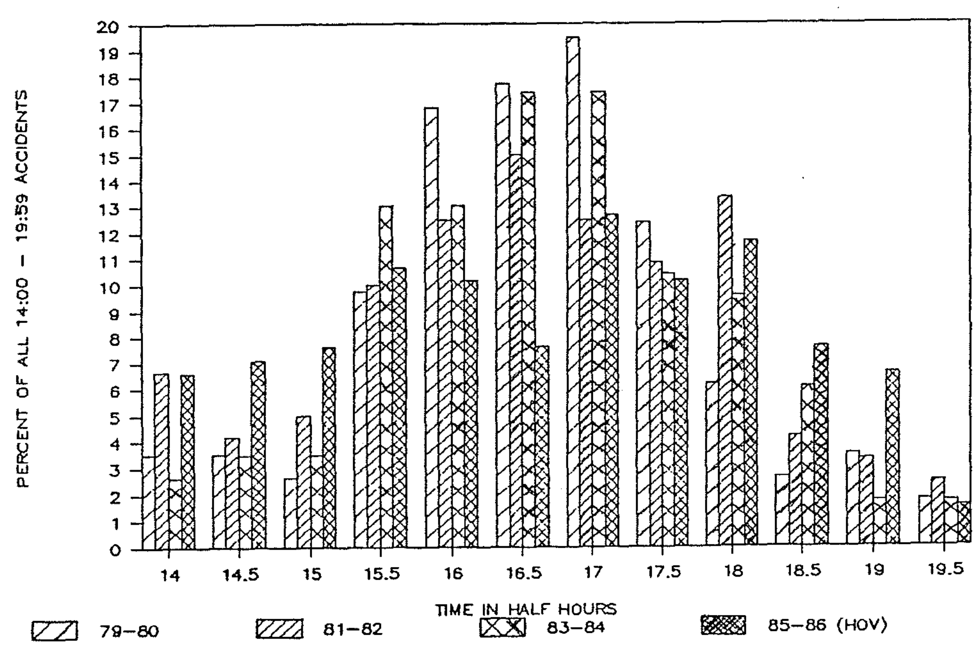

FIGURE 15

SR-91: WEEKDAY ACCIDENTS BY TIME OF DAY
(POSTMILE R8.2 L.A. - R16.8 L.A. (HOV AREA))
BY FOURTEEN-MONTH PERIOD

statistically significant (p = .03). Weekday accidents in this section of SR-91 are more evenly distributed over the afternoon and early evening interval in 1985-86 than in previous years.

A more detailed comparison of temporal distributions on a quarter-hourly basis revealed that systematic shifts in these distributions can be summarized by dividing the overall afternoon/evening interval (2:00-7:59 PM) into four functional intervals with consistent trends. These intervals are: 2:15-3:29 PM, 3:30-3:59 PM, 4:00-5:44 PM, and 5:45-7:14 PM. The distribution of accidents over the four functional intervals is shown for each fourteen-month time interval for the HOV area (mileposts R8.2 to R16.8) in Figure 16. The 2:15-3:29 PM interval is characterized by a substantial increase in accidents for the 1985-86 period. The 3:30-3:59 PM interval is characterized by a

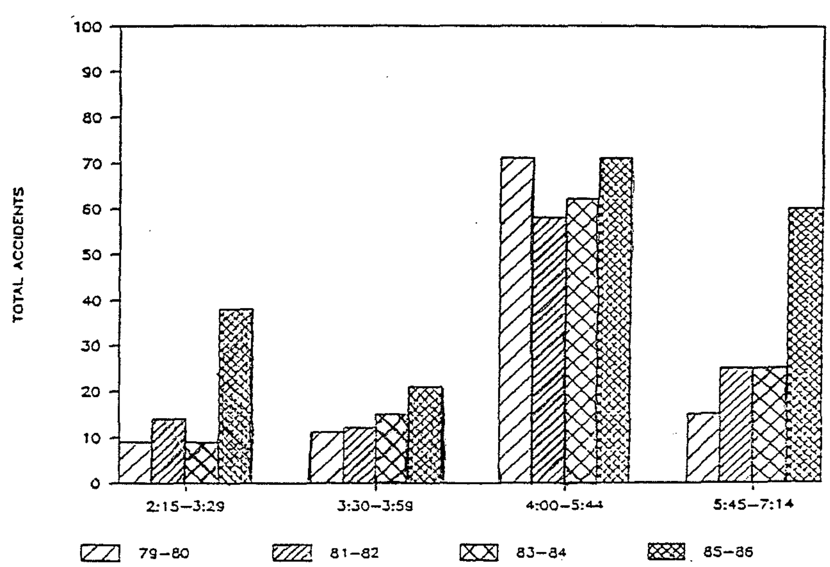

FIGURE 16

SR-91: EASTBOUND WEEKDAY ACCIDENTS BY FUNCTIONAL TIME INTERVAL (POSTMILE R8.2 L.A. - R16.8 L.A. (HOV AREA)) BY FOURTEEN-MONTH PERIOD relatively steady increase over time. The total numbers of accidents during the 4:00-5:44 PM interval is relatively constant over time. Finally, for the 5:45-7:14 PM interval, there is an increase between 1979-80 and 1981-82, no increase between 1981-82 and 1983-84, and a substantial increase from 1983-84 to 1985-86.

Thus, the fourteen-month HOV period is characterized by substantial increases in accidents during the intervals before 3:30 PM and after 5:44 PM, but no increases during the central 4:00-5:44 PM interval; the 3:29-3:59 PM interval represents a transition between intervals of increase and intervals of no change.

The three functional time intervals (2:15-3:29 PM, 4:00-5:44 PM, and 5:45-7:14 PM) were found to exhibit different spatial distributions of accidents. Moreover, two of the time intervals (4:00-5:44 PM and 5:45-7:14 PM) were found to have spatial distributions that were different for the 1985-86 period, compared to previous periods, while the interval 2:15-3:29 PM was found to be the same in 1985-86 as in prior years.

As was noted in the previous section, the first functional time interval, 2:15-3:29 PM, exhibited an increase in the number of accidents in the area of the HOV lane, 1985-86 versus prior years (Figure 16) but no increase in the number of accidents in the influence area. The spatial distribution of these accidents over one-mile categories in the area of the HOV lane is nearly identical for 1985-86 and for previous years.

There are too few accidents in the second interval to support the study of spatial distributions. However, the third functional time interval, 4:00-5:44 PM, exhibited essentially no increase in accidents in the HOV area, pre-HOV to post-HOV, but a substantial increase in accidents downstream of the HOV lane. The accident locations have shifted for both the HOV and control areas, even though the total number of accidents is essentially constant for the HOV area. The percentage distribution of accidents by half mile over the HOV area is shown in Figure 17. There are new peaks in the HOV period at the half miles beginning at postmiles 10.0, 14.5, 15.5, and 16.5; and the HOV period shows lower relative concentrations over the postmile range 11.0 to 14.0.

The concentrations between postmiles 14.5 and 16.5, which are in the general vicinity of the egress and end locations of the HOV lane, indicates a merging problem during congested conditions (when the disparity in speed between vehicles in the HOV lane and those in the general use lanes is greatest). However, there is no absolute increase in the number of accidents

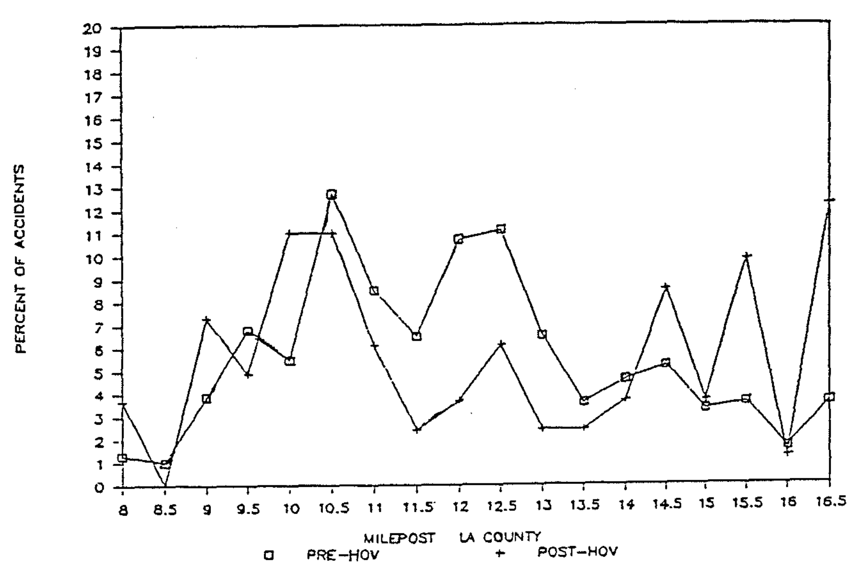

FIGURE 17

SR-91: EASTBOUND ACCIDENTS, WEEKDAYS 4:00-5:44 PM, BY POSTMILE PRE-HOV VERSUS POST-HOV PERIOD occurring during this time interval in the area encompassing the HOV lane, despite the added capacity (and presumed additional volumes) provided by the HOV lane. This indicates that this potential problem is counterbalanced either by improved safety resulting from the additional capacity provided by the HOV lane and by more intense congestion in the general use lanes with the associated lower speeds.

The fourth functional time interval, 5:45-7:14 PM, exhibited increased numbers of accidents, 1985-86 versus prior years, in both the HOV and control areas. For both areas, there was a significant shift in accident locations. The pre-HOV and post-HOV spatial distributions for the HOV section are compared in Figure 18. Some of the 1985-86 areas of concentration are similar

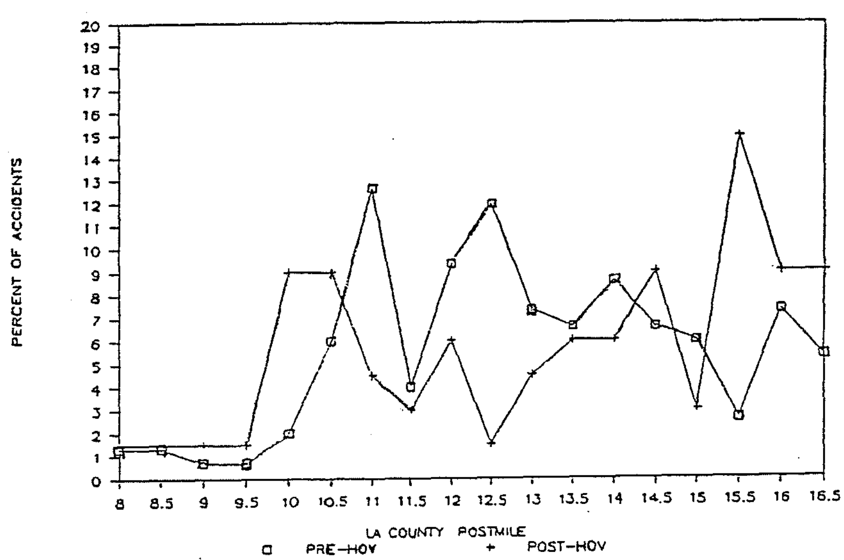

FIGURE 18

SR-91: EASTBOUND ACCIDENTS, WEEKDAYS 5:45-7:14 PM
BY POSTMILE (R8 LA - R16 LA)
BY PRE-HOV VERSUS POST-HOV PERIOD

to those for accidents in the 4:00-5:44 PM interval (Figure 17), but there is even a greater migration of accidents downstream (to postmiles 15.5 to 17.0), a phenomenon consistent with the changes in congestion patterns.

The location and time-of-day interactions are summarized in Table 1. The concentrations of increased accidents in specific locations at specific times represent SR-91 problem areas.

TABLE 1

Time Period (Weekdays Only)	HOV Lane Area (postmile R8-R17 LA)		Control Area (postmile R17 LA-5.6 Orange)	
	Total Accidents 1985-86 vs. Prior Years	Spatial Distribution of Accidents 1985-86 vs. Prior Years	Total Accidents 1985-86 vs. Prior Years	Spatial Distribution of Accidents 1985-86 vs. Prior Years
2:15-3:30 PM	increase	same	same	shifted
3:30-4:00 PM	slight increase	(insufficient sample size)	slight increase	(insufficient sample size)
4:00-5:45 PM	same	shifted	increase	shifted
5:45-7:15 PM	increase	shifted	increase	shifted

Changes over time in the distributions of accidents along the length of the SR-55 freeway were also investigated. Separate analyses were conducted for the northbound and southbound sides.

The distributions of northbound highway accidents for four time periods are graphed in Figure 19 (parts a through d). The four time periods are December 1979-August 1980 (identified as 1980), December 1981-August 1982 (1982), December 1983-August 1984 (1984), and December 1985-August 1986 (the period of HOV operation). The locational distributions are <u>not</u> significantly different over these periods. The distinguishing characteristic of all of the distributions is the substantial concentration in the range postmiles 9.9 to 10.1, which is from just past an on-ramp to 0.1 miles before the connector off to I-5. Approximately 15 percent of all northbound accidents occurred in this 0.2 mile section (representing about 1.5 percent of the roadway) in 1986 and in prior years.

The locational distributions of southbound highway accidents for the four time periods are shown in Figure 20 (a through d). The distributions for essentially all four time periods are characterized by concentrations of accidents in the postmile 9.9 to 10.1 section; in the HOV period approximately 12 percent of all southbound accidents occurred in this 0.3-mile section. This section encompasses a heavily-used on-ramp and is 0.2 to 0.5 miles downstream from the on-ramp for the I-5 connector.

The principal locational shift is for southbound accidents in the range of postmiles 10.7 to 11.6; this range is shown in more detail in Figure 21. There is a new concentration for the HOV period in the postmile 10.7 to 11.0 range that is not present in previous years. Approximately 12.5 percent of all southbound accidents occurred in this 0.3-mile section in 1985-86, but less than 5 percent occurred in that section in any previous corresponding

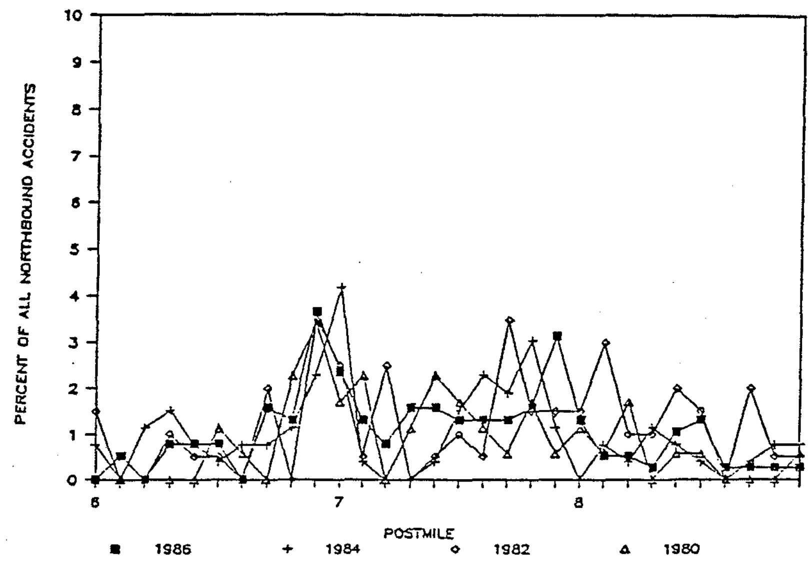

FIGURE 19a

SR-55: PERCENT ACCIDENTS BY TENTH-MILE
NORTHBOUND, POSTMILES 6 TO 9

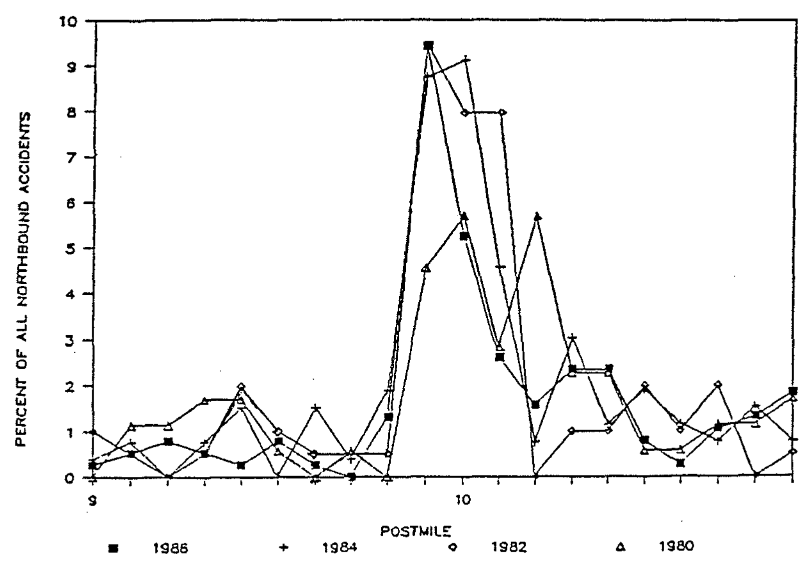

FIGURE 19b

SR-55: PERCENT ACCIDENTS BY TENTH-MILE
NORTHBOUND, POSTMILES 9 TO 11

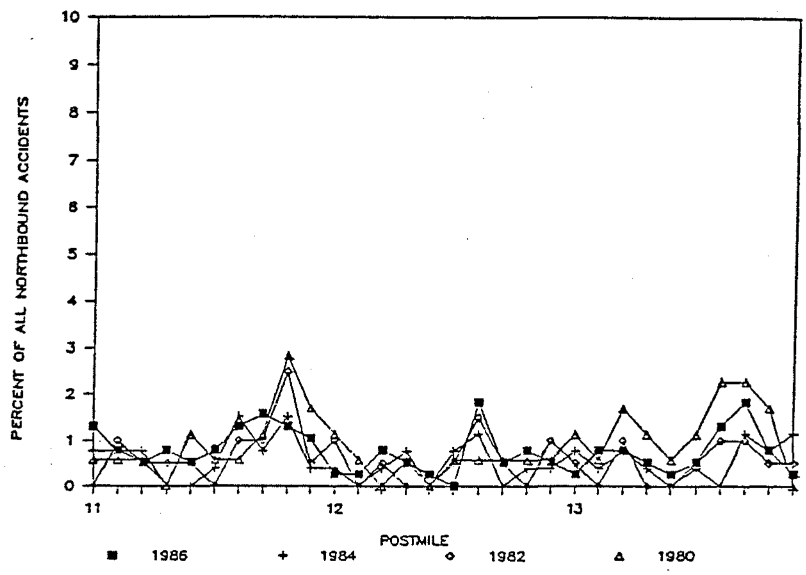

FIGURE 19c

SR-55: PERCENT ACCIDENTS BY TENTH-MILE
NORTHBOUND, POSTMILES 11 TO 14

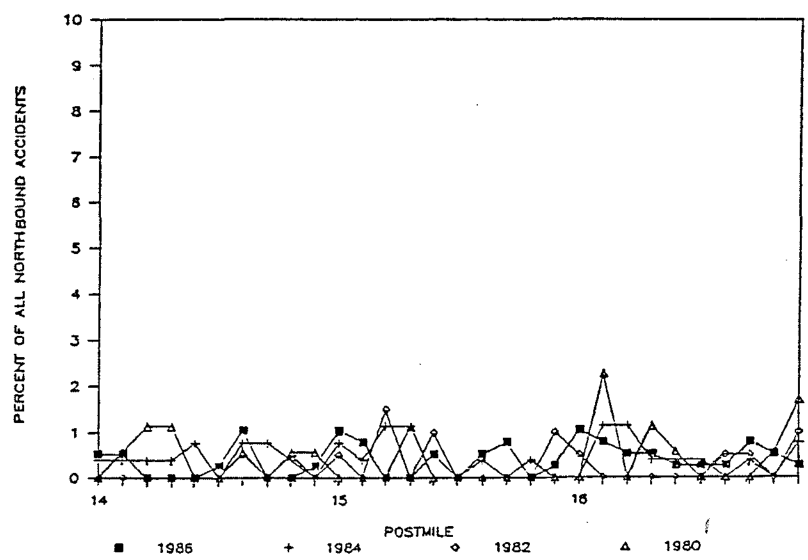

FIGURE 19d

SR-55: PERCENT ACCIDENTS BY TENTH-MILE
NORTHBOUND, POSTMILES 14 TO 17

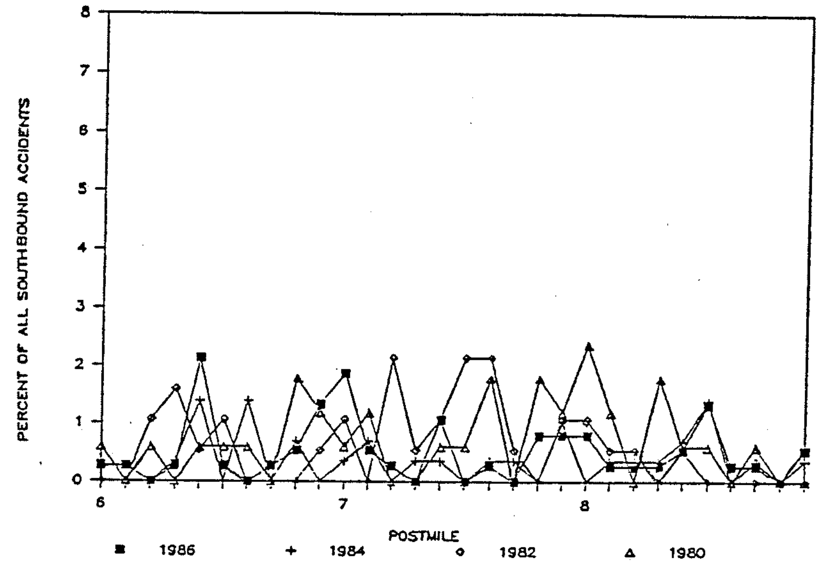

FIGURE 20a

SR-55: PERCENT ACCIDENTS BY TENTH-MILE
SOUTHBOUND, POSTMILES 6 TO 9

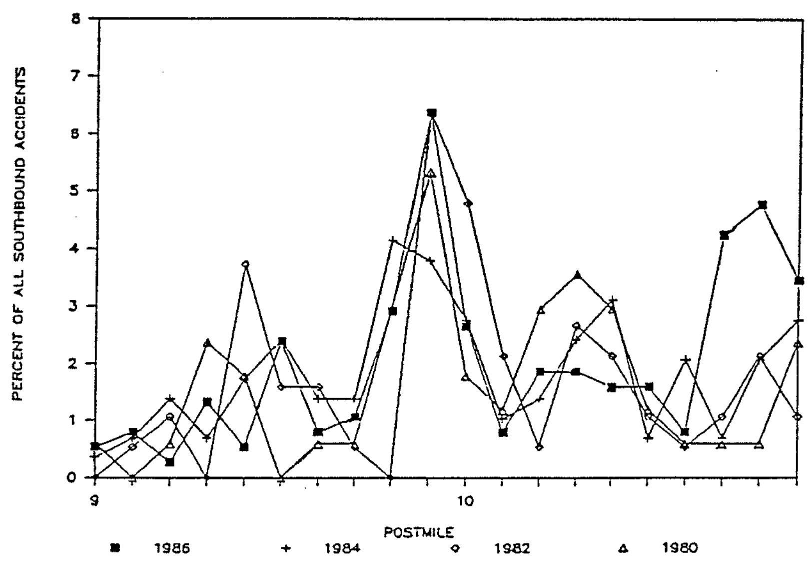

FIGURE 20b

SR-55: PERCENT ACCIDENTS BY TENTH-MILE
SOUTHBOUND, POSTMILES 9 TO 11

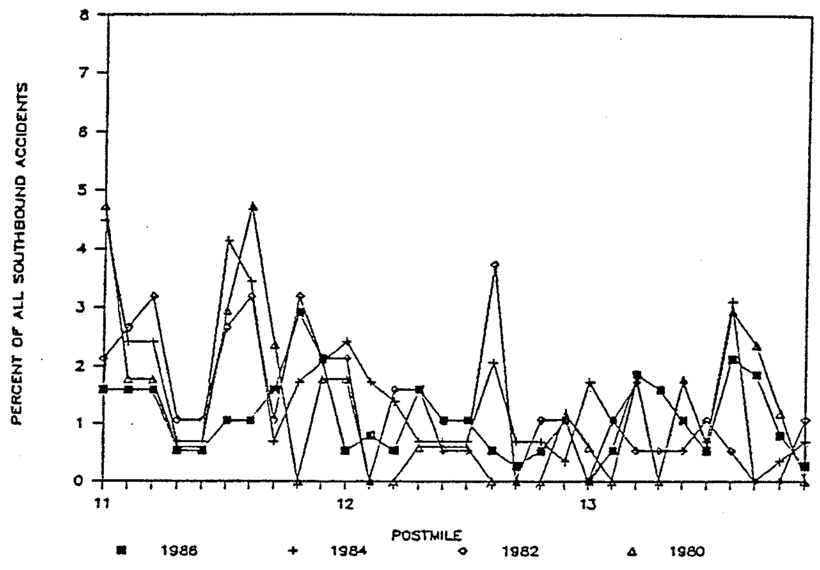

FIGURE 20c

SR-55: PERCENT ACCIDENTS BY TENTH-MILE
SOUTHBOUND, POSTMILES 11 TO 14

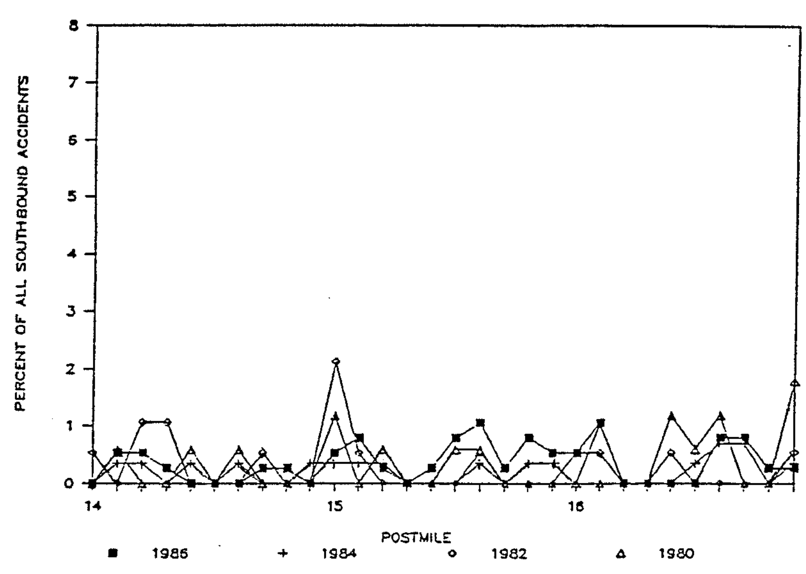

FIGURE 20d

SR-55: PERCENT ACCIDENTS BY TENTH-MILE
SOUTHBOUND, POSTMILES 14 TO 17

nine-month period. This area also encompasses a busy on-ramp and is 0.35 to 0.05 miles upstream from the off-ramp for the I-5 connector, and includes an HOV lane access/egress area. There is a corresponding new relief from accidents for the HOV period in the postmile 11.0 to 11.6 range, immediately upstream of the 10.7 to 11.0 range. Consequently, this shift represents a downstream migration of accidents similar to those found in the case studies of the SR-91 HOV lane.

Both northbound and southbound accidents are concentrated in particular postmile locations. However, the southbound locational distribution has shifted, pre-HOV versus post-HOV, while the northbound distribution has not.

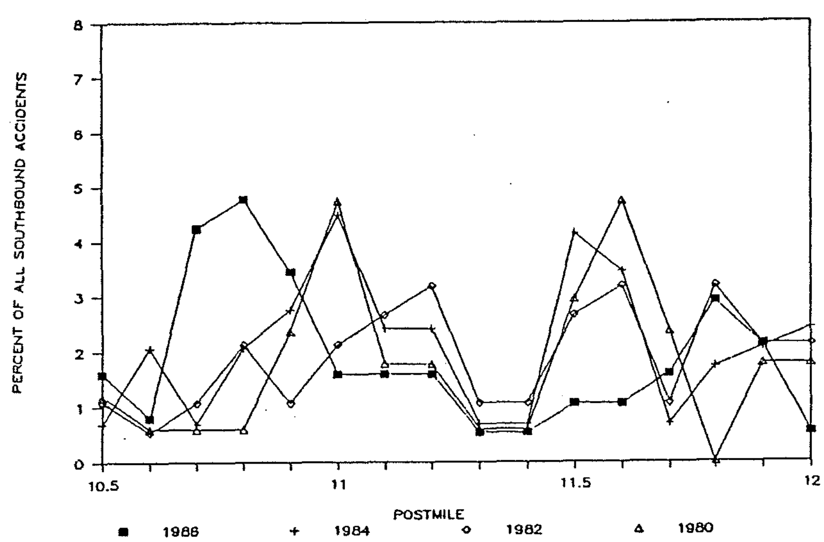

FIGURE 21

SR-55: PERCENT ACCIDENTS BY 10TH-MILE SOUTHBOUND, POSTMILES 10.5 to 12

Further investigation is required, taking into account the locations of HOV lane access/egress areas, collision locations (left roadway area versus other location), and accident characteristics, particularly those related to congestion patterns.

The percentages of all northbound accidents that occur within the postmile ranges of the HOV access/egress areas, for each of seven nine-month periods from December 1978-August 1980 through December 1985-August 1986, are graphed in Figure 22. There is no significant change in the percentage of accidents that occur within the access/egress areas in 1985-86, compared to prior years.

Southbound percentages are shown in Figure 23. As in the case of northbound accidents, there is no significant change over time in the percent of accidents occurring in the postmile ranges of the HOV access/egress areas.

It was found in a preliminary analysis of accident characteristics that a relatively higher proportion of accidents in the HOV period occurred in the vicinity of the number one lane, and a relatively higher proportion of these involved a lane-changing maneuver. However, further analyses revealed that the results of these preliminary analyses are unreliable because of the ambiguity in coding collision locations relative to freeway lanes. Unfortunately, it is not possible to compare specific collision locations before and after construction of the new inside lane. However, analyses of time trends in collision locations on the basis of broad definitions are useful indicators, and it is possible to compare collision locations for accidents within different postmile ranges for the same time period.

The collision locations of accidents in the postmile ranges of the access/egress versus elsewhere are shown in Figures 24 (northbound) and 25 (southbound). The locational differences between access/egress area accidents

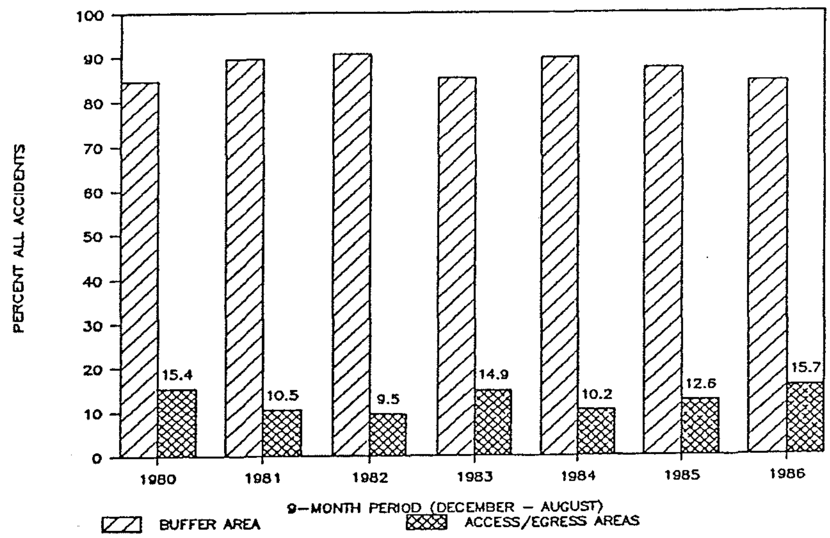

FIGURE 22

SR-55: NORTHBOUND ACCIDENTS
BY HOV BUFFER AND NON-BUFFER AREAS
BY NINE-MONTH PERIODS

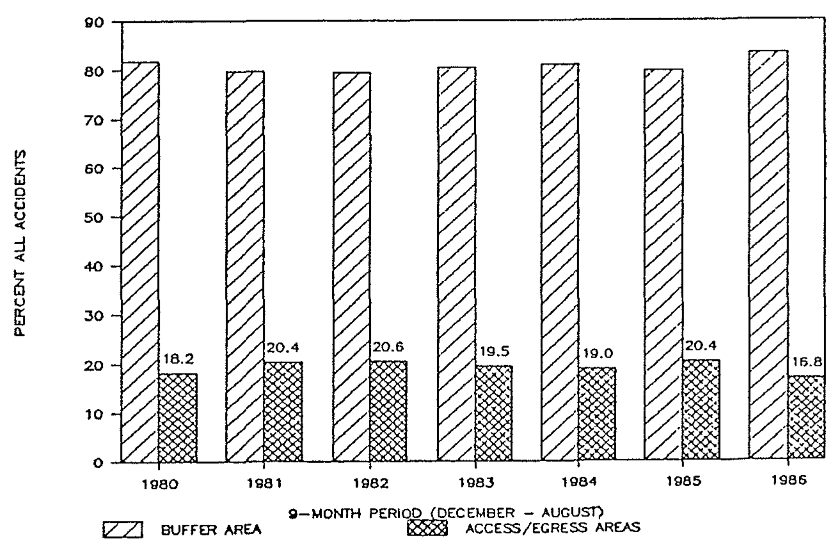

FIGURE 23

SR-55: SOUTHBOUND ACCIDENTS
BY HOV BUFFER AND NON-BUFFER AREAS
BY NINE-MONTH PERIODS

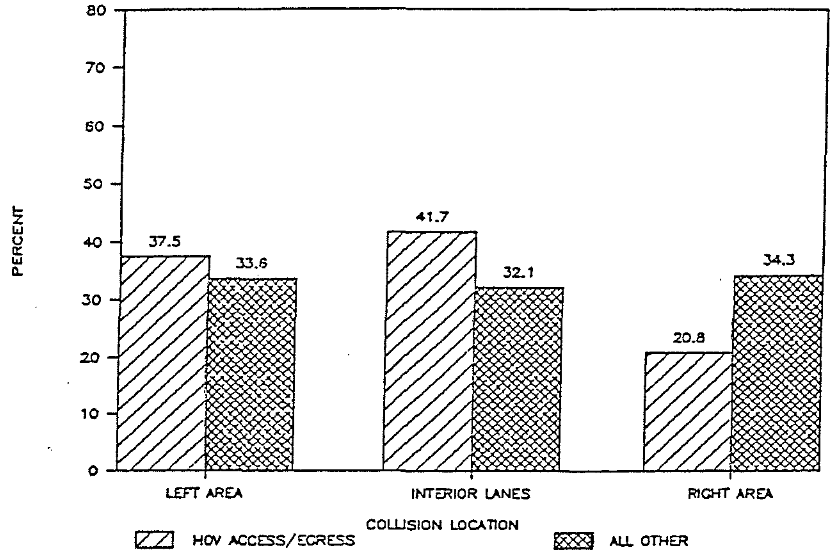

FIGURE 24

SR-55: COLLISION LOCATIONS NORTHBOUND
DECEMBER 1985-AUGUST 1986
BY POSTMILE RANGES

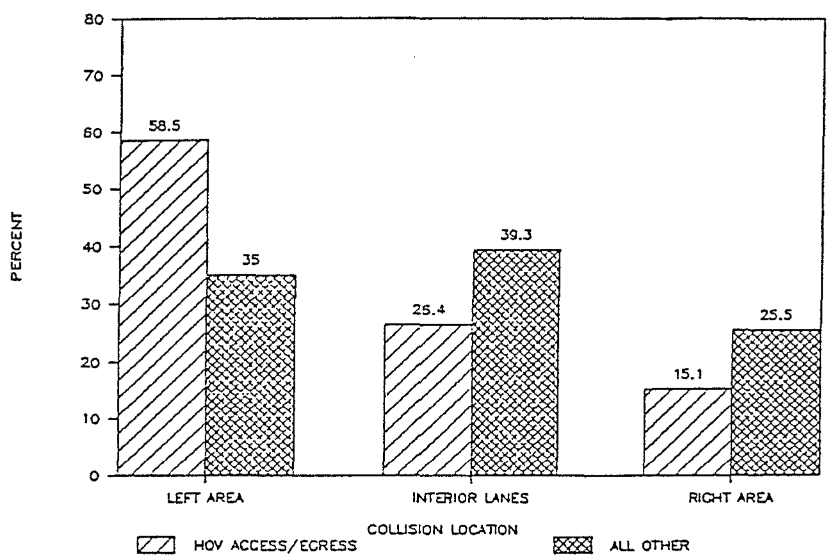

FIGURE 25

SR-55: COLLISION LOCATIONS SOUTHBOUND
DECEMBER 1985-AUGUST 1986
BY POSTMILE RANGES

and accidents in other postmile ranges are significant for the southbound accidents (Figure 24), but not for northbound accidents (Figure 25). Southbound accidents in the postmile ranges of the access/egress areas are relatively more concentrated in the left area of the roadway. The low levels of right-side accidents in the postmile ranges of the HOV access/egress areas are expected, as these areas are not located at or near ramps.

Comparisons of collision locations before and after installation of the HOV lane are difficult because of the potential for coding ambiguity introduced by the added special-use lane. However, limited analyses can be conducted using a gross locational categorization such as that employed in Figures 24 and 25.

Shown in Figures 26 (northbound) and 27 (southbound) are breakdowns of all accidents in the pre-HOV (six nine-month periods combined, 1980-1985) and post-HOV periods into four classes: (1) within the postmile range of the HOV access/egress areas, with the primary collision located left of the interior lane(s), (2) within the postmile range of the access/egress areas, with the collision located in the interior lane(s) or right of them, (3) outside of the postmile range of the access/egress areas, with the collision located left of the interior lane(s), and (4) outside of the postmile range of the access/egress areas, with the collision located in the interior lanes or to the right of them.

For the northbound accidents (Figure 26), there is very little difference between the locational breakdowns for the pre-HOV versus post-HOV periods. There is a slight (statistically insignificant) increase in the total percent of accidents located in the ranges of the HOV access/egress areas, but there is no difference in the split between left and non-left locations for access/egress area accidents, pre-HOV versus post-HOV. There is

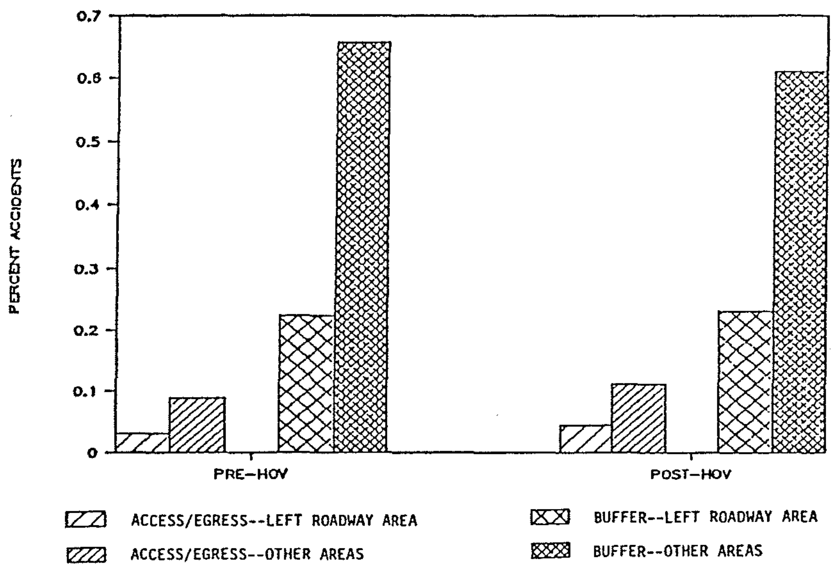

FIGURE 26

SR-55: LOCATIONAL DISTRIBUTIONS OF NORTHBOUND ACCIDENTS PRE-HOV AND POST-HOV IN FOUR CATEGORIES

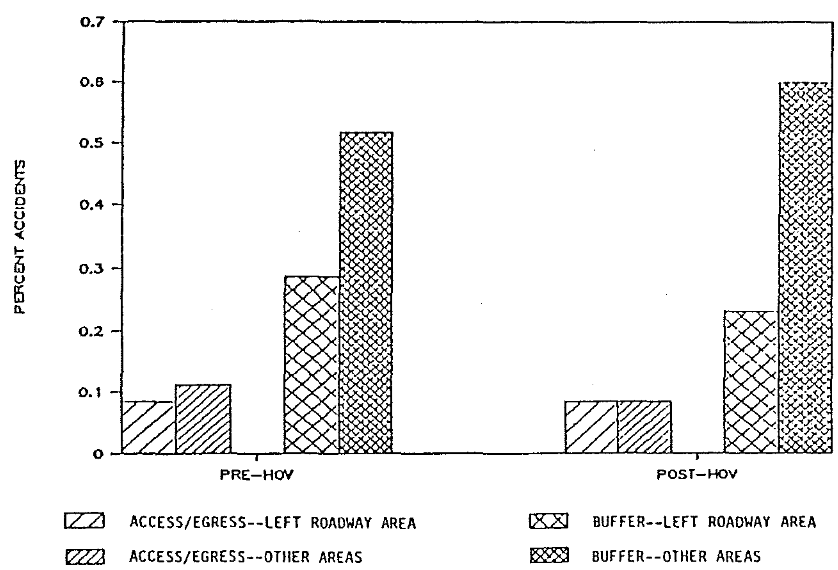

FIGURE 27

SR-55: LOCATIONAL DISTRIBUTIONS OF SOUTHBOUND ACCIDENTS PRE-HOV AND POST-HOV IN FOUR CATEGORIES a slight decrease over time in the percent of accidents located outside the HOV access/egress areas in non-left locations.

For southbound accidents (Figure 27), there is no significant change over time in the total percent of accidents located in the range of the HOV access/egress areas. The relatively high proportion of southbound accidents in the HOV access/egress areas located on the left side of the freeway is approximately the same before and after the HOV lane, and this explains why left-area accidents in the access/egress areas are outstanding in Figure 25. For accidents outside the range of the HOV access/egress areas, there is a decrease in the proportion of accidents located in the left roadway area.

As a final locational analysis, the distributions by postmile of northbound and southbound left-area accidents are shown in Figures 28 and 29. The distributions are limited to the postmile 7.0 to 12.0 range, with 0.2 mile increments. Northbound (Figure 28), there is a new peak in the HOV period for left-area accidents in the postmile 7.4-7.8 range, but this is offset by a relative decrease in left-area accidents in the immediate upstream range of postmile 8.2 to 8.8. There is no HOV access/egress area in the range of the new peak. Downstream, in the 10.8 to 11.0 range, there is a new peak that coincides with an HOV access/egress area. This increased concentration of accidents is not explainable in terms of accident migration from an adjacent postmile range.

Southbound (Figure 29), there has been a substantial increase in the peak in left-area accidents in the HOV period in the range of postmile 9.4-9.6, which coincides with an HOV access/egress area. This new peak in the vicinity of postmile 8.4 is well within the range of the HOV buffer; consequently, there is no explanation for the increase except in terms of possible buffer violations. Other distributional changes in southbound

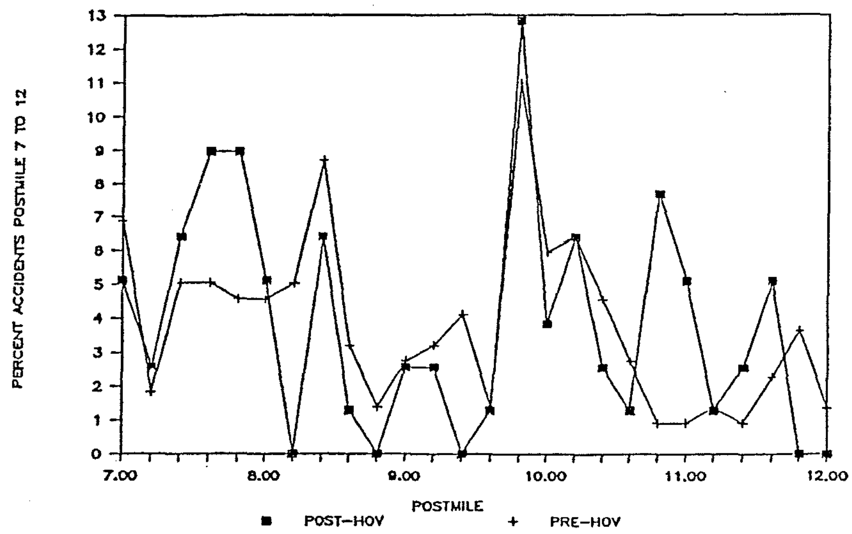

FIGURE 28

SR-55: NORTHBOUND LEFT-AREA ACCIDENTS BY POSTMILE
(0.2 MILE CATEGORIES, POSTMILE 7.0 THROUGH POSTMILE 12.0)

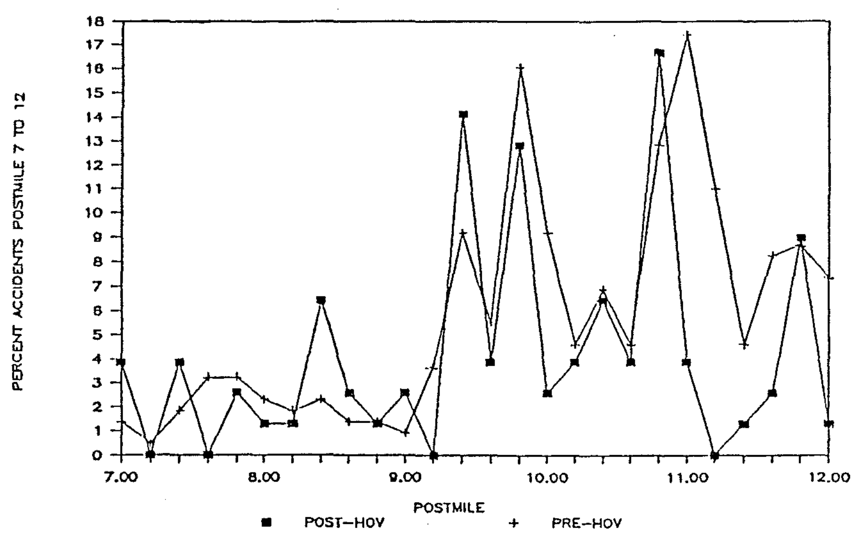

FIGURE 29

SR-55: SOUTHBOUND LEFT-AREA ACCIDENTS BY POSTMILE
(0.2 MILE CATEGORIES, POSTMILE 7.0 THROUGH POSTMILE 12.0)

left-area accidents appear to be shifts from adjacent locations reflecting accident migration due to changes in congestion patterns.

The total number of unexplainable accidents in the new concentrations of left area accidents identified in Figures 28 and 29, over and above the number that would be expected based on previous distributional patterns, is 13 in a nine-month period. This corresponds to less than a 2 percent increase in SR-55 accidents over the course of a year.

There is also an increase in the concentration of southbound accidents in the postmile range from 10.91 (end of the HOV access/egress area) to 10.646 (off-ramp to the I-5 connector). In nine-month periods prior to HOV implementation, between 1.5 percent and 6.3 percent of all southbound accidents were located in this postmile range, with 3.9 percent located there in December 1983-August 1984; in the nine-month HOV period, 8.5 percent of all southbound accidents were located there. This shift in location is statistically significant. However, there is no significant difference between the percent of accidents with collision locations in the left roadway area in the postmile 10.91-10.646 range versus all other non-HOV access/egress areas.

CAUSAL FACTORS IN CHANGING ACCIDENT CONCENTRATIONS

To help determine any causal factors involved in the shifts of accident locations noted for SR-91, four combinations of time-of-day and locations were analyzed that account for almost all of the increase in total weekday accidents on eastbound SR-91 between 2:00 and 7:59 PM for the fourteen months July 1985-August 1986 compared to previous fourteen-month periods. The four concentration groups are:

1. 2:15-3:29 PM / all locations: postmiles R8 to R17 Los Angeles (9 miles)

2. 4:00-5:44 PM / postmiles R14.5 to R15, R15.5 to R16, and R16.5 to R17 (1.5 miles)

3. 5:00-7:14 PM / postmiles R10 to R11.5 (1.5 miles)

4. 5:45-7:14 PM / postmiles R15.5 to R17 (1.5 miles).

The four groups accounted for a 235 percent increase in accidents for the fourteen-month period July 1985-August 1986 over July 1983-August 1984 (Figure 30). The increase from 95 to 117 accidents for all other time interval and location combinations (23 percent) from 1983-84 to 1985-86 is within the range expected from traffic volume increases. Consequently, the four groups of accident concentrations can be a key to understanding changes in the traffic safety situation on SR-91. (There is no relationship between the time-location dimensions and whether or not an accident involves injuries.)

The percent of total accidents in each fourteen-month period accounted for by each of the four concentration groups are graphed in Figure 31. There are substantial increases in the relative concentrations of accidents in groups 2 and 3 between 1981-82 and 1983-84, indicating that factors contributing to these concentrations have been on the rise since 1981-82. However, the increases in the relative concentrations of accidents in groups 1 and 4 are solely between 1983-84 and 1985-86.

Further evidence of causality is obtained by comparing the characteristics of the accidents among the groups for the 1985-86 period. Restricting this comparison to the 1985-86 period allows comparisons of collision locations, because it can be assumed that the ambiguity in location coding related to the HOV lane is randomly distributed among all accident

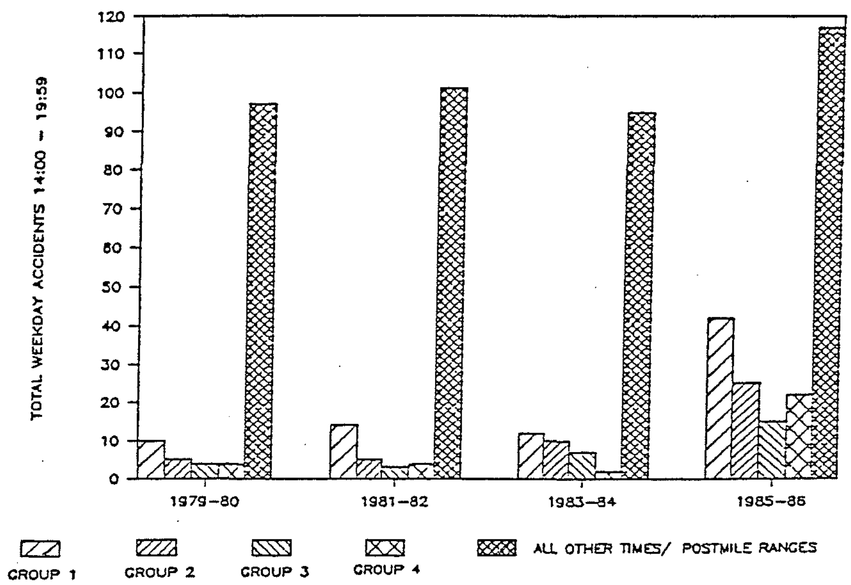

FIGURE 30

SR-91: TOTAL EASTBOUND ACCIDENTS
(POSTMILE R8 LA - R17 LA) BY 14-MONTH PERIOD
BY TIME/POSTMILE CONCENTRATION GROUPS

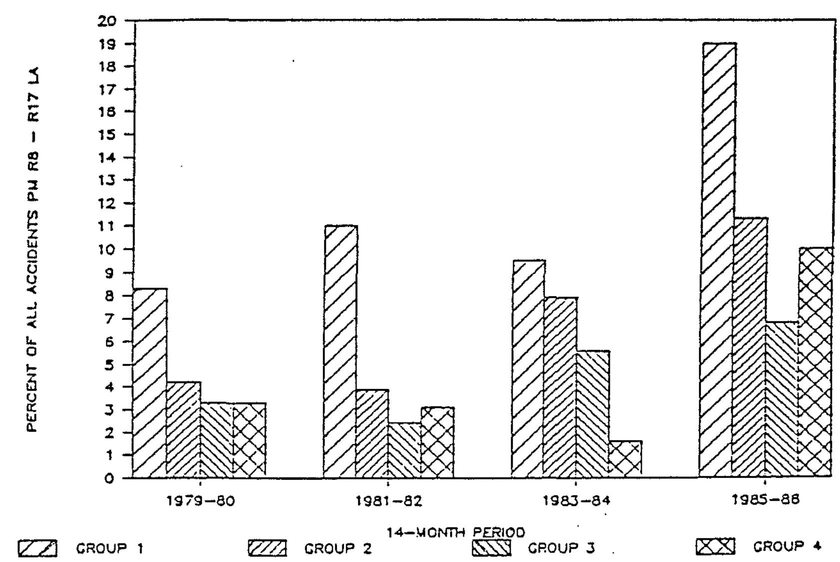

FIGURE 31

SR-91: PERCENT OF ALL WEEKDAY ACCIDENTS, 2:00-8:00 PM
BY 14-MONTH PERIOD, BY TIME/POSTMILE CONCENTRATION GROUPS

times and locations in the HOV period. Importantly, there were no significant differences among the groups on the basis of location of the primary collision.

It was found that group 4 accidents are more likely than accidents of other groups to be rear-end collisions (p = .04), as shown in Figure 32. However, the greatest differences among the groups are in terms of the movements of the first two vehicles prior to collision, as shown in Figure 33: a higher proportion of the vehicles involved in group 2 and group 4 accidents were stopping or slowing, while a higher proportion of vehicles involved in group 3 accidents were changing lanes. No other accident characteristics were significantly different among the groups.

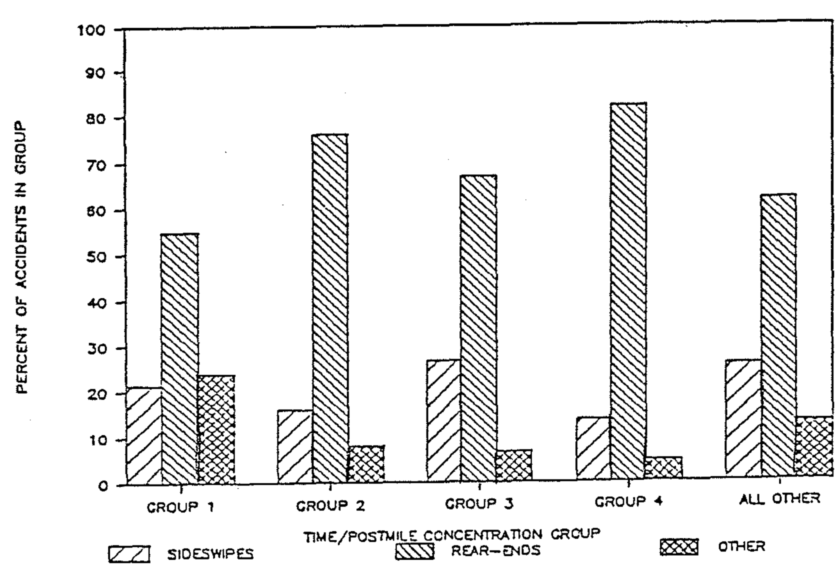

FIGURE 32

SR-91: COLLISION TYPES BY TIME/POSTMILE CONCENTRATION GROUPS
(JULY 1985-AUGUST 1986)

Indications of causality for the increased concentrations of accidents in each of the time-location groups were uncovered by investigating the changes in congestion patterns over time (Figures 11 and 12) and by analyzing the changes over time in the characteristics of the accidents in each group. For group 1 accidents, three characteristics were found to vary systematically over time, as shown in Figure 34: The percent of all collisions that are rear-end collisions increased significantly over time. Second, the percent of all collisions that involved at least one of the first two vehicles slowing or stopping also increased significantly, as did the percent of collisions involving a light truck (pickup or van) as the second vehicle. The accelerating increase over time in these three characteristics indicates increasing congestion levels during the interval 2:15-3:29 PM as a cause of

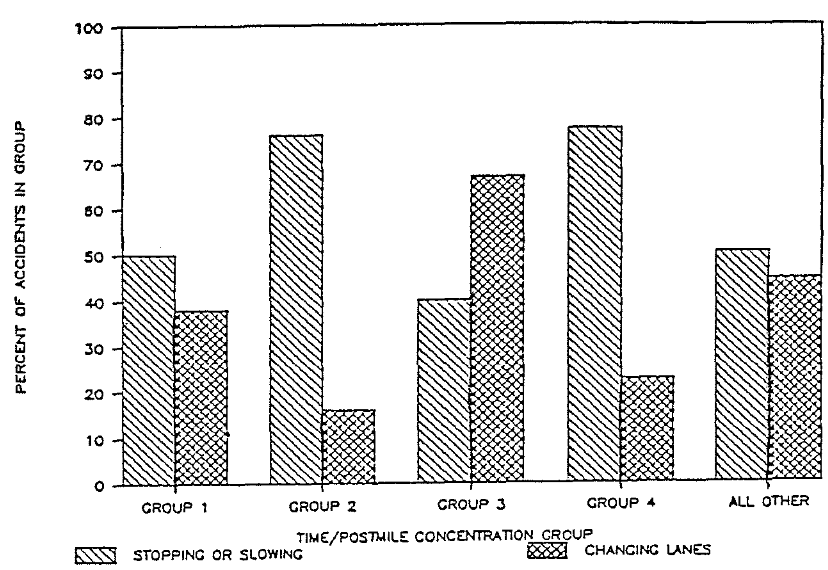

FIGURE 33

SR-91: MOVEMENTS PROCEDING COLLISION
BY TIME/POSTMILE CONCENTRATION GROUPS
(JULY 1985-AUGUST 1986)

this increased accident concentration. There is no indication, based on the location of these accidents, that the HOV lane is a primary contributor to this effect.

For the second concentration group (4:00-5:44 PM, postmiles 14.5-15, 15.5-16, and 16.5-17), five characteristics were found to be systematically changing over time, as shown in Figure 35: percent rear-end collisions, percent collisions with a primary vehicle slowing or stopping, percent collisions with a vehicle changing lanes, and percent collision with a light truck as the second party. Each of these trends is statistically significant. With the exception of the latter characteristic, there has been little change in these characteristics between 1983-84 and the HOV period

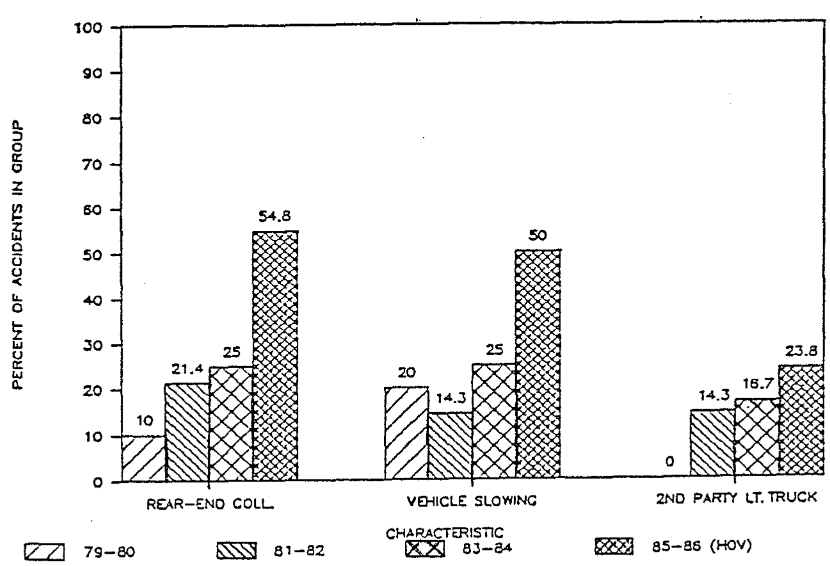

FIGURE 34

SR-91: ACCIDENT CHARACTERISTICS FOR TIME/POSTMILE CONCENTRATION GROUP 1
(2:15-3:30 PM, POSTMILES R8 TO R17)
BY FOURTEEN-MONTH PERIOD

1985-86. Increasing congestion is indicated, as in the case of group 1 accidents.

For the third concentration group, only one characteristic varies systematically over time, and that is the percent of collisions that involves at least one of the first two primary vehicles involved in a lane-changing maneuver (Figure 36). This increase in accident concentration is largely due to increased weaving, possibly caused by the lane drops associated with two off-ramps to major arterials. This increased concentration of accidents is apparently unrelated to the HOV lane.

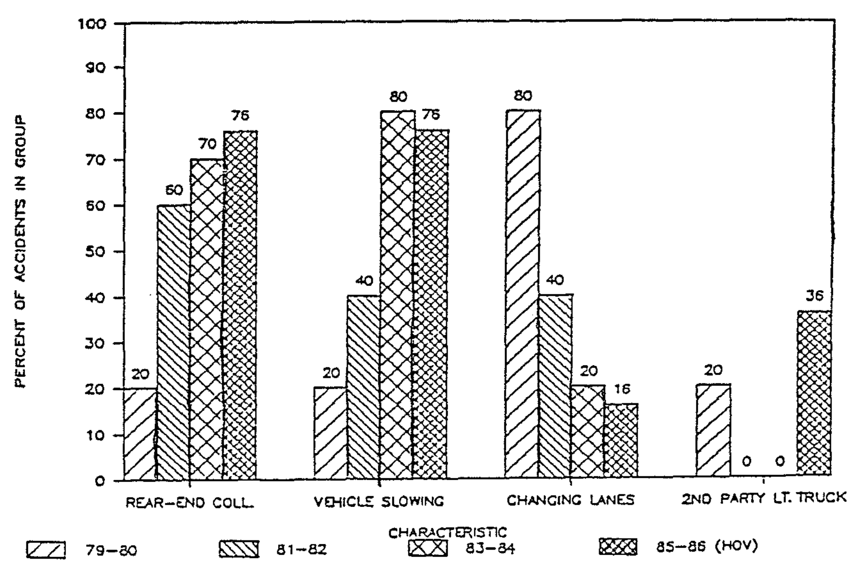

FIGURE 35

SR-91: ACCIDENT CHARACTERISTICS FOR TIME/POSTMILE CONCENTRATION GROUP 2
(4:00-5:45 PM, POSTMILES 14.5, 15.5, AND 16.5)
BY FOURTEEN-MONTH PERIOD

As shown in Figure 12, the postmile range R15.5 to R17 is subject to heavy congestion for much of the period 5:45-7:14 PM, and such congestion was not generally present in the pre-project period (Figure 11).

Concentration group 4 accidents in the 1985-86 period are congestion related, with about 82 percent of them being rear-ends and 77 percent involving slowing or stopping maneuvers. It can be concluded that concentration group 4 accidents are due to traffic bottlenecks at the end of the HOV lane and downstream of the project. This effect is consistent with the migration of accidents detected in the case studies of added mixed-flow lanes (Section 2).

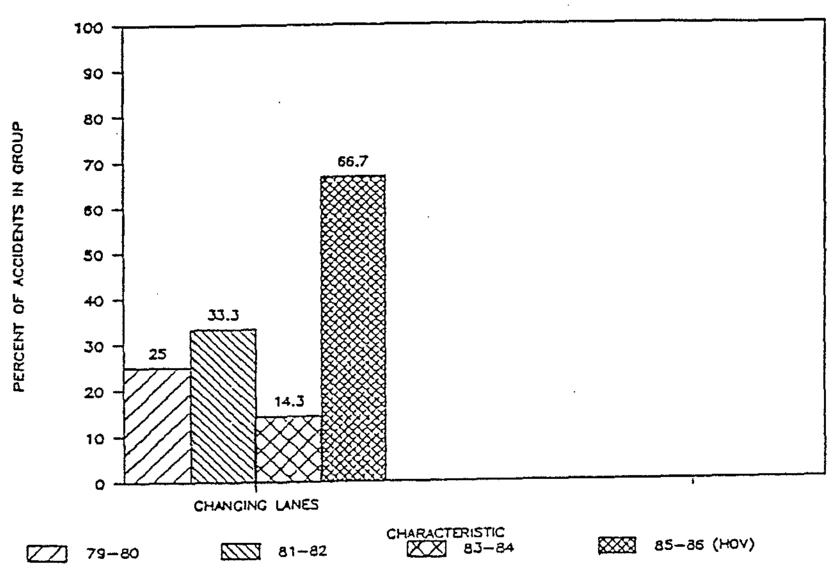

FIGURE 36

SR-91: ACCIDENT CHARACTERISTICS FOR TIME/POSTMILE CONCENTRATION GROUP 3
(5:45-7:15 PM, POSTMILES R10 TO R11.5)
BY FOURTEEN-MONTH PERIOD

ACCIDENTS AND CHANGING CONGESTION PATTERNS

Congestion diagrams of the type described previously were also available for SR-55 for both directions at three points in time: June 1985 (pre-HOV), January, and June 1986 (both post-HOV). These diagrams depict average speeds at postmile locations by time of day and are produced from data recorded by a fleet of cars making repeated trips along the freeway. The data provided by Caltrans were computerized, and are reproduced in Figures 37 through 42 for the three dates and two directions.

In comparing the patterns of congestion for northbound SR-55 during the PM period (Figures 37, 39, and 41), there is a general relief of congestion from June 1985 (Figure 37) to January 1986 (Figure 39), with congestion in the latter period being more segmented, particularly along the time dimension. The added capacity represented by the HOV apparently aided in congestion relief in the first few months of operation, although the June to January comparison is clouded by seasonal factors. However, a comparison of the northbound June 1985 (Figure 37) and June 1986 (Figure 41) congestion diagrams reveals that within seven months of the implementation of the added lane, extremely heavy congestion has returned to most of the length of northbound SR-55 over most of the 2:30 PM to 6:45 PM time period. The downstream shifting of congestion, so apparent in the case of SR-91 (Figures 11 and 12) is only present in the shift of the onset of congestion from approximately postmile 6.5 in 1985 to postmile 7.0 in 1986.

With regard to southbound congestion during the AM period, the comparison between June 1985 (Figure 38) and January 1986 (Figure 40) indicates that the level of congestion relief exhibited for the northbound PM situations is not realized for the southbound AM situation. There is increasing congestion in the 8:30 to 9:45 time period in January, as compared

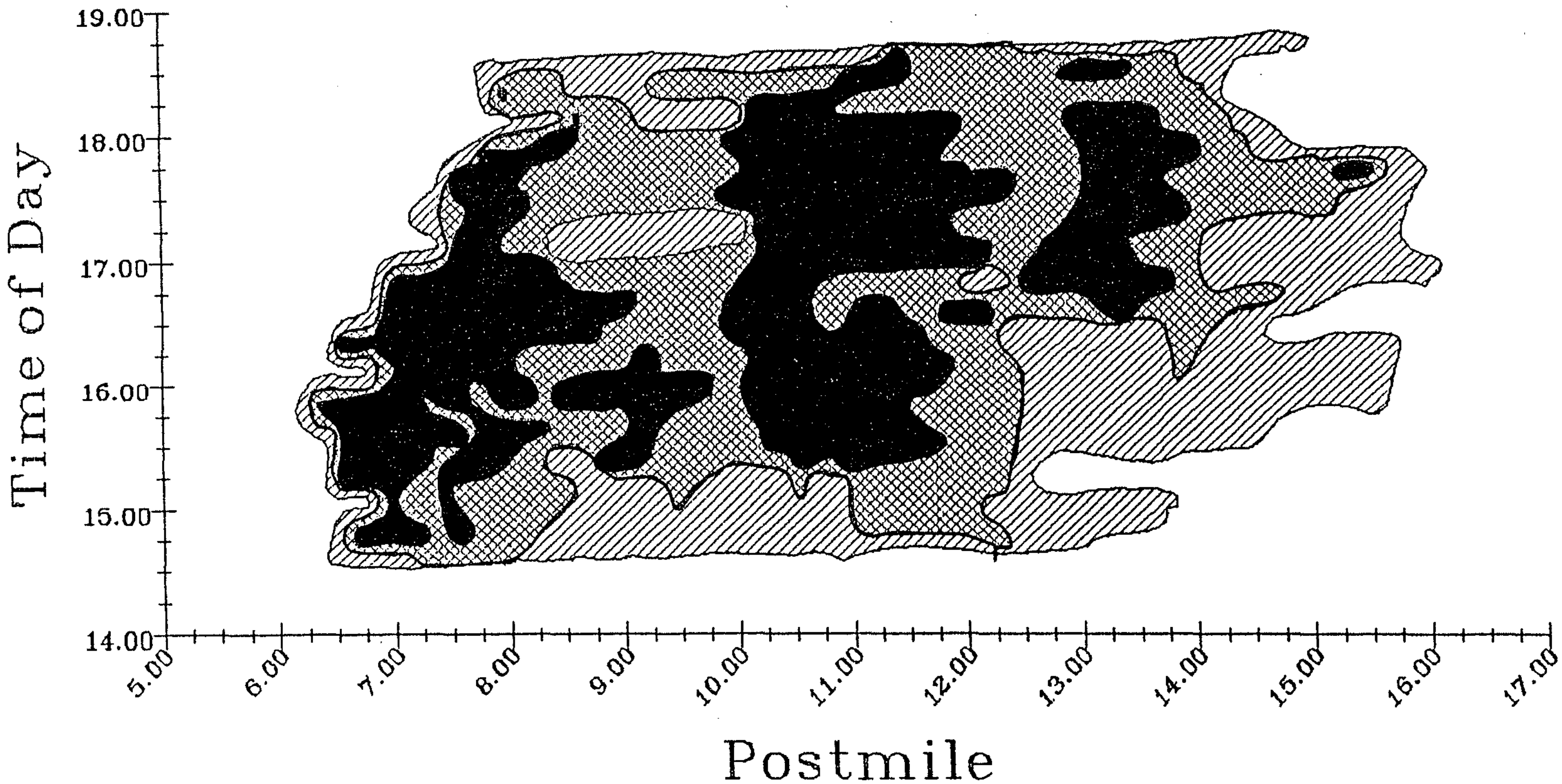

FIGURE 37

CONGESTION DIAGRAM FOR NORTHBOUND SR-55
ON JUNE 4, 1985

OVER 50 MPH 35-50 MPH 20-35 MPH 0-20 MPH

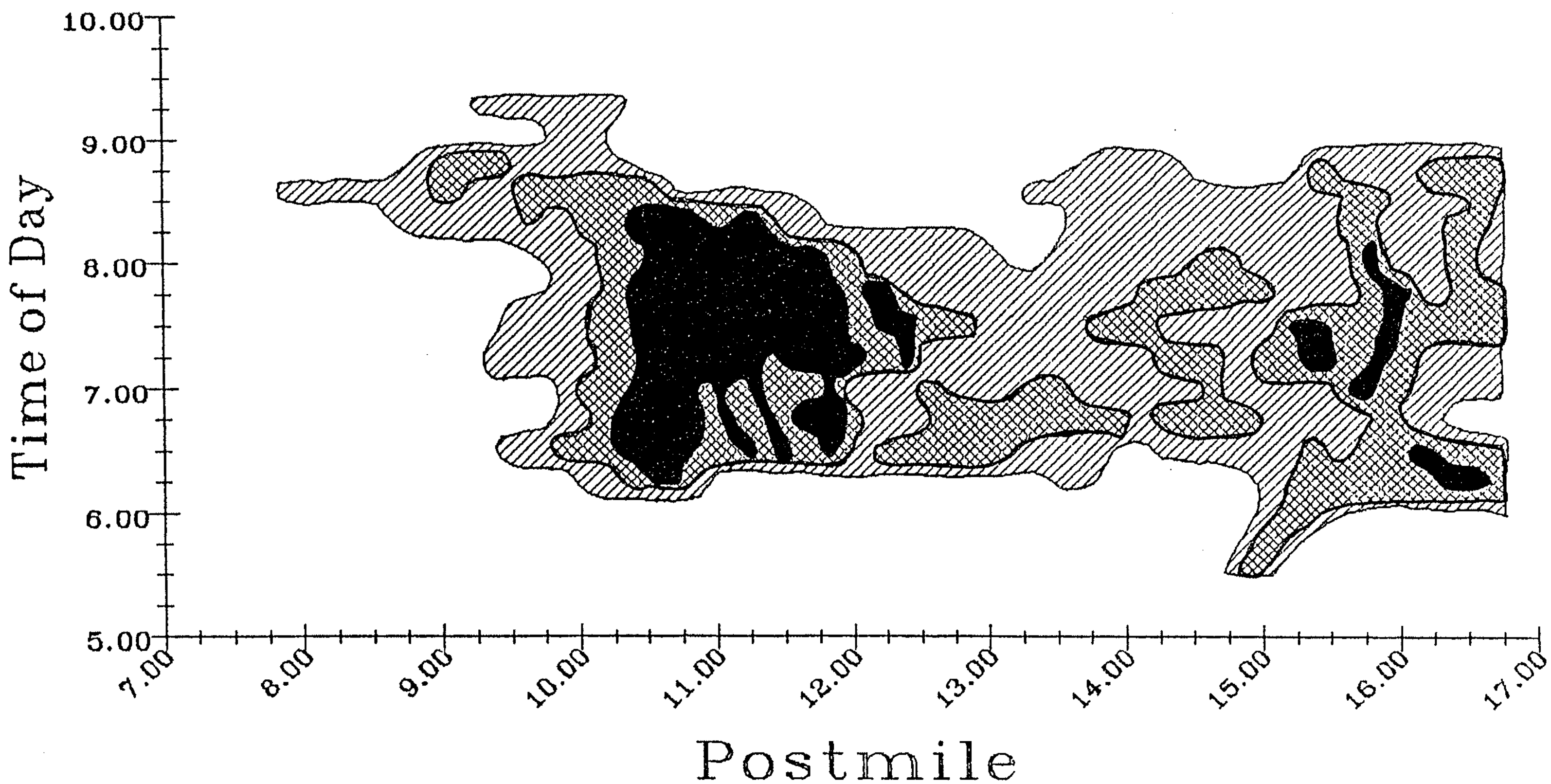

FIGURE 38

CONGESTION DIAGRAM FOR SOUTHBOUND SR-55
ON JUNE 4, 1985

OVER 50 MPH　35-50 MPH　20-35 MPH　0-20 MPH

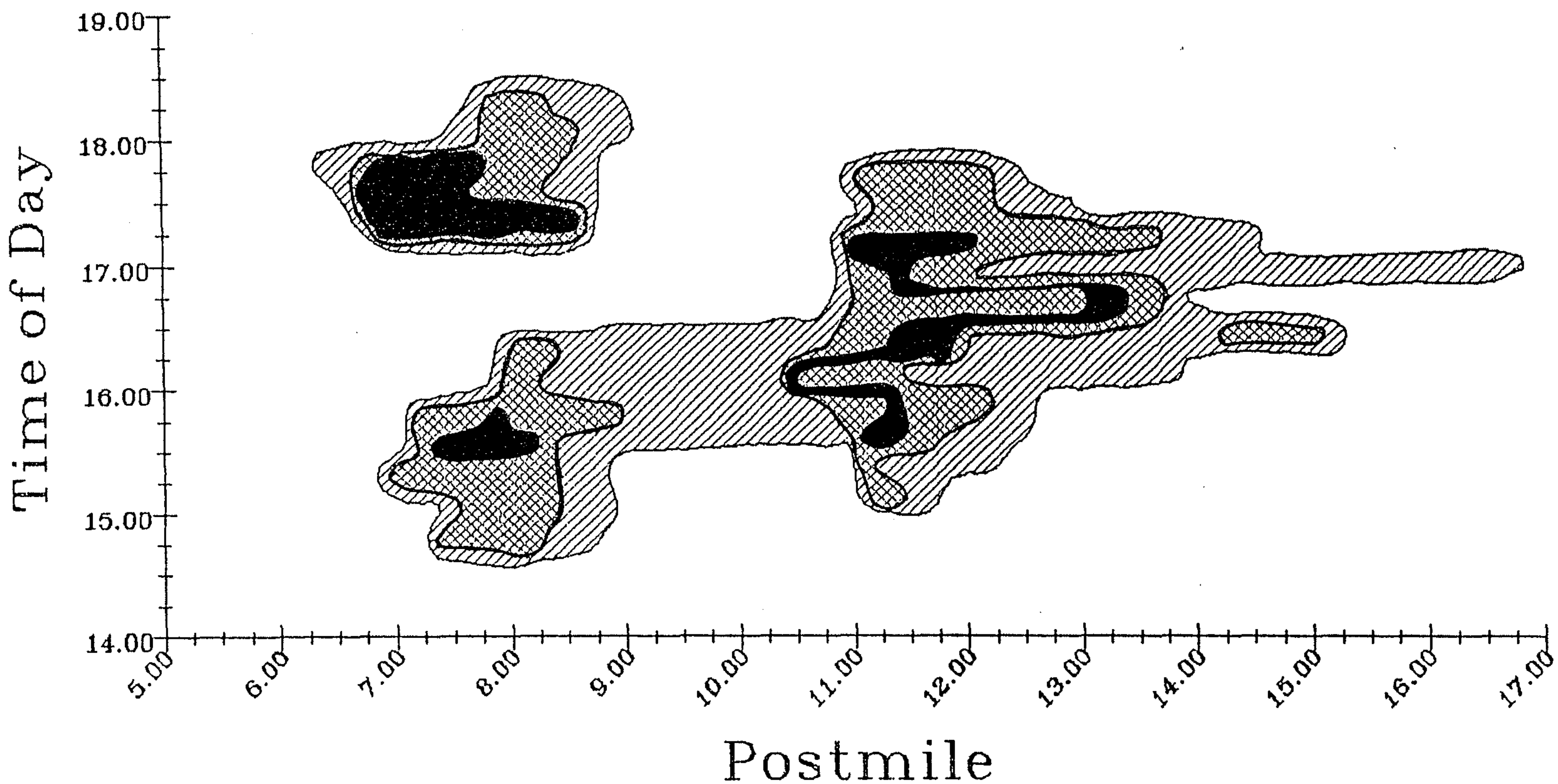

FIGURE 39

CONGESTION DIAGRAM FOR NORTHBOUND SR-55
ON JANUARY 14, 1986

OVER 50 MPH | 35-50 MPH | 20-35 MPH | 0-20 MPH

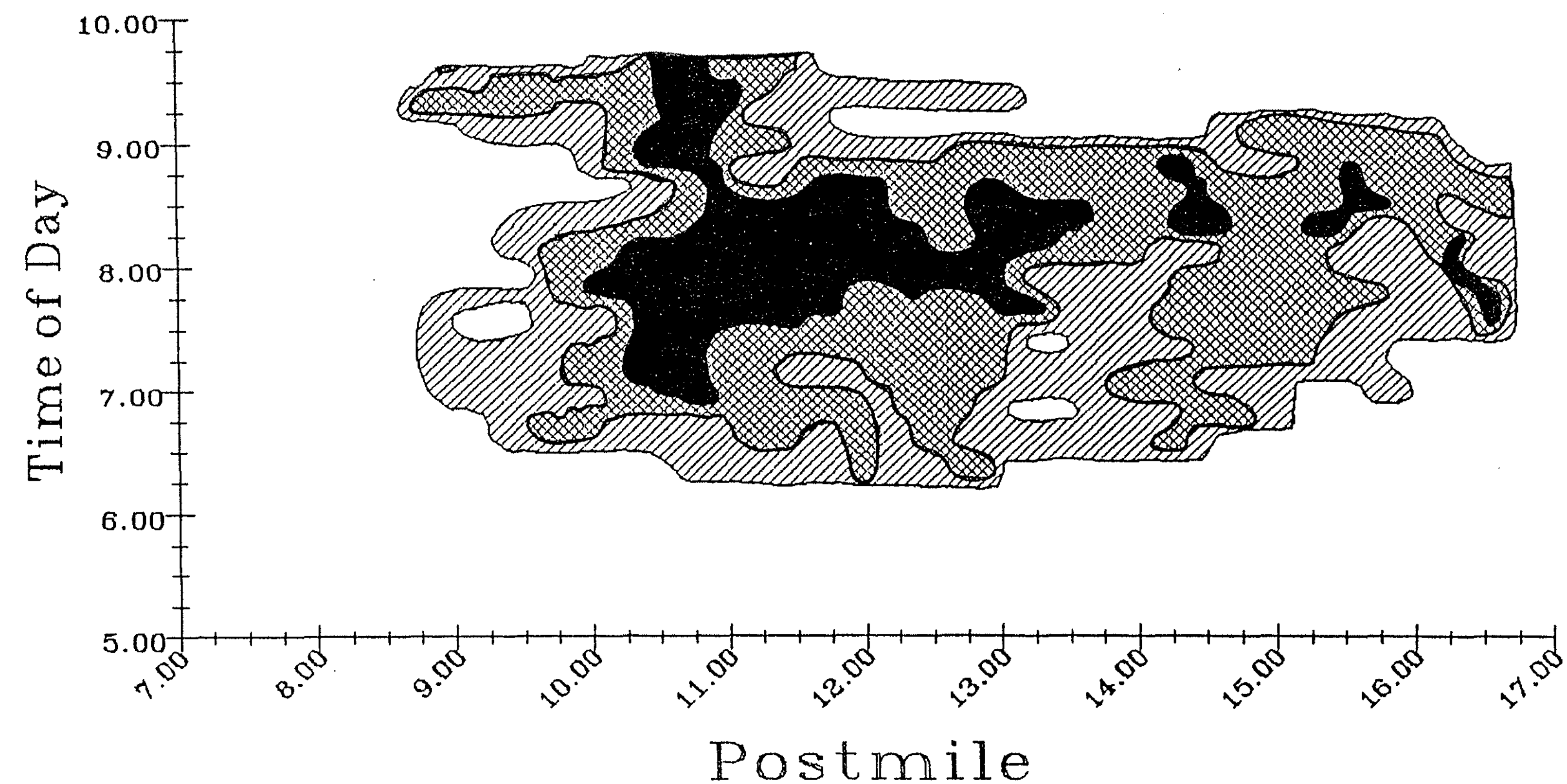

FIGURE 40

CONGESTION DIAGRAM FOR SOUTHBOUND SR-55
ON JANUARY 14, 1986

OVER 50 MPH — 35-50 MPH — 20-35 MPH — 0-20 MPH

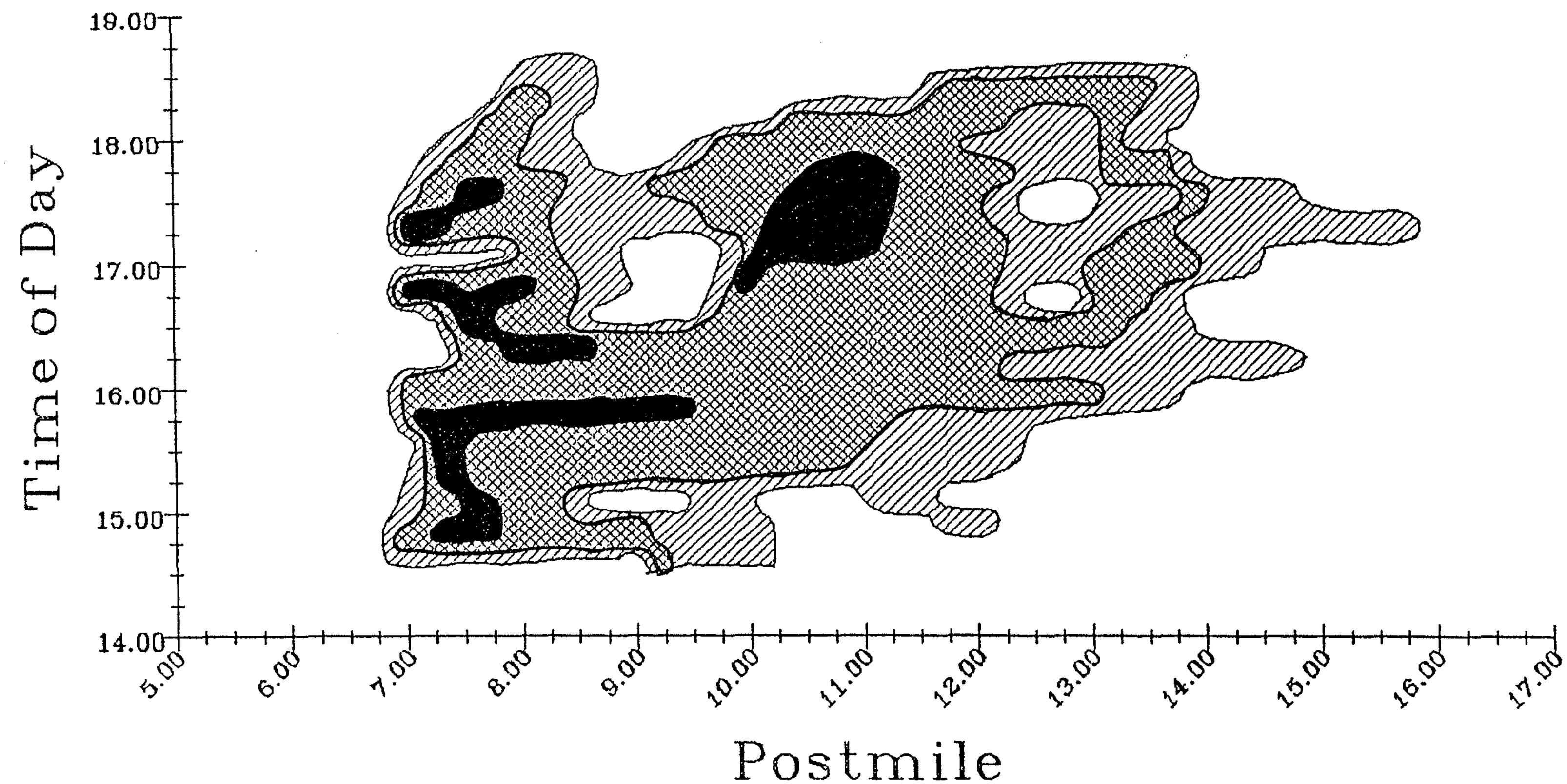

FIGURE 41

CONGESTION DIAGRAM FOR NORTHBOUND SR-55
ON JUNE 3, 1986

OVER 50 MPH
35-50 MPH
20-35 MPH
0-20 MPH

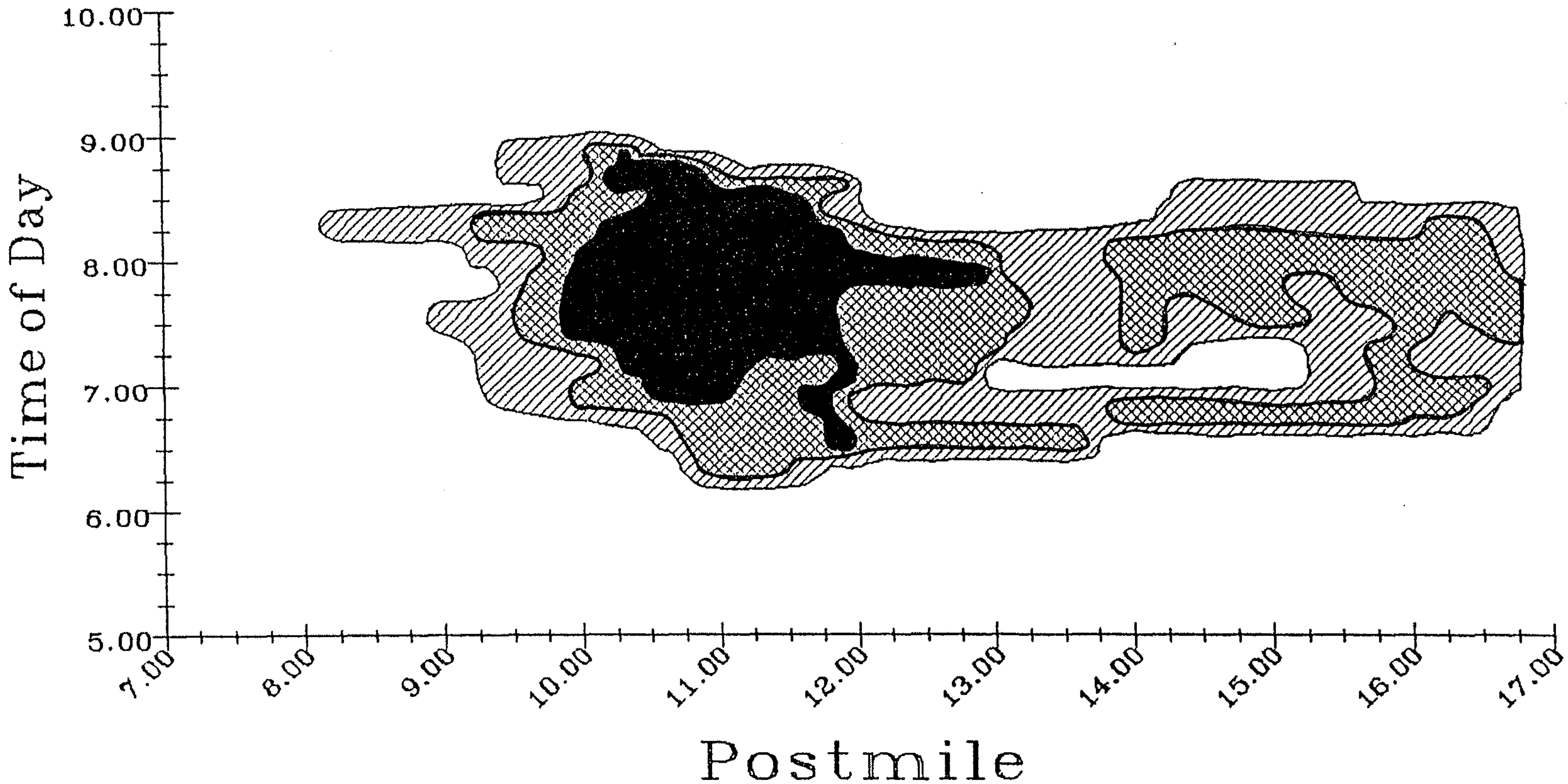

FIGURE 42

CONGESTION DIAGRAM FOR SOUTHBOUND SR-55
ON JUNE 3, 1986

OVER 50 MPH — 35-50 MPH — 20-35 MPH — 0-20 MPH to the previous June. But by June 1986 (Figure 42), the congestion pattern of the previous year is re-established, with the exception that upstream congestion (in the range of postmiles 15.0 to 17.0) is relieved. This upstream relief is consistent with, but less accentuated than, the changes in congestion patterns on SR-91.

These changes in congestion patterns reveal that there has been a substantial degree of latent demand for travel on SR-55. There is increased demand, and perhaps motorists have taken advantage of the extra freeway capacity provided by the added HOV lane and are making new and/or diverted trips on the freeway. These results indicate that the assumption of latent demand for AADT estimates is more appropriate than the assumption of no latent demand.

Tests were conducted to establish the extent to which accidents on SR-55 are related to congestion, and how this relationship might be changing over time. It was established in a preliminary analysis that the proportions of accidents involving three or more vehicles and the proportions of accidents that are sideswipes or rear-end collisions are up, post-HOV versus pre-HOV periods. Similarly, property damage accidents are up, versus injury accidents. All of these types of accidents are generally congestion related. A further investigation was conducted in which comparisons were made between the pre-HOV and post-HOV time periods and for the postmile ranges corresponding to HOV access/egress and buffer areas.

Expected levels of congestion were assigned to all peak-period accidents that occurred during two time periods. The expected congestion levels were measured in terms of the observed speed categories in the congestion diagrams of Figures 37 though 42: greater than 50 MPH, 35-50 MPH, 20-35 MPH, and less than 20 MPH. Peak periods were defined to be the periods covered by the congestion diagrams: 2:30 PM-7:00 PM northbound, and 5:30 AM-10:00 AM southbound. And the relevant time periods were assumed to be April through July 1985 (pre-HOV, corresponding to the congestion diagrams of June 1985) and December 1985 through August 1986 (post-HOV, corresponding to the diagrams of January and June 1986). The assignment of expected congestion levels to accidents was accomplished for the post-HOV time period by interpolating between the congestion diagrams of January and June and extrapolating the interpolation functions to December 1985 and July-August 1986.

The expected congestion levels at the postmile location and time of occurrence of weekday peak northbound accidents is broken down in Figure 43 by pre-HOV and post-HOV time periods. There is a statistically significant change over time in the breakdowns by congestion level: In the post-HOV period there are relatively fewer accidents in the mid-range of congestion (average speeds 20-35 MPH and 35-50 MPH), but there are substantially more accidents in areas and times estimated to have severe congestion (average speeds less than 20 MPH). This is an important indicator of the underlying cause of increases in the number of northbound accidents.

The congestion-level breakdowns for southbound accidents are shown in Figure 44. A pattern similar to that of northbound accidents is emerging for southbound accidents, but the change over time is much less dramatic in the southbound case. In fact, the change in the breakdowns by congestion level, pre-HOV versus post-HOV, is statistically insignificant. It can be concluded that, while congestion plays a role in both northbound and southbound accident causality, the two directions represent different situations.

To uncover further evidence concerning potential accident causality, the characteristics of accidents in the postmile ranges of the access/egress areas were compared over time and to the characteristics of accidents outside these

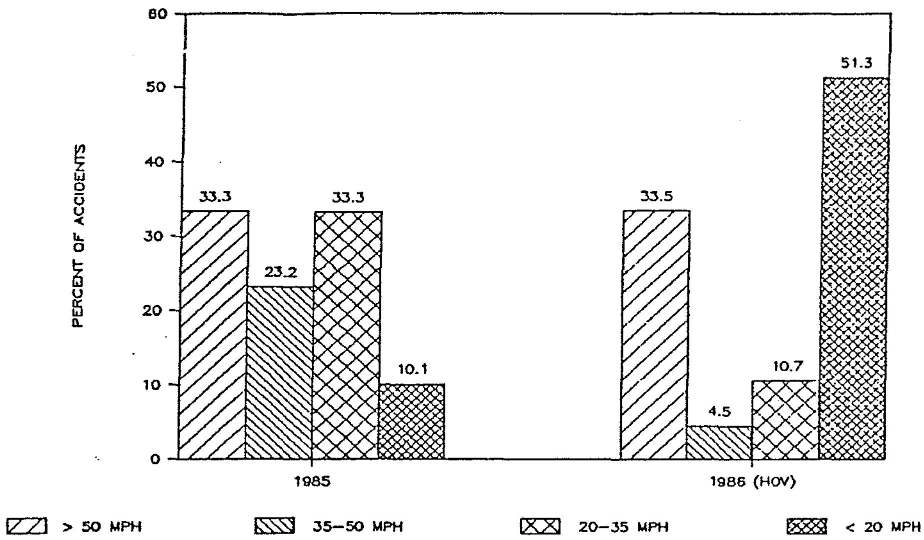

FIGURE 43

SR-55: NORTHBOUND WEEKDAY ACCIDENTS
2:30-7:00 PM BY ESTIMATED AVERAGE TRAFFIC SPEED

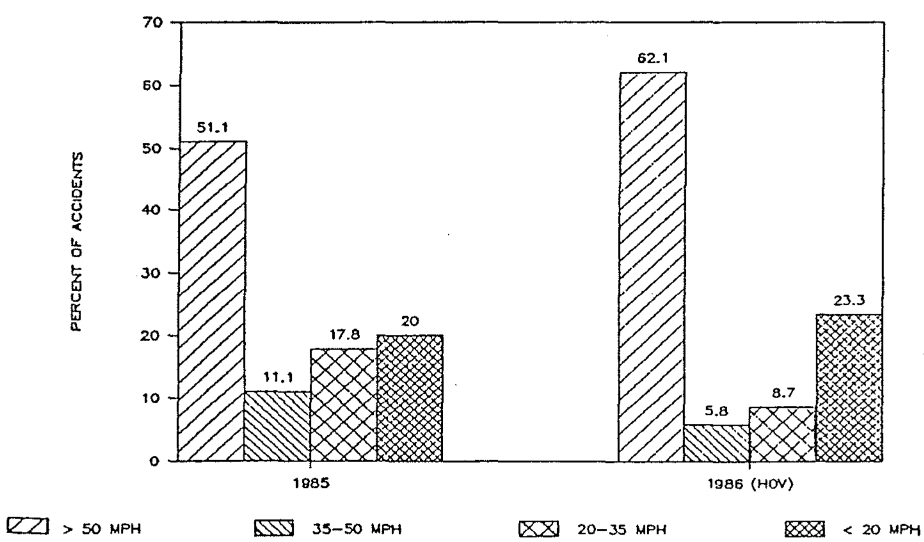

FIGURE 44

SR-55: SOUTHBOUND WEEKDAY ACCIDENTS
5:30-10:00 AM BY ESTIMATED AVERAGE TRAFFIC SPEED

ranges for the 1985-86 HOV period. Shown in Figure 45 are five accident characteristics broken down by pre-HOV versus post-HOV and postmile ranges corresponding to the HOV access/egress areas versus other areas (i.e., the HOV buffer area). Sideswipes are a significantly lower percent of post-HOV collisions within the access/egress areas, but there was no significant difference for pre-HOV collisions. Correspondingly, rear-end collisions are a significantly higher percent of access/egress collisions in the post-HOV period, again with no significant difference between access/egress and other areas in the pre-HOV period. There is also a significantly higher percentage

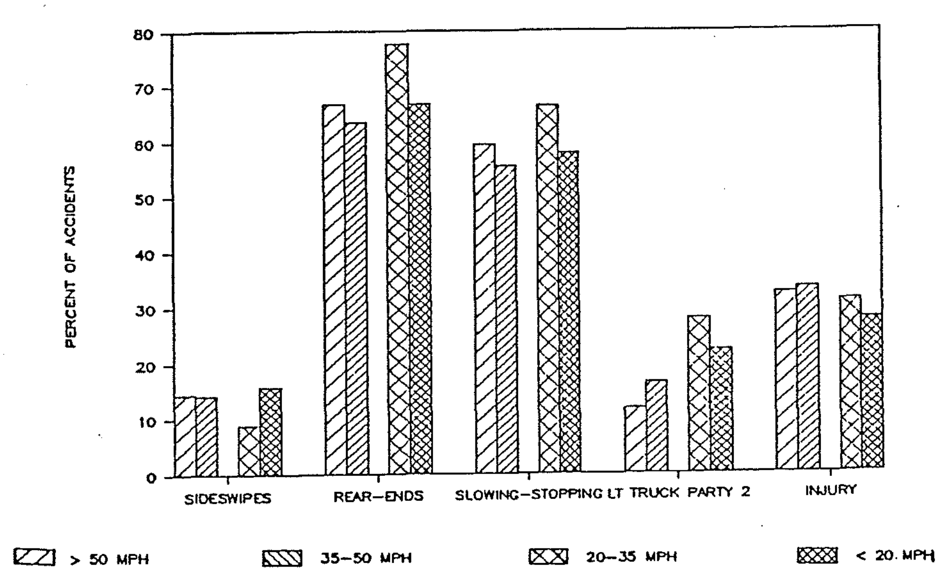

FIGURE 45

SR-55: ACCIDENT CHARACTERISTICS
BY PRE-HOV VERSUS POST-HOV
BY ACCESS/EGRESS AREAS VERSUS OTHER LOCATIONS

of accidents involving vehicles that were slowing or stopped in the access/egress areas in the HOV period with no differences in the pre-HOV period. There are more collisions involving light trucks as the second party in the HOV period, but there is no significant difference between the access/egress and other areas. Finally, none of the differences involving the percentage of injury accidents are significant. The comparisons in Figure 54 are for all accidents, as there were no substantial differences in these characteristics for the northbound and southbound directions. These results indicate that the accidents in the postmile ranges of the HOV access/egress areas are congestion related.

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APPENDIX A:

STATISTICAL TEST CRITERIA

For all statistical tests conducted, the p = .05, or 95 percent, confidence level is consistently used for identifying results from which reliable conclusions can be drawn. That is, there must be less than a 5 percent, or 1 in 20, chance that the accepted results are due solely to random factors.

Accident occurrence is a probabilistic process in terms of location in space and time, as evidenced by the all too familiar incidence of "near misses." Driver misbehaviors or equipment failures have a certain probability of resulting in an accident that is a function of random factors such as the locations of other vehicles and fixtures. If an accident does occur, the probability that the accident will be reported by a police officer in the field depends on the amount of damage sustained, the extent of injury, the location of police patrols, the possible occurrence of other accidents in the area of the police beat, and traffic conditions. It is estimated that only 90 percent of injury accidents and 40 percent of property damage accidents on the California State Highway system are reported by a police officer in the field and are subsequently recorded in the TASAS data base (Smith and Wilmot, 1982). Also, traffic and weather conditions vary significantly over time, adding temporal random components to estimates of roadway "safety."

Consequently, the actual accidents recorded in the TASAS data base for a specific section of roadway and a specific time interval must be viewed as statistical (not deterministic) measures of the roadway safety. The potential error term or random component of the measure is relatively greater for shorter sections of roadway, shorter time intervals, and roadways with less vehicle exposure (lower traffic volumes). Confidence intervals in statistical tests of differences over time or space provide a means of assessing the degree to which observed results are due solely to random factors. These confidence intervals refer to calculated probabilities that the results are due to random factors and are based on statistical distribution theories applied to observed variances and sample sizes. The $p = .05$, or 1 in 20, confidence level is traditionally used in situations where it is important not to reject true results; the $p = .01$, or 1 in 100, confidence level is traditionally used in more conservative situations where it is important not to accept spurious results. The former situation applies here.

Throughout the present report, the probability level for a specific result is generally cited in parentheses. Each level is properly interpreted as the probability that the result is due solely to chance. Statistically significant results are those with probability levels less than $p = .05$.

APPENDIX B:

DATA SOURCES

The principal data source for all reported analyses has been the TASAS (Traffic Accident Surveillance and Analysis System) data base maintained by the California Department of Transportation (Caltrans, 1978). All accident data in the TASAS data base is provided to Caltrans by the California Highway Patrol, and essentially every accident on the State Highway System (or in the vicinity of a State Highway system route on an intersecting road) reported by a police officer in the field is included. The period for which data were available at the onset of the study is January 1, 1979 through August 31, 1986. This covers fourteen full months of HOV operation on SR-91 and nine full months of HOV operation on SR-55.

In addition, data on roadway characteristics (such as the number of lanes by postmile range) were obtained from the highway records in the TASAS data base and from the published 1985 California State Highway Log, District 7 report (Caltrans, 1986). Data on post-project traffic volumes, occupancy rates, and other project operational parameters were obtained from Caltrans project-monitoring reports. Information on congestion levels on both routes SR-91 and SR-55 was provided by computerizing diagrams of speed by postmile and time of day provided for several dates by Caltrans District 7.