Title

HOV Lane Configurationsand Collision Distribution on Freeway Lanes – An Investigation of Historical Collision Data in California

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ABSTRACT

High-Occupancy Vehicle (HOV) lane programs are widely adopted in metropolitan areas in an effort to reduce congestion by encouraging carpooling. However, the operation of HOV lanes may result in traffic interactions that affect safety performance. In this paper, historical data from a number of freeway corridors in California are used to illustrate the distribution of collisions on different lanes on the freeway. The peak hours' data, when compared to those in the non-peak hours, from all corridors indicate that more interactions due to traffic weaving near the HOV lanes might lead to a greater concentration on the inside lanes of the corridors. In addition, a comparison of corridors with continual access with those with dedicated ingress/egress sections also implies that the restricted entrance and exit into the HOV lanes could cause more intense and challenging lane-changing actions and subsequently a greater proportion of collisions near the HOV lanes. The collision data presented in this paper demonstrate the phenomena of collision concentration near HOV lanes, presumably caused by traffic merging and weaving. The results from this study provide valuable insights into the planning of HOV operations and in the identification of safety countermeasures for such facilities.

INTRODUCTION

Transportation systems are faced with increasing demands and constraints concerning usage, operation, safety, funding, and environmental impact. High-Occupancy Vehicle (HOV) lane programs have immense potential to contribute to more efficient and effective transportation systems.

Numerous studies have found HOV lanes to be effective at reducing congestion and all its adverse consequences. However, the success and effectiveness of operating HOV Lanes is not necessarily guaranteed and certain potential issues have been explored. [1-4] In addition, some doubts exist regarding the overall impact on safety and traffic flow.

The purpose of this paper is to enhance understanding of the effect of HOV lanes on safety and traffic flow. We begin with a review of the issues raised in the existing literature and evidence. We then present results of a research project that uses ten years of California data to examine the correlation between HOV-related highway attributes and collision statistics.

BACKGROUND

When collision rates are measured by passenger miles of travel, HOV lanes tend to have lower rates due to the high occupancy restriction [5]. However, safety problems may arise due to operational or geometric modifications resulting from priority treatment for high-occupancy vehicles. The Federal Highway Administration (FHWA) analyzed 22 HOV locations across the country by studying pre- and post- installation peak traffic collision rates [6]. Generally, it was found that the introduction of HOV lanes led to increases in automobile and truck collision rates. For HOV lanes separated from regular lanes, traffic citations for violations of operating improperly in the lane or entering/exiting the lane played a larger role in safety than violations of the minimum occupancy restrictions. One of the report's conclusions is that a major role of highway agencies is to educate drivers on safe HOV lane usage. Also, highway agencies must be vigilant about posting signage, informing drivers of possible exit points in time for the driver to decide whether or not to enter the lane, and clearly delineating the HOV lane from regular lanes.

The Texas Transportation Institute performed a more detailed analysis of the safety issues associated with HOV lanes, focusing particularly on buffer-separated concurrent flow HOV lanes [7]. A review of electronic crash data and crash reports from Dallas examined pre- and post-installation crash characteristics in chosen corridors. Increased crash rates were observed. Although unable to identify a single cause for the increased crash rates in and around HOV lanes, the research team suggested that the increase in collisions could be the result of: a) the loss of the inside shoulder, b) the reduction in widths of general purpose lanes, c) the speed differential between HOV and general purpose lanes, and d) vehicles weaving from lane to lane to gain access or exit the HOV. Based on the findings of the crash data analysis, guidance was developed in selecting advantageous corridor characteristics when considering HOV lane implementation and roadway cross sections.

In a study conducted in the Salt Lake City area, HOV lanes were determined not to be inherently unsafe based on crash data analysis [8]. The study did, however, recommend stricter enforcement, construction of direct-on ramps and off-ramps and installation of prominent signs to increase public awareness. Specific construction, signage, and other information relevant to HOV safety in California is offered by Caltrans [9-10]. Beginning and termination points were also a concern for HOV safety. A design configuration that allows mixed flow traffic to exit could be susceptible to violations.

In another research study, AM and PM peak period crashes over a 30-day period were analyzed along an 11-mile section of Interstate 5 north of Seattle, Washington [11]. The researchers found that HOV-related crashes were not restricted to major points in time and space defined by regular transitions from non-congested to congested operations. However, there was evidence suggesting a greater likelihood of crashes under conditions typified by variation in average vehicle speeds in the immediate vicinity of the crash. The researchers concluded that the dynamic use of variable speed limits could be effective in reducing crashes associated with variations in speed, unnecessary lane changing behavior, and inappropriate car-following behavior.

A study [12] done in early 90's compared freeway sections with and without HOV lanes in California and found higher collision rates during peak periods in freeway sections containing HOV lanes: The peak period collision rates of the HOV lanes were higher than non HOV lanes. However, when HOV lanes were open to mixed-flow traffic during non-HOV hours (that is, the designated HOV lanes were open to all types of traffic), collision rates in these sections were, lower than in freeway sections without HOV lanes. The discrepancies appeared to occur during the heaviest traffic periods.

Another study [13] analyzed crash frequencies and characteristics from a California highway with continuous HOV lane access. The analysis concluded that there was no change in safety on that route with the addition of HOV lanes. However, they did observe that collision locations migrated due to the relief of congestion in areas of lane drops and the creation of more severe traffic bottlenecks downstream.

Cooner and Ranft examined the safety performance of buffer-separated concurrent flow HOV lanes [14]. They focused on the impact of design elements such as buffer width, shoulder presence and lane width, and the impact of the speed differential between HOV and general purpose lanes. Their study found that the speed difference between the HOV and the adjacent general-purpose lane, and the reduction in HOV cross-section, contributed to the increase in crash rates observed after the implementation of the HOV lane.

In summary, previous studies have found that crash rates are not generally higher within HOV lanes themselves, but that the presence of these lanes may or may not increase the risk for highway collisions overall. Some of the HOV-associated factors that were explored included: type of lane separation; design elements such as buffer width, access points, shoulder presence, and lane width; the speed differential between HOV and general-purpose lanes; public awareness and enforcement of proper usage; and association with the heaviest traffic periods.

Review of California collision databases indicates that numerous collisions occur at buffer-separated HOV facilities due to the complexity and frequency of HOV ingress/egress movements. Our preliminary search indicated problems that were particularly noticeable in the following situations:

- two-sided weaving with left and right side access points.
- HOV ingress/egress (merge/diverge) lanes that are insufficiently long in relationship to traffic volume.
- confusion due to traffic control signs and devices for HOV and non-HOV vehicles that are placed in close proximity.
- a combination of closely spaced interchanges and fixed ingress/egress areas, coupled with a large number of highway lanes, which requires HOV users to make multiple and consecutive lane changes under high-volume, high-speed conditions.

Collision Data

This study is a preliminary investigation into the phenomenon of collision concentration in various corridors. We examined a small number of attributes closely associated with HOV lane safety problems in California: collision type and location, highway junctions, traffic weaving patterns, peak traffic, and type of lane access. We used a historical collision database, the Traffic Accident Surveillance and Analysis System (TASAS) - a computerized database that contains historical records of collisions on roadways under the state highway system- to investigate collision on freeways with different configurations: Along with the collision database, TASAS also maintains a highway database that includes a set of geometric and location attributes for highways, ramps, and intersections. Specifically, a comparison was made between two freeway corridors with differences in HOV operation and layout.

In the Northern California region, HOV lanes are operated with continual access and the lanes are restricted to HOV use only in the morning and afternoon peak hours. In contrast, the corridors in the Southern California region have buffer-separated HOV lanes in operation 24 hours per day. The access to HOV lanes in Southern California is through dedicated ingress and egress (entrance and exit) sections at intervals along the freeway, mostly prior to the freeway exits to other highway junctions and after freeway entrance ramps.

To understand data stability and variations of collision frequencies from year to year, a ten-year span of collision data from 1994 through 2003 was utilized to investigate the patterns of collision occurrence on the included freeway corridors (see Table-1). The construction and improvement of freeway facilities in certain regions of California have been quite significant in the last ten years. Furthermore, the ten-year span included certain years when the HOV lanes were not yet operational on selective corridors. Therefore, caution should be exercised when the comparison of data is made across different years and different corridors.

Table 1 lists the corridors that were included in this preliminary review. The selection of the corridors was designed to include both the continuous-access type in Northern California and buffer-separated type in Southern California. Note that the length of the corridor segments is expressed in miles, to be consistent with the post mile numbers contained within the TASAS database and easier for references. The exact corridor segments were suggested by regional transportation engineers, with an emphasis on freeway sections that had significant collision histories. Such a selection unavoidably creates a bias in the collision distributions. However, as will be elaborated later in the paper, a proper comparison of collision patterns across various lanes on the freeway alleviates this bias.

Lane Designation

Figure 1 shows how TASAS defines different traveling lanes on a freeway corridor with multiple lanes. Typically, the HOV lane, either single or multiple, is located on the inside portion of the freeway. The lane adjacent to the HOV lane is referred to as the left lane. The outermost right traveling lane is referred to as the right lane, and lanes between the left and right lanes are referred as interior lane(s). TASAS also defines a number of areas outside of traveling lanes; in this paper, these areas are aggregated as *others*. The percentage of collisions that occurred in these *other* areas ranged between 6% and 14 % of total collisions. However, since our primary objective is to compare collision ratios in traveling lanes, collisions that occurred in these *other* areas were excluded from our analyses.

RESULTS

In this section, collision rates in the corridors from Northern / Southern California are compared to illustrate the potential effects of HOV lane configurations.

Primary Collision Types

Our first step was to categorize the types of collisions that occurred. Figure 2 shows the types of collisions that occurred in the eight freeway sites in 2001 for all traveling lanes and other areas. The distribution of these statistics was similar for 2002 and 2003 (data not shown). Three primary types of collisions occurred on the freeway were(1) rear-end; (2) sideswipe; and (3) hit-object. Nearly 95% of all the collisions occurred along the routes shown in Figure-2 were one of these three types of collisions: there were five other categories that TASAS uses to illustrate different types of collisions. However, since they constitute minimal amount of total collisions, they were aggregated into collisions type *others* in this report. Further analysis showed that between 80% and 89% of the hit-object type occurred at *other* areas (i.e., outside of travel lanes). In order to capture the most meaningful and relevant types of collisions on the traveling lanes, only two of the three major types of collisions (i.e., *rear-end* and *sideswipe*) were analyzed in more detail in this preliminary study. Together, these two types accounted for approximately 75% to 90% of total collisions and 90-98% of collisions that occurred in traveling lanes. Although there were small variations within the three years, the overall distribution of collisions remained reasonably consistent (data not shown).

Access Configuration – Continuous Access vs. Designated Ingress/Egress

The corridors located in the Northern California region have continuous ingress/egress access to HOV lane, such that vehicles can enter or exit the HOV lane at any point. In contrast, the study corridors in the Southern California region are separated by a physical buffer or barrier and traffic is only allowed to enter or exit the HOV lane in designated "ingress/egress" sections. These ingress/egress sections are set up before and after junctions or ramps with other highways. As a result, there is a concentration of lane-change maneuvers in these ingress/egress sections. Since traffic is typically moving at a fast pace, the lane-change maneuvers under heavy traffic conditions impose challenging situations and can potentially lead to collisions due to the close proximity of moving vehicles.

We examined the relative concentration of collisions in the HOV lane and in the adjacent left lane to determine whether we could find a consistent pattern of collisions that differed between the two different types of corridor configurations in this study. Table 2 and Figure 3 demonstrate that there are indeed meaningful discrepancies in the ratios of HOV and left lanes collisions for the different corridors. A greater percentage of collisions were observed in the left lane in limited ingress/egress corridors than continuous in access corridors. Particularly noteworthy are the last four corridors from the Southern California region, when compared to the first three corridors from the Northern California region. These four corridors show a relative increase of approximately 48% over the three Northern California sites: the percent accident distributions observed were 23 and 34 % at the Northern and Southern California sites respectively. The only exception is the fourth corridor, SR-91. Closer examination of SR-91 corridor also revealed that the sites is plagued by a high collision concentration location caused by heavy vegetation blocking the view of the on-ramp and mainline flows. This resulted in higher collision rates in the shoulder lane near the heavy vegetation (about 4 times higher that other section of the corridor). Such concentration of collisions in the right lane resulted in a lower percentage of collisions in the left lane in comparison. This pattern was not observed in any other routes that have limited ingress/egress HOV facility. However, it is beyond the scope of this paper and will not be elaborated here. Due to its unique feature, SR-91 was not included in subsequent analysis shown in Figures 7 ~ 10.

Table 3 and Figure 4 present the same data as Table 2 and Figure 3, but make a distinction between rear-end and sideswipe collisions. The trends are markedly more pronounced for rear-end collisions. Rear-end collisions in the HOV lane are 4% higher in limited-access corridors than in continuous-access corridors and 14% higher in the left lane. In comparison, side-swipe collisions in the HOV lane are only 3% higher in limited-access corridors than in continuous-access corridors while the percent distribution for the left lane was observed to be similar in magnitude.

Peak Hours versus Non-Peak Hours

It is also of considerable interest and importance for traffic management agencies to investigate the effects of traffic demand and congestion during the rush hours on the occurrence of collisions. The understanding of these phenomena will offer insights on the operations of HOV lanes and the corresponding impact on safety performance of the highway network. In this section, we examine whether there are differences in collisions between peak hours and non-peak hours.

In the Northern California study corridors, the HOV facilities are operated only in peak rush hours: 5-10 AM and 3-7 PM, while those in the Southern California regions are in use throughout the day. Figure 5(a) shows the distribution of collisions across different lanes in the Northern CA corridors over the ten-year period of 1994-2003 during peak hours while Figure 5(b) shows corresponding collision distribution for the non-operational hours. It can be seen from comparing figures 5(a) and (b) that the inside lanes (i.e., HOV and left lanes) possess a higher percentage of collisions during the HOV operational hours.

Because the corridors in the Southern California region have a 24-hour operational policy, we first examined their operation only during peak hours, to be able to fairly draw comparisons with the Northern corridors. Figures 6(a) to 6(b) show the distribution of collisions across various lanes in the peak hours and the non-peak hours for HOV facilities with limited access over the same ten-year period. A similarly higher proportion of collisions was observed at inside lanes during the peak hours.

DISCUSSION

In this paper, the historical data from a number of freeway corridors over a ten-year period were used to illustrate the distribution of collisions on different lanes on the freeway. The analysis was conducted to explore the potential effects of the HOV lane configurations. The study includes a selective set of freeway corridors with differences in HOV operation and layout. In the Northern California region, the HOV was operated with continual access and the HOV lane was enforced only in the morning and afternoon peak hours. In contrast, the corridors from the Southern California region have buffer-separated HOV lanes in operation throughout the day. The access to HOV lanes is provided with ingress and egress (entrance and exit) sections at certain sections along the freeway, mostly prior to the freeway exits to other highway junctions and after freeway entrance ramps.

Our findings were based on differences in proportions of collisions by lane type for Northern and Southern California corridors. It should be noted that the proportion of collisions in each lane type is necessarily be affected by the total number of lanes in a corridor as well as the traffic volume in each lane. Because there are ramps and junctions along the corridors, the total number of lanes at any point along a corridor will vary. This is generally true for all corridors included in the study. However, the numbers of lanes in the Southern California corridors are typically greater than those in the Northern regions. Therefore, the findings of a higher proportion of collisions in the Southern Region corridors are not likely caused by the different number of lanes. Assuming the percent utilization (i.e., percent of total flow using different lanes) of each traveling lanes remained relatively constant during the off peak and peak periods, finding from percent study remain valid as hypothesized above.

The merging and diverging of traffic streams across highway lanes sometimes results in challenging situations for drivers. The comparison of data from peak hours vs. non-peak hours offer support to the hypothesis that a greater number of interactions due to traffic weaving near HOV lanes led to a greater concentration of collisions on the inside lanes of the corridors. In addition, a comparison of corridors with continual access with those with dedicated ingress/egress sections also indicates that the restricted entrance and exit into the HOV lanes likely caused more intense and challenging lane-changing actions and subsequently a greater proportion of collisions near the HOV lanes.

In order to better understand the correlation between HOV configurations and collision concentration, the current study should be expanded to further investigate the exact location of individual collisions at or near the ingress / egress sections. The distribution of collision types can provide additional evidence in the assertion of probable safety complications resulting from HOV layout and operational policies. Differences in traffic volumes in different lanes may also have a significant effect on the collision occurrence and distribution. Furthermore, in-depth site investigation of collision concentration locations is necessary to confirm the suspected causes and identify associated countermeasures. These remain topics of future study.

ACKNOWLEDGEMENTS

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Table 1 List of Freeway Corridors Included in Data Analysis

Type	County	Freeway	Postmile		Length of the Segment (Mile)
			Start PM	End PM	
Continuous Access	ALA/CC	I-80 E	ALA 3.373	ALA 8.036	15.029
			CC 0.000	CC10.043	
	ALA	I-880 N	13.51	20.876	7.366
	SCL	SR-101 S	R 26.4	39.92	13.886
Limited Ingress/Egress	LA	SR-91 W	R 16.895	R 19.434	2.557
	LA	I-210 E	R 24.784	R 36.407	11.932
	LA	I-405 S	16.555	R 21.175	4.565
	ORA	SR-55 N	7	R 17.825	10.927
	ORA	SR-57 S	11.083	R 22.551	11.468

Table 2 Distribution of Rear-End and Sideswipe Collisions, 2001-2003

Type	Route	HOV	Left	Interior	Right	Total	Accidents per mile
Continuous Access	I-80 E	72 (4%)	410 (25%)	854 (52%)	304 (19%)	1640 (100%)	109.12
	I-880 N	57 (5%)	279 (23%)	475 (39%)	405 (33%)	1216 (100%)	165.08
	SR-101 S	41 (4%)	202 (21%)	438 (46%)	273 (29%)	954 (100%)	68.7
Limited Ingress/Egress	SR-91 W	18 (2%)	131 (18%)	205 (28%)	391 (52%)	745 (100%)	291.36
	I-210 E	107 (11%)	307 (32%)	355 (37%)	200 (21%)	969 (100%)	81.21
	I-405 S	35 (7%)	150 (32%)	166 (35%)	119 (25%)	470 (100%)	102.96
	SR-55 N	56 (7%)	278 (34%)	359 (43%)	134 (16%)	827 (100%)	75.68
	SR-57 S	112 (7%)	630 (38%)	580 (35%)	323 (20%)	1645 (100%)	143.44

Table 3 Distribution of Rear-end and Sideswipe Collisions in Different Traveling Lanes, 2001-2003

Type	County	Route	Collision Type	HOV	Left	Interior	Right	Total	Ratio
Continous Access	ALA&CC	I-80 E	Sideswipe	23 (5%)	97 (20%)	272 (56%)	94 (19%)	486 (100%)	1640/1767
			Rearend	49 (4%)	313 (27%)	582 (50%)	210 (18%)	1154 (100%)	
	ALA	I-880 N	Sideswipe	9 (4%)	26 (12%)	111 (51%)	72 (33%)	218 (100%)	1216/1304
			Rearend	48 (5%)	253 (25%)	364 (36%)	333 (33%)	998 (100%)	
	SCL	SR-101 S	Sideswipe	17 (7%)	38 (17%)	95 (41%)	80 (35%)	230 (100%)	954/1022
			Rearend	24 (3%)	164 (23%)	343 (47%)	193 (27%)	724 (100%)	
Limited Ingress/Egress	LA	SR-91 W	Sideswipe	6 (7%)	14 (16%)	44 (50%)	24 (27%)	88 (100%)	745/764
			Rearend	12 (2%)	117 (18%)	161 (25%)	367 (56%)	657 (100%)	
	LA	I-210 E	Sideswipe	23 (8%)	42 (15%)	139 (51%)	69 (25%)	273 (100%)	969/1037
			Rearend	84 (12%)	265 (38%)	216 (31%)	131 (19%)	696 (100%)	
	LA	I-405 S	Sideswipe	10 (10%)	22 (22%)	49 (48%)	21 (21%)	102 (100%)	470/504
			Rearend	25 (7%)	128 (35%)	117 (32%)	98 (27%)	368 (100%)	
	ORA	SR-55 N	Sideswipe	24 (11%)	42 (18%)	126 (55%)	36 (16%)	228 (100%)	827/887
			Rearend	32 (5%)	236 (39%)	233 (39%)	98 (16%)	599 (100%)	
	ORA	SR-57 S	Sideswipe	23 (7%)	56 (17%)	187 (55%)	72 (21%)	338 (100%)	1645/1727
			Rearend	89 (7%)	574 (44%)	393 (30%)	251 (19%)	1307 (100%)	

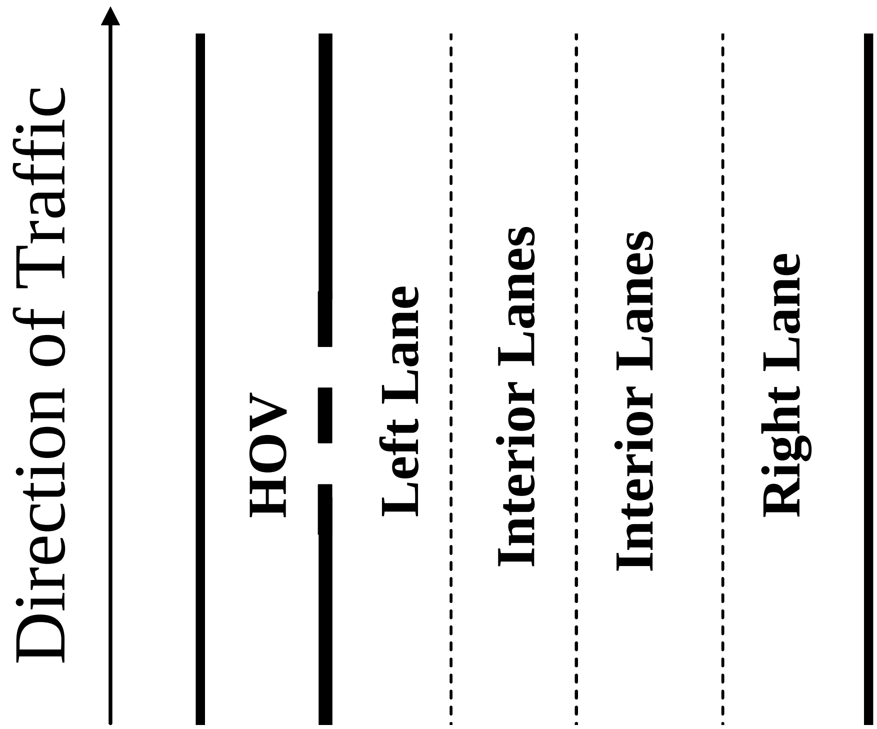


Figure 1 Lane Designation for Freeways with HOV Lane

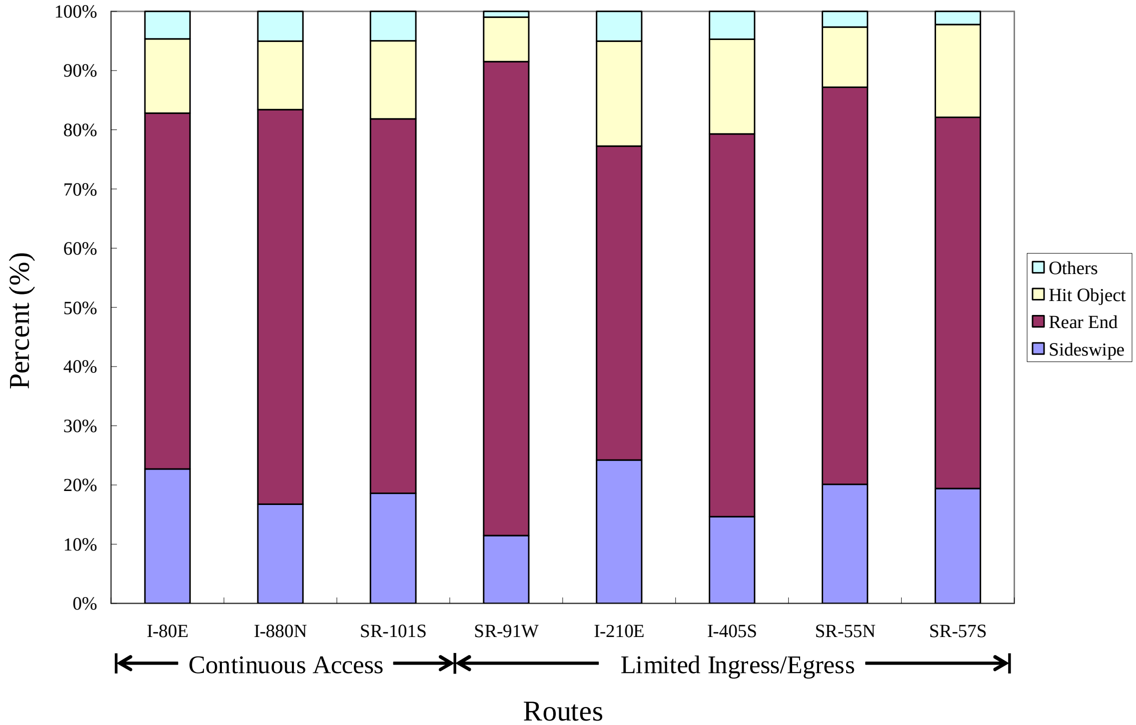


Figure-2 Distribution of Collision Types on Selected Freeway Corridors, 2001

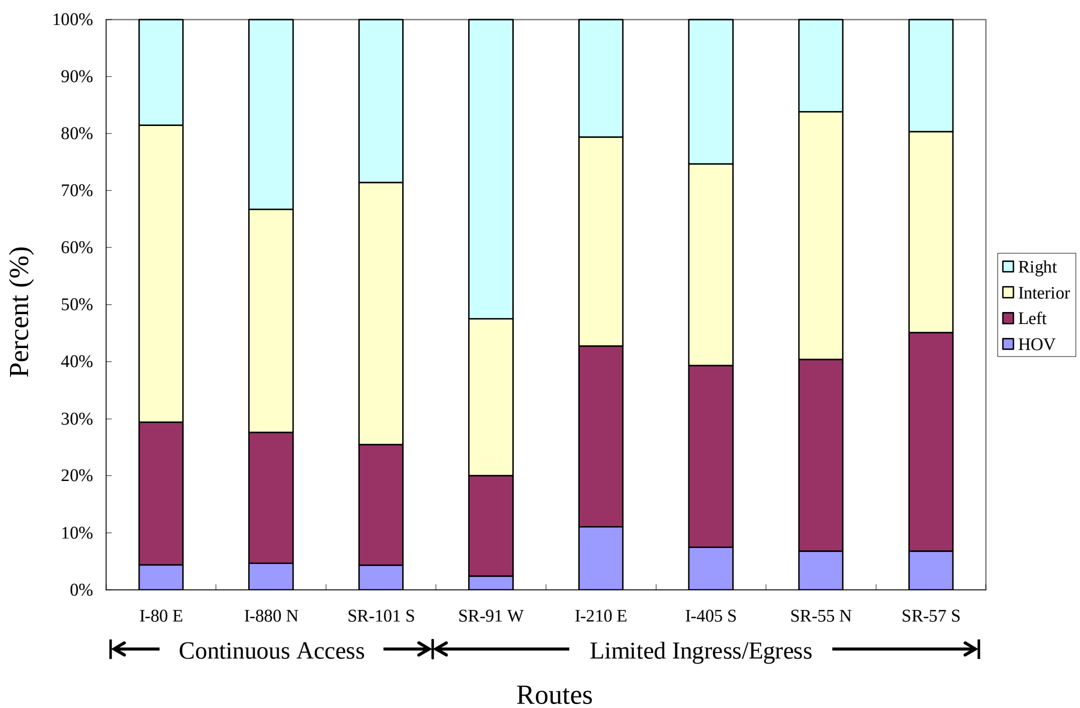


Figure 3 Collision Lane Location on Eight Corridors, 2001-2003

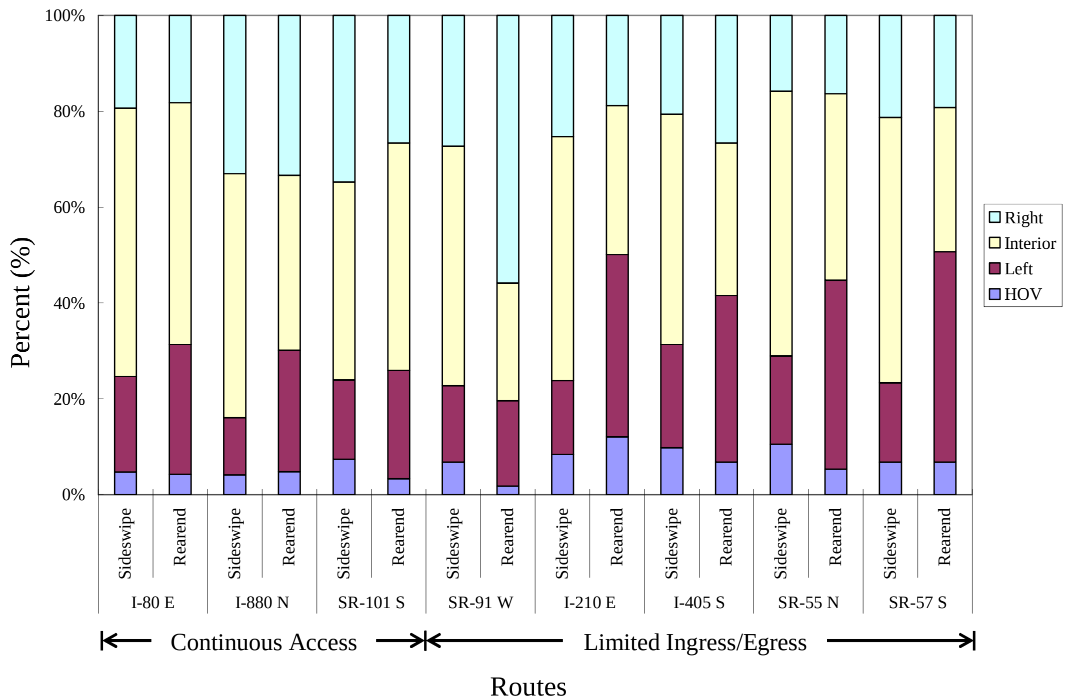
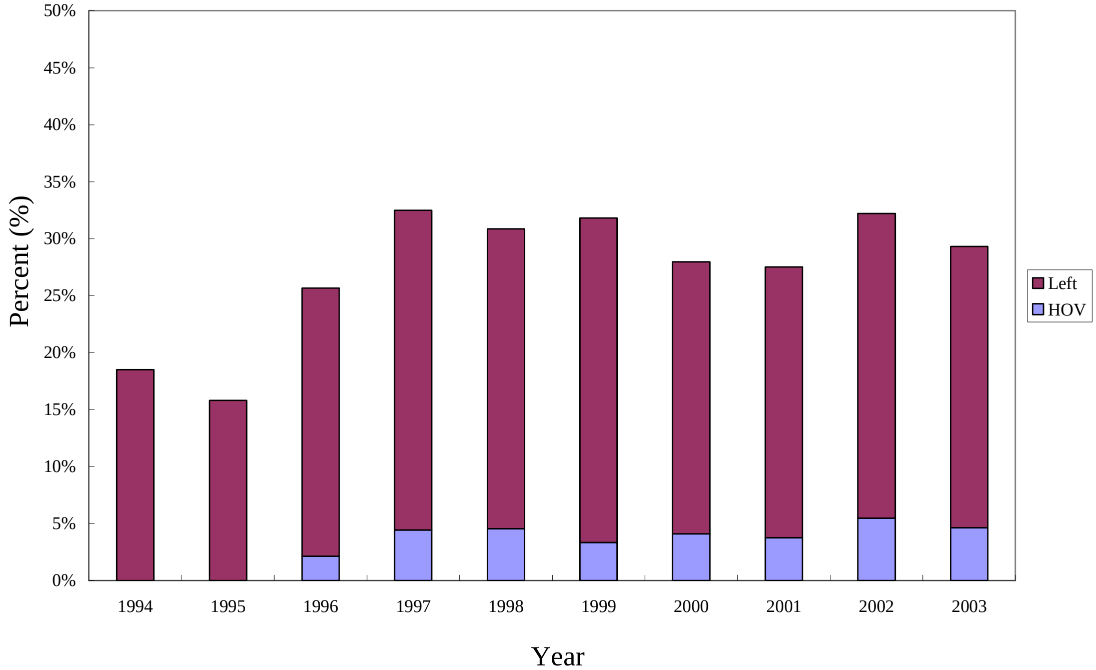
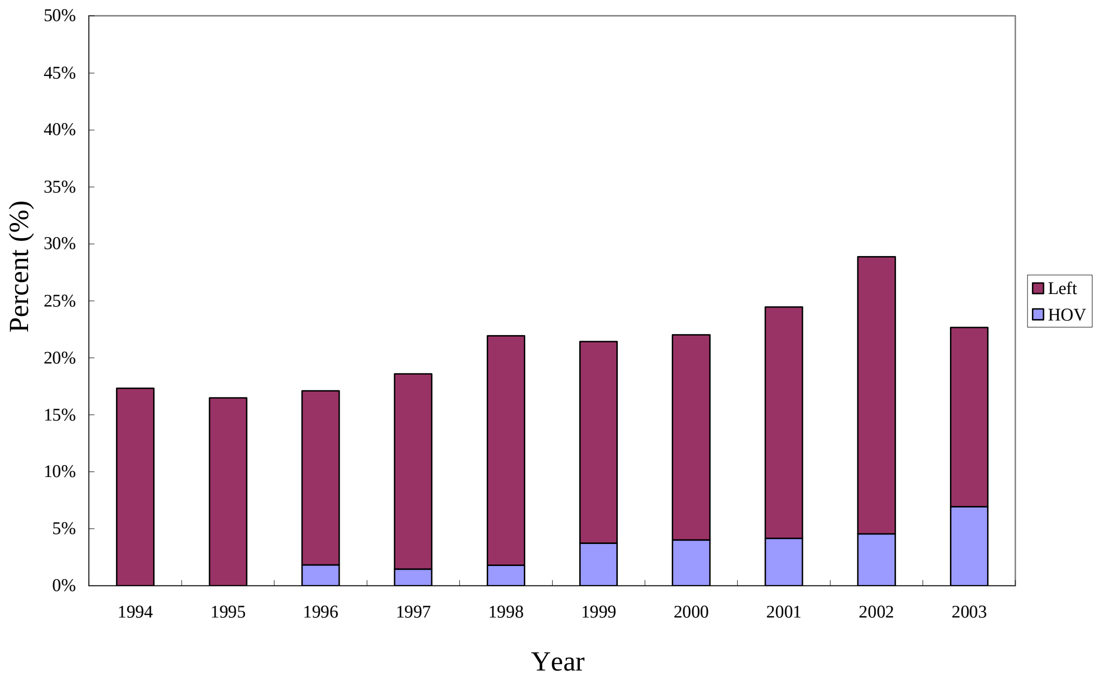


Figure 4 Collision Lane Location for Two Major Types of Collisions, 2001-2003

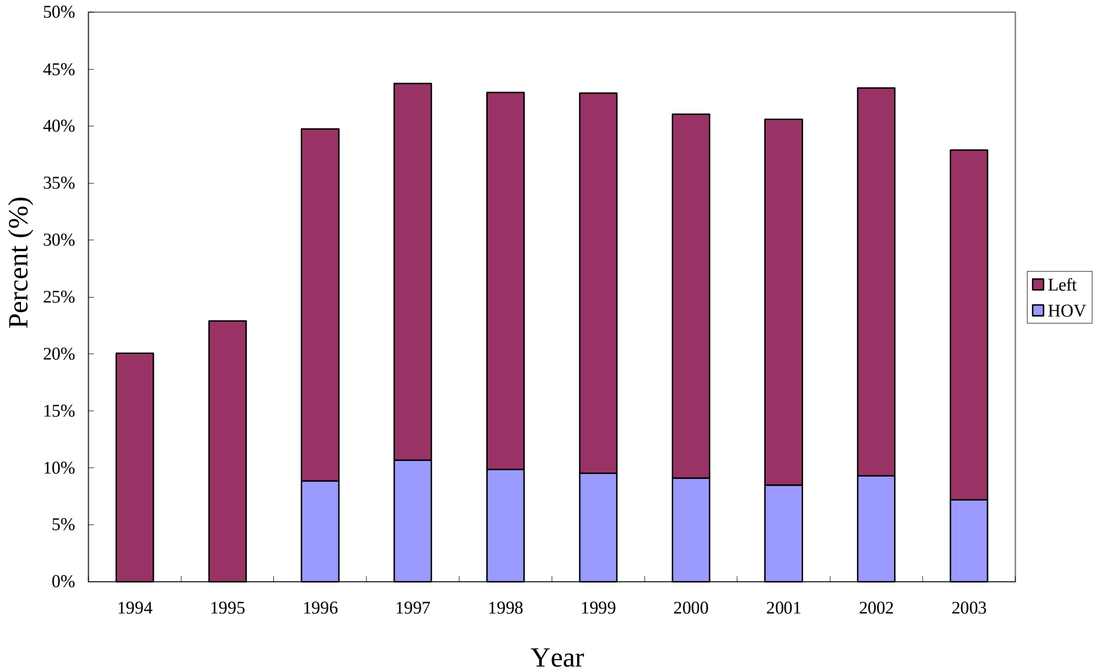


(a) Operational Hours

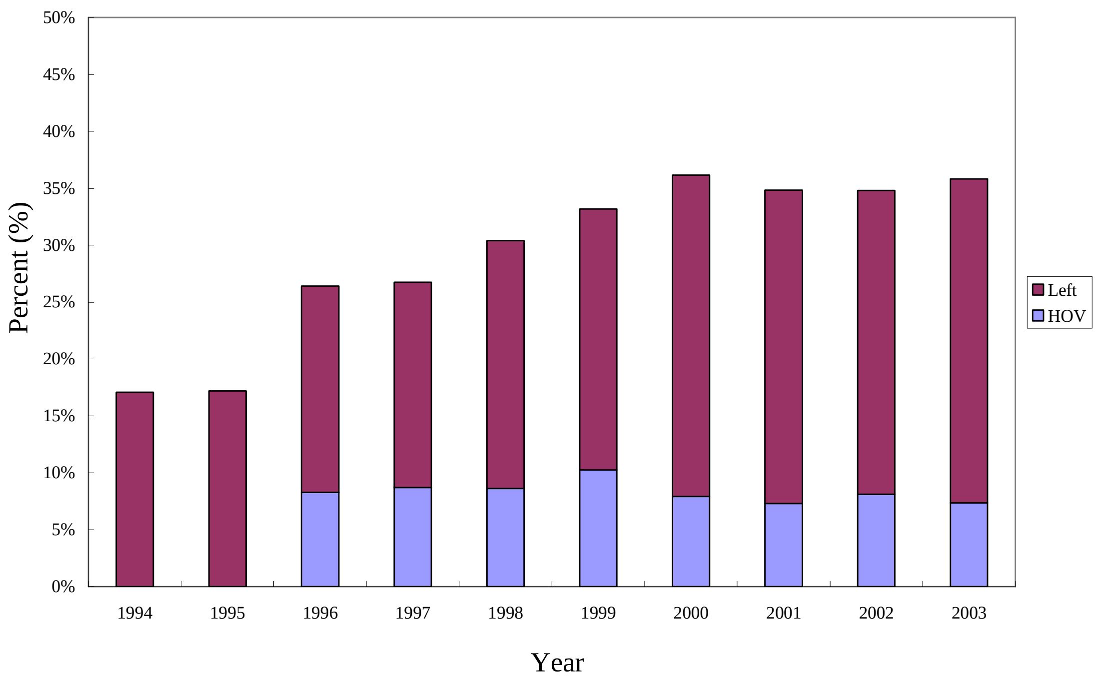


(b) Non-Operational Hours

Figure 5 (a) Operational Hours versus (b) Non-Operational Hours of Corridors with Continuous Access HOV Lane



(a) Peak Hours



(b) Off-Peak Hours

Figure 6 Peak Hours versus Non-Peak Hours of Corridors with Limited Ingress/Egress HOV Lane