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Safety Performance of High-Occupancy Vehicle (HOV) Facilities: Evaluation of HOV Lane Configurations in California

Authors
Jang, Kitae
Chung, Koohong
Ragland, David R
et al.

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Safety Performance of High-Occupancy Vehicle (HOV) Facilities: Evaluation of HOV Lane Configurations in California

Kitae Jang, M.S.
Institute of Transportation Studies
University of California, Berkeley, Traffic Safety Center
2614 Dwight Way #7374
Berkeley, CA, 94720-7374, USA
TEL: 510-642-4348, FAX: 510-643-9922, kitae_jang@berkeley.edu

Koohong Chung, Ph.D., P.E.
California Department of Transportation
Highway Operations Special Studies
111 Grand Ave
Oakland, CA, 94623-0660, USA
TEL: 510-622-5429, FAX: 510-286-4561, koohong_chung@dot.ca.gov

David R. Ragland, Ph.D., MPH
University of California, Berkeley, Traffic Safety Center
2614 Dwight Way #7374
Berkeley, CA, 94720-7374, USA
TEL: 510-642-0655, FAX: 510-643-9922, davidr@berkeley.edu

Ching-Yao Chan, Ph.D., P.E.
California PATH, Headquarters
Institute of Transportation Studies
University of California, Berkeley
Richmond Field Station, Bldg. 452, 1357 S. 46th Street
Richmond, CA, 94804, USA
TEL: 510-665-3621, FAX: 510-665-3757, cychan@path.berkeley.edu

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ABSTRACT

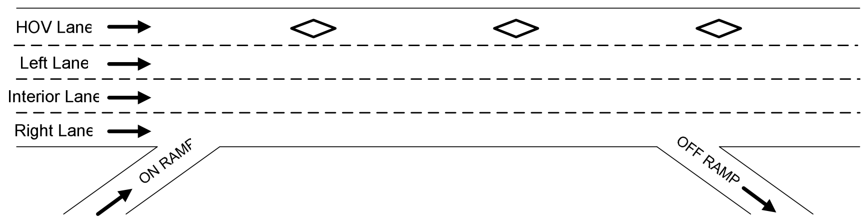
Collision data from High Occupancy Vehicle (HOV) facilities with two different types of access, continuous and limited, are examined in this paper. The findings show that HOV facilities with limited access offer no safety advantages over those with a continuous access. Compared with continuous access HOV lanes, a higher percentage of collisions was concentrated on limited access HOV lanes. Limited access HOV lanes also had higher collision rates. Findings from investigating the relationship between collision rates in HOV lanes with respect to shoulder width, length of access, and the proximity of access to its neighboring ramps are also documented. These findings provide enhanced understanding about the effects of geometric factors on the collision rates in HOV lanes.

1. INTRODUCTION

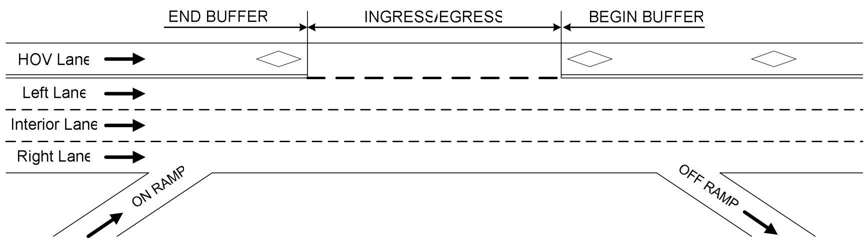
High Occupancy Vehicle (HOV) lanes have been implemented on urban freeways to mitigate continuously growing traffic congestion and improve overall mobility within metropolitan freeway systems. HOV lanes allow vehicles carrying more passengers to bypass the congested General Purpose (GP) lanes, thereby encouraging the use of carpools and public transportation to move more passengers per lane with fewer vehicles. In California, HOV lanes were first introduced in the 1970's and increasingly implemented in congested freeway segments in Southern and Northern California metropolitan regions. As of 2005, HOV lanes comprised 1,305 (directional) lane-miles of freeway, with 895 lane-miles located in Southern California, and 410 in Northern California. Furthermore, 950 additional lane-miles of HOV lanes have been proposed for construction.

Since their inception, two configurations for HOV lanes—continuous and limited—have emerged in California (See Figure 1). Continuous access HOV lanes allow vehicles to enter or exit the HOV facility continuously along the freeway such that lane changing maneuvers are not concentrated at any specified location; on the other hand, traffic operation in the continuous HOV lane is more frequently interrupted by the lane changing vehicles. Limited access HOV lanes have specified ingress and egress locations that permit maneuvers to enter and exit, and are separated from other freeway lanes by buffer zones, demarcated by pavement markings or physical barriers. Such separation is intended to allow less interrupted traffic flows and offer protection to freely flowing traffic in the HOV lane independent of the traffic conditions in GP lanes. Predominant in Northern California, continuous access HOV lanes are in operation only during peak hours (generally, Monday–Friday, 5–9AM, 3–7PM), while limited access HOV lanes, which are predominant in Southern California, are in operation 24 hours a day, seven days a week. Therefore, only the traffic collisions that occurred during the peak hours were used for comparison since the HOV lane with a continuous access operates as a GP outside of the peak hours.

The objective of this study is to understand the effect of different types of HOV access on safety. To this end, this study examines collisions that occurred in HOV and adjacent traveling lanes both at the statewide and corridor level. Section 2 presents some of the relevant previous studies and Section 3 reports the findings from an analysis of the statewide collision data. Findings from an analysis of eight corridors where per lane traffic volume is available are then documented in Section 4. Section 5 discusses the observed relationship among collision rates in HOV facility and geometric attributes, including shoulder width, length of the access, and the proximity of the access to its neighboring ramps. This paper ends with a summary of concluding remarks and future research plan in Section 6.



(a) Continuous Access



(b) Limited Access

Figure 1 HOV facility types in California: (a) continuous access, and (b) limited access

2. PREVIOUS STUDIES

Previous studies [1-5] regarding the safety performance of HOV facilities have focused mainly on comparing collision patterns before and after implementing HOV facilities, and identifying factors influencing collision occurrence rather than comparing the safety performance between different types of HOV facilities.

Cooner and Ranft [1] conducted a before and after comparison study using the collision data from two HOV facilities with buffer-separated limited access. The before and after comparison of corridor collision rates showed a substantial increase in injury collision rates after installation of the buffer-separated HOV lanes. The study suggested that the increased speed differential between HOV and GP lanes, reduced width of GP lanes, loss of the inside shoulder, and difficulty for vehicles in the HOV lane to find gaps in traffic when entering the GP lanes, were contributing factors to the increase in collision rate.

Golob et. al. [2] compared the frequency and characteristics of collisions before and after installation of a HOV lane without physical separation (i.e., buffer-separated) by converting the inner shoulder area to a HOV lane on State Route (SR) 91 in Los Angeles, California. The study concluded that the installation of HOV lanes did not have an adverse effect on the safety performance of the corridor, and that the changes in collision characteristics were due to the changes in spatial and temporal attributes of traffic congestion.

Sullivan and Devadoss [3] studied the impact of HOV facility operation on the safety of selected California freeways. Their study stated that the presence of HOV lanes did not induce any systematic differences in collision patterns but the localized traffic congestion resulted in the clustered collisions. Collision concentration locations were found along the corridors and examined in the study with and without HOV lanes during peak hours.

Case [4] conducted a before and after collision rate comparison study among four different types of HOV facilities with: (i) 0-2 ft. buffer, (ii) 3-8 ft. buffer, (iii) 8ft. buffer with 6 inch raised barrier, and (iv) 13 ft. (full) buffer. According to the study, the installation of (iii) and (iv) did not increase overall collision rates, while increase in the collision rates was observed for (i). The collision rate comparison for design type (ii) was made between HOV and non-HOV sections such that it was not a before and after comparison. Due to the sporadically located collision concentration locations, the author concluded that such a comparison gives unreliable results.

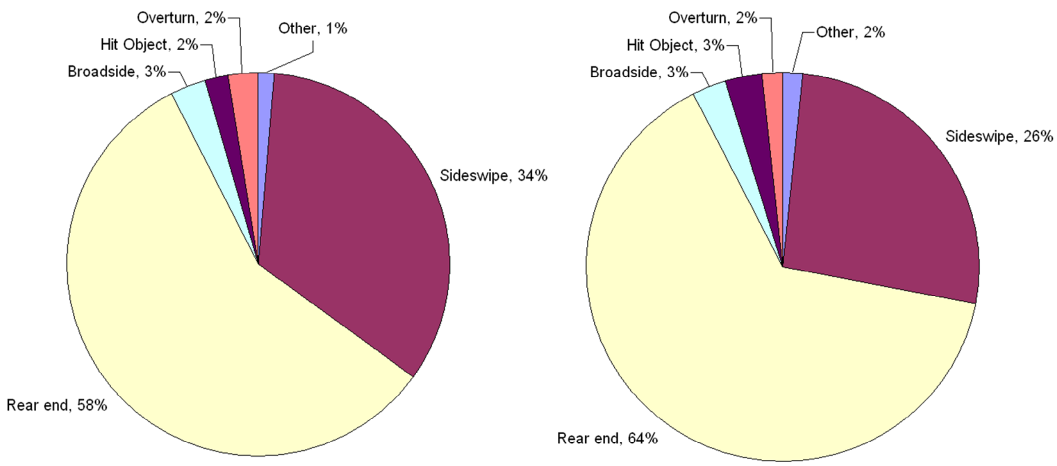
Newman et. al. [5], compared three different types of HOV facilities in California: physically separated, buffer separated (full lane width), and contiguous facilities. In the study, the term “contiguous facility” referred to both continuous access and limited access facilities in which the buffer width is narrower than a full lane (13 ft.). They found that separated facilities were superior to contiguous facilities in terms of safety, but, the study neglected to compare the safety level of continuous and limited access HOV facilities.

3. COMPARISON OF COLLISION DISTRIBUTIONS

A statewide comparison of traffic collisions from the limited and continuous access HOV facilities is the main topic of discussion in this section. Collision data from the Traffic Accident Surveillance and Analysis System (TASAS) between years 1999 and 2003 along 824 miles of freeways with HOV facilities were examined, including 279 miles of HOV lanes with a continuous access and 545 miles with a limited access. These HOV facilities had been constructed prior to 1999 and consist of about 60% of all HOV lanes in California. For the purpose of comparing the collision distributions in different HOV facilities, only the collision data during the peak hours (Monday – Friday, 5-9 AM and 3-7 PM) were analyzed since the continuous access HOV lanes operate as regular lanes outside of the peak hour period.

Figure 2 shows the breakdown of types of collisions observed in the continuous and limited access HOV lanes. Rear-end and sideswipe collisions together comprise over 90 percent of all collisions in both facilities. The difference in the distribution of rear-end versus sideswipe collisions in continuous versus limited access HOV lanes in note worthy. In continuous access HOV lanes, 57 percent of collisions were rear-end and 34 percent were sideswipe collisions. In limited access HOV lanes, 64 percent were rear-end, and 26 percent were side-swipe collisions.

The difference in types of collisions observed in continuous versus limited access HOV lanes could be due to the difference in traffic movements inherent to continuous and limited access HOV facilities. Compared to the limited access HOV lanes, the traffic in continuous access HOV lanes are more likely to be exposed to continuous interaction with traffic in adjacent lanes, and thus there is a greater occurrence of sideswipe collisions. On the other hand, the traffic in limited access HOV lanes are prohibited from changing lanes except at ingress/egress areas and tend to have more interaction with vehicles in the back or front than those in adjacent lanes such that they experience a greater number of rear-end collisions.

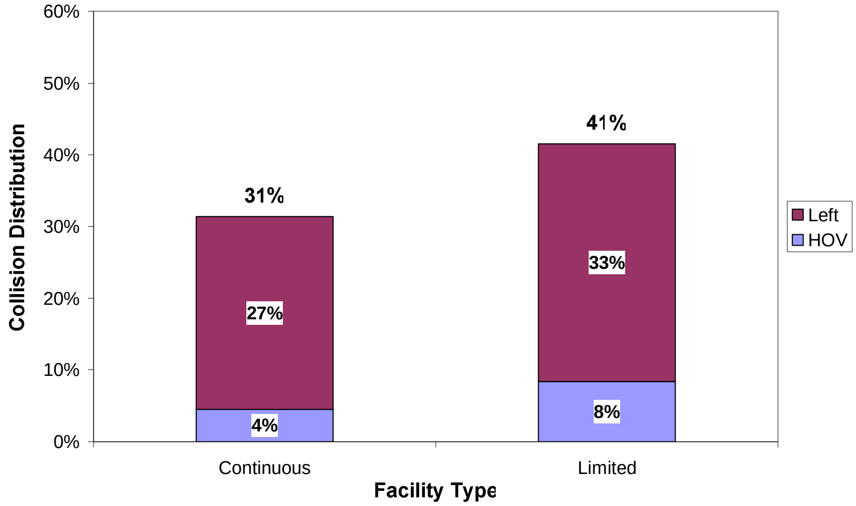


(a) Continuous Access (b) Limited Access

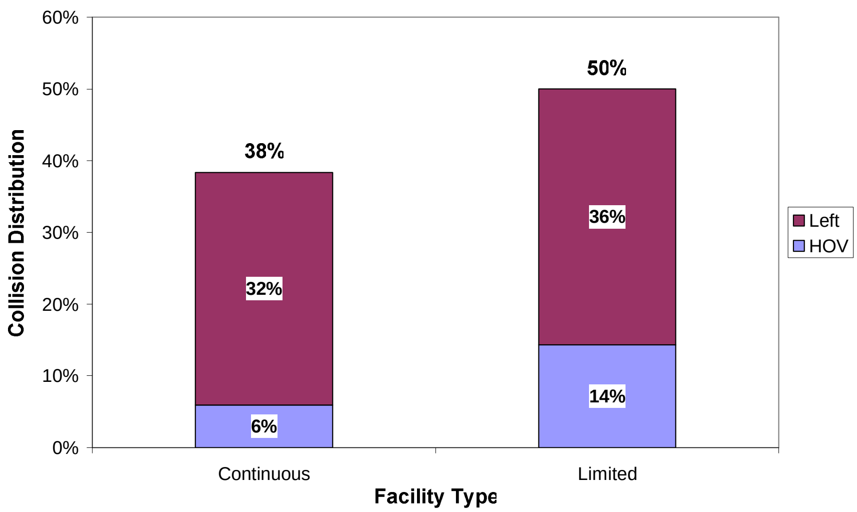
Figure 2 Type of collisions in HOV lanes

The distributions of collisions in the HOV and its adjacent left lanes were examined to determine whether there was a consistent pattern of collisions between two different types of facilities (see Figure 3). The bar charts in Figure 3 show the percentage of traffic collisions that occurred in the HOV and left lanes with respect to the total number of collisions that occurred across all traveling lanes. Figure 3(a) shows that among all the collisions involving Property

Damage Only (PDO), 31% occurred in the HOV lane with continuous access and the adjacent left lane, while 41% of PDO collisions occurred at corresponding locations at the HOV facility with limited access. Figure 3(b) displays similar data for the collisions involving injury or fatality in which HOV facilities with limited access exhibit higher concentration of collisions. The difference in collision distribution may be the result of the difference in lane utilization of traffic such that a more detailed analysis was conducted along the eight corridors ranging from 7.4 to 15.7 miles. The findings from this detailed investigation of the eight routes are presented in the next section.



(a) PDO collision distribution across lanes



(b) fatal and non-fatal injury collision distribution across lanes

Figure 3 Collision distribution across lanes: (a) PDO, and (b) fatal and non-fatal injury

4. COMPARISON OF COLLISION RATES (Selected Routes)

Table 1 shows the list of eight corridors investigated for the subsequent analysis. These freeway segments were recommended for this study by regional transportation engineers from California Department of Transportation (Caltrans) due to their similar traffic characteristics, and reliable per lane traffic volume and detail geometric information.

These routes comprise 40.7 lane-miles of continuous access and 50.9 lane-miles of limited access HOV lanes. Collisions (fatal, non-fatal injury and PDO) that occurred during the peak hours (Monday – Friday, 5–9 AM and 3–7 PM) within HOV and its adjacent left lanes between 1999 and 2003 were used in the analysis and since the comparison was limited to peak hours. Notice that the length of the routes is measured in miles, to be consistent with the post mile numbers contained within the TASAS database.

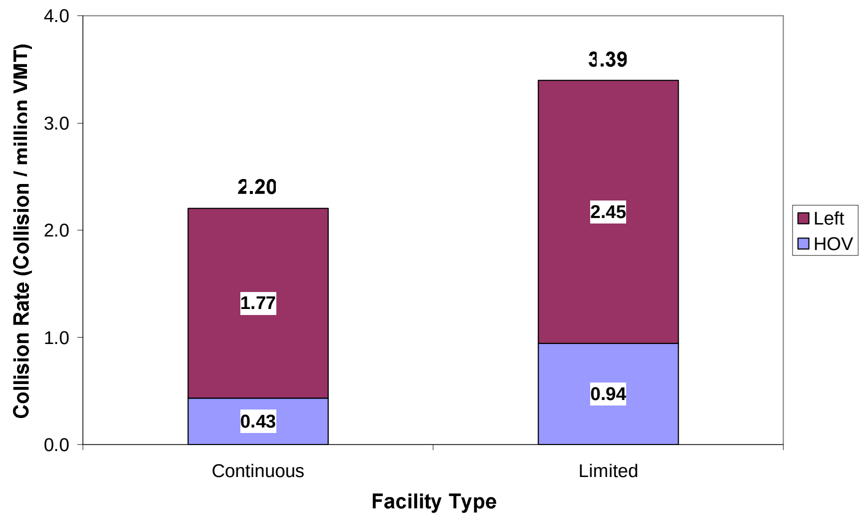
Table 1 List of eight study sites

Facility Type	County	Freeway	Postmile (PM)		Length (Mile)
			Start PM	End PM	
Continuous	Contra Costa	I-80E	0	10	10
	Contra Costa	I-80W	0	9.8	9.8
	Alameda	I-880N	13.5	20.9	7.4
	Santa Clara	SR-101S	26.4	39.9	13.5
Limited	Los Angeles	I-105E	1.2	16.9	15.7
	Los Angeles	I-105W	2.5	16.8	14.3
	Los Angeles	I-210E	24.8	36.4	11.6
	Los Angeles	I-405S	12.9	22.2	9.3

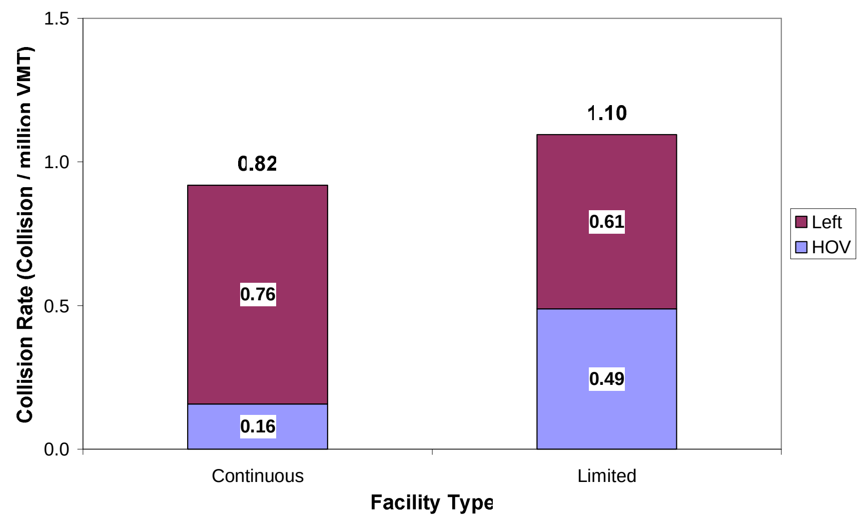
Using traffic volume data from Freeway Performance Measurement System (PeMS) [6], collision per million Vehicle Miles Traveled (VMT) for each of the HOV and its adjacent left lane were calculated by dividing the number of collisions during the peak hours by the product of traffic volume from the same HOV operating hours and lane-miles as shown in the Eq. 1. The result is shown in Figure 4.

$$\text{Collision rate} = \frac{\text{number of collisions} \times 10^6}{\text{total peak hour traffic volume} \times \text{lane-miles}} \qquad \text{Eq. 1}$$

Figure 4 displays collision rates of the HOV and the left lanes. A higher PDO collision rate was observed in both the HOV and the left lanes of the HOV facility with limited access (see Figure 4(a)). However, the fatality and injury related collision rate for the left lane alone was higher for the continuous access HOV facility (see Figure 4(b)).



(a) PDO collision rate



(b) fatal and non-fatal injury collision rate

Figure 4 Collisions rates: (a) PDO, and (b) fatal and non-fatal injury

To determine whether the differences in the collision rates shown in Figure 4 are statistically significant, statistical tests were performed for the HOV lane, left lane, and HOV and left lanes combined. The statistical test used in the study is based on Sichel, and Shiue and Bain [7, 8]. Eq. 2 shows the equation for the statistical test to evaluate the statistical difference between collision rates, which approaches a standard normal distribution asymptotically. It is assumed that collision frequencies on the continuous access facilities, C, and collision frequencies on the limited access facilities, L, are statistically independent over the vehicle miles traveled VMT_C and VMT_L, respectively and also Poisson distributed. C and L, the occurrences of collisions in two different types of HOV facilities, equal to $\lambda_C \cdot VMT_C$ and $\lambda_L \cdot VMT_L$, where λ_C and λ_L are the expected collision frequencies per unit vehicle miles traveled.

$$Z = \frac{L \cdot VMT_C - C \cdot VMT_L}{[VMT_C \cdot VMT_L \cdot (C+L)]^{1/2}} \quad \text{Eq. 2}$$

Since the difference between λ_C and λ_L is our focus, we consider a test of the null hypothesis: $H_0 : \lambda_C = \lambda_L$ at α significance level against the one-sided alternative hypothesis, $H_A : \lambda_C < \lambda_L$. The hypothesis H_0 is rejected at the α level of significance level if $Z \geq z_{1-\alpha}$ against H_A: $\lambda_C < \lambda_L$ where $\Phi(z_\alpha) = \alpha$ and Φ is the cumulative standard normal distribution function. All statistical tests were conducted at 5 % level of significance. The results of statistical tests were examined for the difference of collisions rates between continuous and limited access HOV facilities as summarized in Table 2. λ_C and λ_L in the table 2 are presented in the unit of collision per million VMT.

Table 2 Summary of statistical tests

Facilities	Collision Type	λ_C	λ_L	Test Result
HOV lane	PDO	0.43	0.94	H_0 rejected
	fatal and non-fatal injury	0.16	0.49	H_0 rejected
Left lane	PDO	1.77	2.45	H_0 rejected
	fatal and non-fatal injury	0.76	0.61	H_0 cannot be rejected
HOV and Left lanes combined	PDO	2.20	3.39	H_0 rejected
	fatal and non-fatal injury	0.82	1.10	H_0 rejected

All the null hypotheses except for the difference of injury related collision rates in left lanes were rejected at 5 % significance. In other words, only the difference in fatal and injury collision rates in left lane was not statistically significant at the 95 percent level of confidence while all the other differences in PDO collision rates, and fatal and non-fatal injury collision rates were statistically significant at the 95 percent level of confidence.

The collision rates are lower for HOV lanes than for the left lanes in both limited and continuous access facilities. This is consistent with the finding that the collision distributions across lanes are also lower in the HOV lanes. This could be due to the fact that no vehicles enter the far left lane from its left side whether it is a HOV or median lane. To explore this issue further, an evaluation will be needed to compare HOV lanes with median lanes on freeway segments without HOV lanes.

In summary, HOV lanes in limited access facilities showed higher PDO and injury related collision rates than those with continuous access. For the left lanes, a mixed pattern was observed. The PDO collision rate was lower for the left lane adjacent to the HOV lane with continuous access. Meanwhile, its injury related collision rate appeared to be higher, though the difference was not statistically significant. In the next section, we will discuss the design features that can potentially influence the safety performance of HOV facilities.

5. GEOMETRIC FACTORS

In this section, results from detailed analysis of HOV segments are presented to explain the relationship between collision rates in HOV facility and geometric attributes, including shoulder width, length of the access, and the proximity of the access to its neighboring ramps. The same set of peak hour collision data from the eight routes in the previous section (see Table 1) is used for this part of analysis.

5.1 Shoulder width

The shoulder can be used to accommodate stopped or disabled vehicles and mitigate the disruption to the traffic in traveling lanes. The shoulder can also provide extra maneuvering space for the drivers to avoid potential conflicts with other vehicles, as well as a chance to recover from errors, and to resume normal driving. Providing adequate shoulder width can enhance the safety performance of freeways [9, 10]. Our objective here is to explore the relationship between the shoulder width and the collision rate of the HOV facilities.

An illustration of the effects of shoulder width on safety performance is given in Figure 5, with the observed collision rates for the eight freeway segments plotted against the corresponding shoulder width. Since the shoulder width may vary along a freeway segment, the average throughout the segment is used in the plot. The black solid dot indicates the data from limited access HOV lanes and its data source is annotated next to the dot. The white dot shows the data from the continuous access routes. The data displayed in Figure 5 indicate that collision rates diminish with an increase in shoulder width, regardless of the type of access associated with the HOV lane. The limited access exhibited a higher collision rate compared to the continuous access with comparable shoulder width.

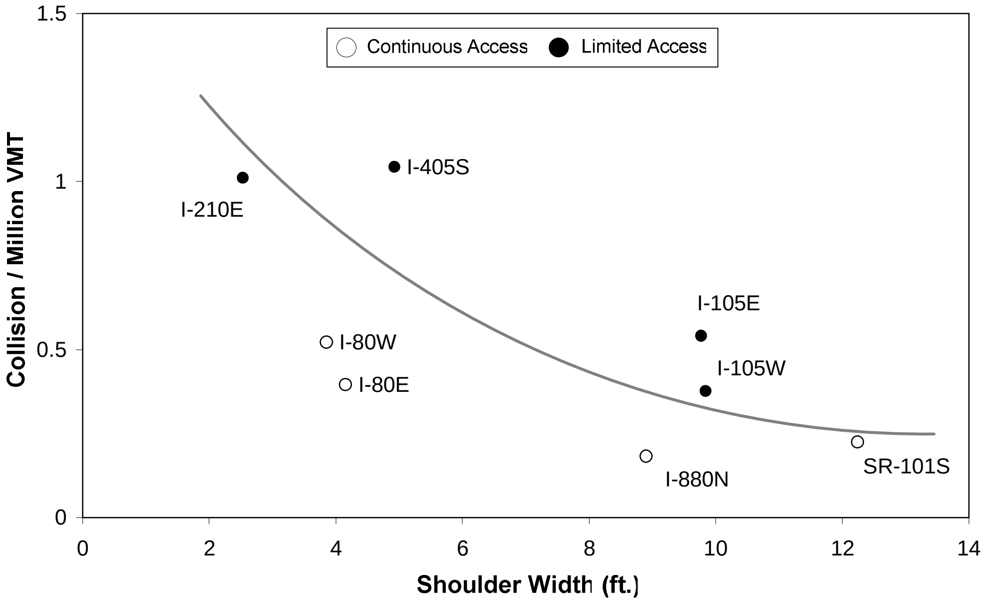


Figure 5 Relationship between shoulder width and collision rate in the HOV lane

5.2 Total (shoulder + HOV lane + buffer) width

We define the total width as the lateral space including the shoulder, the HOV lane and buffer here. Among the three components, shoulder width ranged from 2 to 12.2 feet, lane width varied between 11.5 and 13 feet, and buffer width varied between 0 and 5.2 feet; continuous access facilities have no buffer between HOV and left lane such that their buffer width is considered zero. Most of the variation in total width was contributed by variation in shoulder width, followed by buffer width.

A scatter plot of collision rate versus total width was constructed in Figure 6 and a trend line for each type of HOV facility was estimated based on the scatter plot. Narrower total width was associated with a higher collision rate in both types of HOV lanes. Notably, the trend line for the limited access, shown as a black line, exhibits remarkable resemblance to the trend line of the continuous access, a grey line, but with a vertical shift upward. The pattern implies that given the same amount of total width among the eight routes studied, corridors that employed the continuous access can result in lower collision rates. This could be due to the fact that more shoulder width can be allocated to the continuous access HOV lane since it does not require a buffer.

Our present analysis did not examine the individual influence of each component within the total width in collision rates. More sites need to be evaluated to better understand the individual influence of shoulder, lane, and buffer widths in collision rates.

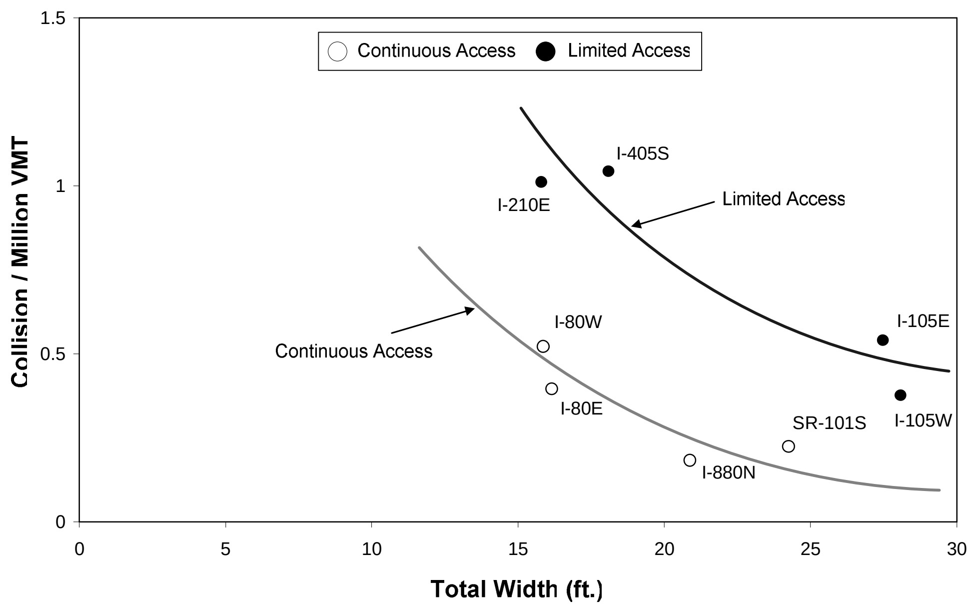


Figure 6 Relationship between total width and collision rate in the HOV lane

5.3 High Collision Concentration Location (HCCL) analysis

Continuous Risk Profile (CRP) is a method that generates a variation of risk measurement interpretable as the number of collisions, or collisions per unit distance along a freeway segment [11]. The CRP plots for HOV and left lanes of the eight routes were constructed to examine the spatial distribution of collision concentration locations along the freeways. Among the eight routes examined, two exemplary routes with continuous and limited access HOV lanes are displayed in Figure 7 and 8, respectively. The peaks in the profile represent collision concentration locations whose collision rate (in number of collision per mile per hour) exceeds the 90th percentile of each route.

The first example is I-880N as shown in Figure 7. Figure 7(a) shows the location of on and off ramps. Figure 7(b) and (c) show CRP plots for the HOV and its adjacent lane. The collision concentration location is marked by the peaks. Note that each of the peaks in the HOV lanes accompanies peaks in adjacent left lanes. This implies that the factors causing the concentration of collisions in the HOV lane appear to affect the collision rate in the left lane.

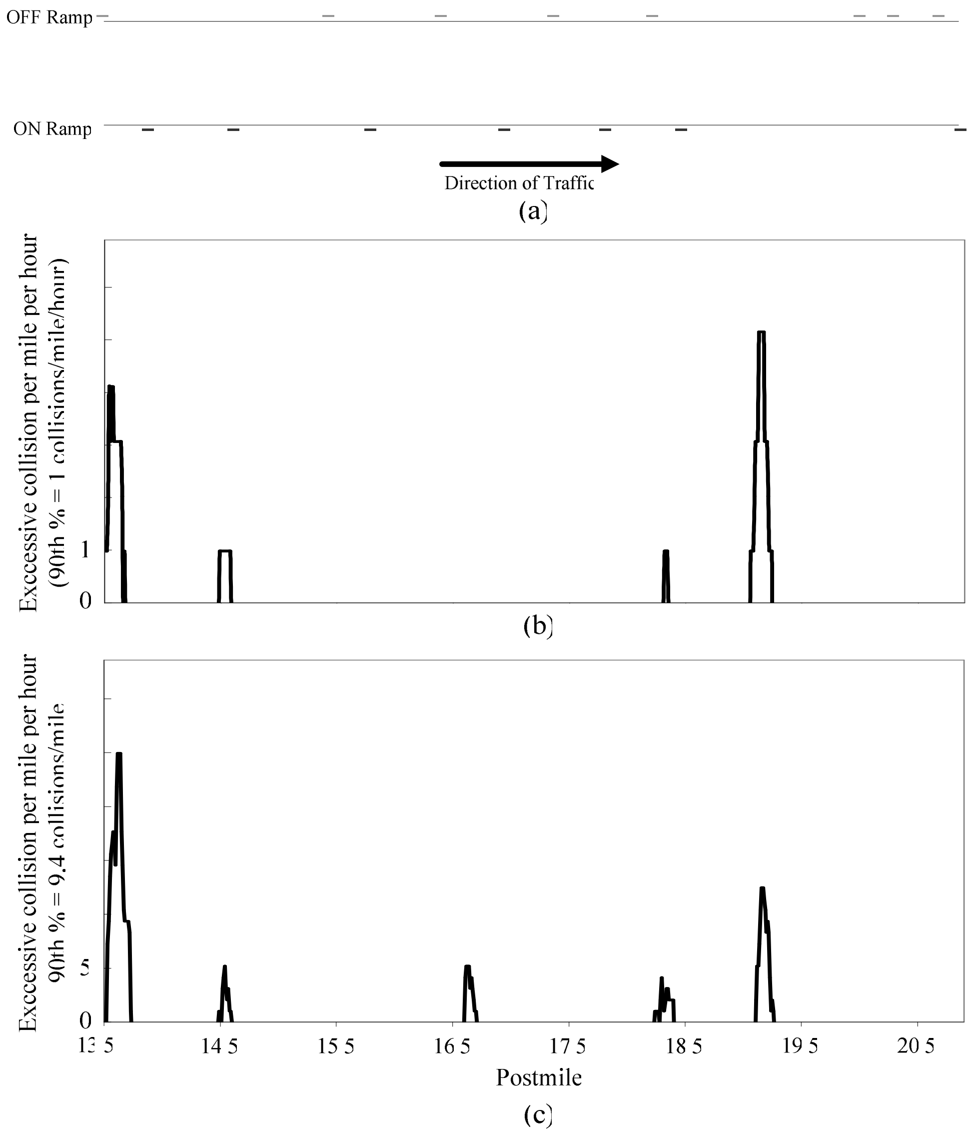


Figure 7 Continuous Risk Profile Plot (I-880N); (a) On- and off-ramps, (b) CRP plot for HOV lane, and (c) CRP plot for Left lane

Figure 8 shows similar plots for I-210E where the HOV facility has limited access and the locations of the access are shown in Figure 8(a). Unlike the patterns observed in Figure 7, not all the peaks shown in the HOV lane accompanied peak in the adjacent lane. These peaks are marked by dotted circles in Figure 8(b). It appears that the buffer, whose function is to provide less interrupted flows at the HOV lane, also mitigates the effect of collision causative factors at the HOV lane in its adjacent lane and vice versa. Notably, a concentration of collisions was observed at the HOV lanes where lane changing was prohibited (see Figure 8(a) and (b)).

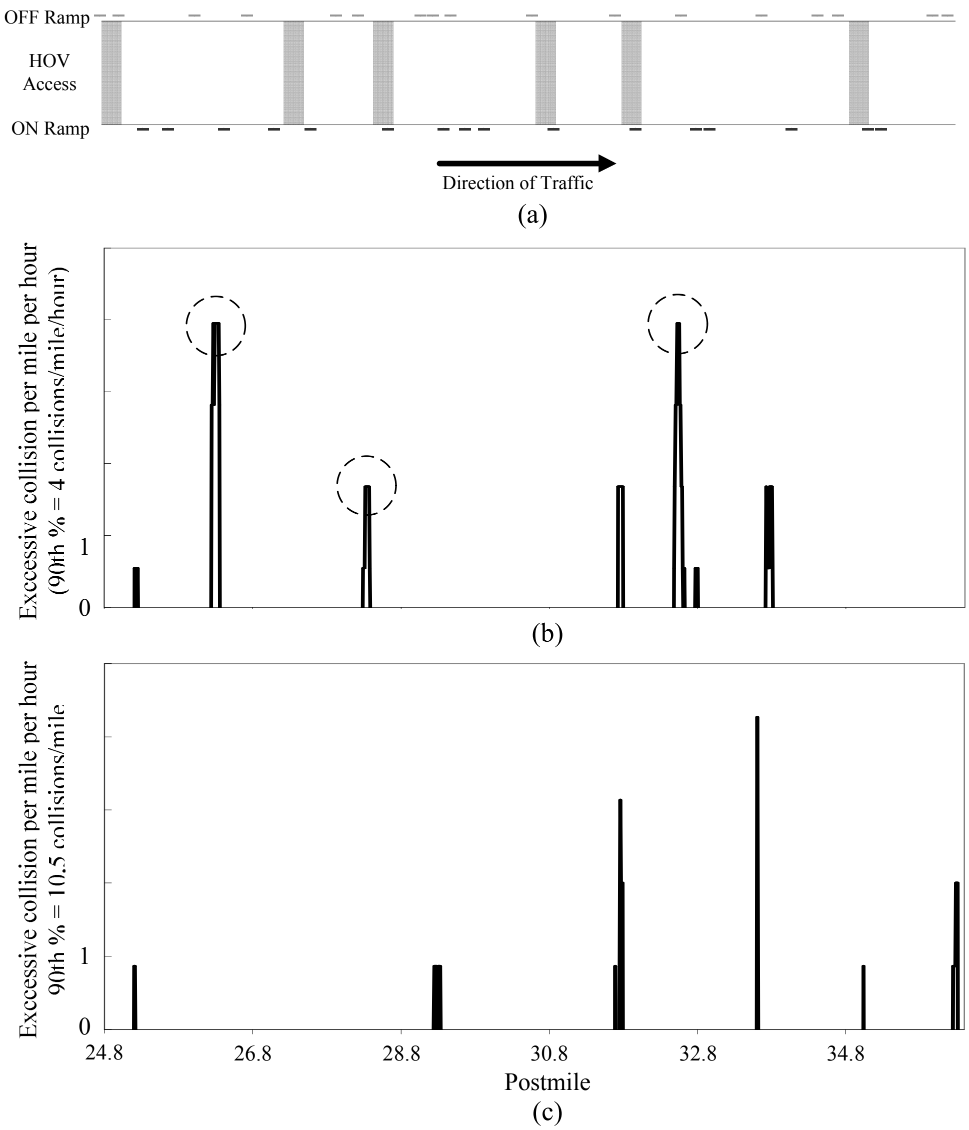


Figure 8 Continuous Risk Profile Plot (I-210E); (a) On-, off-ramps and HOV ingress/egress areas, (b) CRP plot for HOV lane, and (c) CRP plot for Left lane

5.4 INGRESS/EGRESS analysis

Collision rates from 24 different ingress/egress sections along the four limited access HOV lanes shown in Table 1 were plotted with respect to their proximity to the nearest ramp in Figure 9. No apparent systematic relationship was found between the collision rate at the access point and their proximity to the nearby on- or off-ramps. However, three locations displayed significantly higher collision rates than others. It was found, after inspecting the configurations of these three locations, that these three ingress/egress segments were associated with the following common features:

(1) Located within 0.3 mile of the nearest on- or off- ramp,
(2) Short access lengths (0.25 mile), and
(3) High traffic volume in the HOV lane during peak hours (1000–1200 vehicles per hour versus 700–800 vehicles per hour on average).

These factors should be investigated further in subsequent studies

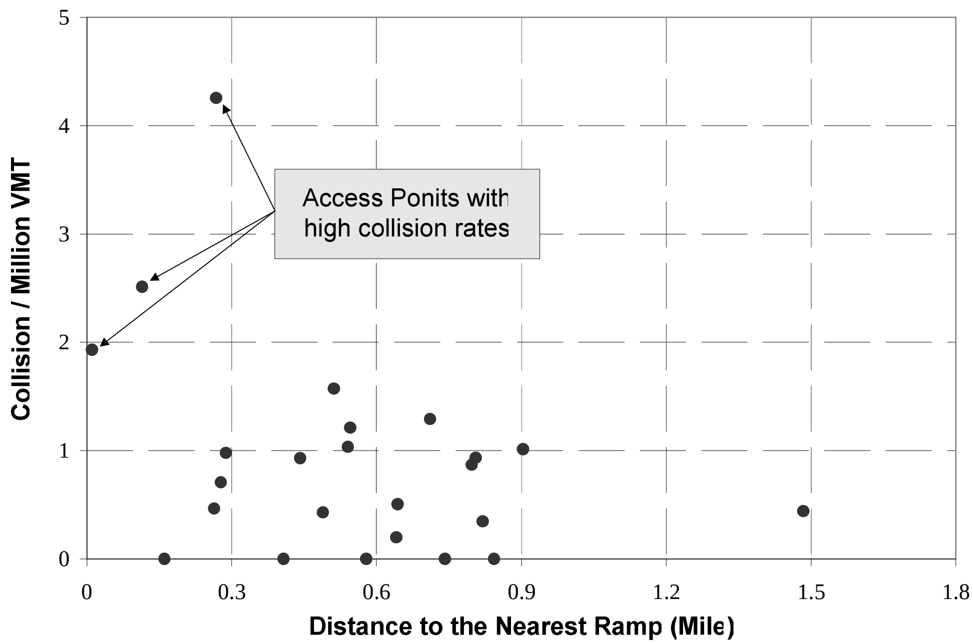


Figure 9 Relationship between collisions per mile per hour and distance to nearest entrance/exit ramp in limited access HOV facilities

6. SUMMARY OF FINDINGS AND FUTURE RESEARCH TOPICS

In this paper, we have examined collision data from High Occupancy Vehicle (HOV) facilities with two different types of access, continuous and limited. The findings show that the HOV facility with limited access offers no safety advantages over the one with continuous access; the combined collision rates of the HOV and its adjacent lanes were higher for the HOV facility with limited access.

We studied the relationship between collision rates in HOV lanes with respect to its shoulder width, length of the access, and the proximity of the access to its neighboring ramps. HOV facilities with shoulder width greater than 8ft displayed significantly lower collision rates regardless of access type. Among the eight routes investigated in this study, corridors that employed the continuous HOV access displayed lower HOV lane collision rates compared to a comparably sized limited access HOV lane, as shown in Figure 8. Furthermore, we found that limited access HOV facilities with a combination of short ingress/egress length and a close proximity to the nearest on- or off-ramp can result in markedly higher collision rates than other limited access freeway segments although these factors need more systematic investigation

In evaluating the relationship between collision rate and the total width, the present study did not attempt to quantify the effect of an individual width element. This is an important question that needs to be further explored since it can be used as a guideline in allocating spaces when there is limited the right-of-way. In addition, more sites need to be studied to further evaluate the relationship between the length of ingress/egress and its proximity to neighboring on or off ramps, as well as the effect of a buffer in mitigating the influence of collision causative factor in the HOV lane on its left lane. These are topics of future research.

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