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HOV Lane Configurations and Safety Performance of California Freeways – An Investigation of Differential Distributions and Statistical Analysis



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**HOV Lane Configurations and Safety Performance of California Freeways – An Investigation of Differential Distributions and Statistical Analysis**

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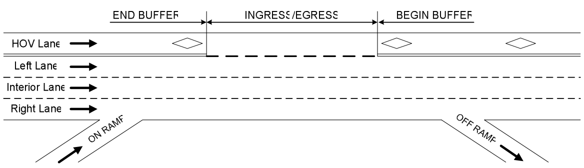
## ABSTRACT

From a recent study of safety evaluation of HOV-equipped freeways, it was found that limited-access HOV lanes appear to have a safety performance disadvantage when measured by collision distribution or collision rates for the HOV lane alone and for the HOV and left lanes combined. This paper describes the work performed to verify the statistical significance of related findings. Several statistical tests were used: empirical cumulative density function (CDF), Kolmogorov-Smirnov Tests, and comparison of means based on Poisson Distributed Samples. The conclusion that continuous-access HOV lanes perform better than limited-access ones by several safety metrics is confirmed by the three separate approaches. In addition, the historical data for the HOV segments and the general-purpose lanes are extracted and compared, which offers supporting evidence for similar conclusions. The work described in this paper offers a methodology of statistical verification and can provide support to assist policy-making in selecting HOV configurations.

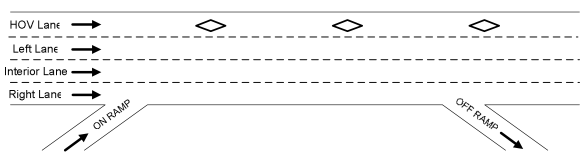
# 1. INTRODUCTION

Limited access High-Occupancy-Vehicle (HOV) facilities were designed to separate typically higher speed traffic in HOV lanes from traffic in adjacent lanes in order to reduce the risk of collisions caused by vehicles weaving between lanes of traffic traveling at different speeds. Using data from California freeways, limited access HOV and the adjacent left lanes were compared with those of continuous access HOV facilities to evaluate the safety of each, and to determine which characteristics could improve performance in either type of facility. Based on these results, limited access HOV facilities do not appear to provide increased safety, whether measured by percentage of collisions, collisions per mile, collisions per VMT, or collision severity. On the contrary, the pattern in fact suggests some trends in the opposite direction. From a strictly safety viewpoint, this suggests that constructing limited access facilities would not achieve the goal of increasing freeway safety. The results highlighted above have been reported in a separate publication and discussed in more details. [1]

While the findings from the aforementioned study offer evidence that limited-access type of facilities appears to be lagging in safety performance, a decision to favor one configuration over the other cannot be conclusive due to the necessary considerations of other performance measures for HOV operations. Furthermore, there are a variety of geometric and operational variables that may have contributed to the differences in safety performance. Thus, it is of great interest and importance that a more vigorous and robust methodology is developed to evaluate the latest findings. This paper is focused on an in-depth statistical evaluation of the differential safety performance exhibited by the two types of HOV facilities as shown in Figure 1. Several alternative statistical tests were performed to verify the findings, and a systematic method is suggested for assessing the comparative distributions from two sample groups.




(a) Limited Access




(b) Continuous Access

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

# 2. COMPARISON OF COLLISION PATTERNS BETWEEN TWO DIFFERENT HOV FACILITIES

Two configurations for HOV lanes—limited and continuous—are prevalent in California. Limited access HOV lanes (predominant in Southern California) have specified locations for ingress and egress HOV maneuvers, and are separated from other freeway lanes by buffer zones demarcated by pavement markings or physical barriers. Such separation is intended to facilitate smooth and safe operation of traffic flows, typically at relatively high speeds, within HOV lanes. Concerns about limited access lanes include possible impacts on traffic maneuvers due to:

- Vehicle lane-changing concentrated near ingress/egress locations, and

- Extensive vehicle lane-changing between freeway ramps and HOV access points within a fixed and often relatively short distance.

Continuous access HOV lanes (predominant in Northern California) do not include a buffer zone. They allow vehicles to enter and exit at any location, and are in operation only during peak hours. Unlike limited access lanes, HOV maneuvers on continuous access HOV lanes continuously interact with traffic on General Purpose (GP) lanes.

A study was conducted in California [1] to compare traffic collision patterns between limited access and continuous access HOV lanes. Evaluation of historical collision database was conducted to investigate the attributes accounting for such differences, if any. While some facilities utilize an actual barrier between HOV and adjacent lanes, the current study focuses only on facilities that are buffer-separated, meaning that the separation is indicated solely by pavement markings.

Table 1 List of study sites

| Facility Type | County | Freeway | Postmile (PM) | | Length | Peak Hours of Study |
|---|---|---|---|---|---|---|
| | | | Start PM | End PM | | |
| Continuous | Contra Costa | I-80E | 0 | 10 | 10 | Weekdays 5~9AM & 3~7PM |
| | Contra Costa | I-80W | 0 | 9.8 | 9.8 | Weekdays 5~9AM & 3~7PM |
| | Alameda | I-880N | 13.5 | 20.9 | 7.4 | Weekdays 5~9AM & 3~7PM |
| | Santa Clara | SR-101S | 26.4 | 39.9 | 13.5 | Weekdays 5~9AM & 3~7PM |
| Limited | Los Angeles | I-105E | 1.2 | 16.9 | 15.7 | Weekdays 5~9AM & 3~7PM |
| | Los Angeles | I-105W | 2.5 | 16.8 | 14.3 | Weekdays 5~9AM & 3~7PM |
| | Los Angeles | I-210E | 24.8 | 36.4 | 11.6 | Weekdays 5~9AM & 3~7PM |
| | Los Angeles | I-405S | 12.9 | 22.2 | 9.3 | Weekdays 5~9AM & 3~7PM |

In the aforementioned study, an extensive network of HOV lanes representing more than 60% of California HOV facilities were used in a state-wide comparison. However, in order to investigate specific geometric attributes and traffic data for thorough analysis of safety performance, study sites were filtered down to a selective list of HOV corridors where detailed geometric and traffic data were available. These corridors were selected due to their similar traffic patterns and were suggested by regional transportation engineers from California Department of Transportation (Caltrans), who were familiar with the configurations and operations of these freeway segments. It is postulated that safety performance of both the HOV lane itself and the adjacent left lane are likely to be affected most by the type of access (limited versus continuous) based on the findings from the previous study comparing safety performance of corridors before and after the addition of HOV lanes [2]. Therefore, in the current study, collision data was evaluated for HOV facilities built with the two different types of access. Table 1 lists the corridors that were included in the statistical evaluation reported in this paper. Four continuous access HOV corridors in Northern California and four limited access from Southern California in the list were constructed before 1999 so that sufficient collision data can be used for evaluation. 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.

All collisions (fatal, injury, and property-damage-only) that occurred within HOV and left lanes between 1999 and 2003 were included in the analysis. Since continuous access HOV lanes are in operation only during peak hours (generally, Monday–Friday, 5–9AM, 3–7PM), the comparison was limited to those hours.

To assess safety performance of HOV facilities, safety performances for both types of HOV facilities were measured by relative distribution of collisions (percent) across lanes and collision per mile per hour. By comparing these two measures together, one could approximate the collision per mile per hour across all traveling lanes. These estimates exhibited no significant or consistent differences between two types of HOV facilities which were located in two different regions. Therefore, this implies that the regional differences in safety performance, at least in the corridors examined in the present study, did not account for the differences of collision measures in HOV and its adjacent left lanes between two different types of facilities. Furthermore, they are compared by using statistical tests on the differences of performance metrics between continuous and limited access HOV lanes. Collision per mile per hour for each type of HOV facility was calculated by dividing collisions in HOV and left lanes during the five-year study period by the lane-miles and operation hours. Compared with continuous access facilities, we observed the following characteristics in limited access HOV facilities based on the data from the eight routes in Table 1:

- A higher percentage of total collisions in the combined HOV and left lanes (49% for limited access, versus 29% percent for continuous access) (i.e., differences in collision distribution across the freeway). The same pattern was observed in HOV lanes only (10% for limited access, versus 4% for continuous access) and left lanes only (39% for limited access, versus 25% for continuous access). See Figure 2.

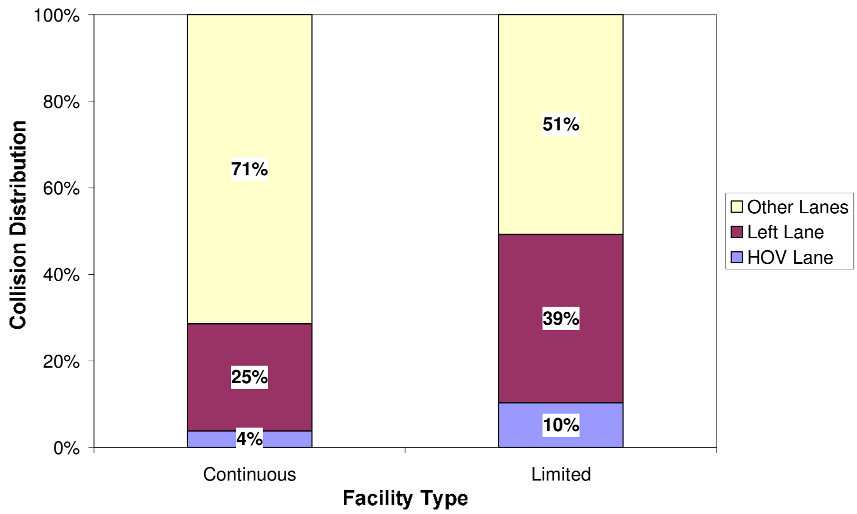



Figure 2 Comparison of Collision Distribution in HOV and Left Lanes

- A higher number of collisions per mile per hour in the combined HOV and left lanes (4.0 collisions per mile for limited access, versus 2.7 for continuous access). The same pattern was observed in HOV lanes (0.8 for limited access, versus 0.4 for continuous access) and left lanes separately (3.2 for limited access, versus 2.3 for continuous access). See Figure 3.

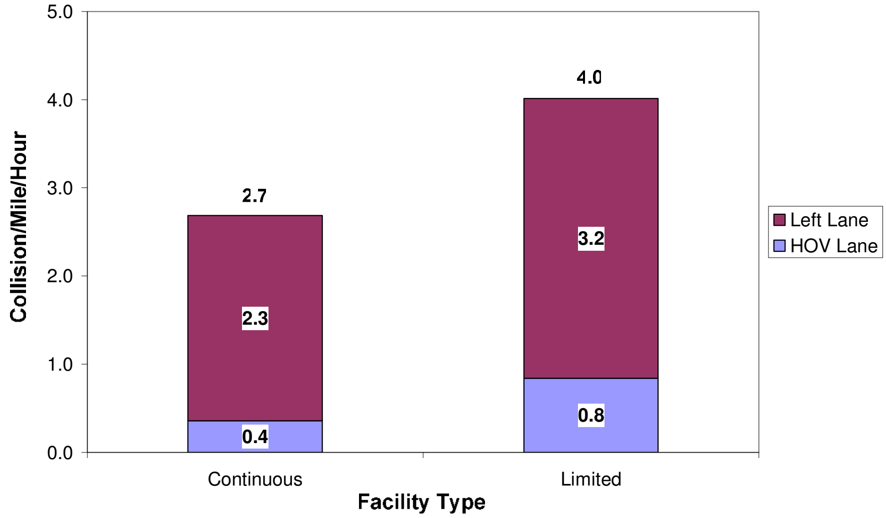



Figure 3 All Collisions per Mile per Hour in HOV and Left Lanes

- A higher number of severe collisions per mile per hour in the HOV lane (0.29 collisions per mile per hour in limited access HOV lanes, versus 0.10 collisions per mile per hour in continuous access HOV lanes), but the opposite pattern in left lanes (0.63 severe collisions per mile per hour in limited access HOV facility left lanes, versus 0.70 collisions per mile per hour in continuous access HOV facility left lanes). The combined number of severe collisions per mile per hour in HOV and left lanes together was still higher for limited access facilities. See Figure 4.

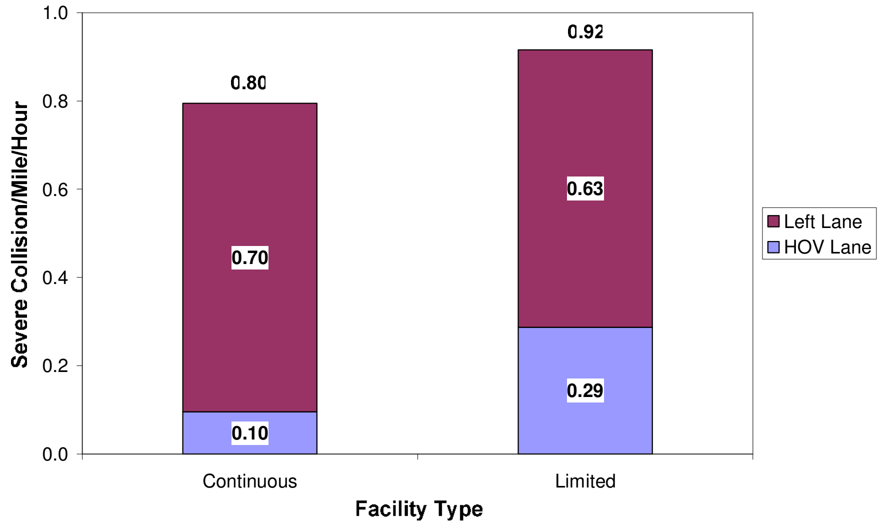



Figure 4 Severe Collisions per Mile per Hour in HOV and Left Lanes

- When traffic volumes are taken into account, and the collisions rates are re-calculated to show the numbers per million-vehicle-traveled, the observations given above are still valid to indicate that limited-access HOV facilities have a higher level of collision rates. The results are shown in Figures 5 and 6, which correspond to Figures 3 and 4 respectively.

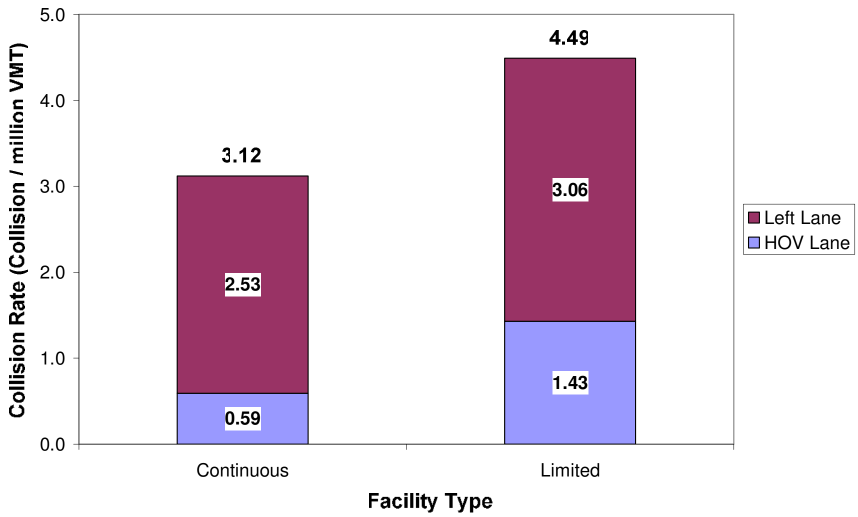



Figure 5 All Collisions per Million-Vehicle-Traveled In HOV and Left Lanes

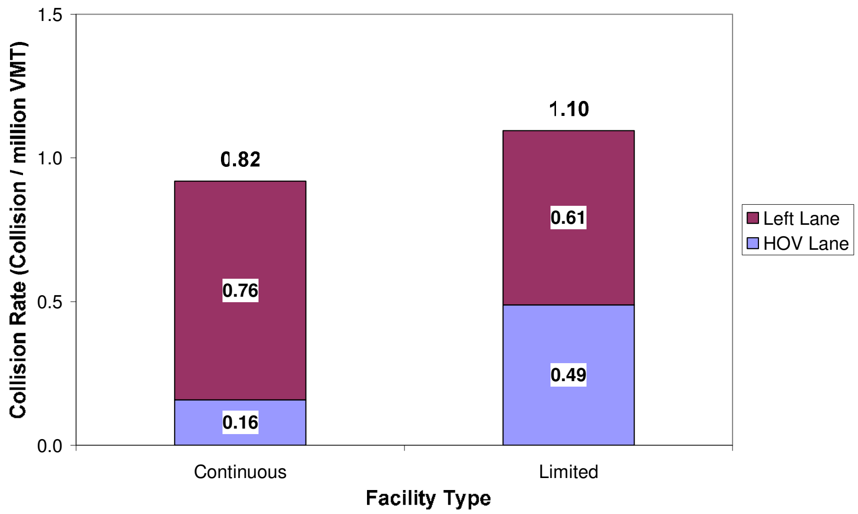



Figure 6 Severe Collisions per Million-Vehicle-Traveled In HOV and Left Lanes

In summary, when compared with HOV lanes in continuous access facilities, HOV lanes in limited access facilities experienced:

- A higher percent of collisions compared with other lanes,
- A higher number of total collisions per mile per hour, and
- A higher number of severe collisions per mile per hour.
- The collision rates measured by traffic volume (per million vehicles travelled) offer the same differential in performance.

The differential for left lanes was somewhat different from the pattern for HOV lanes. Compared with left lanes in continuous access facilities, left lanes in limited access facilities had

- A higher percentage of collisions,
- A higher collision rate, but
- A ***lower*** crash rate of severe collisions.

## 2. STATISTICAL SIGNIFICANCE OF DIFFERENCES BETWEEN TWO HOV FACILITIES

In this section, several approaches for evaluating the statistical significance of the findings mentioned in the previous section will be introduced and the results demonstrated.

### 3.1. Empirical Cumulative Density Function (CDF) of Collisions on HOV and left lanes

Empirical CDF is a cumulative density function which describes the probability distribution of a random variable X less than a given value, x, directly from the data rather than theoretical functions. Empirical CDFs of collisions were constructed through the following data generation process.

(i) Within the TASAS database, freeways are partitioned at the location where geometric features change such that within the segment, geometric features are homogeneous within each segment. This segmentation scheme is maintained in the process of extracting collision records for the purpose of evaluation here.

(ii) Collisions are identified as property-damage-only (PDO) or severe (fatal and injury) to be separated into two data sets. This is based on the consideration that PDO and severe collisions are of different criticality levels, which may have resulted from different causal factors and may offer distinct characteristics in statistical analysis.

(iii) The collisions records ***in both HOV and left lanes*** for all segments were used to calculate the collisions per unit distance, for which the unit of Mile is used so that the values are compatible with the prevalent measures used in historical TASAS studies.

(iv) The 5-year historical data in the period of 1999-2003 for limited-access and continuous-access facilities are processed and used to construct two empirical distribution curves, expressed in cumulative density functions. (CDF) This period of time window was selected to be consistent with all data sources that provide detailed collision, traffic, and configuration information for the selected HOV corridors.

(v) Empirical CDF is constructed by using Kaplan-Meier method. [3] Kaplan-Meier method (also called product-limit method) is originally developed to estimate survival functions especially when the sample size varies during the observation. In the present study, the number of freeway segments, the sample size, is invariant such that Kaplan-Meier method generates equivalently the empirical distribution.

The application of the Kaplan-Meier method for this study is described as follows. Let C be the random variable that measures the collision per mile and $S$(c) be the probability that a segment of freeways has a certain collision per mile exceeding c. For a freeway segment from the population of size N, let the observed collision per mile less than the maximum collision per mile of N freeway segments be $c_i$. Corresponding to each $c_i$, $n_i$ is the number of freeways segments that have the collisions per mile, $c_i$. The Kaplan-Meier estimator is the nonparametric maximum likelihood estimate of $S$(c), which has a product of the form;

$$S(c) = \prod_{c_i \le c} \frac{N - n_i}{N} = P[C > c]$$

Consequently, cumulative distribution function, F(c), can be derived by using S(c).

$$F(c) = P[C \le c] = 1 - P[C > c] = 1 - S(c)$$

(vi) Figure 7 shows an example of the CDF of severe collisions for two types of facilities. The horizontal axis represents the number of collisions per mile, and the vertical axis indicates the value of cumulative percentage of all segments with a specific number of collisions. For example, the blue curve for limited access has a value of 0.9 corresponding to the horizontal axis at x=1. This means that 90 percent of limited-access segment has no severe collisions during the period of 1999 to 2003.

Figure 7 depicts the cumulative distribution of severe collisions for two types of HOV facilities and it reveals that:

- Approximately 5% of continuous-access HOV lane segments have one or more severe collisions per mile.
- Approximately 10% of limited-access HOV lane segments have one or more collisions per mile.

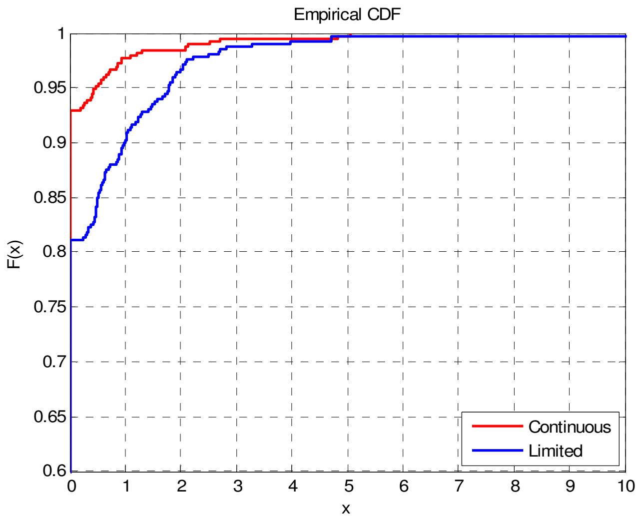



Figure 7 HOV Severe Collisions Empirical Cumulative Distribution Function (CDF)

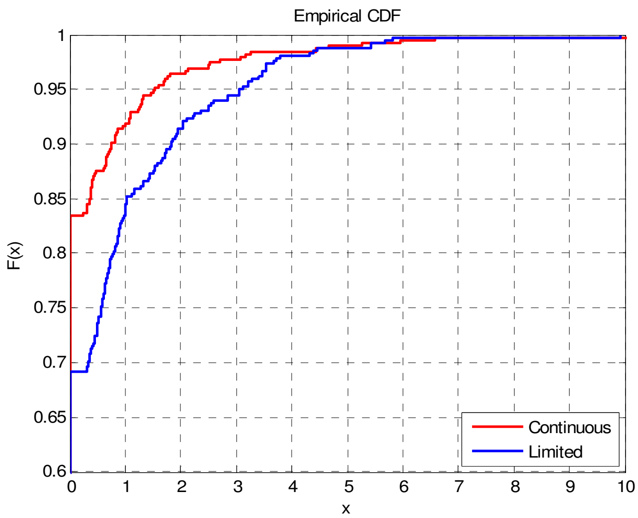



Figure 8 HOV PDO collisions Empirical Cumulative Distribution Function (CDF)

Figure 8 depicts the cumulative distribution of PDO collisions for two types of HOV facilities, and it reveals that:

- Approximately 8% of continuous-access HOV lane segments have one or more PDO collisions per mile.
- Approximately 15% of limited-access HOV lane segments have one or more PDO collisions per mile.

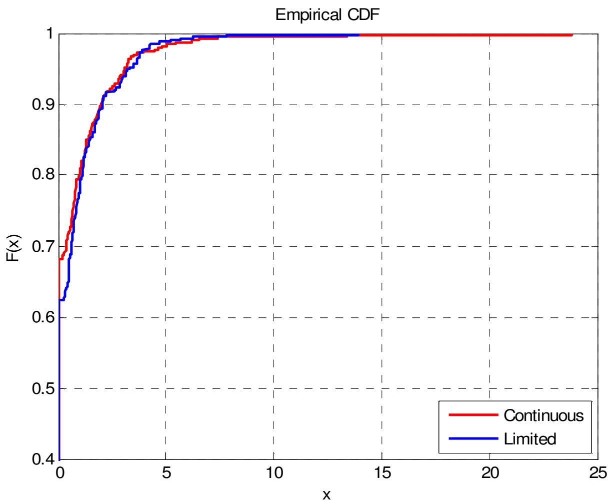



Figure 9 Left severe collisions Empirical Cumulative Distribution Function (CDF)

Figure 9 depicts the cumulative distribution of severe collisions for the left lanes with two types of HOV facilities, and it reveals that:

- Approximately 32% of continuous-access left lane segments have one or more PDO collisions per mile.
- Approximately 37% of limited-access left lane segments have one or more PDO collisions per mile.
- In the higher collision per mile per hour region on the right tail, continuous access left lanes show higher probability than limited access left lanes. This implies that there are more segments with low collision per mile per hour in the limited-access group but more segments with high collision per mile per hour in the continuous-access group. Such distributional difference explains the fact found in Section 2, higher severe left collisions per mile per hour in continuous access.

Figure 10 depicts the cumulative distribution of PDO collisions for the left lanes with two types of HOV facilities, and it reveals that:

- Approximately 45% of continuous-access HOV lane segments have one or more PDO collisions per mile.
- Approximately 60% of limited-access HOV lane segments have one or more PDO collisions per mile.

The CDF distribution graphs above illustrate the comparative performance of HOV and Left lanes in two different types of access configurations. Based on a review of the CDFs, the following conclusions can be made:

- A higher percentage of limited-access HOV lanes have one or more severe or PDO collisions per mile than those of continuous-access lanes.

- On average, this implies that the collision per mile numbers will be higher in limited-access HOV lanes than continuous-access HOV lanes.
- This phenomenon, while expressed in a different manner, is consistent with the results given in the previous sections for a selective set of corridors under detailed-analysis.

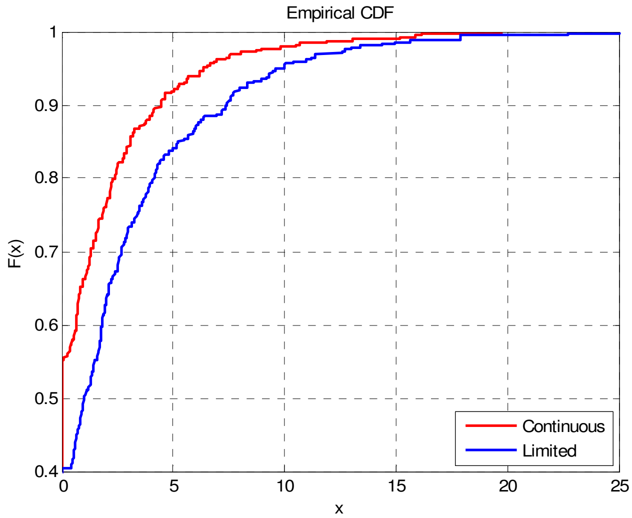



Figure 10 Left PDO collisions Empirical Cumulative Distribution Function (CDF)

### 3.2. Statistical Comparison of CDF Based on Kolmogorov-Smirnov Tests

The Kolmogorov-Smirnov test (K-S test) is a goodness of fit test used to examine the statistically significant difference between two probability distributions based on finite samples. [4, 5] The test is nonparametric in the sense that no assumption is made concerning the distribution underlying the sample data, while it can sensitively measure the differences in both location and shape of the empirical CDFs of the two sample groups. The test is applicable to compare each pair of distributions from two different HOV facilities.

To describe the application of K-S test, we can begin by stating the null hypothesis. $F_C(c)$ and $F_L(c)$ are two empirical CDFs from continuous and limited access HOV facilities, respectively. The null and alternative hypotheses:

$H_0$: $F_C(c) = F_L(c)$
Versus
$H_A$: $F_C(c) \neq F_L(c)$ or $F_C(c) > F_L(c)$ or $F_C(c) < F_L(c)$

The test statistic, D, is derived by taking the maximum absolute difference over the value of c between two empirical CDFs, $F_C(c)$ and $F_L(c)$. Graphically, Equation (1) can be interpreted as maximum vertical displacement between two distributions in Figures 7-10.

$$D = \max_c \left| F_C(c) - F_L(c) \right| \qquad \text{Eq. (1)}$$

Comparing D against a critical value derived from the confidence level, α, and the number of samples from each group, one can determine whether to reject the null hypothesis or not.

Table 2 summarizes the results of K-S test of each collision type between continuous and limited access HOV facilities with three different null hypotheses. The "Reject" and "Accept" given in the table is determined with respect to the null hypothesis. In other words, the "Reject" in the cell indicates rejecting the null hypothesis $H_0$ and accepting the alternative hypothesis, $H_A$ and "Accept" means that the test accepting the null hypothesis, $H_0$ against the alternative hypothesis, $H_A$.

Except for the left-lane severe collision comparison, all the K-S test results lead to the conclusion that $F_C(c)$ is not equal to $F_L(c)$ and $F_C(c)$ is greater than $F_L(c)$. The conclusion that $F_C(c)$ is greater than $F_L(c)$ means that $F_C(c)$ has higher cumulative probability density than $F_L(c)$ at c. Compared to limited access HOV facilities, therefore, it is implied that fewer numbers of freeway segments from the continuous-access group has collision per mile per hour higher than c. This statistical test confirms the findings summarized in Section 2.

Table 2 Hypothesis test at 5% confidence level

| | $H_A$: $F_C(c) \neq F_L(c)$ | $H_A$: $F_C(c) > F_L(c)$ | $H_A$: $F_C(c) < F_L(c)$ |
|---|---|---|---|
| HOV Severe Collisions<br>$H_0$: $F_C(c) = F_L(c)$ | Reject | Reject | Accept |
| HOV PDO Collisions<br>$H_0$: $F_C(c) = F_L(c)$ | Reject | Reject | Accept |
| Left Severe Collisions<br>$H_0$: $F_C(c) = F_L(c)$ | Accept | Accept | Accept |
| Left PDO Collisions<br>$H_0$: $F_C(c) = F_L(c)$ | Reject | Reject | Accept |

**3.3 Statistical Comparison of Means from Two Poisson Distributed Samples**

In this section, the differences in safety performance measured in Section 2 were compared with statistical tests based on an approached developed for two Poisson variables. Test statistics were derived for both distribution and collision per mile per hour comparisons.

**3.3.1 Statistical test for the differences between collision distributions**

Let $C_C$ and $C_L$ denote the numbers of collisions observed in a specific lane in two independent sets of C and L Bernoulli trials (i.e. total collisions across lanes), respectively. In the analysis, all collisions that occurred in continuous and limited access HOV facilities are considered to be C and L, where $p_C$ and $p_L$ represent the true collision distribution associated with each set of trials (i.e. total collisions across lanes). Let $p_e = \dfrac{C_C + C_L}{C + L}$ and define the test statistic:

$$z = \frac{\dfrac{C_C}{C} + \dfrac{C_L}{L}}{\sqrt{\dfrac{p_e(1-p_e)}{C} + \dfrac{p_e(1-p_e)}{L}}} \sim \mathrm{N}(0,1)$$

Using the test statistic, the null hypothesis, $H_0$, at α significance level against one-sided alternative, $H_A$, can be performed ($H_0 : p_C = p_L$ versus $H_A$: $p_C < p_L$). The hypothesis $H_0$ is rejected at the α level of significance level if $Z \geq z_{1-\alpha}$, where $\Phi(z_\alpha)= \alpha$. [6]

The statistical tests were performed on each pair of collision distributions in Figure2 and the results are summarized in Table 3. The statistical test rejects all the null hypotheses and confirms the differences in distributions between continuous and limited access HOV lanes at 95% confidence level.

Table 3 Hypothesis test at 5% significance

| | $H_A$: $p_C \neq p_L$ | $H_A$: $p_C > p_L$ | $H_A$: $p_C < p_L$ |
|---|---|---|---|
| HOV Total Collisions $H_0$: $p_C = p_L$ | Reject | Reject | Accept |
| Left Total Collisions $H_0$: $p_C = p_L$ | Reject | Reject | Accept |
| Other Total Collisions $H_0$: $p_C = p_L$ | Reject | Accept | Reject |

**3.2.2 Statistical test for the differences between collisions per mile per hour**

It is assumed that collisions occurred in continuous and limited access HOV facilities follow two different Poisson processes. In the analysis, these two Poisson processes were observed for fixed mile-hours, $s_C$ and $s_L$, different in continuous and limited access HOV lanes. Let $C_C$ and $C_L$ represent the number of collisions observed within $s_C$ and $s_L$ respectively. Then, the expected collision per mile per hour can be estimated for both facilities as $\lambda_C= C_C / s_C$ and $\lambda_L = C_L / s_L$. Based on these assumptions, we can derive a test statistic, which is asymptotically normally distributed.

$$Z = \frac{s_C \cdot C_L - s_L \cdot C_C}{\left[s_L \cdot s_C \cdot (C_C \times C_L)\right]^{1/2}} \sim N(0,1)$$

Table 4 Hypothesis test at 5% confidence level

| | $H_A$: $\lambda_C \neq \lambda_L$ | $H_A$: $\lambda_C < \lambda_L$ | $H_A$: $\lambda_C > \lambda_L$ |
|---|---|---|---|
| HOV Severe Collisions $H_0$: $\lambda_C = \lambda_L$ | Reject | Reject | Accept |
| HOV PDO Collisions $H_0$: $\lambda_C = \lambda_L$ | Reject | Reject | Accept |
| Left Severe Collisions $H_0$: $\lambda_C = \lambda_L$ | Accept | Accept | Reject |
| Left PDO Collisions $H_0$: $\lambda_C = \lambda_L$ | Reject | Reject | Accept |

Since the differences between two collisions per mile per hour are of our interest, tests of the null hypothesis, $H_0 : \lambda_C = \lambda_L$ at α significance level was conducted against the three alternative hypotheses, either $H_A$: $\lambda_C < \lambda_L$, $H_A$: $\lambda_C > \lambda_L$ and $H_A$: $\lambda_C \neq \lambda_L$. The hypothesis $H_0$ is rejected at the α level of significance level by comparing the test statistic with standard normal distribution. [6, 7] The statistical tests were also conducted for all the differences between continuous and limited access HOV lanes shown in Figure 3 and 4 and the results are summarized in Table 4. The statistical test rejects all the null hypotheses and confirms the differences in collision rates between continuous and limited access HOV lanes at 95% confidence level.

## 4. SAFETY PERFORMANCE OF GENERAL-PURPOSE LANES ALONG HOV CORRIDORS

In this section, historical collision data on the genera-purpose (GP) lanes along the eight HOV corridors used for the study are extracted to be compared to the safety performance of HOV with different access types. For the purpose of illustrations below, the data from the 3-year period of 2003-2005 were used. The freeway corridors were divided into segments, based on their geometric features such as lane numbers and shoulder configurations. The number of collisions that occurred on each segment are totaled and divided by the length of the segments, resulting in a collision rate measured by number of collisions per mile.

### 4.1 Continuous Access HOV Corridors

Table 5 Segments of Continuous Access HOV Corridors

| Number of Segments | Route and Direction | Number of Segments |
|---|---|---|
| Santa Clara County | I-101 SB | 90 |
| Alameda County | I-880 NB | 60 |
| Contra Costa County | I-80 WB | 121 |
| Contra Costa County | I-80 EB | 122 |
| Total Number of Segments | | 393 |

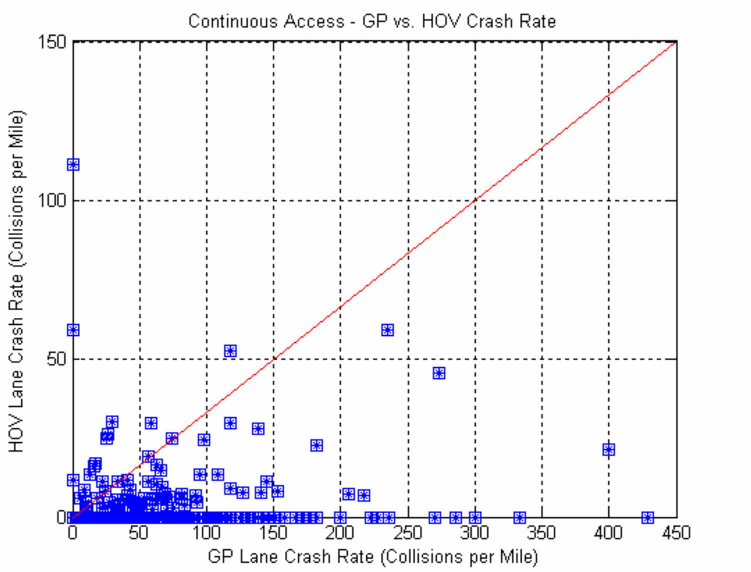



Figure 11 Collisions per Mile of HOV versus GP Lanes with Continuous-Access

Table 5 lists the number of segments that were extracted from the continuous-access corridors. The corresponding HOV and GP collision rates are plotted in Figure 11. Note that the scale for x- and y-axes are set different at a ratio of 3 to 1. For most of the segments, there are 3-4 GP lanes versus one HOV lane. The red line represents an approximate boundary line of equivalence rates for GP and HOV lanes. In Figure 11:

- There are a large number of data points with zero values of crash rates for the HOV lane alone.
- There are more points located on the lower or right side of the boundary line, implying that the HOV lane is generally safer than the GP lanes.
- There are situations where either HOV or GP have disproportionally high collision rates than its counterpart for the same segment.
- There are also a selective set of segments where both HOV and GP are both higher when compared to other segments. These segments deserve further investigation to understand the contributing factors.

### 4.2 Limited Access HOV Corridors

Table 6 Segments of Limited Access HOV Corridors

| Number of Segments | Route and Direction | Number of Segments |
|---|---|---|
| Los Angeles County | I-210 WB | 119 |
| Los Angeles County | I-405 SB | 80 |
| Los Angeles County | I-105 EB | 114 |
| Los Angeles County | I-105 WB | 105 |
| Total Number of Segments | | 418 |

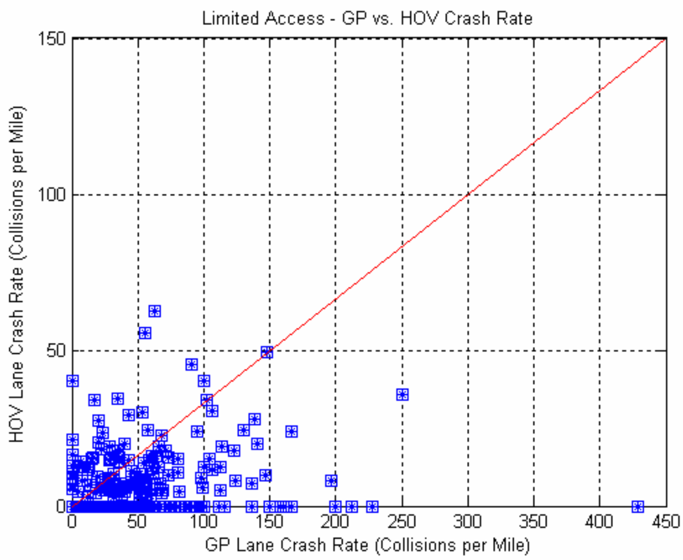



Figure 12 Collisions per Mile of HOV versus GP Lanes with Continuous-Access

Table 6 lists the number of segments that were extracted from the limited-access corridors. The corresponding HOV and GP collision rates are plotted in Figure 11, with the scale for x- and y-axes set differently at a ratio of 3 to 1 for the same reason mentioned above. The red line represents an approximate boundary line of equivalence rates for GP and HOV lanes. It can be observed from Figure 12 that:

- The four observations stated above for continuous-access facilities still apply.
- However, there are more data points on the upper side of the boundary line in Figure 12 than Figure 11. This implies that the safety performance of limited-access HOV

lanes is relatively poor. This again confirms the conclusions that were reached in previous sections.

**4.3 Position of Segments Relative to Ingress/Egress in Limited Access HOV Corridors**

One significant design feature in limited-access HOV facilities is the placement and length of ingress/egress areas, where traffic is allowed to enter and exit. In the current HOV safety study, it has also been found that some collision concentration locations on freeways are near the ingress/egress or transition areas. Therefore, it is of great interests and relevance to inspect the relationship between the collision rates of freeway segments and its distance to the traffic-transition locations.

The data samples for limited-access HOV corridors used in Section 4.2 are further denoted with two parameters:

- Distance from transition: the mid point of the segment to the last transition area upstream. If the distance is greater than 4 miles, the value is set to 10 as this parameter becomes non-critical with diminishing influence from the transition areas.
- Distance to transition: the mid point of the segment to the first transition area downstream. If the distance is greater than 4 miles, the value is set to 10.

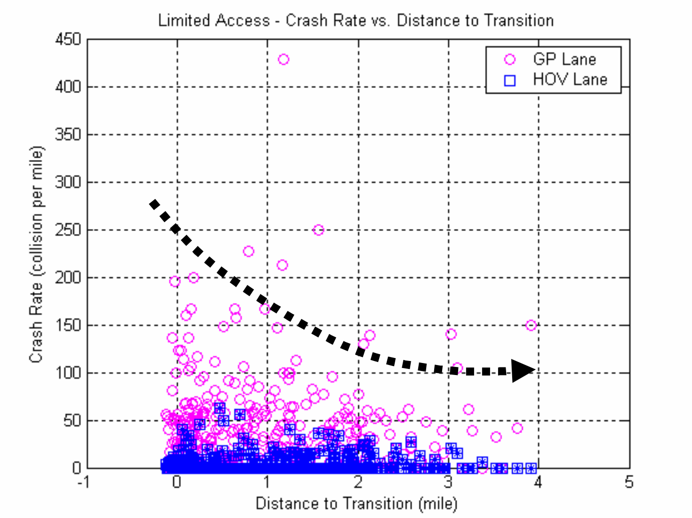



Figure 13A Collision Rates versus Distance to Transition

Figures 13A and 13B show a scatter plot of all data points for distance-to-transition and distance-from-transition respectively. These two graphs reveal several interesting reservations:

- More data points are clustered in the regions that are closer to the transition area. In other words, the closer the segment is to a transition area, the more likely it is to have a higher crash rate.
- The negative effect caused by the closeness to transition areas gradually diminishes as the distance becomes greater, shown by the two arrowed curves in the figures.
- The transition should not be expected to have residual effects for a long distance, therefore those segments with higher crash rates located further away are likely to be associated with other factors.

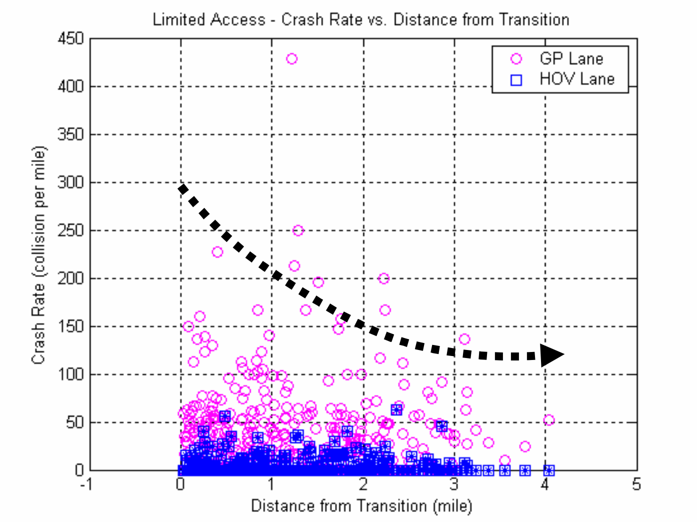



Figure 13B Collision Rates versus Distance from Transition

## 5. CONCLUSION

From a recent study of safety evaluation of HOV-equipped freeways, it was found that limited-access HOV lanes appeared to have a safety performance disadvantage when measured by collision distribution or collision rates for the HOV lane alone and for the HOV and left lanes combined. In order to further assess the significance of these findings and to assist policy-making in selecting HOV configurations, it is important that the performance differentials between two types of HOV facilities are verified vigorously.

This paper describes the procedures of using several statistical tests to validate the results. The approaches include the use of empirical cumulative density function (CDF), Kolmogorov-Smirnov Tests, and comparison of means based on Poisson Distributed Samples. The findings that continuous-access HOV lanes perform better than limited-access ones by several safety metrics are verified by these different approaches. In addition, the historical data for the HOV segments and the general-purpose lanes are extracted and compared. It also revealed similar observations with the same conclusion.

The phenomenon of certain segments possessing non-ideal safety performance can be complex as there are a variety of geometric and operational variables that may have contributed to the differences in safety performance. In-depth investigation of collision concentration locations should be conducted to examine individual cases more thoroughly. The locations of ingress/egress areas appear to have a strong correlation with the crash rates of freeway segments for HOV and GP lanes both. The placement of access areas and their position relative to freeway ramps and junctions is another area of study that deserves greater attention. These remain topics of future studies.

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