STATE OF CALIFORNIA DEPARTMENT OF TRANSPORTATION

TECHNICAL REPORT DOCUMENTATION PAGE

TR0003 (REV. 10/98)

1. REPORT NUMBER	2. GOVERNMENT ASSOCIATION NUMBER	3. RECIPIENT'S CATALOG NUMBER
CA09-0969		ISSN 1055-1425

4. TITLE AND SUBTITLE	5. REPORT DATE
Quantifying the Performance of Countermeasures for Collision Concentration Related to Ramp/Freeway Mainline Junctions	January 2009
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) David R. Ragland, Joon ho Lee, Ching-Yao Chan	8. PERFORMING ORGANIZATION REPORT NO. UCB-ITS-PRR-2009-04
9. PERFORMING ORGANIZATION NAME AND ADDRESS Institute of Transportation Studies University of California, Berkeley Berkeley, CA 94720	10. WORK UNIT NUMBER 193 11. CONTRACT OR GRANT NUMBER 65A0208
12. SPONSORING AGENCY AND ADDRESS California Department of Transportation Division of Research and Innovation, MS-83 1227 O Street Sacramento CA 95814	13. TYPE OF REPORT AND PERIOD COVERED Final Report October 2005 to March 2009 14. SPONSORING AGENCY CODE

15. SUPPLEMENTAL NOTES

16. ABSTRACT

This study performed before-and-after analyses (comparisons of collisions before and after the construction of auxiliary lanes) on collision rate at nine study sites in California in order to achieve two objectives: (i) to estimate the freeway Crash/Collision Reduction Factor (CRF) for auxiliary lanes, and (ii) to develop design guidelines for the construction of auxiliary lanes. Findings indicate that on average, collision rates decreased by 17.3 percent at nine study sites. The study also found that after construction of auxiliary lanes at two study sites, collision rates increased when there were high ramp flows, or when a lane-drop bottleneck was formed near the downstream off-ramp location. As a result of the increase in collision rates at these sites, the construction of auxiliary lanes may not be an appropriate measure if the candidate site has high ramp flows, or if the construction is likely to form a lane-drop bottleneck. When these guidelines are followed, auxiliary lanes reduce collisions 34.0 percent within study sites.

17. KEY WORDS	18. DISTRIBUTION STATEMENT	
Freeways, Ramps, Freeway Junctions, Collision Reduction Factors, Crash Reduction Factors, Auxiliary Lanes, Acceleration Lanes, Deceleration Lanes, Weaving Section, Safety, Traffic Accidents, and Collisions	No restrictions	
19. SECURITY CLASSIFICATION (of this report) None	20. NUMBER OF PAGES 48	21. PRICE

DISCLAIMER STATEMENT

CALIFORNIA PATH PROGRAM
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY

Quantifying the Performance of Countermeasures for Collision Concentration Related to Ramp/Freeway Mainline Junctions

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California PATH Research Report
UCB-ITS-PRR-2009-4

This work was performed as part of the California PATH Program of the University of California, in cooperation with the State of California Business, Transportation, and Housing Agency, Department of Transportation, and the United States Department of Transportation, Federal Highway Administration.

Final Report for 6600

January 2009

ISSN 1055-1425

Quantifying the Performance of Countermeasures for Collision Concentration Related to Ramp/Freeway Mainline Junctions

Task Order 6600

January 7, 2009

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California Department of Transportation

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ACKNOWLEDGMENTS

The University of California Traffic Safety Center (TSC) and Partners for Advanced Transit and Highways (PATH) appreciate and acknowledge the contributions of the Department's Advisory Committee for this research project:

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GLOSSARY OF ACRONYMS AND TERMS

Auxiliary Lane: an acceleration lane from the on-ramp, a deceleration lane to the off-ramp, or a connected (full) auxiliary lane from the on-ramp to the off-ramp.

Weaving section: a weaving section indicates a freeway segment between an on-ramp and an off-ramp. It is typically formed when an on-ramp is closely followed by a downstream off-ramp and these two are joined by an auxiliary lane.

CRF: Crash/Collision Reduction Factor, or the expected reduction in collisions after a countermeasure is implemented.

HCCL: High Collision Concentration Location.

EXECUTIVE SUMMARY/ABSTRACT

1. SYNOPSIS

This study performed before-and-after analyses (comparisons of collisions before and after the construction of auxiliary lanes) on collision rate at nine study sites in California in order to achieve two objectives: (i) to estimate the freeway Crash/Collision Reduction Factor (CRF) for auxiliary lanes, and (ii) to develop design guidelines for the construction of auxiliary lanes. Findings indicate that on average, collision rates decreased by 16 percent (Vehicle-Mile-Traveled-weighted) at nine study sites. The study also found that after construction of auxiliary lanes at two study sites, collision rates increased when there were high ramp flows, or when a lane-drop bottleneck was formed near the downstream off-ramp location. As a result of the increase in collision rates at these sites, the construction of auxiliary lanes may not be an appropriate measure if the candidate site has high ramp flows, or if the construction is likely to form a lane-drop bottleneck. When these guidelines are followed, auxiliary lanes reduce collisions 31 percent within study sites.

2. BACKGROUND

The objective of this study was to quantify the effectiveness of different types of countermeasures installed near ramps, primarily by estimating the Crash/Collision Reduction Factor (CRF) of auxiliary lanes. The CRF is defined as the percentage of collision reduction that is expected after a countermeasure is implemented at a specific site.

Auxiliary lanes are defined as lanes for acceleration from on-ramps or for deceleration to off-ramps, or are connected (full) lanes for both. Auxiliary lanes are different from general-purpose lanes in that the former are used only for lane changing maneuvers. Auxiliary lanes improve traffic operation by managing congestion near on/off-ramps. They also enable lane changing vehicles to more easily execute their maneuvers without interacting with main traffic flow. For these reasons, they are expected to reduce collisions that take place near ramps.

However, a review of recent literature reveals that only a few states documented the CRF for auxiliary lanes, finding a CRF range of 10 to 25 percent. Furthermore, there are few studies that have attempted to estimate or validate CRF. This study estimated the CRF for auxiliary lanes, which are tailored to traffic conditions in California. Before-and-after analysis was performed on nine California freeway sites with auxiliary lanes, using freeway collision data.

DATA SOURCES AND METHODS

The number of collisions during three-year periods before the construction of auxiliary lanes was compared to collisions during three-year periods after construction. Changes in collision rates were further analyzed: (i) within a weaving section if its length is longer than 4000 ft, or (ii) 4000 ft downstream of the on-ramp and/pr 4000 ft upstream of the off-ramp if the length is shorter than 4000 ft. Data for the study were collected from the following sources:

Study sites

The number of collisions before and after the construction of auxiliary lanes was compared at nine study sites in California. Eight of these sites were from Southern California, and one from Northern California. Four had connected (full) auxiliary lanes; the others had deceleration lanes, acceleration lanes, or both, near their ramps.

Collisions

Collision data were extracted from Traffic Accidents Surveillance and Analysis System (TASAS). TASAS is a collision database that records information associated with each collision that occurs within the California state freeway system. Collision data used in this study include collisions that occurred in all traveling lanes during three-year periods before and after the construction. These collision data were converted to collision rate (the number of collisions per Million VMT per year) for comparison.

Traffic data for freeway and ramp flows

Annual Average Daily Traffic (ADT) for freeway flow and for ramp flow were extracted from the Caltrans database. The latest freeway ADT data prior to auxiliary lane construction and the first data after construction were used. In case of ramp ADT, data are recorded every three or six years. In some cases, no ramp data were available prior to or after construction. In these cases, yearly ramp ADT data closest to the time when construction began or closest to its completion were used.

Geometric Features

The following data sources were used to identify changes in geometric configuration after the construction of auxiliary lanes:

- Highway Performance Monitoring System (HPMS): a federally mandated inventory system and planning tool, designed to assess the nation's highway system.
- California Department of Transportation Document Retrieval System (DRS): a document database that enables users to search for, view, and print documents including as-built plans and survey files by using a browser on the California DOT intranet.
- Aerial Photos from Google Earth (http://earth.google.com): a virtual globe program that maps the earth via the superimposition of images obtained from satellite imagery, aerial photography, and GIS 3D globe.

3. SUMMARY OF RESULTS

Collision rates (i.e., the number of collisions per Vehicle Mile Traveled (VMT) per year) at nine study sites were compared before and after the construction of auxiliary lanes. Comparisons were also made among collision rates.

Findings indicate that six study sites showed reductions in collision. On average, collision rate decreased by 16 percent after the construction.

Detailed analysis of each site, however, revealed that the increase in collision rate at some sites was caused not by auxiliary lane construction, but by other factors:

- A lane-drop bottleneck was formulated at one site, contributing to the increase in collision rate at the location.
- A weave between major freeways with heavy congestion due to high ramp flows resulted in the increase in collision rate at another site.

When these locations were not included in the analysis, full-day collision rate decreased by 31 percent within study sites.

4. CONCLUSIONS

The construction of auxiliary lanes was found to reduce collision rate at six out of nine study sites. On average, collision rate decreased by 31 percent.

For two sites, outside factors resulted in increases in collision rates after construction. Based on this finding, the construction of auxiliary lanes may not be appropriate if:

- the potential site has high ramp flows with congestion, or
- construction is likely to form a lane-drop bottleneck.

Following these guidelines for the construction of auxiliary lanes has the potential to result in a significant reduction in collisions.

Keywords: Freeways, Collision Reduction Factors, Crash Reduction Factors, Auxiliary Lanes, Acceleration Lanes, Deceleration Lanes, Weaving Section, Safety, Traffic Accidents, and Collisions

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1. DEFINITIONS AND BACKGROUND

The objective of this study was to quantify the effectiveness of different types of countermeasures installed near ramps, primarily by estimating the Crash/Collision Reduction Factor (CRF) of auxiliary lanes. The CRF was defined as the percentage of collision reductions that might be expected after implementing a given countermeasure at a specific site.

Auxiliary lanes were defined as lanes for acceleration from on-ramps or for deceleration to off-ramps, or connected (full) lanes for both. Auxiliary lanes are different from general-purpose lanes in that the former are used only for lane changing vehicles. The intent of auxiliary lanes is to improve traffic operation by managing congestion near on/off-ramps. They also enable lane changing vehicles to more easily execute their maneuvers without interacting with the main freeway traffic flow. For these reasons, they were expected to reduce collisions near ramps.

A review of recent literature revealed that only a few states have estimated the CRF for auxiliary lanes, and these CRFs range from 10 to 25 percent.[1] Furthermore, there are few studies that have attempted to validate these CRFs. This study was designed to estimate the CRF for auxiliary lanes, with particular relevance for traffic conditions in California. Before-and-after analysis was performed on nine California freeway sites with auxiliary lanes, using freeway collision data.

Section 2 summarizes previous studies on traffic collisions in the vicinity of ramps. Section 3 states the objective of the present study. Section 4 explains the technical approach and data sources for the analysis. Section 5 summarizes results from the before-and-after analysis, and Section 6 presents results at each site are presented in detail. Section 7 discusses topics for future study. Appendix A presents the results of an alternative approach for estimating the effect of auxiliary lanes on collisions, cross-sectional comparisons.

2. SUMMARY OF PREVIOUS STUDIES

Previous studies regarding traffic safety in the vicinity of ramps have focused mainly on collisions within ramps and/or auxiliary lanes.

An earlier study by the California Department of Transportation (Caltrans) evaluated the effect of ramp configuration, type and geometry on collisions by performing descriptive analysis and using ANOVA (Analysis of Variance) models. The study found that

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[1] Agent, Kenneth R. et.al, Development of Accident Reduction Factors, *Research Report KTC-96-13*. Kentucky, Transportation Center College of Engineering, 1996

geometric design was not a determining factor for collisions compared to other variables.[2]

In a study by Bauer, statistical models were developed to define the relationship between traffic collisions in the auxiliary lanes and other variables such as geometric design elements, traffic volume, and the presence of a speed-change lane. These statistical models included the Poisson and negative binomial regressions. The study found that most variability can be explained by ramp Annual Average Daily Traffic (ADT) and mainline freeway ADT, area type (rural/urban), ramp type (on/off), ramp configuration, and the combined length of a ramp and speed-change lane.[3]

One study developed a statistical model to estimate collision frequencies for entire ramps as a function of the length of the speed-change lane, among other variables. According to this model, the longer the speed-change lane, the less the collision frequency.[4]

Another study applied existing predictive models to ramp collisions, and calibrated parameters. Forty-four ramps were selected and used in the calibration process. According to these results, exit ramps have more collisions than entrance ramps, and ramps that are not free flow experience twice as many collisions as other types of ramps. [5]

Previous studies evaluated how auxiliary lanes influence collisions in the ramps and/or auxiliary lanes, but did not estimate their effect on freeway collisions in mainline traffic. Auxiliary lanes are designed to improve traffic operation near ramps, reducing nearby traffic congestion. The construction of auxiliary lanes would be expected to affect the rate of collisions on the freeway itself. In light of this, the present study developed CRFs for auxiliary lanes by comparing freeway collisions before-and-after the construction of auxiliary lanes.

3. STUDY OBJECTIVES

The objectives of this study were to (i) estimate the freeway Crash/Collision Reduction Factor (CRF) for auxiliary lanes, and to (ii) develop design guidelines for the construction of auxiliary lanes. The data sources used are presented below, in Section 4.

[2] Khorashadi, A., Effect of ramp type and geometry on accidents, *FHWA/CA/TE-98/13*, California Department of Transportation, 1998
[3] Bauer, K. M., and Harwood, D. W., Statistical models of accidents on interchange ramps and speed-change lanes, *FHWA-RD-97-106*, FHWA, U.S. Department of Transportation, 1998
[4] Bared, J., Giering, G. L., and Warren D. L., Safety of evaluation of acceleration and deceleration lane lengths, *ITE Journal, May 1999*, p 50-54
[5] Loard D. and Bonneson J. A., Calibration of predictive models for estimating safety of ramp design configurations, *Journal of Transportation Research Board, No. 1908,* Transportation Research Board of the National Academies, Washington, D.C., 2005, p 88-95

4. DATA SOURCES AND TECHNICAL APPROACHES

To compare collision patterns before and after the construction of auxiliary lanes, a variety of data were gathered at the nine study sites where auxiliary lanes were constructed. Collision data were compared within the relatively short time frame of three years before and after construction to minimize any outside factors or changes to the lanes (e.g., freeway/ramp flows and changes to geometric configurations). Data sources and their applications are identified below.

Study sites

Locations	Route	On-ramp	Off-ramp	PM (on)	PM (off)	Aux. Lane	Const. Begin	Const. End
12-ORA	SR55N	Chapman	Katella	13.898	15.108	Full	05/1999	07/2002
12-ORA	SR55N	Katella	Lincoln	15.222	16.823	Acc./Dec.	05/1999	07/2002
12-ORA	SR55S	Lincoln	Katella	16.715	15.383	Dec.	05/1999	07/2002
12-ORA	SR55S	Katella	Chapman	15.109	13.921	Full	05/1999	07/2002
4-ALA	SR238N	EB580	RTE185	R14.78	15.011	Full	07/1999	10/2000
7-LA	I5S	Florence	Pioneer	6.495	5.276	Acc./Dec.	02/1997	06/1998
7-LA	I710N	-	EB Del Amo	-	10.687	Dec.	01/2001	04/2004
7-LA	I710N	EB Del Amo	WB Del Amo	10.745	10.922	Full	01/2001	04/2004
7-LA	I710S	Del Amo	-	10.92	-	Acc.	01/2002	04/2004

Table 1. Studv sites

The locations in table 1 indicate the districts and the counties of the study sites. Locations where there were enough data before and after the construction of auxiliary lanes were chosen with assistance from Caltrans. The table also shows the type of auxiliary lane that was constructed at each location.

Collisions

Collision data were extracted from Traffic Accidents Surveillance and Analysis System (TASAS). TASAS is a collision database that records information on each collision within the California state freeway system.[6]

Collision data used in this study include collisions that occurred in all traveling lanes during three-year periods before and after construction. These collision data were converted to collision rate, the number of collisions per Million VMT per year, for comparison. They were then compared at each site (see figure 1): (i) within a weaving

[6] California Department of Transportation, California DOT traffic manual, Ch. 3. Accident and roadway records, 2004

section (between an on-ramp and an off-ramp) if its length is longer than 4000 ft., or (ii) 4000 ft downstream of the on-ramp and/or 4000 ft upstream of the off-ramp if the length is shorter than 4000 ft (see figure 1)[7].

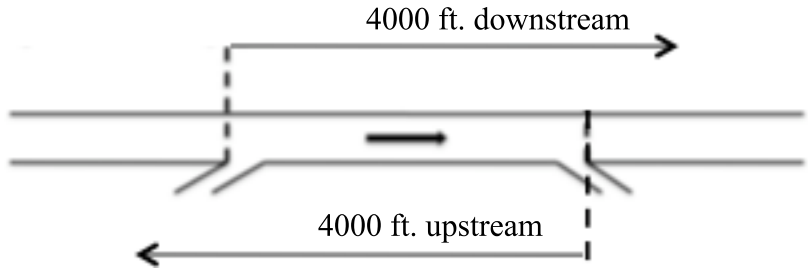

Figure 1. Location of collision data if the weaving section is shorter than 4000 ft

Traffic data for freeway and ramp flows
Annual Average Daily Traffic (ADT) for freeway flows and for ramp flows were extracted from the Caltrans Traffic Data Branch.

Data were collected to document changes in traffic flow over time. Yearly ramp ADT data *closest* to the time when construction began or ended at each site were used for the analysis. In the case of ramp ADT, data were recorded at either three- or six-year intervals. In some cases, however, ramp data were not available.

Geometric Features
There were three sources for geometric information on the study sites:

- Highway Performance Monitoring System (HPMS): a federally mandated inventory system and planning tool, designed to assess the nation's highway system.
- California Department of Transportation Document Retrieval System (DRS): a document database that enables users to search for, view, and print documents including as-built plans and survey files by using a browser on the California DOT intranet.
- Aerial Photos from Google Earth (http://earth.google.com): a virtual globe program that maps the earth via the superimposition of images obtained from satellite imagery, aerial photography, and GIS 3D globe.

This information was used in the analysis to identify changes in geometric configuration after the construction of auxiliary lanes.

[7] The Highway Capacity Manual assumes that study sites influence traffic up to 4000 ft. up/downstream.

5. SUMMARY OF BEFORE-AND-AFTER ANALYSIS ON COLLISION RATE

Figure 2 show collision rate (i.e., the number of collisions per million Vehicle Mile Traveled (VMT) per year) before and after the construction of auxiliary lanes at nine study sites. Bars on the left show collision rate before construction, and on the right after construction.

The results show that six sites experienced reductions in collision rates. On average, collision rates decreased by 16 percent.

However, detailed investigation revealed that the collision rates increase at some sites were caused not by auxiliary lane construction, but by other factors:

i. A lane-drop bottleneck was formulated at site 2, contributing to the increase in collision rate.
ii. Site 5 has a short weave between two major freeways with heavy congestion due to high ramp flows, resulting in an increase in collision rate.

When these locations (sites 2 and 5) were not included in the analysis, on average collision rates decreased by 31 percent within study sites.

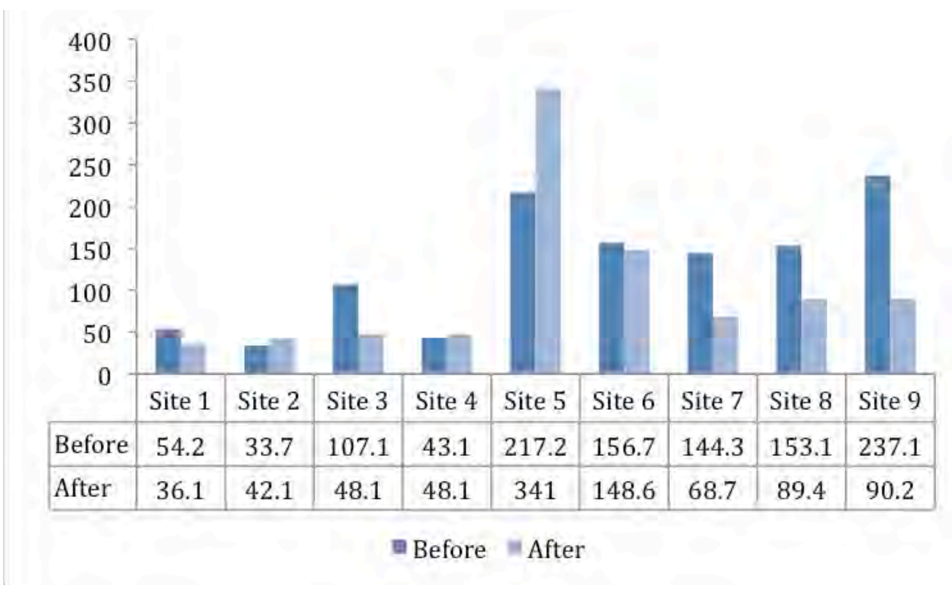

Figure 2. Comparison of before-after collision rates at nine study sites

6. BEFORE-AND-AFTER ANALYSIS ON INDIVIDUAL SITES

This section presents the geometric configuration and traffic volume of the study sites, and examines the change in collision rate at each site.

6.1. SITES 1 AND 2, SR-55N

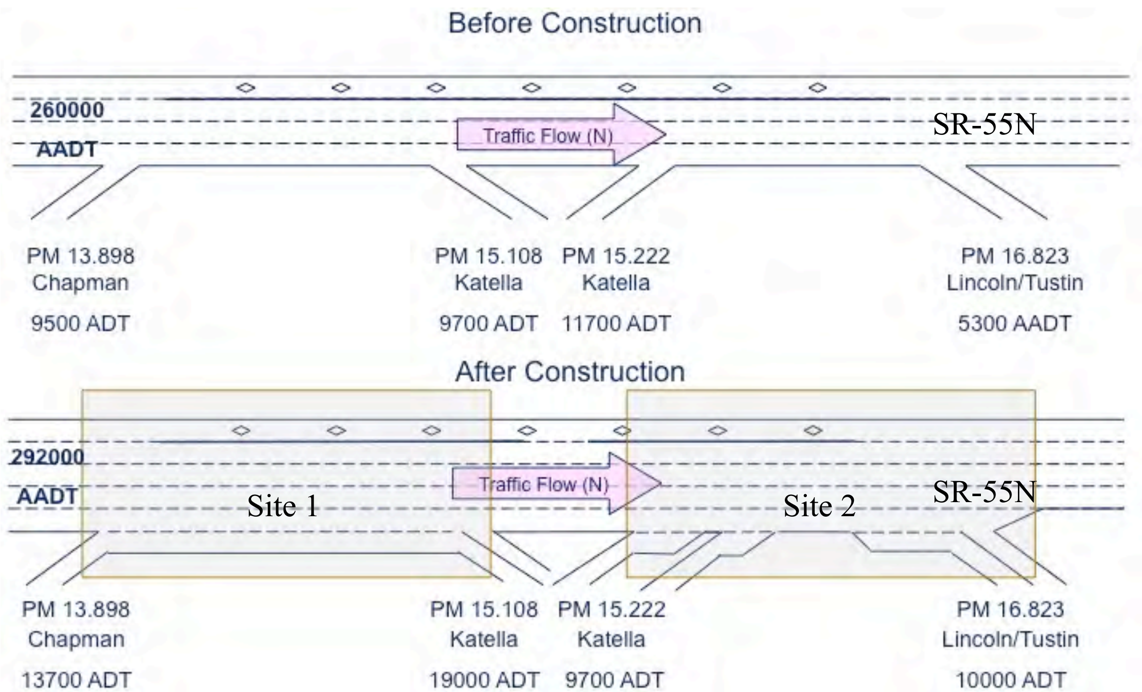

Figure 3. Geometric configuration of study sites 1 and 2

Figure 3 shows the geometric configuration of sites 1 and 2 on SR-55N in Orange County with freeway and ramp volumes before and after the construction of auxiliary lanes. Traffic is traveling from left to right. The sketch of the sites on the top indicates the geometric configuration before construction; the bottom sketch shows the configuration after construction. A connected (full) auxiliary lane was constructed at site 1, and both an acceleration and a deceleration lane were added to site 2 between May 1999 and July 2002. Also note that during this construction period, one additional general-purpose lane was added to the location. Freeway ADT shown on the top indicates traffic volumes in 1998 (before construction), and those on the bottom are from the volume data in 2003 (after construction). Ramp ADT prior to construction were from year 2000 and after construction were from year 2003 or 2006 (i.e., Chapman and Katella on-ramps from 2006; Katella and Lincoln off-ramps from 2003).

The change in collision rate at these sites is summarized in table 2. After construction of the auxiliary lanes, collision rate decreased at site 1 in spite of the increase in both freeway and ramp flows. However, collision rate at site 2 increased after construction.

	Site 1	Site 2
Before	54.2	33.7
After	36.1	42.1

Table 2. Collision rate (number of collisions per Million VMT per year) at sites 1 and 2

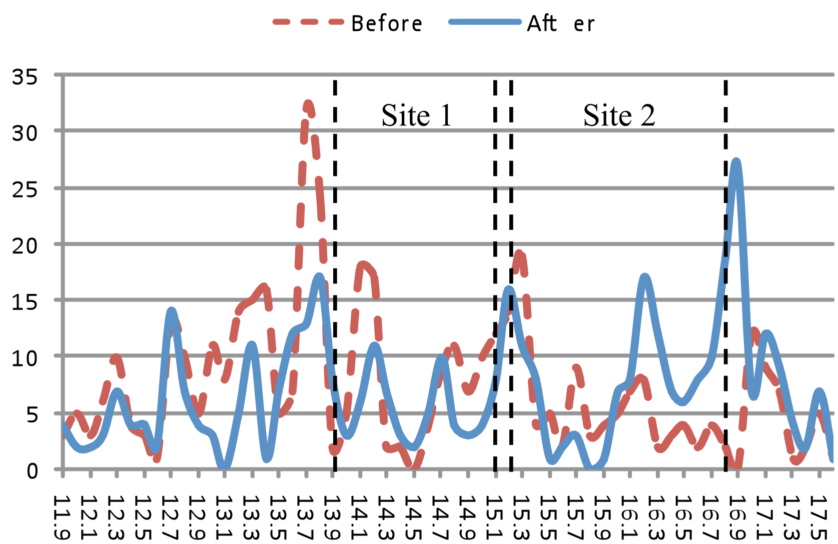

Figure 4. Collision profile of study sites 1 and 2

Collision profile of the sites 1 and 2 are shown in figure 4. X-axis represents postmile and y-axis represents the number of collisions within 0.5 mile before and after the constructions of auxiliary lanes. Traffic is moving from left to right. Dotted and Solid curves respectively show the number of collisions before and after the constructions. As can be seen in the figure, the construction resulted in the reduction at site 1 but the increase at site 2. Note the high concentration of the collisions near Lincoln off-ramp (pm 16.823). Construction at site 2 created a lane-drop near the Lincoln off-ramp, and this lane drop may have caused the increase in collision rate at site 2 and its downstream. For this reason, site 2 was not considered when calculating the CRF for auxiliary lanes.

6.2. SITES 3 AND 4, SR-55S

Figure 5 shows the geometric configuration of sites 3 and 4 on SR-55S in Orange County with freeway and ramp volumes before and after the construction of auxiliary lanes. Traffic is traveling from right to left. Note that this location is exactly opposite sites 1 and 2, previously shown in figure 3. The top sketch indicates the geometric configuration before construction; the bottom sketch shows the configuration after construction. A deceleration lane was constructed at site 3, and a connected (full) auxiliary lane was added to site 2 between May 1999 and July 2002. Also note that during this period, one additional general-purpose lane was added to this location. Freeway ADT shown on the top indicates traffic volume in 1998 (before construction), and on the bottom in 2003 (after construction). Ramp ADT prior to construction were from year 2000 and after construction were from year 2003 or 2006 (i.e., Chapman off-ramp from 2006; Katella on/off-ramps and Lincoln on-ramp from 2003).

The change in collision rate at these locations is summarized in table 3. After construction of the auxiliary lanes, collision rate decreased at site 3 in spite of the increase in freeway flows. However, collision rate at site 4 increased after construction. Note that there was a major connector to SR-22 within one mile downstream of the Chapman off-ramp (site 4), and the construction of auxiliary lanes and one additional general-purpose lane may have increased congestion near the downstream of site 4, while reducing congestion near the Lincoln on-ramp. The relocation of the congestion may have transferred collisions from site 3 to site 4.

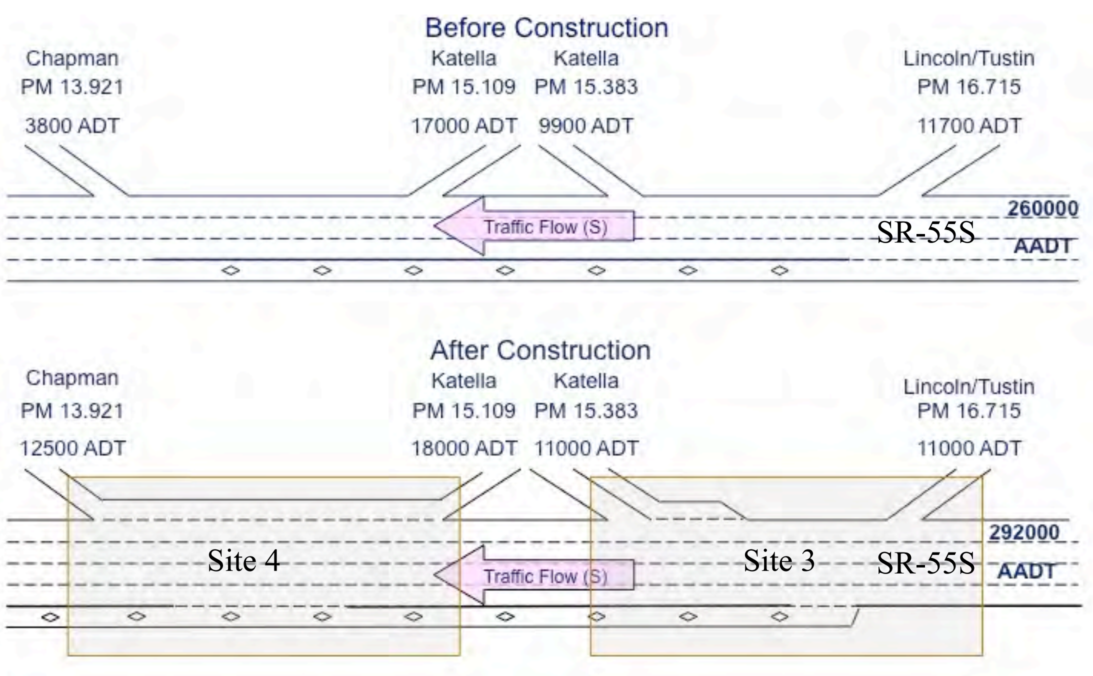

Figure 5. Geometric configuration of study sites 3 and 4

	Site 3	Site 4
Before	107.1	43.1
After	48.1	48.1

Table 3. Collision rate (number of collisions per Million VMT per year) at sites 3 and 4

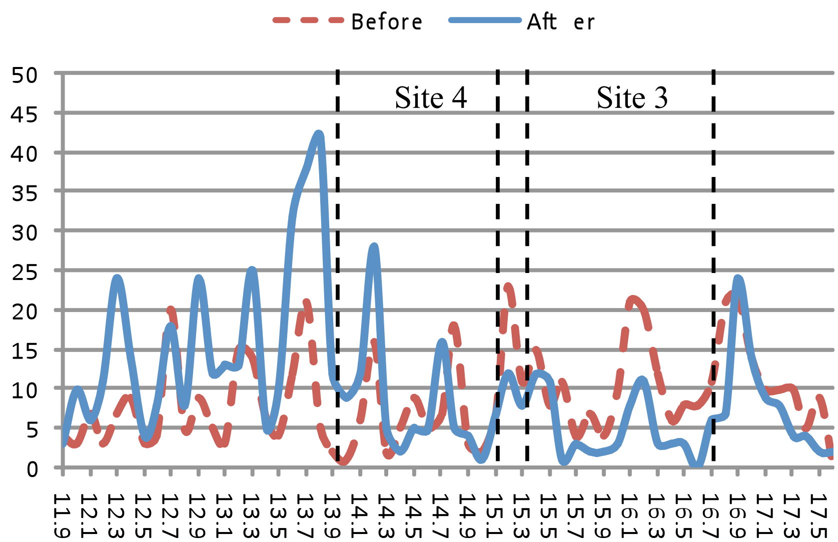

Figure 6. Collision profile of study sites 3 and 4

Figure 6 shows collision profile of the sites 3 and 4. The construction resulted in the reduction at site 3 but the increase at site 4. Collision increases downstream of site 4 was potentially caused by downstream ramps, but it could not be verified due to lack of available data.

6.3. SITE 5, SR-238N

Figure 7 shows the geometric configuration of site 5 on SR-238N in Alameda County with freeway and ramp volumes before and after the construction of auxiliary lanes. Traffic is traveling from right to left. The top sketch indicates the geometric configuration before construction; the bottom sketch shows the configuration after construction. A connected (full) auxiliary lane was constructed at site 5 between July 1999 and October 2000. Freeway ADT shown on the top indicates traffic volume in 1998 (before construction), and on the bottom in 2001 (after construction). Ramp ADT prior to construction were from year 1997 and after construction from year 2000.

The change in collision rate at this location is summarized in table 4. After the construction of the auxiliary lane, collision rate significantly increased at site 5.

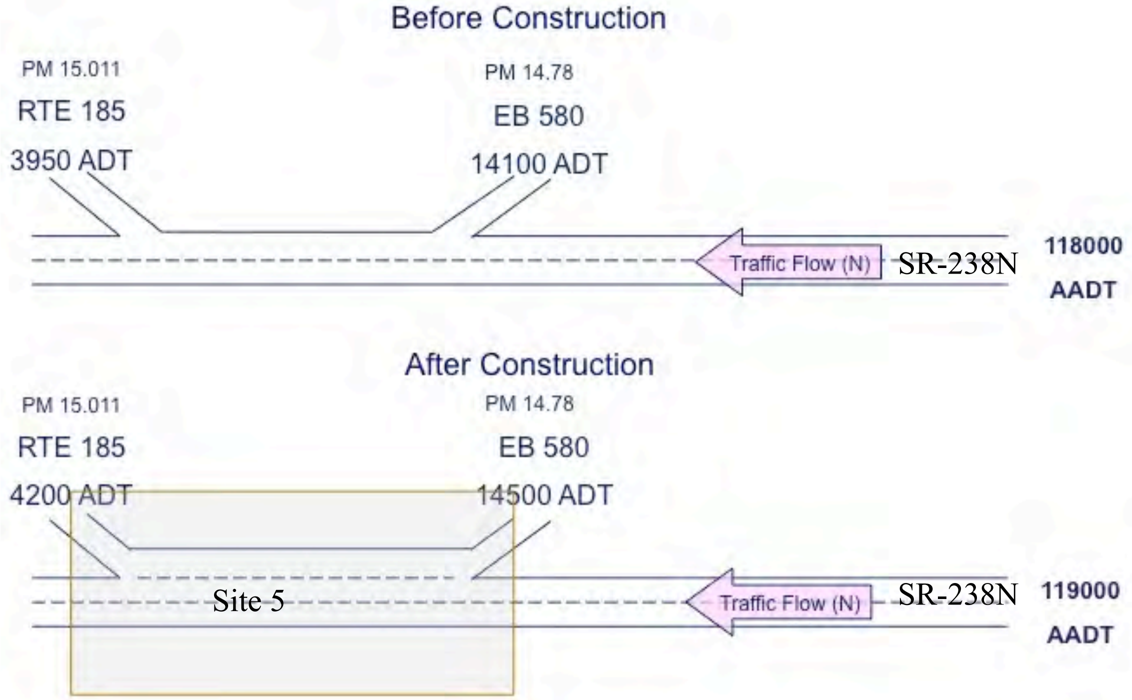

Figure 5. Geometric configuration of study site 5

	Site 5
Before	217.2
After	341.0

Table 4. Collision rate (number of collisions per Million VMT per year) at site 5

Figure 8 shows collision profile of the site 5. The construction resulted in the significant increase at site 5. This location has a weave between two major freeways with heavy congestion identified by the Highway Congestion Monitoring Program (HICOMP) in year 1998. HICOMP data revealed that the site became congested between 6:30 a.m. and 9:30 a.m., the morning rush, and between 3:50 and 6:35 p.m., the evening rush. The increase in collision rate at this site was due to significant congestion combined with high ramp flows. For this reason, site 5 was not considered when calculating the CRF for auxiliary lanes.

Collision contour maps at site 5 are shown in figure 9. X-axis represents postmiles of collisions, and y-axis in the figure indicates collision location coded in Tasas. These are sorted in such a way that those on the top represent locations near the median lane, and those on the bottom represent locations near right shoulder. Higher peak in the figure indicate higher number of collisions. High peaks can be seen in the right lane within the study site and its upstream. It is conjectured that this increase was caused by the short weave between two major freeways with heavy congestion, and for this reason this site was not included when calculating collision reduction factor.

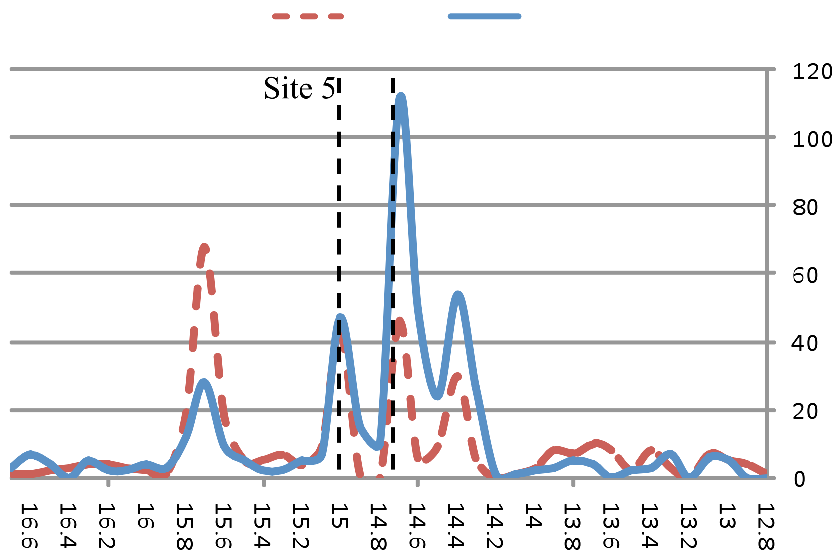

Figure 8. Collision profile of study site 5

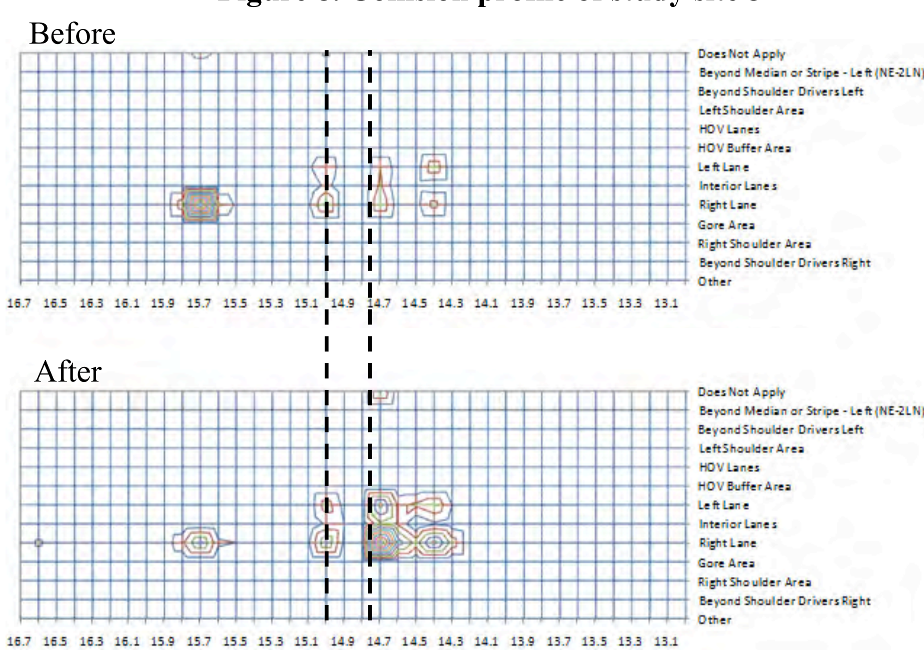

Figure 9. Collision contour map of study site 5

6.4. SITE 6, I-5S

Figure 10 shows the geometric configuration of site 6 on I-5S in Los Angeles with freeway and ramp volumes before and after the construction of auxiliary lanes. Traffic is traveling from right to left. The top sketch indicates the geometric configuration before construction; the bottom sketch shows the configuration after construction. Two acceleration lanes were constructed at the Orr/Day and Florence on-ramps between February 1997 and June 1998. Freeway ADT on the top show traffic volume in 1996, before construction. Data on the bottom show traffic volume in 1999, after construction. Ramp ADT prior to construction were from year 1998 or 2001 (i.e., Florence on-ramp: 1998; Orr/Day and Pioneer on-ramps: 2001); after construction, data were from year 2001.

The change in collision rate at this location is summarized in table 5. After the construction of the auxiliary lanes, collision rate decreased significantly at site 6. In addition, figure 11 shows collision profile of the site 6. Again the figure shows small reductions at site 6.

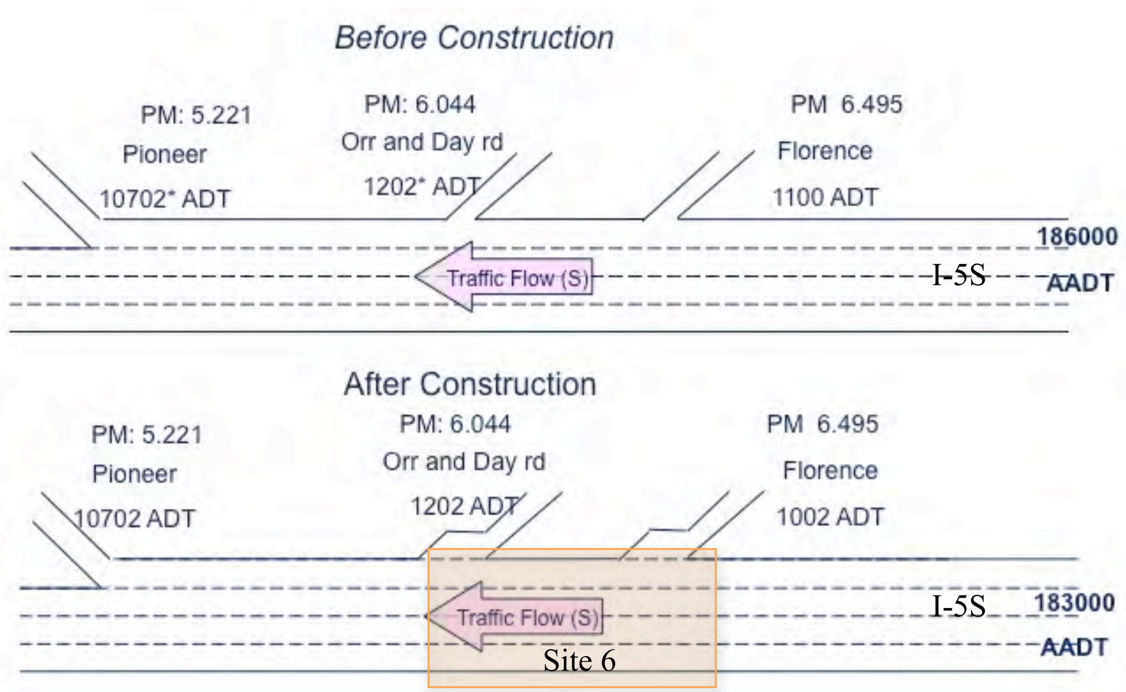

Figure 10. Geometric configuration of study site 6

	Site 6
Before	156.7
After	148.6

Table 5. Collision rate (number of collisions per Million VMT per year) at site 6

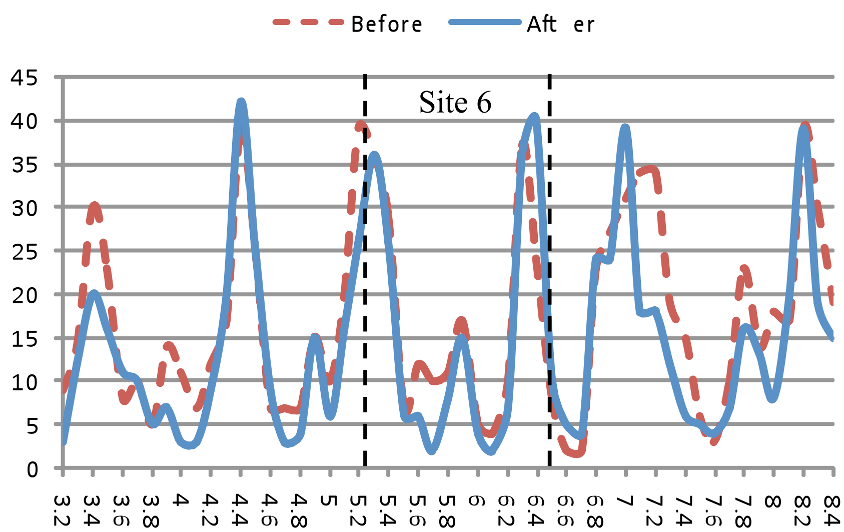

Figure 11. Collision profile of study site 6

6.5. SITES 7 AND 8, I-710N

Figure 12 shows the geometric configuration of sites 7 and 8 on I-710N in Los Angeles with freeway and ramp volume before and after the construction of auxiliary lanes. Traffic is traveling from left to right. The top sketch indicates the geometric configuration before construction; the bottom sketch shows the configuration after construction. A deceleration lane was constructed at site 7 and a connected (full) auxiliary lane was added at site 8 between January 2002 and April 2004. Freeway ADT on the top show traffic volume before construction in 2001, and the bottom shows volume data after construction in 2005. Ramp ADT were from year 2001 both before and after construction.

The change in collision rate at these sites is summarized in table 6. After construction of the auxiliary lanes, collision rate decreased significantly at both sites 5 and 6. Figure 13 shows collision profile of sites 7 and 8. Again the figure shows significant reductions at both sites. Collision contour maps at both sites are shown in figure 9. Note that the construction significantly reduced collisions on the right shoulder and its beyond.

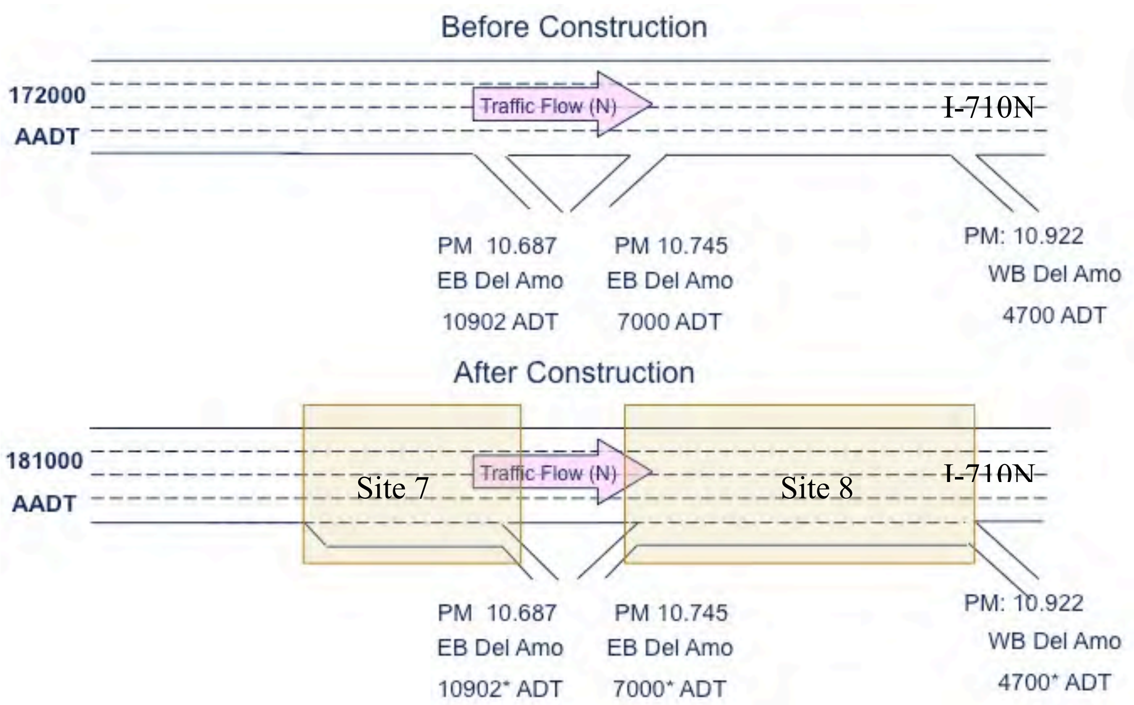

Figure 12. Geometric configuration of study sites 7 and 8

	Site 7	Site 8
Before	144.3	153.1
After	68.7	89.4

Table 6. Collision rate (number of collisions per Million VMT per year) at sites 7 and 8

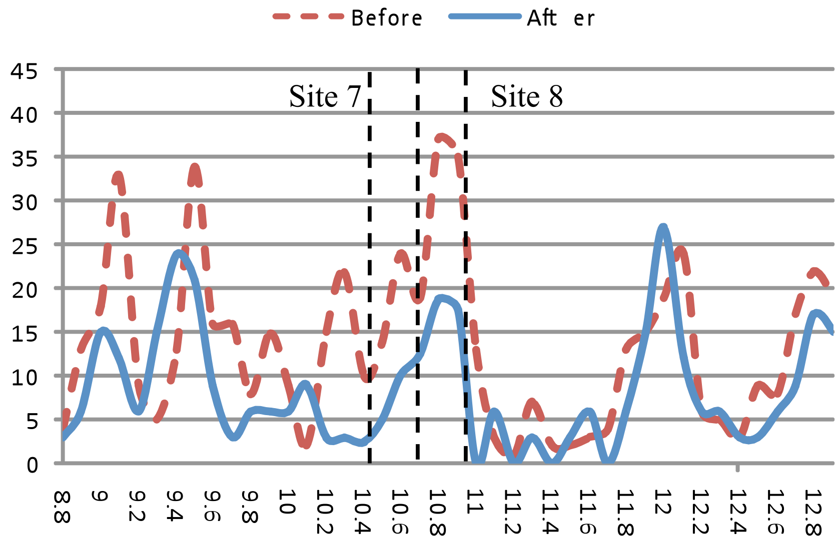

Figure 13. Collision profile of study sites 7 and 8

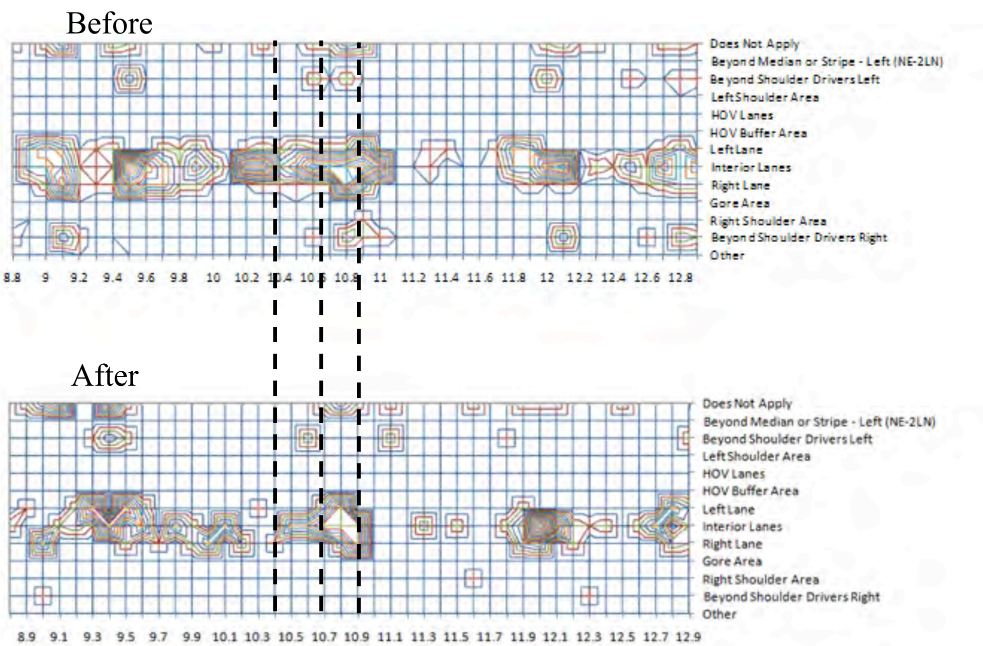

Figure 14. Collision contour map of study sites 7 and 8

6.6. SITE 9, I-710S

Figure 15 shows the geometric configuration of site 9 on I-710S in Los Angeles with freeway and ramp volumes before and after the construction of auxiliary lanes. Traffic is traveling from left to right. The top sketch indicates the geometric configuration before construction; the bottom sketch shows the configuration after construction. An acceleration lane was constructed at the Del Amo on-ramp between January 2002 and April 2004. Freeway ADT on the top show traffic volume before construction in 2001; data on the bottom show traffic volume in 2005, after the construction. Ramp ADT were from year 2001 for both before and after construction.

The change in collision rate at these locations is summarized in table 7. After the construction of the auxiliary lanes, collision rate decreased significantly at site 9. Figure 16 shows collision profile of site 9, and shows significant reductions at the site.

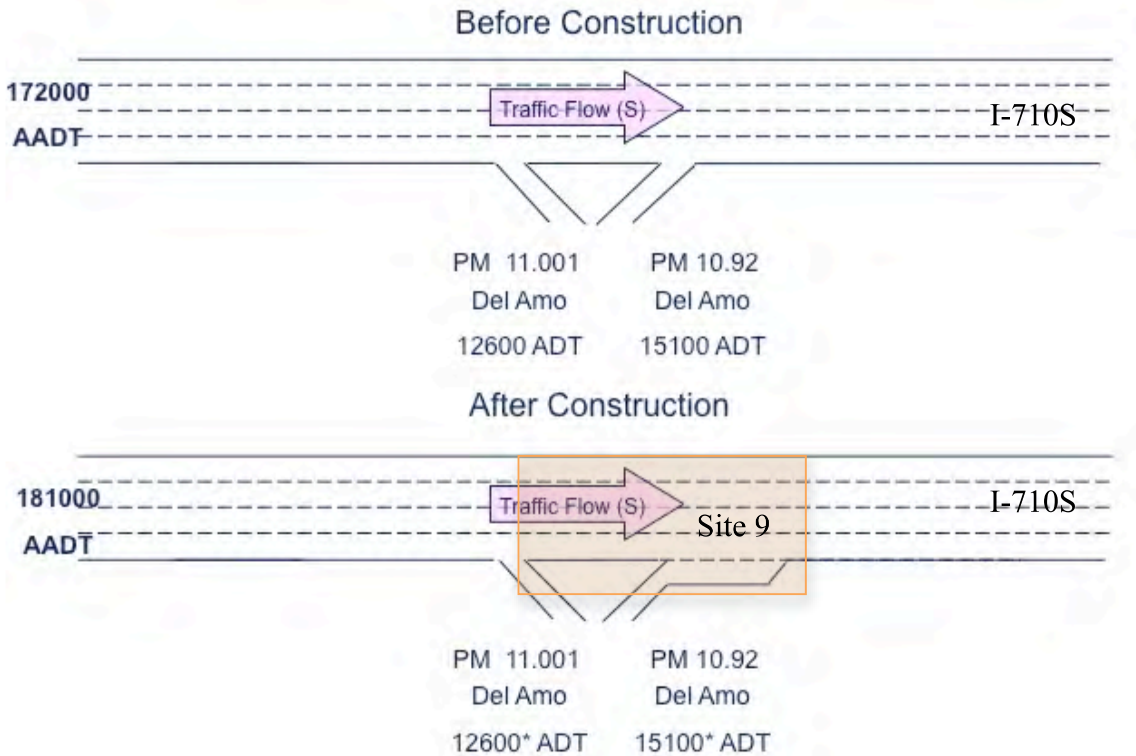

Figure 15. Geometric configuration of study site 9

	Site 9
Before	237.1
After	90.2

Table 7. Collision rate (number of collisions per Million VMT per year) at site 9

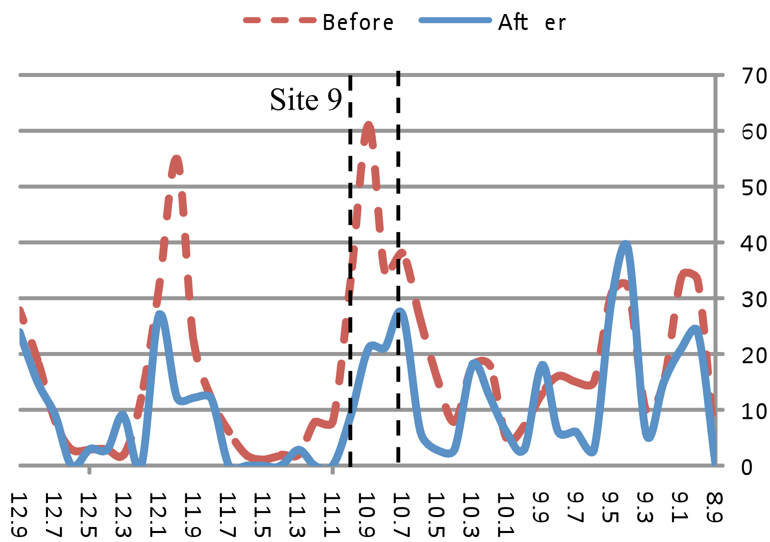

Figure 16. Collision profile of study site 9

7. CONCLUSIONS AND IMPLICATIONS

The before-and-after analysis reveals that the construction of auxiliary lanes resulted in reductions in collision rate at all nine sites. On average, collision rate decreased by 16 percent.

Detailed analysis of the two sites where collision rate increased significantly after the construction of auxiliary lanes revealed that increases occurred when:

- A site was congested with high ramp flows (1200 ft weave between major freeways with 18000 ADT ramp flows), or
- a lane-drop bottleneck was formed near the downstream off-ramp location (e.g., site 2).

These results suggest that the construction of auxiliary lanes may not be appropriate if:

- the potential site has high ramp flows, or
- construction is likely to result in a lane-drop bottleneck.

When the conditions of locations 2 and 5 were left out of CRF calculations, the CRF for auxiliary lanes was reduced by 31 percent within study sites. It follows that if the guidelines above are followed, avoiding the conditions present at sites 2 and 5, collision rate would be reduced.

8. FUTURE RESEARCH

This section discusses potential topics for future studies.

8.1. DETAILED COLLISION REDUCTION FACTORS

With additional sites it would be possible to quantify the CRF for each type of auxiliary lane. Most states use identical CRFs for acceleration and deceleration lanes, but there are currently no CRFs for connected (full) auxiliary lanes. Because each type of auxiliary lane influences traffic operation differently, it is reasonable to expect that the CRFs for deceleration, acceleration, and connected (full) auxiliary lanes would differ from one another.

8.2. RAMP COLLISION REDUCTION FACTORS

Quantify the CRF of auxiliary lanes for ramp collisions, using the current nine study sites. This study was limited to freeway collisions in California. It did not include ramp collisions, but it would be possible to estimate the CRF for ramp collisions after the construction of auxiliary lanes at the current study sites. Before-and-after and cross-sectional comparisons could be performed for this estimation.

8.3. IDENTIFICATION OF HIGH COLLISION CONCENTRATION LOCATIONS IN THE VICINITY OF RAMPS AND WEAVING SECTIONS

Conduct system-wide review to determine potential sites for auxiliary lanes (and/or other potential counter measures). This study found that auxiliary lanes are effective in reducing freeway collisions. An important addition to this finding would be to locate candidate sites for the construction of auxiliary lanes (or other possible countermeasures), by identifying HCCLs in the vicinity of ramps and/or weaving sections. Detailed site-specific investigations could be performed to look into the cause of high collisions at each location, and to formulate recommendations for proper safety countermeasures.

The recommended study would identify locations that are distributed along ramps and weaving sections, where a preliminary analysis indicated that the distribution of collision rates have long right tails (i.e., a high rate of HCCLs). Results of the preliminary analysis on I-5 are shown in figures 17-20. The northbound direction was found to have 850 ramps, and the southbound direction 878 ramps. The number of collisions per vehicle-mile traveled within 4000 ft. up/downstream of ramps, or within weaving sections including their 4000 ft. up/downstream is shown in the figures.

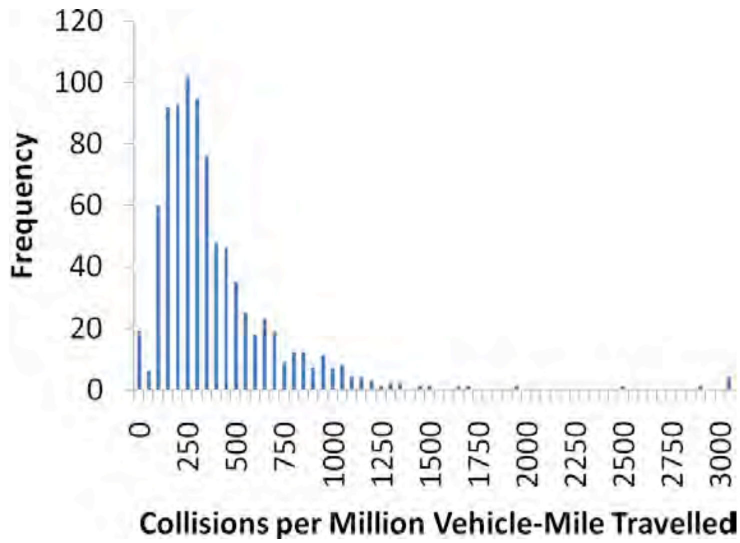

Figure 17. Northbound, ramps & 4000 ft. up/downstream

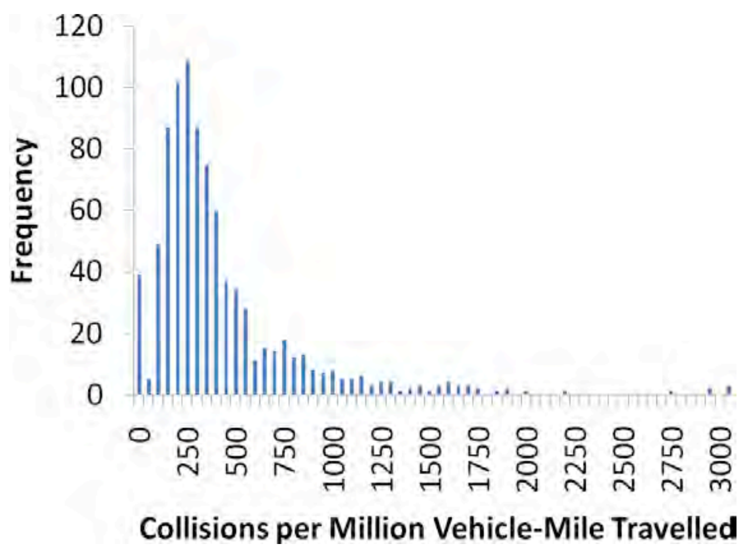

Figure 18. Southbound, ramps & 4000 ft. up/downstream

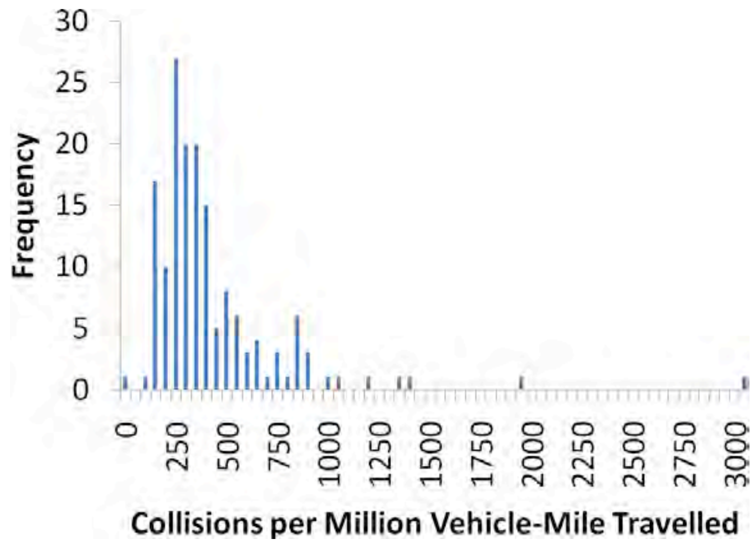

Figure 19. Northbound, weaving sections & 4000 ft. up/downstream

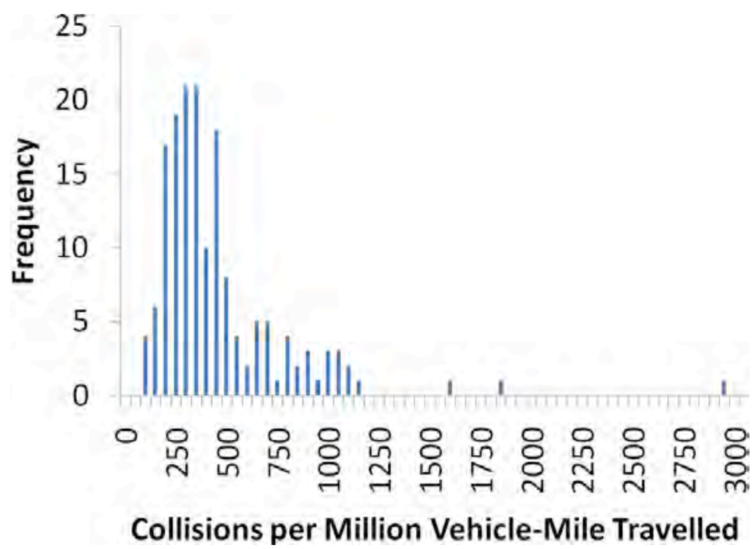

Figure 20. Southbound, weaving sections & 4000 ft. up/downstream

APPENDIX A: CROSS-SECTIONAL ANALYSIS

The preliminary results of a cross-sectional analysis of collisions within weaving sections are presented in this appendix. The objective of this approach was to quantify the relationship between collision rate that occurred within weaving sections and explanatory variables using regression modeling such as:

$$\begin{aligned}\text{Number of Collisions} = \; & \beta_0 + \beta_1 * \text{AADT} \\ & + \beta_2 * \text{on-ramp flows} \\ & + \beta_3 * \text{length of weaving section}\end{aligned}$$

A.1. DATA

Detailed information on 50 weaving sections on I-5, I-8, I-15, SR-50, SR-78, SR-94, and SR-125 was collected. Nine of the sites had connected auxiliary lanes, two had both acceleration and deceleration lanes, and 39 had only acceleration lanes. Acceleration/deceleration lanes were defined by the existence of a dotted line for lane changing, as shown in figure 21. That is, if there was a dotted line in the vicinity of the on-ramp, it was determined that there was an acceleration lane.

Figure 21. Example of an acceleration lane and its length

Collision data were extracted from TASAS year 2000 to 2006. Traffic volume (i.e., freeway and on/off-ramp flows) was collected from PeMS detector data. Geometric information at each site was obtained from aerial photos.

A.2. VARIABLES FOR THE MODEL

The model's dependent variable (Y) was the annual average number of collisions on freeway lanes in weaving sections (between an on-ramp and an off-ramp). Note that the dependent variable does not include collisions on the shoulders (see figure 22).

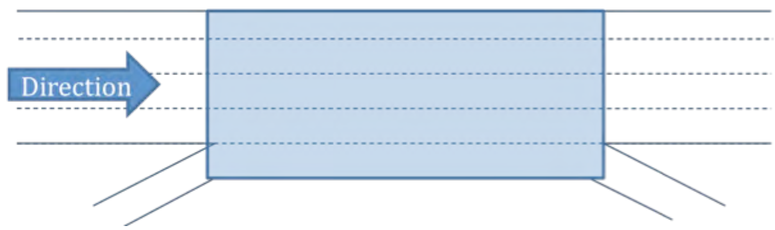

Figure 22. Location of the dependent variable

Explanatory variables (Xs) in the model are:

1) Freeway traffic volume
2) On-ramp flow
3) Off-ramp flow
4) Length of weaving sections
5) Length of acceleration and deceleration lanes
6) Dummy for connected auxiliary lanes (0= none, 1= connected)

To estimate traffic volume (explanatory variables 1, 2, and 3), maximum values of daily traffic volume were used in place of average values. This is because PeMS detector data were frequently missing due to communication errors. The length of auxiliary lanes and weaving sections were measured from aerial photographs (see figure 21). In case of connected auxiliary lanes, the length of weaving sections was defined as the length of both acceleration and deceleration lanes (i.e., the length of the acceleration lane = the length of the deceleration lane = the length of the weaving section).

A.3. CROSS-SECTIONAL ANALYSIS ON EACH VARIABLE

The linear relationship between collision rate and each explanatory variable is shown in figures 23-30. Among the explanatory variables, freeway flow and on-ramp flow per length of weaving section showed a significant positive correlation with collision rate. In other words, as freeway/on-ramp flows increase, or as the length of the weaving section decreases, collision rate increases. Figure 28 shows that longer acceleration lanes decreased the number of collisions, while the same pattern was not found in the case of deceleration lanes. Note that figures 28 and 29 represent the nine of fifty weaving sections that included connected auxiliary lanes. Figure 30 shows that the group of weaving sections with connected auxiliary lanes had a relatively small number of collisions compared to weaving sections without connected auxiliary lanes.

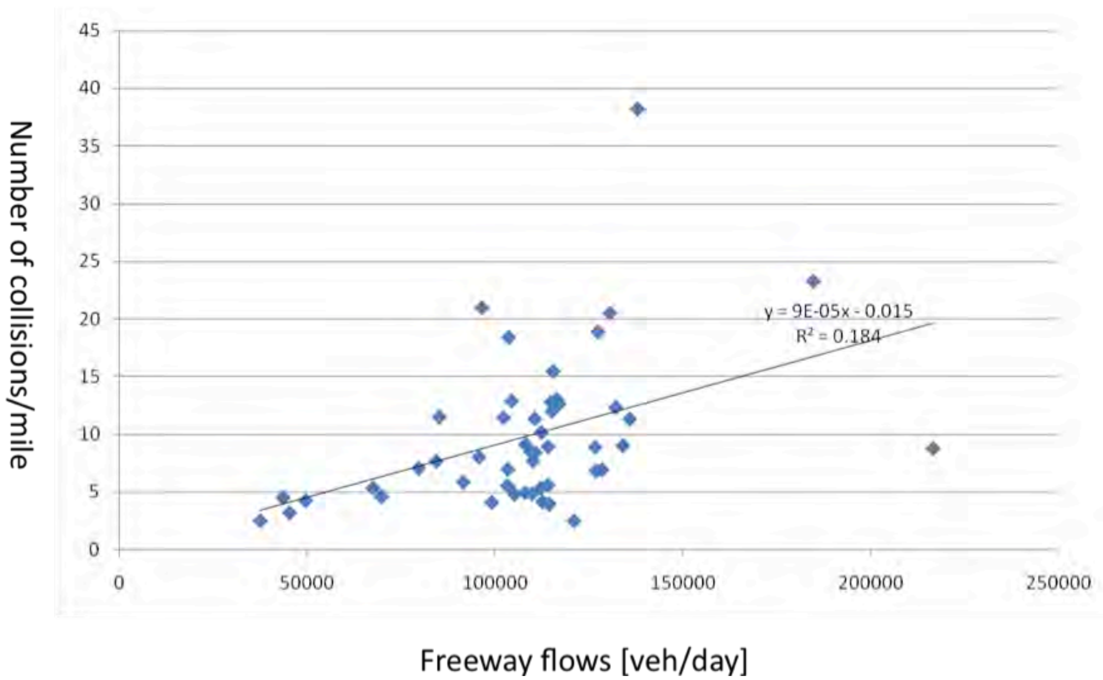

Figure 23. Collision rate vs. freeway flow

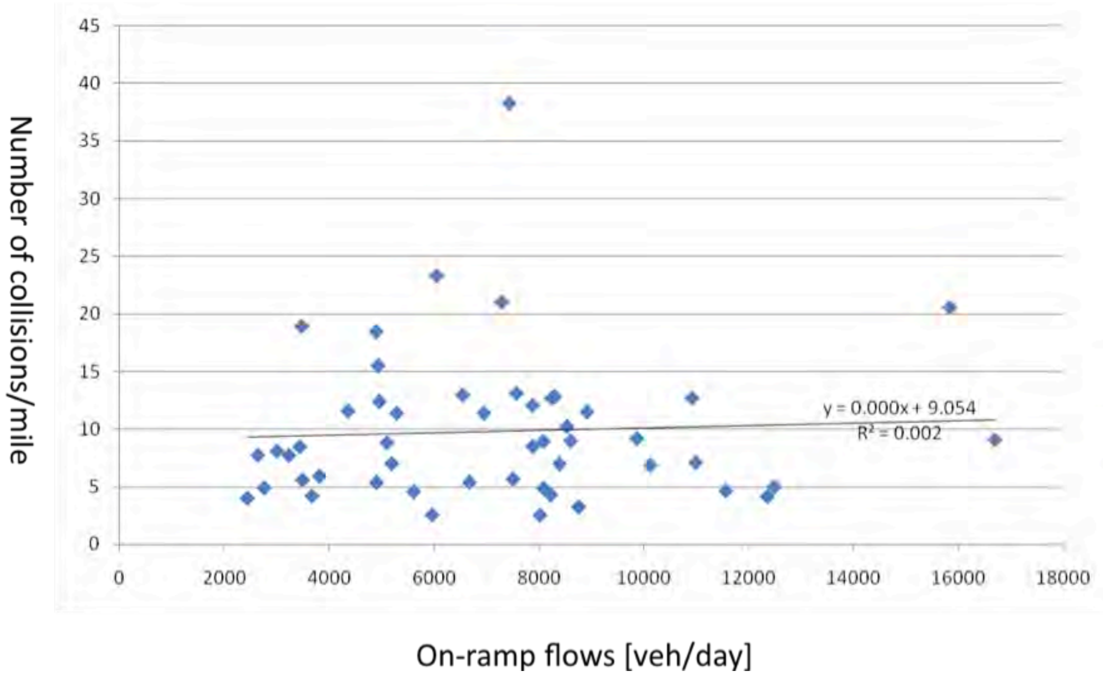

Figure 24. Collision rate vs. on-ramp flow

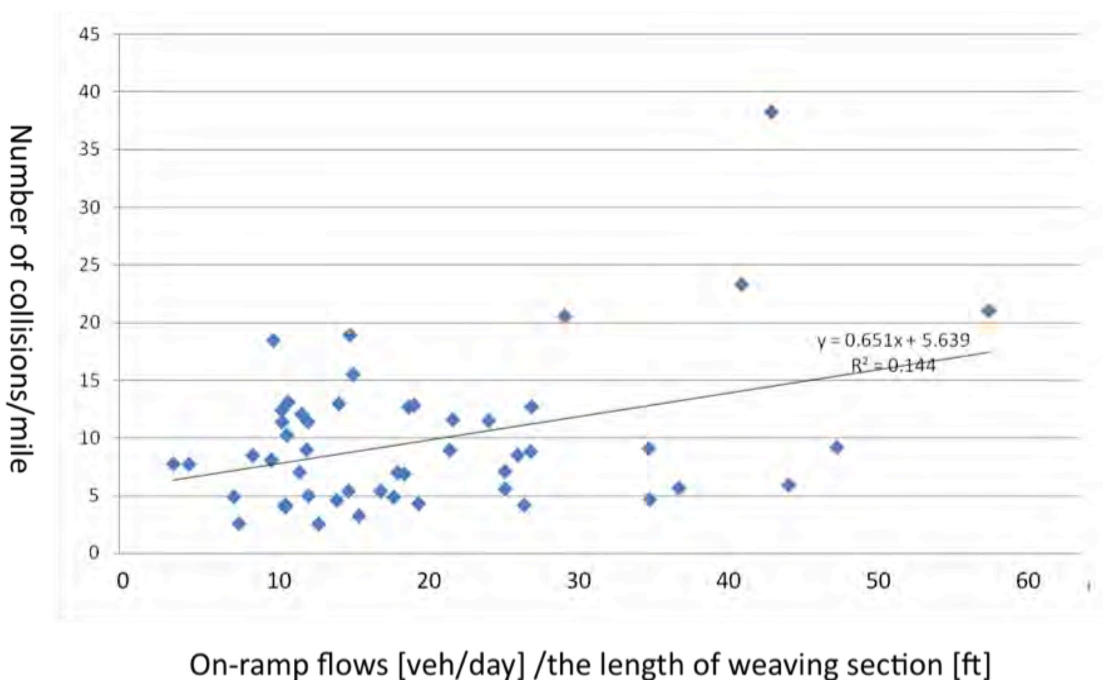

Figure 25. Collision rate vs. on-ramp flow/weaving-section length

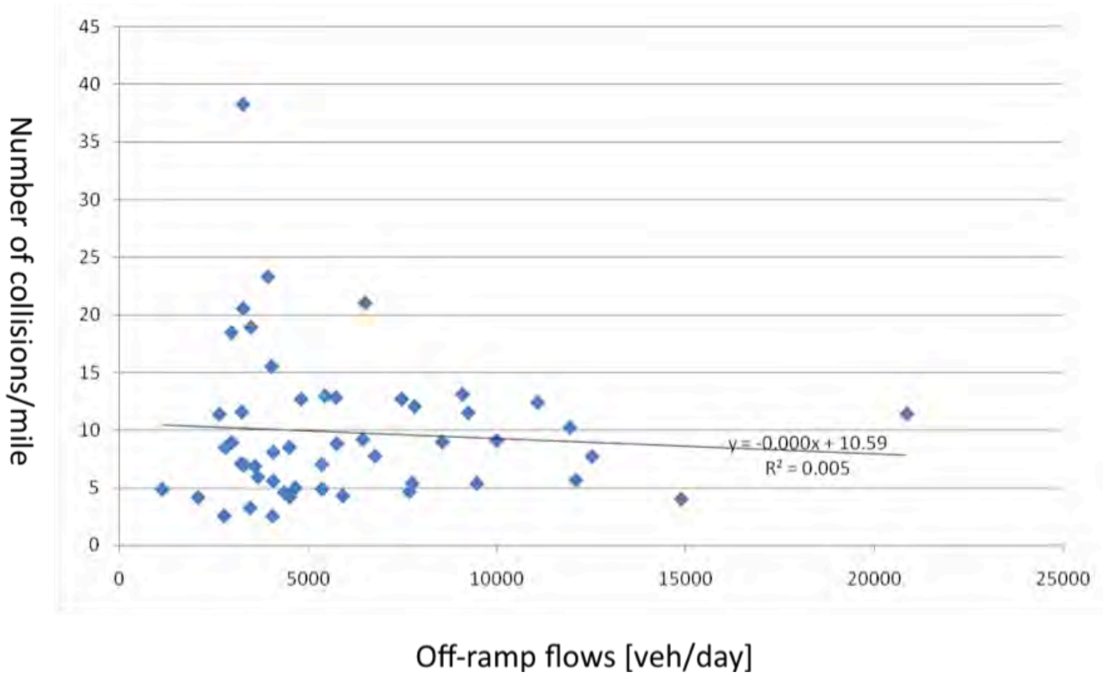

Figure 26. Collision rate vs. off-ramp flow

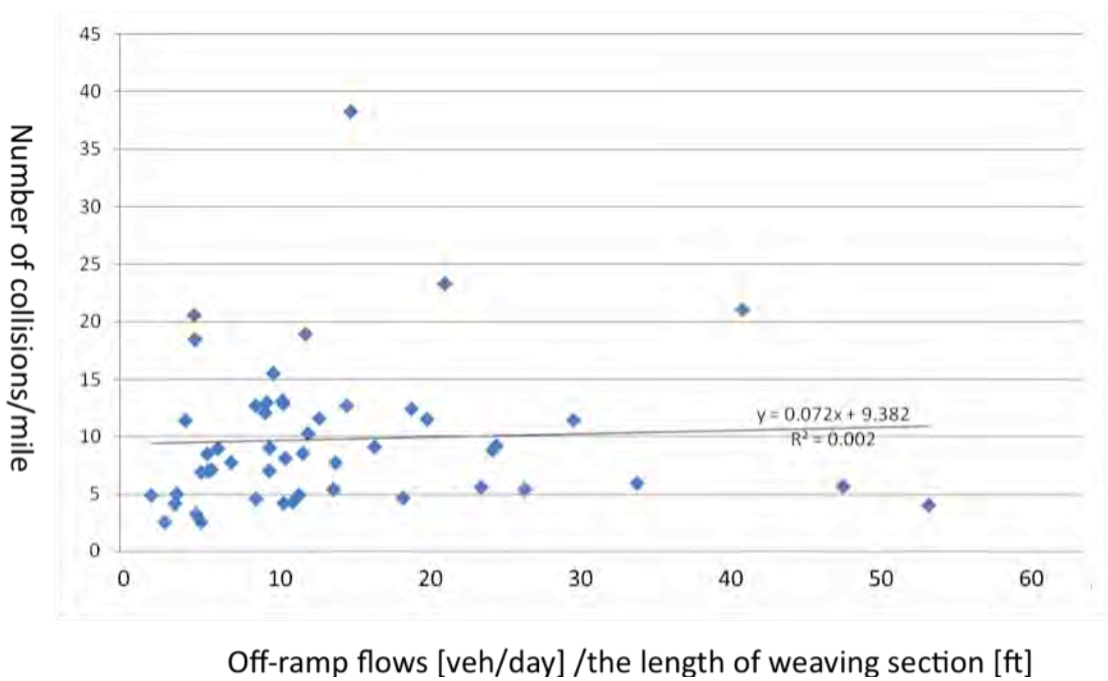

Figure 27. Collision rate vs. off-ramp flow/weaving section length

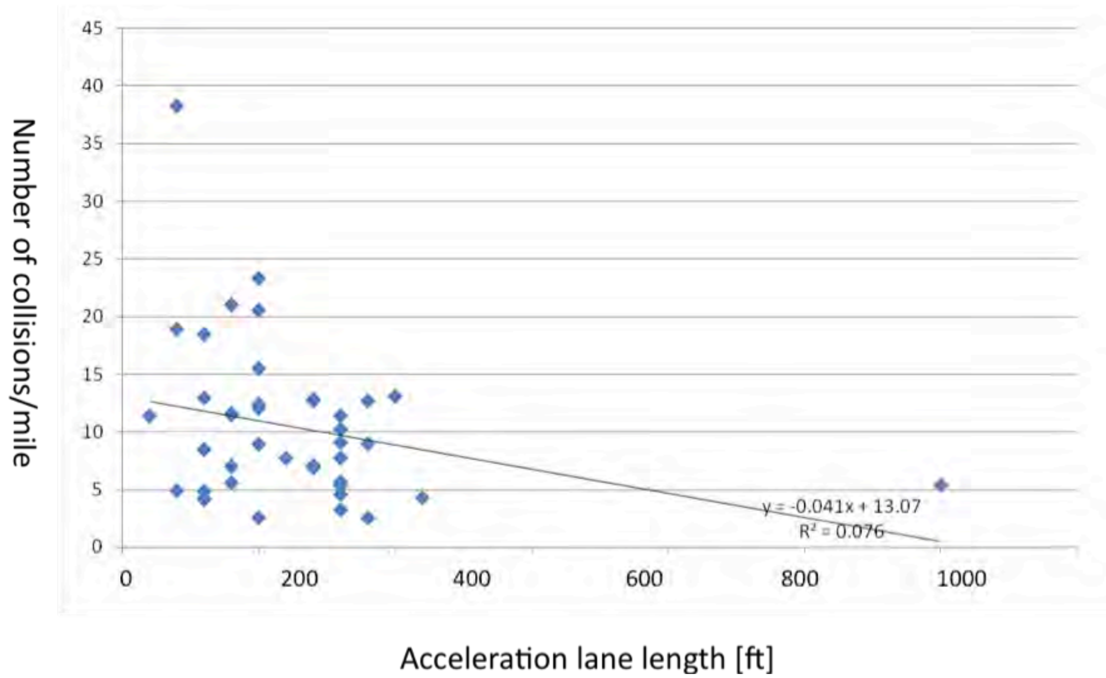

Figure 28. Collision rate vs. acceleration lane length

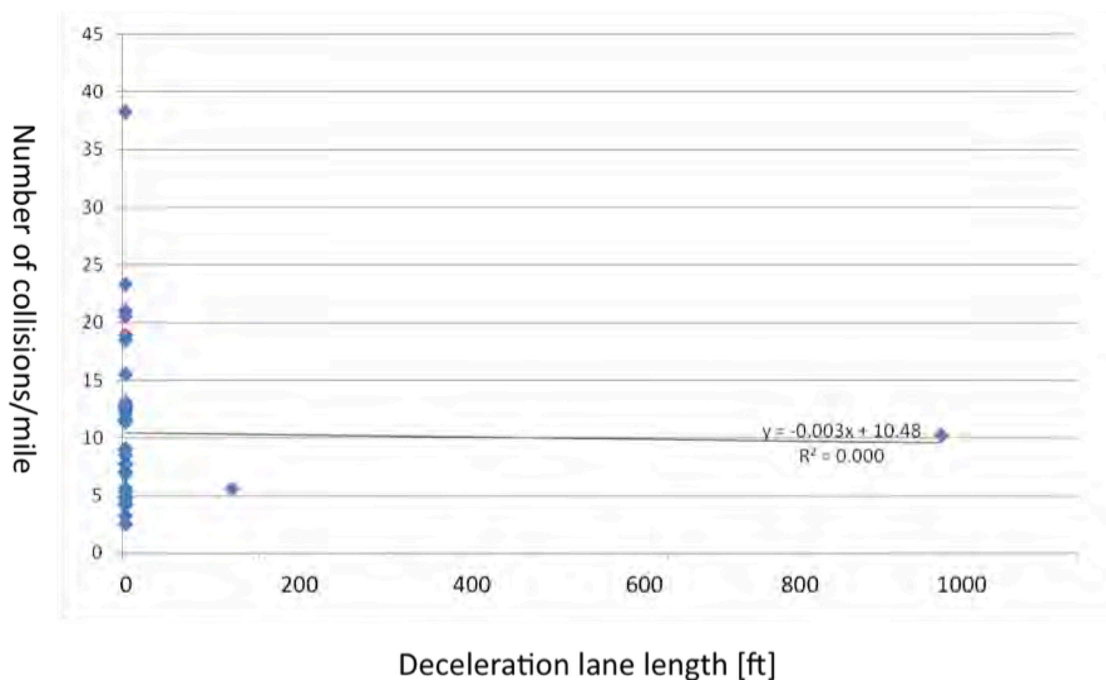

Figure 29. Collision rate vs. deceleration lane length

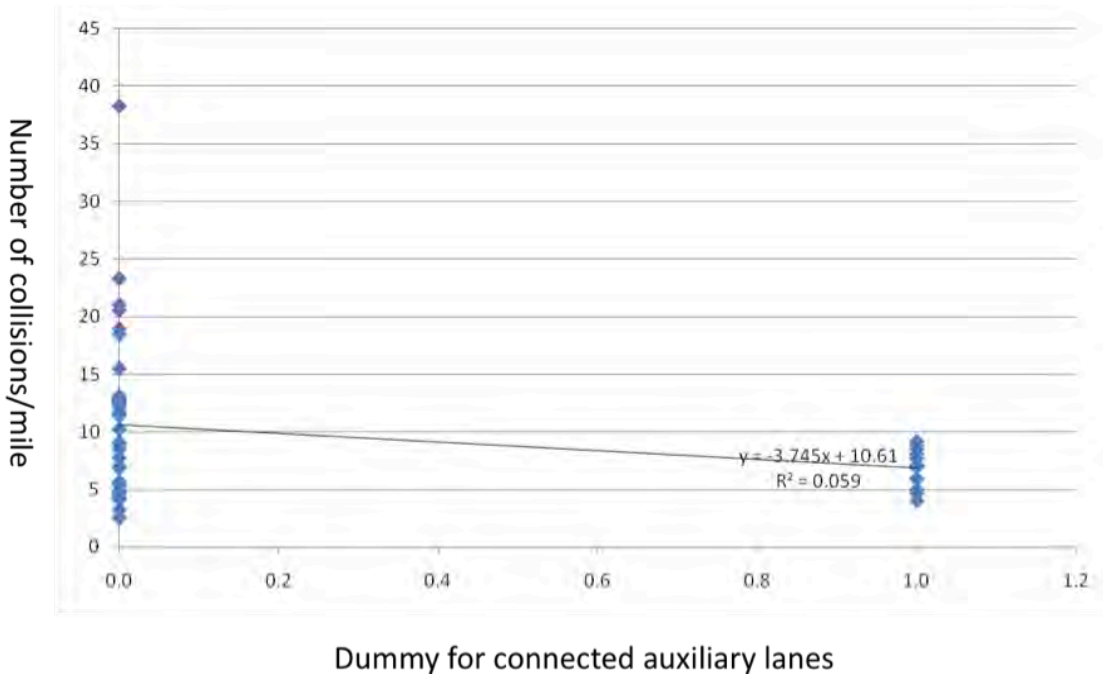

Figure 30. Collision rate vs. dummy variable for connected auxiliary lanes

(1=auxiliary lanes; 0=no auxiliary lanes)

A.4. REGRESSION MODEL

Several linear additive models are formulated and tested, and it is found that the following model had the best fit (the highest R-square) and a reasonable relationship between explanatory and dependent variables.

$$Collision = \beta_0 + \beta_1 * \frac{freeway\_flows}{\#\ of\ lane} + \beta_2 * \#\ of\ lane + \beta_3 * \frac{on\_ramp\ flows}{\text{distance} * \#\ of\ lane}$$
$$+ \beta_5 * dummy(connected) + \beta_6 * \frac{acc\_length}{\text{distance}}$$

Table 8 shows the estimation result (the values of the parameters and their p-values) of this linear model. Explanatory variables related to individual lane flows and on-ramp flows exhibit low p-values, suggesting that these two variables are statistically significant. Both of them have positive values, which would be expected. The model indicates that the number of lanes increases the number of collisions, but the model's p-value indicates that the result is not statistically significant at a level of 0.05. The acceleration lane length has a negative beta value, which would also be expected. However, because its p-value is 0.1550, we cannot reject the null hypothesis (i.e., the beta of the acceleration lane length is equal to 0). The dummy for connected auxiliary lanes is positive, suggesting that the existence of connected auxiliary lanes increase the number of collisions. However, note that the length of connected auxiliary lanes is already taken into account in the model as the length of the acceleration lane. This could explain the positive value of the parameter for the dummy variable.

Variables	Value of beta	P-values
Constant	-0.0108	0.0012
Individual lane flows	4.297*E-07	0.0002
Number of lane	0.0008	0.2579
On-ramp flow/the length of weaving section	0.0021	0.0002
Dummy for connected auxiliary lane	0.0118	0.1917
Acceleration lane length	-0.0136	0.1550

Table 8. Results of the regression modeling

A.5. CONCLUSIONS OF CROSS-SECTIONAL ANALYSIS

The results of the cross-sectional analysis indicate that the number of collisions per Million VMT, or collision rate, increases as:

1) individual lane flow increases
2) the number of lanes increases
3) on-ramp flow increases
4) the length of the weaving section decreases
5) the length of the acceleration lane decreases

Interestingly among the variables, the beta for the dummy of connected auxiliary lanes was positive (0.018). In other words, the model indicates that the existence of connected auxiliary lanes increases the number of collisions. However, note that the length of connected auxiliary lanes was already taken into account in the model as the length of the acceleration lane. Therefore, the result (positive beta for connected auxiliary lanes) suggests that the connected auxiliary lane may not have distinctive effects other than reducing the number of collisions by providing longer acceleration lanes.

Though the cross-sectional analysis did not find any strong correlation between collision rate and the length of deceleration or off-ramp flow, just two of the nine locations had deceleration lanes. A conclusion that these two factors have no significant effect on collisions is therefore not warranted. To further develop a cross-sectional analysis, additional data need to be extracted from more weaving sections. Additional explanatory variables also need to be collected that may have been omitted. The present study used PeMS detector data, but it would be important to test the model with Caltrans freeway and ramp ADT data as well. The regression model could also be improved by the addition of explanatory variables for traffic congestion or various interaction terms between explanatory variables. In addition, it would be useful to test other models (e.g., Negative-binomial and Poisson).