Safety Evaluation of Corner Clearance at Signalized Intersections

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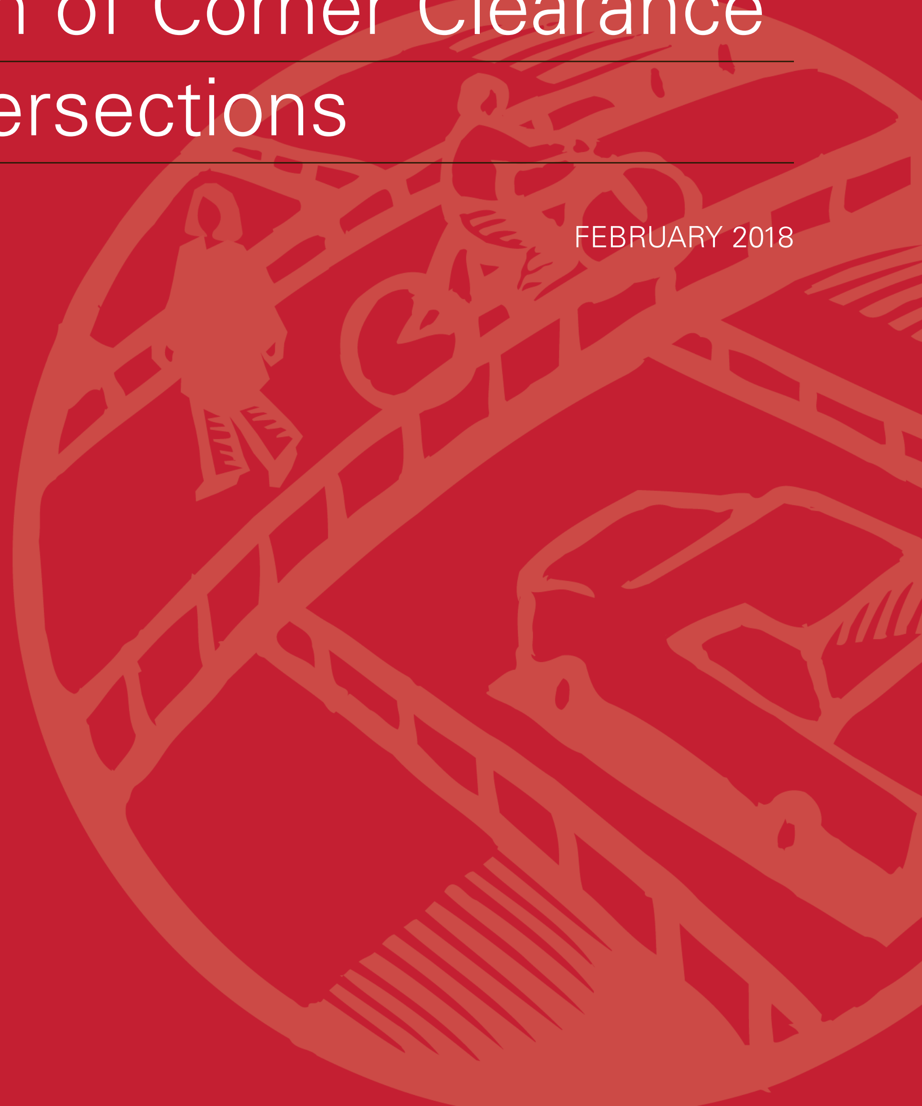

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Federal Highway Administration

Research, Development, and Technology
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FOREWORD

The research documented in this report was conducted as part of the Federal Highway Administration's (FHWA's) Evaluation of Low-Cost Safety Improvements Pooled Fund Study (ELCSI-PFS). FHWA established this PFS in 2005 to conduct research on the effectiveness of the safety improvements identified by the National Cooperative Highway Research Program *Report 500 Guides* as part of the implementation of the AASHTO Strategic Highway Safety Plan. The ELCSI-PFS studies provide a crash modification factor and benefit–cost economic analysis for each of the targeted safety strategies identified as priorities by the pooled fund member States.

This study evaluates corner clearance at signalized intersections in the State of California and the City of Charlotte, North Carolina. For limited corner clearance on the approach corners, the results indicate statistically significant reductions in total, fatal and injury, and rear-end crashes. The results also indicated reductions in sideswipe and nighttime crashes, and increases in right-angle and turning crashes. This study suggests that removing access on mainline receiving corners to improve corner clearance—with reasonable assumptions for cost, service life, and the value of a statistical life—can be cost effective for reducing crashes at signalized intersections. This document is intended for safety engineers, highway designers, planners, and practitioners at State and local agencies involved with AASHTO Strategic Highway Safety Plan implementation.

Jonathan Porter, Ph.D.
Acting Director, Office of Safety
Research and Development

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<tr><td colspan="5">16. Abstract
This study evaluates corner clearance at signalized intersections under the Development of Crash Modification Factors program for the Evaluation of Low-Cost Safety Improvements Pooled Fund Study. Geometric, traffic, and crash data were obtained for signalized intersections with various corner clearances from the State of California and the City of Charlotte, North Carolina. A cross-sectional analysis was conducted to estimate the effects of corner clearance while controlling for other differences among study sites. The estimated CMFs indicated that more limited clearance (i.e., driveway(s) within 50 ft of the signalized intersection) on receiving corners was associated with increases for all crash types, based on the data included in this analysis. These increases were statistically significant at the 90-percent level or greater for total, fatal and injury, rear-end, sideswipe, right-angle, and nighttime crashes. Only the results for turning crashes were not statistically significant at the 90-percent level. For limited corner clearance on the approach corners, the results indicated statistically significant reductions in total, fatal and injury, and rear-end crashes. The results also indicated reductions in sideswipe and nighttime crashes, and increases in right-angle and turning crashes, but none of these results were statistically significant at the 90-percent level.</td></tr>
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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LIST OF ABBREVIATIONS

AADT	annual average daily traffic
B/C	benefit–cost
CMF	crash modification factor
DCMF	Development of Crash Modification Factors
ELCSI-PFS	Evaluation of Low-Cost Safety Improvements Pooled Fund Study
FHWA	Federal Highway Administration
FID	feature identifier
GIS	geographic information system
GPS	global positioning system
HSIS	Highway Safety Information System
KML	Keyhole Markup Language
NCHRP	National Cooperative Highway Research Program
PDO	property-damage-only
SE	standard error
USD	United States dollar
USDOT	United States Department of Transportation
ZINB	zero-inflated negative binomial

EXECUTIVE SUMMARY

The Federal Highway Administration established the Development of Crash Modification Factors (DCMF) program in 2012 to address highway safety research needs for evaluating new and innovative safety improvement strategies by developing reliable quantitative estimates of their effectiveness in reducing crashes. The ultimate goal of the DCMF program is to save lives by identifying new strategies that effectively reduce crashes and to promote those strategies for nationwide implementation by providing measures of their safety effectiveness and benefit–cost (B/C) ratios through research. State transportation departments and other transportation agencies need to have objective measures of safety effectiveness before investing in broad applications of safety countermeasures. Forty State transportation departments provide technical feedback on safety improvements to the DCMF program and implement new safety improvements to facilitate evaluations. These States are members of the Evaluation of Low-Cost Safety Improvements Pooled Fund Study, which functions under the DCMF program.

This study investigates the safety effects of corner clearance on the mainline at four-leg, signalized intersections. Previous studies have explored various access management techniques and the effects of access points on safety at a corridor level. However, little quantitative information is available for the safety effects of driveways located near the corners of a signalized intersection and the effects of access management strategies on intersection crashes.

The research team obtained crash, geometric, and traffic data for four-leg, signalized intersections with various corner clearances in California and Charlotte, North Carolina, then conducted a cross-sectional analysis to estimate the effects of corner clearance while controlling for other factors. The team used propensity score matching to select reference intersections with similar characteristics to those with limited corner clearances. The analysis controlled for changes in safety due to differences in traffic volume and other differences among intersections with various corner clearances. The base condition for the evaluation was a four-leg, signalized intersection without limited clearance on all mainline corners.

The estimated crash modification factors (CMFs) indicated that more limited clearance on receiving corners (i.e., driveway(s) on receiving approaches within 50 ft of the signalized intersection) was associated with increases for all crash types, based on the data included in this analysis. The estimated CMFs indicated that more limited clearance on receiving corners was associated with increases for all crash types, based on the data included in this analysis. The following CMFs for one and two receiving corners, respectively, were statistically significant at the 90-percent level for these crash types:

- Total crash—1.33 (standard error (SE) = 0.11) and 1.76 (SE=0.30).
- Fatal and injury—1.29 (SE = 0.11) and 1.68 (SE = 0.29).
- Rear-end—1.36 (SE = 0.14) and 1.86 (SE = 0.38).
- Sideswipe—1.31 (SE = 0.14) and 1.71 (SE=0.38).
- Right-angle—1.42 (SE = 0.20) and 2.02 (SE = 0.56).
- Nighttime—1.29 (SE = 0.13) and 1.67 (SE = 0.35).

The CMFs for turning crashes were 1.22 (SE = 0.15) and 1.49 (SE = 0.36) for one and two receiving corners, respectively. These were the only results that were not statistically significant at the 90-percent level.

For limited corner clearance on the approach corners, the results indicated statistically significant reductions in total, fatal and injury, and rear-end crashes. The results also indicated reductions in sideswipe and nighttime crashes and increases in right-angle and turning crashes, but none of these results were statistically significant at the 90-percent level. In other words, each additional mainline approach corner with at least one driveway within 50 ft of the corner was statistically associated with decreases in these crash types. Although nonintuitive, this may be the result of localized congestion on the approach corners of an intersection. The total CMFs for one and two approach corners were 0.82 and 0.67 (SE = 0.08 and 0.13), respectively. Similarly, the CMFs for fatal and injury were 0.79 and 0.62 (SE = 0.08 and 0.13). The CMFs for rear-end crashes were 0.79 and 0.63 (SE = 0.09 and 0.15). The estimated CMFs for sideswipe, right-angle, turning, and nighttime crashes indicated a mix of no changes, a slight increase, or a slight decrease in crashes associated with limited clearance on the approach corners, and none of these results were statistically significant.

The disaggregate analysis sought to identify those conditions under which the strategy is most effective. Several variables were considered in the disaggregate analysis, including major and minor road traffic volume, number of lanes on the major and minor road, posted speed limit, driveway density, and presence of left- and right-turn lanes. The disaggregate analysis did not indicate any differential effect of corner clearance at the 80-percent confidence level.

The economic analysis, based on total crashes and assuming a 10-year service life, resulted in an average B/C ratio of at least 294 to 1 for most intersections when removing or relocating access at one or more mainline receiving corners with limited corner clearance. With the United States Department of Transportation–recommended sensitivity analysis, these values could range from 162 to 1 up to 405 to 1. While this research suggests the presence of driveways on mainline approach corners does not increase total, fatal and injury, rear-end, and sideswipe crashes, more research is required before agencies may consider this as a strategy for reducing crashes.

These results suggest that removing or relocating driveways on the mainline receiving corners can be cost effective in reducing crashes at signalized intersections.

CHAPTER 1. INTRODUCTION

BACKGROUND ON STRATEGY

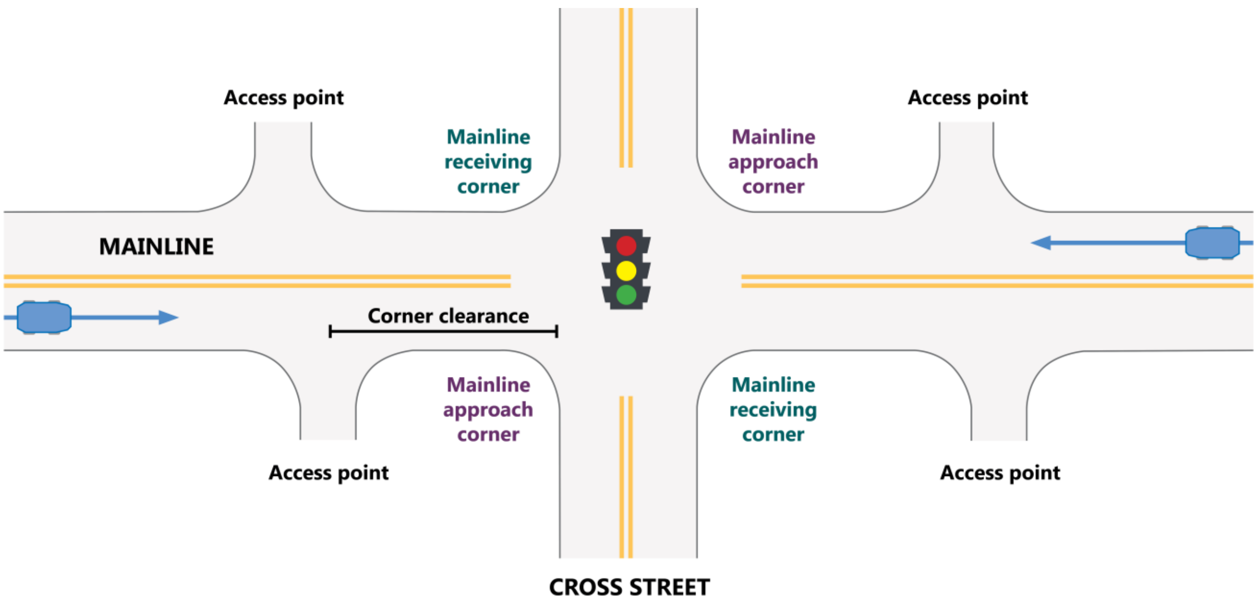
Corner clearance is defined as the distance between an intersection and the nearest driveway or access point along the approach. Adequate corner clearance is an important factor in the safety and operations at intersections. AASHTO's *A Policy on Geometric Design of Highways and Streets* (also known as "The Green Book") notes that driveways should not be located within the functional area of an at-grade intersection or in the influence area of an adjacent driveway.(1) However, the presence of conflicting driveways within the functional area is often unavoidable, especially in urban environments. Limited corner clearance, or the presence of driveways in proximity to intersections, is suspected to have negative effects on operational efficiency, capacity, and safety due to driveway turning movements conflicting with vehicles at the larger intersection.

While inadequate corner clearance is a concern for all types of intersections, signalized intersections develop recurring queues within the functional area of the intersection that can lead to conflicts with vehicles turning into and out of driveways. Approaches to signalized intersections also have more lanes on average than other types of at-grade intersections, which can cause difficulties for drivers leaving driveways to weave and maneuver into their desired lanes.

Figure 1 shows a photo of a signalized intersection with limited corner clearance. Refer to the appendix for further examples of intersections included in this study.

Figure 1. Photo. Signalized intersection with limited receiving corner clearance.

States have proposed access management strategies to balance the safety and operational efficiency of intersections while maintaining access to properties along and adjacent to the roadway. National Cooperative Highway Research Program (NCHRP) Report 500 Guide, Volume 12: *A Guide for Reducing Collisions at Signalized Intersections*, notes that improving access management near signalized intersections is one of seven objectives for improving the safety of signalized intersections.[(2)] Inadequate corner clearance is often a reason why access management strategies are proposed at intersections during safety reviews. However, there is limited information available about the quantitative safety effects of corner clearances. This study serves to address the need for research into the safety effects of corner clearances on the mainline approach and receiving corners at four-leg, signalized intersections. Figure 2 shows a general layout of a study site in this evaluation, illustrating the measurement of corner clearance and defining mainline approach and receiving corners.



Source: FHWA.

Figure 2. Schematic. General layout of study site.

BACKGROUND ON STUDY

The Federal Highway Administration (FHWA) established the Development of Crash Modification Factors (DCMF) program in 2012 to address highway safety research needs for evaluating new and innovative safety improvement strategies by developing reliable quantitative estimates of their effectiveness in reducing crashes. The ultimate goal of the DCMF program is to save lives by identifying new safety strategies that effectively reduce crashes and to promote those strategies for nationwide implementation by providing measures of their safety effectiveness and benefit–cost (B/C) ratios through research. State transportation departments and other transportation agencies need objective measures for safety effectiveness and B/C ratios before investing in broad applications of new strategies for safety improvements. Forty State transportation departments provide technical feedback on safety improvements to the DCMF program and implement new safety improvements to facilitate evaluations. These States are members of the Evaluation of Low-Cost Safety Improvements Pooled Fund Study, which functions under the DCMF program.

LITERATURE REVIEW

The research team conducted a literature review concentrated on the safety effects of corner clearance distance as well as access spacing and various management strategies regarding property access. Most evaluations to date have focused on corridor safety effects rather than intersection safety. The following provides a summary of the salient research related to specific strategies.

Kwigizile et al. examined changes in the number of crashes at urban signalized intersections as a result of corner clearance and other variables.(3) A zero-inflated negative binomial (ZINB) model was selected from four model forms as the best model for determining the safety effects of the treatment. The authors modeled corner clearance as the number of corner clearances (i.e., number of access points) and the average corner clearance in feet, with a maximum of 250 ft. Table 1 shows the ZINB model results.

The results indicate that increased corner clearance and fewer access points yield fewer crashes. Commercial driveways with limited corner clearance led to higher crash rates than residential access. Signals with higher minor road volumes had a higher number of crashes. Crashes generally increased with the addition of left-turn lanes and through lanes, with through lanes leading to a greater increase.

Table 1. ZINB model estimation results adapted from Kwigizile et al.(3)

Explanatory Variables	Coefficient	Statistic
Regression part		
Commercial land use	0.377	3.59
Traffic flow ratio (minor AADT/major AADT)	0.063	2.00
Natural logarithm of average corner clearance	–0.509	–3.26
Number of left turn lanes	0.208	2.60
Number of through lanes	0.112	3.80
Constant	3.929	4.74
Inflation part		
Number of corner clearance	–0.564	–2.57
Natural logarithm of average corner clearance	–0.873	–1.57
Constant	4.375	1.48

AADT = annual average daily traffic.

CHAPTER 2. OBJECTIVE

The objective of this research was to examine the safety effects of various corner clearances at signalized intersections in the State of California and the City of Charlotte, North Carolina, measured by changes in crash frequency. Target crash types included the following:

- Total—all crashes within 250 ft of intersection (all types and severities combined).

- Fatal and injury—all injury crashes within 250 ft of intersection fatal injury, incapacitating injury, non-capacitating injury, and possible injury.

- Rear-end—all crashes within 250 ft of intersection and the accident type coded as rear-end.

- Sideswipe—all crashes within 250 ft of intersection and the accident type coded as sideswipe.

- Right-angle—all crashes within 250 ft of intersection and the accident type coded as broadside or angle.

- Right and left turn—all crashes within 250 ft of intersection and the driver's action prior to collision coded as turning right or turning left.

- Nighttime—all crashes within 250 ft of intersection and light condition coded as dusk, dark, and dawn.

A further objective was to address the following questions:

- Do effects vary by level of traffic volume on major and minor routes?
- Do effects vary by lane configuration of major and minor routes?
- Do effects vary by posted speed limit on the major route?
- Do effects vary by median presence on the major route?
- Do effects vary by presence of turning lanes on the major route?

The evaluation of overall effectiveness included the consideration of the removal of driveway costs and crash savings in terms of the B/C ratio.

Meeting these objectives placed some special requirements on the data collection and analysis tasks, including the need to do the following:

- Select a large enough sample size to detect, with statistical significance, what may be small changes in safety for some crash types.

- Identify appropriate study sites with varied corner clearances.

- Properly account for changes in safety due to differences in traffic volume and other factors unrelated to corner clearance.

CHAPTER 3. STUDY DESIGN

While the current state-of-the-art method for developing high-quality crash modification factors (CMFs) is to employ an Empirical Bayes before–after study design, several factors can preclude its use. One of these factors is the availability of treatment information, including the installation date and location for the treatment of interest. For strategies such as closing or opening an access point (driveway) and changing the corner clearance, there is often insufficient information to determine the exact timing of the treatment. Obtaining records of traffic and crashes before and after the change is likely infeasible. Using FHWA's *A Guide to Developing Quality Crash Modification Factors*, the research team determined that a rigorous cross-sectional study design would serve as a suitable alternative.[4] The following study design considerations include steps to account for potential biases and sample size considerations in cross-sectional analysis.

ACCOUNTING FOR POTENTIAL ISSUES AND SOURCES OF BIAS

An observational cross-sectional study design is a type of study used to analyze a representative sample at a specific point in time. The researcher estimates the safety effect by taking the ratio of the average crash frequency for two groups, one with the feature of interest and the other without the feature of interest. The feature of interest could also be a continuous variable, and the safety effect is estimated based on the predicted crash frequency at different values of the variable representing the feature of interest. In this case, the feature of interest is the corner clearance. For this method to work, the study sites should be similar in all regards except for the feature of interest. In practice, this is difficult to accomplish, and researchers typically use multivariable regression models to estimate the safety effects of the feature of interest while controlling for other characteristics that vary among sites.

Multivariable regression models use explanatory variables, such as geometric and operational characteristics, to predict a response variable, such as frequency of crashes. While cross-sectional models provide a means to estimate the safety effects of treatments, these models are susceptible to a number of biases that researchers should account for during sampling and modeling. The research team identified the following issues and biases from the *Recommended Protocols for Developing Crash Modification Factors* that are potentially applicable to this study.[5] A list of general issues with safety evaluations is provided in the next section, followed by a list of potential biases specific to cross-sectional studies. The research team made an effort to address all applicable biases.

General Issues

- **Measure of effectiveness.** Direct measures of safety effectiveness, including crash frequency and severity, are preferable over surrogate measures. This study employed a crash-based analysis to evaluate the safety impacts of corner clearance at signalized intersections.

- **Exposure.** Neither crash frequency nor severity alone provides adequate information to determine the safety effectiveness of a particular design feature. Exposure is an important factor in assessing crash risks. This study used traffic volumes on the major and minor roads (i.e., total entering volume) of each intersection as explanatory variables.

- **Sample size.** Crashes are rare and random events. It is necessary to include a sufficient number of sites and/or years in the study sample with enough crashes to develop a valid relationship between the treatment and safety effect. The following section, Sample Size Considerations, presents a lengthier discussion of sample size for this study.

- **Site selection bias.** In highway safety, transportation departments often select sites for treatment based on need. In other words, sites with the highest crash frequency, severity, or potential for improvement are addressed first. When countermeasure evaluations use these sites exclusively, the results of the evaluation are only applicable to sites with similar safety issues. The research team selected sites for this study based on the intersection type of interest (i.e., four-leg, signalized intersections) with various corner clearance and geometric characteristics, rather than crash experience. The research team used propensity score matching, discussed later in this chapter, to select suitable reference sites and to help to mitigate potential site selection bias.

- **Crash data quality.** There is no national standard for crash data reporting. Although many States adopt some or all of the Model Minimum Uniform Crash Criteria data elements, there is a lack of uniformity in crash data across jurisdictions, and most crash data are susceptible to issues with data quality and timeliness. It is necessary to account for these types of issues in the study design and analysis. For example, if the reporting threshold varies among States in the study, and crash data from those States are aggregated in modeling, then the analyst should account for the difference in thresholds. The data used in this research are from the Highway Safety Information System (HSIS) database, which ensures a higher level of quality control and documentation in each participating State than data obtained directly from State agencies.

Issues Specific to Cross-Sectional Models

- **Control of confounding factors.** Confounding factors are significant predictors of the response variable and are associated with the treatment in question. Driveways near the corners of signalized intersections are often present at higher traffic volumes, but they are not a consequence of higher volumes (e.g., gas stations, businesses in high-traffic areas). Traffic volume is also a significant predictor of crashes and is, therefore, a potential confounding factor. Consequently, the model accounts for it as an independent variable. While difficult to control for all potential confounding factors, the research team considered and addressed these factors to the extent possible in the study design and evaluation. The research team used propensity score matching, discussed later in this chapter, to select suitable reference sites and to help to mitigate potential confounding effects.

- **Omitted variable bias.** It is difficult to account for the potential effects of omitted variable bias in an observational cross-sectional study such as this. The research team addressed omitted variable bias to the extent possible by carefully considering the roadway and traffic characteristics that the models should include. With the rich data in

HSIS, the research team tested a wide range of variables in the models and selected suitable variables for the final models. There was some potential for omitted variable bias due to other factors the models do not include directly, such as weather, driver population, and vehicle fleet. The results of this research indicate that factors relating to corridor operations may have improved the models.

- **Selection of appropriate functional form.** The research team applied generalized linear modeling techniques to calibrate crash prediction models. The research team specified a log-linear relationship using a negative binomial error structure, following the state of the art in modeling crash data. The negative binomial error structure is recognized as more appropriate for crash counts than the normal distribution used in conventional regression modeling. The negative binomial error structure also has advantages over the Poisson distribution, allowing for overdispersion that is often present in crash data.

- **Correlation among independent variables.** Correlation refers to the degree of association among variables. A high degree of correlation among the predictor variables makes it difficult to determine a reliable estimate of the effects of specific predictor variables. The research team examined the correlation matrix to determine the extent of correlation among independent variables and used it to prioritize variables for inclusion.

- **Overfitting of prediction models.** Overfitting is related to the concept of diminishing returns. At some point in the analysis, adding additional independent variables to the model is unnecessary because they do not significantly improve the model fit. Overfitting also increases the opportunity to introduce intercorrelation between independent variables. The research team considered several combinations of predictor variables and employed relative goodness-of-fit measures to penalize models with greater estimated parameters.

- **Low sample mean and sample size.** The research team dismissed low sample mean as a potential issue as many sites had experienced one or more crashes during the study period. The research team addressed sample size through preliminary sample size estimates (see Sample Size Considerations) and during the early stages of the study and analysis.

- **Temporal and spatial correlation.** Temporal correlation may arise if a study uses multiple observations for the same site. In this study, the research team aggregated 3 years of data into a single observation at each site. The research team dismissed temporal correlation as a potential issue as a result. Spatial correlation was a potential issue. To help account for spatial correlation, the research team selected the sample corridors from various regions of California to achieve diversity of sites with respect to weather, topography, and driver population.

- **Endogenous independent variables.** Endogeneity occurs when one or more of the independent variables depend on the dependent variable. For example, States may install left-turn lanes due to the frequency of left-turn crashes at an intersection, and thus their presence depends on crash frequency. The potential concern in an observational cross-sectional study is incorrectly associating treatments with higher crashes when compared with sites where the treatments are absent and may be prone to lower crash frequency. The research team used propensity score matching, discussed later in this chapter, to select suitable reference sites and to help to mitigate potential endogeneity issues.

SAMPLE SIZE CONSIDERATIONS

For crash-based studies, the total number of crashes is the primary measure of sample size, rather than sites or years. However, including a sufficient number of sites and years in the study is necessary to attain an adequate sample of crashes. Further, selecting sites based on features of interest, and not crash history, is important to minimize the potential for site selection bias and increase the applicability of the results.

The number of locations required for multivariable regression models depends on a number of factors, including the following:

- Average crash frequency.
- The number of variables desired in a model.
- The level of statistical significance desired in a model.
- The amount of variation in each variable of interest across sample sites.

The determination of whether or not the sample size is adequate can only be made once preliminary modeling is complete. If the variables of interest are not statistically significant, then more data are required to detect statistically significant differences, or it is necessary to accept a lower level of confidence. Estimation of the required sample size for cross-sectional studies is difficult, and it requires an iterative process, although through experience and familiarity with specific databases it is possible to develop an educated guess.

Table 2 presents the average crashes per site-year for the sample sites by number of approach and receiving corners with clearance less than 50 ft. The 275 sites represent nearly 1,225 total crashes per year and are reasonably representative of the range of site characteristics at four-leg, signalized intersections. While there was no formal stratification of the data by site characteristics during site selection, the research team included sites with a range of traffic volumes and other characteristics among sites to increase the practical applicability of the results. This sample data are likely sufficient to develop reliable cross-sectional models. The information in table 2 should not be used to make simple comparisons of crashes per year between different groups, since it does not account for factors, other than the strategy, that may cause a change in safety between groups. Such comparisons are properly done with the regression-based analysis, as presented later.

Table 2. Crashes per site-year from data collection sites.

Corner Clearance Less than 50 ft	Zero Approach Corner Sites (Crashes per Site-Year)	One Approach Corner Sites (Crashes per Site-Year)	Two Approach Corner Sites (Crashes per Site-Year)	All Sites (Crashes per Site-Year)
Zero receiving corners	141 (4.99)	31 (1.98)	5 (1.33)	177 (4.36)
One receiving corner	41 (6.05)	30 (3.78)	4 (1.75)	75 (4.91)
Two receiving corners	13 (2.72)	7 (6.48)	3 (1.22)	23 (3.66)
Combined	195 (5.06)	68 (3.23)	12 (1.44)	275 (4.45)

PROPENSITY SCORE MATCHING

In experimental studies, researchers select a sample from the reference population and apply the treatment randomly to one group while leaving another group untreated for control purposes. Using this approach, the treatment and control groups are similar, and the only difference is the presence of treatment. This helps to ensure the treatment effect does not include effects due to other differences between the two groups.

In observational studies, it is desirable to replicate the random assignment of treatment while accounting for the fact that States often select sites for treatment based on safety and operational performance measures. Matching treatment and reference sites that have similar characteristics helps to reduce the potential for site selection bias and confounding factors. Selecting reference sites that are geometrically and operationally similar to treatment sites provides a more reliable comparison in cross-sectional studies, and propensity score matching is a rigorous approach to match treatment and reference sites.

This study employed propensity score matching to select reference sites that closely match the treatment sites in terms of general site characteristics. Propensity score matching was based on regression modeling. The research team developed a regression model to estimate scores (i.e., the probability of treatment or nontreatment) for all treatment and non-treatment sites based on site characteristics. The research team then used propensity scores to select reference sites most comparable with treatment sites for forming the study sample. Detailed discussions of propensity score matching and its application in traffic safety research are available in papers by Rosenbaum and Rubin, and Sasidharan and Donnell.[6,7]

It is important to note that in this study there were no "treated" or "untreated" sites. The "treatment" of interest in this study was corner clearance at signalized intersections, and its value varies. Therefore, the terms "treatment," "treated," and "untreated" are all nominal, and the discussions related to these terms need to be considered in that context. A group of intersections with similar values for corner clearance was considered "treated" and the rest "untreated." Specifically, intersections with at least one corner with a clearance less than 50 ft on the mainline belonged to the treatment group (treated), while those with no corners with a clearance less than 50 ft on the mainline were considered the reference group (untreated).

The research team implemented this process in an effort to group intersections with similar corner clearances in the same category. This process also allowed the research team to use the propensity score matching technique to account for differences among sites with corner clearances less than 50 ft and sites with corner clearances greater than 50 ft. Moreover, the process allowed the research team to explore additional corner clearance distances as potential cutoff points for separating the dataset into two categories and applying the propensity score matching. Therefore, the research team tested the following corner clearance distances: 50, 75, 100, 150, 250, and 500 ft.

CHAPTER 4. METHODOLOGY

The research team used an observational cross-sectional study design for the evaluation. At the most basic level, the safety effect was estimated by taking the ratio of the average crash frequency for two groups, one with the treatment and the other without the treatment. The two groups of sites should be similar in all regards except for the presence of the treatment. This is difficult to accomplish in practice, and the research team adopted the propensity score matching technique to match treatment and reference sites while using multivariable regression modeling to control for other characteristics that vary among sites.

The research team employed multivariable regression to develop the statistical relationships between the dependent variables and a set of predictor variables. In this case, crash frequency was the dependent variable; the research team considered several predictor variables, including treatment presence, traffic volume, and other roadway characteristics. The regression coefficients for each predictor variable represented the expected change in crash frequency due to a unit change in the predictor variable with all else being equal.

The research team applied generalized linear modeling techniques to develop the crash prediction models and specified a log-linear relationship using a negative binomial error structure. The negative binomial error structure has advantages over the Poisson distribution in that it allows for overdispersion of the variance that is often present in crash data.

After developing a propensity score-matched dataset, the research team employed the following protocol to develop the multivariable models:

- Step 1—Develop base models with traffic volume only.
- Step 2—Explore the value of including other predictor variables.
- Step 3—Select the final model with the variable of interest (corner clearance), traffic volume, and other predictor variables as appropriate.

The research team determined the appropriate form for the base models (Step 1) according to the procedure outlined in Hauer.[(8)] The research team added predictor variables to the base models and assessed them one at a time to determine the appropriate functional form and value added. The team then used various functional forms to assess potential relationships between crash frequency and continuous variables (e.g., speed limit) and to determine if the continuous variables could be best represented as continuous or indicator variables (e.g., use indicator variables for different speed limits). In this process, the research team also used a correlation matrix to consider correlations among predictor variables and prioritize the inclusion of correlated variables in the final models. Once the research team had included a variable in the model, they examined estimated parameters and associated standard errors (SEs) to determine the following:

- Is the direction of effect (i.e., expected decrease or increase in crashes) in general agreement with expectations?
- Does the magnitude of the effect seem reasonable?
- Are the parameters of the model estimated with statistical significance?
- Does the estimated overdispersion parameter improve significantly?

CHAPTER 5. DATA COLLECTION

The analysis and discussions presented in this study relied on two data sets: one from the State of California and the other from the City of Charlotte, North Carolina. The original plan was to collect data from California with geographical representation from both the northern and southern regions of the State. After the preliminary analysis of California data, the FHWA approved another effort to collect additional data from the City of Charlotte, North Carolina. The data sources for these two study areas differed in many ways and required the research team to develop separate data collection methods for each dataset. The following sections discuss the details of data collection efforts.

CALIFORNIA DATA COLLECTION

The California data for this study came from the following separate sources:

- **Prior FHWA study.** The research team obtained corner clearance, key geometric features, and operational characteristics from a geographic information system (GIS) database developed under a previous FHWA-funded project entitled Safety Evaluation of Access Management Policies and Techniques.[9]

- **HSIS.** The research team obtained intersection, roadway, and 3 years (2009–2011) of traffic and crash data from the HSIS database.

The current study relied on GIS files compiled under the prior FHWA study to identify candidate intersections for this evaluation. In that study, the researchers collected the original data and developed the GIS files using a combination of tools and techniques, including global positioning system (GPS) location tagging, narrated video logs in the field, and manual measurements in ArcGIS.[9] The GIS files provided intersection locations, traffic control type (i.e., stop-controlled or signalized), and corner clearance at signalized locations. The HSIS data supplemented the GIS dataset with annual average daily traffic (AADT), reported crashes, number of lanes, lane width, speed limit, and other geometric characteristics. The GIS dataset included California and several other States. The research team initially considered all these candidate States. Ultimately, California was the only dataset collected and used for this study. California HSIS files provided cross-street name for each intersection, a key piece of information to linking GIS and HSIS data.

The research team implemented the following key steps in the data collection effort:

- Step 1—Generate the latitude and longitude of all intersections in GIS using ArcGIS's Calculate Geometry tool. Export the attribute tables from ArcGIS into text file format, and then import the data into MS Excel and separate the intersections by traffic control type (i.e., stop-controlled or signalized).

- Step 2—Use Keyhole Markup Language (KML) to convert signalized intersection locations (GPS coordinates) from Step 1 into place markers for Google® Earth™. Import KML files into Google® Earth™.

- Step 3—Check candidate intersections to determine if they meet the following criteria:

    - At least 500 ft from another signalized intersection and at least 350 ft from a stop-controlled intersection. This effort used the Ruler tool in Google® Earth™ for distance measurement.
    - No irregularity in terms of configuration and operation (e.g., no frontage roads, no extreme skew angle) or location (e.g., not at freeway interchange).

- Step 4—Locate the intersection in the HSIS file, and mark it with the feature identifier (FID) for that same intersection from GIS. The FID is a unique identifier from ArcGIS and shown in the Google® Earth™ KML files. The research team used the cross-street names to relate sites across the two datasets. The street names of the upstream and downstream intersections were available for additional verification. The FID allows data matching from HSIS and GIS. In this step, the analyst also used the Google® Earth™ measurement tool to measure the length of right- and left-turn lanes on the mainline.

Figure 3 and figure 4 illustrate the process with an example of an intersection on Route 82 in Northern California. In this example, the analyst identified a signalized intersection at Henderson Avenue in Google® Earth™. This intersection is approximately 670 ft from the nearest stop-controlled intersection (Sycamore Terrace); there are no other stop-controlled intersections within 350 ft, and no other signalized intersections within 500 ft of this intersection. It meets the two criteria listed in Step 3 above, and the analyst selected it as a candidate. The cross-street name—Henderson Avenue, as shown in figure 3—was located in the HSIS intersection inventory in figure 4. The nearby intersection, Sycamore Terrace, was used to confirm the location of interest.

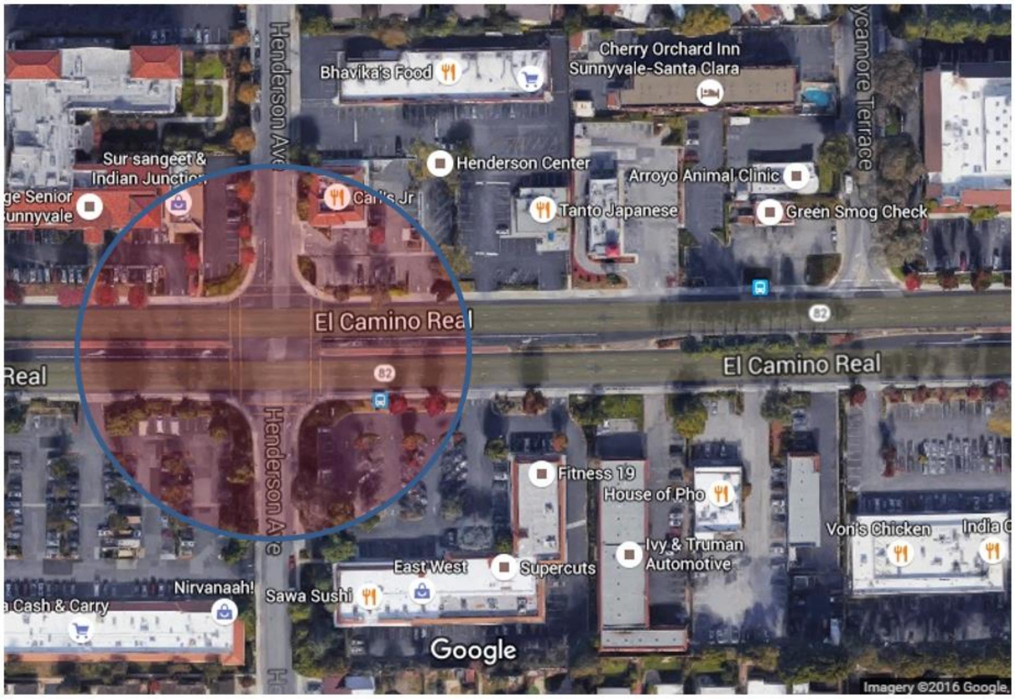


Figure 3. Screenshot. Select study location in Google® Earth™ (circle added by research team to indicate intersection of interest).[(10)]

rte_nbr	county	int_desc	FID	NB_EB_Turn_lane	SB_WB_Turn_lane	trf_cntl	milepost	int_prf	xstaadt	cntyrte
82	43	SYCAMORE TERRACE				B	14.712		401	04082 43 D
82	43	HENDERSON AVE	114	273	370	P	14.832		5300	04082 43 D
82	43	POPLAR AVE	113	241	378	P	14.892		2600	04082 43 D
82	43	NORMAN DRIVE				B	14.991		600	04082 43 D
82	43	E FREMONT AVE				B	15.22		2300	04082 43 D
82	43	WOLFE RD	140	448	431	P	15.32		20000	04082 43 D
82	43	MARIA LANE				B	15.602		1100	04082 43 D
82	43	REMINGTON DR-F OAKS AVE				P	16.16		11800	04082 43 D

Source: FHWA, data acquired from HSIS.

Figure 4. Screenshot. Locate and verify intersection in HSIS data file.

The research team used milepost, county, and route numbers to identify and link crashes from the HSIS crash data files to each intersection. The team included all crashes that occurred within a 500-ft influence zone from the center of the intersection (i.e., 250 ft upstream and 250 ft downstream). They used the number of vehicles involved and crash severity to develop multiple vehicle and fatal and injury data categories. The research team used accident type (ACCTYPE) and movement preceding accident (MISCACT) to identify crashes for rear-end, sideswipe, right-angle, and turning (left-turn and right-turn) categories.

CHARLOTTE DATA COLLECTION

The data for Charlotte, North Carolina, came from the following two sources:

- **HSIS.** The research team obtained intersection, traffic, and crash data files from HSIS. The data came in GIS shapefiles that allowed the research team to employ various spatial analysis tools in GIS to process the data. The GIS data also provided intersection location information for data collection from Google® Earth™.

- **Google® Earth™.** The research team obtained corner clearance, intersection configuration, number of lanes, driveway density, and the general characteristics of the corridor on which the intersection is located from Google® Earth™ using satellite imagery, Street View™ images, and measurement tools.

These two data sources are further described in the following sections.

INTERSECTION, TRAFFIC, AND CRASH DATA

The GIS shapefiles were a part of a raw dataset processed from HSIS. The roadway shapefiles included all roadway segments in Charlotte, North Carolina. Key attributes of each segment included AADT and number of lanes. Intersection shapefiles have information on location (GPS coordinates) and traffic control types (e.g., signalized and stop-controlled). Crash data shapefiles had location information (GPS coordinates) and key crash characteristics to identify and separate crashes by crash type and severity. The research team imported these data files into ArcGIS as separate layers and used spatial and analytical tools to perform the following tasks:

- **Determine intersection type.** The research team used the type of traffic control in the attribute table of the intersection data layer to separate all signalized intersections. These candidate study locations went through a second round of screening, removing candidate intersections within 500 ft of another signalized intersection or within 350 ft of another stop-controlled intersection. The research team extracted identification number, location information (GPS coordinates), and intersection description (names of intersecting routes) for the final list of candidate intersections for supplemental data collection using Google® Earth™ (discussed in the next section).

- **Determine number of legs, number of lanes, and AADT for each approach.** The research team overlaid intersection and roadway layers, and used spatial analysis tools in ArcGIS to create a 10-ft buffer around each intersection, represented by the center of the intersection. The number of roadway segments within each 10-ft buffer represented the number of legs. In this process, the research team determined the number of lanes by approach and the maximum, minimum, and average AADT values associated with the roadway segments. The AADT values included 3 years of data (2009–2011). The research team used the AADT and number of lanes for classifying the mainline and cross street (i.e., the approach with more lanes and larger AADT was designated as the mainline).

- **Identify and count crashes for each intersection.** The research team used spatial and analytical tools in ArcGIS to count and assign crashes to each intersection. Specifically, they used a 250-ft buffer around each intersection and tallied the crashes within the 50-ft buffer assigned to each intersection. The Charlotte Department of Transportation recommended a 150-ft radius for assigning intersection crashes; however, for consistency with the California dataset, the research team decided to use a 250-ft radius from the center of each intersection. In addition to the total crash count, the research team used key crash characteristics, including severity, crash type, and light condition to identify fatal and injury, rear-end, right-angle, sideswipe, and nighttime crashes. The dataset included 3 years of crash data (2009–2011).

Figure 5 shows a screen capture of ArcGIS, illustrating these tasks. The lines represent roadways, and each circle represents the 250-ft radius from the center of an intersection. Each dot represents a crash. If a dot falls within a circle, that crash is counted and assigned to the intersection. It is also worth noting that crashes are assigned to intersections based solely on location (within 250 ft from the center of intersection).

Source: FHWA, data acquired from HSIS.

Figure 5. Screenshot. Example of Charlotte data layers in ArcGIS.

CORNER CLEARANCE, INTERSECTION, AND CORRIDOR CHARACTERISTICS

The research team used KML to create place markers in Google® Earth™ for all candidate study intersections exported from ArcGIS, as described in the previous section. Intersection location information (GPS coordinates) was used to place a marker at the center of each intersection. Intersection identification numbers and descriptions were coded to attach to each marker for easy identification and verification of the location. After creating and importing the KML file into

Google® Earth™, the research team manually collected and confirmed the following data elements:

- **Corner clearance.** The research team used the measurement tool in Google® Earth™ to measure the distance from the corner to the nearest driveway.

- **Number of driveways.** The research team counted the number of driveways on both sides of the road and the length of the segment in which these driveways were located. The count and measurement extended two to three traffic signals upstream and downstream from the signalized intersection of interest. Number of driveways and distance were used to calculate the driveway density.

- **Median type.** The research team visually determined the type of median in the vicinity of the intersection.

- **Presence and lengths of turning lanes.** The research team collected both the presence and lengths of exclusive left- and right-turn lanes.

- **Type of land use.** The research team used Google® Street View™ to visually determine the land use type (i.e., residential, commercial, or mixed-use) in the vicinity of the intersection.

In this process, the research team also verified number of legs, number of lanes, and the designation of the mainline and cross streets collected using the GIS tools described in the previous section. In some instances, the research team identified discrepancies between GIS data and Google® Earth™ related to intersection configuration and number of lanes. For discrepancies, data from Google® Earth™ were used.

Figure 6 shows the use of the measurement tool for collecting corner clearance from Google® Earth™. At this location, there are no driveways or access points within 250 ft of the signalized intersection along the mainline. As such, this site was a candidate reference site.

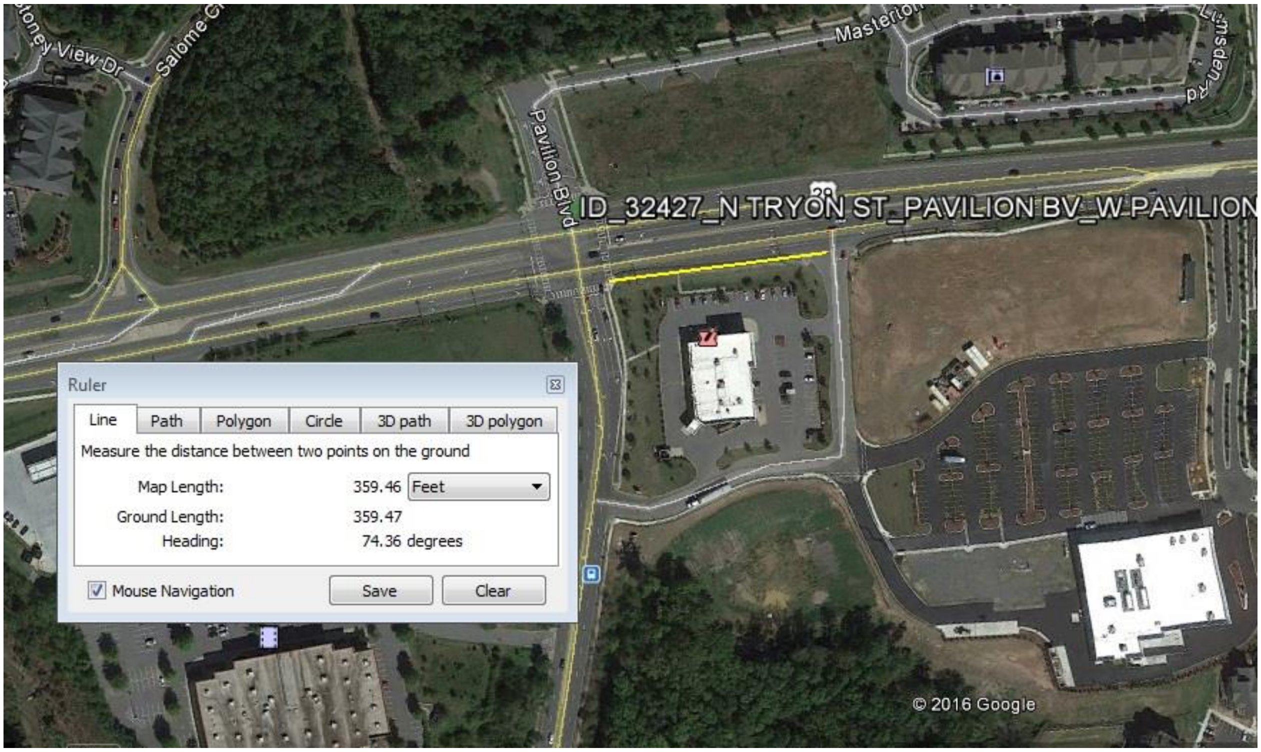


Figure 6. Screenshot. Measuring corner clearance in Google® Earth™.[11]

DATA SUMMARY

The research team collected and aggregated 3 years of data for the analysis. Table 3 presents the summary of the final dataset with 275 signalized intersections included in the analysis. The final dataset accounts for the dataset corrections discussed in chapter 6 and propensity score matching. Indicator variables are either 0 or 1, indicating the absence or presence of the characteristic, respectively. The mean value of an indicator variable represents the proportion of sites for which the indicator is 1. For example, the indicator for 50 mph or higher posted speed on the mainline in table 3 has a mean value of 0.44. This implies that 44 percent of locations have a posted speed of 50 mph or higher (indicator value = 1) and 56 percent of locations have a posted speed of less than 50 mph (indicator value = 0). It is worth noting that there are overlaps between turning crashes and other crash types (e.g., a rear-end crash can be related to a turning maneuver, so it was also coded as a turning crash).

Table 3. Data summary for signalized intersections and corner clearance.

Description	Mean	Min	Max
Number of total crashes (crashes/3 years)	13.4	0	166
Number of fatal and injury crashes (crashes/3 years)	5.7	0	51
Number of rear-end crashes (crashes/3 years)	6.9	0	99
Number of sideswipe crashes (crashes/3 years)	1.9	0	31
Number of angle crashes (crashes/3 years)	3.7	0	36
Number of turning (right or left) crashes (crashes/3 years)	1.9	0	16
Number of nighttime crashes (crashes/3 years)	3.6	0	65
AADT on the mainline (vehicles/day)	37,945	10,406	93,000
AADT on the cross street (vehicles/day)	8,598	500	48,000
Indicator for intersection in Northern California (1 if in Northern California, 0 otherwise)	0.45	0	1
Indicator for intersection in Southern California (1 if in Southern California, 0 otherwise)	0.36	0	1
Indicator for intersection in Charlotte (1 if in Charlotte, 0 if in California)	0.19	0	1
Number of approach corners with clearance of 50 ft or less	0.33	0	2
Number of receiving corners with clearance of 50 ft or less	0.44	0	2
Number of approach corners with clearance of 75 ft or less	0.46	0	2
Number of receiving corners with clearance of 75 ft or less	0.61	0	2
Number of approach corners with clearance of 100 ft or less	0.64	0	2
Number of receiving corners with clearance of 100 ft or less	0.79	0	2
Number of approach corners with clearance of 150 ft or less	0.90	0	2
Number of receiving corners with clearance of 150 ft or less	0.96	0	2
Number of approach corners with clearance of 250 ft or less	1.14	0	2
Number of receiving corners with clearance of 250 ft or less	1.19	0	2
Indicator for mainline with posted speed of 50 mph or more (1 if 50 mph or higher, 0 otherwise)	0.44	0	1
Indicator for mainline with 11 ft or narrower lanes (1 if 11 ft or narrower lanes, 0 otherwise)	0.31	0	1
Indicator for residential area (1 for residential, 0 otherwise)	0.16	0	1
Driveway density (driveways/mile)	41.74	0	111

CHAPTER 6. DEVELOPMENT OF SAFETY PERFORMANCE FUNCTIONS

This chapter presents the crash prediction models. The research team used generalized linear modeling to estimate model coefficients assuming a negative binomial error distribution, which is consistent with the state of research in developing these models. In specifying a negative binomial error structure, the modeling analysis iteratively estimated the dispersion parameter, *k*, from the model and the data. For a given dataset, smaller values of *k* indicate relatively better models.

The research team first generated a correlation matrix for all potential explanatory variables. The correlation between predictors was key to minimizing the negative effects of multicollinearity. Having two highly correlated variables in a model may result in erratic changes of the estimated coefficients and lead to biased model estimation results. The correlation matrix was used as guidance throughout the model specification and development process.

The safety performance function development began with the simplest functional form in which only traffic volumes were included. Each potential predictor was then added to the model, and the goodness of fit was evaluated. During the initial examination of data, the research team found that the cross-street AADTs at some locations appeared abnormally small for signalized intersections. Seven of the 400 candidate study locations had fewer than 100 vehicles per day on the cross streets; therefore, the research team examined locations with up to 500 and 1,000 vehicles per day, and the number of locations increased to 17 and 34, respectively. All of these intersections with abnormal AADTs were located in California. The research team conducted a thorough examination of these intersections in Google® Earth™, Google® Street View™, and HSIS, looking at 10 years of HSIS roadway data. The effort confirmed that no mistakes had been made in matching the traffic volumes. The abnormally low AADT values had originated from the HSIS data files. Visual verification suggested that these very low AADT values appeared to be improbable. Aerial images in Google® Earth™ showed long vehicle queues and large parking lots on the cross streets at a majority of these intersections. Although this was not enough for a reliable estimate of the cross-street AADT, the evidence demonstrated the inaccuracy of these very low AADT values. The research team examined the impacts of these low AADT values on the model parameters by estimating and comparing several models for total crashes as follows:

- Model 1—Include all intersections with cross-street AADT as originally collected (i.e., include sites with abnormally low AADT values).
- Model 2—Exclude 17 intersections with cross-street AADT less than 500 vehicles per day.
- Model 3—Replace all AADT values less than 500 vehicles per day with 500 vehicles per day for 17 intersections.
- Model 4—Replace all AADT values less than 1,000 vehicles per day with 500 vehicles per day for 34 intersections.

- Model 5—Replace all AADT values less than 1,000 vehicles per day with 1,000 vehicles per day for 34 intersections.

The results showed minimal differences among these five models. In the end, the research team selected Model 3, replacing the cross-street AADT values for 17 intersections with values of 500 vehicles per day. The data summary presented in table 3 for 275 intersection reflects this correction.

The data for this study represent three regions: Northern California, Southern California, and the largest city in North Carolina. It is reasonable to assume that these three regions might have inherently different characteristics that can affect the safety outcomes or at least crash counts at signalized intersections. These elements could be unknown, immeasurable, or unavailable for the analyses conducted in this study. For example, the climate and the driver population in Charlotte are probably not the same as those in California. The research team tested this assumption by estimating crash prediction models using separate subsets of data from each of the three regions and comparing the model parameters. The test results revealed little difference between Northern and Southern California in this regard, so all intersections from California were considered as one group. The tests indicated larger differences between Charlotte and California sites, but the 95-percent intervals of the model parameters still overlapped. This process and its results supported the decision to analyze all intersections together as a single dataset and use an indicator to account for the inherent differences between California and Charlotte.

The research team developed crash prediction models separately for total, fatal and injury, rear-end, sideswipe, right-angle, and right- and left-turn crashes at signalized intersections. Combinations of clearances on both approach and receiving corners were tested. The research team decided to use a corner clearance of 50 ft for all models after considering the overall model fit and the practicality of potential applications. The following sections present the crash prediction models for these crash types. The definition of variables included in the final crash prediction models are as follows:

- *TOTAL* = predicted number of total crashes (all types and severities) in 3 years.
- *FI* = predicted number of fatal and injury crashes in 3 years.
- *REAREND* = predicted number of rear-end crashes in 3 years.
- *SIDESWP* = predicted number of sideswipe crashes in 3 years.
- *ANGLE* = predicted number of right-angle crashes in 3 years.
- *TURN* = predicted number of right- and left-turn crashes in 3 years.
- *NIGHT* = predicted number of nighttime crashes in 3 years.
- *CLT* = indicator for intersections from Charlotte (1 if intersection from Charlotte, 0 if intersection from California).

- *MLAADT* = AADT on the mainline (vehicles/day).
- *XSTAADT* = AADT on the cross street (vehicles/day).
- *AADT* = total entering volume at intersection (*MLAADT* + *XSTAADT*).
- *APPCOR50* = number of approach corners with clearance of 50 ft or less.
- *RECCOR50* = number of receiving corners with clearance of 50 ft or less.
- *SPD50PLUS* = indicator for posted speed (1 if 50+ mph on mainline, 0 otherwise).
- *LW11LESS* = indicator for mainline with 11-ft or narrower lanes.
- *DRWYDEN* = driveway density (average number of driveways on both sides of the road per mile).
- *RESID* = indicator for land use type where the intersection is located (1 if it is mostly residential, 0 otherwise).

CRASH PREDICTION MODEL FOR TOTAL CRASHES

Figure 7 presents the functional form of the crash prediction model.

$$TOTAL = MLAADT^{\beta_1} \times XSTAADT^{\beta_2} \times e^{(\beta_3 \times CLT + \beta_4 \times SPD50PLUS + \beta_5 \times LW11LESS + \beta_6 \times APCOR50 + \beta_7 \times RECOR50 + \beta_8)}$$

Figure 7. Equation. Model for total crashes.

Table 4 presents the model parameters for total crashes.

Table 4. Model parameters for total crashes.

Variable	Coefficient	Estimated Value	SE	P-Value
Mainline AADT	β_1	0.616	0.128	<0.01
Cross-street AADT	β_2	0.295	0.051	<0.01
Indicator for intersection in Charlotte	β_3	2.365	0.174	<0.01
50 mph or higher posted speed	β_4	0.497	0.118	<0.01
Mainline with 11-ft lane or narrower	β_5	–0.492	0.127	<0.01
Number of approach corners with clearance of 50 ft or less	β_6	–0.199	0.099	0.05
Number of receiving corners with clearance of 50 ft or less	β_7	0.282	0.084	<0.01
Intercept term	β_8	–7.442	1.281	<0.01
Dispersion parameter (*k*)	—	0.517	0.058	—

—Not applicable.

CRASH PREDICTION MODEL FOR FATAL AND INJURY CRASHES

Figure 8 presents the functional form of the crash prediction model.

$$FI = MLAADT^{\beta_1} \times XSTAADT^{\beta_2} \times e^{(\beta_3 \times CLT + \beta_4 \times SPD50PLUS + \beta_5 \times LW11LESS + \beta_6 \times APCOR50 + \beta_7 \times RECOR50 + \beta_8)}$$

Figure 8. Equation. Model for fatal and injury crashes.

Table 5 presents the model parameters for fatal and injury crashes.

Table 5. Model parameters for fatal and injury crashes.

Variable	Coefficient	Estimated Value	SE	P-Value
Mainline AADT	β_1	0.685	0.134	<0.01
Cross-street AADT	β_2	0.257	0.054	<0.01
Indicator for intersection in Charlotte	β_3	1.978	0.173	<0.01
50 mph or higher posted speed	β_4	0.331	0.124	<0.01
Mainline with 11-ft lane or narrower	β_5	–0.349	0.125	<0.01
Number of approach corners with clearance of 50 ft or less	β_6	–0.238	0.104	0.02
Number of receiving corners with clearance of 50 ft or less	β_7	0.258	0.085	<0.01
Intercept term	β_8	–8.464	1.344	<0.01
Dispersion parameter (*k*)	—	0.431	0.063	—

—Not applicable.

CRASH PREDICTION MODEL FOR REAR-END CRASHES

Figure 9 presents the functional form of the crash prediction model.

$$REAREND = MLAADT^{\beta_1} \times XSTAADT^{\beta_2} \times e^{(\beta_3 \times CLT + \beta_4 \times SPD50PLUS + \beta_5 \times LW11LESS + \beta_6 \times APCOR50 + \beta_7 \times RECOR50 + \beta_8 \times DRWYDEN + \beta_9)}$$

Figure 9. Equation. Model for rear-end crashes.

Table 6 presents the model parameters for rear-end crashes. In table 6, driveway density has a negative coefficient estimate. This indicates that an increase in driveway density is statistically associated with a reduction in rear-end crashes. It is important to emphasize that the driveway density in this context represents the longer roadway segment on that corridor. The driveway density in this model does not suggest that having more driveways near an intersection reduces rear-end crashes.

Table 6. Model parameters for rear-end crashes.

Variable	Coefficient	Estimated Value	SE	P-Value
Mainline AADT	β_1	0.827	0.155	<0.01
Cross-street AADT	β_2	0.263	0.060	<0.01
Indicator for intersection in Charlotte	β_3	1.910	0.204	<0.01
50 mph or higher posted speed	β_4	0.332	0.153	0.03
Mainline with 11-ft lane or narrower	β_5	–0.461	0.159	<0.01
Number of approach corners with clearance of 50 ft or less	β_6	–0.234	0.119	0.05
Number of receiving corners with clearance of 50 ft or less	β_7	0.311	0.101	<0.01
Driveway density	β_8	–0.006	0.003	0.05
Intercept term	β_9	–9.529	1.542	<0.01
Dispersion parameter (*k*)	—	0.670	0.080	—

—Not applicable.

CRASH PREDICTION MODEL FOR SIDESWIPE CRASHES

Figure 10 presents the functional form of the crash prediction model.

$$SIDESWIPE = MLAADT^{\beta_1} \times XSTAADT^{\beta_2} \times e^{(\beta_3 \times CLT + \beta_4 \times SPD50PLUS + \beta_5 \times LW11LESS + \beta_6 \times APCOR50 + \beta_7 \times RECOR50 + \beta_8 \times RESID + \beta_9)}$$

Figure 10. Equation. Model for sideswipe crashes.

Table 7 presents the model parameters for sideswipe crashes.

Table 7. Model parameters for sideswipe crashes.

Variable	Coefficient	Estimated Value	SE	P-Value
Mainline AADT	β_1	0.663	0.178	<0.01
Cross-street AADT	β_2	0.388	0.076	<0.01
Indicator for intersection in Charlotte	β_3	1.968	0.222	<0.01
50 mph or higher posted speed	β_4	0.618	0.172	<0.01
Mainline with 11-ft lane or narrower	β_5	–0.346	0.166	0.04
Number of approach corners with clearance of 50 ft or less	β_6	–0.186	0.139	0.18
Number of receiving corners with clearance of 50 ft or less	β_7	0.269	0.109	0.01
Indicator for residential area	β_8	–0.601	0.212	<0.01
Intercept term	β_9	–10.560	1.825	<0.01
Dispersion parameter (*k*)	—	0.466	0.096	—

—Not applicable.

CRASH PREDICTION MODEL FOR RIGHT-ANGLE CRASHES

Figure 11 presents the functional form of the crash prediction model.

$$ANGLE = AADT^{\beta_1} \times e^{(\beta_2 \times CLT + \beta_3 \times SPD50PLUS + \beta_4 \times LW11LESS + \beta_5 \times APCOR50 + \beta_6 \times RECOR50 + \beta_7)}$$

Figure 11. Equation. Model for right-angle crashes.

Table 8 presents the model parameters for right-angle crashes.

Table 8. Model parameters for right-angle crashes.

Variable	Coefficient	Estimated Value	SE	P-Value
Intersection AADT	β_1	0.641	0.196	<0.01
Indicator for intersection in Charlotte	β_2	3.260	0.270	<0.01
50 mph or higher posted speed	β_3	0.732	0.196	<0.01
Mainline with 11-ft lane or narrower	B_4	–0.822	0.211	<0.01
Number of approach corners with clearance of 50 ft or less	β_5	0.031	0.158	0.84
Number of receiving corners with clearance of 50 ft or less	β_6	0.352	0.137	0.01
Intercept term	β_7	–7.014	2.079	<0.01
Dispersion parameter (*k*)	—	1.096	0.182	—

—Not applicable.

CRASH PREDICTION MODEL FOR TURNING CRASHES

Figure 12 presents the functional form of the crash prediction model.

$$TURN = AADT^{\beta_1} \times e^{(\beta_2 \times CLT + \beta_3 \times SPD50PLUS + \beta_4 \times LW11LESS + \beta_5 \times APCOR50 + \beta_6 \times RECOR50 + \beta_7)}$$

Figure 12. Equation. Model for turning crashes.

Table 9 presents the model parameters for turning (right- or left-turn) crashes.

Table 9. Model parameters for turning crashes.

Variable	Coefficient	Estimated Value	SE	P-Value
Intersection AADT	β_1	0.923	0.189	<0.01
Indicator for intersection in Charlotte	β_2	2.560	0.236	<0.01
50 mph or higher posted speed	β_3	0.574	0.186	<0.01
Mainline with 11-ft lane or narrower	β_4	–0.537	0.181	<0.01
Number of approach corners with clearance of 50 ft or less	β_5	0.004	0.147	0.98
Number of receiving corners with clearance of 50 ft or less	β_6	0.199	0.120	0.10
Intercept term	β_7	–10.270	2.018	<0.01
Dispersion parameter (*k*)	—	0.639	0.124	—

—Not applicable.

CRASH PREDICTION MODEL FOR NIGHTTIME CRASHES

Figure 13 presents the functional form of the crash prediction model.

$$NIGHT = MLAADT^{\beta_1} \times XSTAADT^{\beta_2} \times e^{(\beta_3 \times CLT + \beta_4 \times SPD50PLUS + \beta_5 \times LW11LESS + \beta_6 \times APCOR50 + \beta_7 \times RECOR50 + \beta_8)}$$

Figure 13. Equation. Model for nighttime crashes.

Table 10 presents the model parameters for nighttime crashes.

Table 10. Model parameters for nighttime crashes.

Variable	Coefficient	Estimated Value	SE	P-Value
Mainline AADT	β_1	0.986	0.164	<0.01
Cross-street AADT	β_2	0.282	0.069	<0.01
Indicator for intersection in Charlotte	β_3	2.675	0.217	<0.01
50 mph or higher posted speed	β_4	0.501	0.160	<0.01
Mainline with 11-ft lane or narrower	β_5	–0.463	0.154	<0.01
Number of approach corners with clearance of 50 ft or less	β_6	–0.067	0.129	0.60
Number of receiving corners with clearance of 50 ft or less	β_7	0.257	0.103	0.01
Intercept term	β_8	–12.720	1.669	<0.01
Dispersion parameter (*k*)	—	0.545	0.089	—

—Not applicable.

CHAPTER 7. CROSS-SECTIONAL EVALUATION RESULTS

AGGREGATE ANALYSIS

Table 11 through table 16 present the estimated CMFs and related SE for each of the following target crash types.

- Total—all crashes within 250 ft of intersection (all types and severity levels combined).
- Fatal and injury—all injury crashes within 250 ft of intersection.
- Rear-end—all crashes coded as "rear-end" within 250 ft of intersection.
- Sideswipe—all crashes coded as "sideswipe" within 250 ft of intersection.
- Right-angle—all crashes coded as "right-angle" within 250 ft of intersection.
- Turning—all crashes coded as "right-turn" or "left-turn" within 250 ft of intersection.
- Nighttime—all crashes with lighting condition coded as "dark," "dawn," or "dusk" within 250 ft of intersection.

This study presents aggregate results by number of approach and receiving corners with driveways within 50 ft of the intersection. The study presents results separately for the number of approach corners (i.e., one or two) and number of receiving corners (i.e., one or two) compared to no driveways within 50 ft of the intersection on the approach or receiving corners, respectively.

For total crashes, the CMFs were 0.82 and 0.67 for corner clearance of 50 ft or less on one and two approach corners, respectively, compared to no driveways within 50 ft of both approach corners. The CMFs were 1.33 and 1.76 for corner clearance of 50 ft or less on one and two receiving corners, respectively, compared to no driveways within 50 ft of both receiving corners. All CMF estimates were statistically significant at the 95-percent confidence level.

Table 11. Results for total crashes.

Number of Corner(s) With Limited Clearance	CMF	SE
1 approach corner with driveway(s) within 50 ft	0.82**	0.08
2 approach corners with driveway(s) within 50 ft	0.67**	0.13
1 receiving corner with driveway(s) within 50 ft	1.33**	0.11
2 receiving corners with driveway(s) within 50 ft	1.76**	0.30

**Statistically significant results at the 95-percent confidence level.

For fatal and injury crashes, the CMFs were 0.79 and 0.62 for corner clearance of 50 ft or less on one and two approach corners, respectively, compared to no driveways within 50 ft of both approach corners. The CMFs were 1.29 and 1.68 for corner clearance of 50 ft or less on one and two receiving corners, respectively, compared to no driveways within 50 ft of both receiving corners. All CMF estimates were statistically significant at the 95-percent confidence level.

Table 12. Results for fatal and injury crashes.

Number of Corner(s) With Limited Clearance	CMF	SE
1 approach corner with driveway(s) within 50 ft	0.79**	0.08
2 approach corners with driveway(s) within 50 ft	0.62**	0.13
1 receiving corner with driveway(s) within 50 ft	1.29**	0.11
2 receiving corners with driveway(s) within 50 ft	1.68**	0.29

**Statistically significant results at the 95-percent confidence level.

For rear-end crashes, the CMFs were 0.79 and 0.63 for corner clearance of 50 ft or less on one and two approach corners, respectively, compared to no driveways within 50 ft of both approach corners. The CMFs were 1.36 and 1.86 for corner clearance of 50 ft or less on one and two receiving corners, respectively, compared to no driveways within 50 ft of both receiving corners. The CMF estimates were statistically significant at the 95-percent confidence level.

Table 13. Results for rear-end crashes.

Number of Corner(s) With Limited Clearance	CMF	SE
1 approach corner with driveway(s) within 50 ft	0.79**	0.09
2 approach corners with driveway(s) within 50 ft	0.63**	0.15
1 receiving corner with driveway(s) within 50 ft	1.36**	0.14
2 receiving corners with driveway(s) within 50 ft	1.86**	0.38

**Statistically significant results at the 95-percent confidence level.

For sideswipe crashes, the CMFs were 0.83 and 0.69 for corner clearance of 50 ft or less on one and two approach corners, respectively, compared to no driveways within 50 ft of both approach corners. These two CMF estimates were not statistically significant at the 90-percent confidence level. The CMFs were 1.31 and 1.71 for corner clearance of 50 ft or less on one and two receiving corners, respectively, compared to no driveways within 50 ft of both receiving corners. The CMF for one corner was statistically significant at the 95-percent confidence level, and the CMF for two corners was statistically significant at the 90-percent confidence level.

Table 14. Results for sideswipe crashes.

Number of Corner(s) With Limited Clearance	CMF	SE
1 approach corner with driveway(s) within 50 ft	0.83	0.12
2 approach corners with driveway(s) within 50 ft	0.69	0.19
1 receiving corner with driveway(s) within 50 ft	1.31**	0.14
2 receiving corners with driveway(s) within 50 ft	1.71*	0.38

*Statistically significant results at the 90-percent confidence level.
**Statistically significant results at the 95-percent confidence level.

For right-angle crashes, the CMFs were 1.03 and 1.06 for corner clearance of 50 ft or less on one and two approach corners, respectively, compared to no driveways within 50 ft of both approach corners. Neither CMF estimates were statistically significant at the 90-percent confidence level. The CMFs were 1.42 and 2.02 for corner clearance of 50 ft or less on one and two receiving corners, respectively, compared to no driveways within 50 ft of both receiving corners. The CMF estimate for one corner was statistically significant at the 95-percent confidence level, and the CMF for two corners was statistically significant at the 90-percent confidence level.

Table 15. Results for right-angle crashes.

Number of Corner(s) With Limited Clearance	CMF	SE
1 approach corner with driveway(s) within 50 ft	1.03	0.16
2 approach corners with driveway(s) within 50 ft	1.06	0.34
1 receiving corner with driveway(s) within 50 ft	1.42**	0.20
2 receiving corners with driveway(s) within 50 ft	2.02*	0.56

*Statistically significant results at the 90-percent confidence level.
**Statistically significant results at the 95-percent confidence level.

For turning (right- or left-turn) crashes, the CMFs were 1.00 and 1.01 for corner clearance of 50 ft or less on one and two approach corners, respectively, compared to no driveways within 50 ft of both approach corners. The CMFs were 1.22 and 1.49 for corner clearance of 50 ft or less on one and two receiving corners, respectively, compared to no driveways within 50 ft of both receiving corners. None of these CMF estimates were statistically significant at the 90-percent confidence level.

Table 16. Results for turning crashes.

Number of Corner(s) With Limited Clearance	CMF	SE
1 approach corner with driveway(s) within 50 ft	1.00	0.15
2 approach corners with driveway(s) within 50 ft	1.01	0.30
1 receiving corner with driveway(s) within 50 ft	1.22	0.15
2 receiving corners with driveway(s) within 50 ft	1.49	0.36

For nighttime crashes, the CMFs were 0.94 and 0.87 for corner clearance of 50 ft or less on one and two approach corners, respectively, compared to no driveways within 50 ft of both approach corners. These two CMF estimates were not statistically significant at the 90-percent confidence level. The CMFs were 1.29 and 1.67 for corner clearance of 50 ft or less on one and two receiving corners, respectively, compared to no driveways within 50 ft of both receiving corners. The CMF estimate for one receiving corner was statistically significant at the 95-percent confidence level, and the CMF for two corners was statistically significant at the 90-percent confidence level.

Table 17. Results for nighttime crashes.

Number of Corner(s) With Limited Clearance	CMF	SE
1 approach corner with driveway(s) within 50 ft	0.94	0.12
2 approach corners with driveway(s) within 50 ft	0.87	0.23
1 receiving corner with driveway(s) within 50 ft	1.29**	0.13
2 receiving corners with driveway(s) within 50 ft	1.67*	0.35

*Statistically significant results at the 90-percent confidence level.
**Statistically significant results at the 95-percent confidence level.

DISAGGREGATE ANALYSIS

The objective of the disaggregate analysis was to identify specific CMFs by crash type and different conditions. The analysis could also reveal those conditions under which the strategy was more effective. The research team considered several variables in the disaggregate analysis, including major and minor road traffic volume, number of lanes on the major and minor road, posted speed limit on the mainline, driveway density on the mainline, and presence of left- and right-turn lanes on the mainline. The multivariable regression models included interaction terms to investigate the potential differential effects of corner clearance with respect to the interacted variable. For example, the interaction term for major road traffic volume and number of major road approaches with driveways within 50 ft is the product of the two variables. A statistically significant interaction term would indicate an apparent differential effect of corner clearance across different traffic volumes or the other variables of interest.

The analysis results indicated that none of the interaction terms were statistically significant at even an 80-percent confidence level. While these results indicated no differential effect of corner clearance, the sample size may have been too small to detect differential effects at the desired level of confidence.

CHAPTER 8. ECONOMIC ANALYSIS

The research team conducted an economic analysis to estimate the cost-effectiveness of changing corner clearance at mainline access points near signalized intersections. The economic analysis examined the effect on total crashes from removing mainline access points on the receiving corners of four-leg, signalized intersections within a corner clearance distance of 50 ft. Due to the cross-sectional nature of this study and the uncertainty around the results—which is discussed further in chapter 10—the research team does not advocate adding access points on approaches as a crash-reduction measure at this time. However, the research team expects no safety disbenefits in total crashes from keeping access points with limited corner clearance (less than 50 ft) on the mainline approach corner for an average intersection. The research team used the total CMF rather than considering separate effects of fatal and injury and property-damage-only (PDO) crashes because the CMFs by severity are relatively consistent with total crashes (i.e., within 10-percent difference).

For this analysis, the research team assumed increasing corner clearance involved the removal of driveways with corner clearance of 50 ft or less by installing concrete curbing and a sidewalk in place of the mainline access for a commercial property. The intent was to shift traffic to an existing access on the cross street or further downstream (corner clearance more than 50 ft) on the mainline. The cost did not include the construction of a new access point, which, if necessary, would drastically increase the estimated cost of the treatment. The research team assumed that another mainline or cross-street access could continue to provide access to the property. Based on cost information for concrete sidewalks with curb and gutter from *NCHRP Report 500: Volume 10: A Guide for Reducing Collisions Involving Pedestrians*, curbing costs an average of $15 per linear foot, and walkways cost $11 per square foot.(12) Assuming a sidewalk width of 6 ft, the average installation cost is $81 per linear foot of curb and sidewalk. Although most access points are narrower, the analysis used a conservative assumption of 100 ft of curb and sidewalk to connect walkways on either side of an existing driveway. Given these assumptions, the construction cost for removing access points was approximately $8,100 per access point per corner. The research team assumed that the construction cost per corner was the same regardless of the number of corners treated.

The research team assumed that the service life of the treatment was 10 years. Although the corner clearance will not deteriorate, the research team used a conservative service life of 10 years as a period in which significant maintenance and operations costs are unlikely. As such, this study assumes annual maintenance and operations costs to be negligible.

The FHWA Office of Safety Research and Development suggested using the Office of Management and Budget *Circular A-4* as a resource for the real discount rate of 7 percent to calculate the present value benefits and costs of the treatment over the service life.(13) With this information, the analysis used a capital recovery factor of 7.02.

The research team used FHWA mean comprehensive crash costs by crash geometry as a basis for the benefit calculations.(14) The mean comprehensive crash cost for a fatal and injury crash was $158,177 in 2001 U.S. dollars (USD). The cost for a PDO crash was $7,428 in 2001 USD. The research team weighted these values using the distribution of crash severities across study sites (i.e., approximately 43 percent fatal and injury crashes) to determine the mean comprehensive cost of a total crash as $71,553 in 2001 USD. At the time of analysis, the research team updated this value to 2016 USD by applying the ratio of the United States Department of Transportation (USDOT) 2016 value of a statistical life of $9.6 million to the 2001 value of $3.8 million, yielding an aggregate 2016 cost of $176,998 for a total crash.[14,15]

To determine the safety benefits of increasing corner clearance, the research team analyzed the safety effects of removing access points with less than 50 ft of corner clearance on one or both mainline receiving corners of an average signalized intersection that had two receiving corners with limited clearance. Table 2 gives an average crash frequency of 4.36 crashes per site per year at four-leg, signalized intersections with no limited corner clearance on receiving corners. The research team multiplied this average crash frequency by the total CMFs of 1.33 and 1.76 from table 11 to estimate the crash frequency at sites with limited clearance on one (5.80 crashes per site per year) and two receiving corners (7.67 crashes per site per year). The research team used the differences in crash frequency between sites with two and one limited clearance corners (1.87 crashes per site per year) and two and zero limited clearance corners (3.31 crashes per site per year) as the average reduction of total crashes in each scenario.

The research team calculated the annual economic benefits by multiplying the total crash reduction per site per year by the average cost of a total crash, and then annualizing the result over the service life. USDOT recommended conducting a sensitivity analysis by assuming values of a statistical life of 0.55 and 1.38 times the 2016 value as lower and upper bounds.[15] Researchers can apply these factors directly to the estimated B/C ratios. Table 18 presents the results.

Table 18. BC ratios for removing receiving corner access points from a site with limited clearance on two receiving corners.

Number of Access Points With Limited Corner Clearance Removed	Lower B/C	Average B/C	Upper B/C
1	161.6	293.9	405.5
2	285.7	519.4	716.7

These results suggest that removing access on mainline receiving corners to improve corner clearance—with reasonable assumptions on cost, service life, and the value of a statistical life—can be cost effective for reducing crashes at signalized intersections.

It is important to note that these results represented the change in total crashes under average conditions with several cost assumptions. The research team recommends conducting an economic analysis to determine if improving corner clearance is likely to be cost effective for specific sites where proposed projects are considered. Table 11 through table 17 list the CMFs for other crash types and severities that analysts should use when considering the safety effects of corner clearance.

CHAPTER 9. SUMMARY AND CONCLUSIONS

The objective of this study was to undertake a rigorous cross-sectional evaluation of the safety effects, as measured by crash frequency, of mainline corner clearance at four-leg, signalized intersections. The study compared signalized intersections with various corner clearance using data from the State of California and the City of Charlotte, North Carolina, to examine the effects on specific crash types: total, fatal and injury, rear-end, sideswipe, right-angle, turning, and nighttime crashes. The study did not investigate the effects of corner clearance on the cross-street approaches, or intersections with three legs or more than four legs.

Table 19 and table 20 present the recommended CMFs for numbers of approach and receiving corners with limited clearance, respectively, at signalized intersections based on the aggregate analysis results. The disaggregate analyses by traffic volumes, number of lanes, posted speeds, driveway density, and the presence of exclusive right- and left-turn lanes indicated no differential effects of corner clearance on the specific crash types. However, the sample size may have been too small to detect differential effects at the desired level of confidence.

Table 19. Recommended CMFs for limited approach corner clearance.

Crash Type	CMF for 1 Approach Corner With Driveway(s) Within 50 ft (SE)	CMF for 2 Approach Corners With Driveway(s) Within 50 ft (SE)
Total crashes	0.82** (0.08)	0.67** (0.13)
Fatal and injury crashes	0.79** (0.08)	0.62** (0.13)
Rear-end crashes	0.79** (0.09)	0.63** (0.15)
Sideswipe crashes	0.83 (0.12)	0.69 (0.19)
Right-angle crashes	1.03 (0.16)	1.06 (0.34)
Turning crashes	1.00 (0.15)	1.01 (0.30)
Nighttime crashes	0.94 (0.12)	0.87 (0.23)

**Statistically significant results at the 95-percent confidence level.

Table 20. Recommended CMFs for limited receiving corner clearance.

Crash Type	CMF for 1 Receiving Corner With Driveway(s) Within 50 ft (SE)	CMF for 2 receiving Corners With Driveway(s) Within 50 ft (SE)
Total crashes	1.33** (0.11)	1.76** (0.30)
Fatal and injury crashes	1.29** (0.11)	1.68** (0.29)
Rear-end crashes	1.36** (0.14)	1.86** (0.38)
Sideswipe crashes	1.31** (0.14)	1.71* (0.38)
Right-angle crashes	1.42** (0.20)	2.02* (0.56)
Turning crashes	1.22 (0.15)	1.49 (0.36)
Nighttime crashes	1.29** (0.13)	1.67* (0.35)

*Statistically significant results at the 90-percent confidence level.
**Statistically significant results at the 95-percent confidence level.

The introduction of access points in proximity to the intersection area increases the number of potential conflict points on the approaches. Logically, this is expected to increase crashes. The estimated CMFs indicated that more limited clearance on receiving corners was associated with increases for all crash types, based on the data included in this analysis. These increases were statistically significant at the 90-percent level or greater for total, fatal and injury, rear-end, sideswipe, right-angle, and nighttime crashes. Only the results for turning crashes were not statistically significant at the 90-percent level. For limited corner clearance on the approach corners, the results indicated statistically significant reductions in total, fatal and injury, and rear-end crashes. The results also indicated reductions in sideswipe and nighttime crashes, and increases in right-angle and turning crashes, but none of these results were statistically significant at the 90-percent level. The next section discusses these results in more detail.

The economic analysis resulted in an average B/C ratio of at least 294 to 1 for most intersections when removing access at one mainline receiving corner with limited corner clearance. The analysis assumed another access to the property is available beyond 50 ft from the intersection or on the cross street. With the USDOT recommended sensitivity analysis, these values could range from 162 to 1 up to 405 to 1. Removing access at both mainline receiving corners provided a higher B/C ratio. This study based the economic analysis on total crashes only. Including other crash types would change the resulting estimate of the project benefit, and may have different effects for intersections with different crash type distributions than represented by the sample in this study. Further, the economic analysis did not include the effects of adding or removing driveways on the approach corners. While the results suggest that adding driveways on the approach corners may reduce specific crash types, these results require further study. As such, the economic analysis assumed there are no disbenefits—with respect to total crashes—to leaving existing driveways in place on the approach corners.

These results suggest that removing or relocating driveways on mainline receiving corners can be highly cost effective in reducing total crashes at four-leg, signalized intersections.

CHAPTER 10. DISCUSSION

The CMFs for limited corner clearance on the receiving corners were consistent with expectation, indicating statistically significant increases in total, fatal and injury, rear-end, sideswipe, right-angle, and nighttime crashes. For limited corner clearance on the approach corners, the CMFs were counterintuitive, indicating statistically significant decreases in total, fatal and injury, and rear-end crashes. Intuition and past research suggest that limiting corner clearance (i.e., allowing driveways) on all corners would negatively affect safety due to complex and conflicting turning movements from the traffic into and, particularly, out of driveways in proximity to the functional area of the intersection. However, these particular CMFs in question (i.e., decreases in total, fatal and injury, and rear-end crashes for limited corner clearance on the approach corners) are among the most statistically significant results derived from this evaluation. The research team proposes a number of possible explanations for these results that are counter to the general hypothesis of the study.

As shown in table 3, rear-end crashes constitute more than half of all crashes, while angle crashes account for approximately one-quarter of all crashes. The reduction in rear-end crashes likely outweighs the increase in angle crashes and leads to the overall reduction in total crashes and fatal and injury crashes for this situation. Therefore, this discussion focuses on rear-end and angle crashes. The research team proposed the following potential hypotheses:

- The reduction in rear-end crashes on the approach corners may be associated with localized congestion from vehicles turning into and out of the driveways near the approach corners of an intersection. The vehicles turning into and out of driveways may lead to an increase in driveway-related angle crashes, as the CMFs indicate, although not with statistical significance. However, this reduction in operating speeds results in fewer rear-end crashes and likely fewer angle crashes within the adjacent signalized intersection, which tend to be more severe than driveway-related crashes. With a much higher proportion in overall crashes, the decrease in rear-end crashes is likely to be larger than any increase in angle collisions. This results in an overall reduction in total and fatal and injury crashes. The statistically significant driveway density coefficient in the model for rear-end crashes shown in table 6 seems to support this hypothesis.

- After passing through the signalized intersection, vehicles may accelerate. The interactions and conflicts from the turning vehicles (into and out of the driveways) on the receiving corners are likely to result in more crashes for all crash types. The turning vehicles from the cross streets also add to the overall traffic and likelihood of conflicts on the receiving corners. The mainline AADT on the receiving corners may not reflect this added traffic from the cross street and therefore is not captured in the model.

- The overall context of the sites with limited corner clearance is responsible for the difference rather than the specific effects of corner clearance. The limited corner clearance could be a surrogate for another factor that affects safety performance that is not captured in the models. That is, those intersections with more driveways on the approaches may have more traffic and are more likely to be congested than those without driveways on the approach simply by the nature of the roadway, not because of the presence of the driveway (e.g., stores and gas stations are there to serve the heavier traffic). The context of the intersection within the corridor is difficult to control for in a cross-sectional evaluation. In this study, the research team collected and analyzed corridor characteristic data elements, including driveway density (number of driveways per mile) and type of land use (residential, commercial, or mixed-use). The model estimation results suggest limited or no statistically significant effects of these elements on crashes. The evaluation set out to investigate the safety effects at intersections rather than the entire corridor and, as such, could not collect and include more corridor-related characteristics in the models or examine the effects on crashes along the related corridors.

Future research could explore the hypotheses proposed and discussed in this study. Crash prediction models that include operations-related factors—such as mean operating speeds, a speed profile for intersections along the mainline, or level of service—would greatly improve the results in determining the safety effects of corner clearance. Controlling for these types of factors may better explain the effects of corner clearance on rear-end and angle crashes and, therefore, on total and fatal and injury crashes. Future research could also verify the results using data from other States. The results presented in this study are based on data from the State of California and the City of Charlotte, North Carolina.

Readers may be able to test the hypotheses anecdotally as well. If a comparison of intersections in a jurisdiction shows that intersections with limited corner clearance are located along more congested corridors and have similar crash type distributions to the sample intersections in this study, then the reduction in rear-end crashes due to limited corner clearance on the approach is probably a result of the area type rather than the corner clearance. Therefore, improving corner clearance on mainline approaches may be less likely to increase rear-end crashes as a result. If the area type and crash type distribution do not follow with this hypothesis and the sample data, the results of this evaluation may not be as accurate when applied to those sites.

Additionally, the sample intersections used in this evaluation were not selected as a result of safety concerns due to angle crashes. In practice, potential projects are more likely to address corner clearance at intersections with a higher proportion of angle or turning crashes than represented in this study. Consequently, projects addressing approach corners may have a higher chance of reducing total crashes and yielding a higher net benefit when improving corner clearance than implied in the results of this evaluation.

APPENDIX. EXAMPLE INTERSECTIONS

This appendix presents photos of intersections used in this study. Figure 14 displays a street-level view of a signalized intersection with limited corner clearance on a mainline approach corner. Figure 15 displays a street-level view of a signalized intersection with limited corner clearance on a mainline receiving corner. Figure 16 displays an aerial view of a signalized intersection with limited corner clearance on all mainline corners. Figure 17 displays an aerial view of a signalized intersection with unrestricted corner clearance on all mainline corners.

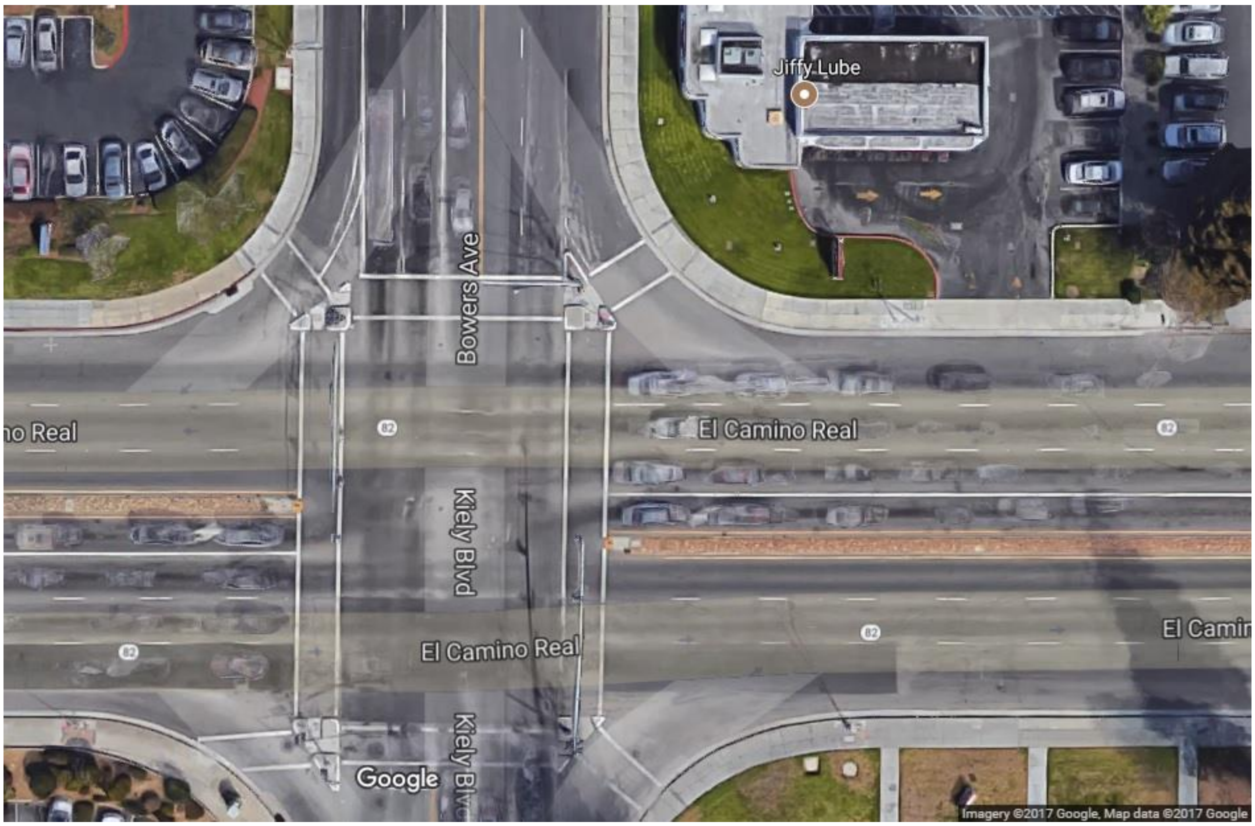


Figure 14. Screenshot. Intersection with limited approach corner clearance from Google® Maps™.(16)

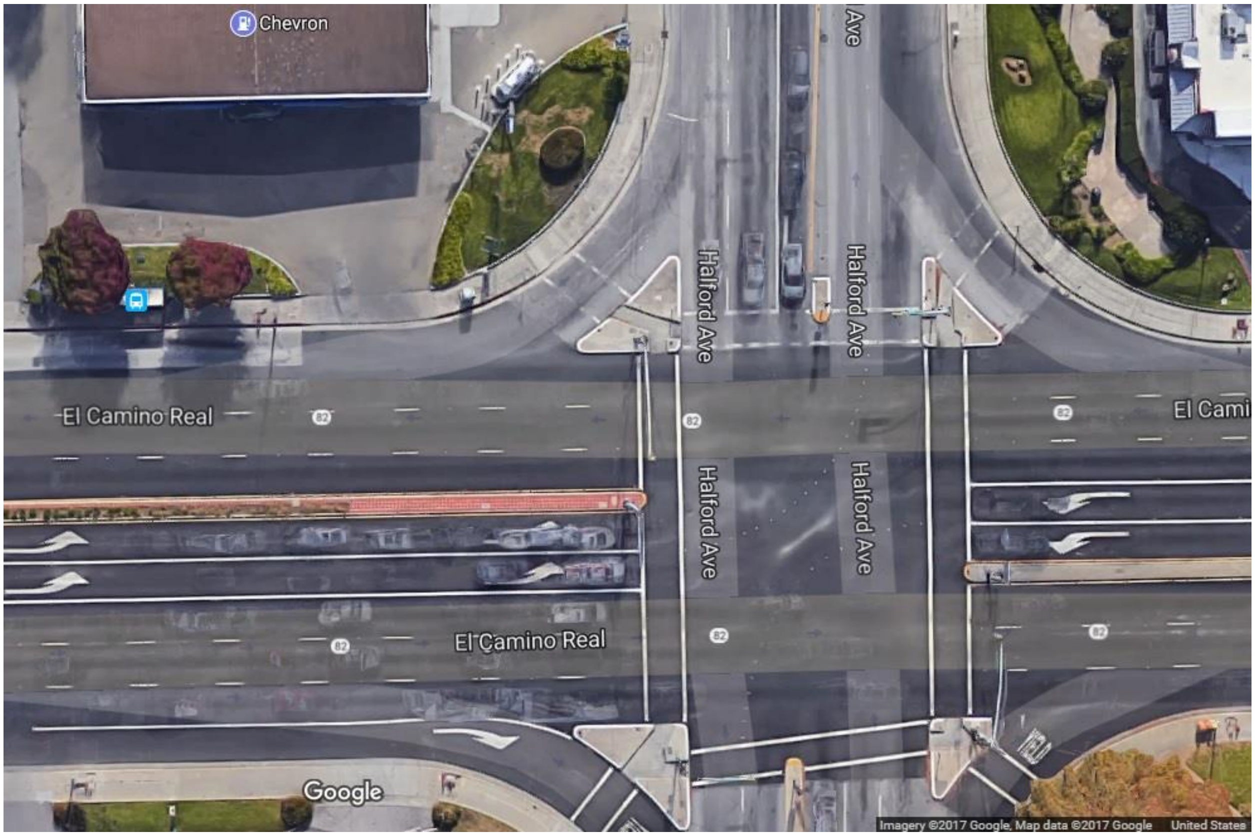


Figure 15. Screenshot. Intersection with limited receiving corner clearance from Google® Maps™.[(17)]

Figure 16. Screenshot. Intersection with limited corner clearance on all mainline corners from Google® Maps™.(18)

Figure 17. Screenshot. Intersection without limited corner clearance on all mainline corners from Google® Maps™.[19]

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