Safety Evaluation of Access Management Policies and Techniques

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FOREWORD

Access management (AM) is the process that provides (or manages) access to land development while preserving safety, capacity, and speed on the surrounding road network. A growing number of agencies have included closing, consolidating, or improving driveways, median openings, and intersections as part of their AM implementation strategy. However, these same agencies are often challenged to provide rigorous justifications that explain the safety benefits of their policies, practices, and strategies.

The objective of this research was to develop crash prediction models for evaluating the safety effects of corridor AM policies and strategies on urban, suburban, and urbanizing arterials. Corridor-level crash prediction models were developed using more than 600 mi of detailed corridor data from four different regions in the United States. Agencies can use the crash prediction models to assess the safety impacts of their decisions related to corridor AM.

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16. Abstract

Access management (AM) is the process that provides (or manages) access to land development while preserving safety, capacity, and speed on the surrounding road network. These benefits have been increasingly recognized at all levels of government, and a growing number of agencies are managing access by requiring driveway permit applications and establishing where new access should be allowed. They are also closing, consolidating, or improving driveways, median openings, and intersections as part of their AM implementation strategy. However, these decisions are often challenged for various reasons, and there have been few scientifically rigorous evaluations to quantify the safety effects of corridor AM. As such, there is a need to provide additional information to help rationalize decisions related to AM so that agencies can better explain the safety benefits of their policies and practices. This study seeks to fill some of the safety-related research gaps—namely, to quantify the safety impacts of corridor AM decisions.

The objective of this research was to evaluate the safety effects of corridor AM policies and strategies on urban, suburban, and urbanizing arterials. Crash prediction models were developed using more than 600 mi of detailed corridor data from four different regions in the United States. The crash prediction models were estimated using generalized linear modeling. Agencies can use the crash prediction models to assess the safety impacts of their decisions related to corridor AM.

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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 AND SYMBOLS

4D	four-lane divided arterial
4U	four-lane undivided arterial
AADT	annual average daily traffic
AASHTO	American Association of State Highway and Transportation Officials
ACCDENS	number of driveways plus unsignalized intersections per mile
ADT	average daily traffic
AM	access management
AVGAADT	average of the annual average daily traffic
b	coefficient estimated for the annual average daily traffic term in the models
c_i	vector of coefficients estimated for independent variables included in the models
CMF	crash modification factor
DRWYDENS	number of driveways per mile
EB	empirical Bayes
FHWA	Federal Highway Administration
GIS	Geographic Information System
GLM	generalized linear modeling
GPS	Global Positioning System
HSIS	Highway Safety Information System
ID	identity
k	dispersion parameter
MAXSPCSIG	maximum spacing of signalized intersections
MEDOPDENS	number of median openings per mile
MEDOPLT	number of median openings with a left-turn lane
MEDOPNOLT	number of median openings without a left-turn lane
MINSPCSIG	minimum spacing of signalized intersections
MVMT	million vehicle-miles traveled
NO3LEGFULLUNSIG	number of three-legged full-movement unsignalized intersections
NO3LEGLFMOUNSIG	number of three-legged unsignalized intersections with no left-turn movement from crossroad
NO3LEGLIMUNSIG	number of three-legged limited-movement unsignalized intersections
NO3LEGRIROUNSIG	number of three-legged right-in/right-out unsignalized intersections
NO3LEGSIG	number of three-legged signalized intersections
NO3LEGUNSIG	number of three-legged unsignalized intersections
NO4LEGFULLUNSIG	number of four-legged full-movement unsignalized intersections
NO4LEGLFMOUNSIG	number of four-legged unsignalized intersections with no left-turn movement from crossroad
NO4LEGLIMUNSIG	number of four-legged limited-movement unsignalized intersections
NO4LEGRIROUNSIG	number of four-legged right-in/right-out unsignalized intersections
NO4LEGSIG	number of four-legged signalized intersections
NO4LEGUNSIG	number of four-legged unsignalized intersections
NO5LEGSIG	number of five-legged signalized intersections

NO5LEGUNSIG	number of five-legged unsignalized intersections
NOCOMFULLDRWY	number of commercial full-movement driveways
NOCOMLIMDRWY	number of commercial limited-movement driveways
NODRWYS	number of driveways
NOLTLSIG	number of signalized intersections with a left-turn lane on the mainline
NOLTLUNSIG	number of unsignalized intersections with a left-turn lane
NOMEDOP	number of median openings
NOMEDOPLT	number of median openings with a left-turn lane
NOMEDOPNOLT	number of median openings without a left-turn lane
NORESFULLDRWY	number of residential full-movement driveways
NORESLIMDRWY	number of residential limited-movement driveways
NORTLSIG	number of signalized intersections with a right-turn lane on the mainline
NORTLUNSIG	number of unsignalized intersections with a right-turn lane
NOSIG	number of signalized intersections
NOUNSIG	number of unsignalized intersections
PC	personal computer
PROPDIV	proportion of corridor length with divided median
PROPFRONTRD	proportion of corridor length with a frontage road
PROPFULLDEV	proportion of corridor length with full roadside development
PROPLANE1	proportion of corridor length with two lanes
PROPLANE2	proportion of corridor length with three or four lanes
PROPLANE3	proportion of corridor length with five or more lanes
PROPLIGHT	proportion of corridor length with illumination present
PROPLIMCONN	proportion of corridor length with limited connectivity on adjacent developments
PROPMODCONN	proportion of corridor length with moderate connectivity on adjacent developments
PROPNODEV	proportion of corridor length with no roadside development
PROPPARTDEV	proportion of corridor length with partial adjacent development
PROPPOORPVMNT	proportion of corridor length with a poor pavement condition
PROPSIGCONN	proportion of corridor length with significant connectivity on adjacent developments
PROPTWLTL	proportion of corridor length with two-way left-turn lane
PROPUNDIV	proportion of corridor length with an undivided median
PROPVC	proportion of corridor length with visual clutter
SIGDENS	number of signalized intersections per mile
SPCOFFLT	minimum spacing from off-ramp to available left turn onto mainline from same side of road
SPCOFFRT	minimum spacing from off-ramp to available right turn onto mainline from same side of road
SPCON	minimum spacing from on-ramp to available right turn onto mainline from same side of road
SPEED_LIMIT	posted speed limit
TWLTL	two-way left-turn lane

UNSIGDENS	number of unsignalized intersections per mile
USGS	United States Geological Survey
vpd	vehicles per day
w	EB weight
X_i	vector of independent variables included in the model

CHAPTER 1. INTRODUCTION

STUDY BACKGROUND

Access management (AM) is the process that provides (or manages) access to land development while preserving the flow of traffic on the surrounding road network in terms of safety, capacity, and speed. AM provides important benefits to the transportation system. These benefits have been increasingly recognized at all levels of government, and a growing number of States, cities, counties, and planning regions are managing access by requiring driveway permit applications and establishing where new access should be allowed. These agencies are also closing, consolidating, or improving driveways, median openings, and intersections as part of their AM implementation strategy. However, these decisions are often challenged for various reasons.

There is a need for additional information, which would help agencies make decisions related to AM and better explain the safety and operational benefits of their policies and practices. Previous studies and empirical evidence have shown positive operational and safety benefits associated with good AM practices. While the operational effects of AM have been investigated quantitatively through different modeling and analysis approaches, there have been few scientifically rigorous evaluations to quantify the safety effectiveness, particularly for corridor AM. The Federal Highway Administration (FHWA) initiated this study to help fill some of the research gaps—namely, to quantify the safety impacts of corridor AM decisions.

The study team solicited input from a panel of State and local representatives to identify AM principles and design factors that should be included in a corridor-level model. Based on input from the panel and availability of data, the study team prioritized the principles as shown in table 1.

Table 1. Prioritization of AM policies and techniques.

AM Strategy	Applicable AM Principles	Priority
Establish unsignalized access spacing criteria.	Limit the number of conflict points. Separate conflict areas.	1
Establish signal spacing criteria.	Locate signals to favor through movements. Limit the number of conflict points. Separate conflict areas.	1
Establish spacing criteria for interchange crossroads.	Limit the number of conflict points. Separate conflict areas.	1
Establish spacing criteria for median openings/crossovers.	Limit the number of conflict points. Separate conflict areas.	1
Establish corner clearance criteria.	Preserve the functional area of intersections. Separate conflict areas.	1
Provide median and accommodate left turns and U-turns.	Limit the number of conflict points. Separate conflict areas. Manage left-turn movements.	1
Provide left-turn lane.	Remove turning vehicles from through-traffic lanes.	1
Close or modify median opening and accommodate left turns and U-turns.	Limit the number of conflict points. Separate conflict areas. Manage left-turn movements.	1
Provide TWLTL.	Remove turning vehicles from through-traffic lanes.	2
Provide right-turn lane.	Remove turning vehicles from through-traffic lanes.	2
Provide frontage/backage road.	Limit the number of conflict points. Remove turning vehicles from through-traffic lanes.	2
Provide internal cross connectivity.	Limit the number of conflict points. Remove turning vehicles from through-traffic lanes.	2

TWLTL = two-way left-turn lane; 1 = highest priority; 2 = secondary priority.

OVERVIEW OF STRATEGIES

The following AM strategies/policies are considered in this research project and discussed in the following sections:

- Access spacing.
  - Unsignalized access spacing (including intersections and driveways).
  - Traffic signal spacing.
  - Interchange crossroad spacing (distance from ramp to nearest turning opportunity from driveway or intersecting road).
  - Corner clearance.

- Roadway cross section.
    - Median type.
    - Median opening spacing.
- Property access.
    - Frontage/backage roads.
    - Internal cross connectivity.

Table 2 illustrates how these strategies/policies relate to achieving the safety objectives of basic AM principles.

Table 2. Strategies/policies in relation to AM safety principles (adapted from V.G. Stover, 2007).[(1)]

AM Principle	AM Strategy/Policy	Limit Conflicts	Separate Conflicts	Reduce Conflicts
Access spacing	Unsignalized access spacing	—	X	—
Access spacing	Traffic signal spacing	—	X	—
Access spacing	Interchange crossroad spacing	—	X	—
Access spacing	Corner clearance	—	X	—
Roadway cross section	Median type: TWLTL	—	—	X
Roadway cross section	Median type: nontraversable median	X	—	—
Roadway cross section	Median type: Replace TWLTL with nontraversable median	X	X	—
Roadway cross section	Directional median opening	X	—	—
Roadway cross section	Median opening spacing	—	X	—
Property access	Frontage/backage roads	X	X	—
Property access	Internal cross connectivity	X	X	—

TWLTL = two-way left-turn lane; X = the strategy/policy can achieve the specified safety objective.
—The strategy/policy does not accomplish the specified safety objective.

Access Spacing

Unsignalized Access Spacing (Intersections and Driveways)

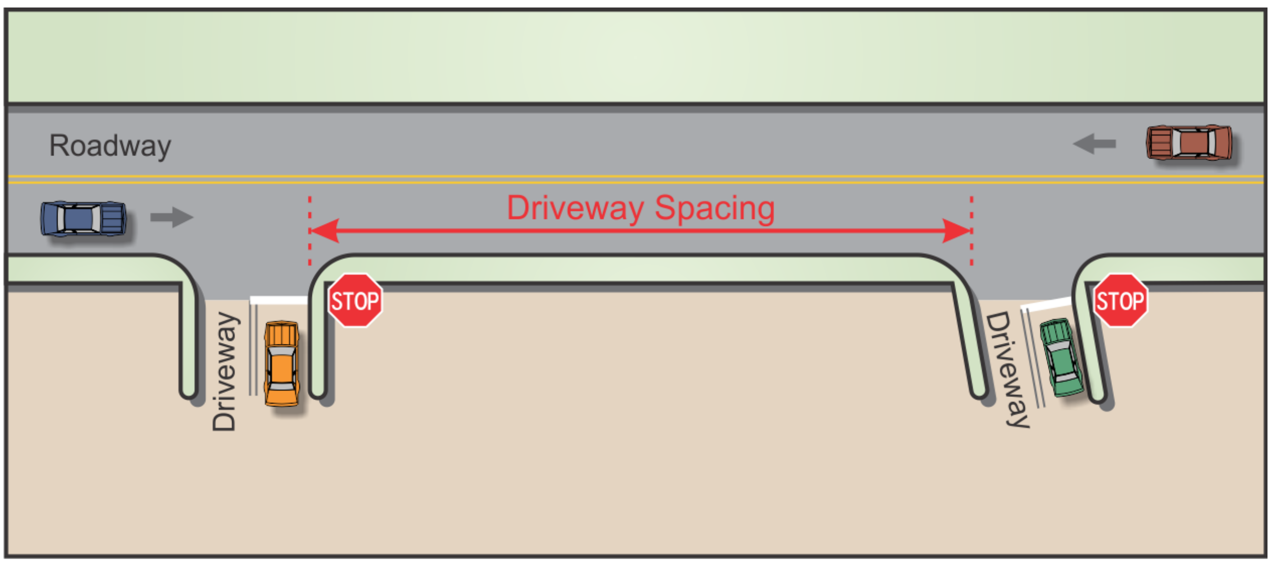
Access points, commonly referred to as "driveways" or "street intersections," introduce conflicts and friction into the flow of traffic along a roadway. Vehicles entering and leaving the roadway often slow the movement of through traffic, and the difference in speeds between through-traffic and turning-traffic increases the potential for crashes. American Association of State Highway

Transportation Officials' (AASHTO) *A Policy on Geometric Design of Highways and Streets* (i.e., the "Green Book") indicates that the number of crashes is disproportionately higher at driveways than at other intersections. Therefore, driveway design and location merit special consideration (pp. 729–731).[(2)]

Where an access point is needed, its location should be selected to minimize its adverse effects on roadway safety and traffic flow. Increasing the spacing between access points through proper planning of future access and closing or consolidating existing access improves traffic flow and safety along the roadway by achieving the following:

- Reducing the number of conflicts per mile.
- Providing a greater distance for motorists to anticipate and recover from turning maneuvers.
- Providing opportunities for the construction of acceleration lanes, deceleration lanes, or exclusive left-turn or right-turn lanes.

Figure 1 illustrates the spacing distance between two adjacent unsignalized driveways, where the distance is measured from the nearest edges of each driveway. Some agencies choose to measure the spacing distance from the centerlines of the adjacent driveways.



Source: FHWA.

Figure 1. Illustration. Unsignalized driveway spacing.

Traffic Signal Spacing

Establishing traffic signal spacing criteria for arterial roadways is one of the most important and basic AM techniques. These criteria apply to both signalized driveways and signalized public roadway intersections.

The proper spacing of traffic signals, in terms of frequency and uniformity, is one of the most important and basic AM techniques because of the effects traffic signals have on arterial safety and traffic flow. Frequency refers to the number of traffic signals for a given length of roadway and is sometimes referred to as "signal density." It is typically expressed as the number of signals per mile. Uniformity refers to the variation in the distances between individual traffic signals along a given length of roadway. It is desirable to minimize this variation and to space traffic signals at uniform distances as shown in figure 2.

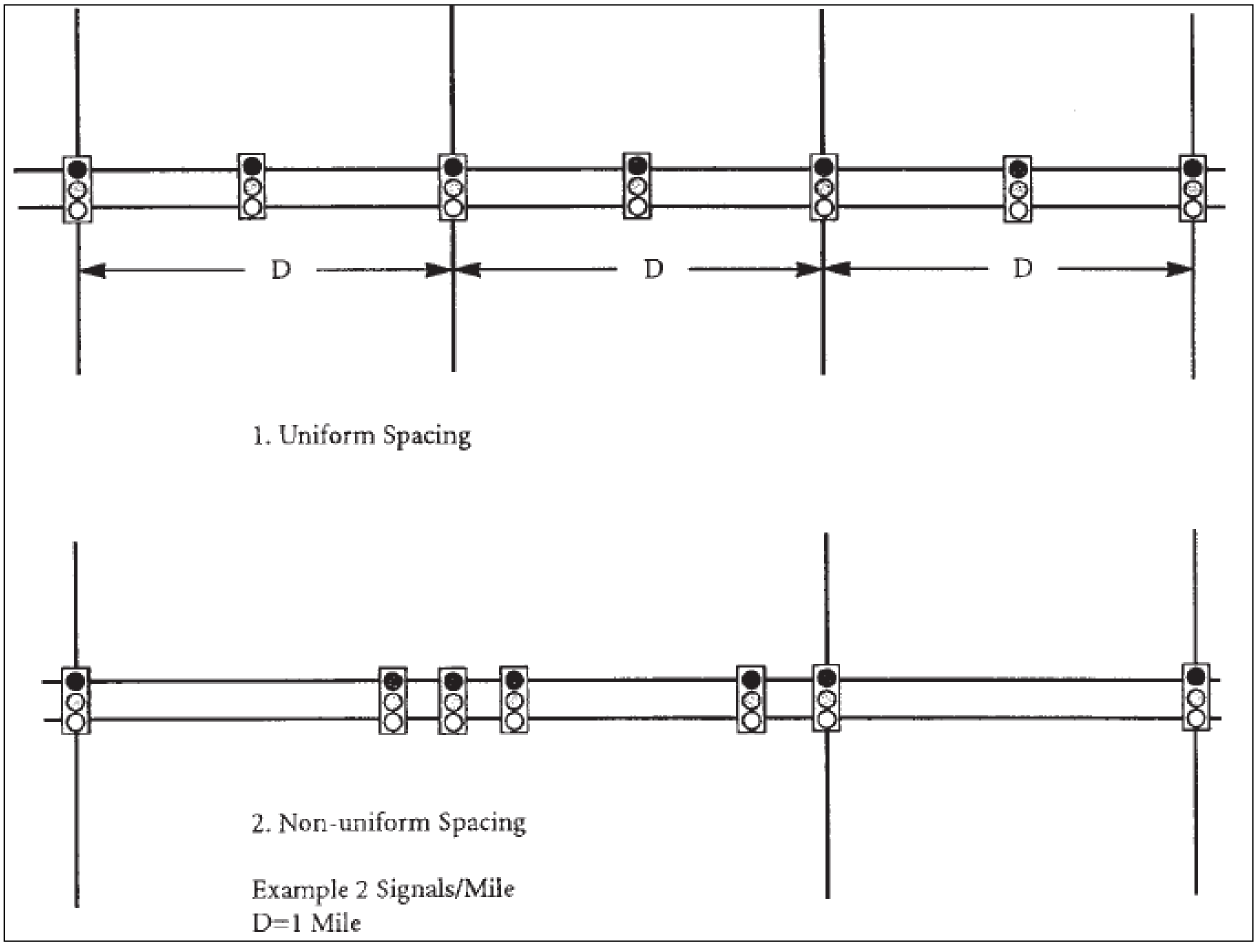


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Figure 2. Illustration. Comparison of uniform and nonuniform signal spacing (figure 5 in Gluck, Levinson, and Stover, 1999).[(3)]

Closely spaced or improperly spaced traffic signals can result in increased crash rates, frequent stops, unnecessary delays for motorists and pedestrians, increased fuel consumption, and excessive vehicular emissions.

For example, if a 2-mi segment of roadway would require four traffic signals (i.e., a signal density of two signals/mile), it is generally more desirable to space the signals at a uniform distance along the roadway (e.g., every ½ mi), rather than space them irregularly (e.g., 1 mi, ¼ mi, ½ mi, and ¼ mi). Properly spaced traffic signals allow for the efficient progression of motor vehicle and pedestrian traffic as well as provide an agency with greater flexibility in developing signal timing plans to reduce traffic conflicts.

Interchange Crossroad Spacing

Freeway interchanges provide the means of moving traffic between freeways and intersecting crossroads. Although direct property access is prohibited on the freeway itself, safety and operational problems can arise when driveways and intersections along the crossroad are spaced too close to the interchange ramp termini. Heavy weaving volumes, complex traffic signal operations, frequent crashes, and recurrent congestion could result. In addition, driveways and median breaks that are provided for direct access to properties along the crossroad compound these problems.

Managing access on crossroads in the vicinity of interchanges protects the longevity of both the interchange and the intersecting crossroad by reducing crash rates, minimizing congestion, and simplifying driving tasks. Improperly managing access on the crossroad near the interchange may cause congestion and potential crashes, thereby shortening the life cycle of the interchange. In addition, it may cause significant impairment of crossroad and freeway mainline safety and operations. For these reasons, AM should be applied to interchange crossroads such that access points, including both driveways and intersections, are sufficiently separated from freeway interchange ramp termini.

Corner Clearance

Protecting the functional integrity of intersections is extremely important from the safety and operations perspectives. One strategy to help accomplish this is to locate driveways outside the functional area of an intersection. As shown in figure 3, the intersection functional area extends beyond the physical intersection limits to include the upstream approaches, where deceleration, maneuvering, and queuing take place, as well as the downstream departure area beyond the intersection, where driveways could introduce conflicts and generate queues backing up through the intersection. As noted in AASHTO's *A Policy on Geometric Design of Highways and Streets*, driveways should not be located within the functional area of an intersection or in the influence area of an adjacent driveway.(2)

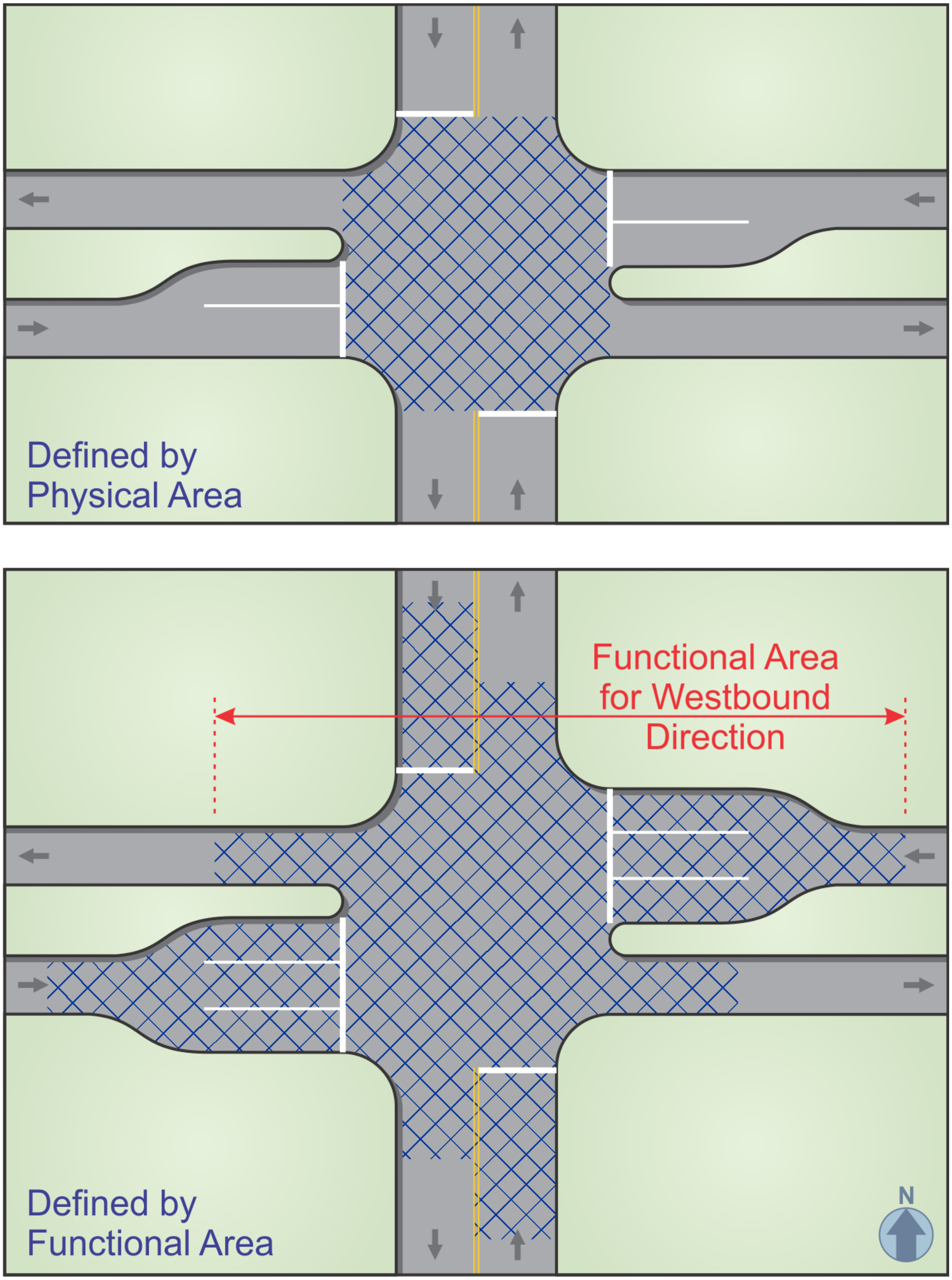


Figure 3. Illustration. Intersection physical area versus functional area (adapted from *Transportation Research Circular 456*, figure 4).[(4)]

Roadway Cross Section

Median Type (Raised, TWLTL, Undivided)

Installations of nontraversable (i.e., raised) medians with provisions for median openings to accommodate left turns and U-turns have proven to be among the most effective techniques for reducing conflicts and improving traffic operations along roadways. The installation of a nontraversable median reduces the number of conflicts along a highway corridor by restricting driveways (not located at median openings) to right-in/right-out movements and directing left-turn and U-turn movements to designated median openings as shown in figure 4.

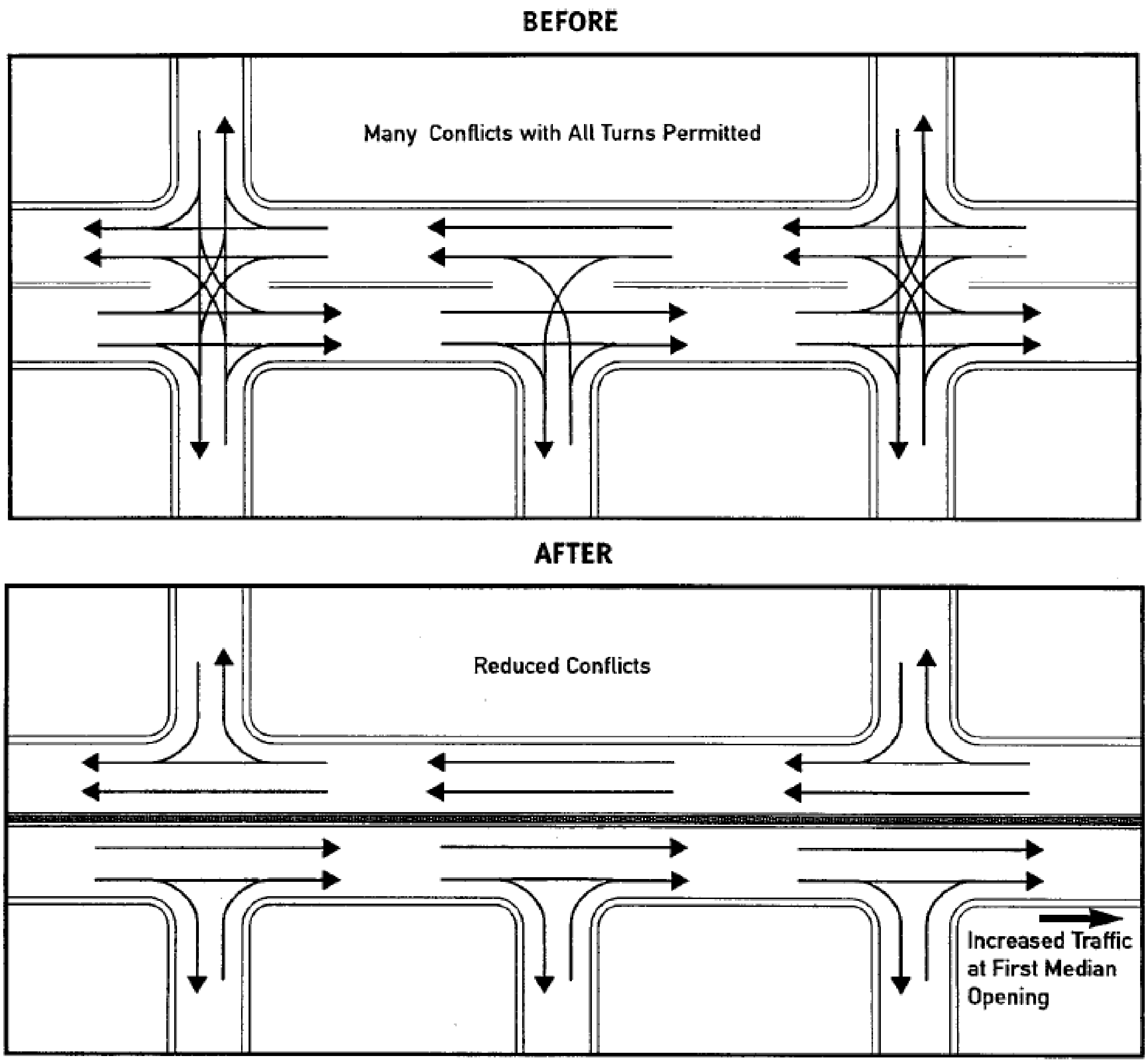


Figure 4. Illustration. Allowable traffic movements before and after raised median installation (figure 30 in Gluck, Levinson, and Stover, 1999).[3]

Allowing unrestricted left-turn movements to and from all access driveways increases the number of vehicular conflict points with other vehicles, pedestrians, and bicyclists. Left-turning vehicles have been shown to account for nearly three-quarters (74 percent) of all access-related crashes.

Nontraversable medians with designated median openings to allow for left-turn and U-turn movements offer the following advantages over the other types of roadway cross sections:

- Vehicles traveling in opposite directions are physically separated, eliminating the propensity for head-on crashes.

- When properly designed, the physical space provided for the deceleration and storage of left-turning and U-turning vehicles occurs outside the through-traffic lanes. The resulting reduction in speed differential between the turning and through vehicles improves traffic operations and reduces the potential for crashes.

- At a full-median opening, the width of the nontraversable median provides a refuge area for passenger cars, making a two-stage left turn from a side street (i.e., crossing traffic approaching from the left, and then turning left and merging with traffic approaching from the right) or traveling straight across the roadway.

- The number of left-turn conflicts with vehicles, pedestrians, and bicyclists is reduced.

- The nontraversable median provides a refuge area for pedestrians crossing the roadway at intersections. In addition, midblock pedestrian crossings can be provided and signalized without interfering with traffic progression (i.e., by stopping traffic approaching from the left first, and then stopping traffic from the right).

- Locations for making left turns and U-turns are clearly identifiable to the driver, thus reducing driver workload.

- Nontraversable medians reduce the frequency and severity of crashes compared with both undivided roadways and roadways with a two-way left-turn lane (TWLTL).

Median Opening Spacing

The Florida Department of Transportation's *Median Handbook* (Interim Version) indicates that "restrictive medians and well-designed median openings are known to be some of the most important features in a safe and efficient highway system."[5] A median opening is an opening in a nontraversable median that provides for crossing and turning traffic. A "full" median opening allows all turning movements, whereas a "partial" median opening allows only specific movements and physically prohibits all other movements. To realize the safety benefits, median openings should not encroach on the functional area of another median opening or intersection (see figure 3 for an illustration of a functional area).

Property Access

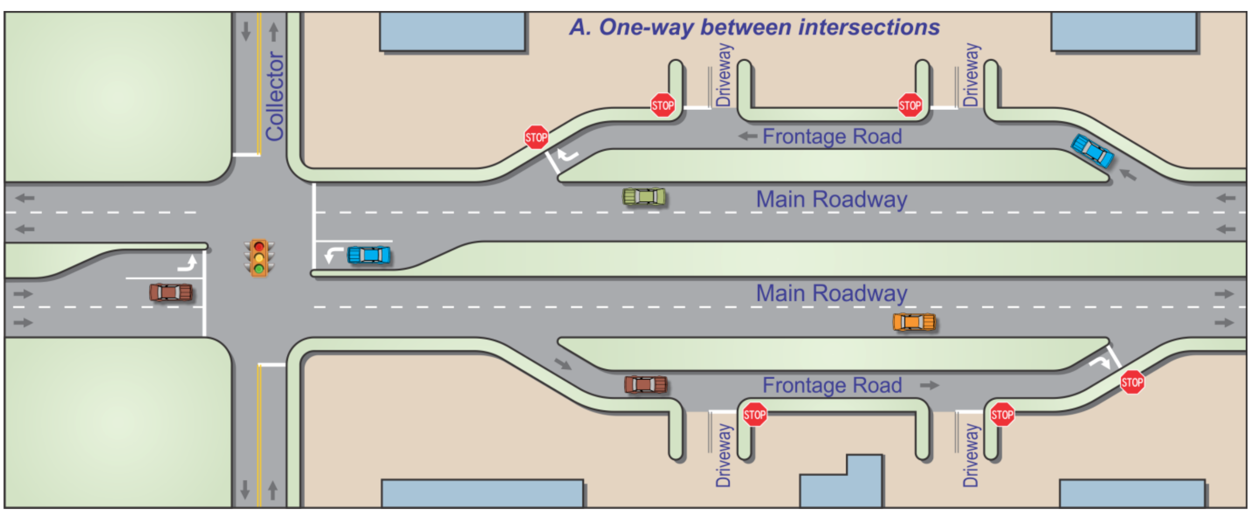
In addition to the location and design of access points for a specific property, there are also strategies to provide reasonable access for a particular property, or properties, such that the resulting access configuration provides for safer and more efficient traffic operations. The following two strategies of this type were included in this research project and are described below:

- Frontage/backage roads.
- Shared driveways and internal cross connectivity.

A third strategy, providing access via secondary roadways (i.e., a roadway that has a lower access classification than the intersecting primary roadway), was not included because of the implications it has for traffic circulation patterns on the surrounding roadway network.

Frontage/Backage Roads

A frontage road is an access roadway that is generally aligned parallel to a main roadway and is located between the right-of-way of the main roadway and the front building setback line. Frontage roads are used as an AM technique to provide direct access to properties and separate through traffic from local access-related traffic. This reduces the frequency and severity of conflicts along the main roadway as well as traffic delays. In addition, the resulting increase in spacing between intersections along the main roadway facilitates the design of auxiliary lanes for deceleration and acceleration, further improving traffic safety and operations. A "backage" road—also called a "reverse frontage road" or "reverse access"—serves a similar purpose but is located behind the properties that front the main roadway. Frontage and backage roads may be configured for one-way operation or two-way operation. Figure 5 illustrates one potential frontage road configuration.

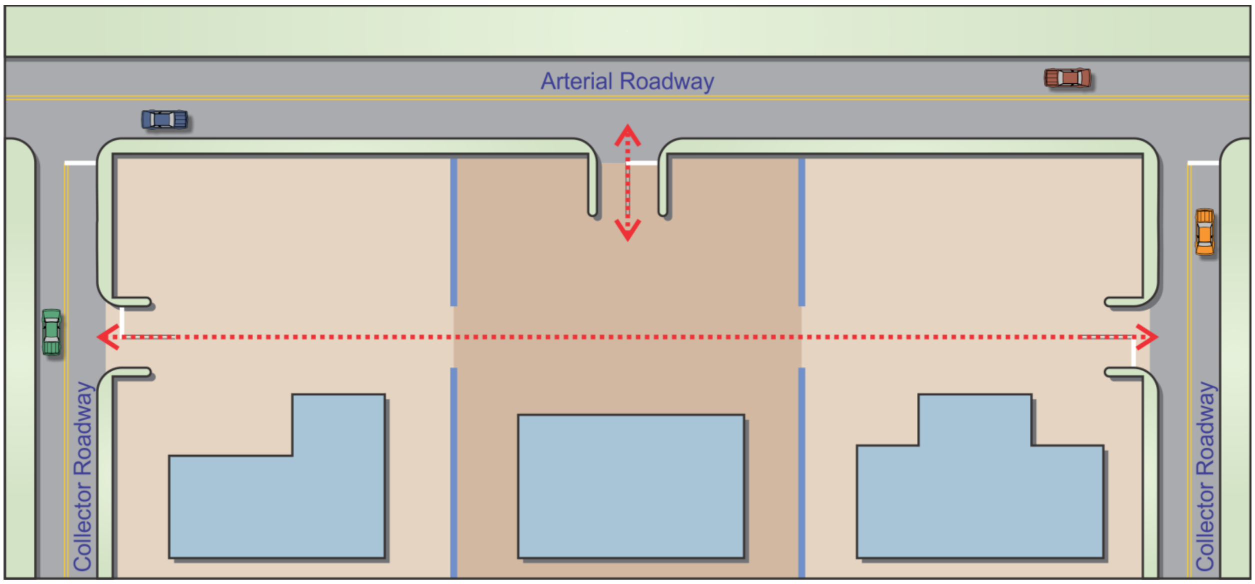


Source: FHWA.

Figure 5. Illustration. Potential frontage road configuration.

Shared Driveways and Internal Cross-Connectivity

AM promotes the implementation of shared-access driveways and cross-access easements between (compatible) adjacent properties, where possible, which allow pedestrians and vehicles to circulate between properties without reentering the abutting roadway (see figure 6). The sharing of access driveways improves roadway safety and operations by reducing the number of conflict points and separating conflict points along these roadways. The longer spacing between access driveways also facilitates the provision of left-turn and right-turn lanes, eliminating conflicts between through and turning movements. In addition, smoother traffic flow on the abutting street helps to reduce the propensity for vehicular crashes and to increase egress capacity.



Source: FHWA.

Figure 6. Illustration. Improved access configuration with cross connectivity.

LITERATURE REVIEW

This section relates the findings of previous research to the AM strategies that were considered for inclusion in the models to estimate the relationship between corridor AM and safety. Salient literature sources—including definitive AM-related research documents such as NCHRP Report 395, *Capacity and Operational Effects of Midblock Left-Turn Lanes*; NCHRP Report 420, *Impacts of Access Management Techniques*; and NCHRP Report 524, *Safety of U-Turns at Unsignalized Median Openings*—are reflected in this document to help establish what past research has shown to be the relationship between the selected AM strategies and safety.[6,3,7]

The following AM strategies/policies are being considered in this research project and discussed in the following sections:

- Access spacing.
    - Unsignalized access spacing (including intersections and driveways) and corner clearance.

  - Traffic signal spacing.
  - Interchange crossroad spacing (distance from ramp to nearest turning opportunity from driveway or intersecting road).

- Roadway cross section.

  - Median type.
  - Median opening spacing.

- Property access.

  - Frontage/backage roads.
  - Internal cross connectivity.

Access Spacing

Unsignalized Access Spacing (Intersections and Driveways) and Corner Clearance

Gluck, Levinson, and Stover, in *Impacts of Access Management Techniques* (NCHRP Report 420), compiled numerous studies from the 1950s through the 1990s to identify the relationship between access frequency or density and crash rates.(3) Although the specific relationships vary, reflecting differences in road geometry, operating speeds, and intersection and driveway traffic volumes, the studies had a consistent finding that increasing the frequency/density of accesses translates into higher crash rates.

The research for NCHRP Report 420 included comprehensive safety analyses that were performed on crash information obtained for some 386 roadway segments in multiple States.(3) This produced a series of three graphs for quantifying the relationship between crash rates and signalized and unsignalized access densities. All three figures have been incorporated into the 2004 (and subsequent) edition(s) of AASHTO's *A Policy on Geometric Design of Highways and Streets.*(2)

Figure 7 illustrates the increase in crash rates for each type of median treatment as the total access density increases. The addition of each driveway per mile in urban or suburban areas would increase the annual crash rate by 0.11 to 0.18 crashes per million vehicle-miles traveled (MVMT) on undivided highways and by 0.09 to 0.13 crashes per MVMT on highways with TWLTLs or nontraversable medians.

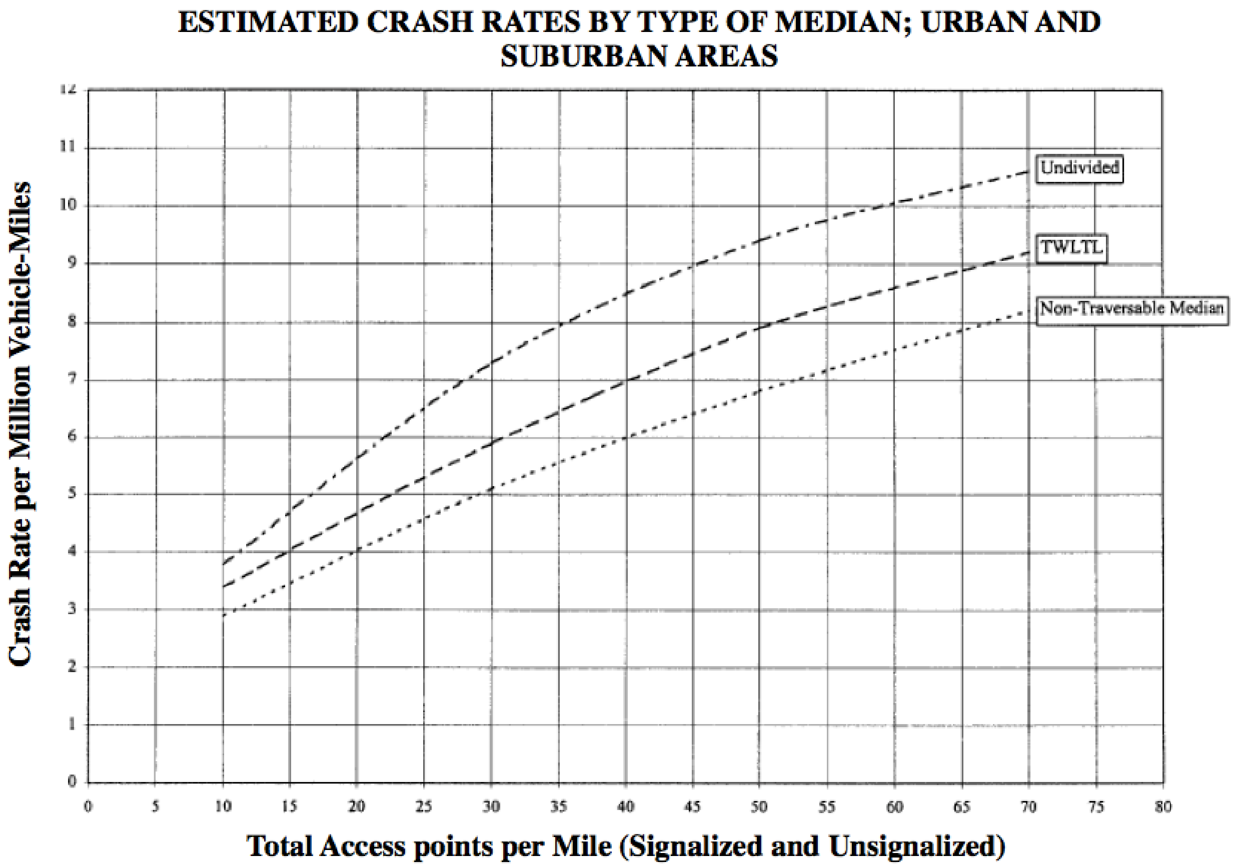


Figure 7. Graph. Relationship between total access points per mile and crash rate (figure 24 in Gluck, Levinson, and Stover, 1999).[(3)]

Gluck and Levinson, in *The Relationship Between Access Density and Accident Rates: Comparisons of NCHRP Report 420 and Minnesota Data* (NCHRP Research Results Digest 247), supplemented the research presented in NCHRP Report 420 with respect to the relationship between access density and crash rates by using additional data from Minnesota to confirm these relationships.[(8)] The results showed crash rate patterns in Minnesota that were similar to those summarized in NCHRP Report 420. Specifically, both datasets exhibited an increase in crash rates as access density increased and as signal density increased and lower crash rates for nontraversable medians relative to undivided facilities. Note that Minnesota has a relatively low number of roadway miles with TWLTLs. These results supported the recommended safety indices presented in NCHRP Report 420.[(3)]

Huffman and Poplin, in *The Relationship Between Intersection Density and Vehicular Crash Rate on the Kansas State Highway System*, analyzed a variety of roadway classifications on the Kansas State Highway System, including two-lane undivided, four-lane undivided, and five-lane.[(9)] The two-lane and four-lane undivided classifications were further subdivided into urban and rural, whereas the five-lane classification was limited to urban highway segments. In all cases, crash rates were found to increase with increasing intersection density, indicating that intersection density has a direct bearing on the safety of the traveling public.

Eisele and Frawley, in *Estimating the Safety and Operational Impact of Raised Medians and Driveway Density: Experiences From Texas and Oklahoma Case Studies*, analyzed the relationship between access density and crash rates based on before–after studies of 11 corridors in Texas and Oklahoma that underwent access consolidation and/or median improvements.(10) The results of a linear-regression analysis indicated that increasing access density results in an increase in the crash rate, irrespective of the median type (undivided, TWLTL, or raised median). A regression line was plotted that yielded an R-squared value of 0.48. Although the regression line explained only about half of the variability in the data, the relationship between access density and crash rate was clearly found to be a positive correlation.

Signal Spacing

The research performed by Gluck and Levinson in *The Relationship Between Access Density and Accident Rates: Comparisons of NCHRP Report 420 and Minnesota Data* (NCHRP Research Results Digest 247) confirmed the relationship identified in NCHRP Report 420 between crash rates and signal density.(8) Both datasets exhibited an increase in crash rates as signal density increased. These results supported the recommended safety indices presented in NCHRP Report 420. Figure 8 illustrates the relationship developed between crash rate and access density, including the impacts of traffic signal density.

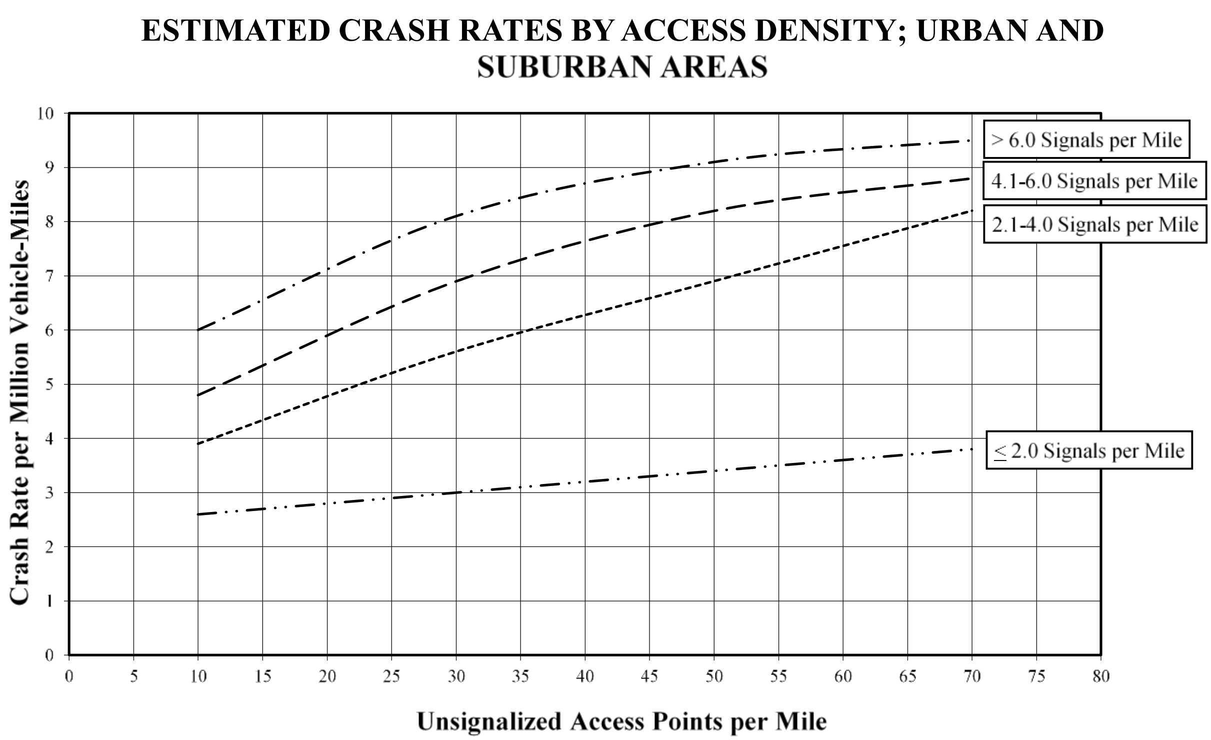


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Figure 8. Graph. Relationship between access points per mile and crash rate (figure 26 in Gluck, Levinson, and Stover, 1999).(3)

NCHRP Report 420 also presented information from Lee County, Florida, on the effects of traffic signal densities on crash rates from 1993. As shown in figure 9, doubling the signal density from two to four signals per mile increases the crash rate by approximately 2.5 times. As noted in NCHRP Report 420, the safety impacts of increased traffic signal spacing may be confounded, in part, by the traffic volumes on intersecting roadways and the common practice of using vehicle-miles of travel for comparing crash rates rather than the crashes per entering vehicles.

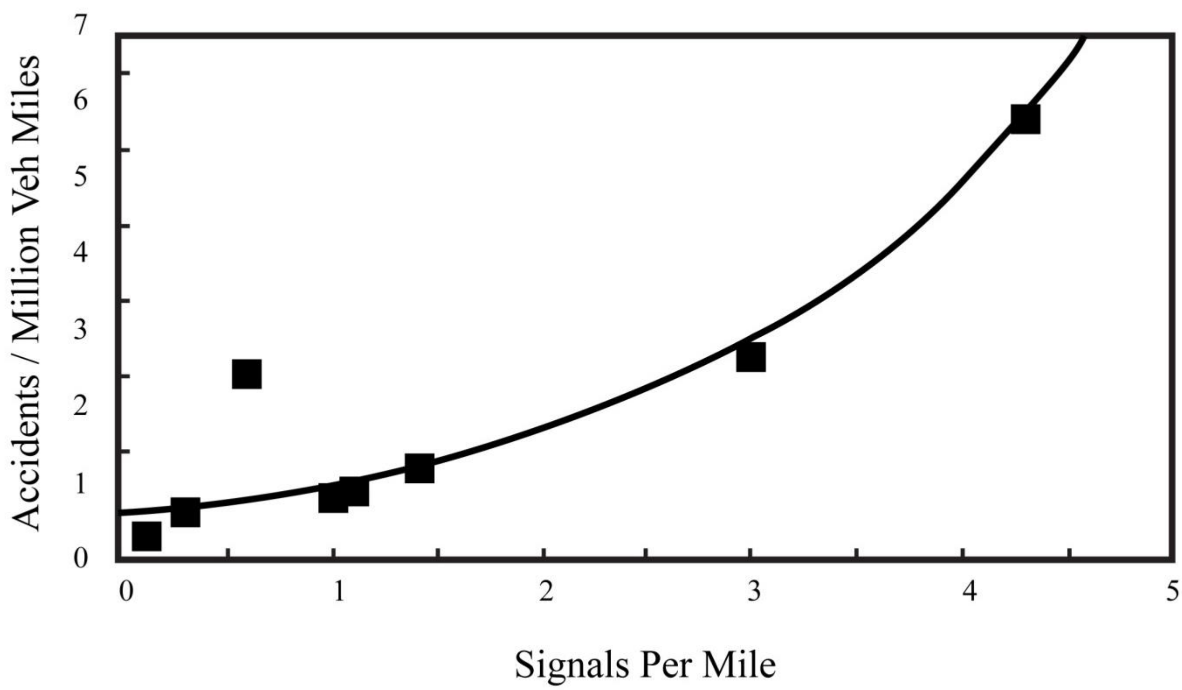


Figure 9. Graph. Relationship between signals per mile and crash rate (figure 6 in Gluck, Levinson, and Stover, 1999).[(3)]

Schultz, Braley, and Boschert, in *Correlating Access Management to Crash Rate, Severity, and Collision Type*, applied stepwise linear regression analysis to identify correlations between AM techniques and crash patterns.[(11)] The results indicated that crash rates were correlated with signals per mile and that, on average, each signal corresponded to 0.92 crash per MVMT.

Interchange Crossroad Spacing

There has been limited research on the relationship between safety and the spacing of access points in the vicinity of an interchange. Rakha and the other researchers involved in the project that produced the *Access Control Design on Highway Interchanges* report developed a methodology to evaluate the safety impacts of different access spacing standards on crossroads at interchanges. The analysis results demonstrated the shortcomings of the 100-ft urban spacing guideline.[(12)]

The relationship between safety and the spacing of access points in the vicinity of an interchange generally varies depending on the existing (or anticipated future) traffic control devices at the intersection between the freeway ramp terminal and the crossroad. For example, where the freeway ramp terminal and crossroad are signalized, the relationship between safety and access spacing is based on the signal spacing. For other traffic control, the relationship between safety and access spacing may be a function of other parameters, such as unsignalized access spacing (intersections and driveways). However, where the ramp terminates as a free-flow merge or under yield control on a crossroad, the dynamics between the crash rate and spacing are more complex, owing to the various movements and operations involved. These include the merge where the ramp traffic enters the arterial and, for traffic turning left downstream, the weaving movement to enter the left lane and the transition into a left-turn lane.

Roadway Cross Section

Median Type (Raised, TWLTL, Undivided)

The research by Schultz, Braley, and Boschert in *Correlating Access Management to Crash Rate, Severity, and Collision Type* indicated that the presence of a raised median corresponded to a reduction of 1.23 crashes per MVMT.[(11)] In addition, raised medians were negatively correlated with right-angle collisions, while TWLTLs were positively correlated with opposite-direction collisions.

The research performed by Gluck, Levinson, and Stover for NCHRP Report 420, which was discussed in the Access Spacing section, also investigated the relationship between median type and crash rates.[(3)] Figure 7 (shown earlier in the Access Spacing section) illustrates the relationship developed between crash rate and roadway cross section.

The literature search in NCHRP Report 420 found that many studies had analyzed the safety benefits of installing TWLTLs or nontraversable medians on undivided highways and replacing TWLTLs with nontraversable medians. There were mainly two types of studies. Some studies (particularly those where TWLTLs or medians were installed on undivided highways) report results of before–after comparisons for a given facility. Other studies compared crash experience and rates on highways with different cross sections (i.e., medians versus TWLTLs).[(3)]

Both types of studies found that crash rates were reduced when TWLTLs or medians were introduced on undivided, multilane highways. Most studies and the models derived from them also suggest that safety is improved where nontraversable medians replace TWLTLs. NCHRP Report 420 found that, overall, TWLTLs had a 20-percent lower crash rate, and nontraversable medians had a 40-percent lower crash rate than undivided road sections. These patterns appeared to be consistent for all access density ranges.[(3)]

Bonneson and McCoy, in *Capacity and Operational Effects of Midblock Left-Turn Lanes* (NCHRP Report 395), presented procedures for estimating the safety (and operational) impacts of different midblock left-turn treatments.[(6)] They also included guidelines for selecting among nontraversable medians, TWLTLs, and undivided cross sections. They included a series of tables to estimate annual crash frequencies for ¼-mi road segments.

The research in NCHRP Report 395 compared the different outcomes from a number of crash prediction models developed by different researchers. A composite finding suggested that as traffic volumes exceed approximately 15,000 average daily traffic (ADT), a raised median is safer than a TWLTL. Both are safer than no median (i.e., an undivided roadway) for volumes at least as low as 10,000 ADT.[(6)]

Eisele and Frawley, in *Estimating the Safety and Operational Impact of Raised Medians and Driveway Density: Experiences From Texas and Oklahoma Case Studies*, investigated the relationship between access density and crash rate for raised median and nonraised median corridors separately.[(10)] The relationship was still positively correlated but was slightly steeper for the nonraised median corridors than for the raised median corridors. The researchers concluded that when the number of conflict points is reduced through introduction of a raised median, there are relatively lower crash rates (which result in a reduced slope of the regression line).

Hallmark and the other researchers indicated in the *Toolbox to Assess Tradeoffs Between Safety, Operations, and Air Quality for Intersection and Access Management Strategies: Final Report* that FHWA, in 2003, evaluated data from seven States and suggested that raised medians reduced crashes by more than 40 percent in urban areas and that a study of corridors in Iowa found that the use of TWLTLs reduced crashes by 70 percent.[(13)]

Median Opening Spacing

Kach, in *The Comparative Accident Experience of Directional and Bi-Directional Signalized Intersections*, analyzed the safety effects of replacing full-median openings with directional crossovers.[(14)] The mean intersection-related crash rates overall were about 15 percent lower for the directional crossovers. The corresponding rates for intersection-related injury crashes were about 30 percent lower for the directional crossovers.

Potts and the other researchers involved with the research for *Safety of U-Turns at Unsignalized Median Openings* (NCHRP Report 524) investigated the safety and operational effect of U-turns at unsignalized median openings.[(7)] The safety performance of typical median opening designs was documented, and guidelines for the use, location, and design of unsignalized median openings were developed. The research included unsignalized median openings on all types of divided highways, but the focus was urban/suburban arterials because these present the greatest current challenge to highway agencies with respect to AM. The following are among the research conclusions:

- For urban arterial corridors, average median opening crash rates are slightly lower for conventional three-legged median openings than for conventional four-legged median openings.
- For urban arterial corridors, average median opening crash rates for directional three-legged median openings are about 48 percent lower than for conventional three-legged median openings.
- For urban arterial corridors, average median opening crash rates for directional four-legged median openings are about 15 percent lower than for conventional four-legged intersections.
- The minimum spacing between median openings currently used by highway agencies in rural areas ranges from 500 to 2,640 ft. In urban areas, the minimum spacing between median openings ranges from 300 to 2,640 ft in highway agency policies. In most cases, highway agencies use spacing between median openings in the upper end of these ranges,

but there is no indication that safety problems result from occasional use of median opening spacing as short as 300 to 500 ft.

Property Access

Although property access strategies can reduce conflicts along the arterial, no literature was found that quantified the safety impacts of these strategies. Studies of the relationship between safety and property access strategies (i.e., frontage/backage roads and internal cross connectivity) could be complicated by an extensive roadway network that could be involved and require investigation. The analysis network would need to include the arterial from which the property has access, the larger network that would include the frontage/backage road (and intersections), as well as facilities that are used for cross connectivity. Relevant variables to consider include the configuration of the frontage/backage road, whether it is one-way or two-way, and the separation distances between it and the parallel arterial.

CHAPTER 2. STUDY OBJECTIVE AND SCOPE

The objective of this research was to develop corridor-level crash prediction models to evaluate the potential safety effects of AM strategies. Functional specifications were developed for applying the various crash prediction models. Agencies can apply the functional specifications through a series of algorithms to assess the safety impacts of their decisions related to AM.

The intent of this study was to focus on corridors based on functional classification, area type, and land use. All corridors included in this study are functionally classified as arterials and fall under one of nine area type/land use scenarios. Table 3 identifies these categories and defines each.

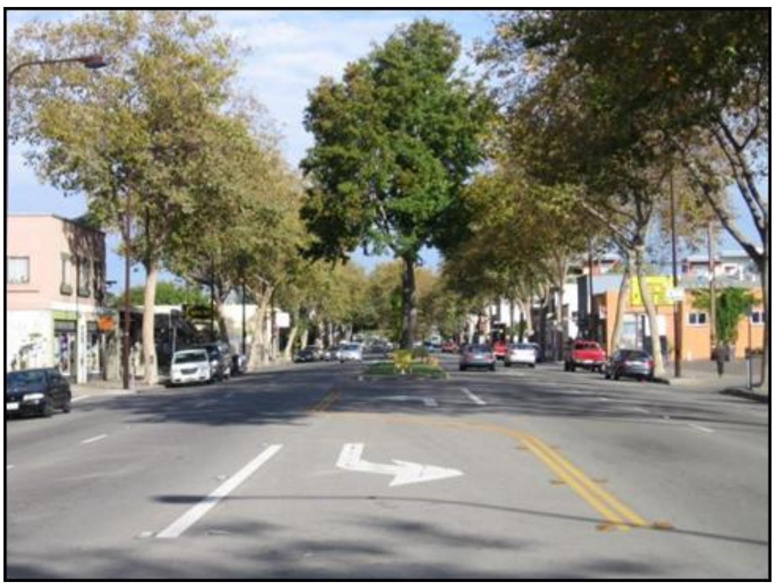
Table 3. Area type and land use categories.

Area Type	Land Use
Urban: metropolitan area with population of at least 250,000	Residential
Urban: metropolitan area with population of at least 250,000	Commercial
Urban: metropolitan area with population of at least 250,000	Mixed-use
Suburban: nearby areas with population of 50,000 to 250,000	Residential
Suburban: nearby areas with population of 50,000 to 250,000	Commercial
Suburban: nearby areas with population of 50,000 to 250,000	Mixed-use
Urbanizing: areas with build-out plans to reach or exceed population of 50,000	Residential
Urbanizing: areas with build-out plans to reach or exceed population of 50,000	Commercial
Urbanizing: areas with build-out plans to reach or exceed population of 50,000	Mixed-use

Residential and commercial areas are characterized by the type of development but are differentiated by the type and distribution of vehicles accessing the areas. Residential areas serve mainly passenger cars, while commercial areas serve a larger proportion of heavy vehicles. Commercial areas are generally defined as those areas with office buildings and other businesses that operate primarily during normal business hours on weekdays. Commercial areas, as defined in this study, do not include large shopping centers (e.g., malls) that have a larger percentage of trips on the weekends. Mixed-use area types are defined as those areas with a balanced mix of both commercial and residential establishments and access points. Figure 10 and figure 11 provide two examples of corridors included in the study.

Source: FHWA.

Figure 10. Photo. Example of an urban arterial in a residential area.



Source: FHWA.

Figure 11. Photo. Example of a suburban arterial in a commercial area.

CHAPTER 3. METHODOLOGY

Study designs fall into one of two general study types: experimental and observational. Experimental studies are planned; that is, entities identified for some treatment are then randomly assigned to either a treatment or to a control group that is left untreated. Observational studies are not planned; that is, data are collected by observing the performance of entities, where the treatment is implemented at some sites, not on the basis of a planned experiment. While experimental studies are useful to control for factors other than the treatment of interest, they are often excluded in highway safety research because of ethical concerns regarding experimentation in road safety. Thus, observational studies are more common in road safety research and are the basis for this study.

Several observational study designs are available to assess the safety impacts of AM strategies. Well-designed before–after studies are often preferred to estimate crash modification factors (CMFs), while cross-sectional models are often necessary to develop crash prediction models. In this case, the objective was to develop crash prediction models, so a cross-sectional approach was selected.

The safety impact of a given feature can be derived from a cross-sectional study by comparing the safety of a group of sites with that feature with the safety of a group of sites without that feature. This type of comparison directly relates to the investigation of AM strategies (e.g., TWLTL versus undivided road). The safety effect is estimated by taking the ratio of the average crash frequency for the two groups. For this method to work, the two groups should be similar in all ways except the feature of interest. In practice, this is difficult to accomplish, and multiple variable regression models are used to estimate the effects of one feature while controlling for other characteristics that vary among the sites. These cross-sectional models are also called "crash prediction models," which are mathematical equations that relate crash frequency with site characteristics. While cross-sectional models provide a means to estimate the safety impacts of AM strategies, there are potential issues that need to be addressed. Table 4 identifies potential issues and biases associated with cross-sectional models and opportunities to overcome these limitations.

Table 4. Potential issues and opportunities related to cross-sectional studies.

Potential Issue/Bias	Opportunity to Address Issue/Bias
Selection of appropriate functional form	Evaluate alternate model forms to describe the relationship between crash frequency and site characteristics.
Accounting for State-to-State differences	Include indicator variable in model to identify respective State/region for each site. Calibrate model for other jurisdictions if data are available.
Correlation or collinearity among independent variables	Assess the extent of the issue by examining the correlation matrix of the variables included in the model.
Overfitting of prediction models	Apply cross validation by randomly dividing the dataset into two parts, with one part used for estimating the model and the other part for validation. Use relative goodness-of-fit measures such as the Akaike information criterion and Bayesian information criterion that penalize models with more estimated parameters.
Low sample mean and sample size	Select a subsample with a lower mean than the full sample and estimate model coefficients to check the stability of the parameter estimates and dispersion parameter. Plan for appropriate data collection to obtain an adequate sample size.
Bias due to aggregation, averaging, or incompleteness in data	Avoid aggregating multiple years of data in a single observation.
Temporal and spatial correlation	Employ full Bayesian modeling techniques if spatial correlation is a concern. Consider generalized estimating equations, random effects models, and negative multinomial models for temporal correlation.
Endogenous independent variables	Employ simultaneous equations techniques.
Omitted variable bias	Use matched pairs where pairs of sites are selected such that their characteristics are similar except for the treatment of interest.
Misspecification of structure or systematic variation and residuals	Employ an appropriate model form such as the negative binomial model discussed previously.
Correlation between crash types and injury severities	Employ simultaneous estimations of multiple models.

The following potential biases were identified in this study with an explanation of how they were addressed or dismissed:

- **Selection of appropriate functional form.** Generalized linear modeling (GLM) techniques were applied to develop corridor-level crash prediction models. A log-linear relationship was specified using a negative binomial error structure following the state of the art in modeling crash data. The negative binomial error structure is now recognized as more appropriate for crash counts than the normal distribution assumed in conventional regression modeling. The negative binomial error structure also has advantages over the

Poisson distribution in that it allows for the overdispersion that is often present in crash data. The appropriate model form for each variable was determined following a review of the data.

- **Accounting for State-to-State differences.** Data from four regions were used to develop the final crash prediction models, and indicator variables were included in the models to identify the respective region for each corridor.

- **Correlation among independent variables.** The correlation matrix of the estimated parameters was examined to determine the extent of correlation among independent variables. Several AM strategies are highly correlated, and it was necessary to develop multiple models with subsets of the independent variables rather than one single model with all variables.

- **Overfitting of prediction models.** Relatively few parameters were included in the final models because of the correlation issue. Consequently, overfitting was dismissed as a potential issue.

- **Low sample mean and sample size.** Corridor-level models help to overcome issues related to low sample mean because each site (i.e., corridor) typically experiences multiple crashes per year. Sample size was addressed during the early planning stages of the study, and more than 600 mi of data were obtained to provide a large database for analysis. When possible, 3 yr of crash data were obtained to further increase the sample size.

- **Aggregation, averaging, or incompleteness in data.** Data were obtained from various sources and supplemented with field measurements to ensure a relatively complete and accurate dataset. While multiple years of crash data were used in the analysis, the number of years was also included as an independent variable to account for the multiple years of data (i.e., the model prediction results in crashes per year). Only a maximum of 3 yr of data were used for any site.

- **Temporal and spatial correlation.** Temporal correlation may arise if multiple observations are used for the same entity. In this case, multiple years of data were used for each corridor, but these data were aggregated into a single observation because the maximum was limited to 3 yr, and the number of years was included as an independent variable. Spatial correlation is a potential issue, but the corridors were selected from four regions and were relatively dispersed within each of the regions. Indicator variables were also included to account for similarities within regions.

- **Endogenous independent variables.** Endogeneity arises when one or more of the independent variables depend on the dependent variable. For example, left-turn lanes may be installed because of the frequency of left-turn crashes at an intersection. A cross-sectional model that predicts crash frequency based on the presence of left-turn lanes and other factors may conclude that left-turn lanes increase crashes. Similar examples could be drawn for other AM strategies. In this study, endogeneity was not considered to be a substantial threat because data were aggregated at the corridor level.

- **Omitted variable bias.** It is difficult, if not impossible, to completely account for the potential effects of omitted variable bias in an observational cross-sectional study. In this case, omitted variable bias was addressed to the extent possible by carefully considering the roadway and traffic characteristics that should be included in the models. Detailed data were collected for each corridor, and numerous variables were tested for suitability in the models. There is the potential for omitted variable bias due to other factors such as weather, driver population, and vehicle fleet, but a regional indicator variable was included in the models to help to account for these differences among the regions.

CHAPTER 4. DATA COLLECTION

Detailed data were collected for more than 600 mi of corridors across four regions of the United States. The regions included North Carolina (Raleigh, Cary, and Wake Forest), Minnesota (St. Paul and Minneapolis), Northern California (Oakland, Sacramento, San Francisco, and San Jose), and Southern California (Los Angeles and San Diego). This section identifies the procedures for selecting corridors, collecting and verifying data, and merging the various sources of data for analysis.

IDENTIFYING CANDIDATE CORRIDORS

State and local agencies were contacted to solicit candidate corridors for inclusion in the study. Guidance was provided on what constituted suitable corridors to assist the State and local agencies with this process. The critical factors for corridor selection included the following:

- No major construction activity during the study period.
- Availability of crash, traffic volume, and roadway inventory data.
- Arterial functional classification (e.g., principal arterial, minor arterial).
- Display of at least one of the target AM strategies.
- Area type of urban, suburban, or urbanizing.
- Land use of residential, commercial, or mixed-use.

The desired sample size was 150 mi for each region with a relatively equal number of miles for each area type (i.e., urban, suburban, and urbanizing) and land use category (i.e., commercial, mixed-use, and residential). Some agencies were able to provide a relatively large number of miles of candidate corridors, while others were only able to provide a partial list owing to limited staffing availability. Consequently, the study team identified additional corridors, extending existing corridors where possible, and vetted the list with the respective agencies.

The greatest challenge in this task was avoiding areas with construction activity because records of construction activity were not readily available. To overcome this challenge, the study team employed multiple search and confirmation methods. First, the team used historical aerial photography to check for major changes between past and present conditions. (Further details are provided in the Corridor Screening and Supplemental Data Collection and Verification sections below.) Past and present aerial photography was obtained from the United States Geological Survey (USGS), and Google® Earth™ was also employed using the historical imagery feature.

COLLECTING HIGHWAY SAFETY INFORMATION SYSTEM DATA

The Highway Safety Information System (HSIS) contains readily available crash, roadway, and traffic volume data for selected States. By design, the three States included in this study—California, Minnesota, and North Carolina—are all members of HSIS. The HSIS guidebooks were examined, and any potentially useful HSIS variables were requested. At the time of the HSIS data request, the most recent year of available data was 2008. Therefore, the study period for this project includes 2006 to 2008. Appendix A identifies the variables received from the roadway, crash, and vehicle files for each of the three States.

The HSIS data provided a starting point for the corridor-level databases and were also used to screen potential corridors. The team checked each candidate corridor for the availability of HSIS data; if a candidate corridor could not be found within the HSIS data, it was immediately rejected. To perform queries within HSIS data, the route number and mileposts were needed for each corridor. This task was accomplished with the help of the respective agencies.

CORRIDOR SCREENING

Three rounds of screening were employed to ensure no major construction activities or changes occurred along the corridors during the study period. As described previously, initial screening was conducted by the agencies through a review of construction records.

The study team performed a second phase of screening using HSIS data. The HSIS roadway files from 2006 to 2008 were compared to each other to detect changes that would indicate construction activity (e.g., number of lanes, lane width, shoulder width, median type, median width, and mileposts). In a small number of cases, changes were detected. Of these, the most common were small changes in median width. However, the changes from year to year appear to be the result of slight differences in data coding and not actual physical changes. As a result, no corridors were eliminated by this process.

The team performed a third round of screening using historical aerial imagery. The team identified high-resolution aerial imagery for the identified corridors from the USGS National Seamless Server. By comparing historical aerial images with current conditions, the team was able to identify where changes had taken place during the study period.

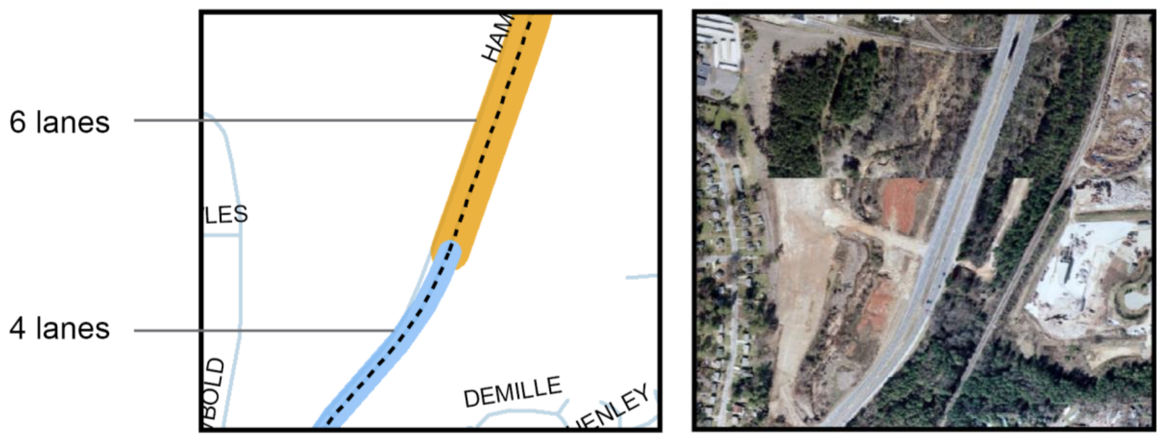
Where major changes were identified, the team did not select the candidate corridor for inclusion unless the start and end dates of construction activity could be determined. If the construction activity did not include the entire study period, then the corridor was included in the study using a subset of data that did not include the construction period. Examples of major changes include the addition of through lanes, the construction of a new interchange or new ramps to an existing interchange, and the development of large commercial properties or subdivisions along a corridor.

Corridors with minor changes remained in the dataset for analysis. An example of a minor change is the addition of a single commercial or residential driveway. The team did not want to eliminate an entire corridor from the study merely because of these types of isolated changes. Two approaches were considered to deal with instances of isolated changes. The preferred approach was to contact the agency responsible for the roadway and obtain maintenance records for that specific location. While this was the preferred approach, it was dependent on the availability of records and assistance from the State. The alternative approach was to exclude the section of the corridor around the change (e.g., new signal). In other words, the team segmented the corridor to avoid the section with the change.

SUPPLEMENTAL DATA COLLECTION AND VERIFICATION

The HSIS data as well as the area type and land use information obtained during the corridor identification provided a starting point for the database of features needed for this project. However, all information had to be verified and augmented with additional data from aerial photography and field visits. As described above, aerial imagery was obtained for corridor screening purposes (i.e., checking for changes indicating construction activity). The aerial imagery was also used to verify the land use, number of through lanes, and median type for each corridor.

In North Carolina, the team superimposed the HSIS data on aerial photos, using ArcMap™ to expedite the verification process. The objective was to visually display the median type and number of lanes from HSIS geospatially using color-coded symbols. This way, the HSIS data could be compared rapidly with the conditions shown by the high-resolution imagery. Figure 12 presents an example of this approach for one of the corridors (Hammond Road). The images on the left show the HSIS data, which were verified using aerial imagery of the corresponding segments on the right.



Source: FHWA

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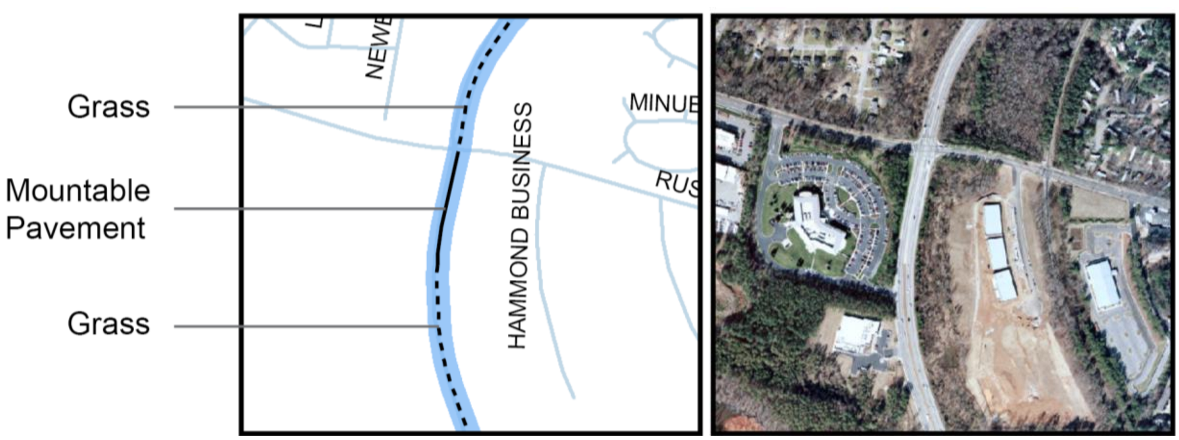
A. Illustration of number of lanes.

B. Photo of number of lanes.



Source: FHWA

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C. Illustration of median type.

D. Photo of median type.

Figure 12. Illustrations and photos. Verifying HSIS data with aerial photos.[(15)]

The process of superimposing HSIS data on the aerial imagery was time-consuming and labor-intensive. In addition, the study team identified inconsistencies in the HSIS data, including primary variables such as number of lanes, median type, and posted speed. Subsequently, it was determined that this information should be obtained from field visits and aerial imagery rather than the HSIS database for the remaining regions.

For California and Minnesota, the basic roadway characteristics (i.e., number of lanes and median type) were obtained from aerial imagery that was taken during the study period. The data were then compared with video logs obtained during the field visits to identify any differences. Figure 13 displays an example of a high-resolution aerial image from one of the study corridors, and figure 14 shows the corresponding street view from the field review video log. If inconsistencies were identified between the imagery and video, the study team explored the segment further to determine when the change occurred.

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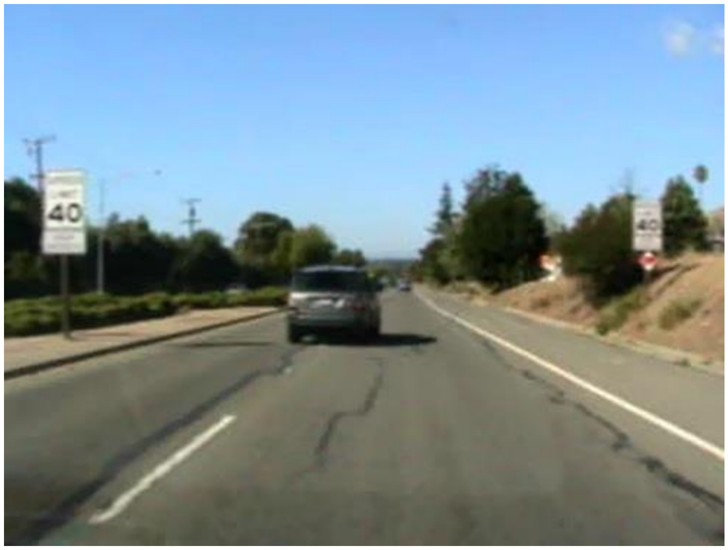
Note: The double-headed arrow was inserted by authors to indicate the direction of which the image in figure 14 was captured.

Figure 13. Screen shot. Verifying data with aerial imagery.(16)



Source: FHWA.

Figure 14. Photo. Verifying data with video.

Aside from median type and number of lanes, aerial imagery was also used to collect information that was unavailable from HSIS. These data included the frontage type (fully, partially, or undeveloped), presence of a frontage or backage road, extent of internal cross connectivity, and condition of pavement markings (poor or not). Collecting this information was straightforward because these parameters did not change frequently along a given corridor. Consequently, the beginning and ending mileposts were rapidly noted for the above parameters.

Finally, the aerial imagery was used to collect information regarding access points, including the location, type, and density. Specifically, unsignalized access spacing, driveway spacing, interchange spacing, median spacing, and corner clearance were obtained from aerial imagery. However, collecting data on these features was more complicated and required the setup of an ArcGIS™ database as discussed in the following section.

SETUP OF GEOGRAPHIC INFORMATION SYSTEM (GIS) DATABASE TO FACILITATE DATA COLLECTION

ArcGIS™ feature classes were created for signalized intersections, unsignalized intersections, driveways, and medians. This allowed data collectors to insert symbols representing these objects on the aerial images of the corridors. Data fields were created for each object so its characteristics could be noted. The characteristics collected for each object are summarized in table 5.

Table 5. Objects and characteristics coded in ArcGIS™.

Object Type	Characteristics
Driveways	Type (commercial or residential) Movements permitted (limited movement or full movement)
Median openings and crossovers	Presence of left-turn lane
Unsignalized intersections	Type (two-way stop-control, all-way stop-control, or roundabout) Presence of left-turn lane(s) on mainline Presence of right-turn lane(s) on mainline Presence of left-turn lane(s) on cross street Presence of right-turn lane(s) on cross street Movements permitted (right-in/right-out, left-from-major-only, or full) Maximum number of through lanes on the cross street
Signalized intersections	Number of approaches Presence of left-turn lane(s) on mainline Presence of right-turn lane(s) on mainline Presence of left-turn lane(s) on cross street Presence of right-turn lane(s) on cross street Presence of nontraditional accommodation of left turns Maximum number of through lanes on the cross street

Figure 15 is an example of these objects for a 1-mi section of a study corridor (California Route 1). In total, the study corridors contained more than 1,500 signalized intersections, 3,500 unsignalized intersections, and 15,000 driveways.

©U.S. Geological Survey.
Note: Overlay symbols and legend were inserted by project team to indicate driveway types and intersection traffic control.

Figure 15. Image. Example of point objects for a 1-mi corridor.(17)

FIELD DATA COLLECTION AND VERIFICATION

Field visits were used to collect additional information and verify the data obtained from HSIS and the aerial imagery. The HSIS data and aerial imagery provided many but not all of the required features data. The following information was still needed:

- Presence of street lighting.
- Presence of visual clutter (e.g., excessive signage, roadside advertisements, banners).
- Detailed signalized intersection data, including the following:
    - Turning restrictions on mainline.
    - Turning restrictions on cross street.
    - Left-turn phasing.

In the first two regions (North Carolina and Northern California), the ArcMap™ files (aerial imagery, layers, and feature classes) were transferred to a touch-screen tablet personal computer (PC) for fieldwork. The ArcMap™ files were used to create ArcPad™ versions, which enabled the team to insert corridor features onto the aerial imagery. The tablet PC was linked with a Global Positioning System (GPS) device to identify the precise location in the field relative to the aerial imagery. This method allowed the team to “drop” specific features (e.g., driveways and intersections) on the aerial images with the tablet PC and enter detailed characteristics for each feature.

Figure 16 shows the tablet PC and GPS equipment used for the field data collection and verification. The engineer is holding the tablet PC, noting specific characteristics of the intersection, while the GPS device is mounted atop a backpack system. Note that this photo was taken while verifying the functionality of the equipment; the actual field data collection was performed from a vehicle with the equipment mounted inside the vehicle.

Source: FHWA.

Figure 16. Photo. Data collection equipment used for field visit.

This method proved to be extremely cumbersome and time consuming. It was anticipated that the GPS unit would help synchronize the location of the vehicle with the location on the GIS map. This was generally not the case because the GPS unit needed several satellites in range to provide the level of accuracy needed for this project. In an attempt to overcome the satellite coverage issue, satellite “schedules” were used to identify the magnitude and time of coverage for the study corridors. However, the optimal schedule of the satellites did not always fit with the data collection times and routes. Therefore, the data collection procedure was revised.

The revised procedure included narrated video logs to document the attributes of each corridor, and the data were then entered in a spreadsheet in an office setting. Using this method, it was possible to conduct the field reviews with one driver and a digital video camera, which was mounted to the front windshield facing the direction of travel. The video captured the specific corridor details while the driver noted changes in the characteristics (e.g., number of lanes, median type, speed limit, and lighting). The narration was particularly useful for the data reduction process because the data analyst could listen to the video and readily identify changes. The analyst could then stop the video and enter the data in a spreadsheet as changes occurred along the route. To help ensure consistency in the field data collection process, a procedure (provided in appendix B) was formulated and provided to every team member participating in the process.

POST PROCESSING

From the previous data collection tasks, data were obtained in various formats. Some information was stored in Microsoft® Word documents (e.g., area type, land use, and frontage type), specifying the beginning and ending points. HSIS data were provided in Microsoft® Excel format. General corridor characteristics and specific attributes for signalized intersections were identified in the video logs. Other information was identified and stored in the form of ArcGIS™ feature datasets (e.g., intersections and driveways). The corner clearances and ramp spacing information required specific measurements to be made using ArcGIS™.

Transforming all these data sources into a well-integrated database to serve as the basis for statistical computation required a post-processing step. In this step, multiple tasks were performed, and the following identifies the general sequence of tasks:

1. **General corridor information.** A spreadsheet was developed and populated to identify the general corridor data, including a unique corridor identity (ID), route number, beginning milepost, ending milepost, beginning cross street, ending cross street, area type, and land use for each corridor. The video logs were then used to populate additional data fields for each corridor, including the type of operation, number of lanes, median type, posted speed limit, lighting presence, condition of pavement markings, and visual clutter. Data from the aerial images were then added, including the frontage type, internal cross connectivity, and presence of a frontage/backage road. HSIS data were then appended to identify the specific fields needed to match crash data.

2. **Segmentation.** Within each corridor, new segment links were created anytime one or more of the variables changed. The beginning and ending mileposts were identified for each individual link. The links were then aggregated based on area type and land use to create the study corridors. Specifically, each study corridor was consistent with respect to area type and land use, but other variables were allowed to change. Each study corridor was assigned a unique ID, and spreadsheets were then created for each corridor and linked using the unique ID.

3. **Driveway spacing.** The ArcGIS™ files were used to query the driveway information for each study corridor. The total number of driveways was identified for each study corridor as a whole and by direction. The driveway information was also provided by direction for

commercial and residential driveways and also for full- and limited-movement driveways.

4. **Unsignalized intersection spacing.** The ArcGIS™ files were used to query the unsignalized intersection information for each study corridor. Several variables were created, including the total number of unsignalized intersections, minimum spacing, maximum spacing, number with right-turn lanes, number with left-turn lanes, and number of unsignalized intersections by legs (i.e., three-legged, four-legged, and five-legged) and turning restrictions (full movement, right-in/right-out, and left-from-major-only).

5. **Signalized intersection spacing and corner clearance.** The ArcGIS™ files were used to query the signalized intersection information for each study corridor. Several variables were created, including the total number of signalized intersections, minimum spacing, maximum spacing, number with right-turn lanes, number with left-turn lanes, number of signalized intersections by legs (i.e., three-legged, four-legged, and five-legged), number of interchange-related intersections, and number of signalized intersections by turning restrictions (full or limited movement). The corner clearance was also identified for each signalized intersection, including measurements of the distance to the nearest driveway for the approach and receiving lanes in both directions.

6. **Median openings and crossovers.** The ArcGIS™ files were used to query the median opening information for each study corridor with a median. The total number of median openings was identified for each study corridor along with the number of median openings with and without left-turn lanes.

7. **Interchange-related spacing.** The ArcGIS™ files were used to query the interchange-related spacing information for each study corridor. Specifically, the ramp location and type were identified for each interchange. For off-ramps, the distances to the first downstream driveway (on right), the first median opening allowing left turns, and the first major intersection were measured. For on-ramps, the distances from the last driveway (on right) and major intersection were measured.

As noted previously, the segmentation process required that homogeneous segment links be combined into study corridors to achieve a reasonable length for each site. In this way, some variables were summed over all links making up a study corridor (e.g., number of driveways). In other cases, new variables reflecting the percentage of the total length were created (e.g., number of lanes). This process also required that the county route and milepost information for each link be retained for matching with the crash and traffic volume data because, in some cases, the county routes change within a corridor. The crash data from 2006 to 2008 obtained from HSIS were queried to match crashes to the study sites. The annual average daily traffic (AADT) and percentage truck variables were calculated as weighted averages, weighting by the lengths of the links within a corridor. AADT represents the bidirectional traffic volume for a segment.

CHAPTER 5. SUMMARY STATISTICS

The result of the data collection and post processing was a total of 245 corridors representing more than 600 mi. Table 6 and table 7 present the number and mileage of corridors by area type and land use, respectively.

Table 6. Number of corridors by area type and land use.

Scenario	Commercial	Mixed-Use	Residential	Total
Urban	34	32	27	93
Suburban	29	33	28	90
Urbanizing	27	13	22	62
Total	90	78	77	245

Table 7. Mileage of corridors by area type and land use.

Scenario	Commercial (mi)	Mixed-Use (mi)	Residential (mi)	Total (mi)
Urban	79.1	92.4	48.7	220.2
Suburban	64.3	119.7	57.0	241.0
Urbanizing	63.8	31.9	62.4	158.3
Total	207.4	244.1	168.2	619.5

The crash types of interest include total, injury, turning, rear-end, and right-angle. Note that each State has specific crash codes, and therefore, the definitions vary slightly. The crash types are identified in table 8 with the associated definitions for each region.

Table 8. Crash type definitions.

Crash Type	Definition
Total	All regions: all crashes
Injury	All regions: KABC on KABCO scale
Turning	California: any involved vehicle making a turn Minnesota: left turn or right turn North Carolina: rear-end turn, left-turn same roadway, left-turn different roadway, right-turn same roadway, right-turn different roadway
Rear-end	California and Minnesota: rear-end North Carolina: rear-end slow or stop and rear-end turn
Right-angle	California: broadside and no vehicle turning Minnesota: right-angle North Carolina: angle

Note: North Carolina crashes coded as rear-end turn crashes are included in both rear-end and turning crashes. Because the specific crash types cannot be summed to get total crashes, it was decided that double-counting should not pose a problem for the crash type models.
The KABCO scale is used to represent injury severity in crash reporting (K is fatal injury, A is incapacitating injury, B is non-incapacitating injury, C is possible injury, and O is property damage only).

The following is an overview of the data collected in each of the four regions with the corresponding summary statistics for all variables.

REGION 1: NORTH CAROLINA

Data were collected for 74 corridors in North Carolina, totaling nearly 150 mi. Table 9 indicates the centerline miles of corridor data included in the models for each of the nine scenarios (urban commercial, urban mixed-use, urban residential, suburban commercial, suburban mixed-use, suburban residential, urbanizing commercial, urbanizing mixed-use, and urbanizing residential).

Table 9. North Carolina mileage by area type and land use.

Scenario	Commercial	Mixed-Use	Residential	Total
Urban	23.5	15.3	23.7	62.5
Suburban	11.3	35.8	9.1	56.2
Urbanizing	11.7	8.3	9.7	29.7
Total	46.5	59.4	42.5	148.4

In preparation for data analysis, variables were transformed into a format appropriate for modeling, and new variable names were assigned. Table 10 presents the variable names, brief descriptions, and summary statistics, including the number of corridors and minimum, maximum, mean, and standard deviations for all independent variables. The summary statistics are computed based on corridor-level data. For some variables, the number of corridors is fewer than 74 because a variable is not relevant to all corridors. For example, if there is no median, then the number of median openings is not a relevant variable.

Table 10. Summary statistics for North Carolina independent variables.

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
PROPLANE1	Proportion of total length with two lanes	74	0.00	1.00	0.11	0.28
PROPLANE2	Proportion of total length with three or four lanes	74	0.00	2.03	0.79	0.38
PROPLANE3	Proportion of total length with five or more lanes	74	0.00	1.00	0.10	0.24
PROPDIV	Proportion of total length with curb or raised concrete median	74	0.00	2.03	0.50	0.48
PROPTWLTL	Proportion of total length with a TWLTL	74	0.00	1.00	0.31	0.40
PROPUNDIV	Proportion of total length with an undivided median	74	0.00	1.00	0.19	0.35
PROPNODEV	Proportion of total length with no adjacent development	74	0.00	1.00	0.11	0.29
PROPPARTDEV	Proportion of total length with partial adjacent development	74	0.00	2.03	0.86	0.35
PROPFULLDEV	Proportion of total length with full adjacent development	74	0.00	1.00	0.04	0.17
PROPLIGHT	Proportion of total length with illumination present	74	0.00	2.03	0.78	0.44
PROPPOORPVMNT	Proportion of total length with poor pavement condition	72	0.00	1.00	0.06	0.20
PROPVC	Proportion of total length with visual clutter	74	0.00	1.00	0.07	0.23
PROPLIMCONN	Proportion of total length with limited connectivity on adjacent developments	74	0.00	2.03	0.28	0.42
PROPMODCONN	Proportion of total length with moderate connectivity on adjacent developments	74	0.00	1.00	0.18	0.29
PROPSIGCONN	Proportion of total length with significant connectivity on adjacent developments	74	0.00	1.00	0.54	0.43
PROPFRONTRD	Proportion of total length with a frontage road	74	0.00	0.42	0.01	0.06
DRWYDENS	Number of driveways/mile	74	0.00	53.55	13.86	13.34
UNSIGDENS	Number of unsignalized intersections per mile	74	0.00	12.05	5.48	2.64
ACCDENS	Number of driveways plus unsignalized intersections per mile	74	0.92	65.60	19.33	14.78
SIGDENS	Number of signalized intersections per mile	74	0.00	9.04	2.37	1.46
NODRWYS	Number of driveways	74	0.00	112.00	24.91	25.36
NOCOMFULLDRWY	Number of commercial full-movement driveways	74	0.00	78.00	6.47	13.53
NORESFULLDRWY	Number of residential full-movement driveways	74	0.00	88.00	9.95	16.76
NOCOMLIMDRWY	Number of commercial limited-movement driveways	74	0.00	39.00	5.50	7.63
NORESLIMDRWY	Number of residential limited-movement driveways	74	0.00	40.00	2.99	7.86
NOUNSIG	Number of unsignalized intersections	74	0.00	34.00	10.03	7.21
NO3LEGUNSIG	Number of 3-legged unsignalized intersections	74	0.00	39.00	7.82	6.68
NO4LEGUNSIG	Number of 4-legged unsignalized intersections	74	0.00	15.00	2.55	2.82
NO3LEGFULLUNSIG	Number of 3-legged full-movement unsignalized intersections	74	0.00	25.00	5.27	5.22
NO3LEGLIMUNSIG	Number of 3-legged limited-movement unsignalized intersections	74	0.00	13.00	2.35	2.67
NO3LEGRIROUNSIG	Number of 3-legged right-in/right-out unsignalized intersections	74	0.00	11.00	2.19	2.45

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
NO3LEGLFMOUNSIG	Number of 3-legged unsignalized intersections with no left-turn movement from crossroad	74	0.00	3.00	0.16	0.50
NO4LEGFULLUNSIG	Number of 4-legged full-movement unsignalized intersections	74	0.00	15.00	2.15	2.43
NO4LEGLIMUNSIG	Number of 4-legged limited-movement unsignalized intersections	74	0.00	2.00	0.22	0.53
NO4LEGRIROUNSIG	Number of 4-legged right-in/right-out unsignalized intersections	74	0.00	1.00	0.11	0.31
NO4LEGLFMOUNSIG	Number of 4-legged unsignalized intersections with no left-turn movement from crossroad	74	0.00	2.00	0.11	0.39
NORTLUNSIG	Number of unsignalized intersections with a right-turn lane	74	0.00	14.00	1.76	2.44
NOLTLUNSIG	Number of unsignalized intersections with a left-turn lane	74	0.00	31.00	6.53	7.02
NOSIG	Number of signalized intersections	74	0.00	15.00	4.27	3.07
MINSPCSIG	Minimum spacing of signalized intersections (feet)	64	201.00	12,228.00	1,841.00	1,822.00
MAXSPCSIG	Maximum spacing of signalized intersections (feet)	64	977.00	14,810.00	4,286.00	2,621.00
NOFULLSIG	Number of full-movement signalized intersections	74	0.00	12.00	3.82	2.65
NOLIMSIG	Number of limited-movement signalized intersections	74	0.00	3.00	0.22	0.56
NOINTSIG	Number of interchange-related signalized intersections	74	0.00	2.00	0.38	0.70
NONRORSIG	Number of no-right-turn-on-red on mainline signalized intersections	74	0.00	1.00	0.07	0.25
NONLTSIG	Number of no-left-turn on mainline signalized intersections	74	0.00	2.00	0.09	0.38
NONUTURNSIG	Number of no-U-turn on mainline signalized intersections	74	0.00	1.00	0.15	0.36
NONRORXSIG	Number of no-right-turn-on-red on crossroad signalized intersections	74	0.00	2.00	0.12	0.37
NONLTSXIG	Number of no-left-turn on crossroad signalized intersections	74	0.00	1.00	0.01	0.12
NONUTURNXSIG	Number of no-U-turn on crossroad signalized intersections	74	0.00	1.00	0.03	0.16
NOLTPSIG	Number of signalized intersections with left-turn protection	74	0.00	15.00	3.74	3.00
NO3LEGSIG	Number of 3-legged signalized intersections	74	0.00	4.00	0.80	0.94
NO4LEGSIG	Number of 4-legged signalized intersections	74	0.00	12.00	3.45	2.55
NO5LEGSIG	Number of 5-legged signalized intersections	74	0.00	1.00	0.03	0.16
NORTLSIG	Number of signalized intersections with a right-turn lane on the mainline	74	0.00	9.00	2.65	2.14
NOLTLSIG	Number of signalized intersections with a left-turn lane on the mainline	74	0.00	15.00	4.09	3.01
NOMEDOP	Number of median openings	57	0.00	15.00	2.56	3.39
NOMEDOPLT	Number of median openings with a left-turn lane	57	0.00	12.00	2.32	2.99
NOMEDOPNOLT	Number of median openings without a left-turn lane	57	0.00	6.00	0.25	1.06
SPEED_LIMIT	Posted speed limit (miles per hour)	74	35.00	55.00	45.00	4.53
AVGPCTTRK	Average percentage trucks in traffic	74	0.00	16.14	4.83	2.65
AVGAADT	Average AADT; bidirectional traffic volume for a corridor	74	50.00	46,087.00	18,887.00	10,347.00

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
SPCOFFLT	Minimum spacing from off-ramp to available left turn onto mainline from same side of road (feet)	22	376.00	1,991.00	774.00	392.00
SPCOFFRT	Minimum spacing from off-ramp to available right turn onto mainline from same side of road (feet)	22	281.00	1,991.00	735.00	417.00
SPCON	Minimum spacing from on-ramp to available right turn onto mainline from same side of road (feet)	23	0.00	2,446.00	864.00	684.00

St. Dev. = standard deviation.

Table 11 provides similar summary statistics for the dependent variables (i.e., number of crashes per mile per year by crash type). The dependent variable is presented as crash rate, which is the number of crashes divided by the segment length and by the years of crash data for a given corridor. The summary statistics for crash rate are presented based on corridor-level data. For example, the minimum total crash rate observed for a single corridor is 0.84 crash/mi/yr.

Table 11. Summary statistics for North Carolina dependent variables.

Dependent Variable (crashes/mi/yr)	Corridors	Minimum	Maximum	Mean	St. Dev.
Total crashes	74	0.84	195.31	28.57	25.91
Injury crashes	74	0.00	40.74	7.22	5.70
Rear-end crashes	74	0.00	69.63	12.91	11.76
Right-angle crashes	74	0.00	52.10	4.31	6.39
Turning crashes	74	0.00	24.44	4.94	4.73

St. Dev. = standard deviation.

REGION 2: NORTHERN CALIFORNIA

Data were collected for 61 corridors in Northern California, totaling more than 160 mi. Table 12 indicates the centerline miles of corridor data included in the models for each of the nine scenarios (urban commercial, urban mixed-use, urban residential, suburban commercial, suburban mixed-use, suburban residential, urbanizing commercial, urbanizing mixed-use, and urbanizing residential).

Table 12. Northern California mileage by area type and land use.

Scenario	Commercial	Mixed-Use	Residential	Total
Urban	24.80	36.39	12.50	73.69
Suburban	13.82	24.60	15.61	54.03
Urbanizing	9.54	8.55	18.30	36.39
Total	48.16	69.54	46.41	164.11

In preparation for data analysis, variables were transformed into a format appropriate for modeling, and new variable names were assigned. Table 13 presents the variable names, brief descriptions, and summary statistics, including the number of corridors and minimum, maximum, mean, and standard deviations for all independent variables. The summary statistics are computed based on corridor-level data. For some variables, the number of corridors is fewer than 61 because a variable is not relevant to all corridors. For example, if there is no median, then the number of median openings is not a relevant variable.

Table 13. Summary statistics for Northern California independent variables.

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
PROPLANE1	Proportion of total length with two lanes	61	0.00	1.00	0.21	0.37
PROPLANE2	Proportion of total length with three or four lanes	61	0.00	1.00	0.48	0.43
PROPLANE3	Proportion of total length with five or more lanes	61	0.00	1.00	0.31	0.43
PROPDIV	Proportion of total length with curb or raised concrete median	61	0.00	1.00	0.57	0.45
PROPTWLTL	Proportion of total length with a TWLTL	61	0.00	1.00	0.15	0.28
PROPUNDIV	Proportion of total length with an undivided median	61	0.00	1.00	0.29	0.39
PROPNODEV	Proportion of total length with no adjacent development	61	0.00	1.00	0.05	0.16
PROPPARTDEV	Proportion of total length with partial adjacent development	61	0.00	1.00	0.56	0.45
PROPFULLDEV	Proportion of total length with full adjacent development	61	0.00	1.00	0.39	0.45
PROPLIGHT	Proportion of total length with illumination present	61	0.00	1.00	0.74	0.40
PROPPOORPVMNT	Proportion of total length with poor pavement condition	61	0.00	1.00	0.03	0.14
PROPVC	Proportion of total length with visual clutter	61	0.00	1.00	0.23	0.39
PROPLIMCONN	Proportion of total length with limited connectivity on adjacent developments	61	0.00	1.00	0.38	0.42
PROPMODCONN	Proportion of total length with moderate connectivity on adjacent developments	61	0.00	1.00	0.36	0.40
PROPSIGCONN	Proportion of total length with significant connectivity on adjacent developments	61	0.00	1.00	0.26	0.38
PROPFRONTRD	Proportion of total length with a frontage road	61	0.00	1.00	0.34	0.39
DRWYDENS	Number of driveways per mile	61	0.00	135.52	36.63	27.21
UNSIGDENS	Number of unsignalized intersections per mile	61	0.00	18.71	6.60	4.24
ACCDENS	Number of driveways plus unsignalized intersections per mile	61	0.00	144.14	43.24	29.28
SIGDENS	Number of signalized intersections per mile	61	0.00	9.09	3.69	2.06
NODRWYS	Number of driveways	61	0.00	627.00	102.57	130.63
NOCOMFULLDRWY	Number of commercial full-movement driveways	61	0.00	415.00	23.74	57.65
NORESFULLDRWY	Number of residential full-movement driveways	61	0.00	358.00	16.46	50.86
NOCOMLIMDRWY	Number of commercial limited-movement driveways	61	0.00	477.00	50.67	85.64
NORESLIMDRWY	Number of residential limited-movement driveways	61	0.00	382.00	11.70	49.88
NOUNSIG	Number of unsignalized intersections	61	0.00	137.00	17.43	22.03
NO3LEGUNSIG	Number of 3-legged unsignalized intersections	61	0.00	92.00	13.72	17.12
NO4LEGUNSIG	Number of 4-legged unsignalized intersections	61	0.00	45.00	3.67	7.20
NO5LEGUNSIG	Number of 5-legged unsignalized intersections	61	0.00	1.00	0.03	0.18
NO3LEGFULLUNSIG	Number of 3-legged full-movement unsignalized intersections	61	0.00	68.00	7.54	10.99
NO3LEGLIMUNSIG	Number of 3-legged limited-movement unsignalized intersections	61	0.00	36.00	6.34	9.24
NO3LEGRIROUNSIG	Number of 3-legged right-in/right-out unsignalized intersections	61	0.00	36.00	6.03	8.75

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
NO3LEGLFMOUNSIG	Number of 3-legged unsignalized intersections with no left-turn movement from crossroad	61	0.00	3.00	0.30	0.74
NO4LEGFULLUNSIG	Number of 4-legged full-movement unsignalized intersections	61	0.00	45.00	3.23	7.04
NO4LEGLIMUNSIG	Number of 4-legged limited-movement unsignalized intersections	61	0.00	12.00	0.44	2.16
NO4LEGRIROUNSIG	Number of 4-legged right-in/right-out unsignalized intersections	61	0.00	12.00	0.43	2.16
NO4LEGLFMOUNSIG	Number of 4-legged unsignalized intersections with no left-turn movement from crossroad	61	0.00	1.00	0.02	0.13
NORTLUNSIG	Number of unsignalized intersections with a right-turn lane	61	0.00	5.00	0.72	1.25
NOLTLUNSIG	Number of unsignalized intersections with a left-turn lane	61	0.00	89.00	7.90	13.13
NOSIG	Number of signalized intersections	61	0.00	54.00	9.57	10.34
MINSPCSIG	Minimum spacing of signalized intersections (feet)	54	109.00	4,471.00	992.00	1,093.00
MAXSPCSIG	Maximum spacing of signalized intersections (feet)	54	296.00	7,265.00	2,661	1,610.00
NOFULLSIG	Number of full-movement signalized intersections	61	0.00	54.00	9.57	10.34
NOINTSIG	Number of interchange-related signalized intersections	61	0.00	3.00	0.36	0.78
NO3LEGSIG	Number of 3-legged signalized intersections	61	0.00	14.00	2.34	2.94
NO4LEGSIG	Number of 4-legged signalized intersections	61	0.00	41.00	7.08	8.03
NO5LEGSIG	Number of 5-legged signalized intersections	61	0.00	5.00	0.20	0.75
NORTLSIG	Number of signalized intersections with a right-turn lane on the mainline	61	0.00	9.00	2.52	2.34
NOLTLSIG	Number of signalized intersections with a left-turn lane on the mainline	61	0.00	42.00	7.75	9.42
NOMEDOP	Number of median openings	57	0.00	42.00	4.61	7.87
NOMEDOPLT	Number of median openings with a left-turn lane	57	0.00	34.00	4.09	6.92
NOMEDOPNOLT	Number of median openings without a left-turn lane	57	0.00	8.00	0.54	1.64
SPEED_LIMIT	Posted speed limit (miles per hour)	61	25.00	55.00	39.10	7.39
AVGAADT	Average AADT; bidirectional traffic volume for a corridor	61	6,233.00	86,773.00	28,954.00	14,095.00
SPCOFFLT	Minimum spacing from off-ramp to available left turn onto mainline from same side of road (feet)	14	45.00	2,214.00	564.00	617.00
SPCOFFRT	Minimum spacing from off-ramp to available right turn onto mainline from same side of road (feet)	14	21.00	1,048.00	248.00	322.00
SPCON	Minimum spacing from on-ramp to available right turn onto mainline from same side of road (feet)	11	29.00	1,276.00	267.00	358.00

St. Dev. = standard deviation.

Table 14 provides similar summary statistics for the dependent variables (i.e., number of crashes per mile per year by crash type). The dependent variable is presented as crash rate, which is the number of crashes divided by the segment length and by the years of crash data for a given corridor. The summary statistics for crash rate are presented based on corridor-level data. For example, the minimum total crash rate observed for a single corridor is 0.18 crash/mi/yr.

Table 14. Summary statistics for Northern California dependent variables.

Dependent Variable (crashes/mi/yr)	Corridors	Minimum	Maximum	Mean	St. Dev.
Total crashes	61	0.18	64.52	20.16	15.27
Injury crashes	61	0.00	24.29	8.34	6.35
Rear-end crashes	61	0.00	25.57	8.82	7.07
Right-angle crashes	61	0.00	16.67	2.32	3.09
Turning crashes	61	0.00	17.18	5.23	4.23

St. Dev. = standard deviation.

REGION 3: SOUTHERN CALIFORNIA

Data were collected for 51 corridors in Southern California, totaling nearly 150 mi. Table 15 indicates the centerline miles of corridor data included in the models for each of the nine scenarios (urban commercial, urban mixed-use, urban residential, suburban commercial, suburban mixed-use, suburban residential, urbanizing commercial, urbanizing mixed-use, and urbanizing residential).

Table 15. Southern California mileage by area type and land use.

Scenario	Commercial	Mixed-Use	Residential	Total
Urban	14.71	23.32	1.30	39.33
Suburban	22.18	40.20	14.41	76.79
Urbanizing	19.00	0.54	12.54	32.08
Total	55.89	64.06	28.25	148.20

In preparation for data analysis, variables were transformed into a format appropriate for modeling, and new variable names were assigned. Table 16 presents the variable names, brief descriptions, and summary statistics, including the number of corridors and minimum, maximum, mean, and standard deviations for all independent variables. The summary statistics are computed based on corridor-level data. For some variables, the number of corridors is fewer than 51 because a variable is not relevant to all corridors. For example, if there is no median, then the number of median openings is not a relevant variable.

Table 16. Summary statistics for Southern California independent variables.

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
PROPLANE1	Proportion of total length with two lanes	51	0.00	1.00	0.05	0.21
PROPLANE2	Proportion of total length with three or four lanes	51	0.00	1.00	0.58	0.45
PROPLANE3	Proportion of total length with five or more lanes	51	0.00	1.00	0.30	0.41
PROPDIV	Proportion of total length with curb or raised concrete median	51	0.00	1.00	0.44	0.44
PROPTWLTL	Proportion of total length with a TWLTL	51	0.00	1.00	0.33	0.39
PROPUNDIV	Proportion of total length with an undivided median	51	0.00	1.00	0.23	0.36
PROPNODEV	Proportion of total length with no adjacent development	51	0.00	1.00	0.07	0.22
PROPPARTDEV	Proportion of total length with partial adjacent development	51	0.00	1.00	0.54	0.44
PROPFULLDEV	Proportion of total length with full adjacent development	51	0.00	1.00	0.38	0.43
PROPLIGHT	Proportion of total length with illumination present	51	0.00	1.00	0.80	0.36
PROPPOORPVMNT	Proportion of total length with poor pavement condition	51	0.00	1.00	0.00	0.00
PROPVC	Proportion of total length with visual clutter	51	0.00	1.00	0.41	0.44
PROPLIMCONN	Proportion of total length with limited connectivity on adjacent developments	51	0.00	1.00	0.62	0.39
PROPMODCONN	Proportion of total length with moderate connectivity on adjacent developments	51	0.00	1.00	0.33	0.37
PROPSIGCONN	Proportion of total length with significant connectivity on adjacent developments	51	0.00	1.00	0.05	0.16
PROPFRONTRD	Proportion of total length with a frontage road	50	0.00	1.00	0.40	0.41
DRWYDENS	Number of driveways per mile	51	0.00	85.71	29.19	21.58
UNSIGDENS	Number of unsignalized intersections per mile	51	0.00	16.07	6.14	4.04
ACCDENS	Number of driveways plus unsignalized intersections per mile	51	0.61	100.00	35.33	24.27
SIGDENS	Number of signalized intersections per mile	51	0.00	8.84	3.36	1.84
NODRWYS	Number of driveways	51	0.00	684.00	91.59	138.02
NOCOMFULLDRWY	Number of commercial full-movement driveways	51	0.00	448.00	41.88	75.50
NORESFULLDRWY	Number of residential full-movement driveways	51	0.00	128.00	10.90	23.00
NOCOMLIMDRWY	Number of commercial limited-movement driveways	51	0.00	614.00	34.49	92.38
NORESLIMDRWY	Number of residential limited-movement driveways	51	0.00	94.00	4.31	18.98
NOUNSIG	Number of unsignalized intersections	51	0.00	141.00	18.98	27.02
NO3LEGUNSIG	Number of 3-legged unsignalized intersections	51	0.00	102.00	13.80	19.63
NO4LEGUNSIG	Number of 4-legged unsignalized intersections	51	0.00	39.00	5.16	8.71
NO5LEGUNSIG	Number of 5-legged unsignalized intersections	51	0.00	1.00	0.02	0.14
NO3LEGFULLUNSIG	Number of 3-legged full-movement unsignalized intersections	51	0.00	56.00	8.57	11.84
NO3LEGLIMUNSIG	Number of 3-legged limited-movement unsignalized intersections	51	0.00	86.00	5.04	13.67
NO3LEGRIROUNSIG	Number of 3-legged right-in/right-out unsignalized intersections	51	1.00	82.00	4.65	12.74

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
NO3LEGLFMOUNSIG	Number of 3-legged left from major only unsignalized intersections	51	0.00	6.00	0.35	1.15
NO4LEGFULLUNSIG	Number of 4-legged full-movement unsignalized intersections	51	0.00	38.00	5.12	8.58
NO4LEGLIMUNSIG	Number of 4-legged limited-movement unsignalized intersections	51	0.00	1.00	0.04	0.20
NO4LEGLFMOUNSIG	Number of 4-legged left from major only unsignalized intersections	51	0.00	1.00	0.04	0.20
NORTLUNSIG	Number of unsignalized intersections with a right-turn lane	51	0.00	8.00	0.39	1.44
NOLTLUNSIG	Number of unsignalized intersections with a left-turn lane	51	0.00	84.00	11.20	16.20
NOSIG	Number of signalized intersections	51	0.00	66.00	9.94	13.93
MINSPCSIG	Minimum spacing of signalized intersections (feet)	48	139.00	5,541.00	1,135.00	1,027.00
MAXSPCSIG	Maximum spacing of signalized intersections (feet)	48	583.00	17,546.00	2,835.00	2,560.00
NO3LEGSIG	Number of 3-legged signalized intersections	51	0.00	11.00	1.35	2.00
NO4LEGSIG	Number of 4-legged signalized intersections	51	0.00	57.00	8.59	12.34
NO5LEGSIG	Number of 5-legged signalized intersections	51	0.00	1.00	0.02	0.14
NORTLSIG	Number of signalized intersections with a right-turn lane on the mainline	50	0.00	25.00	2.82	4.57
NOLTLSIG	Number of signalized intersections with a left-turn lane on the mainline	50	0.00	63.00	9.64	13.54
NOMEDOP	Number of median openings	32	0.00	40.00	6.31	10.01
NOMEDOPLT	Number of median openings with a left-turn lane	32	0.00	40.00	5.22	9.72
NOMEDOPNOLT	Number of median openings without a left-turn lane	32	0.00	7.00	1.09	2.12
SPEED_LIMIT	Posted speed limit (miles per hour)	51	25.00	55.00	41.96	5.75
AVGAADT	Average AADT; bidirectional traffic volume for a corridor	51	11,538.00	76,837.00	36,663.00	16,244.00
SPCOFFLT	Minimum spacing from off-ramp to available left turn onto mainline from same side of road (feet)	6	129.00	550.00	336.00	137.00
SPCOFFRT	Minimum spacing from off-ramp to available right turn onto mainline from same side of road (feet)	6	20.00	360.00	204.00	140.00
SPCON	Minimum spacing from on-ramp to available right turn onto mainline from same side of road (feet)	4	33.00	255.00	158.00	105.00

St. Dev. = standard deviation.

Table 17 provides similar summary statistics for the dependent variables (i.e., number of crashes per mile per year by crash type). The dependent variable is presented as crash rate, which is the number of crashes divided by the segment length and by the years of crash data for a given corridor. The summary statistics for crash rate are presented based on corridor-level data. For example, the minimum total crash rate observed for a single corridor is 1.14 crashes/mi/yr.

Table 17. Summary statistics for Southern California dependent variables.

Dependent Variable (crashes/mi/yr)	Corridors	Minimum	Maximum	Mean	St. Dev.
Total crashes	51	1.14	108.99	23.29	19.66
Injury crashes	51	0.33	33.61	10.34	6.55
Rear-end crashes	51	0.00	43.60	9.60	9.27
Right-angle crashes	51	0.00	14.99	2.46	2.77
Turning crashes	51	0.33	35.88	7.19	6.29

St. Dev. = standard deviation.

REGION 4: MINNESOTA

Data were collected for 59 corridors in Minnesota, totaling nearly 160 mi. Table 18 indicates the centerline miles of corridor data included in the models for each of the nine scenarios (urban commercial, urban mixed-use, urban residential, suburban commercial, suburban mixed-use, suburban residential, urbanizing commercial, urbanizing mixed-use, and urbanizing residential).

Table 18. Minnesota mileage by area type and land use.

Scenario	Commercial	Mixed-Use	Residential	Total
Urban	16.13	17.39	11.19	44.71
Suburban	17.03	19.12	17.88	54.03
Urbanizing	23.61	14.54	21.93	60.08
Total	56.77	51.05	51.00	158.82

In preparation for data analysis, variables were transformed into a format appropriate for modeling, and new variable names were assigned. Table 19 presents the variable names, brief descriptions, and summary statistics, including the number of corridors and minimum, maximum, mean, and standard deviations for all independent variables. The summary statistics are computed based on corridor-level data. For some variables, the number of corridors is fewer than 59 because a variable is not relevant to all corridors. For example, if there is no median, then the number of median openings is not a relevant variable.

Table 19. Summary statistics for Minnesota independent variables.

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
PROPLANE1	Proportion of total length with two lanes	59	0.00	1.00	0.31	0.43
PROPLANE2	Proportion of total length with three or four lanes	59	0.00	1.00	0.66	0.43
PROPLANE3	Proportion of total length with five or more lanes	59	0.00	1.00	0.03	0.14
PROPDIV	Proportion of total length with curb or raised concrete median	59	0.00	1.00	0.55	0.45
PROPTWLTL	Proportion of total length with a TWLTL	59	0.00	1.00	0.07	0.21
PROPUNDIV	Proportion of total length with an undivided median	59	0.00	1.00	0.38	0.43
PROPNODEV	Proportion of total length with no adjacent development	59	0.00	0.40	0.02	0.08
PROPPARTDEV	Proportion of total length with partial adjacent development	59	0.00	1.00	0.86	0.27
PROPFULLDEV	Proportion of total length with full adjacent development	59	0.00	1.00	0.12	0.27
PROPLIGHT	Proportion of total length with illumination present	59	0.00	1.00	0.48	0.46
PROPPOORPVMNT	Proportion of total length with poor pavement condition	59	0.00	1.00	0.06	0.21
PROPVC	Proportion of total length with visual clutter	59	0.00	1.00	0.22	0.34
PROPLIMCONN	Proportion of total length with limited connectivity on adjacent developments	59	0.00	1.00	0.71	0.35
PROPMODCONN	Proportion of total length with moderate connectivity on adjacent developments	59	0.00	1.00	0.25	0.32
PROPSIGCONN	Proportion of total length with significant connectivity on adjacent developments	59	0.00	1.00	0.04	0.18
PROPFRONTRD	Proportion of total length with a frontage road	59	0.00	1.00	0.60	0.41
DRWYDENS	Number of driveways per mile	59	0.00	73.86	16.06	16.99
UNSIGDENS	Number of unsignalized intersections per mile	59	0.00	15.24	5.04	4.08
ACCDENS	Number of driveways plus unsignalized intersections per mile	59	0.00	79.72	21.10	20.02
SIGDENS	Number of signalized intersections per mile	59	0.21	7.21	2.64	1.63
NODRWYS	Number of driveways	59	0.00	221.00	38.19	45.99
NOCOMFULLDRWY	Number of commercial full-movement driveways	59	0.00	89.00	13.68	21.18
NORESFULLDRWY	Number of residential full-movement driveways	59	0.00	160.00	16.93	33.00
NOCOMLIMDRWY	Number of commercial limited-movement driveways	59	0.00	62.00	6.47	14.16
NORESLIMDRWY	Number of residential limited-movement driveways	59	0.00	15.00	1.10	2.75
NOUNSIG	Number of unsignalized intersections	59	0.00	51.00	12.59	12.61
NO3LEGUNSIG	Number of 3-legged unsignalized intersections	59	0.00	38.00	8.03	8.73
NO4LEGUNSIG	Number of 4-legged unsignalized intersections	59	0.00	22.00	4.47	5.65
NO5LEGUNSIG	Number of 5-legged unsignalized intersections	59	0.00	1.00	0.07	0.25
NO3LEGFULLUNSIG	Number of 3-legged full-movement unsignalized intersections	59	0.00	38.00	5.73	8.38
NO3LEGLIMUNSIG	Number of 3-legged limited-movement unsignalized intersections	59	0.00	12.00	2.32	3.31
NO3LEGRIROUNSIG	Number of 3-legged right-in/right-out unsignalized intersections	59	0.00	11.00	2.12	3.11

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
NO3LEGLFMOUNSIG	Number of 3-legged left from major only unsignalized intersections	59	0.00	2.00	0.20	0.48
NO4LEGFULLUNSIG	Number of 4-legged full-movement unsignalized intersections	59	0.00	22.00	4.47	5.66
NO4LEGLIMUNSIG	Number of 4-legged limited movement unsignalized intersections	59	0.00	1.00	0.02	0.13
NORTLUNSIG	Number of unsignalized intersections with a right-turn lane	59	0.00	19.00	3.32	4.24
NOLTLUNSIG	Number of unsignalized intersections with a left-turn lane	59	0.00	29.00	4.39	6.23
NOSIG	Number of signalized intersections	59	1.00	19.00	6.03	4.25
MINSPCSIG	Minimum spacing of signalized intersections (feet)	54	141.00	6,538.00	1,421.00	1,325.00
MAXSPCSIG	Maximum spacing of signalized intersections (feet)	54	143.00	27,595.00	4,007.00	3,997.00
NO3LEGSIG	Number of 3-legged signalized intersections	59	0.00	4.00	0.68	1.12
NO4LEGSIG	Number of 4-legged signalized intersections	59	1.00	17.00	5.32	3.73
NO5LEGSIG	Number of 5-legged signalized intersections	59	0.00	2.00	0.03	0.26
NORTLSIG	Number of signalized intersections with major road right-turn lane	59	0.00	11.00	3.76	2.88
NOLTLSIG	Number of signalized intersections with major road left-turn lane	59	0.00	17.00	5.03	3.66
NOMEDOP	Number of median openings	47	0.00	22.00	2.66	4.29
NOMEDOPLT	Number of median openings with a left-turn lane	47	0.00	17.00	2.45	3.96
NOMEDOPNOLT	Number of median openings without a left-turn lane	47	0.00	5.00	0.36	1.05
SPEED_LIMIT	Posted speed limit (miles per hour)	59	30.00	60.00	42.97	9.88
AVGAADT	Average AADT; bidirectional traffic volume for a corridor	59	5,423.00	70,333.00	24,111.00	13,794.00
AVGCOMMAADT	Average commercial vehicle AADT	59	101.00	4,038.00	894.00	709.00
SPCOFFLT	Minimum spacing from off-ramp to available left turn onto mainline from same side of road (feet)	25	142.00	2,640.00	831.00	601.00
SPCOFFRT	Minimum spacing from off-ramp to available right turn onto mainline from same side of road (feet)	25	142.00	2,640.00	802.00	598.00
SPCON	Minimum spacing from on-ramp to available right turn onto mainline from same side of road (feet)	26	70.00	3,500.00	723.00	727.00

St. Dev. = standard deviation.

Table 20 provides similar summary statistics for the dependent variables (i.e., number of crashes per mile per year by crash type). The dependent variable is presented as crash rate, which is the number of crashes divided by the segment length and by the years of crash data for a given corridor. The summary statistics for crash rate are presented based on corridor-level data. For example, the minimum total crash rate observed for a single corridor is 3.10 crashes/mi/yr.

Table 20. Summary statistics for Minnesota dependent variables.

Dependent Variable (crashes/mi/yr)	Corridors	Minimum	Maximum	Mean	St. Dev.
Total crashes	59	3.10	140.26	33.32	27.55
Injury crashes	59	1.19	52.39	11.07	10.80
Rear-end crashes	59	0.33	67.83	16.13	16.33
Right-angle crashes	59	0.36	27.64	5.72	6.10
Turning crashes	59	0.00	23.93	2.49	3.52

St. Dev. = standard deviation.

CHAPTER 6. ANALYSIS

GLM techniques were applied to estimate the models. A negative binomial error structure was specified, following the state of the art in modeling crash data. The negative binomial structure is now recognized as more appropriate for crash counts than the normal distribution assumed in conventional regression modeling. Crash counts per year by crash type were used as estimates of the dependent variable, while corresponding roadway characteristics and traffic volume data were used as the independent variables.

Preliminary models were developed for each of the four regions (Northern California, Southern California, Minnesota, and North Carolina). Within each land use type (i.e., mixed-use, commercial, and residential), each corridor was identified as located within an urban, suburban, or urbanizing area. All area types were combined within the respective land use type to develop reliable models. A factor variable was included in each model to account for any differences attributable to area type, but the differences were minor and not statistically significant. This is not to say there is no difference in crash patterns among area types, but the data did not allow quantification of this relationship. It is also likely that area type is better described by other variables in the model. For example, the traffic volume, number of lanes, access density, and frontage development can be used to describe the characteristics of a corridor and are more quantitative than defining a corridor as “urban, suburban, or urbanizing.” Therefore, area type was not included in the final models.

The first step in the analysis process was to develop a model using only *AADT* as a predictor variable and both the number of years and corridor length as offset variables. The general form of this model is given by the equation in figure 17.

$$Crashes = years * segment\ length * \alpha * AADT^{\beta}$$

Figure 17. Equation. General form of crash prediction model.

Where:

α = constant term estimated from the regression model.
β = estimated coefficient from the regression model for AADT.

The general model was successfully developed in each scenario, and there were no apparent outliers or errors in the data. Additional variables were then investigated. This investigation involved entering each variable one at a time such that only AADT and the new variable of interest were included. The estimated parameter and its standard error were examined to determine the following:

- Whether the direction and magnitude of effect were logical.
- Whether the estimate was close to being statistically significant.
- Whether the estimated dispersion parameter (k) improved significantly. The properties of k were such that lower values indicate a better fit.

Alternate model forms were explored using the procedure described by Hauer and Bamfo.[18] To summarize, a model with AADT as the only explanatory variable was first estimated. Then, for a variable of interest, the model was used to predict the number of crashes for each site. The sum of observed crashes for all sites was then divided by the sum of predicted crashes for all sites with the same value of the explanatory variable, or range of values in the case of continuous variables. A plot of the observed to predicted ratios for the range of the explanatory variables is then used to examine trends that would suggest an appropriate model form for the explanatory variable. It was determined that the exponential model form is appropriate because of its flexibility, and this form was retained for development of the final models.

Pearson correlation statistics were computed for each dependent and independent variable. The correlation matrix was not the primary driver of model building but helped to identify those variables most associated with the different crash types. This also helped to identify independent variables that were highly correlated. High correlation between independent variables can be problematic in developing models. Specifically, the inclusion of highly correlated variables can lead to illogical results. While omitting a highly correlated variable may help avoid this issue, doing so limits the practicality of the results if one is interested in the safety impacts of the omitted variable. In this study, the research team estimated a series of models with various combinations of variables as a reasonable compromise between statistical efficiency and practicality. This addressed issues related to correlation and provided information for all variables of interest.

The next step was to enter the most promising variables into the model in combinations. Some variables were dropped because the effect was not statistically significant or because the direction of effect was illogical. The latter case was likely due to highly correlated variables in the model. In some cases, it was necessary to choose between two or more variables, removing highly correlated variables from the model. The main factors in these decisions were improvement in overall model fit and selection of the variables that were most likely of interest in the application of the model to AM.

Following the development of preliminary models for each region, feedback was requested from the steering committee on which variables with promise were most desired in the models. Not all variables could be included in the models owing to both sample size limitations and correlation between potential explanatory variables. Therefore, the steering committee was asked to identify the explanatory variables that would be most useful to practitioners. The following variables were indicated to be most important for practical use according to the feedback:

- Adjacent land use (i.e., no development, partial development, full development).
- Driveway density.
- Median type (i.e., undivided, TWLTL, divided).
- Number of median openings.
- Signalized intersection density.
- Posted speed limit.

Of these variables, all were included in various models except for posted speed limit. It should be noted that vehicle speed is related to the severity of a crash, but the posted speed limit was not included in these models because it was not statistically significant after accounting for other variables. Posted speed tends to be highly correlated with other variables such as access density and frontage type. This is likely the reason it could not be included in the final models. It is also possible that posted speed does not provide an accurate representation of the actual speeds (i.e., operating speed may be a better alternative for capturing the impacts of speed).

Other variables were also explored for potential inclusion in the models. For example, the number of lanes is a common variable to describe the characteristics of a roadway. In this case, the number of lanes was allowed to vary throughout a corridor (i.e., a new corridor was not defined if the number of lanes changed). This helped to avoid issues related to frequent section breaks (e.g., low crash counts associated with short segments). To describe the variation in lanes within a corridor, the following variables were defined:

- *PROPLANE1* = proportion of total length with two lanes.
- *PROPLANE2* = proportion with three or four lanes.
- *PROPLANE3* = proportion with five or more lanes.

The following section discusses the final modeling results, and the final models are presented in appendix C.

CHAPTER 7. RESULTS

The models are presented in one of two forms. In most cases, the model form is represented by the equation in figure 18. In these cases, the result is expressed as crashes per mile per year. In other cases, the traffic volume variable is not statistically significant, indicating a linear relationship between traffic volume and crashes. In these limited cases, the model form is reduced to the equation in figure 19, and the result is expressed as crashes per MVMT. The result from the equation in figure 19 is multiplied by *MVMT* to express the result as crashes per mile per year.

$$Crashes/mile/year = \exp^{(intercept+region)} * (AADT)^{b} * \exp^{(c_1 * X_1 + \ldots + c_n * X_n)}$$

Figure 18. Equation. Crash prediction model with regional calibration.

$$Crashes/MVMT = \exp^{(intercept+region)} * \exp^{(c_1 * X_1 + \ldots + c_n * X_n)}$$

Figure 19. Equation. Normalized crash prediction model with regional calibration.

Where:

intercept = coefficient estimated for the model to account for unobserved variables.

region = coefficient estimated for the model when the applicable region is North Carolina or Minnesota; a value of 0 is used if the applicable region is Northern California or Southern California.

AADT = annual average daily two-way traffic for the corridor.

b = coefficient estimated for the AADT term in the model.

c_i = a vector of coefficients estimated for the other independent variables included in the model.

x_i = a vector of other independent variables included in the model (i.e., the specific roadway attributes such as access density).

An indicator variable is included in the equations in figure 18 and figure 19 to identify the region in which the corridor is located. In this study, the corridors were located in North Carolina, Minnesota, Northern California, or Southern California. The regional indicator variable accounts for differences between regions such as those related to crash reporting practices, driver demographics, weather, and other non-access-related factors affecting reported crashes. The regional indicators for Northern and Southern California were similar, and it was determined that the variables were sufficiently close to be considered as one region. Similarly, the regional indicators for Minnesota and North Carolina were sufficiently similar to consider them as one region. The aggregate regions helped to increase sample sizes within the models (i.e., two regions instead of four) and reflect the similarities in data between the aggregated regions. Summary statistics are provided by region in table 10 through table 20. An examination of the summary statistics revealed similarities among the corridors in the aggregated regions. When applying the models in appendix C, users should select an applicable region based on a comparison between the corridor of interest and the summary statistics in appendix D, not on geographic proximity.

The final models are presented in appendix C, organized by land use (mixed-use, commercial, and residential) and crash type (total, injury, turning, rear-end, and right-angle). Table 21 through table 23 provide an overview of the structure of appendix C, including a summary of the models and explanatory variables for each land use and crash type combination. The following specific notes should be considered when applying the models:

- Specific crash types cannot be summed to calculate total crashes because models were not developed for all possible crash types.

- North Carolina crashes coded as rear-end turn crashes are included in both rear-end and turning crashes. Because the specific crash types cannot be summed to calculate total crashes, it was determined that double-counting should not pose a problem for the crash type models.

- Models are not provided for property-damage-only crashes because of the inconsistent reporting of these crashes. The national focus is on fatal and injury crashes, and models are provided to assess the impacts on these severe crashes.

- All explanatory variables could not be accommodated in a single model; hence, there are the following alternate model forms with various combinations of variables:

    - In some cases, it is necessary to select from multiple available models because one or more models were successfully developed for each land use type/crash type combination. Further discussion of model selection and related examples are provided in chapter 8.

    - In some cases, explanatory variables are included for a specific crash type but not for the land use of interest. Further consideration of these variables is provided in chapter 8.

    - In some cases, explanatory variables could not be included in any models because of their lack of statistical significance or an illogical direction of effect. Further consideration of these variables is provided in chapter 8 and in appendix E.

Table 21. Overview of mixed-use models by crash type.

Crash Type	Model	*ACCDENS*	*MEDOPDENS*	*PROPDIV*	*PROPFULLDEV*	*PROPLANE1*	*PROPNODEV*	*PROPVC*	*PROPTWLTL*	*SIGDENS*	*UNSIGDENS*
Total	1	X	—	—	—	X	—	—	—	X	—
Total	2	—	—	—	—	X	—	—	—	X	X
Total	3	—	—	—	—	—	X	—	—	—	—
Injury	1	—	—	—	—	X		—	—	X	—
Injury	2	—	—	—	—	X	X	—	—	—	—
Turning	1	X	—	—	—	—	—	—	—	X	—
Turning	2	—	—	—	—	—		—	—	X	X
Turning	3	—	—	—	—	—	X	—	—	—	—
Rear-end	1	—	—	—	—	—	—	—	—	X	—
Rear-end	2	—	—	—	—	X	—	—	—	X	—
Right-angle	1	X	—	—	—	—	—	—	—	X	—
Right-angle	2	—	X	X	—	—	—	—	—	—	—
Right-angle	3	—	—	—	X	—	—	—	—	—	—

—Variable that is not included in a model.
X = explanatory variable in a model; *ACCDENS* = number of driveways plus unsignalized intersections per mile; *MEDOPDENS* = number of median openings per mile; *PROPDIV* = proportion of corridor length with divided median; *PROPFULLDEV* = proportion of corridor length with full roadside development; *PROPLANE1* = proportion of corridor length with two lanes; *PROPNODEV* = proportion of length with no roadside development; *PROPVC* = proportion of length with visual clutter; *PROPTWLTL* = proportion of corridor length with TWLTL; *SIGDENS* = number of signalized intersections per mile; *UNSIGDENS* = number of unsignalized intersections per mile.

Table 22. Overview of commercial models by crash type.

Crash Type	Model	*ACCDENS*	*MEDOPDENS*	*PROPDIV*	*PROPFULLDEV*	*PROPLANE1*	*PROPNODEV*	*PROPVC*	*PROPTWLTL*	*SIGDENS*	*UNSIGDENS*
Total	1	X	—	—	—	—	—	—	—	X	—
Total	2	—	—	—	—	—	X	—	—	—	—
Injury	1	X	—	—	—	—	—	—	—	X	—
Injury	2	—	—	—	—	X	X	—	—	—	—
Injury	3	—	—	—	—	X	—	X	—	—	—
Injury	4	—	—	—	—	X	—	—	—	X	—
Turning	1	X	—	—	—	—	—	—	—	X	—
Turning	2	—	—	—	—	X	X	—	—	—	—
Rear-end	1	—	—	—	—	X	—	—	—	X	—
Rear-end	2	—	—	—	—	—	—	—	—	X	—
Right-angle	1	X	—	—	—	—	—	—	—	X	—
Right-angle	2	—	—	—	X	—	—	—	—	—	—

—Variable that is not included in a model.
X = explanatory variable in a model; *ACCDENS* = number of driveways plus unsignalized intersections per mile; *MEDOPDENS* = number of median openings per mile; *PROPDIV* = proportion of corridor length with divided median; *PROPFULLDEV* = proportion of corridor length with full roadside development; *PROPLANE1* = proportion of corridor length with two lanes; *PROPNODEV* = proportion of length with no roadside development; *PROPVC* = proportion of length with visual clutter; *PROPTWLTL* = proportion of corridor length with TWLTL; *SIGDENS* = number of signalized intersections per mile; *UNSIGDENS* = number of unsignalized intersections per mile.

Table 23. Overview of residential models by crash type.

Crash Type	Model	*ACCDENS*	*MEDOPDENS*	*PROPDIV*	*PROPFULLDEV*	*PROPLANE1*	*PROPNODEV*	*PROPVC*	*PROPTWLTL*	*SIGDENS*	*UNSIGDENS*
Total	1	—	—	—	X	X	—	—	—	X	—
Total	2	—	—	—	—	X	—	—	—	X	—
Total	3	X	—	—	—	—	—	—	—	—	—
Total	4	—	—	—	—	—	X	—	—	—	—
Injury	1	—	—	—	—	X	—	—	—	X	—
Injury	2	—	—	—	X	X	—	—	—	—	—
Turning	1	—	—	—	—	—	—	—	—	X	X
Turning	2	—	—	—	—	—	—	—	—	X	X
Turning	3	X	—	—	—	—	—	—	—	X	—
Turning	4	—	—	—	—	—	X	—	—	—	—
Rear-end	1	—	—	—	—	—	—	—	—	X	—
Rear-end	2	—	—	—	—	X	—	—	X	—	—
Rear-end	3	—	—	—	—	X	—	—	—	X	—
Right-angle	1	—	—	—	—	—	—	—	—	—	—
Right-angle	2	—	—	—	X	X	—	—	—	X	—
Right-angle	3	X	—	—	—	—	—	—	—	X	—

—Variable that is not included in a model.
X = explanatory variable in a model; *ACCDENS* = number of driveways plus unsignalized intersections per mile; *MEDOPDENS* = number of median openings per mile; *PROPDIV* = proportion of corridor length with divided median; *PROPFULLDEV* = proportion of corridor length with full roadside development; *PROPLANE1* = proportion of corridor length with two lanes; *PROPNODEV* = proportion of length with no roadside development; *PROPVC* = proportion of length with visual clutter; *PROPTWLTL* = proportion of corridor length with TWLTL; *SIGDENS* = number of signalized intersections per mile; *UNSIGDENS* = number of unsignalized intersections per mile.

CHAPTER 8. GUIDANCE FOR PRACTICAL APPLICATION OF THE MODELS

This chapter is intended to guide a user through the steps required to select and apply the most appropriate model(s) for estimating the safety impacts of a contemplated AM strategy or combination of strategies for a corridor. The model selection and application process involves the following four steps.

1. Select land use and region.
2. Select crash types and variables of interest.
3. Select analysis type of interest.
4. Select applicable model(s) and perform analysis.

The remainder of this chapter provides a detailed discussion of the four-step process. Chapter 9 provides numerical sample problems to illustrate the steps presented here.

STEP 1: SELECT LAND USE AND REGION

Select the applicable land use and region based on the application context. The land use categories include mixed-use, commercial, or residential as defined in chapter 2. Regions include North Carolina, Minnesota, Northern California, or Southern California. One consideration in selecting an applicable region is a comparison of local values with the mean values of the variables in each region (see appendix D). It is recommended that users select an applicable region based on the summary statistics that best match their study corridor rather than selecting the region based on geographic proximity. The result of this step is the identification of the most applicable land use type and region.

STEP 2: SELECT CRASH TYPES AND VARIABLES OF INTEREST

Select the crash types and variables of interest. The selection of crash types and variables determines which model(s) will be needed. The potential crash types include total, injury, turning, rear-end, and right-angle as defined in table 8. The potential variables of interest include *AADT*, *corridor length*, and the following access-related characteristics:

- *ACCDENS* = number of driveways plus unsignalized intersections per mile.
- *MEDOPDENS* = number of median openings per mile.
- *PROPDIV* = proportion of corridor length with divided median.
- *PROPFULLDEV* = proportion of corridor length with full roadside development.
- *PROPLANE1* = proportion of corridor length with two lanes.
- *PROPNODEV* = proportion of length with no roadside development.
- *PROPVC* = proportion of length with visual clutter.
- *PROPTWLTL* = proportion of corridor length with TWLTL.
- *SIGDENS* = number of signalized intersections per mile.
- *UNSIGDENS* = number of unsignalized intersections per mile.

STEP 3: SELECT ANALYSIS TYPE OF INTEREST

Select the analysis type of interest from the following two choices:

- **Analysis option 1.** Compare relative safety impact of strategies. This option applies to both existing corridors and new construction and provides an estimate of the change in predicted crashes or the percent change in crashes based on a proposed change in corridor characteristics (e.g., traffic volume, corridor length, and AM strategies). The results are presented as the change in predicted crash frequency or the percent change in crashes per year for alternative scenarios (e.g., scenario B is expected to result in 10 percent more injury crashes per year than scenario A). It is not appropriate to use this type of analysis in an economic evaluation because it does not account for the expected number of crashes (only the relative change). Note: Apply algorithm 1 in step 4.

- **Analysis option 2.** Compare expected crashes between strategies. This option applies to existing corridors with an available crash history and provides an estimate of the expected crashes per year; however, it requires the observed crash history for the study corridor. The EB method is employed, combining the observed crash history and the predicted crashes from the model to obtain the expected number of crashes. The EB method corrects for several potential sources of bias, including variables that are not in the model. The results are presented as the expected crash frequency per year for each alternative. The results from this analysis may be used to compare the expected number of crashes by type among various scenarios and can be used in an economic evaluation (e.g., benefit–cost analysis). Note: Apply algorithm 2 in step 4.

STEP 4: SELECT APPLICABLE MODEL(S) AND PERFORM ANALYSIS

Select the applicable model(s) based on table 24 through table 26. Note the following factors, in priority order, were considered when populating table 24 through table 26 when more than one option was available in appendix C for the land use and crash type of interest:

1. Statistical significance of the coefficients for the variables of interest as indicated by the size of the *p*-value; a lower *p*-value indicates a higher level of significance.

2. A smaller value of *k* indicates a better fitting model.

Continue to algorithm 1 or algorithm 2 based on the analysis type selected in step 3 and the applicable models identified in table 24 through table 26. Recall that algorithm 1 applies to analysis option 1, and algorithm 2 applies to analysis option 2. Sample problems are presented in chapter 9 to illustrate various scenarios, and the following guiding principles are common to all scenarios:

- If necessary, models may be extrapolated with caution across land use types for a given crash type. However, models for one crash type may not be extrapolated to another crash type.

- In some situations, it may not be possible to estimate the impacts of a strategy for all or some crash types.

- If several crash types are selected, the sum of differences between two alternatives for specific crash types cannot be greater than the number of all crash types combined. If this occurs, the estimate for all crash types combined should be equal to the sum of the specific crash types. Similarly, the estimate for injury crashes cannot be greater than total crashes.

- The analyst should review the minimum and maximum values of each variable of interest for the given land use and region (see appendix D). If an entered value is outside the range of data on which the model is based, the analyst should note that the model may not provide a reliable estimate of the effect of that variable.

- If analysis option 2 is selected in step 3 (i.e., compare expected crashes between strategies), the models should be calibrated for the local jurisdiction when possible. Model calibration is discussed in chapter 10.

Table 24. Relevant models by crash type of interest—mixed land use.

Crash Type	Variables Available for Specified Land Use	Applicable Model (Table No.)	Variables Available Through Extrapolation	Applicable Model for Extrapolation of Variables (Table No.)	Applicable Base Model for Extrapolation and EB Method (Table No.)
Total	*ACCDENS*	Table 34	—	—	Table 35
Total	*PROPLANE1*	Table 35	—	—	Table 35
Total	*PROPNODEV*	Table 36	—	—	Table 35
Total	*SIGDENS*	Table 35	—	—	Table 35
Total	*UNSIGDENS*	Table 35	—	—	Table 35
Total	—	—	*PROPFULLDEV*	Table 59	Table 35
Injury	*PROPLANE1*	Table 38	—	—	Table 38
Injury	*PROPNODEV*	Table 38	—	—	Table 38
Injury	*SIGDENS*	Table 37	—	—	Table 38
Injury	—	—	*ACCDENS*	Table 49	Table 38
Injury	—	—	*PROPVC*	Table 51	Table 38
Injury	—	—	*PROPFULLDEV*	Table 64	Table 38
Turning	*ACCDENS*	Table 39	—	—	Table 40
Turning	*PROPNODEV*	Table 41	—	—	Table 40
Turning	*SIGDENS*	Table 39	—	—	Table 40
Turning	*UNSIGDENS*	Table 40	—	—	Table 40
Turning	—	—	*PROPLANE1*	Table 54	Table 40
Rear-end	*PROPLANE1*	Table 43	—	—	Table 43
Rear-end	*SIGDENS*	Table 43	—	—	Table 43
Rear-end	—	—	*PROPTWLTL*	Table 70	Table 43
Right-angle	*ACCDENS*	Table 44	—	—	Table 44
Right-angle	*MEDOPDENS*	Table 45	—	—	Table 44
Right-angle	*PROPDIV*	Table 45	—	—	Table 44
Right-angle	*PROPFULLDEV*	Table 46	—	—	Table 44
Right-angle	*SIGDENS*	Table 44	—	—	Table 44
Right-angle	—	—	*PROPLANE1*	Table 73	Table 44

—Not applicable.

Table 25. Relevant models by crash type of interest—commercial land use.

Crash Type	Variables Available for Specified Land Use	Applicable Model (Table No.)	Variables Available Through Extrapolation	Applicable Model for Extrapolation of Variables (Table No.)	Applicable Base Model for Extrapolation and EB Method (Table No.)
Total	*ACCDENS*	Table 47	—	—	Table 47
Total	*SIGDENS*	Table 47	—	—	Table 47
Total	*PROPNODEV*	Table 48	—	—	Table 47
Total	—	—	*UNSIGDENS*	Table 35	Table 47
Total	—	—	*PROPLANE1*	Table 34	Table 47
Total	—	—	*PROPFULLDEV*	Table 59	Table 47
Injury	*ACCDENS*	Table 49	—	—	Table 52
Injury	*SIGDENS*	Table 52	—	—	Table 52
Injury	*PROPNODEV*	Table 50	—	—	Table 52
Injury	*PROPLANE1*	Table 52	—	—	Table 52
Injury	*PROPVC*	Table 51	—	—	Table 52
Injury	—	—	*PROPFULLDEV*	Table 64	Table 52
Turning	*ACCDENS*	Table 53	—	—	Table 53
Turning	*SIGDENS*	Table 53	—	—	Table 53
Turning	*PROPNODEV*	Table 54	—	—	Table 53
Turning	*PROPLANE1*	Table 54	—	—	Table 53
Turning	—	—	*UNSIGDENS*	Table 40	Table 53
Rear-end	*SIGDENS*	Table 56	—	—	Table 56
Rear-end	*PROPLANE1*	Table 56	—	—	Table 56
Rear-end	—	—	*PROPTWLTL*	Table 70	Table 56
Right-angle	*ACCDENS*	Table 57	—	—	Table 57
Right-angle	*SIGDENS*	Table 57	—	—	Table 57
Right-angle	*PROPFULLDEV*	Table 58	—	—	Table 57
Right-angle	—	—	*MEDOPDENS*	Table 45	Table 57
Right-angle	—	—	*PROPDIV*	Table 45	Table 57
Right- angle	—	—	*PROPLANE1*	Table 73	Table 57

—Not applicable.

Table 26. Relevant models by crash type of interest—residential land use.

Crash Type	Variables Available for Specified Land Use	Applicable Model (Table No.)	Variables Available Through Extrapolation	Applicable Model for Extrapolation of Variables (Table No.)	Applicable Base Model for Extrapolation and EB Method (Table No.)
Total	*PROPLANE1*	Table 59	—	—	Table 59
Total	*SIGDENS*	Table 59	—	—	Table 59
Total	*PROPFULLDEV*	Table 59	—	—	Table 59
Total	*ACCDENS*	Table 61	—	—	Table 59
Total	*PROPNODEV*	Table 62	—	—	Table 59
Injury	*PROPLANE1*	Table 64	—	—	Table 63
Injury	*SIGDENS*	Table 63	—	—	Table 63
Injury	*PROPFULLDEV*	Table 64	—	—	Table 63
Injury	—	—	*ACCDENS*	Table 49	Table 63
Injury	—	—	*PROPNODEV*	Table 38	Table 63
Injury	—	—	*PROPVC*	Table 51	Table 63
Turning	*UNSIGDENS*	Table 66	—	—	Table 66
Turning	*SIGDENS*	Table 67	—	—	Table 66
Turning	*ACCDENS*	Table 67	—	—	Table 66
Turning	*PROPNODEV*	Table 68	—	—	Table 66
Turning	—	—	*PROPLANE1*	Table 54	Table 66
Rear-end	*SIGDENS*	Table 69	—	—	Table 70
Rear-end	*PROPLANE1*	Table 70	—	—	Table 70
Rear-end	*PROPTWLTL*	Table 70	—	—	Table 70
Right-angle	*SIGDENS*	Table 73	—	—	Table 73
Right-angle	*PROPLANE1*	Table 73	—	—	Table 73
Right-angle	*PROPFULLDEV*	Table 73	—	—	Table 73
Right-angle	*ACCDENS*	Table 74	—	—	Table 73

—Not applicable.

ALGORITHM 1

Algorithm 1 pertains to analysis option 1, comparing the relative safety impact of two alternatives, alternative A and alternative B, one of which can be a do-nothing alternative.

Step 4.1.1: Data for Conditions of Interest

The user identifies values for alternative A and alternative B, including *corridor length*, *AADT*, and all variables of interest for all models to be used in the analysis. A value must be provided for *corridor length* and *AADT*. For all other variables, a default value may be used if a value cannot be entered (default values are given in appendix D). The default value is the mean value for the variable of interest and is determined by the land use and region selected.

Step 4.1.2: Calculations for Nonextrapolated Variables

Using the model(s) from column 3 in table 24 through table 26, compute the predicted crashes for existing conditions based on the values identified for alternative A. The next calculation only changes the variable(s) of interest, and the following two cases may be distinguished:

- Case 1. All variables of interest appear in one model for the crash type of interest. In this case, compute the predicted crashes for proposed conditions based on the values identified for alternative B.
- Case 2. One or more variables of interest exist in multiple models for the crash type of interest. In this case, it is necessary to avoid double-counting the effect of variables. From a computational perspective, it is important to focus on one variable at a time. For each variable of interest, separately compute the predicted crashes for proposed conditions using the applicable model and the value identified for alternative B. The predicted crashes for each proposed condition are subtracted from the predicted crashes for the existing conditions (alternative A) to estimate the impact of each individual variable of interest. The impacts of the individual variables are then summed to estimate the aggregate impact of alternative B. Similarly, if either *corridor length* or *AADT* changes in alternative B, these changes are considered in isolation. The appropriate model for considering *corridor length* or *AADT* changes is identified in column 6 of table 24 through table 26. In this case, all variables, with the exception of *corridor length* and *AADT,* are kept constant, and the predicted crashes are computed for alternative B.

Step 4.1.3: Calculations for Extrapolated Variables

Variables available through extrapolation of another land use model are identified in column 4 of table 24 through table 26. The extrapolation method first requires the use of a base model from the land use and crash type of interest to predict crashes for existing conditions. Then, a model is selected from another land use to estimate the impacts of the variables of interest. For each variable to be considered through extrapolation, take following steps.

Step 4.1.3a Baseline Predicted Crashes for Existing Condition

Use the applicable base model from table 24 through table 26 with the values from the existing condition (alternative A) to estimate the baseline predicted crashes for the existing condition.

Step 4.1.3b Estimate the Impacts of the Variables of Interest for Existing Conditions

The effects of the variables of interest for the existing conditions are estimated using the equation in figure 20:

$$\textit{Multiplier} = \exp^{(\textit{coefficient})*(\textit{Variable Proposed Value} - \textit{Variable Default Value})}$$

Figure 20. Equation. Formula to estimate effects of variables of interest for existing conditions.

The *coefficient* is obtained for the variable of interest from the extrapolation model identified in column 5 of table 24 through table 26. The *Variable Actual Value* is obtained from the existing condition (alternative A). The *Variable Default Value* is the mean value of the variable of interest for the region and land use type from which that model was developed. Default values can be found in appendix D.

Step 4.1.3c Adjusted Predicted Crashes for Existing Condition

The estimate from step 4.1.3b is then multiplied by the estimate from step 4.1.3a to compute the adjusted predicted crashes for existing conditions.

Step 4.1.3d Baseline Predicted Crashes for Proposed Condition

Use the applicable base model from table 24 through table 26 with the values from the proposed condition (alternative B) to estimate the baseline predicted crashes for the proposed condition.

Step 4.1.3e Estimate the Impacts of the Variables of Interest for Proposed Conditions

The effects of the variables of interest for the proposed conditions are estimated using the equation in figure 20.

The *coefficient* is obtained for the variable of interest from the extrapolation model identified in column 5 of table 24 through table 26. The *Variable Proposed Value* is obtained from the proposed condition (alternative B). The *Variable Default Value* is the mean value of the variable of interest for the region and land use type from which that model was developed. Default values can be found in appendix D.

Step 4.1.3f Adjusted Predicted Crashes for Proposed Condition

The estimate from step 4.1.3e is then multiplied by the estimate from step 4.1.3d to compute the adjusted predicted crashes for proposed conditions.

Step 4.1.4: Estimated Safety Impacts

The results from steps 4.1.2 and 4.1.3 can be used to compare the predicted crashes per year for alternative A and alternative B. The results may be presented as the difference or the percent change in predicted crashes per year.

ALGORITHM 2

Algorithm 2 pertains to analysis option 2, comparing expected crashes for existing and proposed conditions. Recall that one of the conditions is the existing condition because a crash history is required to apply algorithm 2. In this context, alternative A is the existing condition, and alternative B is the proposed condition.

Step 4.2.1: Data for Conditions of Interest

The user identifies values for alternative A and alternative B, including *corridor length*, *AADT*, and all variables of interest for all models to be used in the analysis. A value must be provided for *corridor length* and *AADT*. For all other variables, a default value may be used if a value cannot be entered (default values are given in appendix D). The default value is the mean value for the variable of interest and is determined by the land use and region selected. The observed crash history for the existing condition is also identified, including the number of years of crash data and crash totals for each crash type selected. Finally, the user must identify a calibration factor for all crash types selected. The default value is 1.0, but a user may compute a local calibration factor based on the procedure described in chapter 10.

Step 4.2.2: Prediction for Existing Condition

Steps 4.2.2a through 4.2.2d are completed for each crash type selected. The baseline predicted crashes for the existing condition are modified using the EB method, which uses the crash history of the corridor. The EB method is used to compute the expected crashes.[19]

Step 4.2.2a Baseline Predicted Crashes for Existing Conditions

Use the applicable base model from column 6 of table 24 through table 26 with the values from alternative A to estimate the baseline predicted crashes for the existing condition.

Step 4.2.2b Estimated EB Weight

The EB weight (w) is estimated using the formula in figure 21.

$$w = 1 / [1 + (k * \mathit{years} * \mathit{step\ 4.2.2a\ estimate})]$$

Figure 21. Equation. Formula to estimate *w*.

Note that k is given for each specific model in appendix C.

Step 4.2.2c Expected Crashes for Existing Condition

The annual expected crash frequency (*EB estimate*) for existing conditions is calculated using the formula in figure 22.

$$\mathit{EB\ Estimate} = [w * (\mathit{step\ 4.2.2a\ estimate})] + [(1 - w) * (\mathit{observed\ crashes/years\ of\ data})]$$

Figure 22. Equation. Formula to estimate the annual expected crash frequency (*EB estimate*).

Step 4.2.2d Estimated EB Correction Factor

The *EB correction factor* is calculated as the expected crashes for existing conditions (step 4.2.2c) divided by the baseline predicted crashes for existing conditions (step 4.2.2a).

Step 4.2.3: Prediction for Proposed Condition

Step 4.2.3a Difference in Predicted Crashes for Existing and Proposed Condition

Apply steps 4.1.2 through 4.1.4 from algorithm 1 using the existing and proposed conditions as inputs. The result is an estimate of the difference in predicted crash frequency for the existing and proposed conditions.

Step 4.2.3b Adjusted Predicted Crashes for Existing Condition

Add the difference in predicted crashes from step 4.2.3a to the baseline predicted crashes for existing conditions from step 4.2.2a.

Step 4.2.3c Expected Crashes for Proposed Condition

Multiply the adjusted predicted crashes for the existing condition from step 4.2.3b by the *EB correction factor* from step 4.2.2d.

Step 4.2.4: Estimated Safety Impacts

The results from algorithm 2 can be used to compare the expected crashes per year for alternative A and alternative B. The expected crashes for the existing condition are estimated from step 4.2.2c. The expected crashes for the proposed condition are estimated from step 4.2.3c. The results may be presented as the difference or the percent change in expected crashes per year.

CHAPTER 9. SAMPLE PROBLEMS TO ILLUSTRATE THE USE OF THE MODELS

Six sample problems are presented in this chapter. For each sample problem, the four-step process presented in chapter 8 is referenced. The six sample problems apply to the following six scenarios:

- **Scenario 1.** All variables of interest are available in one (and only one) model for the land use and crash type of interest. Analysis option 1 is selected to estimate the relative safety impacts of alternatives.
- **Scenario 2.** Variables of interest appear in different models for the same land use and crash type of interest (i.e., using a combination of models to assess the impacts of multiple variables because some variables of interest are in one model, while other variables of interest are in another model). Analysis option 1 is selected to estimate the relative safety impacts of alternatives.
- **Scenario 3.** Variables of interest appear in models for different crash types (i.e., assessing the impacts of a variable over different crash types). Analysis option 1 is selected to estimate the relative safety impacts of alternatives.
- **Scenario 4.** All variables of interest are available in one or more models for the land use and crash type of interest. Analysis option 2 is selected to estimate the expected crashes for the given alternatives.
- **Scenario 5.** Variables of interest are available for a given crash type but not for the land use type of interest (i.e., extrapolating the impacts of a variable on a given crash type from models related to a different land use). Analysis option 1 is selected to estimate the relative safety impacts of alternatives.
- **Scenario 6.** Variables of interest do not appear in any models for any crash type or land use. Sample problem 6 and appendix E provide further guidance.

SAMPLE PROBLEM 1

Estimate the effect of multiple variables that are all in the same model (scenario 1).

Problem Definition

A planned development is expected to increase existing traffic volumes by 50 percent and change the general characteristics of a residential corridor in an urbanizing area. The new development will increase the frontage from 30 to 100 percent. A new signalized intersection is proposed in the middle of the corridor to help accommodate the expected growth. A concern has been raised regarding the potential increase in right-angle crashes because these tend to be severe. It is desired to predict the number of right-angle crashes for both the existing and proposed conditions. The predicted crashes will be compared to estimate the relative impacts of the proposed changes.

Step 1: Select Land Use and Region

This is a residential corridor. After reviewing the summary statistics for residential land use in each of the four regions from which the models were developed and comparing them to the local data, it is determined that the corridor is most comparable to North Carolina.

Step 2: Select Crash Types and Variables of Interest

As noted in the problem definition, right-angle crashes are of interest. In this case, the variables of interest are *PROPFULLDEV* and *SIGDENS*.

Step 3: Select Analysis Type of Interest

It is desired to estimate the relative safety of two alternatives, one of which is the do-nothing alternative (i.e., existing conditions). In this case, analysis option 1 (algorithm 1) is applicable because the objective is to compare the relative safety impacts.

Step 4: Select Applicable Model(s) and Perform Analysis

Table 26 presents the applicable models for right-angle crashes in a residential land use. The applicable model for *PROPFULLDEV* is residential right-angle model 2 (table 73). The applicable model for *SIGDENS* is residential right-angle model 2 (table 73). The applicable model is the same for the variables of interest, so multiple models and extrapolated variables are not required. Note that all variables are available to apply this model, so no default values are required.

The model coefficients from table 73 are as follows: *intercept* (–1.4079), *region* (0.8858 if North Carolina or Minnesota; 0 otherwise), *AADT* (0.1332), *SIGDENS* (0.2267), *PROPLANE1* (–0.3633), and *PROPFULLDEV* (0.4295). The equation in figure 18 is applicable to this model.

Step 4.1.1: Data for Conditions of Interest

The data for the existing condition (do-nothing alternative A) are the following:

- *Corridor length* = 2.5 mi.
- *AADT* = 15,000 vehicles per day (vpd).
- No signalized intersections: *SIGDENS* = 0 signals/mi.
- Entire length of corridor is two lanes: *PROPLANE1* = 1.0.
- Current frontage development is 30 percent: *PROPFULLDEV* = 0.30.

The data for the proposed condition (alternative B) are the following:

- *Corridor length* = 2.5 mi.
- *AADT* = 22,500 vpd (50-percent increase).

- 1 new signal: *SIGDENS* = 1 signal/2.5 mi = 0.4 signal/mi.
- Entire length of corridor is two lanes: *PROPLANE1* = 1.0 (unchanged).
- Frontage development increased from 30 to 100 percent: *PROPFULLDEV* = 1.0.

Step 4.1.2: Calculations for Nonextrapolated Variables

Case 1 applies when all variables of interest appear in only one model. Figure 23 and figure 24 predict right-angle crashes per year.

Predicted right-angle crashes/year (existing)

$$= (length) * \exp^{(intercept+region)} * (AADT)^{0.1332} * \exp^{(0.2267*SIGDENS-0.3633*PROPLANE1+0.4295*PROPFULLDEV)}$$

$$= (2.5) * \exp^{(-1.4079+0.8858)} * (15{,}000)^{0.1332} * \exp^{(0.2267*0-0.3633*1.0+0.4295*0.3)}$$

$$= 4.22 \text{ right-angle crashes/year}$$

Figure 23. Equations. *Calculation of predicted right-angle crashes/year (existing)*.

Predicted right-angle crashes/year (proposed)

$$= (length) * \exp^{(intercept+region)} * (AADT)^{0.1332} * \exp^{(0.2267*SIGDENS-0.3633*PROPLANE1+0.4295*PROPFULLDEV)}$$

$$= (2.5) * \exp^{(-1.4079+0.8858)} * (22{,}500)^{0.1332} * \exp^{(0.2267*0.40-0.3633*1.0+0.4295*1.0)}$$

$$= 6.59 \text{ right-angle crashes/year}$$

Figure 24. Equations. *Calculation of predicted right-angle crashes/year (proposed)*.

Step 4.1.3: Calculations for Extrapolated Variables

There are no extrapolated variables, so this step is not applicable.

Step 4.1.4: Estimated Safety Impacts

Because this is case 1 in step 4.1.2, the difference in predicted crashes per year between the two alternatives is obtained directly from the model predictions obtained in step 4.1.2. The estimated effect of increasing development over the entire corridor, adding the signalized intersection, and the associated growth in mainline AADT is an increase of (6.59–4.22) = 2.37 right-angle crashes/yr. The proposed alternative is predicted to increase right-angle crashes by 56 percent (i.e., 6.59/4.22).

In this sample problem, it was desired to compare the predicted right-angle crashes for existing and proposed conditions. The following computations are provided to illustrate the process for comparing the percent change in crashes related to the change in each individual variable:

- The relative effect of increasing the signal density is $\exp^{(0.2267)} = 1.25$ (i.e., a 25-percent increase in right-angle crashes for each additional signal per mile). In this case, the signal density was increased from 0.0 to 0.4 signal/mi, so the relative impact for this corridor is $\exp^{(0.2267 * (0.4 - 0.0))} = 1.09$ (i.e., a 9-percent increase in right-angle crashes).

- The relative effect of increasing the proportion of frontage development from 30 to 100 percent is $\exp^{(0.4295 * (1.0 - 0.3))} = 1.35$ (i.e., a 35-percent increase in right-angle crashes for a 70-percent increase in frontage development).

SAMPLE PROBLEM 2

Estimate the effect of changes in two or more variables that are not all accommodated in the same model (scenario 2).

Problem Definition

On a mixed-use corridor, changes are being proposed that would eliminate existing roadside development while reducing the overall access density. This would involve the removal of several access points in parts of the corridor, which will reduce the corridor totals by 20 driveways and 10 unsignalized intersections. The proportion of the corridor with no development will increase from 0 to 15 percent. It is desired to estimate the relative effect of the proposed changes on total crashes. It is assumed that all other variables, including AADT on the mainline, will not change.

Step 1: Select Land Use and Region

This is a mixed-use corridor. After reviewing the summary statistics for mixed land use in each of the four regions from which the models were developed and comparing them with the local data, it is determined that the corridor is most comparable to Northern California.

Step 2: Select Crash Types and Variables of Interest

As noted in the problem definition, total crashes are of interest. In this case, the variables of interest are *ACCDENS* (i.e., density of driveways plus unsignalized intersections) and *PROPNODEV*.

Step 3: Select Analysis Type of Interest

It is desired to estimate the relative safety of two alternatives, one of which is the do-nothing alternative (i.e., existing conditions). In this case, analysis option 1 (algorithm 1) is applicable because the objective is to compare the relative safety impacts.

Step 4: Select Applicable Model(s) and Perform Analysis

Table 24 presents the applicable models for total crashes in a mixed land use. The applicable model for *ACCDENS* is mixed/total model 1 (table 34). The applicable model for *PROPNODEV* is mixed/total model 3 (table 36). The applicable model is different for the variables of interest, so it is necessary to apply multiple models to estimate the effects. In this case, extrapolated variables are not required. Note that all variables are available to apply the models, so no default values are required.

The model coefficients for total crashes from table 34 are: *intercept* (–3.1845), *region* (1.1410 if North Carolina or Minnesota; 0 otherwise), *AADT* (0.5187), *ACCDENS* (0.0053), *SIGDENS* (0.1095), and *PROPLANE1* (–0.5185). The equation in figure 18 is applicable to this model.

The model coefficients for total crashes from table 36 are *intercept* (–0.8926), *region* (0.6166 if North Carolina or Minnesota; 0 otherwise), *AADT* (0.3766), and *PROPNODEV* (–0.4252). The equation in figure 18 is applicable to this model.

Step 4.1.1: Data for Conditions of Interest

The data for the existing condition (do-nothing alternative A) are the following:

- *Corridor length* = 8 mi.
- *AADT* = 30,000 vpd.
- 9 signalized intersections: *SIGDENS* = 9 signals/8 mi = 1.13 signals/mi.
- 35 unsignalized intersections and 40 driveways: *ACCDENS* = 75 access points/8 mi = 9.38 access points/mi.
- Length of roadway with two lanes is 6 mi: *PROPLANE1* = 6.0/8.0 = 0.75.
- Length of roadway with no roadside development is 0 mi: *PROPNODEV* = 0.

The data for the proposed condition (alternative B) are the following:

- *Corridor length* = 8 mi (unchanged).
- *AADT* = 30,000 vpd (unchanged).
- 9 signalized intersections: *SIGDENS* = 9 signals/8 mi = 1.13 signals/mi(unchanged).
- 20 unsignalized intersections and 25 driveways: *ACCDENS* = 45 access points/8 mi = 5.63 access points/mi.
- Length of roadway with two lanes is 6 mi: *PROPLANE1* = 6.0/8.0 = 0.75 (unchanged).
- Length of roadway with no roadside development: *PROPNODEV* = 0.15.

Step 4.1.2: Calculations for Nonextrapolated Variables

Case 2 applies when the two variables of interest (*ACCDENS* and *PROPNODEV*) appear in separate models. Therefore, it is necessary to consider the effects of each variable separately and then combine the effects to estimate the total impact of alternative B.

Effect of ACCDENS (Table 34)

Figure 25 and figure 26 predict *ACCDENS* for this situation.

Predicted total crashes/year (existing)

$$= (length) * \exp^{(intercept+region)} * (AADT)^{0.5187} * \exp^{(0.0053*ACCDENS+0.1095*SIGDENS-0.5185*PROPLANE1)}$$

$$= (8.0) * \exp^{(-3.1845+0)} * (30{,}000)^{0.5187} * \exp^{(0.0053*9.38+0.1095*1.13-0.5185*0.75)}$$

$$= 56.08 \text{ total crashes/year}$$

Figure 25. Equations. Effect of *ACCDENS*: *predicted total crashes/year (existing)*.

Predicted total crashes/year (proposed)

$$= (length) * \exp^{(intercept+region)} * (AADT)^{0.5187} * \exp^{(0.0053*ACCDENS+0.1095*SIGDENS-0.5185*PROPLANE1)}$$

$$= (8.0) * \exp^{(-3.1845+0)} * (30{,}000)^{0.5187} * \exp^{(0.0053*5.63+0.1095*1.13-0.5185*0.75)}$$

$$= 54.98 \text{ total crashes/year}$$

Figure 26. Equations. Effect of *ACCDENS*: *predicted total crashes/year (proposed)*.

Effect of PROPNODEV (Table 36)

Figure 27 and figure 28 calculate the effect of *PROPNODEV*.

Predicted total crashes/year (existing)

$$= (length) * \exp^{(intercept+region)} * (AADT)^{0.3766} * \exp^{(-0.4252*PROPNODEV)}$$

$$= (8.0) * \exp^{(-0.8926+0)} * (30{,}000)^{0.3766} * \exp^{(-0.4252*0)}$$

$$= 159.05 \text{ total crashes/year}$$

Figure 27. Equations. Effect of *PROPNODEV*: *predicted total crashes/year (existing)*.

Predicted total crashes/year (proposed)

$$= (length) * \exp^{(intercept+region)} * (AADT)^{0.3766} * \exp^{(-0.4252*PROPNODEV)}$$

$$= (8.0) * \exp^{(-0.8926+0)} * (30{,}000)^{0.3766} * \exp^{(-0.4252*0.15)}$$

$$= 149.22 \text{ total crashes/year}$$

Figure 28. Equations. Effect of *PROPNODEV*: *predicted total crashes/year (proposed)*.

Step 4.1.3: Calculations for Extrapolated Variables

There are no extrapolated variables, so this step is not applicable.

Step 4.1.4: Estimated Safety Impacts

The total change in safety is estimated as the sum of changes from the individual models. The change in total predicted crashes related to the change in *ACCDENS* is (56.08 – 54.98) = 1.10 crashes/yr, and the change in total predicted crashes related to the change in *PROPNODEV* is (159.05 – 149.22) = 9.83 crashes/yr. The change in total predicted crashes from all modifications (alternative B as a whole) is a reduction of 10.93 total crashes per year (1.10 + 9.83). The proposed alternative is predicted to reduce total crashes by 5 percent: (54.98 + 149.22)/(56.08 + 159.05).

SAMPLE PROBLEM 3

Estimate the effect of a change in a single variable that is accommodated in models for different crash types (scenario 3).

Problem Definition

For a mixed-use corridor, a proposal has been made to increase the number of driveways by 10 and the number of unsignalized intersections by 5. It is desired to estimate the relative effect of the proposed changes on all available crash types. All other corridor characteristics, including the mainline AADT, are assumed to remain constant.

Step 1: Select Land Use and Region

This is a mixed-use corridor. After reviewing the summary statistics for mixed land use in each of the four regions from which the models were developed and comparing them with the local data, it is determined that the corridor is most comparable to Southern California.

Step 2: Select Crash Types and Variables of Interest

As noted in the problem definition, it is desired to estimate the relative effect of the proposed changes on all available crash types. In this case, the variable of interest is *ACCDENS*, which is the density of driveways plus unsignalized intersections.

Step 3: Select Analysis Type of Interest

It is desired to estimate the relative safety between two alternatives, one of which is the do-nothing alternative (i.e., existing conditions). In this case, analysis option 1 (algorithm 1) is applicable because the objective is to compare the relative safety impacts.

Step 4: Select Applicable Model(s) and Perform Analysis

Table 24 presents the applicable models for various crash types in a mixed land use. For mixed land use, *ACCDENS* is directly available in models for total crashes, turning crashes, and right-angle crashes. *ACCDENS* is not included in any mixed land use models for injury or rear-end crashes without extrapolating from another land use type. (Note that the extrapolation is covered in sample problem 5.) The applicable models for *ACCDENS* include mixed/total model 1 (table 34), mixed/turning model 1 (table 39), and mixed/right-angle model 1 (table 44). The applicable models are for different crash types, so it is necessary to apply the models separately to estimate the effects by crash type. In this case, extrapolated variables are not considered. Note that all variables are available to apply the models, so no default values are required.

The model coefficients for total crashes are given in table 34 as *intercept* (–3.1845), *region* (1.1410 if North Carolina or Minnesota; 0 otherwise), *AADT* (0.5187), *ACCDENS* (0.0053), *SIGDENS* (0.1095), and *PROPLANE1* (–0.5185). The equation in figure 18 is applicable to this model.

The model coefficients for turning crashes are given in table 39 as *intercept* (–2.1083), *region* (0.9647 if North Carolina or Minnesota; 0 otherwise), *SIGDENS* (0.1865), and *ACCDENS* (0.0088). The equation in figure 19 is applicable to this model. Note that the result is expressed as crashes per MVMT. The result is multiplied by *MVMT* to express it as crashes per mile per year.

The model coefficients for right-angle crashes are given in table 44 as *intercept* (–5.8048), *region* (1.8390 if North Carolina or Minnesota; 0 otherwise), *AADT* (0.4656), *ACCDENS* (0.0112), and *SIGDENS* (0.2284). The equation in figure 19 is applicable to this model.

Step 4.1.1: Data for Conditions of Interest

The data for the existing condition (do-nothing alternative A) are the following:

- *Corridor length* = 2.5 mi.
- *AADT* = 25,000 vpd.
- 10 signalized intersections: *SIGDENS* = 10 signals/2.5 mi = 4.0 signals/mi.
- 30 unsignalized intersections and 80 driveways: *ACCDENS* = (80 driveways + 30 unsignalized intersections)/2.5 mi = 44.0 access points/mi.
- Length of roadway with two lanes is 0.625 mi: *PROPLANE1* = 0.625/2.5 = 0.25.

The data for the proposed condition (alternative B) are the following:

- *Corridor length* = 2.5 mi.
- *AADT* = 25,000 vpd (unchanged).
- 10 signalized intersections: *SIGDENS* = 4.0 signals/mi (unchanged).
- 35 unsignalized intersections and 90 driveways: *ACCDENS* = (90 driveways + 35 unsignalized intersections)/2.5 mi = 50.0 access points/mi.
- Length of roadway with two lanes is 0.625 mi: *PROPLANE1*= 0.25 (unchanged).

Step 4.1.2: Calculations for Nonextrapolated Variables

Case 1 applies because there is only one variable of interest (*ACCDENS*).

Total Crashes (Table 34)

Figure 29 and figure 30 predict the total crashes per year.

Predicted total crashes/year (existing)

$= (\mathit{length}) * \exp^{(\mathit{intercept}+\mathit{region})} * (\mathit{AADT})^{0.5187} * \exp^{(0.0053*\mathit{ACCDENS}+0.1095*\mathit{SIGDENS}-0.5185*\mathit{PROPLANE1})}$

$= (2.5) * \exp^{(-3.1845+0)} * (25{,}000)^{0.5187} * \exp^{(0.0053*44.0+0.1095*4.0-0.5185*0.25)}$

= 33.99 total crashes/year

Figure 29. Equations. Total crashes: *predicted total crashes/year (existing)*.

Predicted total crashes/year (proposed)

$= (\mathit{length}) * \exp^{(\mathit{intercept}+\mathit{region})} * (\mathit{AADT})^{0.5187} * \exp^{(0.0053*\mathit{ACCDENS}+0.1095*\mathit{SIGDENS}-0.5185*\mathit{PROPLANE1})}$

$= (2.5) * \exp^{(-3.1845+0)} * (25{,}000)^{0.5187} * \exp^{(0.0053*50.0+0.1095*4.0-0.5185*0.25)}$

= 35.09 total crashes/year

Figure 30. Equations. Total crashes: *predicted crashes/year (proposed)*.

Turning Crashes (Table 39)

Figure 31 and figure 32 predict the number of turning crashes per year.

Predicted turning crashes/year (existing)

$= (\mathit{MVMT}) * \exp^{(\mathit{intercept}+\mathit{region})} * \exp^{(0.0088*\mathit{ACCDENS}+0.1865*\mathit{SIGDENS})}$

$= (2.5*25{,}000*365/1{,}000{,}000) * \exp^{(-2.1083+0)} * \exp^{(0.0088*44.0+0.1865*4.0)}$

= 8.60 turning crashes/year

Figure 31. Equations. Turning crashes: *predicted turning crashes/year (existing)*.

Predicted turning crashes/year (proposed)

$= (\mathit{MVMT}) * \exp^{(\mathit{intercept}+\mathit{region})} * \exp^{(0.0088*\mathit{ACCDENS}+0.1865*\mathit{SIGDENS})}$

$= (2.5*25{,}000*365/1{,}000{,}000) * \exp^{(-2.1083+0)} * \exp^{(0.0088*50.0+0.1865*4.0)}$

= 9.07 turning crashes/year

Figure 32. Equations. Turning crashes: *predicted turning crashes/year (proposed)*.

Right-Angle Crashes (Table 44)

Figure 33 and figure 34 predict the number of right-angle crashes per year.

Predicted right-angle crashes/year (existing)

$= (\mathit{length}) * \exp^{(\mathit{intercept}+\mathit{region})} * (\mathit{AADT})^{0.4656} * \exp^{(0.0112*\mathit{ACCDENS}+0.2284*\mathit{SIGDENS})}$

$= (2.5) * \exp^{(-5.8048+0)} * (25{,}000)^{0.4656} * \exp^{(0.0112*44.0+0.2284*4.0)}$

= 3.43 right-angle crashes/year

Figure 33. Equations. Right-angle crashes: *predicted right-angle crashes/year (existing)*.

Predicted right-angle crashes/year (proposed)

$$= (length) * \exp^{(intercept+region)} * (AADT)^{0.4656} * \exp^{(0.0112*ACCDENS+0.2284*SIGDENS)}$$

$$= (2.5) * \exp^{(-5.8048+0)} * (25{,}000)^{0.4656} * \exp^{(0.0112*50.0+0.2284*4.0)}$$

$$= 3.67 \text{ right-angle crashes/year}$$

Figure 34. Equations. Right-angle crashes: *predicted right-angle crashes/year (proposed)*.

Step 4.1.3: Calculations for Extrapolated Variables

There are no extrapolated variables, so this step is not applicable.

Step 4.1.4: Estimated Safety Impacts

The estimated effect of increasing the number of driveways from 80 to 90 and the number of unsignalized intersections from 30 to 35 is as follows:

- Total crashes: An increase of (35.09 – 33.99) = 1.10 total crashes/yr.
- Turning crashes: An increase of (9.07 – 8.60) = 0.47 turning crash/yr.
- Right-angle crashes: An increase of (3.67 – 3.43) = 0.24 right-angle crash/yr.

SAMPLE PROBLEM 4

Compare the expected crashes for two alternatives to select the most appropriate alternative (scenario 4).

Problem Definition

For a mixed-use corridor, a proposal has been made to increase the number of driveways by 10 and the number of unsignalized intersections by 5. An alternate proposal will increase the number of driveways by eight and the number of unsignalized intersections by four. It is desired to estimate the impact of each proposed alternative in terms of the project cost and expected number of right-angle crashes per year. All other corridor characteristics, including the mainline AADT, are assumed to remain constant. Note that this problem uses the same situation as sample problem 3 but incorporates the observed crash history.

Step 1: Select Land Use and Region

This is a mixed-use corridor. After reviewing the summary statistics for mixed land use in each of the four regions from which the models were developed and comparing them with the local data, it is determined that the corridor is most comparable to Southern California.

Step 2: Select Crash Types and Variables of Interest

As noted in the problem definition, it is desired to estimate the effect of the proposed changes on the expected number of right-angle crashes. In this case, the variable of interest is *ACCDENS,* which is the density of driveways plus unsignalized intersections.

Step 3: Select Analysis Type of Interest

It is desired to estimate the impact of each proposed alternative in terms of the project cost and expected number of right-angle crashes per year. A more precise estimate is required because the difference in expected crashes is to be compared with the difference in costs of the two alternatives. In this case, analysis option 2 (algorithm 2) is applicable because the objective is to estimate the expected crashes for the given alternatives.

Step 4: Select Applicable Model(s) and Perform Analysis

Table 24 presents the applicable models for right-angle crashes in a mixed land use. The applicable model for *ACCDENS* is mixed/right-angle model 1 (table 44). Because the EB method is to be applied as part of algorithm 2, it is necessary to select a base model from the last column of table 24. The applicable base model for applying the EB method is mixed/right-angle model 1 (table 24). In this case, the base model and the model for *ACCDENS* are the same. Note that extrapolated variables are not considered, and all variables are available to apply the models, so no default values are required.

The model coefficients for right-angle crashes are given in table 44 as *intercept* (–5.8048), *region* (1.8390 if North Carolina or Minnesota; 0 otherwise), *AADT* (0.4656), *ACCDENS* (0.0112), and *SIGDENS* (0.2284). The equation in figure 18 is applicable to this model.

Step 4.2.1: Data for Conditions of Interest

The data for the existing condition (do-nothing alternative A) are the following:

- *Corridor length* = 2.5 mi.
- *AADT* = 25,000 vpd.
- 10 signalized intersections: *SIGDENS* = 10 signals/2.5 mi = 4.0 signals/mi.
- 30 unsignalized intersections and 80 driveways: *ACCDENS* = (80 driveways + 30 unsignalized intersections)/2.5 mi = 44.0 access points/mi.
- Length of roadway with two lanes is 0.625 mi: *PROPLANE1* = 0.625/2.5 = 0.25.
- Crash history includes 17 right-angle crashes in the most recent 4-yr period.

The data for proposed condition 1 (alternative B) are the following:

- *Corridor length* = 2.5 mi.
- *AADT* = 25,000 vpd (unchanged).
- 10 signalized intersections: *SIGDENS* = 4.0 signals/mi (unchanged).

- 35 unsignalized intersections and 90 driveways: *ACCDENS* = (90 driveways + 35 unsignalized intersections)/2.5 mi = 50.0 access points/mi.

- Length of roadway with two lanes is 0.625 mi: *PROPLANE1* = 0.25 (unchanged).

The data for proposed condition 2 (alternative C) are the following:

- *Corridor length* = 2.5 mi.

- *AADT* = 25,000 vpd (unchanged).

- 10 signalized intersections: *SIGDENS* = 4.0 signals/mi (unchanged).

- 34 unsignalized intersections and 88 driveways: *ACCDENS* = (88 driveways + 34 unsignalized intersections)/2.5 mi = 48.8 access points/mi.

- Length of roadway with two lanes is 0.625 mi: *PROPLANE1* = 0.25 (unchanged).

Step 4.2.2: Prediction for Existing Condition

Step 4.2.2a Baseline Predicted Right-Angle Crashes/Year (Existing Alternative A)

Use the base model (table 44) with the values from alternative A to estimate the baseline predicted crashes for the existing condition as shown in figure 35.

Baseline predicted right-angle crashes/year (existing alternative A)

$$= (length) * \exp^{(intercept+region)} * (AADT)^{0.4656} * \exp^{(0.0112*ACCDENS+0.2284*SIGDENS)}$$

$$= (2.5) * \exp^{(-5.8048+0)} * (25{,}000)^{0.4656} * \exp^{(0.0112*44.0+0.2284*4.0)}$$

$$= 3.43 \text{ right-angle crashes/year}$$

Figure 35. Equations. *Baseline predicted right-angle crashes/year (existing alternative A)*.

Step 4.2.2b Estimated EB Weight

w is estimated using the equation in figure 36.

$$w = 1 / [1 + (k * years * \text{step 4.2.2a estimate})]$$

$$= 1 / [1 + (0.5585 * 1 * 3.43)]$$

$$= 0.3430$$

Figure 36. Equations. Estimate of *w*.

Note that the *k* is given for each specific model in appendix C. For the base model for mixed-use, right-angle crashes (table 44), the value of *k* = 0.5585.

Step 4.2.2c Expected Right-Angle Crashes/Year (Existing Alternative A)

The annual expected crash frequency (*EB estimate*) for existing conditions is calculated using the equation in figure 37.

$EB\ Estimate = [w * (step\ 4.2.2a\ estimate)] + [(1 - w) * (observed\ crashes/years\ of\ data)]$

$= 0.3430 * 3.43 + (1 - 0.3430) * (17 / 4)$

$= 3.97$ right-angle crashes/year

Figure 37. Equations. *Expected right-angle crashes/year (existing alternative A).*

Step 4.2.2d Estimated EB Correction Factor

The *EB correction factor* is calculated as the expected crashes for the existing condition (step 4.2.2c) divided by the baseline predicted crashes for the existing condition (step 4.2.2a). Figure 38 calculates the *EB correction factor*:

Expected crashes (existing) / baseline predicted crashes (existing) = 3.97/3.43 = 1.16

Figure 38. Equation. Estimate *EB correction factor*.

This factor is used to adjust predictions for alternative scenarios and helps to account for several sources of potential bias, including variables that are omitted from the model.

Step 4.2.3: Prediction for Proposed Condition

Step 4.2.3a Difference in Predicted Right-Angle Crashes/Year for Existing and Proposed Condition

Apply steps 4.1.2 through 4.1.4 from algorithm 1 using the existing and proposed conditions as inputs. The result is an estimate of the difference in predicted crash frequency for the existing and proposed conditions.

Step 4.1.2: Calculations for Nonextrapolated Variables

Figure 39 through figure 41 predict the number of right-angle crashes per year.

Predicted right-angle crashes/year (existing alternative A)

$= (length) * \exp^{(intercept+region)} * (AADT)^{0.4656} * \exp^{(0.0112*ACCDENS+0.2284*SIGDENS)}$

$= (2.5) * \exp^{(-5.8048+0)} * (25{,}000)^{0.4656} * \exp^{(0.0112*44.0+0.2284*4.0)}$

$= 3.43$ right-angle crashes/year

Figure 39. Equations. *Predicted right-angle crashes/year (existing alternative A).*

Predicted right-angle crashes/year (proposed alternative B)

$= (length) * \exp^{(intercept+region)} * (AADT)^{0.4656} * \exp^{(0.0112*ACCDENS+0.2284*SIGDENS)}$

$= (2.5) * \exp^{(-5.8048+0)} * (25{,}000)^{0.4656} * \exp^{(0.0112*50.0+0.2284*4.0)}$

$= 3.67$ right-angle crashes/year

Figure 40. Equations. *Predicted right-angle crashes/year (proposed alternative B).*

Predicted right-angle crashes/year (proposed alternative C)

$$= (length) * \exp^{(intercept+region)} * (AADT)^{0.4656} * \exp^{(0.0112*ACCDENS+0.2284*SIGDENS)}$$

$$= (2.5) * \exp^{(-5.8048+0)} * (25{,}000)^{0.4656} * \exp^{(0.0112*48.8+0.2284*4.0)}$$

$$= 3.62 \text{ right-angle crashes/year}$$

Figure 41. Equations. *Predicted right-angle crashes/year (proposed alternative C)*.

Step 4.1.3: Calculations for Extrapolated Variables

There are no extrapolated variables, so this step is not applicable.

Step 4.1.4: Estimated Difference in Crashes/Year for Different Alternatives

Comparing alternative A and alternative B (i.e., an increase in the number of driveways by 10 and an increase in the number of unsignalized intersections by 5 for a mixed-use corridor), the predicted change in right-angle crashes is an increase of (3.67 – 3.43) = 0.24 right-angle crash/yr.

Comparing alternative A and alternative C (i.e., an increase in the number of driveways by 8 and an increase in the number unsignalized intersections by 4 for a mixed-use corridor), the predicted change in right-angle crashes is an increase of (3.62 – 3.43) = 0.19 right-angle crash/yr.

Step 4.2.3b Adjusted Predicted Right-Angle Crashes/Year for Existing Condition

Add the difference in predicted crashes for existing and proposed conditions from step 4.2.3a to the baseline predicted crashes for existing conditions from step 4.2.2a, as shown in figure 42.

Alternative B: 0.24 + 3.43 = 3.67 right-angle crashes.

Alternative C: 0.19 + 3.43 = 3.62 right-angle crashes.

Figure 42. Equations. *Adjusted predicted right-angle crashes/year* for existing condition.

Step 4.2.3c Expected Right-Angle Crashes/Year for Proposed Condition

Multiply the adjusted predicted crashes for the existing condition from step 4.2.3b by the *EB correction factor* from step 4.2.2d, as shown in figure 43.

Alternative B: 3.67 * 1.16 = 4.26 right-angle crashes/year.

Alternative C: 3.62 * 1.16 = 4.20 right-angle crashes/year.

Figure 43. Equations. *Expected right-angle crashes/year* for proposed condition.

Step 4.2.4: Estimated Safety Impacts

The results are provided as the expected crash frequencies per year for the crash types selected under both alternatives. The estimates for the existing conditions are from step 4.2.2c, and the estimates for the following proposed conditions are from step 4.2.3c:

- **Alternative B:** The estimated effect of alternative B compared with alternative A (i.e., increasing the number of driveways from 80 to 90 and increasing the number of unsignalized intersections from 30 to 35) on right-angle crashes is an increase of (4.26 – 3.97) = 0.29 right-angle crash/yr.

- **Alternative C:** The estimated effect of alternative C compared with alternative A (i.e., increasing the number of driveways from 80 to 88 and increasing the number of unsignalized intersections from 30 to 34) on right-angle crashes is an increase of (4.20 – 3.97) = 0.23 right-angle crash/yr.

This sample problem included calculations for right-angle crashes only. A similar method would be applied to compute the *EB correction factor* for other crash types using the crash history for those specific crash types. The applicable correction factor would then be applied to the model predictions for alternative scenarios to estimate the expected crashes for other crash types of interest. Recall that the results from individual crash type models should not be summed to estimate total crashes.

SAMPLE PROBLEM 5

Estimate the safety impact of variables that are available for a given crash type but not for the land use type of interest (scenario 5). In this case, it is necessary to use extrapolation. The extrapolation method first requires the use of a model from the land use and crash type of interest to predict crashes for existing conditions. Then, a model is selected from another land use to estimate the impacts of the variables of interest.

Problem Definition

For a commercial corridor, a proposal has been made to install a divided median for the entire length of the corridor. Presently, the corridor is partially divided. In the segment that is to be divided (currently undivided), a single median opening would be provided. It is desired to estimate the relative safety impact of the proposed changes on right-angle crashes. All other corridor characteristics, including the AADT, are assumed to remain constant.

Step 1: Select Land Use and Region

This is a commercial corridor. After reviewing the summary statistics for commercial use in each of the four regions from which the models were developed and comparing them to the local data, it is determined that the corridor is most comparable to Minnesota.

Step 2: Select Crash Types and Variables of Interest

As noted in the problem definition, it is desired to estimate the relative effect of the proposed changes on right-angle crashes. In this case, the variables of interest include the proportion of corridor with divided median (*PROPDIV*) and density of median openings (*MEDOPDENS*).

Step 3: Select Analysis Type of Interest

It is desired to estimate the relative safety of two alternatives, one of which is the do-nothing alternative (i.e., existing conditions). In this case, analysis option 1 (algorithm 1) is applicable because the objective is to compare the relative safety impacts.

Step 4: Select Applicable Model(s) and Perform Analysis

Table 25 presents the applicable models for right-angle crashes in a commercial land use. There are no directly applicable models for *PROPDIV* or *MEDOPDENS*, but column 4 indicates that these variables may be considered through extrapolation. The applicable model for *PROPDIV* is mixed/right-angle model 2 (table 45). The applicable model for *MEDOPDENS* is mixed/right-angle model 2 (table 45). In this case, the applicable models are the same for the two variables of interest. It is also necessary to select a base model from the last column of table 25 for use in the extrapolation process. The applicable base model for extrapolation is commercial/right-angle model 1 (table 57). Note that default values are required from appendix D for use in the extrapolation process.

The model coefficients to estimate the impact of the variables of interest on right-angle crashes are given in table 45 as *PROPDIV* (–0.4710) and *MEDOPDENS* (0.1901). Note that only the coefficients for the variables of interest are required from this model.

The model coefficients for the base model are given in table 57 as *intercept* (–1.6746), *region* (1.4756 if North Carolina or Minnesota; 0 otherwise), *AADT* (0.1238), *ACCDENS* (0.0165), and *SIGDENS* (0.1532). The equation in figure 18 is applicable to this model.

Step 4.1.1: Data for Conditions of Interest

The data for the existing condition (alternative A) are the following:

- *Corridor length* = 5 mi.
- *AADT* = 46,000 vpd.
- 18 signalized intersections: *SIGDENS* = 18 signals/5 mi = 3.6 signals/mi
- 23 unsignalized intersections and 240 driveways: *ACCDENS* = (240 driveways + 23 unsignalized intersections)/5 mi = 52.6 access points/mi.
- Length of roadway with divided median is 3 mi: *PROPDIV* = 3/5 = 0.6.
- Number of median openings is 8: *MEDOPDENS* = 8 median openings/5 mi = 1.6 median openings/mi.

The data for the proposed condition (alternative B) are the following:

- *Corridor length* = 5 mi.
- *AADT* = 46,000 vpd.
- 18 signalized intersections: *SIGDENS* = 3.6 signals/mi (unchanged).
- 23 unsignalized intersections and 240 driveways: *ACCDENS* = 52.6 access points/mi (unchanged).

- Length of roadway with divided median is 5 mi: *PROPDIV* = 5/5 = 1.0.
- Number of median openings is 9: *MEDOPDENS* = 9 median openings/5 mi = 1.8 median openings/mi.

Step 4.1.2: Calculations for Nonextrapolated Variables

The effects are extrapolated from a model for a different land use, so this step is not applicable.

Step 4.1.3: Calculations for Extrapolated Variables

For each of the two variables to be considered through extrapolation, the following steps are taken.

Step 4.1.3a Baseline Predicted Right-Angle Crashes/Year (Existing)

Use the base model (table 57) with the values from the existing condition (alternative A) to estimate the baseline predicted crashes for the existing condition as shown in figure 44.

Baseline predicted right-angle crashes/year (existing alternative A)

$$= (length) * \exp^{(intercept+region)} * (AADT)^{0.1238} * \exp^{(0.0165*ACCDENS+0.1532*SIGDENS)}$$

$$= (5.0) * \exp^{(-1.6746+1.4756)} * (46{,}000)^{0.1238} * \exp^{(0.0165*52.6+0.1532*3.6)}$$

$$= 64.01 \text{ right-angle crashes/year}$$

Figure 44. Equations. *Baseline predicted right-angle crashes/year (existing)*.

Step 4.1.3b Estimate the Impacts of the Variables of Interest for Existing Conditions

The effects of the variables of interest for the existing conditions are estimated using the equation in figure 45 along with the coefficients in table 45 and the values from alternative A:

$$Multiplier = \exp^{(coefficient)*(Variable\ Actual\ Value - Variable\ Default\ Value)}$$

Figure 45. Equation. Estimate of the impacts of the variables of interest for existing conditions.

The coefficients for *PROPDIV* and *MEDOPDENS* are -0.4710 and 0.1901. The mean value of *PROPDIV* and *MEDOPDENS* are obtained from appendix D for the land use and region from which the model was developed. In this example, the corridor of interest is similar to Minnesota, and the model is based on data for a mixed land use. From appendix D, the mean values for *PROPDIV* and *MEDOPDENS* from mixed-use corridors in Minnesota are 0.61 and 1.47, respectively (table 76), and the multipliers are calculated as shown in figure 46.

$$Multiplier_{PROPDIV} = \exp^{-0.4710(PROPDIV\ existing - PROPDIV\ mean)} = \exp^{-0.4710(0.60 - 0.61)} = 1.00$$

$$Multiplier_{MEDOPDENS} = \exp^{0.1901(MEDOPDENS\ existing - MEDOPDENS\ mean)} = \exp^{0.1901(1.60 - 1.47)} = 1.03$$

Figure 46. Equations. Estimation of multipliers.

Step 4.1.3c Adjusted Predicted Right-Angle Crashes/Year (Existing Alternative A)

The estimate from step 4.1.3b is then multiplied by the estimate from step 4.1.3a, as shown in figure 47.

Adjusted predicted right-angle crashes/year (existing alternative A)

$= Multiplier_{PROPDIV} * Multiplier_{MEDOPDENS} * \textit{Existing predicted right-angle crashes/year}$

= 1.00 * 1.03 * 64.01 right-angle crashes/year

= 65.93 right-angle crashes/year

Figure 47. Equations. *Adjusted predicted right-angle crashes/year (existing alternative A)*.

Step 4.1.3d Baseline Predicted Right-Angle Crashes/Year (Proposed)

Use the base model (table 57) with the values from the proposed condition (alternative B) to estimate the baseline predicted crashes for the proposed condition. In this case, there are no anticipated changes in the variables included in the base model; therefore, the estimate remains the same as the baseline predicted crashes for the existing conditions (64.01 right-angle crashes per year).

Step 4.1.3e Estimate the Impacts of the Variables of Interest for Proposed Conditions

The effects of the variables of interest for the proposed conditions are estimated using the equation in figure 20 along with the coefficients in table 45 and the values from alternative B.

The coefficients for *PROPDIV* and *MEDOPDENS* are –0.4710 and 0.1901. The mean value of *PROPDIV* and *MEDOPDENS* are obtained from appendix D for the land use and region from which the model was developed. In this example, the corridor of interest is similar to Minnesota, and the model is based on data for a mixed land use. From appendix D, the mean values for *PROPDIV* and *MEDOPDENS* from mixed-use corridors in Minnesota are 0.61 and 1.47, respectively (table 76), and the multipliers are calculated as shown in figure 48.

$$Multiplier_{PROPDIV} = \exp^{-0.4710(PROPDIV\ proposed\ -\ PROPDIV\ mean)} = \exp^{-0.4710(1.00-0.61)} = 0.83$$

$$Multiplier_{MEDOPDENS} = \exp^{0.1901(MEDOPDENS\ proposed\ -\ MEDOPDENS\ mean)} = \exp^{0.1901(1.80-1.47)} = 1.06$$

Figure 48. Equations. Estimation of multipliers.

Step 4.1.3f Adjusted Predicted Right-Angle Crashes/Year (Proposed Alternative B)

The estimate from step 4.1.3e is then multiplied by the estimate from step 4.1.3d. as shown in figure 49.

Adjusted predicted right-angle crashes/year (proposed alternative B)

$= Multiplier_{PROPDIV} * Multiplier_{MEDOPDENS} * \textit{Predicted right-angle crashes/year (proposed)}$

= 0.83 * 1.06 * 64.01 right-angle crashes/year

= 56.32 right-angle crashes/year

Figure 49. Equations. *Adjusted predicted right-angle crashes/year (proposed alternative B)*.

Step 4.1.4: Estimated Safety Impacts

The adjusted predicted crash frequency for proposed conditions (step 4.1.3f) is subtracted from the adjusted predicted crash frequency for existing conditions (step 4.1.3c). The result is the difference in the predicted crash frequency for alternative B compared with alternative A. The impact of the proposed conditions (i.e., installing a median along the remainder of the corridor with a single median opening) is a reduction of (65.93 – 56.32) = 9.61 right-angle crashes/yr.

SAMPLE PROBLEM 6

Estimate effects when one or more variables of interest do not appear in any models for any crash type of interest or land use (scenario 6).

When a variable is not included in any of the models, it is not possible to quantify the effects of those variables in the manner shown in the previous sample problems. Instead, qualitative assessments could be made based on relationships identified from basic summary statistics. To facilitate such an assessment, appendix E provides the correlation coefficients between the variables of interest that do not appear in any models and the various crash types by land use.

Correlation coefficients range between –1.0 and 1.0. A positive coefficient indicates that higher values of a variable are correlated with a higher crash frequency. A negative coefficient indicates that higher values of a variable are correlated with a lower crash frequency. The closer the coefficient is to –1.0 or 1.0, the stronger the correlation.

It is critical to employ caution and judgment when using correlation coefficients to assess the potential impact of a variable. Specifically, it must be noted that no other variables, including traffic volume, are accounted for in the correlation coefficients, which can result in completely erroneous relationships.

To provide a point of reference, the parameter estimates and *p*-values are also provided with the correlation coefficients. The parameter estimates are based on a restricted model in which only traffic volume and the variable of interest are included. Where the correlation coefficient and the parameter estimate differ (i.e., opposite signs), it may be an indication that other factors are confounding the results or that the association is not statistically significant.

Example of Logical Effects

Several of the variables in appendix E are related to the spacing of intersections and access points such as the minimum spacing of signalized intersections (*MINSPCSIG*). For all crash types in all three land use scenarios, the correlation coefficient is negative for *MINSPCSIG* as shown in table 27. This indicates that greater minimum signal spacing is correlated with fewer crashes. It should be noted that traffic volume is not considered in the estimation of correlation coefficients.

The model coefficients and associated *p*-values are also provided in table 27 (shown in parentheses below the respective correlation coefficients). The only other variable considered in the estimation of the model coefficients is *AADT*, so the results should be interpreted with caution because other important factors may be omitted. All of the model coefficients are negative, indicating that greater minimum signal spacing may reduce crashes for these crash types. This is consistent with the correlation coefficients. Further, many of the *p*-values are less than 0.10, particularly for commercial and residential land use, indicating that the effects are statistically significant.

Table 27. Correlation coefficients for *MINSPCSIG* (model coefficient, *p*-value).

Land Use	Total	Injury	Turning	Rear-End	Right-Angle
Mixed-use	–0.1800 (–0.0001, 0.2200)	–0.2100 (–0.0001, 0.2600)	–0.1600 (–0.0001, 0.3600)	–0.2000 (–0.0002, 0.1100)	–0.2100 (–0.0002, 0.0700)
Commercial	–0.2100 (–0.0002, 0.0000)	–0.2200 (–0.0002, 0.0000)	–0.1600 (–0.0001, 0.0300)	–0.2200 (–0.0003, 0.0000)	–0.2300 (–0.0002, 0.0000)
Residential	–0.3400 (–0.0002, 0.0100)	–0.3300 (–0.0002, 0.0000)	–0.2200 (–0.0001, 0.1100)	–0.3300 (–0.0003, 0.0000)	–0.3100 (–0.0001, 0.3400)

Example of Illogical Effects

Several of the variables in appendix E are related to the presence of left-turn lanes, such as the number of signalized intersections with a left-turn lane on the mainline (*NOLTLSIG*). For all crash types in all three land use scenarios, the correlation coefficient is positive for *NOLTLSIG* as shown in table 28. This indicates that left-turn lanes are correlated with higher numbers of crashes. What is not considered is that left-turn lanes are often installed along corridors with higher traffic volumes, which typically experience more crashes because of the higher volumes.

The model coefficients and associated *p*-values are also provided in table 28 (shown in parentheses below the respective correlation coefficients). The only other variable considered in the estimation of the model coefficients is *AADT*, so the results should be interpreted with caution because other important factors may be omitted. Some of the coefficients are negative, indicating that left-turn lanes may reduce crashes for these crash types. This is counterintuitive to the correlation coefficients and should indicate to the user that the results may be unreliable, and there may be other factors that should be considered. In addition, all *p*-values are much greater than 0.10, indicating that the effects are not statistically significant.

Table 28. Correlation coefficients for *NOLTLSIG* (model coefficient, *p*-value).

Land Use	Total	Injury	Turning	Rear-End	Right-Angle
Mixed-use	0.790 (0.009, 0.282)	0.860 (0.011, 0.192)	0.740 (0.010, 0.328)	0.590 (0.004, 0.690)	0.860 (0.014, 0.168)
Commercial	0.730 (0.011, 0.259)	0.800 (0.010, 0.282)	0.650 (0.006, 0.583)	0.460 (0.013, 0.355)	0.810 (0.017, 0.173)
Residential	0.620 (–0.003, 0.911)	0.670 (0.005, 0.811)	0.590 (0.008, 0.765)	0.500 (0.017, 0.604)	0.390 (–0.027, 0.351)

CHAPTER 10. CALIBRATION

Calibration of the models involves the estimation and application of adjustment factors for applying the models in a jurisdiction and time period that are different from those used to develop the original models. The factors reflect differences in crash experience due to differences in terrain, climate, crash definition, and reporting. The following procedure, based on AASHTO's *Highway Safety Manual*, is suggested for approximating calibration factors, recognizing that there will be limitations in availability of data required for more thorough procedures:

1. For a given crash type and land use, consider which alternative model requires data for which a suitably large dataset can be assembled. Note that models with the most variables are preferred. The calibration sample should average at least 100 crashes/yr for the most recent 3-yr period and contain at least 10 corridors. Note that if the data cannot be assembled for all crash and land use types, the procedure is applied to datasets that are available, and the calibration factor estimated in step 3 is assumed for the crash type and land use types for which calibration data are unavailable.(20)

2. Use the model for the region deemed most similar to the jurisdiction of interest to estimate the sum of predicted crashes over all corridors in the dataset for the 3-yr period. Note that the assessment of which region is most similar is not critical; the region is mainly used to define a base condition, but experience-based judgment may be used in assessing the reasonableness of the calibration factor estimated in step 3.(20)

3. Estimate the calibration factor as the ratio of the sum of the observed crashes in the calibration dataset to the sum of the predicted crashes from the model output.(20)

4. Apply the calibration factor to the base region multiplier to obtain the multiplier for the jurisdiction of interest.(20)

Example: Suppose it is desired to calibrate the model for predicting total crashes on commercial corridors in a jurisdiction. A total of 10 commercial corridors are identified for use in the calibration process. The dataset includes 328 reported crashes for the 3-yr period. Note that there are more than 100 crashes/yr for the 10 corridors combined, so this satisfies the requirements in step 1 of the calibration process.

Step 1. Based on a review of table 25, there are two alternative models for predicting total crashes on commercial corridors. Model 1 includes *ACCDENS* and *SIGDENS*, and model 2 includes *PROPNODEV*. If data are available for *ACCDENS* and *SIGDENS* for each of the 10 corridors, then model 1 would be selected because it includes more variables than model 2. In this example, assume that data are not available for *ACCDENS*, but data are available for *PROPNODEV*. Thus, model 2 is selected for use in calibration based on availability of data. The detailed information for model 2 is provided in table 48, and the model form is given by the equation in figure 18, where $\exp^{(intercept + region)}$ is the regional multiplier.

Step 2. Based on a comparison of local roadway characteristics and crash statistics, it was determined that Minnesota is most similar to the jurisdiction of interest. The model is applied to predict crashes for each of the 10 corridors in each year, and the results are summed. A total of 360.25 crashes are predicted for the 10 corridors over the 3-yr period.

Step 3. The estimated calibration factor is calculated using the equation in figure 50:

$$\textit{Sum of observed crashes /sum of predicted crashes} = 328/360.25 = 0.910$$

Figure 50. Equation. *Estimated calibration factor*.

Step 4. The original multiplier from table 48 is shown in figure 51:

$$\textit{Original multiplier} = \exp^{(\textit{intercept+region})} = \exp^{(-0.6854+0.6166)} = 0.9335$$

Figure 51. Equation. *Original multiplier*.

The calibrated multiplier for use in the jurisdiction of interest is shown in figure 52:

$$\textit{Calibrated multiplier = calibration factor * original multiplier} = 0.910 * 0.9335 = 0.8495$$

Figure 52. Equation. Estimation of *calibrated multiplier*.

The calibrated model for the jurisdiction is shown in figure 53:

$$\textit{Total crashes/mile/year = calibrated multiplier} * (\textit{AADT})^{b} * \exp^{(c_1 * X_1 + \ldots + c_n * X_n)}$$
$$\textit{Total crashes/mile/year} = 0.8495 * (\textit{AADT})^{0.3766} * \exp^{(-04252*\textit{PROPNODEV})}$$

Figure 53. Equations. Minnesota crash prediction model.

In the same way, multipliers can be obtained for all other crash types and land use types of interest. If data are unavailable or insufficient to estimate a calibration factor for specific crash types for the same land use type (commercial in this example), the calibration factor for total crashes (0.910) can be applied to the models for other crash types of interest for commercial corridors. Similarly, if data are unavailable or insufficient to estimate a calibration factor for other land use categories for the same crash type (total crashes in this example), the calibration factor for total crashes (0.910) can be applied to the models for total crashes for other land use categories of interest.

CHAPTER 11. VALIDATION

Traditional validation involves calculating and assessing goodness-of-fit measures for applying the model to an independent dataset not used in the model development process. Often, as is the case here, it is necessary to use all data for the model development, so validity needs to be assessed using alternative methods. The alternative method applied in this report uses previous studies to assess the reasonableness of the effects indicated by the independent variables in the models. The assessment is done for two sets of variables—those for which effects can be implied from AASHTO's *Highway Safety Manual* predictive models and those for which CMFs can be obtained from FHWA's CMF Clearinghouse.[20,21]

COMPARISON WITH HIGHWAY SAFETY MANUAL PREDICTIVE MODELS

For this exercise, the implied effects of two variables—*PROPDIV* and *ACCDENS*—were compared with the implied effects of models for urban and suburban arterials in AASHTO's *Highway Safety Manual*.[20]

For *PROPDIV*, there was only one model for which this variable was significant and had the intuitively correct sign—right-angle crashes for mixed land use (table 45). The implied CMF for right-angle crashes for installing a raised median ($PROPDIV = 1$) in a corridor where there was no median ($PROPDIV = 0$) is $\exp^{(-0.4710)} = 0.624$. The CMFs inferred for four-lane arterials from the *Highway Safety Manual,* Part C Predictive Method, depend on AADT, driveway spacing, and driveway type. For total crashes, the inferred CMFs for major commercial land use from the *Highway Safety Manual* models range from 0.456 for 40 driveways/mi and 5,000 AADT to 0.676 for an arterial with no driveways and AADT of 40,000. Thus, even considering that the comparison is for two different crash types, it can be concluded that the implied CMF from the model in table 45 is reasonably consistent with the CMF implied from the *Highway Safety Manual* models. [20]

For *ACCDENS* (access density), the CMFs inferred from the *Highway Safety Manual,* Part C Predictive Method, are shown in table 29, taken from Persaud et al.[22] The *Highway Safety Manual* provides separate models for multivehicle driveway and nondriveway crashes per mile, considering the AADT, the number and type of driveways, and whether or not the arterial is divided.[20] Thus, the inferred CMFs for changing driveway spacing depend on these factors as shown in table 29. Based on table 34, the CMF for total crashes for reducing driveway density by 10/mi for mixed-use corridors is $\exp^{(0.0053*(-10))} = 0.948$. Similarly, the CMFs are 0.933 and 0.969 for commercial and residential land uses based on the coefficients for *ACCDENS* in table 47 and table 61, respectively. These CMFs are reasonably consistent with those in table 29, considering that the data for this project are a mixture of undivided and divided roads (mean *PROPDIV* ranges from 0.31 to 0.33 for residential and from 0.44 to 0.73 for other land uses) and that mean *AADTs* range from 15,000 to 32,000 vpd for residential and from 20,000 to 46,000 vpd for other land uses. In addition, both sets of numbers indicate a larger CMF (i.e., less reduction) for residential than for commercial land use, which is further evidence of consistency.

Table 29. Driveway density CMFs inferred from the *Highway Safety Manual* predictive models for multivehicle crashes on urban four-lane undivided and divided arterials.[22]

Driveway Reduction	AADT	Commercial 4U	Commercial 4D	Residential 4U	Residential 4D
From 40 to 30/mi	5,000	0.817	0.886	0.853	0.922
From 40 to 30/mi	10,000	0.823	0.922	0.859	0.950
From 40 to 30/mi	15,000	0.826	0.927	0.863	0.954
From 40 to 30/mi	20,000	0.829	0.930	0.866	0.956
From 40 to 30/mi	25,000	0.830	0.933	0.868	0.958
From 40 to 30/mi	30,000	0.832	0.935	0.870	0.959
From 40 to 30/mi	35,000	0.833	0.936	0.872	0.961
From 40 to 30/mi	40,000	0.835	0.938	0.873	0.962
From 20 to 10/mi	5,000	0.712	0.895	0.791	0.937
From 20 to 10/mi	10,000	0.725	0.908	0.804	0.945
From 20 to 10/mi	15,000	0.733	0.914	0.812	0.949
From 20 to 10/mi	20,000	0.739	0.919	0.817	0.952
From 20 to 10/mi	25,000	0.743	0.922	0.821	0.954
From 20 to 10/mi	30,000	0.747	0.925	0.825	0.956
From 20 to 10/mi	35,000	0.750	0.927	0.827	0.957
From 20 to 10/mi	40,000	0.753	0.929	0.830	0.958

4U = four-lane undivided arterial; 4D = four-lane divided arterial.

COMPARISON WITH EFFECTS FOR OTHER VARIABLES IN THE CMF CLEARINGHOUSE

For this exercise, the implied effects of three variables—*MEDOPDENS*, *SIGDENS*, and *UNSIGDENS*—were compared with the information on effects derived from the CMF Clearinghouse, which were all from a single publication by Mauga and Kaseko.[23] Those effects were also from cross-sectional regression models and pertained to corridors classified as "urban." It was decided to use the mixed-use models from this project for the comparison.

For *MEDOPDENS*, there was only one mixed-use model for which this variable was significant and had the intuitively correct sign—right-angle crashes for mixed land use (table 45). The implied CMF for increasing the median openings by 1 per mi is $\exp^{0.1901} = 1.21$. Increasing by 2 and 3 per mi gives CMFs of 1.46 and 1.77, respectively. The 3-star CMF from the CMF Clearinghouse is $\exp^{0.0985} = 1.10$ for increasing median openings by 1 per mi and 1.22 and 1.34 for increases of 2 and 3 median openings per mi. The standard error of the *MEDOPDENS* coefficient is 0.0844, which would indicate that the CMF from the Clearinghouse is within the range of approximately one standard error. On this basis, it can be concluded that the implied CMF from the model in table 45 is reasonably consistent with the CMF implied from the CMF Clearinghouse.

For *SIGDENS*, the CMFs implied from the mixed-use models with the lowest *k* are shown in table 30. Also shown are the 3-star CMFs from the CMF Clearinghouse for urban environments, which are assumed to be comparable to corridors in mixed land use. The discrepancy between the two sets of implied CMFs is not surprising in that the CMF would be highly variable, depending on the nonintersection crash frequency in the corridor and on the traffic volumes at the signalized intersections. This suggests that caution should be exercised in using models with this variable for corridors that differ greatly from those used to develop the models.

Table 30. Comparison of implied CMFs for *SIGDENS*.

Crash Type	Implied CMF Source	Increase Signalized Intersection Density by 1/mi	Increase Signalized Intersection Density by 2/mi	Increase Signalized Intersection Density by 3/mi
All	Model (table 35)	1.100	1.211	1.332
All	Clearinghouse	1.401	1.567	1.657
Rear-end	Model (table 43)	1.064	1.132	1.205
Rear-end	Clearinghouse	1.381	1.537	1.622

For *UNSIGDENS*, there was only one comparable mixed-use model for which this variable was significant and had the intuitively correct sign—total crashes (table 35). The implied CMF for increasing the unsignalized access density by 1 per mi is $\exp^{0.0471} = 1.048$. Increasing by 2 and 3 unsignalized intersections per mi gives CMFs of 1.099 and 1.151, respectively. The 3-star CMF from the CMF Clearinghouse is $\exp^{0.0126} = 1.013$ for increasing unsignalized intersections by 1 per mi. The CMFs from the Clearinghouse for increases of 2 and 3 unsignalized intersections per mi are 1.026 and 1.039, respectively. As was the case for *SIGDENS*, the discrepancy is not surprising in that the CMF would be highly variable, depending on the nonintersection crash frequency in the corridor and on the traffic volumes at the unsignalized intersections. This suggests that caution should be exercised in using models with this variable for corridors with characteristics that differ greatly from those corridors used to develop the models.

CHAPTER 12. SAFETY EVALUATION TOOL AND FUNCTIONAL SPECIFICATIONS

A safety evaluation tool was developed based on the results of this research to help facilitate the safety evaluation of AM policies and techniques. To facilitate the development of such a tool, functional specifications were developed and provided in a separate document. The functional specifications provide guidance for incorporating the crash prediction models in a software package. The functional specifications identify, in a general sense, how the safety evaluation tool works and the default values for the various models and land use scenarios. Readers are encouraged to use the software to help with the computations shown in the previous chapters.

CHAPTER 13. CONCLUSIONS

This research was performed to develop corridor-level crash prediction models to estimate and analyze the safety effects of selected AM techniques for different area types, land uses, roadway variables, and traffic volumes. More than 600 mi of detailed corridor data were collected across four regions of the United States to facilitate the model estimation process. It was not possible to develop a single model for each crash type and land use scenario because of the strong correlations among many of the variables of interest. As a result, 41 crash prediction models were estimated for specific land use and crash type scenarios. In most cases, multiple models are presented for each land use and crash type scenario; the alternate models contain subsets of AM strategies in an attempt to account for strong correlations among variables. A four-step process is provided to guide users through the model selection and application process, but it is envisioned that a simple software tool will be developed to simplify this process based on the functional specifications. Several sample problems are also provided to illustrate the various uses of the models and to demonstrate the model selection and application process.

These models represent the first of their kind for evaluating the safety effects of AM strategies at the corridor level based on national data. Although the results of this research will help to advance the knowledge base and state of the practice, the crash prediction models are not without limitations, including the following:

- **Omitted variables.** Ideally, a single-crash prediction model would include all desired variables of interest. This was not a preferred option in this study because of the strong correlation among several of the independent variables. To overcome issues related to correlation, all variables could not be included in a single model. Other variables were omitted because of illogical effects and lack of statistical significance. As a result, most models have few variables, and median type is not represented in most models.

- **Inability to quantify effects of turning restrictions.** Detailed data were collected to identify the type of access points (e.g., residential versus commercial driveway) and the associated turning restrictions (e.g., full-movement, right-in/right-out, and left-from-major-only). Incorporating this information in the models proved difficult. Variables were created to represent these characteristics at the corridor level, but the results were not statistically significant. Although detailed data are available for each point, the models were not developed to assess the impacts of individual points (i.e., a specific driveway or intersection). Therefore, differences between full- and limited-movement access points and between three-legged and four-legged intersections are not clear from these models.

- **Lack of volumes on cross streets and driveways.** Traffic volume is a key variable in predicting crashes. The objective of this study was to develop corridor-level crash prediction models, so a weighted average of the traffic volume along the corridor was used to account for exposure. The major road volume was included, but the minor road volume and driveway volumes were not included.

- **Inability to quantify effects of interchange cross-road spacing.** Detailed data were collected to represent various characteristics of interchange crossroads (e.g., distance from ramp terminal to nearest turning opportunity); however, relatively few interchanges were included in the dataset, and the results were not statistically significant.

Based on the results of this research and lessons learned during the completion of the study, there are several opportunities for future research as follows:

- **Increase sample size and regional diversity.** There is an opportunity to increase the number of sites and years of data in the database. Increasing the sample size will likely improve the models and allow for additional analysis of the variables of interest. Specifically, this effort could focus on resolving the shortcomings noted previously.

- **Corroborate results.** Cross-sectional methods are useful for developing crash prediction models, but there are several sources of potential bias as discussed in chapter 3. Rigorous before–after studies are preferred for estimating the effects of an individual strategy (e.g., AM characteristic). There is an opportunity to corroborate the results of these crash prediction models by collecting additional data to undertake before–after evaluations of each individual strategy.

- **Separate models for nondriveway and driveway crashes.** This study estimated models for a variety of crash types, including total, injury, turning, rear-end, and right-angle. It may be of interest to estimate additional models to explore the effects of specific AM strategies on driveway and nondriveway crashes. This was not possible as part of this study because of the lack of specific information in the crash data (i.e., California does not indicate driveway-related crashes). Additional research could investigate the suitability of developing these separate models while considering the potential for extensive geographic diversity in how driveway and nondriveway crashes are defined.

- **Develop *Highway Safety Manual*–type algorithms.** The AASHTO *Highway Safety Manual* provides methods for estimating the expected number of crashes for individual intersections and homogeneous segments.[20] These estimates can be combined to estimate the crashes for a given corridor. The AASHTO *Highway Safety Manual* uses a system of base models to predict crashes for an average scenario, and adjustment factors (i.e., CMFs) are used to adjust the base predictions to reflect actual conditions.[20] The models developed in this study are corridor-level models, but there may be an opportunity to use these as base models for average conditions and apply corridor-level adjustment factors to reflect actual corridor conditions. Additional research could investigate the suitability of using these models for this purpose.

APPENDIX A. HSIS VARIABLES OBTAINED FOR EACH STATE

Table 31 through table 33 describe the variables obtained for each State.

Table 31. HSIS data obtained for California.

Name	Description	File
AADT	Annual average daily traffic	Road
ACCESS	Access control	Road
BEGMP	Beginning milepost	Road
CNTYRTE	County route number	Road
CURB1	Curb and landscape	Road
DESG_SPD	Design speed	Road
DISTRICT	District	Road
ENDMP	Ending milepost	Road
FUNC_CLS	Functional classification	Road
HWY_GRP	Highway group	Road
LANEWID	Average lane width	Road
LSHL_WD2	Left shoulder width road 2	Road
LSHLDWID	Left shoulder width road 1	Road
MED_TYPE	Median type	Road
MEDWID	Median width	Road
NO_LANES	Number of lanes	Road
PAV_WDL	Left paved shoulder width road 1	Road
PAV_WDL2	Left paved shoulder width road 2	Road
PAV_WDR2	Right paved shoulder width road 2	Road
PSMILPRF	Post-mile prefix	Road
RO_SEQ	Route order sequence	Road
RODWYCLS	Roadway class	Road
RSHL_WD2	Right shoulder width road 2	Road
RSHLDWID	Right shoulder width road 1	Road
RTE_NBR	Route number	Road
RTE_SUF	Roadway route suffix	Road
RURURB	Rural urban	Road
SEG_LNG	Section length	Road
SURF_TYP2	Surface type road 2	Road
SURF_TYP	Surface type road 1	Road
SURF_WD2	Traveled-way width road 2	Road
SURF_WID	Traveled-way width road 1	Road
TERRAIN	Terrain type	Road
TOLL	Toll and forest roads	Road
CASENO	Unique accident number	Vehicle
CAUSE	Contribution factor	Vehicle
CONTRIB1	1st associated factor	Vehicle
CONTRIB2	2nd associated factor	Vehicle
DIR_TRVL	Direction of travel	Vehicle
MISCACT1	Preceding movement	Vehicle
PHYSCOND	Driver physical condition	Vehicle

Name	Description	File
SCHLBUS	School bus	Vehicle
TRK_CODE	Truck code	Vehicle
VEH_AT_FAULT	Vehicle at fault	Vehicle
VEHNO	Vehicle number	Vehicle
VEHTYPE	Vehicle type	Vehicle
ACC_DATE	Accident date	Accident
ACCTYPE	Accident/collision type	Accident
CASENO	Accident case number	Accident
CAUSE1	Primary collision factor	Accident
CNTYRTE	County route number	Accident
CNTYNAME	County name	Accident
COUNTY	County	Accident
HOUR	Time of accident	Accident
INT_RMP	Intersection/ramp access location	Accident
LIGHT	Light condition	Accident
LOC_TYP	Location type	Accident
MILEPOST	Milepost	Accident
NUMVEHS	Number of vehicles	Accident
PED_ACTN	Pedestrian action	Accident
RD_DEF	Roadway condition	Accident
RODWYCLS	Roadway classification	Accident
RTE_NBR	Route number	Accident
RTE_SUF	Roadway route suffix	Accident
SDE_HWY	Side-of-highway	Accident
SEVERITY	Accident severity	Accident
VEH_INVL	Motor vehicles involved	Accident
WEATHER	Weather condition	Accident

Table 32. HSIS data obtained for Minnesota.

Name	Description	File
AADT	Annual average daily traffic	Road
ACCESS	Access control	Road
BEGMP	Beginning milepost	Road
COMM_ADT	Average commercial AADT	Road
CURB1	Curb and landscape road 1	Road
CURB2	Curb and landscape road 2	Road
DISTRICT	District	Road
ENDMP	Ending milepost	Road
FUNC_CLS	Functional classification	Road
INTE_CAT	Intersection category	Road
LANEWID	Average lane width	Road
LSHL_TY2	Left shoulder type road 2	Road
LSHL_TY	Left shoulder type road 1	Road
LSHL_WD2	Left shoulder width road 2	Road
LSHLDWID	Left shoulder width road 1	Road
MED_TYPE	Median type	Road
MEDWID	Median width	Road
NO_LANES	Number of lanes	Road
ONEWAY	Divided and one-way code	Road
RODWYCLS	Roadway class	Road
ROW	Right-of-way width	Road
RSHL_TY2	Right shoulder type road 2	Road
RSHL_TYP	Right shoulder width road 1	Road
RSHL_WD2	Right shoulder width road 2	Road
RSHLDWID	Right shoulder width road 1	Road
RTE_NBR	Route number	Road
RTE_SYS	Route system	Road
RTSYSNBR	Combined system/route	Road
SEG_LNG	Section length	Road
SURF_TY2	Surface type road 2	Road
SURF_TYP	Surface type road 1	Road
SURF_WD2	Surface width road 2	Road
SURF_WID	Surface width road 1	Road
URB_MNC	Urban/municipal code	Road
CASENO	Unique accident number	Vehicle
CONTRIB1	1st associated factor	Vehicle
CONTRIB2	2nd associated factor	Vehicle
EVENT1	Sequence of event—1	Vehicle
EVENT2	Sequence of event—2	Vehicle
EVENT3	Sequence of event—3	Vehicle
MISCACT1	Movement preceding collision	Vehicle
MOST_EVENT	Most harmful event	Vehicle
PHYSCOND	Physical condition of driver	Vehicle
VEH_DIR	Initial vehicle direction	Vehicle
VEHNO	Relative vehicle number	Vehicle
VEHTYPE	Type of vehicle	Vehicle

Name	Description	File
ACC_DATE	Accident date	Accident
ACCDIGM	Diagram of accident code	Accident
ACCTYPE	Accident/collision type	Accident
CASENO	Accident case number	Accident
COUNTY	County	Accident
HOUR	Time of accident	Accident
INTERCH	Interchange element code	Accident
LIGHT	Light condition	Accident
LOC_TYP	Location type	Accident
MILEPOST	Milepost	Accident
NUMVEHS	Number of vehicles	Accident
RD_CHAR1	Road characteristics	Accident
RDSURF	Road surface conditions	Accident
RODWYCLS	Roadway classification	Accident
RTE_NBR	Route number	Accident
RTE_SYS	Route system	Accident
SCHLBUS	School bus involved	Accident
SEVERITY	Accident severity	Accident
SPEED	Posted speed limit	Accident
TRF_CNTL	Traffic control devices	Accident
TRVL_DIR	Travel direction	Accident
WEATHER	Weather condition	Accident

Table 33. HSIS data obtained for North Carolina.

Name	Description	File
AADT	Annual average daily traffic	Road
ACCESS	Access control	Road
AREATYPE	Area type	Road
BEGMP	Beginning milepost	Road
CNTYRTE	County route number	Road
COUNTY	County	Road
DHRVOL	Design hour volume	Road
ENDMP	Ending milepost	Road
FUNC_CLS	Functional classification	Road
LSHL_TYP	Left shoulder type	Road
LSHLDWID	Left shoulder width	Road
MED_TYPE	Median type	Road
MEDWID	Median width	Road
NO_LANES	Number of lanes	Road
PCT_TRK	Percentage truck	Road
PEAK_TRK	Percent commercial vehicles in peak	Road
RODWYCLS	Roadway class	Road
ROW	Right of way	Road
RSHL_TYP	Right shoulder type	Road
RSHLDWID	Right shoulder width	Road
RTE_NBR	Route number	Road
SEG_LNG	Section length	Road
SPD_LIMT	Speed limit	Road
SURF_TYP	Surface type	Road
SURF_WID	Surface width	Road
TERRAIN	Terrain type	Road
TRK_RTE	Truck route	Road
TRNLNWD	Turn lane width	Road
URB_POP	Rural/urban by population	Road
WTDSGSPD	Weighted design speed	Road
ACC_DATE	Accident date	Accident
ACCTYPE	Accident/collision type	Accident
CASENO	Accident case number	Accident
CNTYRTE	County route number	Accident
DEVELOP	Development amount	Accident
FRMRD_CL	From road class	Accident
LIGHT	Light condition	Accident
LOC_TYPE	Accident location type	Accident
MILEPOST	Milepost	Accident
NUMVEHS	Number of vehicles	Accident
POP_GRP	Urban/rural codes	Accident
RD_CHAR1	Road alignment	Accident
RD_CONF	Road configuration	Accident
RDSURF	Surface condition	Accident
RTE_NBR	Route number	Accident
SEVERITY	Accident severity	Accident

Name	Description	File
TRF_CNTL	Traffic control	Accident
WEATHER	Weather condition	Accident
BODY	Cargo body type	Vehicle
CONTRIB	Contributing factors	Vehicle
DIR_TRVL	Direction of travel	Vehicle
EVENT	Sequence of events	Vehicle
MANEUVER	Vehicle maneuver	Vehicle
PEDACT	Pedestrian action	Vehicle
PHYSCOND	Driver condition	Vehicle
SCH_BUS	School bus involved	Vehicle
SPDLIM	Posted speed limit	Vehicle
VEHNO	Vehicle number	Vehicle
VEHTYPE	Vehicle type	Vehicle
VISION	Vision obstruction	Vehicle

APPENDIX B. FIELD DATA COLLECTION PROTOCOL

A data collector will make preferably no more than two runs along each corridor. The first trip should focus on identifying the general corridor characteristics (e.g., number of lanes, median type, speed limit, and lighting presence) and making broad, corridor-level observations (e.g., visual clutter and frontage type). The second trip should be used to obtain signalized intersection data. All data are to be recorded using a digital video camera, and the driver should narrate the video to indicate the specific details.

RUN 1

The driver continues through the entire corridor and notes the following features as well as any changes in the features. If features change, note the approximate cross street.

- Study corridor (primary route, beginning cross street, and ending cross street).
- Direction of travel.
- Type of operation (one-way or two-way).
- Number of lanes.
- Median type.
- Posted speed limit (if no posted speed limit, note the general operating speed of other vehicles).
- Lighting presence.
- Condition of pavement markings.
- Visual clutter.

RUN 2

The driver travels the corridor in the opposite direction and notes the following features related to each signalized intersection:

- Turning restrictions—major and minor road.
    - None (full movement).
    - No left turns.
    - No U-turns.
    - No right-turn-on-red.
- Protected left turn for mainline.

- Yes.
- No.

- Presence of nontraditional accommodation of left turn.
  - Michigan U-turn.
  - Superstreet.
  - New Jersey jug-handle.
  - Other.

APPENDIX C. SUMMARY OF MODELS BY LAND USE AND CRASH TYPE

This appendix presents the final crash prediction models organized by land use (mixed-use, commercial, and residential) and crash type (total, injury, turning, rear-end, and right-angle). In most cases, the model form is represented by the equation in figure 18. In these cases, the result is expressed as crashes per mile per year. In other cases, the traffic volume variable is not statistically significant, indicating a linear relationship between traffic volume and crashes. In these limited cases, the model form is reduced to the equation in figure 19, and the result is expressed as crashes per MVMT. The result from the equation in figure 19 is multiplied by *MVMT* to express the result as crashes per mile per year.

MIXED-USE MODELS

Total Crashes

Table 34 through table 36 present three alternate models for mixed-use total crashes. The model form for mixed-use total crashes is shown in figure 18.

Table 34. Alternate model 1 for mixed-use total crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–3.1845	1.9550	0.1033
Region	1.1410	0.2316	<0.0001
AADT	0.5187	0.1819	0.0043
ACCDENS	0.0053	0.0044	0.2279
SIGDENS	0.1095	0.0607	0.0710
PROPLANE1	–0.5185	0.3789	0.1711
k	0.5073	—	—

Note: The *p*-values for *ACCDENS* and *PROPLANE1* are larger than desirable. Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Table 35. Alternate model 2 for mixed-use total crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–3.2905	1.8743	0.0792
Region	1.0533	0.2086	<0.0001
AADT	0.5266	0.1738	0.0024
UNSIGDENS	0.0471	0.0224	0.0354
SIGDENS	0.0957	0.0594	0.1072
PROPLANE1	–0.6376	0.3796	0.0931
k	0.4897	—	—

Note: Similar model to alternate model 1, but excluding driveways. Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Table 36. Alternate model 3 for mixed-use total crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–0.8926	0.5021	0.0755
Region	0.6166	0.1013	<0.0001
AADT	0.3766	0.0468	<0.0001
PROPNODEV	–0.4252	0.2268	0.0608
k	0.5165	—	—

Note: This model was developed from the dataset combining all land use types with factor variables representing the land use. Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Injury Crashes

Table 37 and table 38 present two alternate models for mixed-use injury crashes. The model form for mixed-use injury crashes is shown in figure 18.

Table 37. Alternate model 1 for mixed-use injury crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–3.5700	1.7816	0.0451
Region	0.5695	0.1980	0.0040
AADT	0.5010	0.1659	0.0025
SIGDENS	0.1239	0.0556	0.0258
PROPLANE1	–0.5814	0.3582	0.1046
k	0.4248	—	—

Note: Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Table 38. Alternate model 2 for mixed-use injury crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–1.7775	0.5964	0.0029
Region	0.2465	0.0931	0.0081
AADT	0.3880	0.0558	<0.0001
PROPNODEV	–0.3159	0.2201	0.1511
PROPLANE1	–0.6623	0.1404	<0.0001
k	0.4151	—	—

Note: The *p*-value for *PROPNODEV* is larger than desirable. This model was developed from the dataset combining all land use types with factor variables representing the land use. Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Turning Crashes

Table 39 through table 41 present three alternate models for mixed-use turning crashes. The model form for alternate model 1 and model 2 is shown in figure 19. The model form for alternate model 3 is shown in figure 18.

Table 39. Alternate model 1 for mixed-use turning crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–2.1083	0.4338	<0.0001
Region	0.9647	0.2843	0.0007
SIGDENS	0.1865	0.0754	0.0134
ACCDENS	0.0088	0.0061	0.1486
k	0.7920	—	—

Note: The *p*-value for *ACCDENS* is larger than desirable. Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Table 40. Alternate model 2 for mixed-use turning crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–2.0792	0.3963	<0.0001
Region	0.8015	0.2354	0.0007
SIGDENS	0.1797	0.0742	0.0154
UNSIGDENS	0.0582	0.0323	0.0719
k	0.7780	—	—

Note: Similar model to alternate model 1, but excluding driveways. The overall fit of the model improves, and the *p*-value for unsignalized intersections is improved. Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Table 41. Alternate model 3 for mixed-use turning crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–0.4146	0.7632	0.5870
Region	–0.3163	0.1301	0.0150
AADT	0.2179	0.0729	0.0028
PROPNODEV	–0.5890	0.2827	0.0372
k	0.7791	—	—

Note: This model was developed from the dataset combining all land use types with factor variables representing the land use. Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Rear-End Crashes

Table 42 and table 43 present two alternate models for mixed-use rear-end crashes. The model form for mixed-use rear-end crashes is shown in figure 18.

Table 42. Alternate model 1 for mixed-use rear-end crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–6.6976	1.9985	0.0008
Region	1.2289	0.2479	<0.0001
AADT	0.7901	0.1876	<0.0001
SIGDENS	0.1122	0.0702	0.1099
k	0.7006	—	—

Note: Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Table 43. Alternate model 2 for mixed-use rear-end crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–3.3091	0.6700	<0.0001
Region	0.8113	0.1136	<0.0001
AADT	0.5015	0.0618	<0.0001
SIGDENS	0.0621	0.0380	0.1021
PROPLANE1	–0.5548	0.1713	0.0012
k	0.6098	—	—

Note: This model was developed from the dataset combining all land use types with factor variables representing the land use. Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Right-Angle Crashes

Table 44 through table 46 present three alternate models for mixed-use right-angle crashes. The model form for mixed-use right-angle crashes is shown in figure 18.

Table 44. Alternate model 1 for mixed-use right-angle crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–5.8048	1.9472	0.0029
Region	1.8390	0.2616	<0.0001
AADT	0.4656	0.1856	0.0121
ACCDENS	0.0112	0.0051	0.0267
SIGDENS	0.2284	0.0637	0.0003
k	0.5585	—	—

Note: Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Table 45. Alternate model 2 for mixed-use right-angle crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–5.2671	2.1768	0.0155
Region	1.2134	0.2457	<0.0001
AADT	0.5678	0.2103	0.0069
PROPDIV	–0.4710	0.3461	0.1736
MEDOPDENS	0.1901	0.0884	0.0316
k	0.6796	—	—

Note: The *p*-value for *PROPDIV* is higher than desirable, but the direction of effect for *PROPDIV* and *MEDOPDENS* is logical. Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Table 46. Alternate model 3 for mixed-use right-angle crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–2.1485	0.6851	0.0017
Region	1.2344	0.1377	<0.0001
AADT	0.2433	0.0648	0.0002
PROPFULLDEV	0.6787	0.1846	0.0002
k	0.7674	—	—

Note: This model was developed from the dataset combining all land use types with factor variables representing the land use. Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

COMMERCIAL MODELS

Total Crashes

Table 47 and table 48 present two alternate models for commercial total crashes. The model form for commercial total crashes is shown in figure 18.

Table 47. Alternate model 1 for commercial total crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–0.7017	0.6873	0.3073
Region	0.8353	0.1883	<0.0001
AADT	0.3094	0.0660	<0.0001
ACCDENS	0.0069	0.0048	0.1507
SIGDENS	0.1002	0.0523	0.0556
k	0.4890	—	—

Note: The *p*-value for *ACCDENS* is higher than desirable. Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Table 48. Alternate model 2 for commercial total crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–0.6854	0.5010	0.1713
Region	0.6166	0.1013	<0.0001
AADT	0.3766	0.0468	<0.0001
PROPNODEV	–0.4252	0.2268	0.0608
k	0.5165	—	—

Note: This model was developed from the dataset combining all land use types with factor variables representing the land use. Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Injury Crashes

Table 49 through table 52 present four alternate models for commercial injury crashes. The model form for commercial injury crashes is shown in figure 18.

Table 49. Alternate model 1 for commercial injury crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–2.0602	0.7991	0.0099
Region	0.4672	0.1815	0.0100
AADT	0.3649	0.0766	<0.0001
ACCDENS	0.0085	0.0047	0.0679
SIGDENS	0.0566	0.0512	0.2696
k	0.4406	—	—

Note: The *p*-value for *SIGDENS* is higher than desirable. Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Table 50. Alternate model 2 for commercial injury crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–0.9792	0.8386	0.2430
Region	0.2383	0.1497	0.1113
AADT	0.3225	0.0797	<0.0001
PROPNODEV	–0.6472	0.3040	0.0333
PROPLANE1	–0.6047	0.2631	0.0216
k	0.4228	—	—

Note: Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Table 51. Alternate model 3 for commercial injury crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	0.2127	0.7288	0.7704
Region	0.6769	0.1559	<0.0001
AADT	0.2705	0.0697	0.0001
PROPVC	0.5421	0.1990	0.0064
PROPLANE1	–0.6244	0.2566	0.0150
k	0.4739	—	—

Note: Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Table 52. Alternate model 4 for commercial injury crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–1.9690	0.5862	0.0008
Region	0.3056	0.0923	0.0009
AADT	0.3751	0.0548	<0.0001
SIGDENS	0.1075	0.0300	0.0003
PROPLANE1	–0.5245	0.1430	0.0002
k	0.3951	—	—

Note: This model was developed from the dataset combining all land use types with factor variables representing the land use. Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Turning Crashes

Table 53 and table 54 present two alternate models for commercial turning crashes. The model form for commercial turning crashes is shown in figure 18.

Table 53. Alternate model 1 for commercial turning crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–0.9816	0.9366	0.2946
Region	—	—	—
AADT	0.1650	0.0960	0.0855
ACCDENS	0.0110	0.0052	0.0359
SIGDENS	0.1995	0.0660	0.0025
k	0.7140	—	—

Note: Region is not included; a value of 0 is assumed for all regions.
—Not applicable.

Table 54. Alternate model 2 for commercial turning crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	0.0085	1.1277	0.9940
Region	–0.2548	0.2101	0.2251
AADT	0.1947	0.1068	0.0685
PROPNODEV	–0.6967	0.4150	0.0932
PROPLANE1	–0.7328	0.3577	0.0405
k	0.7802	—	—

Note: Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Rear-End Crashes

Table 55 and table 56 present two alternate models for commercial rear-end crashes. The model form for commercial rear-end crashes is shown in figure 18.

Table 55. Alternate model 1 for commercial rear-end crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–3.2746	0.8502	0.0001
Region	0.8114	0.1786	<0.0001
AADT	0.5050	0.0827	<0.0001
SIGDENS	0.0924	0.0552	0.0941
k	0.6055	—	—

Note: Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Table 56. Alternate model 2 for commercial rear-end crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–3.0651	0.6691	<0.0001
Region	0.8113	0.1136	<0.0001
AADT	0.5015	0.0618	<0.0001
PROPLANE1	–0.5548	0.1713	0.0012
SIGDENS	0.0621	0.0380	0.1021
k	0.6098	—	—

Note: This model was developed from the dataset combining all land use types with factor variables representing the land use. Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Right-Angle Crashes

Table 57 and table 58 present two alternate models for commercial right-angle crashes. The model form for commercial right-angle crashes is shown in figure 18.

Table 57. Alternate model 1 for commercial right-angle crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–1.6746	0.9312	0.0721
Region	1.4756	0.2388	<0.001
AADT	0.1238	0.0912	0.1745
ACCDENS	0.0165	0.0064	0.0099
SIGDENS	0.1532	0.0658	0.0199
k	0.7288	—	—

Note: The *p*-value for *AADT* is higher than desirable. Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Table 58. Alternate model 2 for commercial right-angle crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–1.9023	0.6838	0.0054
Region	1.2344	0.1377	<0.0001
AADT	0.2433	0.0648	0.0002
PROPFULLDEV	0.6787	0.1846	0.0002
k	0.7674	—	—

Note: This model was developed from the dataset combining all land use types with factor variables representing the land use. Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

RESIDENTIAL MODELS

Total Crashes

Table 59 through table 62 present four alternate models for residential total crashes. The model form for residential total crashes is shown in figure 18.

Table 59. Alternate model 1 for residential total crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–0.5615	0.7076	0.4275
Region	0.4443	0.1533	0.0038
AADT	0.3094	0.0673	<0.0001
PROPLANE1	–0.5479	0.1702	0.0013
SIGDENS	0.1262	0.0629	0.0449
PROPFULLDEV	0.3371	0.2317	0.1456
k	0.3277	—	—

Note: The *p*-value for *PROPFULLDEV* is larger than desirable. Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Table 60. Alternate model 2 for residential total crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–0.4764	0.7211	0.5088
Region	0.3824	0.1499	0.0108
AADT	0.3025	0.0685	<0.0001
PROPLANE1	–0.5260	0.1722	0.0023
SIGDENS	0.1576	0.0622	0.0113
k	0.3384	—	—

Note: This model is the same as alternate model 1 but without *PROPFULLDEV*. Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Table 61. Alternate model 3 for residential total crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–1.3644	0.4953	0.0059
Region	0.6850	0.1107	<0.0001
AADT	0.3883	0.0463	<0.0001
ACCDENS	0.0032	0.0022	0.1375
k	0.5181	—	—

Note: This model was developed from the dataset combining all land use types with factor variables representing the land use; region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Table 62. Alternate model 4 for residential total crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–1.1048	0.4876	0.0235
Region	0.6166	0.1013	<0.0001
AADT	0.3766	0.0468	<0.0001
PROPNODEV	–0.4252	0.2268	0.0608
k	0.5165	—	—

Note: This model was developed from the dataset combining all land use types with factor variables representing the land use; region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Injury Crashes

Table 63 and table 64 present two alternate models for residential injury crashes. The model form for residential injury crashes is shown in figure 18.

Table 63. Alternate model 1 for residential injury crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–2.7357	0.8556	0.0014
Region	0.1656	0.1423	0.2447
AADT	0.4189	0.0820	<0.0001
PROPLANE1	–0.4040	0.1669	0.0155
SIGDENS	0.2081	0.0539	0.0001
k	0.2663	—	—

Note: Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Table 64. Alternate model 2 for residential injury crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–2.7379	0.9147	0.0028
Region	0.2303	0.1603	0.1509
AADT	0.4615	0.0867	<0.0001
PROPLANE1	–0.6125	0.1715	0.0004
PROPFULLDEV	0.3720	0.2273	0.1017
k	0.3220	—	—

Note: region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Turning Crashes

Table 65 through table 68 present four alternate models for residential turning crashes. The model form for residential turning crashes is shown in figure 18.

Table 65. Alternate model 1 for residential turning crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–2.5087	1.0439	0.0163
Region	—	—	—
AADT	0.2949	0.1008	0.0034
UNSIGDENS	0.0589	0.0289	0.0416
SIGDENS	0.2173	0.0845	0.0101
k	0.6710	—	—

Note: Region is not included; a value of 0 is assumed for all regions.
—Not applicable.

Table 66. Alternate model 2 for residential turning crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–1.1275	1.1225	0.3152
Region	–0.6520	0.2073	0.0017
AADT	0.1826	0.1059	0.0846
UNSIGDENS	0.0635	0.0283	0.0247
SIGDENS	0.2244	0.0818	0.0061
k	0.5792	—	—

Note: This model is the same as alternate model 1 but with the *Region* variable included. Note the large reduction in the *AADT* parameter; region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Table 67. Alternate model 3 for residential turning crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–0.9528	0.7286	0.1910
Region	–0.1651	0.1339	0.2174
AADT	0.1759	0.0708	0.0130
ACCDENS	0.0052	0.0028	0.0643
SIGDENS	0.1821	0.0426	<0.0001
k	0.7030	—	—

Note: This model was developed from the dataset combining all land use types with factor variables representing the land use; region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Table 68. Alternate model 4 for residential turning crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–0.7154	0.7477	0.3387
Region	–0.3163	0.1301	0.0150
AADT	0.2179	0.0729	0.0028
PROPNODEV	–0.5890	0.2827	0.0372
k	0.7791	—	—

Note: This model was developed from the dataset combining all land use types with factor variables representing the land use; region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Rear-End Crashes

Table 69 through table 71 present three alternate models for residential rear-end crashes. The model form for residential rear-end crashes is shown in figure 18.

Table 69. Alternate model 1 for residential rear-end crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–3.8941	0.9816	<0.0001
Region	0.5803	0.1984	0.0034
AADT	0.5392	0.0945	<0.0001
SIGDENS	0.1675	0.0864	0.0527
k	0.5541	—	—

Note: Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Table 70. Alternate model 2 for residential rear-end crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–2.6180	1.0221	0.0104
Region	0.5406	0.1865	0.0037
AADT	0.4782	0.0967	<0.0001
PROPLANE1	–0.8174	0.2078	<0.0001
PROPTWLTL	–0.5600	0.2439	0.0217
k	0.4803	—	—

Note: Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Table 71. Alternate model 3 for residential rear-end crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–3.3056	0.6549	<0.0001
Region	0.8113	0.1136	<0.0001
AADT	0.5015	0.0618	<0.0001
PROPLANE1	–0.5548	0.1713	0.0012
SIGDENS	0.0621	0.0380	0.1021
k	0.6098		

Note: This model was developed from the dataset combining all land use types with factor variables representing the land use; region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Right-Angle Crashes

Table 72 through table 74 present three alternate models for residential right-angle crashes. The model form for residential right-angle crashes is shown in figure 18.

Table 72. Alternate model 1 for residential right-angle crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–1.8958	1.1271	0.0926
Region	0.8655	0.2364	0.0003
AADT	0.2357	0.1098	0.0319
k	0.7812	—	—

Note: Region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Table 73. Alternate model 2 for residential right-angle crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–1.4079	1.0732	0.1896
Region	0.8858	0.2180	<0.0001
AADT	0.1332	0.1051	0.2049
SIGDENS	0.2267	0.0750	0.0025
PROPLANE1	–0.3633	0.2383	0.1274
PROPFULLDEV	0.4295	0.3125	0.1693
k	0.5555	—	—

Note: The *p*-values for *AADT*, *PROPLANE1*, and *PROPFULLDEV* are higher than desirable; region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

Table 74. Alternate model 3 for residential right-angle crashes.

Variable	Estimate	Standard Error	*p*-Value
Intercept	–2.1173	0.6540	0.0012
Region	1.1970	0.1314	<0.0001
AADT	0.1768	0.0639	0.0057
SIGDENS	0.2084	0.0390	<0.0001
ACCDENS	0.0044	0.0028	0.1078
k	0.6790	—	—

Note: This model was developed from the dataset combining all land use types with factor variables representing the land use; region is included for North Carolina or Minnesota; a value of 0 if in Northern or Southern California.
—Not applicable.

APPENDIX D. SUMMARY STATISTICS BY LAND USE AND REGION

Appendix D provides a summary of each variable by land use and region in table 75 through table 86. The following summary statistics are used in aspects of the model application, such as default values for the models:

- **Identification of applicable region**. The summary statistics should be used to identify the region that is most applicable to the local conditions. Users should compare summary statistics only for variables that are reasonably available and select the region that is most similar to their data. This selection will determine the intercept terms for the models as well as the default values for all variables.

- **Extrapolation of models**. The extrapolation of results between land use models requires the use of summary statistics for the land use and region of interest.

MIXED-USE

Table 75. Summary statistics for North Carolina mixed-use land use.

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
Total	Total crashes/mile-year	26	5.85	65.15	28.55	17.01
Injury	Injury crashes/mile-year	26	0.69	19.35	7.81	4.57
Turning	Turning crashes/mile-year	26	1.26	14.44	5.24	4.17
Rear-end	Rear-end crashes/mile-year	26	1.38	33.84	13.29	9.34
Right-angle	Right-angle crashes/mile-year	26	0.34	11.11	3.61	2.97
PROPLANE1	Proportion of total length with two lanes	26	0.00	0.76	0.07	0.20
PROPLANE2	Proportion of total length with three or four lanes	26	0.00	1.00	0.82	0.29
PROPLANE3	Proportion of total length with five or more lanes	26	0.00	1.00	0.11	0.24
PROPDIV	Proportion of total length with curb or raised concrete median	26	0.00	1.00	0.63	0.42
PROPTWLTL	Proportion of total length with a TWLTL	26	0.00	1.00	0.30	0.42
PROPUNDIV	Proportion of total length with an undivided median	26	0.00	0.76	0.07	0.20
PROPNODEV	Proportion of total length with no adjacent development	26	0.00	1.00	0.10	0.28
PROPPARTDEV	Proportion of total length with partial adjacent development	26	0.00	1.00	0.90	0.28
PROPFULLDEV	Proportion of total length with full adjacent development	26	0.00	0.00	0.00	0.00
PROPLIGHT	Proportion of total length with illumination present	26	0.00	1.00	0.85	0.35
PROPPOORPVMNT	Proportion of total length with a poor pavement condition	26	0.00	1.00	0.05	0.20
PROPVC	Proportion of total length with visual clutter	26	0.00	1.00	0.06	0.20
PROPLIMCONN	Proportion of total length with limited connectivity on adjacent developments	26	0.00	1.00	0.23	0.35
PROPMODCONN	Proportion of total length with moderate connectivity on adjacent developments	26	0.00	1.00	0.21	0.34
PROPSIGCONN	Proportion of total length with significant connectivity on adjacent developments	26	0.00	1.00	0.56	0.44
PROPFRONTRD	Proportion of total length with a frontage road	26	0.00	0.11	0.01	0.02
DRWYDENS	Number of driveways per mile	26	1.47	38.93	12.85	10.23
UNSIGDENS	Number of unsignalized intersections per mile	26	0.75	10.48	5.35	2.62
ACCDENS	Number of driveways plus unsignalized intersections per mile	26	2.26	46.92	18.20	11.96
SIGDENS	Number of signalized intersections per mile	26	0.73	4.74	2.45	1.10
MEDOPDENS	Number of median openings per mile	24	0.00	4.72	1.61	1.43
NODRWYS	Number of driveways	26	3.00	112.00	28.31	29.16
NOCOMFULLDRWY	Number of commercial full-movement driveways	26	0.00	69.00	6.19	14.13
NORESFULLDRWY	Number of residential full-movement driveways	26	0.00	88.00	9.04	17.54
NOCOMLIMDRWY	Number of commercial limited-movement driveways	26	0.00	20.00	6.54	6.24
NORESLIMDRWY	Number of residential limited-movement driveways	26	0.00	40.00	6.54	12.01

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
NOUNSIG	Number of unsignalized intersections	26	2.00	31.00	10.69	6.39
NO3LEGUNSIG	Number of 3-legged unsignalized intersections	26	1.00	27.00	7.77	5.46
NO4LEGUNSIG	Number of 4-legged unsignalized intersections	26	0.00	14.00	2.92	3.14
NO5LEGUNSIG	Number of 5-legged unsignalized intersections	26	0.00	0.00	0.00	0.00
NO3LEGFULLUNSIG	Number of 3-legged full-movement unsignalized intersections	26	0.00	25.00	5.31	5.42
NO3LEGLIMUNSIG	Number of 3-legged limited-movement unsignalized intersections	26	0.00	9.00	2.88	2.30
NO3LEGRIROUNSIG	Number of 3-legged right-in/right-out unsignalized intersections	26	0.00	8.00	2.81	2.19
NO3LEGLFMOUNSIG	Number of 3-legged unsignalized intersections with no left-turn movement from crossroad	26	0.00	1.00	0.08	0.27
NO4LEGFULLUNSIG	Number of 4-legged full-movement unsignalized intersections	26	0.00	7.00	2.12	1.99
NO4LEGLIMUNSIG	Number of 4-legged limited-movement unsignalized intersections	26	0.00	2.00	0.27	0.67
NO4LEGRIROUNSIG	Number of 4-legged right-in/right-out unsignalized intersections	26	0.00	1.00	0.08	0.27
NO4LEGLFMOUNSIG	Number of 4-legged unsignalized intersections with no left-turn movement from crossroad	26	0.00	2.00	0.19	0.49
NORTLUNSIG	Number of unsignalized intersections with a right-turn lane	26	0.00	9.00	1.77	2.18
NOLTLUNSIG	Number of unsignalized intersections with a left-turn lane	26	0.00	29.00	7.08	6.90
NOSIG	Number of signalized intersections	26	1.00	14.00	5.04	2.86
MINSPCSIG	Minimum spacing of signalized intersections (feet)	25	442.00	4,846.00	1,532.00	1,107.00
MAXSPCSIG	Maximum spacing of signalized intersections (feet)	25	1,142.00	14,810.00	4,456.00	2,642.00
NO3LEGSIG	Number of 3-legged signalized intersections	26	0.00	3.00	0.85	0.88
NO4LEGSIG	Number of 4-legged signalized intersections	26	1.00	12.00	4.12	2.58
NO5LEGSIG	Number of 5-legged signalized intersections	26	0.00	1.00	0.08	0.27
NORTLSIG	Number of signalized intersections with a right-turn lane on the mainline	26	0.00	9.00	2.85	2.05
NOLTLSIG	Number of signalized intersections with a left-turn lane on the mainline	26	1.00	14.00	4.77	2.80
NOMEDOP	Number of median openings	24	0.00	15.00	3.54	3.88
MEDOPLT	Number of median openings with a left-turn lane	24	0.00	12.00	3.25	3.26
MEDOPNOLT	Number of median openings without a left-turn lane	24	0.00	5.00	0.29	1.08
SPEED_LIMIT	Posted speed limit (miles per hour)	26	35.00	55.00	46.00	4.08
AVGAADT	Average AADT	26	3,100.00	40,428	19,806.00	8,679.00
SPCOFFLT	Minimum spacing from off-ramp to available left turn onto mainline from same side of road (feet)	10	379.00	1,265.00	676.00	287.27
SPCOFFRT	Minimum spacing from off-ramp to available right turn onto mainline from same side of road (feet)	10	281.00	1,265.00	647.00	312.34
SPCON	Minimum spacing from on-ramp to available right turn onto mainline from same side of road (feet)	11	0.00	1,939.00	646.00	625.47

St. Dev. = standard deviation; TWLTL = two-way left-turn lane.

Table 76. Summary statistics for Minnesota mixed-use land use.

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
Total	Total crashes/mile-year	18	7.22	105.94	38.81	28.87
Injury	Injury crashes/mile-year	18	1.90	40.05	12.66	10.43
Turning	Turning crashes/mile-year	18	0.09	10.16	2.92	2.73
Rear-end	Rear-end crashes/mile-year	18	1.67	67.83	17.87	19.15
Right-angle	Right-angle crashes/mile-year	18	1.30	22.95	7.05	5.47
PROPLANE1	Proportion of total length with two lanes	18	0.00	1.00	0.21	0.33
PROPLANE2	Proportion of total length with three or four lanes	18	0.00	1.00	0.79	0.33
PROPLANE3	Proportion of total length with five or more lanes	18	0.00	0.00	0.00	0.00
PROPDIV	Proportion of total length with curb or raised concrete median	18	0.00	1.00	0.61	0.43
PROPTWLTL	Proportion of total length with a TWLTL	18	0.00	0.73	0.10	0.23
PROPUNDIV	Proportion of total length with an undivided median	18	0.00	1.00	0.29	0.40
PROPNODEV	Proportion of total length with no adjacent development	18	0.00	0.14	0.01	0.03
PROPPARTDEV	Proportion of total length with partial adjacent development	18	0.00	1.00	0.85	0.28
PROPFULLDEV	Proportion of total length with full adjacent development	18	0.00	1.00	0.14	0.29
PROPLIGHT	Proportion of total length with illumination present	18	0.00	1.00	0.57	0.48
PROPPOORPVMNT	Proportion of total length with a poor pavement condition	18	0.00	1.00	0.10	0.26
PROPVC	Proportion of total length with visual clutter	18	0.00	1.00	0.28	0.35
PROPLIMCONN	Proportion of total length with limited connectivity on adjacent developments	18	0.37	1.00	0.77	0.21
PROPMODCONN	Proportion of total length with moderate connectivity on adjacent developments	18	0.00	0.63	0.23	0.21
PROPSIGCONN	Proportion of total length with significant connectivity on adjacent developments	18	0.00	0.00	0.00	0.00
PROPFRONTRD	Proportion of total length with a frontage road	18	0.12	1.00	0.70	0.31
DRWYDENS	Number of driveways per mile	18	0.00	43.56	16.03	14.65
UNSIGDENS	Number of unsignalized intersections per mile	18	0.80	14.93	6.75	4.81
ACCDENS	Number of driveways plus unsignalized intersections per mile	18	1.07	58.49	22.79	19.03
SIGDENS	Number of signalized intersections per mile	18	0.76	6.78	2.93	1.46
MEDOPDENS	Number of median openings per mile	14	0.00	4.46	1.47	1.45
NODRWYS	Number of driveways	18	0.00	127.00	37.11	39.23
NOCOMFULLDRWY	Number of commercial full-movement driveways	18	0.00	0.71	22.00	26.89
NORESFULLDRWY	Number of residential full-movement driveways	18	0.00	38.00	7.89	12.16
NOCOMLIMDRWY	Number of commercial limited-movement driveways	18	0.00	31.00	6.11	10.37
NORESLIMDRWY	Number of residential limited-movement driveways	18	0.00	6.00	1.11	1.91
NOUNSIG	Number of unsignalized intersections	18	2.00	45.00	15.44	11.83
NO3LEGUNSIG	Number of 3-legged unsignalized intersections	18	1.00	23.00	10.28	6.47

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
NO4LEGUNSIG	Number of 4-legged unsignalized intersections	18	0.00	22.00	5.00	6.48
NO5LEGUNSIG	Number of 5-legged unsignalized intersections	18	0.00	1.00	0.11	0.32
NO3LEGFULLUNSIG	Number of 3-legged full-movement unsignalized intersections	18	0.00	18.00	6.28	6.29
NO3LEGLIMUNSIG	Number of 3-legged limited-movement unsignalized intersections	18	0.00	12.00	4.00	4.00
NO3LEGRIROUNSIG	Number of 3-legged right-in/right-out unsignalized intersections	18	0.00	11.00	3.44	3.58
NO3LEGLFMOUNSIG	Number of 3-legged unsignalized intersections with no left-turn movement from crossroad	18	0.00	2.00	0.56	0.70
NO4LEGFULLUNSIG	Number of 4-legged full-movement unsignalized intersections	18	0.00	22.00	5.00	6.48
NO4LEGLIMUNSIG	Number of 4-legged limited-movement unsignalized intersections	18	0.00	0.00	0.00	0.00
NO4LEGRIROUNSIG	Number of 4-legged right-in/right-out unsignalized intersections	18	0.00	0.00	0.00	0.00
NO4LEGLFMOUNSIG	Number of 4-legged left from major only unsignalized intersections	18	0.00	0.00	0.00	0.00
NORTLUNSIG	Number of unsignalized intersections with a right-turn lane	18	0.00	11.00	3.39	3.29
NOLTLUNSIG	Number of unsignalized intersections with a left-turn lane	18	0.00	29.00	7.44	8.49
NOSIG	Number of signalized intersections	18	2.00	17.00	7.39	4.20
MINSPCSIG	Minimum spacing of signalized intersections (feet)	18	250.00	5,285.00	1,160.00	1,303.00
MAXSPCSIG	Maximum spacing of signalized intersections (feet)	18	299.00	9,744.00	3,635.00	2,057.00
NO3LEGSIG	Number of 3-legged signalized intersections	18	0.00	4.00	1.00	1.41
NO4LEGSIG	Number of 4-legged signalized intersections	18	2.00	17.00	6.28	3.85
NO5LEGSIG	Number of 5-legged signalized intersections	18	0.00	2.00	0.11	0.47
NORTLSIG	Number of signalized intersections with a right-turn lane on the mainline	18	1.00	10.00	4.39	3.07
NOLTLSIG	Number of signalized intersections with a left-turn lane on the mainline	18	0.00	14.00	6.11	3.72
NOMEDOP	Number of median openings	14	0.00	16.00	4.07	4.21
NOMEDOPLT	Number of median openings with a left-turn lane	14	0.00	16.00	3.71	4.03
NOMEDOPNOLT	Number of median openings without a left-turn lane	14	0.00	3.00	0.36	0.93
SPEED_LIMIT	Posted speed limit (miles per hour)	18	30.00	60.00	42.00	10.18
AVGAADT	Average AADT	18	7,561.00	42,903.00	23,787.00	9,806.00
SPCOFFLT	Minimum spacing from off-ramp to available left turn onto mainline from same side of road (feet)	9	142.00	2,640.00	1,121.00	784.00
SPCOFFRT	Minimum spacing from off-ramp to available right turn onto mainline from same side of road (feet)	9	142.00	2,640.00	1,121.00	784.00
SPCON	Minimum spacing from on-ramp to available right turn onto mainline from same side of road (feet)	9	70.00	1,671.00	710.00	587.00

St. Dev. = standard deviation; TWLTL = two-way left-turn lane.

Table 77. Summary statistics for Northern California mixed-use land use.

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
Total	Total crashes/mile-year	20	0.18	41.16	18.49	14.12
Injury	Injury crashes/mile-year	20	0.09	19.56	8.66	6.30
Turning	Turning crashes/mile-year	20	0.09	13.81	4.70	4.46
Rear-end	Rear-end crashes/mile-year	20	0.09	21.12	8.44	7.05
Right-angle	Right-angle crashes/mile-year	20	0.00	5.05	1.70	1.49
PROPLANE1	Proportion of total length with two lanes	20	0.00	1.00	0.15	0.32
PROPLANE2	Proportion of total length with three or four lanes	20	0.00	1.00	0.44	0.44
PROPLANE3	Proportion of total length with five or more lanes	20	0.00	1.00	0.41	0.46
PROPDIV	Proportion of total length with curb or raised concrete median	20	0.00	1.00	0.61	0.42
PROPTWLTL	Proportion of total length with a TWLTL	20	0.00	0.68	0.10	0.20
PROPUNDIV	Proportion of total length with an undivided median	20	0.00	1.00	0.29	0.37
PROPNODEV	Proportion of total length with no adjacent development	20	0.00	0.54	0.03	0.12
PROPPARTDEV	Proportion of total length with partial adjacent development	20	0.00	1.00	0.61	0.45
PROPFULLDEV	Proportion of total length with full adjacent development	20	0.00	1.00	0.36	0.45
PROPLIGHT	Proportion of total length with illumination present	20	0.00	1.00	0.76	0.37
PROPPOORPVMNT	Proportion of total length with a poor pavement condition	20	0.00	1.00	0.07	0.23
PROPVC	Proportion of total length with visual clutter	20	0.00	1.00	0.20	0.38
PROPLIMCONN	Proportion of total length with limited connectivity on adjacent developments	20	0.00	1.00	0.30	0.39
PROPMODCONN	Proportion of total length with moderate connectivity on adjacent developments	20	0.00	1.00	0.42	0.39
PROPSIGCONN	Proportion of total length with significant connectivity on adjacent developments	20	0.00	1.00	0.28	0.37
PROPFRONTRD	Proportion of total length with a frontage road	20	0.00	1.00	0.32	0.33
DRWYDENS	Number of driveways per mile	20	0.00	108.53	42.70	26.19
UNSIGDENS	Number of unsignalized intersections per mile	20	1.03	13.31	7.06	4.24
ACCDENS	Number of driveways plus unsignalized intersections per mile	20	1.98	109.56	49.76	27.96
SIGDENS	Number of signalized intersections per mile	20	0.22	6.74	4.02	1.73
MEDOPDENS	Number of median openings per mile	20	0.00	4.67	1.47	1.58
NODRWYS	Number of driveways	20	0.00	420.00	100.00	90.08
NOCOMFULLDRWY	Number of commercial full-movement driveways	20	0.00	81.00	20.15	27.38
NORESFULLDRWY	Number of residential full-movement driveways	20	0.00	76.00	13.15	21.29
NOCOMLIMDRWY	Number of commercial limited-movement driveways	20	0.00	186.00	44.10	47.96
NORESLIMDRWY	Number of residential limited-movement driveways	20	0.00	382.00	22.60	84.74
NOUNSIG	Number of unsignalized intersections	20	2.00	36.00	14.75	10.55
NO3LEGUNSIG	Number of 3-legged unsignalized intersections	20	1.00	33.00	11.76	8.78

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
NO4LEGUNSIG	Number of 4-legged unsignalized intersections	20	0.00	28.00	3.00	6.16
NO5LEGUNSIG	Number of 5-legged unsignalized intersections	20	0.00	0.00	0.00	0.00
NO3LEGFULLUNSIG	Number of 3-legged full-movement unsignalized intersections	20	0.00	22.00	5.35	5.48
NO3LEGLIMUNSIG	Number of 3-legged limited-movement unsignalized intersections	20	0.00	22.00	6.40	6.57
NO3LEGRIROUNSIG	Number of 3-legged right-in/right-out unsignalized intersections	20	0.00	22.00	6.15	6.14
NO3LEGLFMOUNSIG	Number of 3-legged unsignalized intersections with no left-turn movement from crossroad	20	0.00	3.00	0.25	0.72
NO4LEGFULLUNSIG	Number of 4-legged full-movement unsignalized intersections	20	0.00	28.00	2.95	6.19
NO4LEGLIMUNSIG	Number of 4-legged limited-movement unsignalized intersections	20	0.00	1.00	0.05	0.22
NO4LEGRIROUNSIG	Number of 4-legged right-in/right-out unsignalized intersections	20	0.00	1.00	0.05	0.22
NO4LEGLFMOUNSIG	Number of 4-legged unsignalized intersections with no left-turn movement from crossroad	20	0.00	0.00	0.00	0.00
NORTLUNSIG	Number of unsignalized intersections with a right-turn lane	20	0.00	4.00	0.85	1.35
NOLTLUNSIG	Number of unsignalized intersections with a left-turn lane	20	0.00	20.00	4.85	5.19
NOSIG	Number of signalized intersections	20	1.00	24.00	9.15	6.23
MINSPCSIG	Minimum spacing of signalized intersections (feet)	19	231.00	1,755.00	678.00	440.00
MAXSPCSIG	Maximum spacing of signalized intersections (feet)	19	1,181.00	6,094.00	2,481.00	1,232.00
NO3LEGSIG	Number of 3-legged signalized intersections	20	0.00	7.00	2.25	2.15
NO4LEGSIG	Number of 4-legged signalized intersections	20	1.00	20.00	6.70	5.12
NO5LEGSIG	Number of 5-legged signalized intersections	20	0.00	2.00	0.15	0.49
NORTLSIG	Number of signalized intersections with a right-turn lane on the mainline	20	0.00	7.00	2.30	2.05
NOLTLSIG	Number of signalized intersections with a left-turn lane on the mainline	20	1.00	16.00	6.75	4.35
NOMEDOP	Number of median openings	20	0.00	12.00	2.85	3.48
NOMEDOPLT	Number of median openings with a left-turn lane	20	0.00	12.00	2.75	3.39
NOMEDOPNOLT	Number of median openings without a left-turn lane	20	0.00	1.00	0.10	0.31
SPEED_LIMIT	Posted speed limit (miles per hour)	20	30.00	55.00	40.00	7.05
AVGAADT	Average AADT	20	10,018.00	86,773.00	33,724.00	17,160.00
SPCOFFLT	Minimum spacing from off-ramp to available left turn onto mainline from same side of road (feet)	7	45.00	2,214.00	524.00	758.00
SPCOFFRT	Minimum spacing from off-ramp to available right turn onto mainline from same side of road (feet)	7	46.00	726.00	181.00	244.00
SPCON	Minimum spacing from on-ramp to available right turn onto mainline from same side of road (feet)	6	29.00	1,276.00	357.00	468.00

St. Dev. = standard deviation; TWLTL = two-way left-turn lane.

Table 78. Summary statistics for Southern California mixed-use land use.

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
Total	Total crashes/mile-year	14	1.14	61.13	23.04	20.79
Injury	Injury crashes/mile-year	14	1.14	24.87	10.51	7.34
Turning	Turning crashes/mile-year	14	0.86	19.33	7.49	6.53
Rear-end	Rear-end crashes/mile-year	14	0.00	30.07	8.37	8.89
Right-angle	Right-angle crashes/mile-year	14	0.00	12.44	2.73	3.347
PROPLANE1	Proportion of total length with two lanes	14	0.00	0.00	0.00	0.00
PROPLANE2	Proportion of total length with three or four lanes	14	0.00	1.00	0.46	0.46
PROPLANE3	Proportion of total length with five or more lanes	14	0.00	1.00	0.54	0.46
PROPDIV	Proportion of total length with curb or raised concrete median	14	0.00	1.00	0.48	0.43
PROPTWLTL	Proportion of total length with a TWLTL	14	0.00	0.86	0.16	0.26
PROPUNDIV	Proportion of total length with an undivided median	14	0.00	1.00	0.36	0.42
PROPNODEV	Proportion of total length with no adjacent development	14	0.00	0.30	0.02	0.08
PROPPARTDEV	Proportion of total length with partial adjacent development	14	0.00	1.00	0.34	0.42
PROPFULLDEV	Proportion of total length with full adjacent development	14	0.00	1.00	0.64	0.41
PROPLIGHT	Proportion of total length with illumination present	14	0.87	1.00	0.99	0.04
PROPPOORPVMNT	Proportion of total length with a poor pavement condition	14	0.00	0.00	0.00	0.00
PROPVC	Proportion of total length with visual clutter	14	0.00	1.00	0.81	0.29
PROPLIMCONN	Proportion of total length with limited connectivity on adjacent developments	14	0.00	1.00	0.74	0.36
PROPMODCONN	Proportion of total length with moderate connectivity on adjacent developments	14	0.00	1.00	0.24	0.36
PROPSIGCONN	Proportion of total length with significant connectivity on adjacent developments	14	0.00	0.28	0.03	0.08
PROPFRONTRD	Proportion of total length with a frontage road	14	0.00	1.00	0.27	0.33
DRWYDENS	Number of driveways per mile	14	20.10	81.55	44.75	17.37
UNSIGDENS	Number of unsignalized intersections per mile	14	0.57	15.36	7.06	4.04
ACCDENS	Number of driveways plus unsignalized intersections per mile	14	20.68	87.55	51.81	19.76
SIGDENS	Number of signalized intersections per mile	14	2.58	8.84	5.11	1.87
MEDOPDENS	Number of median openings per mile	10	0.00	5.01	1.82	1.92
NODRWYS	Number of driveways	14	16.00	684.00	181.57	220.54
NOCOMFULLDRWY	Number of commercial full-movement driveways	14	0.00	448.00	78.07	119.43
NORESFULLDRWY	Number of residential full-movement driveways	14	0.00	128.00	20.71	36.96
NOCOMLIMDRWY	Number of commercial limited-movement driveways	14	0.00	614.00	76.21	161.99
NORESLIMDRWY	Number of residential limited-movement driveways	14	0.00	32.00	6.57	10.50
NOUNSIG	Number of unsignalized intersections	14	1.00	141.00	33.36	43.28
NO3LEGUNSIG	Number of 3-legged unsignalized intersections	14	0.00	102.00	22.50	30.35

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
NO4LEGUNSIG	Number of 4-legged unsignalized intersections	14	0.00	39.00	10.86	13.84
NO5LEGUNSIG	Number of 5-legged unsignalized intersections	14	0.00	0.00	0.00	0.00
NO3LEGFULLUNSIG	Number of 3-legged full-movement unsignalized intersections	14	0.00	56.00	13.86	16.59
NO3LEGLIMUNSIG	Number of 3-legged limited-movement unsignalized intersections	14	0.00	86.00	8.64	22.84
NO3LEGRIROUNSIG	Number of 3-legged right-in/right-out unsignalized intersections	14	0.00	82.00	8.29	21.82
NO3LEGLFMOUNSIG	Number of 3-legged left from major only unsignalized intersections	14	0.00	4.00	0.36	1.08
NO4LEGFULLUNSIG	Number of 4-legged full-movement unsignalized intersections	14	0.00	38.00	10.71	13.60
NO4LEGLIMUNSIG	Number of 4-legged limited-movement unsignalized intersections	14	0.00	1.00	0.14	0.36
NO4LEGRIROUNSIG	Number of 4-legged right-in/right-out unsignalized intersections	14	0.00	0.00	0.00	0.00
NO4LEGLFMOUNSIG	Number of 4-legged left from major only unsignalized intersections	14	0.00	1.00	0.14	0.36
NORTLUNSIG	Number of unsignalized intersections with a right-turn lane	14	0.00	0.00	0.00	0.00
NOLTLUNSIG	Number of unsignalized intersections with a left-turn lane	14	0.00	84.00	19.21	25.32
NOSIG	Number of signalized intersections	14	3.00	66.00	18.79	21.24
MINSPCSIG	Minimum spacing of signalized intersections (feet)	14	139.00	1,461.00	495.00	388.00
MAXSPCSIG	Maximum spacing of signalized intersections (feet)	14	846.00	4,130.00	1,992.00	1,023.00
NO3LEGSIG	Number of 3-legged signalized intersections	14	0.00	11.00	2.57	2.98
NO4LEGSIG	Number of 4-legged signalized intersections	14	2.00	57.00	16.07	18.52
NO5LEGSIG	Number of 5-legged signalized intersections	14	0.00	1.00	0.07	0.27
NORTLSIG	Number of signalized intersections with a right-turn lane on the mainline	14	0.00	25.00	4.29	6.57
NOLTLSIG	Number of signalized intersections with a left-turn lane on the mainline	14	0.00	63.00	17.79	20.48
NOMEDOP	Number of median openings	10	0.00	40.00	8.70	14.45
NOMEDOPLT	Number of median openings with a left-turn lane	10	0.00	40.00	8.30	14.63
NOMEDOPNOLT	Number of median openings without a left-turn lane	10	0.00	2.00	0.40	0.84
SPEED_LIMIT	Posted speed limit (miles per hour)	14	25.00	45.00	38.00	4.70
AVGAADT	Average AADT	14	17,723.00	67,080.00	45,707.00	15,177.00
SPCOFFLT	Minimum spacing from off-ramp to available left turn onto mainline from same side of road (feet)	3	275.00	360.00	325.00	44.00
SPCOFFRT	Minimum spacing from off-ramp to available right turn onto mainline from same side of road (feet)	3	275.00	360.00	325.00	44.00
SPCON	Minimum spacing from on-ramp to available right turn onto mainline from same side of road (feet)	2	235.00	255.00	245.00	14.00

St. Dev. = standard deviation; TWLTL = two-way left-turn lane.

COMMERCIAL

Table 79. Summary statistics for North Carolina commercial land use.

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
Total	Total crashes/mile-year	24	0.84	195.31	39.21	38.46
Injury	Injury crashes/mile-year	24	0.00	40.74	8.92	8.03
Turning	Turning crashes/mile-year	24	0.00	24.44	6.27	5.86
Rear-end	Rear-end crashes/mile-year	24	0.00	69.63	17.18	16.46
Right-angle	Right-angle crashes/mile-year	24	0.00	52.10	6.73	10.30
PROPLANE1	Proportion of total length with two lanes	24	0.00	1.00	0.21	0.39
PROPLANE2	Proportion of total length with three or four lanes	24	0.00	1.00	0.63	0.42
PROPLANE3	Proportion of total length with five or more lanes	24	0.00	1.00	0.18	0.32
PROPDIV	Proportion of total length with curb or raised concrete median	24	0.00	1.00	0.51	0.46
PROPTWLTL	Proportion of total length with a TWLTL	24	0.00	1.00	0.29	0.37
PROPUNDIV	Proportion of total length with an undivided median	24	0.00	1.00	0.21	0.35
PROPNODEV	Proportion of total length with no adjacent development	24	0.00	1.00	0.15	0.32
PROPPARTDEV	Proportion of total length with partial adjacent development	24	0.00	1.00	0.74	0.38
PROPFULLDEV	Proportion of total length with full adjacent development	24	0.00	1.00	0.11	0.28
PROPLIGHT	Proportion of total length with illumination present	24	0.00	1.00	0.66	0.45
PROPPOORPVMNT	Proportion of total length with a poor pavement condition	23	0.00	0.71	0.05	0.15
PROPVC	Proportion of total length with visual clutter	24	0.00	1.00	0.16	0.34
PROPLIMCONN	Proportion of total length with limited connectivity on adjacent developments	24	0.00	1.00	0.22	0.38
PROPMODCONN	Proportion of total length with moderate connectivity on adjacent developments	24	0.00	0.74	0.12	0.21
PROPSIGCONN	Proportion of total length with significant connectivity on adjacent developments	24	0.00	1.00	0.62	0.41
PROPFRONTRD	Proportion of total length with a frontage road	24	0.00	0.42	0.03	0.10
DRWYDENS	Number of driveways per mile	24	0.00	50.00	10.79	11.90
UNSIGDENS	Number of unsignalized intersections per mile	24	0.00	8.00	4.05	2.19
ACCDENS	Number of driveways plus unsignalized intersections per mile	24	0.92	57.78	14.85	12.63
SIGDENS	Number of signalized intersections per mile	24	0.00	9.04	2.96	2.00
MEDOPDENS	Number of median openings per mile	18	0.00	5.62	0.96	1.45
NODRWYS	Number of driveways	24	0.00	103.00	20.96	25.33
NOCOMFULLDRWY	Number of commercial full-movement driveways	24	0.00	78.00	9.88	17.85
NORESFULLDRWY	Number of residential full-movement driveways	24	0.00	22.00	2.63	6.41
NOCOMLIMDRWY	Number of commercial limited-movement driveways	24	0.00	39.00	8.00	10.17
NORESLIMDRWY	Number of residential limited-movement driveways	24	0.00	5.00	0.46	1.32

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
NOUNSIG	Number of unsignalized intersections	24	0.00	34.00	7.54	7.40
NO3LEGUNSIG	Number of 3-legged unsignalized intersections	24	0.00	19.00	5.63	5.19
NO4LEGUNSIG	Number of 4-legged unsignalized intersections	24	0.00	15.00	1.92	3.09
NO5LEGUNSIG	Number of 5-legged unsignalized intersections	24	0.00	0.00	0.00	0.00
NO3LEGFULLUNSIG	Number of 3-legged full-movement unsignalized intersections	24	0.00	18.00	3.21	3.92
NO3LEGLIMUNSIG	Number of 3-legged limited-movement unsignalized intersections	24	0.00	13.00	2.42	3.09
NO3LEGRIROUNSIG	Number of 3-legged right-in/right-out unsignalized intersections	24	0.00	10.00	2.04	2.56
NO3LEGLFMOUNSIG	Number of 3-legged unsignalized intersections with no left-turn movement from crossroad	24	0.00	3.00	0.38	0.77
NO4LEGFULLUNSIG	Number of 4-legged full-movement unsignalized intersections	24	0.00	15.00	1.71	3.09
NO4LEGLIMUNSIG	Number of 4-legged limited-movement unsignalized intersections	24	0.00	2.00	0.21	0.51
NO4LEGRIROUNSIG	Number of 4-legged right-in/right-out unsignalized intersections	24	0.00	1.00	0.08	0.28
NO4LEGLFMOUNSIG	Number of 4-legged unsignalized intersections with no left-turn movement from crossroad	24	0.00	2.00	0.13	0.45
NORTLUNSIG	Number of unsignalized intersections with a right-turn lane	24	0.00	14.00	2.08	3.23
NOLTLUNSIG	Number of unsignalized intersections with a left-turn lane	24	0.00	31.00	4.79	6.59
NOSIG	Number of signalized intersections	24	0.00	15.00	4.88	3.71
MINSPCSIG	Minimum spacing of signalized intersections (feet)	21	201.00	12,228.00	1,691.00	2,551.00
MAXSPCSIG	Maximum spacing of signalized intersections (feet)	21	977.00	12,228.00	3,934.00	2,936.00
NO3LEGSIG	Number of 3-legged signalized intersections	24	0.00	4.00	0.96	1.16
NO4LEGSIG	Number of 4-legged signalized intersections	24	0.00	11.00	3.88	2.86
NO5LEGSIG	Number of 5-legged signalized intersections	24	0.00	0.00	0.00	0.00
NORTLSIG	Number of signalized intersections with a right-turn lane on the mainline	24	0.00	9.00	3.42	2.32
NOLTLSIG	Number of signalized intersections with a left-turn lane on the mainline	24	0.00	15.00	4.75	3.65
NOMEDOP	Number of median openings	18	0.00	10.00	2.22	3.34
MEDOPLT	Number of median openings with a left-turn lane	18	0.00	10.00	1.89	3.12
MEDOPNOLT	Number of median openings without a left-turn lane	18	0.00	6.00	0.33	1.41
SPEED_LIMIT	Posted speed limit (miles per hour)	24	35.00	55.00	45.00	4.29
AVGAADT	Average AADT	24	50.00	46,087.00	22,085.00	13,311.00
SPCOFFLT	Minimum spacing from off-ramp to available left turn onto mainline from same side of road (feet)	12	376.00	1,991.00	856.00	458.00
SPCOFFRT	Minimum spacing from off-ramp to available right turn onto mainline from same side of road (feet)	12	331.00	1,991.00	808.00	490.00
SPCON	Minimum spacing from on-ramp to available right turn onto mainline from same side of road (feet)	12	189.00	2,446.00	1,063.00	700.00

St. Dev. = standard deviation; TWLTL = two-way left-turn lane.

Table 80. Summary statistics for Minnesota commercial land use.

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
Total	Total crashes/mile-year	20	12.62	140.26	38.85	30.27
Injury	Injury crashes/mile-year	20	12.62	140.26	38.85	30.27
Turning	Turning crashes/mile-year	20	0.22	23.93	3.12	5.12
Rear-end	Rear-end crashes/mile-year	20	5.56	65.28	20.01	15.85
Right-angle	Right-angle crashes/mile-year	20	1.35	27.64	6.29	7.10
PROPLANE1	Proportion of total length with two lanes	20	0.00	1.00	0.12	0.32
PROPLANE2	Proportion of total length with three or four lanes	20	0.00	1.00	0.83	0.32
PROPLANE3	Proportion of total length with five or more lanes	20	0.00	0.37	0.04	0.11
PROPDIV	Proportion of total length with curb or raised concrete median	20	0.00	1.00	0.73	0.41
PROPTWLTL	Proportion of total length with a TWLTL	20	0.00	1.00	0.10	0.29
PROPUNDIV	Proportion of total length with an undivided median	20	0.00	1.00	0.17	0.33
PROPNODEV	Proportion of total length with no adjacent development	20	0.00	0.14	0.01	0.03
PROPPARTDEV	Proportion of total length with partial adjacent development	20	0.50	1.00	0.92	0.16
PROPFULLDEV	Proportion of total length with full adjacent development	20	0.00	0.50	0.07	0.16
PROPLIGHT	Proportion of total length with illumination present	20	0.00	1.00	0.51	0.47
PROPPOORPVMNT	Proportion of total length with a poor pavement condition	20	0.00	1.00	0.10	0.27
PROPVC	Proportion of total length with visual clutter	20	0.00	1.00	0.37	0.41
PROPLIMCONN	Proportion of total length with limited connectivity on adjacent developments	20	0.00	1.00	0.44	0.39
PROPMODCONN	Proportion of total length with moderate connectivity on adjacent developments	20	0.00	1.00	0.50	0.39
PROPSIGCONN	Proportion of total length with significant connectivity on adjacent developments	20	0.00	1.00	0.07	0.23
PROPFRONTRD	Proportion of total length with a frontage road	20	0.00	1.00	0.67	0.40
DRWYDENS	Number of driveways per mile	20	0.00	39.56	10.96	13.27
UNSIGDENS	Number of unsignalized intersections per mile	20	0.00	7.46	2.61	2.22
ACCDENS	Number of driveways plus unsignalized intersections per mile	20	0.00	46.44	13.57	15.23
SIGDENS	Number of signalized intersections per mile	20	0.57	7.21	3.11	1.88
MEDOPDENS	Number of median openings per mile	17	0.00	6.31	0.99	1.52
NODRWYS	Number of driveways	20	0.00	91.00	25.15	30.36
NOCOMFULLDRWY	Number of commercial full-movement driveways	20	0.00	89.00	9.85	20.73
NORESFULLDRWY	Number of residential full-movement driveways	20	0.00	6.00	1.00	1.97
NOCOMLIMDRWY	Number of commercial limited-movement driveways	20	0.00	62.00	12.55	20.92
NORESLIMDRWY	Number of residential limited-movement driveways	20	0.00	15.00	1.75	4.14
NOUNSIG	Number of unsignalized intersections	20	0.00	24.00	7.05	6.59
NO3LEGUNSIG	Number of 3-legged unsignalized intersections	20	0.00	21.00	4.65	5.15

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
NO4LEGUNSIG	Number of 4-legged unsignalized intersections	20	0.00	12.00	2.35	3.31
NO5LEGUNSIG	Number of 5-legged unsignalized intersections	20	0.00	1.00	0.05	0.22
NO3LEGFULLUNSIG	Number of 3-legged full-movement unsignalized intersections	20	0.00	14.00	2.25	3.18
NO3LEGLIMUNSIG	Number of 3-legged limited-movement unsignalized intersections	20	0.00	11.00	2.45	3.43
NO3LEGRIROUNSIG	Number of 3-legged right-in/right-out unsignalized intersections	20	0.00	11.00	2.40	3.45
NO3LEGLFMOUNSIG	Number of 3-legged unsignalized intersections with no left-turn movement from crossroad	20	0.00	1.00	0.05	0.22
NO4LEGFULLUNSIG	Number of 4-legged full-movement unsignalized intersections	20	0.00	13.00	2.35	3.39
NO4LEGLIMUNSIG	Number of 4-legged limited-movement unsignalized intersections	20	0.00	1.00	0.05	0.22
NO4LEGRIROUNSIG	Number of 4-legged right-in/right-out unsignalized intersections	20	0.00	0.00	0.00	0.00
NO4LEGLFMOUNSIG	Number of 4-legged left from major only unsignalized intersections	20	0.00	0.00	0.00	0.00
NORTLUNSIG	Number of unsignalized intersections with a right-turn lane	20	0.00	13.00	3.00	3.67
NOLTLUNSIG	Number of unsignalized intersections with a left-turn lane	20	0.00	14.00	3.70	4.78
NOSIG	Number of signalized intersections	20	2.00	16.00	7.10	3.70
MINSPCSIG	Minimum spacing of signalized intersections (feet)	20	141.00	3,612.00	1,275.00	1,030.00
MAXSPCSIG	Maximum spacing of signalized intersections (feet)	20	143.00	27,595.00	4,535.00	5,702.00
NO3LEGSIG	Number of 3-legged signalized intersections	20	0.00	3.00	0.65	0.93
NO4LEGSIG	Number of 4-legged signalized intersections	20	2.00	13.00	6.45	3.28
NO5LEGSIG	Number of 5-legged signalized intersections	20	0.00	0.00	0.00	0.00
NORTLSIG	Number of signalized intersections with a right-turn lane on the mainline	20	1.00	11.00	4.75	2.65
NOLTLSIG	Number of signalized intersections with a left-turn lane on the mainline	20	2.00	11.00	6.25	2.77
NOMEDOP	Number of median openings	17	0.00	22.00	3.29	5.62
NOMEDOPLT	Number of median openings with a left-turn lane	17	0.00	17.00	3.06	5.10
NOMEDOPNOLT	Number of median openings without a left-turn lane	17	0.00	5.00	0.65	1.50
SPEED_LIMIT	Posted speed limit (miles per hour)	20	30.00	60.00	45.00	10.94
AVGAADT	Average AADT	20	14,295.00	52,858.00	30,402.00	12,016.00
SPCOFFLT	Minimum spacing from off-ramp to available left turn onto mainline from same side of road (feet)	9	142.00	1,554.00	808.00	499.00
SPCOFFRT	Minimum spacing from off-ramp to available right turn onto mainline from same side of road (feet)	9	142.00	1,554.00	749.00	454.00
SPCON	Minimum spacing from on-ramp to available right turn onto mainline from same side of road (feet)	9	93.00	3,500.00	1,053.00	1,011.00

St. Dev. = standard deviation; TWLTL = two-way left-turn lane.

Table 81. Summary statistics for Northern California commercial land use.

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
Total	Total crashes/mile-year	22	0.54	43.84	21.17	14.41
Injury	Injury crashes/mile-year	22	0.32	17.81	7.90	5.30
Turning	Turning crashes/mile-year	22	0.00	12.72	5.34	3.77
Rear-end	Rear-end crashes/mile-year	22	0.00	25.57	9.95	7.92
Right-angle	Right-angle crashes/mile-year	22	0.00	7.02	2.01	1.70
PROPLANE1	Proportion of total length with two lanes	22	0.00	1.00	0.16	0.35
PROPLANE2	Proportion of total length with three or four lanes	22	0.00	1.00	0.49	0.44
PROPLANE3	Proportion of total length with five or more lanes	22	0.00	1.00	0.35	0.43
PROPDIV	Proportion of total length with curb or raised concrete median	22	0.00	1.00	0.64	0.45
PROPTWLTL	Proportion of total length with a TWLTL	22	0.00	1.00	0.23	0.35
PROPUNDIV	Proportion of total length with an undivided median	22	0.00	1.00	0.14	0.28
PROPNODEV	Proportion of total length with no adjacent development	22	0.00	1.00	0.06	0.23
PROPPARTDEV	Proportion of total length with partial adjacent development	22	0.00	1.00	0.43	0.45
PROPFULLDEV	Proportion of total length with full adjacent development	22	0.00	1.00	0.51	0.47
PROPLIGHT	Proportion of total length with illumination present	22	0.00	1.00	0.90	0.24
PROPPOORPVMNT	Proportion of total length with a poor pavement condition	22	0.00	0.10	0.00	0.02
PROPVC	Proportion of total length with visual clutter	22	0.00	1.00	0.29	0.41
PROPLIMCONN	Proportion of total length with limited connectivity on adjacent developments	22	0.00	1.00	0.29	0.37
PROPMODCONN	Proportion of total length with moderate connectivity on adjacent developments	22	0.00	1.00	0.40	0.38
PROPSIGCONN	Proportion of total length with significant connectivity on adjacent developments	22	0.00	1.00	0.31	0.41
PROPFRONTRD	Proportion of total length with a frontage road	22	0.00	1.00	0.18	0.30
DRWYDENS	Number of driveways per mile	22	2.00	67.88	38.82	18.61
UNSIGDENS	Number of unsignalized intersections per mile	22	1.50	13.09	6.41	3.88
ACCDENS	Number of driveways plus unsignalized intersections per mile	22	3.50	72.97	45.23	20.22
SIGDENS	Number of signalized intersections per mile	22	0.00	8.06	4.17	1.96
MEDOPDENS	Number of median openings per mile	21	0.00	6.08	1.88	1.85
NODRWYS	Number of driveways	22	4.00	627.00	137.14	177.62
NOCOMFULLDRWY	Number of commercial full-movement driveways	22	0.00	415.00	43.05	89.66
NORESFULLDRWY	Number of residential full-movement driveways	22	0.00	49.00	2.68	10.40
NOCOMLIMDRWY	Number of commercial limited-movement driveways	22	0.00	477.00	87.73	125.51
NORESLIMDRWY	Number of residential limited-movement driveways	22	0.00	22.00	3.68	6.31
NOUNSIG	Number of unsignalized intersections	22	2.00	137.00	22.45	33.50
NO3LEGUNSIG	Number of 3-legged unsignalized intersections	22	2.00	92.00	18.36	25.27

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
NO4LEGUNSIG	Number of 4-legged unsignalized intersections	22	0.00	45.00	4.09	9.70
NO5LEGUNSIG	Number of 5-legged unsignalized intersections	22	0.00	0.00	0.00	0.00
NO3LEGFULLUNSIG	Number of 3-legged full-movement unsignalized intersections	22	0.00	68.00	9.68	15.93
NO3LEGLIMUNSIG	Number of 3-legged limited-movement unsignalized intersections	22	0.00	36.00	9.14	12.38
NO3LEGRIROUNSIG	Number of 3-legged right-in/right-out unsignalized intersections	22	0.00	36.00	8.68	11.75
NO3LEGLFMOUNSIG	Number of 3-legged unsignalized intersections with no left-turn movement from crossroad	22	0.00	3.00	0.45	0.91
NO4LEGFULLUNSIG	Number of 4-legged full-movement unsignalized intersections	22	0.00	45.00	4.00	9.72
NO4LEGLIMUNSIG	Number of 4-legged limited-movement unsignalized intersections	22	0.00	2.00	0.09	0.43
NO4LEGRIROUNSIG	Number of 4-legged right-in/right-out unsignalized intersections	22	0.00	1.00	0.05	0.21
NO4LEGLFMOUNSIG	Number of 4-legged unsignalized intersections with no left-turn movement from crossroad	22	0.00	1.00	0.05	0.21
NORTLUNSIG	Number of unsignalized intersections with a right-turn lane	22	0.00	5.00	0.50	1.34
NOLTLUNSIG	Number of unsignalized intersections with a left-turn lane	22	0.00	89.00	11.59	19.92
NOSIG	Number of signalized intersections	22	0.00	54.00	12.95	14.86
MINSPCSIG	Minimum spacing of signalized intersections (feet)	19	114.00	3,408.00	650.00	721.00
MAXSPCSIG	Maximum spacing of signalized intersections (feet)	19	735.00	5,745.00	2,133.00	1,199.00
NO3LEGSIG	Number of 3-legged signalized intersections	22	0.00	14.00	3.27	3.95
NO4LEGSIG	Number of 4-legged signalized intersections	22	0.00	41.00	9.50	11.45
NO5LEGSIG	Number of 5-legged signalized intersections	22	0.00	5.00	0.36	1.14
NORTLSIG	Number of signalized intersections with a right-turn lane on the mainline	22	0.00	9.00	2.91	2.51
NOLTLSIG	Number of signalized intersections with a left-turn lane on the mainline	22	0.00	42.00	12.09	13.31
NOMEDOP	Number of median openings	21	0.00	42.00	7.29	11.38
NOMEDOPLT	Number of median openings with a left-turn lane	21	0.00	34.00	6.24	9.88
NOMEDOPNOLT	Number of median openings without a left-turn lane	21	0.00	8.00	1.10	2.47
SPEED_LIMIT	Posted speed limit (miles per hour)	22	30.00	50.00	38.00	5.29
AVGAADT	Average AADT	22	6,233.00	46,014.00	27,364.00	10,725.00
SPCOFFLT	Minimum spacing from off-ramp to available left turn onto mainline from same side of road (feet)	4	200.00	1,483.00	783.00	590.00
SPCOFFRT	Minimum spacing from off-ramp to available right turn onto mainline from same side of road (feet)	4	21.00	1,048.00	311.00	494.00
SPCON	Minimum spacing from on-ramp to available right turn onto mainline from same side of road (feet)	4	32.00	215.00	101.00	79.00

St. Dev. = standard deviation; TWLTL = two-way left-turn lane.

Table 82. Summary statistics for Southern California commercial land use.

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
Total	Total crashes/mile-year	22	1.64	108.99	26.65	22.41
Injury	Injury crashes/mile-year	22	0.33	35.88	8.26	7.65
Turning	Turning crashes/mile-year	22	0.33	35.88	8.26	7.65
Rear-end	Rear-end crashes/mile-year	22	0.33	43.60	11.13	9.80
Right-angle	Right-angle crashes/mile-year	22	0.00	14.99	2.72	3.08
PROPLANE1	Proportion of total length with two lanes	22	0.00	0.47	0.02	0.10
PROPLANE2	Proportion of total length with three or four lanes	22	0.00	1.00	0.56	0.45
PROPLANE3	Proportion of total length with five or more lanes	22	0.00	1.00	0.42	0.46
PROPDIV	Proportion of total length with curb or raised concrete median	22	0.00	1.00	0.44	0.44
PROPTWLTL	Proportion of total length with a TWLTL	22	0.00	1.00	0.41	0.42
PROPUNDIV	Proportion of total length with an undivided median	22	0.00	1.00	0.15	0.30
PROPNODEV	Proportion of total length with no adjacent development	22	0.00	1.00	0.13	0.30
PROPPARTDEV	Proportion of total length with partial adjacent development	22	0.00	1.00	0.55	0.44
PROPFULLDEV	Proportion of total length with full adjacent development	22	0.00	1.00	0.33	0.41
PROPLIGHT	Proportion of total length with illumination present	22	0.00	1.00	0.78	0.39
PROPPOORPVMNT	Proportion of total length with a poor pavement condition	22	0.00	0.00	0.00	0.00
PROPVC	Proportion of total length with visual clutter	22	0.00	1.00	0.30	0.39
PROPLIMCONN	Proportion of total length with limited connectivity on adjacent developments	22	0.00	1.00	0.41	0.37
PROPMODCONN	Proportion of total length with moderate connectivity on adjacent developments	22	0.00	1.00	0.50	0.36
PROPSIGCONN	Proportion of total length with significant connectivity on adjacent developments	22	0.00	1.00	0.09	0.23
PROPFRONTRD	Proportion of total length with a frontage road	22	0.00	1.00	0.36	0.41
DRWYDENS	Number of driveways per mile	22	0.00	63.69	26.81	19.51
UNSIGDENS	Number of unsignalized intersections per mile	22	0.00	16.07	5.69	3.70
ACCDENS	Number of driveways plus unsignalized intersections per mile	22	1.97	79.76	32.50	22.07
SIGDENS	Number of signalized intersections per mile	22	0.00	5.45	3.31	1.30
MEDOPDENS	Number of median openings per mile	15	0.00	12.01	2.06	3.10
NODRWYS	Number of driveways	22	0.00	279.00	73.50	79.34
NOCOMFULLDRWY	Number of commercial full-movement driveways	22	0.00	216.00	38.23	60.13
NORESFULLDRWY	Number of residential full-movement driveways	22	0.00	58.00	5.73	15.04
NOCOMLIMDRWY	Number of commercial limited-movement driveways	22	0.00	152.00	29.45	46.53
NORESLIMDRWY	Number of residential limited-movement driveways	22	0.00	2.00	0.09	0.43
NOUNSIG	Number of unsignalized intersections	22	0.00	58.00	15.55	17.68

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
NO3LEGUNSIG	Number of 3-legged unsignalized intersections	22	0.00	53.00	12.00	14.82
NO4LEGUNSIG	Number of 4-legged unsignalized intersections	22	0.00	21.00	3.55	5.23
NO5LEGUNSIG	Number of 5-legged unsignalized intersections	22	0.00	0.00	0.00	0.00
NO3LEGFULLUNSIG	Number of 3-legged full-movement unsignalized intersections	22	0.00	35.00	6.14	9.75
NO3LEGLIMUNSIG	Number of 3-legged limited-movement unsignalized intersections	22	0.00	37.00	5.41	9.96
NO3LEGRIROUNSIG	Number of 3-legged right-in/right-out unsignalized intersections	22	0.00	29.00	4.73	8.40
NO3LEGLFMOUNSIG	Number of 3-legged left from major only unsignalized intersections	22	0.00	6.00	0.59	1.50
NO4LEGFULLUNSIG	Number of 4-legged full-movement unsignalized intersections	22	0.00	21.00	3.55	5.23
NO4LEGLIMUNSIG	Number of 4-legged limited-movement unsignalized intersections	22	0.00	0.00	0.00	0.00
NO4LEGRIROUNSIG	Number of 4-legged right-in/right-out unsignalized intersections	22	0.00	0.00	0.00	0.00
NO4LEGLFMOUNSIG	Number of 4-legged left from major only unsignalized intersections	22	0.00	0.00	0.00	0.00
NORTLUNSIG	Number of unsignalized intersections with a right-turn lane	22	0.00	8.00	0.73	2.07
NOLTLUNSIG	Number of unsignalized intersections with a left-turn lane	22	0.00	40.00	8.64	11.20
NOSIG	Number of signalized intersections	22	0.00	38.00	8.95	9.72
MINSPCSIG	Minimum spacing of signalized intersections (feet)	21	344.00	2,882.00	1,175.00	833.00
MAXSPCSIG	Maximum spacing of signalized intersections (feet)	21	583.00	7,520.00	2,806.00	1,554.00
NO3LEGSIG	Number of 3-legged signalized intersections	22	0.00	6.00	0.91	1.44
NO4LEGSIG	Number of 4-legged signalized intersections	22	0.00	35.00	8.05	9.13
NO5LEGSIG	Number of 5-legged signalized intersections	22	0.00	0.00	0.00	0.00
NORTLSIG	Number of signalized intersections with a right-turn lane on the mainline	22	0.00	16.00	2.73	4.24
NOLTLSIG	Number of signalized intersections with a left-turn lane on the mainline	22	0.00	37.00	8.68	9.57
NOMEDOP	Number of median openings	15	0.00	31.00	6.20	8.68
NOMEDOPLT	Number of median openings with a left-turn lane	15	0.00	25.00	5.13	7.44
NOMEDOPNOLT	Number of median openings without a left-turn lane	15	0.00	6.00	1.07	1.94
SPEED_LIMIT	Posted speed limit (miles per hour)	22	35.00	50.00	42.00	4.51
AVGAADT	Average AADT	22	11,538.00	66,002.00	34,380.00	14,088.00
SPCOFFLT	Minimum spacing from off-ramp to available left turn onto mainline from same side of road (feet)	3	129.00	550.00	348.00	211.00
SPCOFFRT	Minimum spacing from off-ramp to available right turn onto mainline from same side of road (feet)	3	20.00	134.00	83.00	58.00
SPCON	Minimum spacing from on-ramp to available right turn onto mainline from same side of road (feet)	2	33.00	109.00	71.00	54.00

St. Dev. = standard deviation; TWLTL = two-way left-turn lane.

RESIDENTIAL

Table 83. Summary statistics for North Carolina residential land use.

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
Total	Total crashes/mile-year	24	5.22	39.65	18.04	10.01
Injury	Injury crashes/mile-year	24	1.12	11.58	4.91	2.51
Turning	Turning crashes/mile-year	24	0.00	18.27	3.31	3.57
Rear-end	Rear-end crashes/mile-year	24	0.97	18.97	8.21	5.63
Right-angle	Right-angle crashes/mile-year	24	0.00	7.30	2.75	2.05
PROPLANE1	Proportion of total length with two lanes	24	0.00	1.00	0.11	0.30
PROPLANE2	Proportion of total length with three or four lanes	24	0.00	1.00	0.89	0.30
PROPLANE3	Proportion of total length with five or more lanes	24	0.00	0.00	0.00	0.00
PROPDIV	Proportion of total length with curb or raised concrete median	24	0.00	1.00	0.32	0.43
PROPTWLTL	Proportion of total length with a TWLTL	24	0.00	1.00	0.36	0.42
PROPUNDIV	Proportion of total length with an undivided median	24	0.00	1.00	0.30	0.43
PROPNODEV	Proportion of total length with no adjacent development	24	0.00	1.00	0.09	0.28
PROPPARTDEV	Proportion of total length with partial adjacent development	24	0.00	1.00	0.91	0.28
PROPFULLDEV	Proportion of total length with full adjacent development	24	0.00	0.00	0.00	0.00
PROPLIGHT	Proportion of total length with illumination present	24	0.00	1.00	0.79	0.41
PROPPOORPVMNT	Proportion of total length with a poor pavement condition	24	0.00	1.00	0.08	0.24
PROPVC	Proportion of total length with visual clutter	24	0.00	0.00	0.00	0.00
PROPLIMCONN	Proportion of total length with limited connectivity on adjacent developments	24	0.00	1.00	0.36	0.40
PROPMODCONN	Proportion of total length with moderate connectivity on adjacent developments	24	0.00	1.00	0.19	0.31
PROPSIGCONN	Proportion of total length with significant connectivity on adjacent developments	24	0.00	1.00	0.46	0.45
PROPFRONTRD	Proportion of total length with a frontage road	24	0.00	0.00	0.00	0.00
DRWYDENS	Number of driveways per mile	24	0.00	53.55	17.59	16.82
UNSIGDENS	Number of unsignalized intersections per mile	24	0.73	12.05	6.94	2.42
ACCDENS	Number of driveways plus unsignalized intersections per mile	24	1.46	65.60	24.53	18.13
SIGDENS	Number of signalized intersections per mile	24	0.51	3.75	1.67	0.83
MEDOPDENS	Number of median openings per mile	15	0.00	5.24	1.02	1.59
NODRWYS	Number of driveways	24	0.00	70.00	25.17	21.10
NOCOMFULLDRWY	Number of commercial full-movement driveways	24	0.00	20.00	3.38	4.80
NORESFULLDRWY	Number of residential full-movement driveways	24	0.00	60.00	18.25	19.69
NOCOMLIMDRWY	Number of commercial limited-movement driveways	24	0.00	18.00	1.88	4.19
NORESLIMDRWY	Number of residential limited-movement driveways	24	0.00	18.00	1.67	3.85

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
NOUNSIG	Number of unsignalized intersections	24	2.00	30.00	11.79	7.45
NO3LEGUNSIG	Number of 3-legged unsignalized intersections	24	2.00	39.00	10.08	8.48
NO4LEGUNSIG	Number of 4-legged unsignalized intersections	24	0.00	8.00	2.79	2.11
NO5LEGUNSIG	Number of 5-legged unsignalized intersections	24	0.00	0.00	0.00	0.00
NO3LEGFULLUNSIG	Number of 3-legged full-movement unsignalized intersections	24	1.00	23.00	7.29	5.52
NO3LEGLIMUNSIG	Number of 3-legged limited-movement unsignalized intersections	24	0.00	11.00	1.71	2.54
NO3LEGRIROUNSIG	Number of 3-legged right-in/right-out unsignalized intersections	24	0.00	11.00	1.67	2.57
NO3LEGLFMOUNSIG	Number of 3-legged unsignalized intersections with no left-turn movement from crossroad	24	0.00	1.00	0.04	0.20
NO4LEGFULLUNSIG	Number of 4-legged full-movement unsignalized intersections	24	0.00	8.00	2.63	2.10
NO4LEGLIMUNSIG	Number of 4-legged limited-movement unsignalized intersections	24	0.00	1.00	0.17	0.38
NO4LEGRIROUNSIG	Number of 4-legged right-in/right-out unsignalized intersections	24	0.00	1.00	0.17	0.38
NO4LEGLFMOUNSIG	Number of 4-legged unsignalized intersections with no left-turn movement from crossroad	24	0.00	0.00	0.00	0.00
NORTLUNSIG	Number of unsignalized intersections with a right-turn lane	24	0.00	7.00	1.42	1.77
NOLTLUNSIG	Number of unsignalized intersections with a left-turn lane	24	0.00	30.00	7.67	7.51
NOSIG	Number of signalized intersections	24	1.00	8.00	2.83	1.99
MINSPCSIG	Minimum spacing of signalized intersections (feet)	18	646.00	6,506.00	2,446.00	1,538.00
MAXSPCSIG	Maximum spacing of signalized intersections (feet)	18	1,628.00	11,378.00	4,462.00	2,287.00
NO3LEGSIG	Number of 3-legged signalized intersections	24	0.00	2.00	0.58	0.72
NO4LEGSIG	Number of 4-legged signalized intersections	24	0.00	6.00	2.29	1.76
NO5LEGSIG	Number of 5-legged signalized intersections	24	0.00	0.00	0.00	0.00
NORTLSIG	Number of signalized intersections with a right-turn lane on the mainline	24	0.00	8.00	1.67	1.71
NOLTLSIG	Number of signalized intersections with a left-turn lane on the mainline	24	1.00	8.00	2.71	1.99
NOMEDOP	Number of median openings	15	0.00	7.00	1.40	2.13
MEDOPLT	Number of median openings with a left-turn lane	15	0.00	6.00	1.33	1.95
MEDOPNOLT	Number of median openings without a left-turn lane	15	0.00	1.00	0.07	0.26
SPEED_LIMIT	Posted speed limit (miles per hour)	24	35.00	55.00	44.00	5.10
AVGAADT	Average AADT	24	90.00	31,353.00	14,695.00	7,128.00

St. Dev. = standard deviation; TWLTL = two-way left-turn lane.

Table 84. Summary statistics for Minnesota residential land use.

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
Total	Total crashes/mile-year	21	3.10	79.08	23.35	21.46
Injury	Injury crashes/mile-year	21	1.19	26.43	7.72	7.95
Turning	Turning crashes/mile-year	21	0.00	5.79	1.52	1.76
Rear-end	Rear-end crashes/mile-year	21	0.33	48.49	10.95	13.30
Right-angle	Right-angle crashes/mile-year	21	0.36	24.59	4.04	5.44
PROPLANE1	Proportion of total length with two lanes	21	0.00	1.00	0.56	0.50
PROPLANE2	Proportion of total length with three or four lanes	21	0.00	1.00	0.39	0.49
PROPLANE3	Proportion of total length with five or more lanes	21	0.00	1.00	0.05	0.22
PROPDIV	Proportion of total length with curb or raised concrete median	21	0.00	1.00	0.34	0.44
PROPTWLTL	Proportion of total length with a TWLTL	21	0.00	0.29	0.02	0.06
PROPUNDIV	Proportion of total length with an undivided median	21	0.00	1.00	0.64	0.43
PROPNODEV	Proportion of total length with no adjacent development	21	0.00	0.40	0.05	0.12
PROPPARTDEV	Proportion of total length with partial adjacent development	21	0.00	1.00	0.81	0.34
PROPFULLDEV	Proportion of total length with full adjacent development	21	0.00	1.00	0.14	0.34
PROPLIGHT	Proportion of total length with illumination present	21	0.00	1.00	0.37	0.44
PROPPOORPVMNT	Proportion of total length with a poor pavement condition	21	0.00	0.00	0.00	0.00
PROPVC	Proportion of total length with visual clutter	21	0.00	0.34	0.02	0.07
PROPLIMCONN	Proportion of total length with limited connectivity on adjacent developments	21	0.00	1.00	0.93	0.23
PROPMODCONN	Proportion of total length with moderate connectivity on adjacent developments	21	0.00	0.33	0.03	0.08
PROPSIGCONN	Proportion of total length with significant connectivity on adjacent developments	21	0.00	1.00	0.05	0.22
PROPFRONTRD	Proportion of total length with a frontage road	21	0.00	1.00	0.44	0.46
DRWYDENS	Number of driveways per mile	21	0.00	73.86	20.93	20.91
UNSIGDENS	Number of unsignalized intersections per mile	21	0.00	15.24	5.90	3.83
ACCDENS	Number of driveways plus unsignalized intersections per mile	21	0.00	79.72	26.82	23.26
SIGDENS	Number of signalized intersections per mile	21	0.21	5.49	1.93	1.32
MEDOPDENS	Number of median openings per mile	16	0.00	3.25	0.52	0.98
NODRWYS	Number of driveways	21	0.00	221.00	51.52	59.93
NOCOMFULLDRWY	Number of commercial full-movement driveways	21	0.00	54.00	10.19	13.74
NORESFULLDRWY	Number of residential full-movement driveways	21	0.00	160.00	39.86	46.37
NOCOMLIMDRWY	Number of commercial limited-movement driveways	21	0.00	8.00	1.00	2.30
NORESLIMDRWY	Number of residential limited-movement driveways	21	0.00	5.00	0.48	1.29
NOUNSIG	Number of unsignalized intersections	21	0.00	51.00	15.43	15.95
NO3LEGUNSIG	Number of 3-legged unsignalized intersections	21	0.00	38.00	9.33	11.94

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
NO4LEGUNSIG	Number of 4-legged unsignalized intersections	21	0.00	19.00	6.05	6.25
NO5LEGUNSIG	Number of 5-legged unsignalized intersections	21	0.00	1.00	0.05	0.22
NO3LEGFULLUNSIG	Number of 3-legged full-movement unsignalized intersections	21	0.00	38.00	8.57	11.82
NO3LEGLIMUNSIG	Number of 3-legged limited-movement unsignalized intersections	21	0.00	5.00	0.76	1.41
NO3LEGRIROUNSIG	Number of 3-legged right-in/right-out unsignalized intersections	21	0.00	5.00	0.71	1.42
NO3LEGLFMOUNSIG	Number of 3-legged unsignalized intersections with no left-turn movement from crossroad	21	0.00	1.00	0.05	0.22
NO4LEGFULLUNSIG	Number of 4-legged full-movement unsignalized intersections	21	0.00	19.00	6.05	6.25
NO4LEGLIMUNSIG	Number of 4-legged limited-movement unsignalized intersections	21	0.00	0.00	0.00	0.00
NO4LEGRIROUNSIG	Number of 4-legged right-in/right-out unsignalized intersections	21	0.00	0.00	0.00	0.00
NO4LEGLFMOUNSIG	Number of 4-legged left from major only unsignalized intersections	21	0.00	0.00	0.00	0.00
NORTLUNSIG	Number of unsignalized intersections with a right-turn lane	21	0.00	19.00	3.57	5.46
NOLTLUNSIG	Number of unsignalized intersections with a left-turn lane	21	0.00	18.00	2.43	4.07
NOSIG	Number of signalized intersections	21	1.00	19.00	3.86	4.07
MINSPCSIG	Minimum spacing of signalized intersections (feet)	16	301.00	6,538.00	1,896.00	1,606.00
MAXSPCSIG	Maximum spacing of signalized intersections (feet)	16	504.00	13,545.00	3,767.00	3,142.00
NO3LEGSIG	Number of 3-legged signalized intersections	21	0.00	4.00	0.43	0.98
NO4LEGSIG	Number of 4-legged signalized intersections	21	1.00	15.00	3.43	3.41
NO5LEGSIG	Number of 5-legged signalized intersections	21	0.00	0.00	0.00	0.00
NORTLSIG	Number of signalized intersections with a right-turn lane on the mainline	21	0.00	11.00	2.29	2.41
NOLTLSIG	Number of signalized intersections with a left-turn lane on the mainline	21	1.00	17.00	2.95	3.57
NOMEDOP	Number of median openings	16	0.00	3.00	0.75	1.13
NOMEDOPLT	Number of median openings with a left-turn lane	16	0.00	3.00	0.69	1.01
NOMEDOPNOLT	Number of median openings without a left-turn lane	16	0.00	1.00	0.06	0.25
SPEED_LIMIT	Posted speed limit (miles per hour)	21	30.00	55.00	41.00	8.54
AVGAADT	Average AADT	21	5,423.00	70,333.00	18,397.00	16,092.00
SPCOFFLT	Minimum spacing from off-ramp to available left turn onto mainline from same side of road (feet)	7	321.00	762.00	487.00	170.00
SPCOFFRT	Minimum spacing from off-ramp to available right turn onto mainline from same side of road (feet)	7	321.00	762.00	460.00	179.00
SPCON	Minimum spacing from on-ramp to available right turn onto mainline from same side of road (feet)	8	94.00	762.00	367.00	205.00

St. Dev. = standard deviation; TWLTL = two-way left-turn lane.

Table 85. Summary statistics for Northern California residential land use.

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
Total	Total crashes/mile-year	17	0.19	36.77	15.75	10.49
Injury	Injury crashes/mile-year	17	0.00	20.83	6.75	5.91
Turning	Turning crashes/mile-year	17	0.00	17.18	4.81	4.10
Rear-end	Rear-end crashes/mile-year	17	0.00	15.69	6.56	4.92
Right-angle	Right-angle crashes/mile-year	17	0.00	6.67	1.79	1.97
PROPLANE1	Proportion of total length with two lanes	17	0.00	1.00	0.35	0.43
PROPLANE2	Proportion of total length with three or four lanes	17	0.00	1.00	0.46	0.45
PROPLANE3	Proportion of total length with five or more lanes	17	0.00	1.00	0.18	0.39
PROPDIV	Proportion of total length with curb or raised concrete median	17	0.00	1.00	0.49	0.47
PROPTWLTL	Proportion of total length with a TWLTL	17	0.00	0.97	0.11	0.26
PROPUNDIV	Proportion of total length with an undivided median	17	0.00	1.00	0.40	0.43
PROPNODEV	Proportion of total length with no adjacent development	17	0.00	0.33	0.06	0.13
PROPPARTDEV	Proportion of total length with partial adjacent development	17	0.00	1.00	0.75	0.37
PROPFULLDEV	Proportion of total length with full adjacent development	17	0.00	1.00	0.19	0.36
PROPLIGHT	Proportion of total length with illumination present	17	0.00	1.00	0.46	0.47
PROPPOORPVMNT	Proportion of total length with a poor pavement condition	17	0.00	0.00	0.00	0.00
PROPVC	Proportion of total length with visual clutter	17	0.00	1.00	0.09	0.26
PROPLIMCONN	Proportion of total length with limited connectivity on adjacent developments	17	0.00	1.00	0.54	0.47
PROPMODCONN	Proportion of total length with moderate connectivity on adjacent developments	17	0.00	1.00	0.25	0.43
PROPSIGCONN	Proportion of total length with significant connectivity on adjacent developments	17	0.00	1.00	0.21	0.39
PROPFRONTRD	Proportion of total length with a frontage road	17	0.00	1.00	0.51	0.46
DRWYDENS	Number of driveways per mile	17	0.00	135.52	25.45	35.88
UNSIGDENS	Number of unsignalized intersections per mile	17	0.00	18.71	5.79	4.76
ACCDENS	Number of driveways plus unsignalized intersections per mile	17	0.00	144.14	31.24	38.57
SIGDENS	Number of signalized intersections per mile	17	0.00	9.09	2.46	2.20
MEDOPDENS	Number of median openings per mile	16	0.00	12.30	1.65	3.13
NODRWYS	Number of driveways	17	0.00	393.00	65.00	98.03
NOCOMFULLDRWY	Number of commercial full-movement driveways	17	0.00	35.00	5.35	9.10
NORESFULLDRWY	Number of residential full-movement driveways	17	0.00	358.00	40.12	90.09
NOCOMLIMDRWY	Number of commercial limited-movement driveways	17	0.00	59.00	8.88	15.71
NORESLIMDRWY	Number of residential limited-movement driveways	17	0.00	83.00	10.65	22.23
NOUNSIG	Number of unsignalized intersections	17	0.00	42.00	14.24	12.64
NO3LEGUNSIG	Number of 3-legged unsignalized intersections	17	0.00	36.00	11.29	10.68

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
NO4LEGUNSIG	Number of 4-legged unsignalized intersections	17	0.00	14.00	2.88	3.77
NO5LEGUNSIG	Number of 5-legged unsignalized intersections	17	0.00	1.00	0.06	0.24
NO3LEGFULLUNSIG	Number of 3-legged full-movement unsignalized intersections	17	0.00	27.00	8.24	8.04
NO3LEGLIMUNSIG	Number of 3-legged limited-movement unsignalized intersections	17	0.00	27.00	3.06	6.67
NO3LEGRIROUNSIG	Number of 3-legged right-in/right-out unsignalized intersections	17	0.00	25.00	2.82	6.25
NO3LEGLFMOUNSIG	Number of 3-legged unsignalized intersections with no left-turn movement from crossroad	17	0.00	2.00	0.18	0.53
NO4LEGFULLUNSIG	Number of 4-legged full-movement unsignalized intersections	17	0.00	14.00	2.88	3.77
NO4LEGLIMUNSIG	Number of 4-legged limited-movement unsignalized intersections	17	0.00	0.00	0.00	0.00
NO4LEGRIROUNSIG	Number of 4-legged right-in/right-out unsignalized intersections	17	0.00	0.00	0.00	0.00
NO4LEGLFMOUNSIG	Number of 4-legged unsignalized intersections with no left-turn movement from crossroad	17	0.00	0.00	0.00	0.00
NORTLUNSIG	Number of unsignalized intersections with a right-turn lane	17	0.00	4.00	0.94	1.09
NOLTLUNSIG	Number of unsignalized intersections with a left-turn lane	17	0.00	25.00	7.65	7.42
NOSIG	Number of signalized intersections	17	0.00	24.00	5.88	5.86
MINSPCSIG	Minimum spacing of signalized intersections (feet)	14	109.00	4,471.00	1,677.00	1,658.00
MAXSPCSIG	Maximum spacing of signalized intersections (feet)	14	702.00	7,265.00	3,960.00	1,829.00
NO3LEGSIG	Number of 3-legged signalized intersections	17	0.00	6.00	1.35	2.03
NO4LEGSIG	Number of 4-legged signalized intersections	17	0.00	20.00	4.47	4.81
NO5LEGSIG	Number of 5-legged signalized intersections	17	0.00	1.00	0.06	0.24
NORTLSIG	Number of signalized intersections with a right-turn lane on the mainline	17	0.00	8.00	2.53	2.55
NOLTLSIG	Number of signalized intersections with a left-turn lane on the mainline	17	0.00	23.00	4.06	5.61
NOMEDOP	Number of median openings	16	0.00	19.00	3.31	5.20
NOMEDOPLT	Number of median openings with a left-turn lane	16	0.00	19.00	2.94	4.89
NOMEDOPNOLT	Number of median openings without a left-turn lane	16	0.00	4.00	0.38	1.02
SPEED_LIMIT	Posted speed limit (miles per hour)	17	25.00	55.00	42.00	9.34
AVGAADT	Average AADT	17	10,300.00	69,847.00	26,490.00	13,97.002
SPCOFFLT	Minimum spacing from off-ramp to available left turn onto mainline from same side of road (feet)	3	183.00	662.00	364.00	260.00
SPCOFFRT	Minimum spacing from off-ramp to available right turn onto mainline from same side of road (feet)	3	49.00	662.00	319.00	313.00
SPCON	Minimum spacing from on-ramp to available right turn onto mainline from same side of road (feet)	1	383.00	383.00	383.00	—

St. Dev. = standard deviation; TWLTL = two-way left-turn lane; —Not applicable.

Table 86. Summary statistics for Southern California residential land use.

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
Total	Total crashes/mile-year	13	4.15	51.13	19.39	14.47
Injury	Injury crashes/mile-year	13	1.57	21.51	8.05	5.64
Turning	Turning crashes/mile-year	13	1.04	10.77	5.30	3.13
Rear-end	Rear-end crashes/mile-year	13	2.07	35.50	9.34	9.55
Right-angle	Right-angle crashes/mile-year	13	0.00	4.04	1.51	1.21
PROPLANE1	Proportion of total length with two lanes	13	0.00	1.00	0.18	0.37
PROPLANE2	Proportion of total length with three or four lanes	13	0.00	1.00	0.66	0.47
PROPLANE3	Proportion of total length with five or more lanes	13	0.00	1.00	0.16	0.37
PROPDIV	Proportion of total length with curb or raised concrete median	13	0.00	1.00	0.31	0.44
PROPTWLTL	Proportion of total length with a TWLTL	13	0.00	1.00	0.42	0.43
PROPUNDIV	Proportion of total length with an undivided median	13	0.00	1.00	0.27	0.36
PROPNODEV	Proportion of total length with no adjacent development	13	0.00	0.58	0.05	0.16
PROPPARTDEV	Proportion of total length with partial adjacent development	13	0.00	1.00	0.69	0.41
PROPFULLDEV	Proportion of total length with full adjacent development	13	0.00	1.00	0.25	0.40
PROPLIGHT	Proportion of total length with illumination present	13	0.00	1.00	0.62	0.45
PROPPOORPVMNT	Proportion of total length with a poor pavement condition	13	0.00	0.00	0.00	0.00
PROPVC	Proportion of total length with visual clutter	13	0.00	1.00	0.21	0.38
PROPLIMCONN	Proportion of total length with limited connectivity on adjacent developments	13	0.00	1.00	0.81	0.31
PROPMODCONN	Proportion of total length with moderate connectivity on adjacent developments	13	0.00	1.00	0.19	0.31
PROPSIGCONN	Proportion of total length with significant connectivity on adjacent developments	13	0.00	0.00	0.00	0.00
PROPFRONTRD	Proportion of total length with a frontage road	13	0.00	1.00	0.55	0.46
DRWYDENS	Number of driveways per mile	13	0.00	85.71	19.62	21.98
UNSIGDENS	Number of unsignalized intersections per mile	13	0.61	14.29	6.76	4.42
ACCDENS	Number of driveways plus unsignalized intersections per mile	13	0.61	100.00	26.38	25.42
SIGDENS	Number of signalized intersections per mile	13	0.00	2.56	1.86	0.80
MEDOPDENS	Number of median openings per mile	5	0.00	3.17	1.44	1.24
NODRWYS	Number of driveways	13	0.00	123.00	31.46	33.76
NOCOMFULLDRWY	Number of commercial full-movement driveways	13	0.00	88.00	15.54	25.51
NORESFULLDRWY	Number of residential full-movement driveways	13	0.00	32.00	10.77	12.09
NOCOMLIMDRWY	Number of commercial limited-movement driveways	13	0.00	12.00	3.00	4.40
NORESLIMDRWY	Number of residential limited-movement driveways	13	0.00	26.00	2.15	7.17
NOUNSIG	Number of unsignalized intersections	13	1.00	34.00	11.92	10.05
NO3LEGUNSIG	Number of 3-legged unsignalized intersections	13	1.00	33.00	9.54	8.94

Variable Name	Variable Description	Corridors	Minimum	Maximum	Mean	St. Dev.
NO4LEGUNSIG	Number of 4-legged unsignalized intersections	13	0.00	9.00	2.31	2.53
NO5LEGUNSIG	Number of 5-legged unsignalized intersections	13	0.00	1.00	0.08	0.28
NO3LEGFULLUNSIG	Number of 3-legged full-movement unsignalized intersections	13	0.00	27.00	8.23	8.08
NO3LEGLIMUNSIG	Number of 3-legged limited-movement unsignalized intersections	13	0.00	6.00	1.31	2.29
NO3LEGRIROUNSIG	Number of 3-legged right-in/right-out unsignalized intersections	13	0.00	6.00	1.31	2.29
NO3LEGLFMOUNSIG	Number of 3-legged left from major only unsignalized intersections	13	0.00	0.00	0.00	0.00
NO4LEGFULLUNSIG	Number of 4-legged full-movement unsignalized intersections	13	0.00	9.00	2.31	2.53
NO4LEGLIMUNSIG	Number of 4-legged limited-movement unsignalized intersections	13	0.00	0.00	0.00	0.00
NO4LEGRIROUNSIG	Number of 4-legged right-in/right-out unsignalized intersections	13	0.00	0.00	0.00	0.00
NO4LEGLFMOUNSIG	Number of 4-legged left from major only unsignalized intersections	13	0.00	0.00	0.00	0.00
NORTLUNSIG	Number of unsignalized intersections with a right-turn lane	13	0.00	3.00	0.31	0.85
NOLTLUNSIG	Number of unsignalized intersections with a left-turn lane	13	1.00	25.00	8.62	8.04
NOSIG	Number of signalized intersections	13	0.00	7.00	3.31	1.93
MINSPCSIG	Minimum spacing of signalized intersections (feet)	11	258.00	5,541.00	1,839.00	1,500.00
MAXSPCSIG	Maximum spacing of signalized intersections (feet)	11	817.00	17,546.00	4,241.00	4,580.00
NO3LEGSIG	Number of 3-legged signalized intersections	13	0.00	2.00	0.85	0.90
NO4LEGSIG	Number of 4-legged signalized intersections	13	0.00	5.00	2.46	1.71
NO5LEGSIG	Number of 5-legged signalized intersections	13	0.00	0.00	0.00	0.00
NORTLSIG	Number of signalized intersections with a right-turn lane on the mainline	13	0.00	5.00	1.62	1.56
NOLTLSIG	Number of signalized intersections with a left-turn lane on the mainline	13	0.00	7.00	3.08	1.98
NOMEDOP	Number of median openings	5	0.00	3.00	1.60	1.14
NOMEDOPLT	Number of median openings with a left-turn lane	5	0.00	2.00	1.40	0.89
NOMEDOPNOLT	Number of median openings without a left-turn lane	5	0.00	1.00	0.20	0.45
SPEED_LIMIT	Posted speed limit (miles per hour)	13	40.00	55	47	5.55
AVGAADT	Average AADT	13	15,358.00	76,837.00	32,706.00	18,835.00
SPCOFFLT	Minimum spacing from off-ramp to available left turn onto mainline from same side of road (feet)	0	—	—	—	—
SPCOFFRT	Minimum spacing from off-ramp to available right turn onto mainline from same side of road (feet)	0	—	—	—	—
SPCON	Minimum spacing from on-ramp to available right turn onto mainline from same side of road (feet)	0	—	—	—	—

St. Dev. = standard deviation; TWLTL = two-way left-turn lane; —Not applicable.

APPENDIX E. CORRELATION COEFFICIENTS BY LAND USE

When one or more variables of interest do not appear in any models for crash type or land use, numerical estimates of the effect for such variables would clearly not be possible. However, a qualitative assessment may be undertaken. To facilitate such an assessment, this appendix provides the correlations between these variables and the various crash types by land use. Correlation coefficients range between –1.0 and 1.0. A positive coefficient indicates that higher values of a variable are correlated with a higher crash frequency. A negative coefficient indicates that higher values of a variable are correlated with a lower crash frequency. The closer the coefficient is to –1.0 or 1.0, the stronger the correlation.

To provide a point of reference for comparison, the parameter estimates and *p*-values are also provided with the correlation coefficients. The parameter estimates are based on a restricted model in which only traffic volume and the variable of interest are included. When the correlation coefficient and the parameter estimate differ (i.e., opposite signs), it may be an indication that other factors are confounding the results or that the association is not statistically significant. The correlation coefficients are presented in table 87 through table 89.

MIXED-USE

Table 87. Correlation coefficients for mixed land use.

Variable Name	Variable Description	Total (Parameter Estimate, *p*-Value)	Injury (Parameter Estimate, *p*-Value)	Rear-End (Parameter Estimate, *p*-Value)	Right-Angle (Parameter Estimate, *p*-Value)	Turning (Parameter Estimate, *p*-Value)
PROPLIGHT	Proportion of total length with illumination present	0.12 (0.2109, 0.3593)	0.11 (0.0492, 0.8247)	0.09 (0.0390, 0.8834)	0.11 (0.2229, 0.2796)	0.15 (0.6249, 0.0232)
PROPPOORPVMNT	Proportion of total length with a poor pavement condition	0.18 (0.3568, 0.4024)	0.06 (0.1075, 0.7926)	0.15 (0.3138, 0.5180)	0.48 (0.7756, 0.1035)	0.06 (0.4449, 0.3776)
PROPLIMCONN	Proportion of total length with limited connectivity on adjacent developments	–0.07 (–0.1457, 0.5014)	–0.06 (0.0089, 0.9656)	–0.08 (–0.3030, 0.2214)	0.05 (0.2782, 0.2739)	–0.10 (–0.4870, 0.0553)
PROPMODCONN	Proportion of total length with moderate connectivity on adjacent developments	0.17 (–0.1189, 0.6728)	0.20 (–0.2911, 0.2679)	0.17 (–0.1012, 0.7528)	0.04 (–0.4727, 0.1569)	0.21 (–0.2094, 0.5320)
PROPSIGCONN	Proportion of total length with significant connectivity on adjacent developments	–0.07 (0.2455, 0.2968)	–0.11 (0.1838, 0.4053)	–0.06 (0.4078, 0.1318)	–0.08 (–0.0199, 0.9418)	–0.07 (0.6993, 0.0130)
PROPFRONTRD	Proportion of total length with a frontage road	0.01 (0.0607, 0.8075)	0.03 (0.2803, 0.2291)	0.02 (0.2051, 0.4679)	0.03 (0.2837, 0.3428)	–0.04 (–0.8360, 0.0051)
NOCOMFULLDRWY	Number of commercial full-movement driveways	0.27 (–0.0002, 0.8585)	0.35 (0.0001, 0.9227)	0.15 (–0.0016, 0.2533)	0.28 (0.0012, 0.5580)	0.38 (0.0009, 0.5726)
NORESFULLDRWY	Number of residential full movement driveways	0.05 (–0.0017, 0.6556)	0.11 (–0.0000, 0.9951)	–0.01 (–0.0042, 0.3288)	0.06 (–0.0019, 0.6974)	0.13 (0.0033, 0.4678)
NOCOMLIMDRWY	Number of commercial limited-movement driveways	0.86 (0.0024, 0.0857)	0.89 (0.0018, 0.1385)	0.87 (0.0026, 0.0962)	0.56 (0.0010, 0.4827)	0.90 (0.0029, 0.0899)
NORESLIMDRWY	Number of residential limited-movement driveways	0.06 (–0.0015, 0.4638)	0.11 (–0.0001, 0.9756)	0.05 (–0.0016, 0.5224)	0.06 (–0.0004, 0.8502)	0.04 (–0.0029, 0.2360)
NO3LEGUNSIG	Number of 3-legged unsignalized intersections	0.85 (0.0103, 0.0888)	0.89 (0.0089, 0.0055)	0.81 (0.0094, 0.1585)	0.65 (0.0066, 0.3623)	0.90 (0.0142, 0.0481)
NO4LEGUNSIG	Number of 4-legged unsignalized intersections	0.65 (0.0069, 0.4954)	0.69 (0.0053, 0.5722)	0.57 (–0.0021, 0.8450)	0.64 (0.0218, 0.0835)	0.69 (0.0150, 0.2225)
NO5LEGUNSIG	Number of 5-legged unsignalized intersections	0.00 (0.0761, 0.8897)	–0.03 (–0.1247, 0.8119)	–0.02 (–0.4720, 0.4528)	0.04 (0.3213, 0.6175)	–0.03 (0.1376, 0.8375)
NO3LEGFULLUNSIG	Number of 3-legged full-movement unsignalized intersections	0.39 (0.0036, 0.7052)	0.44 (0.0041, 0.6345)	0.29 (–0.0045, 0.6610)	0.37 (0.0047, 0.6841)	0.47 (0.0171, 0.1445)

Variable Name	Variable Description	Total (Parameter Estimate, *p*-Value)	Injury (Parameter Estimate, *p*-Value)	Rear-End (Parameter Estimate, *p*-Value)	Right-Angle (Parameter Estimate, *p*-Value)	Turning (Parameter Estimate, *p*-Value)
NO3LEGLIMUNSIG	Number of 3-legged limited movement unsignalized intersections	0.88 (0.0172, 0.0734)	0.88 (0.0142, 0.1040)	0.89 (0.0227, 0.0549)	0.60 (0.0079, 0.4378)	0.86 (0.0138, 0.1690)
NO3LEGRIROUNSIG	Number of 3-legged right-in/right-out unsignalized intersections	0.88 (0.0180, 0.0754)	0.88 (0.0144, 0.1128)	0.89 (0.0235, 0.0592)	0.59 (0.0078, 0.4595)	0.87 (0.0151, 0.1581)
NO3LEGLFMOUNSIG	Number of 3-legged unsignalized intersections with no left-turn movement from crossroad	0.61 (0.1883, 0.1140)	0.60 (0.2098, 0.0654)	0.64 (0.2621, 0.0508)	0.49 (0.1881, 0.2265)	0.55 (0.0613, 0.6445)
NO4LEGFULLUNSIG	Number of 4-legged full-movement unsignalized intersections	0.66 (0.0082, 0.4250)	0.69 (0.0064, 0.5051)	0.57 (–0.0013, 0.9048)	0.65 (0.0246, 0.0559)	0.70 (0.0157, 0.2093)
NO4LEGLIMUNSIG	Number of 4-legged limited-movement unsignalized intersections	0.20 (0.0903, 0.6560)	0.21 (0.1464, 0.4419)	0.22 (0.1523, 0.5239)	0.11 (–0.0432, 0.8544)	0.19 (0.3162, 0.1808)
NO4LEGRIROUNSIG	Number of 4-legged right-in/right-out unsignalized intersections	–0.07 (0.1024, 0.8193)	–0.06 (0.1957, 0.6442)	–0.06 (0.2873, 0.5759)	–0.09 (–0.0608, 0.9124)	–0.05 (0.4693, 0.3911)
NO4LEGLFMOUNSIG	Number of 4-legged unsignalized intersections with no left-turn movement from crossroad	0.30 (0.1131, 0.6628)	0.31 (0.1643, 0.4877)	0.32 (0.1318, 0.6486)	0.19 (–0.0497, 0.8651)	0.29 (0.4521, 0.1764)
NORTLUNSIG	Number of unsignalized intersections with a right-turn lane	–0.01 (–0.0345, 0.3565)	–0.06 (–0.0092, 0.8020)	0.03 (–0.0164, 0.7207)	0.05 (–0.0393, 0.3377)	–0.12 (–0.1404, 0.0015)
NOLTLUNSIG	Number of unsignalized intersections with a left-turn lane	0.65 (0.0045, 0.4877)	0.69 (0.0038, 0.5200)	0.57 (0.0022, 0.7608)	0.53 (0.0019, 0.8053)	0.71 (0.0136, 0.0986)
MINSPCSIG	Minimum spacing of signalized intersections (feet)	–0.18 (–0.0001, 0.2238)	–0.21 (–0.0001, 0.2606)	–0.16 (–0.0001, 0.3579)	–0.20 (–0.0002, 0.1127)	–0.21 (–0.0002, 0.0748)
MAXSPCSIG	Maximum spacing of signalized intersections (feet)	–0.07 (–0.0001, 0.0080)	–0.10 (–0.0001, 0.0148)	–0.07 (–0.0001, 0.0307)	–0.04 (–0.0002, 0.0004)	–0.10 (–0.0001, 0.1473)
NO3LEGSIG	Number of 3-legged signalized intersections	0.58 (–0.0030, 0.9401)	0.64 (0.0151, 0.7073)	0.58 (0.0086, 0.8523)	0.34 (–0.0668, 0.1360)	0.62 (0.0202, 0.6778)
NO4LEGSIG	Number of 4-legged signalized intersections	0.79 (0.0123, 0.2144)	0.86 (0.0148, 0.1223)	0.72 (0.0102, 0.3575)	0.63 (0.0143, 0.2582)	0.84 (0.0164, 0.1493)
NO5LEGSIG	Number of 5-legged signalized intersections	0.10 (0.1471, 0.5172)	0.12 (0.1829, 0.3874)	0.04 (0.0121, 0.9627)	0.10 (0.1764, 0.5119)	0.14 (0.2217, 0.4102)
NORTLSIG	Number of signalized intersections with a right-turn lane on the mainline	0.77 (0.0194, 0.3966)	0.77 (0.0292, 0.2023)	0.80 (0.0450, 0.1185)	0.55 (–0.0129, 0.5961)	0.71 (0.0057, 0.8113)

Variable Name	Variable Description	Total (Parameter Estimate, *p*-Value)	Injury (Parameter Estimate, *p*-Value)	Rear-End (Parameter Estimate, *p*-Value)	Right-Angle (Parameter Estimate, *p*-Value)	Turning (Parameter Estimate, *p*-Value)
NOLTLSIG	Number of signalized intersections with a left-turn lane on the mainline	0.79 (0.0094, 0.2824)	0.86 (0.0110, 0.1916)	0.74 (0.0100, 0.3275)	0.59 (0.0041, 0.6898)	0.86 (0.0142, 0.1681)
MEDOPLT	Number of median openings with a left-turn lane	0.35 (–0.0046, 0.7770)	0.47 (–0.0003, 0.9818)	0.27 (–0.0080, 0.6698)	0.15 (–0.0146, 0.4047)	0.49 (0.0028, 0.8818)
MEDOPNOLT	Number of median openings without a left-turn lane	–0.03 (–0.1235, 0.2862)	0.00 (–0.0925, 0.4038)	–0.02 (–0.1431, 0.2643)	–0.02 (0.0506, 0.7439)	–0.06 (–0.2342, 0.0753)
SPEED_LIMIT	Posted speed limit (miles per hour)	0.00 (–0.0253, 0.0471)	–0.02 (–0.0219, 0.0717)	0.05 (–0.0095, 0.5406)	–0.15 (–0.0597, <0.0001)	–0.04 (–0.0324, 0.0629)
SPCOFFLT	Minimum spacing from off-ramp to left turn onto mainline from same side of road (feet)	–0.14 (–0.0000, 0.8225)	–0.15 (0.0000, 0.9214)	–0.07 (–0.0001, 0.7111)	–0.07 (0.0001, 0.6344)	–0.22 (–0.0006, 0.0294)
SPCOFFRT	Minimum spacing from off-ramp to right turn onto mainline from same side of road (feet)	–0.10 (–0.0002, 0.4140)	–0.13 (–0.0000, 0.8689)	0.02 (–0.0002, 0.5206)	–0.05 (–0.0001, 0.6079)	–0.23 (–0.0008, 0.0110)
SPCON	Minimum spacing from on-ramp to right turn onto mainline from same side of road (feet)	–0.19 (–0.0004, 0.1529)	–0.18 (–0.0003, 0.1464)	–0.14 (–0.0002, 0.4334)	–0.20 (–0.0005, 0.0463)	–0.20 (–0.0008, 0.0155)

COMMERCIAL

Table 88. Correlation coefficients for commercial land use.

Variable Name	Variable Description	Total (Parameter Estimate, *p*-Value)	Injury (Parameter Estimate, *p*-Value)	Rear-End (Parameter Estimate, *p*-Value)	Right-Angle (Parameter Estimate, *p*-Value)	Turning (Parameter Estimate, *p*-Value)
PROPLIGHT	Proportion of total length with illumination present	0.16 (0.4145, 0.0326)	0.14 (0.1854, 0.3290)	0.08 (0.2781, 0.2038)	0.18 (0.7569, 0.0033)	0.26 (0.7765, 0.0024)
PROPPOORPVMNT	Proportion of total length with a poor pavement condition	–0.07 (–0.2922, 0.6281)	–0.08 (–0.0709, 0.9013)	–0.12 (–0.8809, 0.1469)	0.06 (0.5952, 0.5056)	–0.09 (–0.1403, 0.8625)
PROPLIMCONN	Proportion of total length with limited connectivity on adjacent developments	0.04 (–0.0245, 0.9095)	0.07 (–0.0430, 0.8415)	0.04 (–0.0396, 0.8643)	–0.03 (–0.0203, 0.9476)	0.04 (–0.2369, 0.4057)
PROPMODCONN	Proportion of total length with moderate connectivity on adjacent developments	–0.05 (–0.0364, 0.8712)	0.03 (0.2718, 0.2157)	–0.04 (–0.0741, 0.7602)	–0.04 (–0.0981, 0.7601)	–0.04 (–0.1183, 0.6871)
PROPSIGCONN	Proportion of total length with significant connectivity on adjacent developments	0.03 (0.1199, 0.5719)	–0.08 (–0.1332, 0.5133)	0.02 (0.1768, 0.4349)	0.09 (0.1613, 0.5785)	0.02 (0.4443, 0.1314)
PROPFRONTRD	Proportion of total length with a frontage road	0.01 (–0.2573, 0.2064)	0.07 (–0.0160, 0.9360)	0.09 (–0.1630, 0.4617)	–0.06 (–0.3225, 0.2517)	–0.10 (–0.8573, 0.0009)
NOCOMFULLDRWY	Number of commercial full-movement driveways	0.47 (0.0019, 0.2220)	0.56 (0.0026, 0.0977)	0.33 (0.0008, 0.6343)	0.37 (0.0030, 0.1655)	0.62 (0.0031, 0.1304)
NORESFULLDRWY	Number of residential full-movement driveways	0.17 (–0.0017, 0.8362)	0.20 (0.0025, 0.7446)	0.10 (–0.0058, 0.5255)	0.18 (0.0071, 0.5264)	0.22 (0.0030, 0.7869)
NOCOMLIMDRWY	Number of commercial limited-movement driveways	0.57 (0.0010, 0.381[illegible]	0.61 [illegible]4, 0.7144)	0.54 (0.0008, 0.4769)	0.29 (0.0005, 0.7386)	0.65 (0.0009, 0.5184)
NORESLIMDRWY	Number of residential limited-movement driveways	0.37 (–0.0022, 0.91[illegible]	[illegible].38 [illegible]1, 0.5861)	0.37 (–0.0006, 0.9774)	0.21 (–0.0140, 0.5867)	0.32 (–0.0074, 0.7660)
NO3LEGUNSIG	Number of 3-legged unsignalized intersections	0.67 (0.0041, 0.4363)	0.74 (0.0031, 0.5586)	0.59 (0.0022, 0.6950)	0.39 (0.0016, 0.8127)	0.76 (0.0062, 0.3703)
NO4LEGUNSIG	Number of 4-legged unsignalized intersections	0.49 (0.0169, 0.2476)	0.50 (0.0176, 0.2297)	0.37 (0.0070, 0.6449)	0.43 (0.0293, 0.1586)	0.56 (0.0284, 0.1560)
NO5LEGUNSIG	Number of 5-legged unsignalized intersections	–0.02 (–0.4711, 0.5265)	–0.04 (–0.5110, 0.4751)	–0.02 (–0.4150, 0.6085)	0.01 (–0.4889, 0.6170)	–0.05 (–0.9245, 0.3389)
NO3LEGFULLUNSIG	Number of 3-legged full-movement unsignalized intersections	0.53 (0.0050, 0.5404)	0.58 (0.0037, 0.6404)	0.40 (–0.0008, 0.9258)	0.38 (0.0065, 0.5468)	0.63 (0.0104, 0.3336)

Variable Name	Variable Description	Total (Parameter Estimate, *p*-Value)	Injury (Parameter Estimate, *p*-Value)	Rear-End (Parameter Estimate, *p*-Value)	Right-Angle (Parameter Estimate, *p*-Value)	Turning (Parameter Estimate, *p*-Value)
NO3LEGLIMUNSIG	Number of 3-legged limited-movement unsignalized intersections	0.58 (0.0056, 0.5640)	0.64 (0.0038, 0.6898)	0.58 (0.0073, 0.4904)	0.26 (–0.0048, 0.7047)	0.62 (0.0042, 0.7302)
NO3LEGRIROUNSIG	Number of 3-legged right-in/right-out unsignalized intersections	0.55 (0.0058, 0.5835)	0.62 (0.0041, 0.6951)	0.56 (0.0081, 0.4845)	0.25 (–0.0060, 0.6660)	0.60 (0.0043, 0.7462)
NO3LEGLFMOUNSIG	Number of 3-legged unsignalized intersections with no left-turn movement from crossroad	0.56 (0.0516, 0.5438)	0.61 (0.0256, 0.7483)	0.57 (0.0346, 0.6991)	0.31 (0.0264, 0.8269)	0.54 (0.0408, 0.7025)
NO4LEGFULLUNSIG	Number of 4-legged full-movement unsignalized intersections	0.48 (0.0169, 0.2475)	0.50 (0.0181, 0.2192)	0.36 (0.0069, 0.6468)	0.42 (0.0298, 0.1529)	0.56 (0.0279, 0.1601)
NO4LEGLIMUNSIG	Number of 4-legged limited-movement unsignalized intersections	0.12 (–0.0492, 0.8217)	0.03 (–0.1666, 0.4353)	0.18 (–0.0250, 0.9150)	0.09 (–0.1863, 0.5236)	–0.01 (–0.0105, 0.9711)
NO4LEGRIROUNSIG	Number of 4-legged right-in/right-out unsignalized intersections	–0.05 (–0.0097, 0.9821)	–0.07 (–0.2114, 0.6155)	–0.05 (0.0273, 0.9539)	–0.08 (–0.4710, 0.4173)	0.00 (0.4605, 0.4045)
NO4LEGLFMOUNSIG	Number of 4-legged unsignalized intersections with no left-turn movement from crossroad	0.21 (–0.0748, 0.8173)	0.10 (–0.2838, 0.3383)	0.30 (–0.0006, 0.9987)	0.15 (–0.2691, 0.5276)	0.00 (–0.3835, 0.3787)
NORTLUNSIG	Number of unsignalized intersections with a right-turn lane	0.32 (–0.0295, 0.3326)	0.32 (–0.0079, 0.7884)	0.43 (–0.0151, 0.6427)	0.23 (–0.0565, 0.1662)	0.03 (–0.0961, 0.0136)
NOLTLUNSIG	Number of unsignalized intersections with a left-turn lane	0.64 (0.0078, 0.2643)	0.68 (0.0070, 0.3137)	0.52 (0.0027, 0.7058)	0.48 (0.0109, 0.2623)	0.72 (0.0138, 0.1445)
MINSPCSIG	Minimum spacing of signalized intersections (feet)	–0.21 (–0.0002, 0.0012)	–0.22 (–0.0002, 0.0008)	–0.16 (–0.0001, 0.0343)	–0.22 (–0.0003, 0.0003)	–0.23 (–0.0002, 0.0006)
MAXSPCSIG	Maximum spacing of signalized intersections (feet)	0.23 (–0.0001, 0.0016)	0.21 (–0.0001, 0.0096)	0.29 (–0.0001, 0.0031)	0.16 (–0.0001, 0.0036)	–0.03 (–0.0001, <0.0001)
NO3LEGSIG	Number of 3-legged signalized intersections	0.38 (0.0069, 0.8363)	0.40 (–0.0068, 0.8345)	0.32 (0.0008, 0.9820)	0.21 (–0.0117, 0.7833)	0.45 (0.0265, 0.5507)

Variable Name	Variable Description	Total (Parameter Estimate, *p*-Value)	Injury (Parameter Estimate, *p*-Value)	Rear-End (Parameter Estimate, *p*-Value)	Right-Angle (Parameter Estimate, *p*-Value)	Turning (Parameter Estimate, *p*-Value)
NO4LEGSIG	Number of 4-legged signalized intersections	0.75 (0.0140, 0.1905)	0.83 (0.0151, 0.1631)	0.67 (0.0069, 0.5435)	0.51 (0.0194, 0.2044)	0.83 (0.0199, 0.1519)
NO5LEGSIG	Number of 5-legged signalized intersections	0.03 (0.0276, 0.8297)	0.05 (0.0335, 0.7782)	0.04 (0.0649, 0.6429)	–0.04 (–0.0478, 0.7742)	0.06 (0.0081, 0.9605)
NORTLSIG	Number of signalized intersections with a right-turn lane on the mainline	0.51 (–0.0009, 0.9743)	0.54 (0.0085, 0.7480)	0.60 (0.0126, 0.6835)	0.31 (–0.0294, 0.4072)	0.32 (–0.0123, 0.7136)
NOLTLSIG	Number of signalized intersections with a left-turn lane on the mainline	0.73 (0.0107, 0.2585)	0.80 (0.0103, 0.2821)	0.65 (0.0055, 0.5827)	0.46 (0.0125, 0.3548)	0.81 (0.0169, 0.1727)
MEDOPLT	Number of median openings with a left-turn lane	0.54 (0.0053, 0.6656)	0.58 (–0.0001, 0.9963)	0.55 (0.0051, 0.7064)	0.23 (–0.0061, 0.6960)	0.54 (0.0026, 0.8714)
MEDOPNOLT	Number of median openings without a left-turn lane	0.26 (0.0008, 0.9867)	0.30 (–0.0171, 0.7046)	0.23 (–0.0047, 0.9293)	0.09 (–0.0377, 0.5061)	0.28 (–0.0269, 0.6578)
SPEED_LIMIT	Posted speed limit (miles per hour)	–0.02 (–0.0175, 0.1768)	–0.08 (–0.0151, 0.1792)	0.13 (–0.0053, 0.7165)	–0.07 (–0.0420, 0.0105)	–0.26 (–0.0422, 0.0191)
SPCOFFLT	Minimum spacing from off-ramp to left turn onto mainline from same side of road (feet)	–0.27 (–0.0009, <0.0001)	–0.26 (–0.0009, 0.0004)	–0.26 (–0.0009, <0.0001)	–0.15 (–0.0009, 0.0238)	–0.34 (–0.0016, <0.0001)
SPCOFFRT	Minimum spacing from off-ramp to right turn onto mainline from same side of road (feet)	–0.23 (–0.0007, 0.0098)	–0.28 (–0.0007, 0.0094)	–0.18 (–0.0007, 0.0056)	–0.05 (–0.0005, 0.2349)	–0.39 (–0.0013, 0.0022)
SPCON	Minimum spacing from on-ramp to right turn onto mainline from same side of road (feet)	–0.24 (–0.0003, 0.0753)	–0.31 (–0.0003, 0.1818)	–0.09 (–0.0002, 0.1939)	–0.12 (–0.0004, 0.1588)	–0.43 (–0.0009, 0.0017)

RESIDENTIAL

Table 89. Correlation coefficients for residential land use.

Variable Name	Variable Description	Total (Parameter Estimate, *p*-Value)	Injury (Parameter Estimate, *p*-Value)	Rear-End (Parameter Estimate, *p*-Value)	Right-Angle (Parameter Estimate, *p*-Value)	Turning (Parameter Estimate, *p*-Value)
PROPLIGHT	Proportion of total length with illumination present	0.02 (0.2319, 0.1731)	0.00 (0.2602, 0.1186)	–0.06 (0.0437, 0.8293)	0.08 (0.4518, 0.0547)	0.15 (0.8585, <0.0001)
PROPPOORPVMNT	Proportion of total length with a poor pavement condition	0.04 (–0.0015, 0.9980)	–0.02 (–0.1620, 0.7781)	0.02 (–0.0690, 0.9248)	0.15 (0.7495, 0.3475)	–0.03 (0.0705, 0.9245)
PROPLIMCONN	Proportion of total length with limited connectivity on adjacent developments	–0.08 (–0.1159, 0.5396)	–0.12 (–0.2165, 0.2404)	–0.10 (–0.0907, 0.6841)	–0.07 (–0.3227, 0.2118)	–0.08 (–0.5314, 0.0344)
PROPMODCONN	Proportion of total length with moderate connectivity on adjacent developments	0.18 (0.1387, 0.5941)	0.27 (0.1547, 0.5494)	0.24 (0.3923, 0.2023)	–0.08 (–0.5664, 0.1228)	0.26 (0.6023, 0.0709)
PROPSIGCONN	Proportion of total length with significant connectivity on adjacent developments	–0.06 (0.0549, 0.8012)	–0.09 (0.1799, 0.4012)	–0.08 (–0.1831, 0.4797)	0.14 (0.7085, 0.0153)	–0.12 (0.1949, 0.4985)
PROPFRONTRD	Proportion of total length with a frontage road	0.21 (0.2815, 0.1540)	0.31 (0.3999, 0.0404)	0.24 (0.2748, 0.2571)	0.08 (0.5250, 0.0500)	0.11 (–0.2668, 0.3005)
NOCOMFULLDRWY	Number of commercial full-movement driveways	0.44 (–0.0006, 0.9051)	0.38 (–0.0012, 0.8194)	0.28 (–0.0042, 0.4789)	0.40 (0.0036, 0.6334)	0.49 (–0.0022, 0.7449)
NORESFULLDRWY	Number of residential full-movement driveways	0.29 (0.0011, 0.4183)	0.18 (0.0009, 0.5606)	0.11 (–0.0007, 0.6470)	0.36 (0.0024, 0.1820)	0.29 (0.0015, 0.4259)
NOCOMLIMDRWY	Number of commercial limited-movement driveways	0.27 (–0.0112, 0.2353)	0.38 (–0.0091, 0.2842)	0.26 (–0.0075, 0.5070)	0.08 (–0.0158, 0.2164)	0.33 (–0.0159, 0.1738)
NORESLIMDRWY	Number of residential limited-movement driveways	0.11 (–0.0121, 0.0529)	0.25 (–0.0093, 0.1029)	0.10 (–0.0112, 0.1311)	–0.03 (–0.0152, 0.0700)	0.21 (–0.0127, 0.1120)
NO3LEGUNSIG	Number of 3-legged unsignalized intersections	0.33 (–0.0157, 0.0384)	0.31 (–0.0148, 0.0452)	0.24 (–0.0200, 0.0226)	0.31 (–0.0099, 0.3571)	0.31 (–0.0112, 0.2864)
NO4LEGUNSIG	Number of 4-legged unsignalized intersections	0.35 (–0.0079, 0.6507)	0.24 (–0.0129, 0.4485)	0.19 (–0.0289, 0.1447)	0.49 (0.0251, 0.3096)	0.16 (–0.0102, 0.6888)
NO5LEGUNSIG	Number of 5-legged unsignalized intersections	–0.11 (–0.8966, 0.0245)	–0.10 (–0.7390, 0.0678)	–0.11 (–1.0360, 0.0285)	–0.06 (–0.5482, 0.3516)	–0.08 (–1.0205, 0.0562)
NO3LEGFULLUNSIG	Number of 3-legged full-movement unsignalized intersections	0.20 (–0.0238, 0.0085)	0.16 (–0.0211, 0.0152)	0.11 (–0.0292, 0.0053)	0.22 (–0.0215, 0.0944)	0.19 (–0.0228, 0.0778)

Variable Name	Variable Description	Total (Parameter Estimate, *p*-Value)	Injury (Parameter Estimate, *p*-Value)	Rear-End (Parameter Estimate, *p*-Value)	Right-Angle (Parameter Estimate, *p*-Value)	Turning (Parameter Estimate, *p*-Value)
NO3LEGLIMUNSIG	Number of 3-legged limited-movement unsignalized intersections	0.37 (0.0045, 0.8554)	0.47 (0.0085, 0.7078)	0.35 (0.0060, 0.8351)	0.20 (0.0198, 0.5954)	0.36 (0.0060, 0.8618)
NO3LEGRIROUNSIG	Number of 3-legged right-in/right-out unsignalized intersections	0.38 (0.0074, 0.7777)	0.47 (0.0115, 0.6306)	0.36 (0.0088, 0.7703)	0.21 (0.0251, 0.5197)	0.36 (0.0088, 0.8089)
NO3LEGLFMOUNSIG	Number of 3-legged unsignalized intersections with no left-turn movement from crossroad	0.14 (–0.2607, 0.3209)	0.25 (–0.2215, 0.3615)	0.10 (–0.3207, 0.2815)	0.05 (–0.2915, 0.4250)	0.23 (–0.1280, 0.7161)
NO4LEGFULLUNSIG	Number of 4-legged full-movement unsignalized intersections	0.35 (–0.0092, 0.5924)	0.25 (–0.0138, 0.4129)	0.19 (–0.0296, 0.1289)	0.49 (0.0246, 0.3141)	0.17 (–0.0148, 0.5494)
NO4LEGLIMUNSIG	Number of 4-legged limited-movement unsignalized intersections	–0.11 (0.5549, 0.1302)	–0.13 (0.5363, 0.1799)	–0.09 (0.5176, 0.2338)	–0.09 (0.0112, 0.9850)	–0.07 (1.2080, 0.0063)
NO4LEGRIROUNSIG	Number of 4-legged right-in/right-out unsignalized intersections	–0.11 (0.5549, 0.1302)	–0.13 (0.5363, 0.1799)	–0.09 (0.5176, 0.2338)	–0.09 (0.0112, 0.9850)	–0.07 (1.2080, 0.0063)
NO4LEGLFMOUNSIG	Number of 4-legged unsignalized intersections with no left-turn movement from crossroad	—	—	—	—	—
NORTLUNSIG	Number of unsignalized intersections with a right-turn lane	0.08 (–0.0831, 0.0007)	0.05 (–0.0671, 0.0045)	0.08 (–0.0987, 0.0023)	0.09 (–0.1015, 0.0020)	–0.15 (–0.1352, <0.0001)
NOLTLUNSIG	Number of unsignalized intersections with a left-turn lane	0.18 (–0.0131, 0.2162)	0.14 (–0.0206, 0.0438)	0.11 (–0.0135, 0.2819)	0.14 (–0.0072, 0.6220)	0.34 (–0.0026, 0.8561)
MINSPCSIG	Minimum spacing of signalized intersections (feet)	–0.34 (–0.0002, 0.0053)	–0.33 (–0.0002, 0.0022)	–0.22 (–0.0001, 0.1095)	–0.33 (–0.0003, <0.0001)	–0.31 (–0.0001, 0.3429)
MAXSPCSIG	Maximum spacing of signalized intersections (feet)	0.21 (–0.0001, 0.0096)	0.19 (–0.0001, 0.0124)	0.21 (–0.0001, 0.0771)	0.09 (–0.0001, 0.0558)	0.23 (–0.0001, 0.0384)
NO3LEGSIG	Number of 3-legged signalized intersections	0.37 (0.0284, 0.6507)	0.45 (0.0710, 0.2392)	0.36 (0.0642, 0.3957)	0.22 (–0.0198, 0.8114)	0.35 (–0.0116, 0.8834)

Variable Name	**Variable Description**	**Total (Parameter Estimate, *p*-Value)**	**Injury (Parameter Estimate, *p*-Value)**	**Rear-End (Parameter Estimate, *p*-Value)**	**Right-Angle (Parameter Estimate, *p*-Value)**	**Turning (Parameter Estimate, *p*-Value)**
NO4LEGSIG	Number of 4-legged signalized intersections	0.69 (0.0394, 0.1479)	0.73 (0.0558, 0.0324)	0.54 (0.0134, 0.6604)	0.63 (0.1127, 0.0028)	0.52 (0.0292, 0.4357)
NO5LEGSIG	Number of 5-legged signalized intersections	0.11 (0.6930, 0.3056)	0.00 (0.0381, 0.9547)	–0.01 (0.0881, 0.9124)	0.09 (1.1129, 0.2223)	0.28 (0.7192, 0.4027)
NORTLSIG	Number of signalized intersections with a right-turn lane on the mainline	0.63 (–0.0063, 0.8532)	0.61 (–0.0018, 0.9555)	0.64 (0.0264, 0.5102)	0.48 (–0.0089, 0.8388)	0.28 (–0.0989, 0.0228)
NOLTLSIG	Number of signalized intersections with a left-turn lane on the mainline	0.62 (–0.0026, 0.9107)	0.67 (0.0051, 0.8111)	0.59 (0.0082, 0.7650)	0.50 (0.0166, 0.6044)	0.39 (–0.0273, 0.3513)
MEDOPLT	Number of median openings with a left-turn lane	0.10 (–0.0186, 0.5991)	0.26 (–0.0101, 0.7715)	0.06 (–0.0269, 0.5045)	–0.01 (–0.0408, 0.3383)	0.28 (0.0342, 0.5411)
MEDOPNOLT	Number of median openings without a left-turn lane	–0.15 (–0.3795, 0.1112)	–0.11 (–0.1744, 0.4988)	–0.18 (–0.6913, 0.0098)	–0.03 (0.1194, 0.6994)	–0.08 (–0.3801, 0.2128)
SPEED_LIMIT	Posted speed limit (miles per hour)	0.08 (0.0001, 0.9935)	0.11 (0.0010, 0.9240)	0.19 (0.0129, 0.3338)	–0.10 (–0.0210, 0.1560)	0.06 (–0.0098, 0.5050)
SPCOFFLT	Minimum spacing from off-ramp to left turn onto mainline from same side of road (feet)	0.28 (0.0032, 0.0020)	0.39 (0.0033, 0.0015)	0.20 (0.0046, 0.0042)	0.32 (0.0039, 0.0149)	0.31 (0.0019, 0.0634)
SPCOFFRT	Minimum spacing from off-ramp to right turn onto mainline from same side of road (feet)	0.07 (0.0025, 0.0117)	0.20 (0.0024, 0.0179)	–0.01 (0.0032, 0.0244)	0.11 (0.0022, 0.1459)	0.28 (0.0016, 0.0817)
SPCON	Minimum spacing from on-ramp to right turn onto mainline from same side of road (feet)	–0.48 (0.0012, 0.2278)	–0.46 (0.0001, 0.9015)	–0.30 (0.0030, 0.0115)	–0.60 (–0.0044, 0.0294)	–0.27 (–0.0043, 0.0002)

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