BUILT ENVIRONMENTAL CORRELATES OF TRAFFIC COLLISIONS

A Dissertation

by

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ABSTRACT

Traffic safety has become an important concern in recent years. Built environmental characteristics have been identified as a critical factor in affecting traffic safety. However, several research gaps remain in the understanding of the built environment–traffic safety relationship. This dissertation explored the complex associations between built environmental characteristics and traffic safety on neighborhood and school scales in the city of Austin, TX.

In Aim 1-1, the author examined local relationships between built environmental attributes and crashes with different levels of injury severity in census block groups in Austin, TX. The results showed that traffic volume, highways/freeways, arterial roads, and commercial uses had consistently positive impacts on total, fatal, serious, minor, and no injury crashes. Some built environmental factors (e.g., highway/freeway, arterial road, and commercial use) had a stronger effect in some areas but were weaker predictors in other places.

In Aim 1-2, this study explored the disparity issue in crashes with different levels of injury severity across neighborhoods with different economic statuses and ethnic compositions in Austin, TX. The findings indicated that some built environmental variables (e.g., arterial road, office land use, and school) only showed significant impacts on traffic safety in areas with high percentages of non-white population and population below the poverty line but not in low-percentage areas.

Aim 2 used two-level binomial logistic models to investigate the influence of built environments on crashes involving elementary school–aged children during school travel time in 78 elementary schools in the Austin Independent School District (AISD), TX. The results showed that roads with higher posted speed limits, highways/freeways and arterials, higher percentages of commercial, office, and industrial land uses around street segments significantly increased the probability of crashes.

In conclusion, it is necessary to develop tailored policies with regard to the characteristics of each area. Moreover, policies related to arterial roads, office uses, and schools may not equally promote traffic safety in areas with different economic statuses and ethnic compositions. For the school travel safety, planners should design a complementary network of low-speed roads in the vicinity of school areas, and arrange roads with residential uses around school area.

DEDICATION

To my family, parents

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Thanks to my family, especially my parents. I am deeply grateful for your love, support, and patience. They are always supportive and given me motivation to achieve my goals

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NOMENCLATURE

AEIS	Academic Excellence Indicator System
AISD	Austin Independent School District
APD	Austin Police Department
GWPR	Geographically Weighted Poisson Regression
MAUP	Modifiable Aerial Unit Problem
MPH	Miles per Hour
TxDOT	Texas Department of Transportation
VIF	Variance Inflation Factor
VMT	Vehicle Miles Traveled

TABLE OF CONTENTS

Page

LIST OF FIGURES

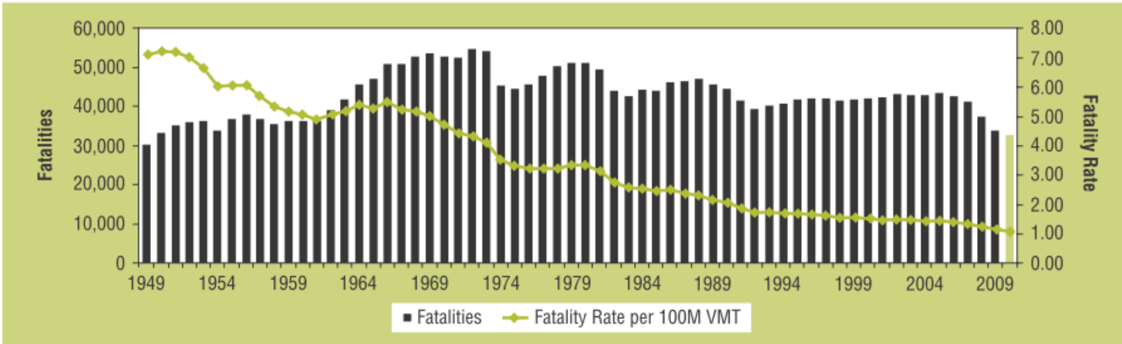
Page

LIST OF TABLES

1. INTRODUCTION

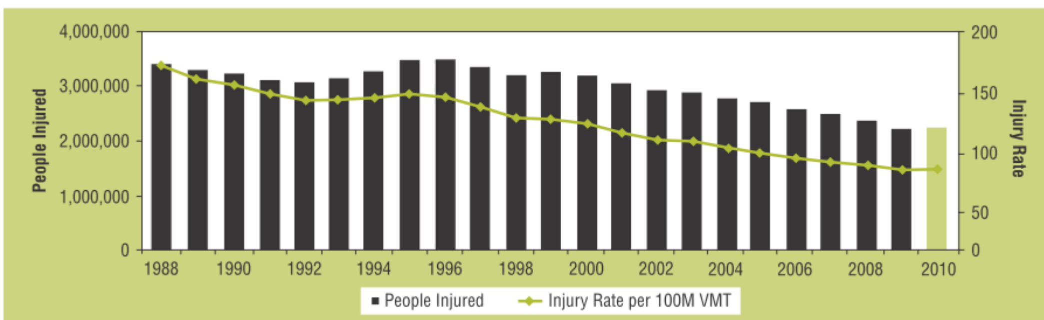
1.1 BACKGROUND

Traffic-related fatalities and injuries have become major concerns in recent years. The estimated cost of motor vehicle crashes was around $230 billion in 2010 in the U.S. (Teigen & Shinkle, 2012). In terms of traffic-related fatalities, the fatality rate per 100 million vehicle miles traveled (VMT) has fallen to a historic low (1.10), and 32,885 people died in motor vehicle traffic crashes – the lowest number since 1949 – in 2010 in the U.S. (Figure 1) (National Highway Traffic Safety Administration, 2012). However, there were still an average of 90 persons who were killed by traffic crashes each day and one person died every 16 minutes in traffic crashes in 2010 in the U.S. (National Highway Traffic Safety Administration, 2012). With respects to traffic-related injuries, in 2010 in the U.S., the injury rate per 100 million vehicle miles traveled (VMT) was 75 (the same as 2009), and about 2.24 million people were injured (a 1% increase compared to 2009) (Figure 2).



1949–1974: National Center for Health Statistics, HEW, and State Accident Summaries (Adjusted to 30-Day Traffic Deaths by NHTSA)
FARS 1975–2009 (Final) 2010 Annual Report File (ARF); Vehicle Miles Traveled (VMT): Federal Highway Administration.

Figure 1
Fatalities and Fatality Rate per 100 Million Vehicle Miles Traveled by Year in the U.S. (National Highway Traffic Safety Administration, 2012)



NASS GES 1988–2010; Vehicle Miles Traveled (VMT): Federal Highway Administration.

Figure 2
People Injured and Injury Rate per 100 Million Vehicle Miles Traveled by Year in the U.S. (National Highway Traffic Safety Administration, 2012)

The three E's framework— Education, Enforcement, and Engineering—has been proposed to prevent traffic-related fatalities and injuries (Gielen, McDonald, & McKenzie, 2012). Multiple strategies from these three perspectives could offer a comprehensive framework for injury prevention.

Education strategies aim to change individual travel behaviors such as driving performance (e.g., driving speed, reaction time, etc.) and pedestrian crossing behaviors (e.g., whether pedestrians stop/look while crossing) through in-class education and in-vehicle training (Sleet & Gielen, 2006). *Enforcement* strategies could change behaviors of drivers and pedestrians/cyclists to promote traffic safety through approaches such as the strict enforcement of seat belt laws, bicycle helmet laws, bans on cell phone use while driving, and speed limit. These enforcement strategies are more effective when the punishment is perceived as severe (Sleet & Gielen, 2006). *Engineering* strategies reduce traffic-related fatalities and injuries by reducing environmental risk factors. Examples of engineering strategies include the construction or provisions of crosswalks, traffic signals, traffic calming devices, and sidewalks and bike lanes that separate non-motorized users from vehicles.

In addition, crashes rates are not equally distributed across different communities or different socioeconomic groups. For example, more socioeconomically deprived areas experienced more traffic crashes (Christie, 1995; Graham & Glaister, 2003; Loukaitou-Sideris, Liggett, & Sung, 2007; Noland, N. J. Klein, & N. K. Tulach, 2013; White, Raeside, & Barker, 2000). Several possible reasons were identified in previous studies, including the possibility of lower household vehicle ownership in low income areas (which in turn generate more pedestrian activities and lead to more conflicts between pedestrians and vehicles) (Noland, N. Klein, & N. Tulach, 2013), insufficient non-motorized infrastructure in low income areas (which increase the danger for pedestrians) (Noland et al., 2013), and higher traffic volumes in areas with more non-white populations (Graham & Glaister, 2003). Moreover, most studies on disparity issues primarily focused on pedestrian injuries. Current evidence regarding disparities in crashes with different levels of injury severity is still limited. Further, possible moderator effects of socio-demographic characteristics on built environment–traffic safety relationships are unclear.

Children are recognized as a particularly vulnerable group for traffic-related fatalities and injuries (National Highway Traffic Safety Administration, 2012). In the U.S., motor-vehicle collisions were the leading cause of death for children with age 4, 11, 12, 13, and 14 in 2010 (National Highway Traffic Safety Administration, 2012). An average of 3 children aged 14 and younger were killed, and 469 within this age range were injured in traffic crashes each day in 2010 in the U.S. (National Highway Traffic Safety Administration, 2012).

1.2 STUDY AIM

This study proposed three study Aims. Aims 1-1 and 1-2 focused on examining the relationships between built environmental attributes and traffic safety at the neighborhood level, and Aim 2 examined this relationship at the school level.

Aim 1-1: To examine the impacts of neighborhood environments on crashes with different levels of injury severity.

Aim 1-2: To explore disparity in crashes with different levels of injury severity across neighborhoods with different economic statuses and ethnic compositions.

Aim 2: To investigate the influences of built environmental factors around schools on crashes involving elementary school–aged children during school travel time.

1.3 SIGNIFICANCE

Recently, researchers on traffic safety have shifted the focus from individual characteristics (e.g., drivers' behaviors when crashes occurred, age, gender, and education of occupants and non-occupants) and traffic engineering measures (e.g., road surface, speed-reducing devices, stop signs, road markings, and signal installations) to built environmental attributes (e.g., street connectivity, land use pattern, etc.) (Ewing & Dumbaugh, 2009). Although scholars have developed conceptual frameworks on traffic safety and identified important built environmental factors that might be related to traffic safety, such as commercial uses, highways/freeways, street connectivity, etc. (Abdel-Aty, Chundi, & Lee, 2007; Moudon, Lin, Jiao, Hurvitz, & Reeves, 2011), questions about the impacts of these factors remain unanswered.

Since crashes are often not evenly distributed spatially (Loukaitou-Sideris et al., 2007), the relationship between built environments and crashes may also vary by areas' characteristics. Most studies on traffic safety have applied Generalized Linear Modeling (GLM) to develop models to guide the traffic safety planning (Hadayeghi, Shalaby, & Persaud, 2010). However, this approach uses fixed coefficients to represent the average relationships between built environmental factors and crashes, and could not investigate the potentially variant associations across different areas. Thus, this study explored the local spatial variations of the relationship between built environments and collisions by using a local model – Geographically Weighted Poisson Regressions (GWPRs). Because collisions with different levels of injury severity tend to occur at different locations featuring different built environmental designs, this study examined the correlates of collisions specific to four types of injury severities (fatal, serious, minor, and no injury).

In addition, limited studies have examined the disparity issue in crashes with different levels of injury severity. Because the influence of built environments on collisions may vary across areas with different economic statuses and ethnic compositions, an area's socio-demographic characteristics may function as a moderator between built environments and traffic safety. This study explored differences in crash frequency across neighborhoods with different economic statuses and ethnic compositions, and further tested the potential moderator effect of socio-demographic characteristics on the built environment–traffic safety association.

Furthermore, areas around major destinations such as schools tend to bring additional traffic and increase risks for crashes, requiring further attention as a highpriority intervention targets for traffic safety improvements. School areas experience an abundant amount of vehicles traffic (e.g., trips picking up children from school) during the morning and afternoon peak periods. For example, there were about 30 billion vehicle miles traveled and 6.6 billion vehicle trips made for taking/picking up children to/from school in 2009 in the U.S. (McDonald, Brown, Marchetti, & Pedroso, 2011). Traffic concerns were identified as a prominent factor for parents to determine child's travel mode to/from school (Martin & Carlson, 2005). Insufficient attention has been devoted to the impacts of school locations and their surrounding community designs on school travel safety. This study used a comprehensive approach to examine a wide range of built environmental attributes, including road environments and neighborhood environments around schools, for their potential links with crashes involving elementary school–aged children during school travel time.

1.4 STRUCTURE OF THE DISSERTATION

This dissertation first introduced the background of traffic safety, the study aims, and the significance of this dissertation research in Section 1. In order to better understand the state of knowledge in this area, a systematic literature review was conducted on the topic of traffic safety. The author summarized characteristics of previous studies, analyzed theories and conceptual frameworks that have been utilized, synthesized the patterns of findings about correlates of traffic safety, and identified three research gaps in Section 2.

In Section 3, a conceptual framework for this study was presented, which was developed based on existing theories and conceptual frameworks from previous studies. To address three identified research gaps, this study focused on three Aims, which were addressed in Sections 4, 5, and 6, respectively. In Section 4, the author examined the local relationships between built environments and crashes with different levels of injury severity. Section 5 explored the disparity issue in traffic safety across neighborhoods with different economic statuses and ethnic compositions. Section 6 examined the effect of built environmental factors on crashes involving elementary school–aged children during school travel time. Section 7 discussed the contributions of this study to the existing literature, limitations of this study, planning and policy implications of study findings, and suggested directions for future studies in this area.

2. LITERATURE REVIEW

2.1 METHODS FOR LITERATURE SEARCH

Recently, researchers and practitioners from urban and transportation planning have started to address the importance of built environments in improving or constraining crash risk (Ewing & Dumbaugh, 2009). This dissertation study reviewed up-to-date research that examined the influence of built environmental attributes on traffic safety in order to guide the selection of study variables.

Computer search was conducted using the PubMed, PsychInfo, EBSCO, Web of Science, Science Direct, ISI Web of Knowledge, National Transportation Library, and Google Scholar databases to identify English-language literature that examined relationships between built environmental attributes and traffic safety. Search terms included “traffic safety,” “crash,” “collision,” “crash frequency,” “crash incidence,” “pedestrian injury,” and “injury severity.” Further, bibliographies of those identified studies were reviewed to identify additional relevant studies.

The search resulted in a total of 102 articles published between 1990 and 2012. Seventeen studies were excluded from the review because they were qualitative studies and did not use quantitative measures. Twenty-two studies that only reported descriptive statistics were also excluded. Ten studies were conference papers and were excluded. Thirteen studies that did not include any built environmental attributes were excluded. In total, 40 peer-reviewed articles were identified and included in this review.

Every included study was recorded in a table with their (a) first author and year of publication; (b) research design (e.g., cross sectional, longitudinal, case control, or quasi-experimental); (c) study context; (d) unit of analysis; (e) statistical method; (f) sample size; and (g) variables that were considered in each study.

To clearly show and compare the review results, correlates of traffic safety recognized from the included studies were categorized as significantly positive (+), significantly negative (-), and not statistically significant (o). Furthermore, the measurement methods for each correlate were recorded.

2.2 CHARACTERISTICS OF PREVIOUS STUDIES

Table 1 reports study designs used in the studies reviewed. Thirty-six (90%) of the 40 studies used cross sectional designs; two employed a case-control design (Agran, Winn, Anderson, Tran, & Del Valle, 1996; Celis, Gomez, Martinez-Sotomayor, Arcila, & Villasenor, 2003; Roberts, Marshall, & Lee-Joe, 1995); one used a quasi-experimental design (LaScala, Johnson, & Gruenewald, 2001); and one employed a longitudinal research design (Yiannakoulias, Scott, Rowe, & Voaklander, 2011). Almost all studies used cross-sectional designs to examine the relationships between built environments and traffic safety. Longitudinal designs may be an appropriate approach because it could explore the causal associations between built environments and traffic safety. In addition, it is also important to examine annual change of crash rates and investigate whether urban development patterns that led by urban and transportation planning make the environment become safer.

Table 1
Study Characteristics of Previous Literature on Traffic Safety

First author and year	Research design	Study context	Analysis unit	Statistical method	Sample size	Included variables
Delmelle (2012)	Cross-sectional	City of Buffalo, NY	Census tract	Spatial error model	90	Population density; employment density; commercial use; income level; race; age; education level; road type.
Ukkusuri (2012)	Cross-sectional	New York	Census tract; zip code	Negative binomial model	2,216 census tracts; 180 zip codes.	Population density; age; commercial use; residential use; school; open space; transit stop; street intersection; road type.
Dumbaugh (2011)	Cross-sectional	San Antonio-Bexar County metropolitan area, TX	Census block group	Negative binomial model	938	Block group area; vehicle miles traveled; income level; age; population density; street intersection; road type; arterial-oriented commercial use; pedestrian-oriented commercial use; big box store.
Desapriya, E. (2011)	Cross-sectional	British Columbia	Each crash observation	Statistic comparison	33	Income level; posted speed limit; gender; daylight.
Ha (2011)	Cross-sectional	City of Buffalo, NY	Census tract	Spatial regression	299	Income level; race; age; population density; employment density; commercial use; school; road density; road type.
Marshell (2011)	Cross-sectional	24 California cities	Census block group	Negative binomial model	1,000	Street intersection; traffic volume; income level; median type.
Miranda-Moreno (2011)	Cross-sectional	City of Montreal, Canada	50, 150, 400, 600m airline buffers from intersection	Two-equation; log-linear; negative binomial model.	519	Traffic volume; street intersection; commercial use; school; residential use; industrial use; park; open space; total employment; total population; bus stop; road type.
Moudon (2011)	Cross-sectional	King county, WA	1/2 km airline crash buffer	Binary logistic regression	711	Average annual daily traffic; office use; commercial use; residential use; age; gender.
Yiannakoulias (2011)	Longitudinal	Edmonton, Canada	Census tract	Generalised linear mixed model	110	Population density; employment density; road density; residential density.
Chong (2010)	Cross-sectional	New South Wales, Australia	Each crash observation	Multiple logistic regression	1,174	Population density; employment density; street intersection.

Table 1 Continued

First author and year	Research design	Study context	Analysis unit	Statistical method	Sample size	Variables
Hadayeghi (2010)	Cross-sectional	City of Toronto	Traffic analysis zone	Geographically weighted regression	481	Traffic volume; total population; street intersection; commercial use; residential use; area.
Kim, J. K. (2010)	Cross-sectional	North Carolina	Each crash observation	Mixed logit model	5,808	Age; gender; traffic signal; traffic sign; commercial use; highway/freeway; weather condition.
Ma, W. J. (2010)	Cross-sectional	Two urban cities, Guangdong, China	Each crash observation	Logistic regression	42,109	Income level; education level; gender; age; family pattern.
Clifton (2009)	Cross-sectional	Baltimore, MD	0.25 mile buffer around each crash observation	Ordered probit model	4,500	% of population aged <15, 16-64, and >65; % of female; population density; transit access; commercial use; residential use; mixed use.
Dumbaugh (2009)	Cross-sectional	San Antonio, TX	Census block group	Negative binomial model	747	Block group area; vehicle miles traveled; income level; age; population density; street intersection; road type; arterial-oriented commercial use; pedestrian-oriented commercial use; big box store.
Schuurman (2009)	Cross-sectional	Vancouver	Hot spot area	Environmental scan	2,358	Bar; school; major road; road type; bus stop; on-street parking.
Wier (2009)	Cross-sectional	San Francisco, CA	Census tract	OLS	176	Traffic volume; street intersection; road type; transit stop; commercial use; residential use; industrial use; total employment; age; income level.
Eluru (2008)	Cross-sectional	U.S.	Each crash observation	Mixed generalized ordered response logit	1,223	Age; gender; vehicle type; posted speed limit; weather condition.
Kim, J. K. (2008)	Cross-sectional	North Carolina	Each crash observation	Multinomial logit model (MNL)	5,808	Age; gender; traffic signal; traffic sign; commercial use; highway/freeway; weather condition.
Abdel-Aty (2007)	Cross-sectional	Orange county, FL	1/2 mile school buffer	Log-linear regression	451	Vehicle type; number of lane; speed limit; median type; traffic control; % of female.

Table 1 Continued

First author and year	Research design	Study context	Analysis unit	Statistical method	Sample size	Variables
Clifton (2007)	Cross-sectional	Baltimore, MD	0.25 mile public school buffer	OLS	163	Type of school; the presence of driveway; the presence of off-street parking; road function class; % of population aged <5; % of population aged 5-15; population density; % of parkland; road density; mixed use; commercial access.
Loukaitou-Sideris (2007)	Cross-sectional	Los Angeles	Census tract	OLS	860	Population density; employment density; traffic volume; race; office use; industrial use; commercial use; residential use.
Poudel-Tandukar (2007)	Cross-sectional	Kathmandu, Nepal	Each crash observation	Multiple logistic regression	1,557	Gender; education level; road behavior.
Sze (2007)	Cross-sectional	Hong Kong	Each crash observation	Logistic regression	73,746	Age; gender; posted speed limit; number of lane.
Dumbaugh (2006)	Cross-sectional	Florida	Each street segment	Negative binomial model	109	Traffic volume; posted speed limit; lane width; median width.
Kim (2006)	Cross-sectional	Hawaii	Census tract	Negative binomial model	5,974	Total population; total employment; commercial use; park; school.
Siddliqui (2006)	Cross-sectional	Florida	Each crash observation	Ordered probit model	160,119	Age; gender; road type; posted speed limit; weather condition; light condition.
Lee (2005)	Cross-sectional	Florida	Each crash observation	Ordered probit model	7,000	Age; gender; vehicle type; traffic control; light condition; weather condition.
de Guevara (2004)	Cross-sectional	Tucson, AZ	Traffic analysis zone	Negative binomial model	859	Population density; employment density; street intersection; bus stop; road type; age.
Flahaut (2004)	Cross-sectional	Belgium	Traffic analysis zone	Spatial logistic model	567	Traffic volume; posted speed limit; road type.

Table 1 Continued

First author and year	Research design	Study context	Analysis unit	Statistical method	Sample size	Variables
LaScala (2004)	Cross-sectional	Four California communities	Census tract	Multiple regression	102	% of adult population divorced; % of households with income under 2,000; % of households with income over 6,000; % of unemployment; % of Black; % of Hispanic; traffic flow; local roadway length; number of elementary school; number of middle school; number of high school
Celis, A. (2003)	Case-control	Guadalajara, Mexico	Each crash observation	Conditional logistic regression	131	Age; gender; education level; housing type; home owner.
Graham (2003)	Cross-sectional	United Kingdom	Wards of England	Negative binomial model	8,414	Population density; employment density; street intersection; traffic volume; weather condition.
Hadayeghi (2003)	Cross-sectional	City of Toronto	Traffic analysis zone	Negative binomial model	463	Traffic volume; total population; street intersection; commercial use; residential use; area; posted speed limit.
Zajac (2003)	Cross-sectional	Rural Connecticut	Each crash observation	Ordered probit model	258	Age; speed limit; vehicle type; light condition; weather condition; traffic volume; on-street parking.
Yiannakoulias (2002)	Cross-sectional	Edmonton	Census tract	Correlation	258	Traffic volume; age; gender; road type.
LaScala (2001)	Quasi-experimental	Four California communities	Census tract	Spatial regression	102	Population density; traffic flow; bar density; restaurant density; age, marital status; income level; race; education level.
LaScala (2000)	Cross-sectional	San Francisco, CA	Census tract	Spatial regression	149	The densities of bars, restaurants, and off-premise outlets; traffic flow; population density; % of age 0-15, 16-29, >55; % of unemployed; % of males; % of high school graduated or higher; median income
Agran (1996)	Case control	North-central Orange county, CA	Each crash observation	Conditional logistic regression	39	Vehicle count; pedestrian count; roadway width; number of vehicles parked on the street.

Table 1 Continued

First author and year	Research design	Study context	Analysis unit	Statistical method	Sample size	Variables
Pitt (1990)	Cross-sectional	Buffalo, Palo Alto, Los Angeles, San Antonio, and Washington.	Each crash observation	Logistic regression	1,035	Age; gender; posted speed limit; traffic control; road type.

Twenty-seven (68%) studies were conducted in the U.S., and few of them were carried out in Canada (Desapriya et al., 2011; Miranda-Moreno, Morency, & El-Geneidy, 2011; Yiannakoulias et al., 2002), New Zealand (Roberts, Ashton, Dunn, & Lee-Joe, 1994; Roberts et al., 1995), the United Kingdom (Graham & Glaister, 2003), Belgium (Flahaut, 2004), and Mexico (Celis et al., 2003). More studies are needed to be conducted outside the U.S.

Different spatial units were utilized to examine the associations between built environments and traffic safety. Existing spatial boundaries (e.g., census tracts, census block groups, traffic analysis zones, and zip code zones) were often employed to take advantage of the associated socio-demographic information available in these units for the analysis. Several studies used school locations (Abdel-Aty et al., 2007; Clifton & Kreamer-Fults, 2007) or crash locations (Clifton, Burnier, & Akar, 2009; Moudon et al., 2011) to generate buffer-based measures for the analysis.

Generalized Linear Modeling (GLM) has been extensively utilized to examine correlates of crashes. Specific methods include logistic regressions (Agran et al., 1996;

Celis et al., 2003; Chong, Poulos, Olivier, Watson, & Grzebieta, 2010; Ma, Nie, Xu, Xu, & Zhang, 2010; Moudon et al., 2011; Pitt, Guyer, Hsieh, & Malek, 1990; Poudel-Tandukar, Nakahara, Ichikawa, Poudel, & Jimba, 2007; Sze & Wong, 2007), negative binomial models (de Guevara, Washington, & Oh, 2004; Dumbaugh & Li, 2011; Dumbaugh & Rae, 2009; Graham & Glaister, 2003; Marshall & Garrick, 2011; Miranda-Moreno et al., 2011; Ukkusuri, Miranda-Moreno, Ramadurai, & Isa-Tavarez, 2012), ordered probit models (Clifton et al., 2009; Siddliqui, Chu, & Guttenplan, 2006; Zajac & Ivan, 2003), log-linear models (Abdel-Aty et al., 2007; Lee & Abdel-Aty, 2005), and logit models (J. K. Kim, Ulfarsson, Shankar, & Mannering, 2010). Among these models, the estimated parameters represent average relationships between dependent variables and independent variables. An implicit assumption of these models is that all relationships do not vary across geographic spaces.

2.3 THEORIES AND CONCEPTUAL FRAMEWORKS FOR TRAFFIC SAFETY

Several theories and conceptual models were developed to explore potential factors related to traffic safety. Earlier theories and models focused on the influence of individual characteristics and behaviors on traffic safety, as represented by the accident proneness theory (i.e., people with some personality disorder are more likely to be involved in accidents) (Greenwood & Yule, 1920) and the causal accident theory (i.e., road users are the cause of accidents) (Petersen, 1996).

Around 2000's, new theories and models paid more attention to traffic system designs and the interactions between designs and human behaviors, such as the system theory (poorly designed transportation systems lead to accidents) (Goetsch, 1998) and the behavior theory (road users adapt their behaviors based on risk factors and road designs they perceive) (Elvik, 2004). In recent years, researchers on urban and transportation planning have given more emphasis on built environmental attributes (Ewing & Dumbaugh, 2009; Ukkusuri et al., 2012; Wier, Weintraub, Humphreys, Seto, & Bhatia, 2009).

The conceptual framework proposed by Ewing and Dumbaugh (2009) focuses on the mechanisms regarding how built environments (i.e. development patterns and roadway designs) influence traffic conditions (i.e., traffic volumes, traffic conflicts, and traffic speeds), which in turn affect traffic safety (Figure 3).

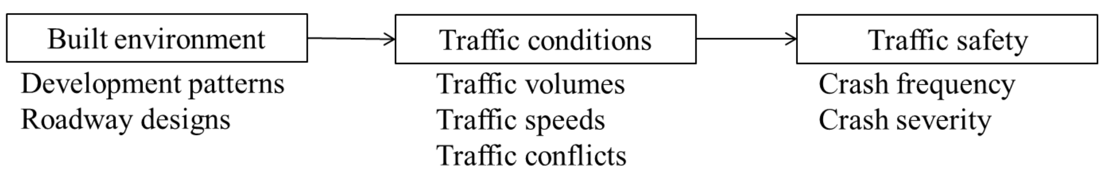


Figure 3
Conceptual Framework Proposed by Ewing and Dumbaugh (2009), p. 348

Moreover, Wier et al. (2009) and Ukkusuri et al. (2012) extended this to a more comprehensive framework (Figure 4), which considered the impacts of built environments, population characteristics, and travel behaviors on crash frequency and severity via traffic conditions. It is believed that traffic volumes and conflicts are the two main factors related to crash frequency, while traffic speeds are the primary determinant for crash severity (Elvik, 2009; Miranda-Moreno et al., 2011).

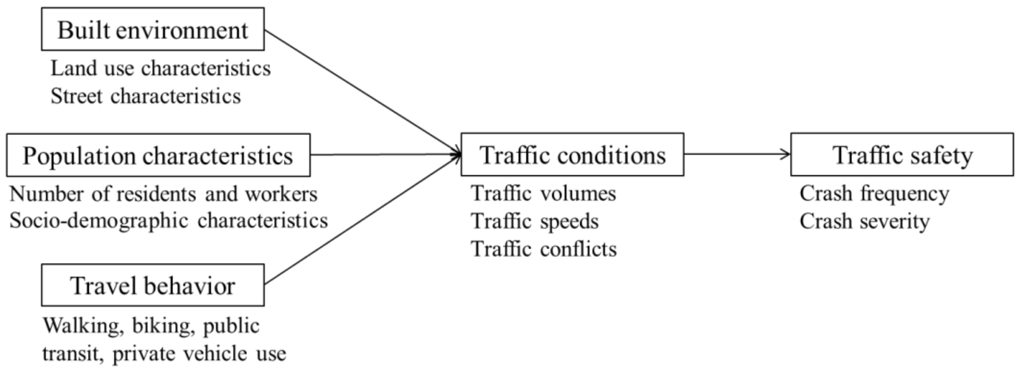


Figure 4
Conceptual Framework Proposed by Wier et al. (2009) by and Ukkusuri et al. (2012)

The conceptual frameworks reviewed in this study have provided a useful guidance in exploring traffic safety issues. However, since the crash is the outcome of the interactions between road users and built environments, the framework that does not consider human behaviors could not explore the interactions between human behaviors and built environmental interventions. The behavioral changes caused by built environmental characteristics are an important determinant for the crash frequency and severity.

2.4 CORRELATES OF TRAFFIC SAFETY

Table 2 summarizes the relationships (e.g., positive, negative, or no associations) between independent variables and traffic safety as reported in the reviewed studies. Researchers have considered different types of collision measures, including all types of collisions aggregated (five of the 40 studies [13%]), motor-vehicle collisions (twenty of the 40 studies [50%]), pedestrian-related collisions (eight of the 40 studies [20%]), bicycle-related collisions (four of the 40 studies [10%]), alcohol-involved collisions (two of the 40 studies [5%]), and crashes with different levels of injury severities (one of the 40 studies [3%]).

Some studies focused on the crashes that involved a specific target population, such as children (Abdel-Aty et al., 2007; Agran et al., 1996; Clifton & Kreamer-Fults, 2007; Desapriya et al., 2011; LaScala, Gruenewald, & Johnson, 2004; Pitt et al., 1990; Yiannakoulias et al., 2002), or that occurred at a specific location, such as intersections (Lee & Abdel-Aty, 2005; Miranda-Moreno et al., 2011).

For the measurement, ten studies examined crash counts in the selected spatial unit such as census tracts, census block groups, and traffic analysis zones (Abdel-Aty et al., 2007; Dumbaugh & Rae, 2009; Dumbaugh, Rae, & Wunneberger, 2011; Lee & Abdel-Aty, 2005; Marshall & Garrick, 2011; Miranda-Moreno et al., 2011; Schuurman, Cinnamon, Crooks, & Hameed, 2009; Ukkusuri et al., 2012; Wier et al., 2009). This method could not consider the relative crash risk because the spatial unit with larger areas may experience more crashes than the unit with smaller areas (Ewing & Dumbaugh, 2009).

Some studies used normalized measurements that could somewhat control the impact of varying sizes of spatial units. For example, Clifton and Kreamer-Fults (2007) utilized the total crash per enrollment of school (all crashes / enrollment of school) to examine its relationship with traffic environments in Baltimore, MD. Also, three studies done by LaScala (2000, 2001, and 2004) used the total crash per mile of street (number of crashes / total miles of streets in the spatial unit). These three studies used the total crash per mile of street since crashes often occur on or streets and street rights-of-way.

Table 2
Findings about Correlates of Traffic Safety

Variables	Definition	Analysis unit	Association	Reference
Crash variable	Count	0.25 mile school buffer		(Clifton & Kreamer-Fults, 2007)
		0.5 mile school buffer		(Abdel-Aty et al., 2007)
		Census block group		(Dumbaugh & Rae, 2009) (Dumbaugh & Li, 2011) (Marshall & Garrick, 2011)
		Census tract		(Ukkusuri et al., 2012)
		Zip code		(Ukkusuri et al., 2012)
		Buffer from intersection (50, 150, 400, 600 m)		(Miranda-Moreno et al., 2011)
	Number of collisions / enrollment of school	0.25 mile school buffer		(Clifton & Kreamer-Fults, 2007)
	Number of collisions / km of roadway	Census tract		(LaScala, Gerber, & Gruenewald, 2000)
Risk exposure				
Traffic volume	Average daily traffic flow (ADT) x 1000	Census tract	+	(LaScala et al., 2000)

+: positive association; –: negative association; o: no association

Table 2 Continued

Variables	Definition	Analysis unit	Association	Reference
Traffic volume	Average annual weekday daily traffic	0.5 km airline crash buffer	+	(Moudon et al., 2011)
		Each crash observation	+	(Zajac & Ivan, 2003)
		Buffer from intersection (50, 150, 400, 600 m)	+	(Miranda-Moreno et al., 2011)
	Aggregated average daily traffic count	Census tract	+	(Wier et al., 2009)
	Vehicle miles traveled (VMT)	Census block group	+	(Dumbaugh & Li, 2011)
	Number of cars per day	Geographic unit	+	(LaScala et al., 2004)
	Count of vehicle	Geographic unit	o	(LaScala et al., 2001)
	Summed traffic volume of all roads / area	Census tract	+	(Yiannakoulias et al., 2002)
			+	(Loukaitou-Sideris et al., 2007)
Built environment				
Posted speed limit	Continuous measure	Each crash observation	o	(Siddliqui et al., 2006)
	<25, 26-40, >40 MPH	0.5 mile school buffer	o	(Abdel-Aty et al., 2007)
	25-50, >50 MPH	Each crash observation	o	(Eluru, Bhat, & Hensher, 2008)
	>=50 kilometers per hour (KPH)	Each crash observation	+	(Desapriya et al., 2011)
Street connectivity	Number of street intersections / street length	Census tract	o	(LaScala et al., 2000)
			o	(Delmelle, Thill, & Ha, 2012)
		Geographic unit	+	(LaScala et al., 2001)
	Number of street intersections / area	Wards of England	+	(Graham & Glaister, 2003)
	Number of street intersections (all types)	Census tract	o	(Wier et al., 2009)
		Buffer from intersection (50, 150, 400, 600 m)	o	(Miranda-Moreno et al., 2011)
	Number of street intersections / number of street intersections + cul-de-sacs	0.25 mile crash buffer	o	(Clifton et al., 2009)
	Number of three-way intersections	Census tract	-	(Ukkusuri et al., 2012)
		Census block group	o	(Dumbaugh & Li, 2011)
	Number of four-way or more intersections	Census tract	+	(Ukkusuri et al., 2012)
		Census block group	+	(Dumbaugh & Li, 2011)

+: positive association; –: negative association; o: no association

Table 2 Continued

Variables	Definition	Analysis unit	Association	Reference
Highway/freeway	Length	Census block group	+	(Dumbaugh & Li, 2011)
	Total miles of highways/freeways / total miles of streets	Census tract	o +	(Wier et al., 2009) (Ukkusuri et al., 2012)
Arterial road	Length	Census block group Buffer from intersection (50, 150, 400, 600 m)	+ o	(Dumbaugh & Li, 2011) (Miranda-Moreno et al., 2011)
	Total miles of arterials / total miles of streets	Census tract	+	(Wier et al., 2009)
On-street parking	Presence (Yes or No)	0.25 mile public school buffer	-	(Clifton & Kreamer-Fults, 2007)
Mixed land use	Square footage of commercial properties / area	0.25 mile public school buffer	+	(Clifton & Kreamer-Fults, 2007)
	Herfindahl-Hirschman index between residential and commercial use	0.25 mile crash buffer	o	(Clifton et al., 2009)
Commercial use	Commercial area / total area	0.25 mile public school buffer 0.25 mile crash buffer Census tract	+ + o + + + +	(Clifton & Kreamer-Fults, 2007) (Clifton et al., 2009) (Wier et al., 2009) (Ukkusuri et al., 2012) (Loukaitou-Sideris et al., 2007) (Delmelle et al., 2012) (Ha & Thill, 2011)
	Count of commercial land uses	Census block group 0.1 m^2 grid Buffer from intersection (50, 150, 400, 600 m)	+ + +	(Dumbaugh & Li, 2011) (I. Kim, Brunner, & Yamashita, 2006) (Miranda-Moreno et al., 2011)
	Count of arterial-oriented commercial uses / total count of commercial uses	Census tract	+	(Wier et al., 2009)
	Count of arterial-oriented commercial uses	Census block group	+	(Dumbaugh & Li, 2011)
	Count of pedestrian-oriented retail and commercial uses	Census block group	-	(Dumbaugh & Li, 2011)
	Count of big box stores	Census block group	+	(Dumbaugh & Li, 2011)

+: positive association; –: negative association; o: no association

Table 2 Continued

Variables	Definition	Analysis unit	Association	Reference
Residential use	Residential area / total area	0.25 mile crash buffer Census tract	o o - o	(Clifton et al., 2009) (Wier et al., 2009) (Ukkusuri et al., 2012) (Yiannakoulias et al., 2011)
	Count of residential uses	Buffer from intersection (50, 150, 400, 600 m)	o	(Miranda-Moreno et al., 2011)
School	Total number of schools	0.1 m^2 grid Buffer from intersection (50, 150, 400, 600 m) Census tract	+ - +	(I. Kim et al., 2006) (Miranda-Moreno et al., 2011) (Ukkusuri et al., 2012)
	Number of elementary schools	Geographic unit	o	(LaScala et al., 2004)
	Number of middle schools	Geographic unit	+	(LaScala et al., 2004)
	Number of high schools	Geographic unit	+	(LaScala et al., 2004)
	Presence of school	0.25 mile crash buffer	o	(Clifton et al., 2009)
	Presence of elementary school	0.25 mile public school buffer	o	(Clifton & Kreamer-Fults, 2007)
	Presence of middle school	0.25 mile public school buffer	o	(Clifton & Kreamer-Fults, 2007)
	Presence of high school	0.25 mile public school buffer	o	(Clifton & Kreamer-Fults, 2007)
Transit service	% of households with a transit stop within 0.25 mile	0.25 mile public school buffer	-	(Clifton & Kreamer-Fults, 2007)
	Presence of bus stop	Hot spot area	o	(Schuurman et al., 2009)
	Number of bus stops / area	Traffic analysis zone	o	(de Guevara et al., 2004)
	Number of bus stops	Buffer from intersection (50, 150, 400, 600 m)	+	(Miranda-Moreno et al., 2011)
	Number of subway stations	Census tract	+	(Ukkusuri et al., 2012)
	Presence of metro stations	Buffer from intersection (50, 150, 400, 600 m)	+	(Miranda-Moreno et al., 2011)
Socio-demographic characteristics				
Population	Number of population / street length	Census tract Geographic unit	+ + +	(LaScala et al., 2000) (Braddock, Lapidus, Gregorio, Kapp, & Banco, 1991) (LaScala et al., 2001)

+: positive association; –: negative association; o: no association

Table 2 Continued

Variables	Definition	Analysis unit	Association	Reference
Population	Total population / area	0.25 mile crash buffer Wards of England Traffic analysis zone Census block group Census tract	o + + + + - +	(Clifton et al., 2009) (Graham & Glaister, 2003) (de Guevara et al., 2004) (Clifton & Kreamer-Fults, 2007) (Loukaitou-Sideris et al., 2007) (Delmelle et al., 2012) (Ha & Thill, 2011)
	Total population	$0.1\ m^2$ grid Wards of England Buffer from intersection (50, 150, 400, 600M) Census tract	+ + o + +	(I. Kim et al., 2006) (Graham & Glaister, 2003) (Miranda-Moreno et al., 2011) (Wier et al., 2009) (Ukkusuri et al., 2012)
Employment	The number of unemployed adults / total population	Census tract Geographic unit	- + - o	(LaScala et al., 2000) (Wier et al., 2009) (LaScala et al., 2004) (LaScala et al., 2001)
	Number of employees / area	Wards of England Census tract	+ + +	(Graham & Glaister, 2003) (Loukaitou-Sideris et al., 2007) (Ha & Thill, 2011)
	Number of employees	Census tract $0.1\ m^2$ grid Traffic analysis zone Buffer from intersection (50, 150, 400, 600 m)	+ + + + o	(Wier et al., 2009) (I. Kim et al., 2006) (de Guevara et al., 2004) (Hadayeghi, Shalaby, & Persaud, 2003) (Miranda-Moreno et al., 2011)
Income	Median household income	Census tract	o o	(LaScala et al., 2000) (Braddock et al., 1991)
	Average per capita income	Census tract	o	(Delmelle et al., 2012)
	% of households with income under US $20, 000 per year	Geographic unit	- o	(LaScala et al., 2004) (LaScala et al., 2001)
	% of households with income higher US $60,000 per year	Geographic unit	o o	(LaScala et al., 2004) (LaScala et al., 2001)

+: positive association; –: negative association; o: no association

Table 2 Continued

Variables	Definition	Analysis unit	Association	Reference
Income	% of households income below poverty level	Census tract	o + +	(Braddock et al., 1991) (Wier et al., 2009) (Ha & Thill, 2011)
Education level	% of population with high school or higher education	Census tract	-	(LaScala et al., 2000)
	% of population with college or higher education	Geographic unit	o o	(LaScala et al., 2004) (LaScala et al., 2001)
	% of people 25 years old with high school or higher education	Census tract	-	(Delmelle et al., 2012)

+: positive association; –: negative association; o: no association

Significant correlates of traffic safety can be grouped into the following broad categories: risk exposures, built environments, and socio-demographic characteristics. The following sections will review corresponding results for each category.

2.4.1 Risk Exposure

Traffic volume

Traffic volumes have been identified as a significant correlate for the crash risk. It is expected that areas with higher volumes of traffic experience more crashes than places with lower traffic volumes. Nine of the ten studies found positive associations between traffic volumes and the number of crashes. For instance, LaScala et al. (2000) reported that census tracts with higher average daily traffic volumes were related to more collisions in San Francisco, CA. A study in Los Angeles, CA found a positive association between traffic volumes and pedestrian-vehicle collisions in census tracts (Loukaitou-Sideris et al., 2007).In terms of the measures, the annual average daily traffic volume was the most common approach to capture traffic volume (Agran et al., 1996; LaScala et al., 2000; LaScala et al., 2004; LaScala et al., 2001; Miranda-Moreno et al., 2011; Moudon et al., 2011; Wier et al., 2009; Yiannakoulias et al., 2002; Zajac & Ivan, 2003).

2.4.2 Built Environment

Several built environmental factors have been studied in previous literature for their impacts on traffic safety. Each identified built environmental attribute is discussed as follows:

Street connectivity

Previous studies showed inconsistent results about the relationships between street connectivity and the number of crashes. Graham and Glaister (2003) found that a greater number of traffic network nodes (indicating a better street connectivity) was associated with more collisions in the United Kingdom. Conversely, a study in Montreal, Canada found no association between the number of intersections and crash frequency (Miranda-Moreno et al., 2011). Delmelle et al. (2012) reported that intersection density had no effect on the number of crashes that involved youth (age < 16) in Buffalo, NY. The possible explanation for the inconsistent results may be that a connected street network indeed increases pedestrian volume and slows the traffic speeds, but also leads to more concentrated traffic volumes and more traffic conflicts.

Different intersection types had different influences on crash frequency (Dumbaugh & Rae, 2009). A New York study demonstrated that four-way and five-way intersections were positively related to collisions, while three-way intersections showed a negative association (Ukkusuri et al., 2012). This is likely because that four-way and five-way intersections produce more conflicting traffic movements than three-leg intersections, which can lead to more crashes (Dumbaugh & Rae, 2009).

In terms of the measures, Clifton et al. (2009) utilized Connected Node Ratio (CNR) (the number of street intersections / the number of street intersections and dead ends). Few studies used the number of street intersections in the analysis unit (Wier et al., 2009). Other studies employed an intersection density measure, such as the number of intersections per kilometer of street (LaScala et al., 2001) or per acre (Graham & Glaister, 2003).

Since previous studies have applied several measurement methods and resulted in inconsistent results, it is possible that different measures might have captured different aspects of street connectivity. Therefore, multiple street connectivity measures should be used in order to capture different aspects of street connectivity and to comprehensively examine the influence of street connectivity on traffic safety.

Posted speed limit

Three of the four studies including speed limit as a study variable reported that higher posted speed limits increased the probability of serious injuries. Desapriya et al. (2011) found that streets with speed limits greater than 50 miles per hour (MPH) were more likely to cause child fatality in British Columbia, Canada. Eluru et al. (2008) also reported that fatal injuries were more likely to occur when roadway speed limits were greater than 50 MPH in the U.S. Findings from these studies agreed that areas with high speed limits are more likely to cause fatal or serious injury.

For the measurement methods, most researchers used categorical groups of posted speed limits to investigate their influences on crashes. For example, Abdel-Aty et al. (2007) used three classifications (e.g., <25 MPH, 26-40 MPH, and >40 MPH) to explore the effect of speed limits on crashes that involved school–aged children (aged 4-18) in Orange county, FL. A British Columbia study on children's traffic safety used 50 MPH as a threshold to measure speed limits (Desapriya et al., 2011). Eluru et al. (2008) generated three classes (e.g., <25 MPH, 25-50 MPH, and >50 MPH) to examine their relationships with motor vehicle collisions in the U.S.

The decision on cut-off values for travel speeds should be considered in relation to the emergency stopping distance for drivers. In general, drivers traveling at a lower speed need less time and distance to come to a complete stop in case of emergency. A typical driver with 40 MPH needs more than 280 feet to stop; a driver with 30 MPH needs over 130 feet; and at 20 MPH, a driver needs about 60 feet (Ewing & Dumbaugh, 2009). Thus, researchers should set up several categories of travel speeds when there is a dramatic drop on emergency stopping distances.

Road type

Different road types have different functions and designs (e.g., road width, shoulder width, median width, etc.). Highways/freeways are designed to maximize the movement function with high travel speeds, and feature design elements such as wide and straight lanes and limited access. Arterial roads are designed with both movement and access functions connecting higher-order highways and lower-order local roads in the road system. They not only carry high-volume traffic with high operating speeds but also enable low-level direct access to surrounding land uses. Local roads are primarily for the access function and often feature low posted speed limits and reduced stopping sight distances, which made it easier for drivers to react to unforeseen hazards (Ewing & Dumbaugh, 2009).

Different road types have been found to influence crashes. For the impacts of highways and freeways, a New York study reported that a higher percentage of freeways caused more crashes (Ukkusuri et al., 2012). A San Antonio, TX study also reported the positive association between total miles of highways/freeways and the number of vehicle-pedestrian crashes in census block groups (Dumbaugh & Li, 2011).

In terms of arterial roads, a San Francisco, CA study reported that the percentage of arterial roads without access to public transit was positively associated with collisions in census tracts (Wier et al., 2009). Dumbaugh and Li (2011) found a positive association between miles of arterials and the number of vehicle-pedestrian collisions in census block groups in San Antonio, TX.

With respect to the measures, three approaches were used to capture road types, including the presence and miles of a specific road type, and the percentage of street length belonging to a specific road type in the spatial unit. The binary variable for presence can only detect whether a specific type of road exists in the analysis unit.

On-street parking

On-street parking is promoted as a pedestrian-oriented design as it can serve as a buffer between pedestrians and automobiles while appropriate safety measures are implemented. Only one study tested the influence of on-street parking and found that the presence of on-street parking reduced the number of pedestrian crashes in Baltimore, MD (Clifton & Kreamer-Fults, 2007). More future studies are needed to address the effect of this design feature on traffic safety.

Mixed land use

Only two articles from this review addressed the relationship between mixed land uses and collisions. Clifton and Kreamer-Fults (2007) found a positive association between the square footage of commercial uses and the number of pedestrian–vehicle collisions within 0.25–mile buffers of public schools in Baltimore, MD. Another study in Baltimore, MD used Herfindahl-Hirschman index between residential and commercial uses (measuring mixed land use by summing the squared size of residential and commercial uses in the spatial unit) and reported that mixed land uses had no effect on fatal collisions (Clifton et al., 2009).

Commercial use

Ten studies included commercial land uses as an independent variable and nine of them reported positive associations between commercial uses and crash frequency. For example, a Hawaiian study showed that a greater number of commercial parcels was associated with more crashes (I. Kim et al., 2006). Ukkusuri et al. (2012) reported a positive relationship between the percentage of commercial uses and the number of crashes in census tracts in New York.

A study in San Antonio, TX demonstrated that different types of commercial uses had different influences on crash frequency (Dumbaugh & Li, 2011). They divided commercial uses into three types: arterial-oriented, pedestrian-oriented, and big box stores. The results showed that arterial-oriented commercial uses and big box stores were associated with increased crashes, while pedestrian-oriented commercial uses showed negative associations with crashes (Dumbaugh & Li, 2011). Moreover, a San Francisco, CA study found no association between all types of commercial uses and crashes, but positive relationships between arterial-oriented commercial uses and collisions (Wier et al., 2009). The possible explanation is that arterial-oriented commercial uses usually provide a direct driveway access from adjacent arterials. The driveway access of entering abutting commercial uses from arterials would be a potential conflict point in causing crashes (Dumbaugh & Li, 2011). Vehicles with high travel speeds on arterials have to decelerate before they turn into driveways leading to commercial land uses. This speed difference causes conflicts between vehicles traveling on arterials and those entering or leaving driveways, thus leading to more crashes.

Residential use

Four of the five studies found no relationships between residential uses and crash frequency. Only one study reported a negative association. Ukkusuri et al. (2012) found that census tracts with higher percentages of residential uses were related to more collisions in New York, NY.

Two types of measurements were used to capture the residential use variable, including the count and percentage measures. Miranda-Moreno et al. (2011) used the number of residential parcels in 50-, 150-, 400-, and 600-meter airline buffers around street intersections in Montreal, Canada. A study in Baltimore, MD used the percentage of residential areas in 0.25-mile crash buffers (Clifton et al., 2009).

School

Three of the six studies found positive associations between the presence or number of schools and crashes. For example, LaScala et al. (2004) found that an area with a middle school was associated with more crashes in four California communities. I. Kim et al. (2006) also reported a positive association between the presence of schools (including elementary, middle, and high schools) and the number of crashes in Hawaii. However, previous studies did not consider the possibly different influence of different types of schools (elementary, middle, or high school) on traffic safety.

Two methods were used to measure the school variable, including the continuous variable capturing the number of elementary, middle, and high schools in the analysis units (LaScala et al., 2004) and the binary variable for the presence of schools (Clifton et al., 2009).

Transit service

For the impacts of transit service on traffic crashes, the results were inconsistent. Two studies reported negative associations. For example, Clifton and Kreamer-Fults (2007) found that a higher percentage of households with transit stops in 0.25-mile buffers was associated with reduced total collisions in Baltimore, MD. The possible explanation might be that areas with more transit stops lead to lower vehicular traffic volumes, which decrease the crash risk. Conversely, two other studies found positive relationships. Ukkusuri et al. (2012) indicated that a greater number of subway stations was associated with more pedestrian–vehicle collisions in New York. Miranda-Moreno et al. (2011) also found that the presence of metro stations and bus stops increased pedestrian–vehicle collisions in Montreal, Canada. It is possible that transit stops produce more pedestrian activities, which increase the conflicts between pedestrians and vehicles.

2.4.3 Socio-Demographic Characteristic

Population

Twelve out of the sixteen studies reported positive associations between population size/density and crashes. For example, Clifton and Kreamer-Fults (2007) found that population density was positively related to crash rates in Baltimore, MD. A study in San Francisco, CA found that areas with more populations had more collisions (Wier et al., 2009). Graham and Glaister (2003) found that areas with more people were related to more pedestrian–vehicle collisions in the United Kingdom. A study in Tucson, AZ reported that population density was positively associated with fatal and injurious collisions in traffic analysis zones (de Guevara et al., 2004).

Employment

Seven of the twelve studies reported positive relationships between total employment and crash incidence. For instance, I. Kim et al. (2006) found that a greater number of jobs in that area was associated with more vehicle crashes in Hawaii. A United Kingdom study found that employment density was positively related to crashes (Graham & Glaister, 2003). Moreover, de Guevara et al. (2004) reported a positive association between the number of employees and injurious crashes in traffic analysis zones in Tucson, AZ.

Income and education

Seven studies examined the impact of income level on crashes and five of them reported no association between income level and crash rates (Braddock et al., 1991; Clifton et al., 2009; Delmelle et al., 2012; LaScala et al., 2000; LaScala et al., 2001). Two other studies reported that census tracts with a higher percentage of household income below poverty level had more collisions (Ha & Thill, 2011; Wier et al., 2009).

Only one of the four studies reported a negative association between education level and crashes. LaScala et al. (2000) indicated that areas with a higher percentage of people with high school or higher education experienced fewer collisions in San Francisco, CA.

2.4.4 Summary

Overall, this review found some variables had consistent relationships with traffic safety. Areas with greater traffic flows, higher four-way intersection density, more commercial uses, and higher employment and population densities were associated with more crashes. Some variables have not been extensively examined and had inconsistent results, such as street connectivity, on-street parking, school, transit service, and income level. Future studies should pay more attention to these understudied variables.

Only one study discussed the influence of built environmental characteristics on crashes with different levels of injury severity (Dumbaugh & Rae, 2009). This San Antonio, TX study found that crashes with different levels of injury severity were related to different factors (Dumbaugh & Rae, 2009). Urban areas with high traffic flows and mixed land uses had more minor and no injury crashes but fewer fatal and serious injury collisions, while suburban areas featuring high vehicle speeds were more likely to have more fatal and serious injuries.

Three were substantial variations in the measurement of built environmental factors in the identified studies. The use of objective measures for built environmental attributes, especially by geographic information systems (GIS), in these studies makes the measurements efficient and accurate. However, there were some methodological limitations with GIS measures, including the use of different buffer sizes, inconsistencies of measurement methods, and diversity of referents and categories cut-off values for posted speed limits (e.g., 25, 40, or 50 MPH).

A common approach to measure built environments is to generate buffers around the specific location (e.g., schools, intersections, etc.). Most previous studies on traffic safety applied one buffer size to examine the effect of built environments on traffic safety, which may be subject to the Modifiable Areal Unit Problem (MAUP). Using different buffer sizes might lead to different influence statistical results about relationships between built environments and traffic safety. Only one study from this review employed multiple airline buffers from the intersection (50m, 150m, 400m and 600m) to examine the impact of built environments on traffic safety (Miranda-Moreno et al., 2011).

Different measurement methods may generate different statistical results. For example, for the influence of street connectivity on traffic safety, those studies that used street intersection density to measure street connectivity found a positive association

(Graham & Glaister, 2003; LaScala et al., 2001), while other studies that utilized the number of street intersections in the analysis unit reported no relationship (Miranda-Moreno et al., 2011; Wier et al., 2009). Future studies should try several measurement methods for each variable.

2.5 RESEARCH GAPS

Based on the systematic review of the existing empirical studies on traffic safety, the author identified several important research gaps that will be addressed in this study to further the understanding about the complex relationships between built environments and traffic safety. These specific research gaps are explained below.

2.5.1 Local Relationships between Crash Severity and Environmental Designs

Two specific literature gaps are discussed in this section: (1) local relationships between built environmental attributes and traffic safety and (2) built environmental correlates of crashes with different levels of injury severity.

Local relationships between built environmental attributes and traffic safety

Two types of statistical approaches have been widely applied to examine the impacts of built environments on traffic safety. The first statistical method is *Generalized Linear Modeling (GLM)* (Hadayeghi et al., 2010). This method could isolate the effects of built environmental factors on traffic safety by controlling other important confounding variables. However, because spatial dependence (correlations between what happens at one location and what happens in other places) often exist for built environmental attributes, corresponding data often violate the assumption of the GLM approach that each observation is independent (Anselin, 1988; Cliff & Ord, 1973).

In response to this problem, researchers have developed a methodology named "*spatial regression (spatial error and lag models)*" (Anselin, 1988). For example, LaScala et al. (2000) employed spatial error models to examine geographic correlates of pedestrian injury collisions across census tracts in San Francisco, CA. LaScala et al. (2001) also used spatial error models to explore factors that were associated with alcohol-related pedestrian injury collisions in four California communities. The model fit improved after accounting for spatial dependence. Flahaut (2004) used spatial lag logistic models to examine the effect of road environments on road safety in Belgium. The results showed a reduction of correlations in error terms after accounting for spatial dependence.

The above two approaches, however, only estimate fixed coefficients for the average relationships between crash variables and independent variables. Their estimated parameters are stationary across the entire study area, and therefore cannot consider the spatial heterogeneity. It is possible that some independent variables may have strong predictive power for crashes at certain locations, but may be weak predictors or insignificant at other locations. Due to the implicit assumption of fixed measures that all relationships remain constant across geographic spaces, the influence of spatial heterogeneity could not be explored by GLM and spatial regressions, and is included in error terms (Hadayeghi et al., 2010).

As an alternative method, local spatial models – Geographically Weighted Poison Regressions (GWPRs) – have been used to consider various coefficients for different sub-areas in the entire study area to examine relationships between crashes and related factors. For example, Hadayeghi et al. (2003) explored the local associations between the number of deaths and socio-demographic characteristics in traffic analysis zones using GWPRs in Toronto, Canada. Another study also used GWPRs to examine the relationships between spatial factors and the number of collisions in traffic analysis zones in Toronto, Canada (Hadayeghi et al., 2010). Both studies supported the existence of significant spatial variations for coefficients between four-leg intersection and the number of collisions. However, these studies only considered the total number of collisions and did not examine crashes with different levels of injury severity (e.g., fatal injuries, serious injuries, etc.).

Built environmental correlates of crashes with different levels of injury severity

Collisions with different levels of injury severity are likely to be related to different built environmental factors. High-density areas with short links to destinations and low vehicle speeds experience high pedestrian activities and are likely to increase the number of injury collisions with lower severity, while low-density areas with low street connectivity and high vehicle speeds have few pedestrian flows but may generate more serious and fatal injury crashes (Clifton et al., 2009; Dumbaugh & Rae, 2009). Therefore, the relationships between built environmental attributes and crash occurrence and injury severity may vary across geographic areas.

2.5.2 Disparity in Traffic Safety

Two gaps are discussed in this section: (1) the existence of disparities in crashes with different levels of injury severity and (2) the possible moderating effect of area's socio demographics on built environment–traffic safety relationships.

The existence of disparities in crashes with different levels of injury severity

A large body of work has explored the effects of socioeconomic deprivation on crashes and found that socioeconomically deprived areas (i.e., areas with lower income or concentrated minority populations) experienced more crashes (Christie, 1995; Graham & Glaister, 2003; Loukaitou-Sideris et al., 2007; Noland et al., 2013; White et al., 2000). For example, a study in Los Angeles, CA found that areas with high concentrations of Latino populations experienced more pedestrian collisions (Loukaitou-Sideris et al., 2007). Noland et al. (2013) also reported that low income census block groups were associated with more pedestrian and motor vehicle crashes in New Jersey, NJ. However, most previous studies on disparity issues primarily focused on pedestrian injuries. Current evidence regarding disparities in crashes with different levels of injury severity is still limited.

The possible moderating effect of area's socio demographics on built environment–traffic safety relationships

Several possible reasons could explain why socioeconomically deprived areas had more crashes. One possible reason for this phenomenon is that low income areas were associated with lower household vehicle ownership and more pedestrian activities (Noland et al., 2013). Another possible explanation is that these low income areas lacked adequate pedestrian infrastructure and therefore exposed pedestrians to more safety threats from vehicle traffic (Noland et al., 2013). However, current empirical evidence is still limited in terms of the specific causes behind economic and ethnic disparities in environmental supports for traffic safety.

Because the influence of built environments on traffic safety may vary across areas with different economic statuses and ethnic compositions, an area's socio demographics may function as a moderator between built environments and traffic safety. Thus, different strategies on environmental interventions in promoting traffic safety may be needed for areas with different socio-demographic characteristics.

2.5.3 Built Environmental Correlates of School Travel Safety

Schools serve as centers for school–aged children's daily activities. Researchers have identified schools as high risk crash locations (Clifton et al., 2009; Clifton & Kreamer-Fults, 2007; LaScala et al., 2004) which experience regular, concentrated, and congested traffic flows, and may impose safety threats for children traveling to and from school (Abdel-Aty et al., 2007; Clifton & Kreamer-Fults, 2007; LaScala et al., 2004). School-aged children made about 15.3 billion trips and traveled about 68.9 billion miles to and from school in 2009 in the U.S. (McDonald et al., 2011). Parents/guardians drove a total of 30.0 billion miles and made 6.6 billion vehicle trips to take/pick up children to and from school in 2009 in the U.S. (McDonald et al., 2011). A significant number of collisions involving school–aged children occur on their journey to/from school (Sharples, Storey, Aynsley-Green, & Eyre, 1990). A study in Toronto, Canada asserted that crash rates involving 5-to-9-year-olds were three times more likely to occur when they travelled to or from school than other times (Warsh, Rothman, Slater, Steverango, & Howard, 2009).

Several factors have been reported to be associated with school travel safety, including children's behaviors (e.g., over-activity), traffic volumes during school travel, and built environments around schools (Corless & Ohland, 1999). However, few studies have focused on the locational and environmental factors linked to those specific crashes involving school–aged children during school travel time.

The community development around the school area could affect traffic safety. In the 20th century, Perry (1929) proposed the concept of the “neighborhood unit” to create a community-centered school. For promoting travel safety, he designed narrow and disconnected streets to prevent cut-through traffic within a given neighborhood. He located commercial and retail uses along arterial roads, and residential uses beside local roads to reduce the traffic volume within the neighborhood. Attention was also given to a central school lcoation so that students were able to live within a half mile walkable distance from their schools and could commute to school in a low-vehicle-speed environment.

As student populations and educational programs continue to grow, local officials and policy makers were motivated to build larger schools to meet their communities' current and future requirements (McDonald, 2010). With the rapid increase in suburban development, a phenomenon commonly called “school sprawl” has emerged (McDonald, 2010). These large schools are commonly built in suburban areas with less expensive land, comparatively further away from the residential areas they serve. Suburban schools are designed primarily for motorist convenience, and often are located near highways and arterial roads, which increases walking/biking distances and crash risks.

Clifton and Kreamer-Fults (2007) explored pedestrian-vehicle crash incidents in 0.25-mile airline buffers around 163 public schools in Baltimore, MD. This study examined the effects of built environments by controlling school characteristics (e.g., school type and enrollment), school site designs (e.g., driveway, parking lot, set back, and recreational facilities), area's socio-demographics (e.g., population density, vehicle ownership, and the percent of population aged less than 5 and between 5 and 15). Areas with higher percentages of non-white populations and populations aged 5-15 and higher population densities were associated with increased crashes. Traffic-generating uses such as commercial access and mixed land uses increased the pedestrian crash frequency. However, because this study did not examine the designs around commercial uses, such as whether these uses were located along arterial roads or designed with pedestrian infrastructure, it could not provide a clear explanation about why the number of crashes was higher in these areas.

Abdel-Aty et al. (2007) examined the impacts of road environments on pedestrian and cyclist crashes involving school–aged children (aged 4 to 18) in 0.5-mile airline buffers around schools in Orange County, FL. They found that middle and high school students were more likely to be involved in crashes on high-speed, multi-lane roads than elementary school students. Warsh et al. (2009) explored the factors related to child pedestrian collisions in school zones and found that more crashes occurred at midblock locations than at intersections. However, these two studies did not account for the influence of traffic volume and school enrollment. Schools with a larger number of students are expected to have greater crash risks than smaller schools. Moreover, the effects of neighborhood environments were not considered.

2.5.4 Summary

Overall, several research gaps were identified from this literature review, such as the need of examining local associations between built environments and traffic safety, built environmental correlates of crashes with different levels of injury severity, the existence of disparities in crashes with different levels of injury severity, the potential moderating effect of socio-demographics among the built environment–traffic safety relationship, and the influence of built environmental attributes on school travel safety. The following section will develop a conceptual framework to guide the selection of study variables in order to address the above research gaps.

3. RESEARCH DESIGN

3.1 CONCEPTUAL FRAMEWORK

Based on the previous works by Wier et al. (2009), Ewing and Dumbaugh (2009), and Ukkusuri et al. (2012), the author proposed a conceptual framework for this dissertation study (Figure 5). Due to the difficulty in measuring traffic speeds and traffic conflicts, this framework does not consider traffic conditions as the mediating variable for the relationship between built environment and traffic safety, but instead aims to explore the direct effects of built environments on traffic safety. Four domains of determinants – risk exposures, built environments, travel behaviors, and socio-demographic characteristics – are hypothesized to be associated with traffic safety in this study. This study focuses on built environments, which are modeled as independent variables, and treats the other three domains as control variables.

Furthermore, this conceptual framework could be applied to different spatial scales, such as the regional, city, neighborhood, and street-levels and specific locations (e.g., crash locations, intersections, schools, etc.).

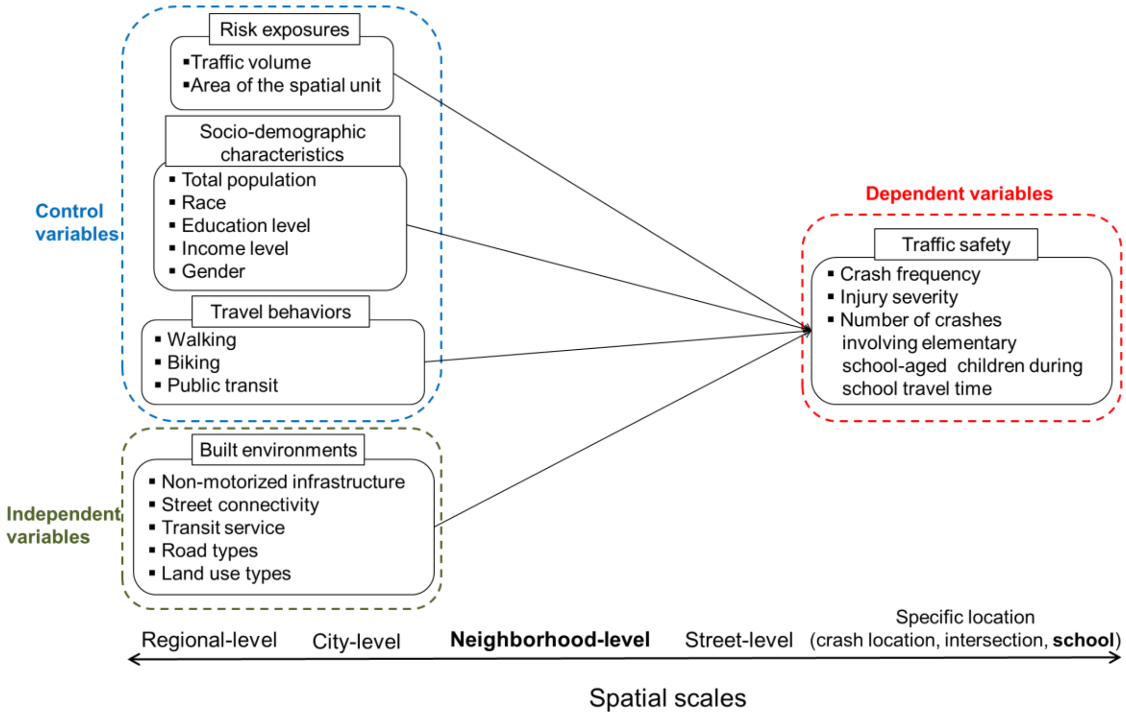


Figure 5
Conceptual Framework for This Study

3.2 RESEARCH QUESTIONS, AIMS, AND HYPOTHESES

From the literature review, three research questions are developed to help fill in the identified knowledge gaps: (1) Do built environments have significant impacts on the frequencies of traffic crashes with different levels of injury severity, and if yes, do such impacts vary across neighborhoods? (2) Is there any disparity in crashes with different levels of injury severity across neighborhoods with different economic statuses and ethnic compositions? (3) How are built environmental designs around schools associated with school travel safety?

To answer these research questions, three Aims and associated hypotheses are proposed according to the conceptual framework. In terms of the spatial scales, this study focuses on the neighborhood level in Aims 1-1 and 1-2, and on the school level in Aim 2.

Aim 1-1: To examine the impacts of neighborhood environments on crashes with different levels of injury severity. This Aim tests the hypothesis that areas with more highways and arterial roads would be related to more fatal and serious injury crashes, while areas with more four-or-more-leg street intersections, more transit stops, and more commercial uses would be associated with more minor and no injury crashes.

Aim 1-2: To explore disparity in crashes with different levels of injury severity across neighborhoods with different economic statuses and ethnic compositions. This Aim tests the hypothesis that areas with lower income or concentrated minority populations would be associated with more crashes.

Aim 2: To examine the built environmental factors around schools that are associated with crashes involving elementary school–aged children during school travel time. This Aim tests the hypothesis that elementary schools surrounded by higher percentages of highways and arterial roads, higher transit stop densities, and higher percentages of commercial uses would be associated with more crashes involving elementary school–aged children during school travel time.

3.3 STUDY DESIGN

This cross-sectional study has three study Aims. Aim 1-1 and Aim 1-2 use neighborhood-level analyses to examine the influence of built environments on crash frequency with different levels of injury severity in census block groups in Austin, TX. Aim 2 uses two-level analysis (street segment-level and school-level) to explore the impact of built environments (road environments and neighborhood environments around schools) on crashes involving elementary school–aged children during school travel time in the Austin Independent School District (AISD), TX.

4. ASSOCIATION BETWEEN NEIGHBORHOOD ENVIRONMENT AND CRASHES WITH DIFFERENT LEVELS OF INJURY SEVERITY

4.1 INTRODUCTION

To address the research gap mentioned in 2.5.1 "Local Relationships between Crash Severity and Environmental Designs," this study examined the local spatial variations in the associations between built environments and collisions in the city of Austin, TX. More specifically, the author explored correlates of collisions specific to four different injury severities (fatal, serious, minor, and no injury) in census block groups by using local models (Geographically Weighted Poisson Regressions [GWPRs]). Moreover, this study compared the performance of global models (negative binomial models) with that of local models (GWPRs) to examine whether local models had better predictive power. The present study contributes to the existing body of the literature on the built environment–traffic safety relationship by considering collisions with different levels of injury severity and by adopting a local approach to investigate the non-stationary associations between built environmental factors and crash frequency.

4.2 METHODS

4.2.1 Study Setting

The city of Austin was chosen as the study area due to (1) the variation of built environmental attributes, (2) the diversity of socio-demographic characteristics (Table 3), and (3) the availability of comprehensive and updated datasets. The wide range of variation in the study setting offers advantageous conditions to examine the relationships between built environments and traffic safety.

Table 3
Built Environmental and Population Characteristics of the City of Austin (Unit of Analysis: Census Block Group)

	Features	Mean (S.D.[c])	Min.[d]-Max.[e]
Built environmental characteristics [a]	Residential density (residents/acre)	17.42 (31.68)	3.00 – 394.54
	Road density (total miles of roads / acre)	0.03 (0.02)	0.01 – 0.17
	Transit density (number of transit stops / acre)	0.03 (0.04)	0 – 0.18
	Land use mix (the evenness of distribution of residential, commercial, and office land uses [f])	0.16 (0.09)	0.03 – 0.34
	Intersection density (number of intersections / acre)	0.15 (0.10)	0.02 – 0.64
Population characteristics [b]	% of Hispanic population (number of Hispanic population / total population)	30.82% (21.37%)	3.84% – 90.17%
	% of white population (number of white population / total population)	72.17% (15.24%)	30.01% – 98.41%
	% of population below the poverty line (number of population below the poverty line/ total population)	16.87% (14.12%)	1.18% – 85.22%

[a] Data sources for built environmental characteristics include parcel-level land use data, street centerline data, and transit stop data from the city of Austin.

[b] The data source for population characteristics is 2010 Census.

[c] S.D.: Standard deviation.

[d] Min.: Minimum.

[e] Max.: Maximum.

[f] (−1)×[(area of R/total area of R, C, and O)×ln (area of R/total area of R, C, and O)+(area of C/total area of R, C, and O)×ln (area of C/total area of R, C, and O)+(area of O/total area of R, C, and O)×ln (area of O/total area of R, C, and O)] / ln (number of land uses present).
R, residential use; C, commercial use; O, office use.

This index measures the evenness of land use distribution based on acres of residential, commercial, and office land uses (Frank, Schmid, Sallis, Chapman, & Saelens, 2005). The value ranges from 0 (single land use) to 1 (an even mix).

Several steps were used to determine the study boundary. The city boundary was first considered as the study boundary. However, the crash data were available only within the Austin Police Department (APD) boundary, which was smaller than the city boundary (Figure 6). Therefore, the APD boundary was selected as the study boundary to ensure data completeness.

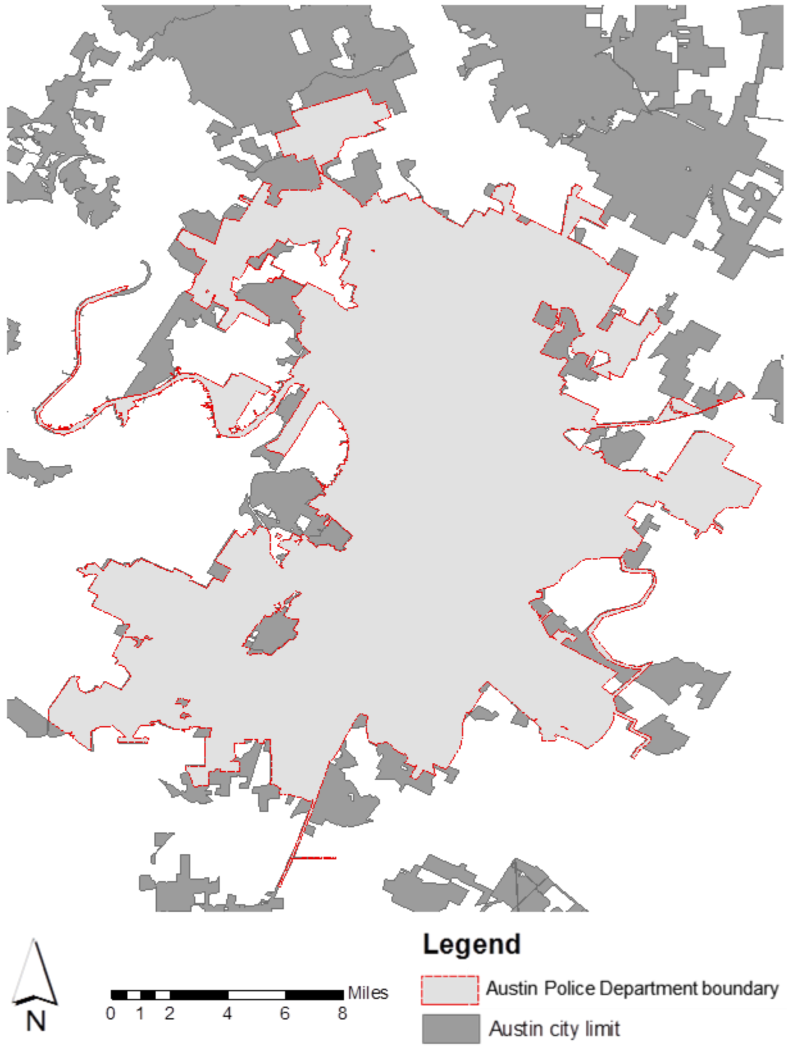


Figure 6
Austin Police Department Boundary and Austin City Limit

After the study boundary was determined, this study explored three types of spatial units (census tracts, census block groups, and traffic analysis zones). Reasons for selection of the unit of analysis are explained in the section below—“4.2.2 Units of Analysis.” This study selected spatial units with their centroids within the APD boundary (if the centroid of the spatial unit was within the APD boundary) to be included in this study.

In addition, because nine years (2004–2012) of crash data were used for the analysis, it is possible that the urban development pattern might have changed significantly during this period, which could have confounding impacts on the built environment–traffic safety relationships. Hence, this study examined changes in the land uses and street patterns during this period to exclude areas with significant changes from this study. In order to detect land use changes, land use data from 2003 and 2010 (the closest years for which the data were available) were compared for their differences in residential, commercial, office, industrial, school, and open space land uses. For each land use type, the author calculated the following four equations in each census tract, census block group, and traffic analysis zone.

Land area difference = land area in 2010 – land area in 2003 .... (1)

The percentage of land area difference = (land area in 2010 – land area in 2003) / land area in 2003 .... (2)

Parcel count difference = number of parcels for each land use type in 2010 – number of parcels for each land use type in 2003.. (3)

The percentage of parcel count difference = (number of parcels for each land use type in 2010 – number of parcels for each land use type in 2003) / number of parcels for each land use in 2003 .... (4)

This study also examined the changes in street patterns between 2007 and 2011 (the closest years for which the data were available) in each census tract, census block group, and traffic analysis zone. The street pattern change was explored through the following two measures.

Change in total lengths of streets = total street miles in 2011 – total street miles in 2007 .... (5)

The percentage of change in total lengths of streets = (total street miles in 2011 – total street miles in 2007) / total street miles in 2007 .... (6)

Some spatial units (0.5% of census tracts, 1.1% of census block groups, and 1.2% of traffic analysis zones) had no commercial, office, industrial, school, or open space land uses in 2003, which made it impossible to calculate the percentage differences. Those units were assigned 1 acre of land area and 1 count of land use parcel in 2003 so that the calculation could be conducted.

Box plots were used to explore the distribution of land area difference, the percentage of land area difference, parcel count difference, and the percentage of parcel count difference for each land use type, street length difference, and the percentage of street length difference (see Appendix A: Urban development change). The spatial units with extreme values (outside the three standard deviations from the mean) in at least one of the six above measures were identified as outliers and excluded from further analysis. After this process, 12 census tracts, 14 census block groups, and 26 traffic analysis zones were excluded; and the remaining 144 census tracts (Figure 7), 426 block groups (Figure 8), and 552 traffic analysis zones (Figure 9) were selected for further consideration in this study.

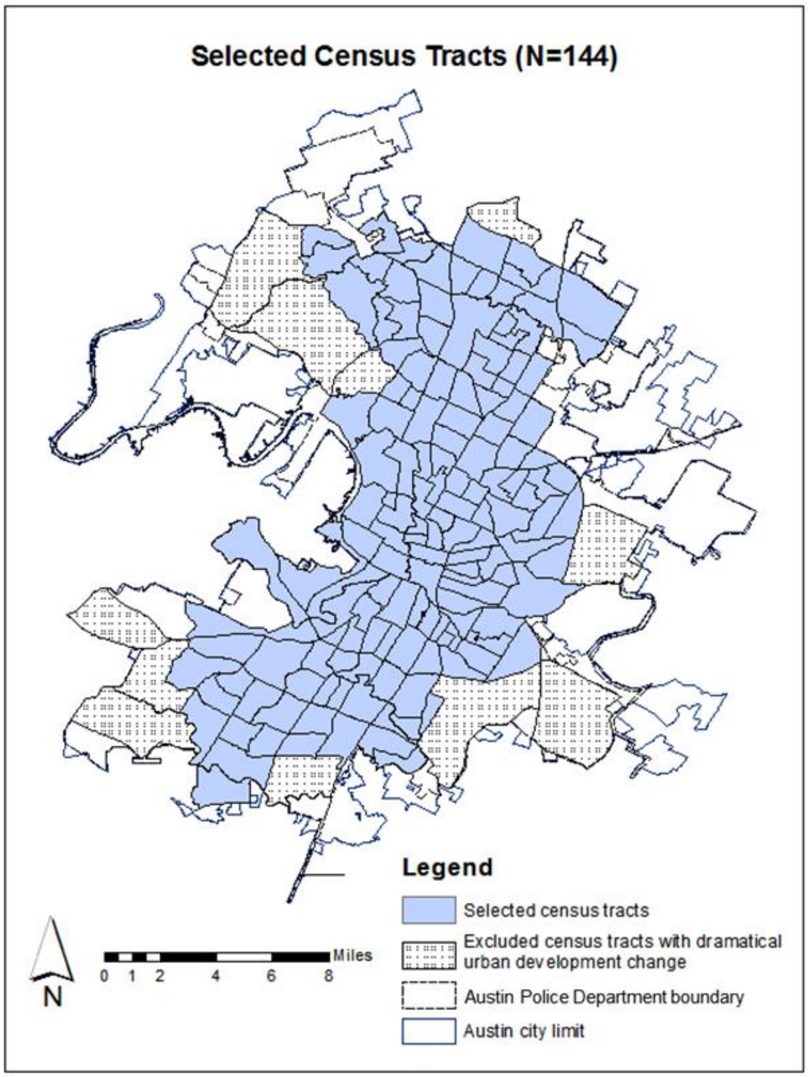


Figure 7
Selected Census Tracts in Austin

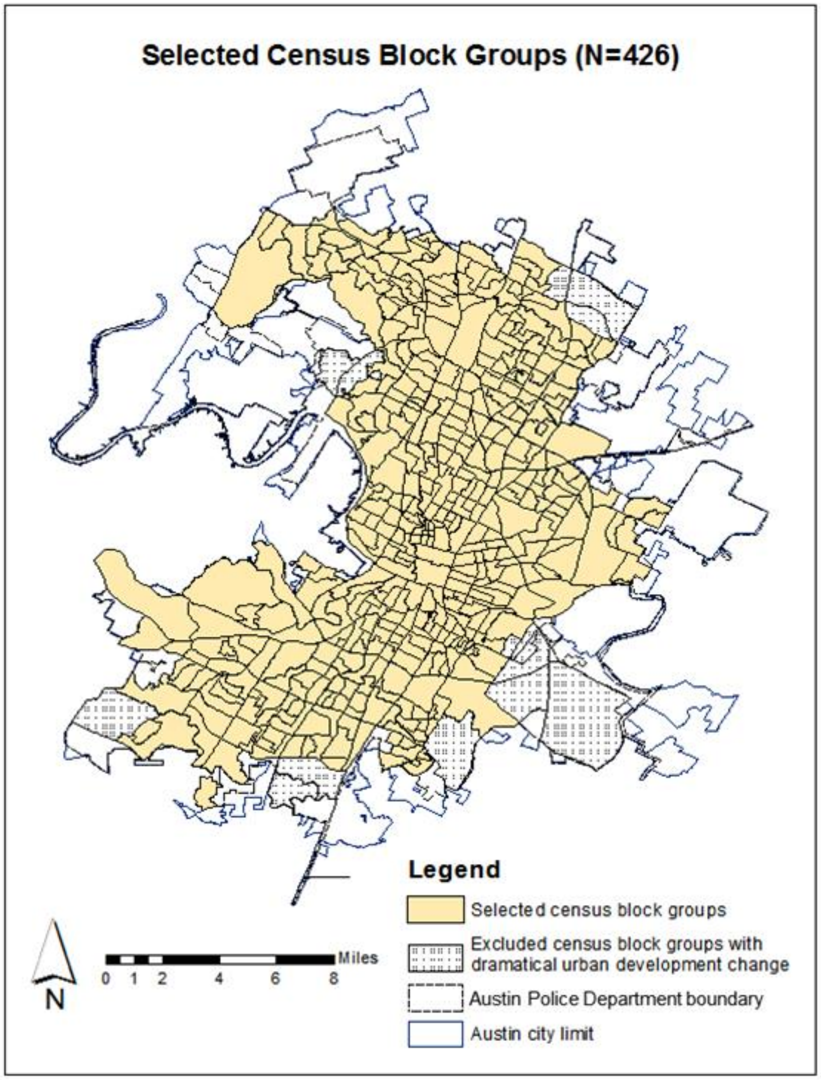


Figure 8
Selected Census Block Groups in Austin

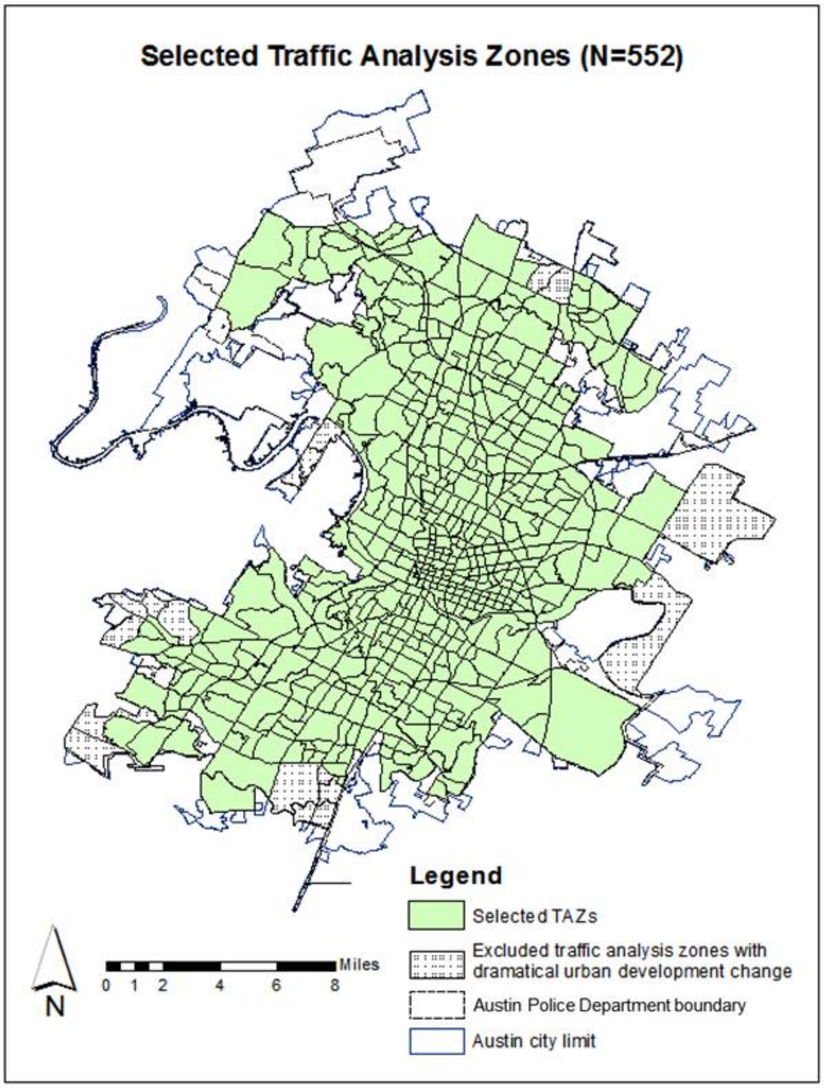


Figure 9
Selected Traffic Analysis Zones in Austin

4.2.2 Units of Analysis

Because this study focuses on the influence of neighborhood-level built environments on traffic safety, ideally the unit of analysis should represent the neighborhood scale most relevant to traffic crashes. However, there is no consistent definition of the "neighborhood scale" in previous studies. Three types of units have been commonly used in traffic safety studies, including census tracts (Delmelle et al., 2012; Ha & Thill, 2011; LaScala et al., 2000; Loukaitou-Sideris et al., 2007; Ukkusuri et al., 2012; Wier et al., 2009), census block groups (Dumbaugh & Li, 2011; Dumbaugh & Rae, 2009), and traffic analysis zones (de Guevara et al., 2004; Hadayeghi et al., 2010). Although census block might also be a feasible unit of analysis, previous studies have never used this unit to explore traffic safety issues and some socio-demographic data do not available at this level, which raises the question about the validity of this unit. Therefore, this study selected census block groups as the most appropriate unit of analyses based on the following assessment of strengths and weaknesses of using different units.

First, census tracts were determined inappropriate because (1) it is necessary to have relatively homogeneous built environmental attributes within each spatial unit and census tracts are relatively large and therefore prone to greater internal variations of built environmental attributes (Dumbaugh & Rae, 2009) and (2) census tracts are relatively large and therefore lead to a relatively small sample size of 144 available for this study, limiting the statistical power for the multivariate analyses. Second, traffic analysis zones were also considered inappropriate because the socio-demographic information was not available for this unit and it would be necessary to use an area apportionment approach to split the population data from the census block or block group into the traffic analysis zone, which may lead to potentially serious measurement errors.

As a result, this section reported influences of built environments on traffic safety using census block groups (N=426) as the unit of analysis. Moreover, analyses were also conducted using census tracts and traffic analyses zones to compare the consistency of the results in these spatial units[1] and the corresponding results were reported in Appendix B: Results in census tracts and traffic analysis zones.

4.2.3 Variables, Data Sources, and Measurements

Dependent variables

Collision data were collected from the APD for nine years (2004 – 2012). These data provided the levels of injury severity (fatal, serious, minor, or no injury) and geographic locations of crashes (X, Y coordinates). Each collision location was geo-coded for spatial analyses in GIS. Because there were limited numbers of fatal and serious crashes in each year in the census block groups, this study aggregated nine years of crash data to calculate the total number of crashes for each level of injury severity (fatal, serious, minor, and no injury) as dependent variables. As shown in Table 4, a total of 337,104 crashes occurred between 2004 and 2012 in the study area. In terms of the injury severity, 0.41% of them were fatal injuries; 0.72% were serious injuries; 53.68%

[1] To deal with the Modifiable Areal Unit Problem (MAUP) issue, several studies have tried to explore scale and zoning effects by examining the analytic results across spatial units with different sizes and zone configurations (Fotheringham & Wong, 1991; Openshaw, 1984; Zhang & Kukadia, 2005). However, there is no consensus on the optimal unit recommended for traffic safety studies. If the results from different scales and zones are relatively stable, there is a greater level of confidence in the interpretation of the findings.

were minor injuries; and 45.19% had no injuries. Minor and no injury crashes were the two most dominant types of injury severity.

Table 4
The Numbers and Percentages of Crashes with Different Levels of Injury Severity between 2004 and 2012 within the Austin Police Department Boundary, TX[a]

	Fatal injury[b]	Serious injury[c]	Minor injury[d]	No injury[e]
2004	64	72	6,074	2,496
2005	174	355	23,364	13,005
2006	170	310	24,039	20,035
2007	182	322	24,589	21,443
2008	146	276	21,405	21,025
2009	164	274	19,791	19,501
2010	133	267	19,615	18,227
2011	146	305	19,499	17,315
2012	220	231	22,583	19,287
Total	1,399	2,412	180,959	152,334
Percentage (%)	0.41%	0.72%	53.68%	45.19%

[a] Data source: 2004-2012 Austin Police Department (APD)
[b] Fatal injury: an injury that results in death;
[c] Serious injury: any injury, other than a fatal injury, that prevents the injured person from walking, driving, or normally continuing the activities the person was capable of performing before the injury occurred;
[d] Minor injury: any injury reported or claimed that is not a fatal injury, incapacitating injury, or non-incapacitating evident injury and includes claim of injuries not evident;
[e] No injury: no injury/property damage only.

In terms of the measurement of crashes, previous studies have primarily used two approaches: crash rate (Clifton & Kreamer-Fults, 2007; LaScala et al., 2000; LaScala et al., 2004; LaScala et al., 2001) and crash count (Abdel-Aty et al., 2007; Dumbaugh & Rae, 2009; Dumbaugh et al., 2011; Marshall & Garrick, 2011; Miranda-Moreno et al., 2011; Ukkusuri et al., 2012; Wier et al., 2009). The crash rate measurement would be generally more preferable because the crash count measure could not control the influence of the area of the spatial unit, as larger areas will naturally involve more crashes than smaller areas.

This study calculated the crash rates (the number of crashes / area of the spatial unit and the number of crashes / mile of street in the spatial unit) and the crash counts in the spatial unit. The two crash rates (the number of crashes / area of the spatial unit and the number of crashes / mile of street in the spatial unit) were not normally distributed even after the log-transformation (see Appendix C: Descriptive statistics of crash variables for Aim 1-1). Meanwhile, the crash count measure has been identified as an efficient approach to deal with non-normalized data and extensively applied in traffic safety research (de Guevara et al., 2004; Dumbaugh & Rae, 2009; I. Kim et al., 2006; Marshall & Garrick, 2011; Ukkusuri et al., 2012), this study used the crash count in the spatial unit as the dependent variable.

Table 5 presents descriptive statistics of crash counts (2004 – 2012) in census block groups. The variance was much higher than the mean for all crash variables. The number of spatial units with zero count of crashes was high for fatal and serious injuries: 43.6% of the census block groups had no fatal injury crashes, and 22.7% of the census block groups had no serious injury crashes. For minor and no injury crashes, the percentages of census block groups having zero crashes were both 1.8%.

Table 5
Descriptive Statistics of Crash Count (2004–2012) in Census Block Groups[a]

		Total crash	Fatal injury[c]	Serious injury[d]	Minor injury[e]	None injury[f]
Census block group (N= 426)	Mean	1017.74	3.93	7.23	565.04	455.78
	Variance	1107253.41	30.56	90.12	328231.02	255913.81
	S.D.[b]	1052.26	5.53	9.49	572.91	505.88
	Minimum	25	0	0	0	0
	Maximum	12677	31	93	5728	6827
	% with zero crash	0%	43.6%	22.7%	1.8%	1.8%

[a] Data source: 2004-2012 Austin Police Department (APD)
[b] S.D.: Standard deviation
[c] Fatal injury: an injury that results in death;
[d] Serious injury: any injury, other than a fatal injury, that prevents the injured person from walking, driving, or normally continuing the activities the person was capable of performing before the injury occurred;
[e] Minor injury: any injury reported or claimed that is not a fatal injury, incapacitating injury, or non-incapacitating evident injury and includes claim of injuries not evident;
[f] No injury: no injury/property damage only.

The author also examined whether the crash counts were over-dispersed (Table 6). The null hypothesis of the test for the negative binomial distribution is that the crash count has no over-dispersion problem. The results indicated that the null hypothesis was rejected for all crash variables. In other words, all crash count variables were over-dispersed.

Table 6
Tests for the Negative Binomial Distribution in Census Block Groups[a]

		Total crash	Fatal injury[b]	Serious injury[c]	Minor injury[d]	None injury[e]
Test of a negative binomial distribution (H_0:No over-dispersed issue)						
Census block group (N= 426)	Ratio of variance to mean	1087.95	7.78	12.46	580.90	561.49
	alpha	0.77	2.55	1.45	0.82	0.75
	Likelihood-ratio test of alpha	3300.05	1621.09	2580.60	1804.87	1541.24
	p-value	<0.001	<0.001	<0.001	<0.001	<0.001

[a] Data source: 2004-2012 Austin Police Department (APD)
[b] Fatal injury: an injury that results in death;
[c] Serious injury: any injury, other than a fatal injury, that prevents the injured person from walking, driving, or normally continuing the activities the person was capable of performing before the injury occurred;
[d] Minor injury: any injury reported or claimed that is not a fatal injury, incapacitating injury, or non-incapacitating evident injury and includes claim of injuries not evident;
[e] No injury: no injury/property damage only.

Independent variables

Table 7 presents selected independent variables, their measurement methods, data sources, time periods, and units of measurement. The selection of independent variables was based on four conceptual domains – risk exposures, socio-demographic characteristics, travel behaviors, and built environments – from the proposed conceptual framework (see Figure 5 in Section 3).

The risk exposure domain was captured by vehicle miles traveled during the nine study years in each census block group and the area of each census block group. Socio-demographic characteristics included total population, population aged 18 years and younger, non-white population, population with the education level less than high school, male population, and population with income below the poverty line. In terms of travel behaviors, because the mode share data for all travel purposes were not available, this study used proxy measures available from the Census data – the numbers of workers commuting to work by walking, biking, and transit.

For built environments, five sub-domains – non-motorized infrastructure, street connectivity, transit service, busy road, and land use type – were examined. Measures for non-motorized infrastructure included total miles of sidewalks and bike lanes in each census block group, and measurements for street connectivity were taken for three-leg and four-or-more-leg intersections separately because previous studies showed that three-leg and four-or-more-leg intersections had different effects on traffic safety (Dumbaugh & Li, 2011). The number of transit stops was used to represent the availability of transit service, and total miles of highways/freeways and arterial roads in each census block group were used to capture information about the prevalence of busy and high-speed roads. With regard to land use types, this study included the counts for residential, commercial, office, industrial, park, and school parcels in each census block group.

Table 7
Study Variables and Their Measurements, Data Sources, Time Periods, and Units of Measurement

Variable	Variable measurement in this study	Raw data		
		Data source	Time of data	Spatial unit of measurement
Dependent variables				
Total crash	Number of total collisions (2004-2012)	Austin Police Department	2004-2012	Point
Fatal-injury crash	Number of collisions with fatality (2004-2012)			
Serious-injury crash	Number of collisions with serious injury (2004-2012)			
Minor-injury crash	Number of collisions with minor injury (2004-2012)			
No-injury crash	Number of collisions with no injury (2004-2012)			
Control variables				
Risk exposure				
Traffic volume (unit: million miles)	Vehicle miles traveled during nine years / 1 million	TxDOT, City of Austin	2006	Point
Area of the spatial unit (unit: hundred acres)	Area of each census block group / 100	U.S. Census Bureau	2010	Census block group
Socio-demographic characteristics				
Total population (thousand)	Total population / 1000	U.S. Census Bureau	2010	Census block group
Population aged under 18 (thousand)	Total population under age 18 / 1000			
Non-white population (thousand)	Total non-white population / 1000			
Population less than high school (thousand)	Total population with education level less than high school / 1000			
Male population (thousand)	Total male population / 1000			
Household below the poverty line (thousand)	Total population below the poverty line / 1000			
Travel behaviors				
Workers commuting by walking (#) (thousand)	Number of workers commuting to work by walking / 1000	U.S. Census Bureau	2010	Census block group
Workers commuting by public transit (#) (thousand)	Number of workers commuting to work by public transit / 1000			
Workers commuting by biking (#) (thousand)	Number of workers commuting to work by biking / 1000			
Independent variables				
Built environments				
Non-motorized infrastructure				
Sidewalk	Total miles of sidewalks	City of Austin	2009	Line
Bike lane	Total miles of bike lanes			
Street connectivity				
Three-leg street intersection	Number of three-leg intersections	City of Austin	2011	Point
Four-or-more-leg street intersection	Number of four-or-more-leg intersections			
Transit service				
Transit stop	Number of transit stops	Capital Metro - Austin Public Transit	2010	Point

Table 7 Continued

Variable	Variable measurement in this study	Raw data		
		Data source	**Time of data**	**Spatial unit of measurement**
Busy road				
Highway/freeway Arterial road	Total miles of highways and freeways Total miles of arterial roads	City of Austin	2011	Line
Land use type				
Residential use Commercial use Office use Industrial use School Park	Total number of residential parcels Total number of commercial parcels Total number of office parcels Total number of industrial parcels Total number of school parcels Total number of park parcels	City of Austin	2010	Parcel

4.2.4 Data Analysis

All point, line, and polygon data were aggregated into the corresponding census block group. This study used both global and local models in order to compare their performances in exploring built environment–traffic safety relationships.

In order to select appropriate global and local models, this study first examined descriptive statistics of dependent and independent variables to understand their distributions. The results showed that crash count was over-dispersed (i.e., the variance was twice greater than the mean).

A related problem for the model selection is the spatial autocorrelation issue. The individual spatial unit could not to be considered independent because the characteristics of the spatial unit may be influenced by adjacent areas (Fotheringham, Brunsdon, & Charlton, 2002). Without considering this problem, the models might violate the assumption that each observation is independent (Anselin, 1988; Cliff & Ord, 1973). For global models, negative binomial regression models were selected for this analysis due to the over-dispersed crash count data. This was because that negative binomial models have been identified as an efficient approach to model over-dispersed count data (Long & Freese, 2006) and have been extensively applied in traffic safety research (de Guevara et al., 2004; Dumbaugh & Rae, 2009; I. Kim et al., 2006; Marshall & Garrick, 2011; Ukkusuri et al., 2012). However, no study using negative binomial models has addressed the issue of spatial autocorrelation because negative binomial models could not address the spatial autocorrelation. In this study, all global models were performed using Stata 12.0.

In terms of local models, this study used Geographically Weighted Poisson Regressions (GWPRs) to test spatial variations in the associations between crashes and related factors. GWPRs consider spatial autocorrelation by including the relative locations in intercept estimations through spatial weight matrixes[2] and consider spatial heterogeneity by multiplying coordinates of each regression point with each independent variable (Fotheringham et al., 2002). More specifically, the relationships between dependent variables and each independent variable were calculated for each census block groups across the city of Austin, TX. GWPRs estimate spatially varying relationships by getting varying local estimates over geographic spaces. Thus, the formula is:

$$\ln(A) = \ln(\beta_0(\mu_i)) + \sum_k \beta_k(\mu_i) x_{ik} + \varepsilon_i \qquad (7)$$

[2] Spatial regressions (spatial lag and spatial error models) also use spatial weight matrixes to account relationships between spatial objects by relative locations to consider spatial autocorrelation issue. Moreover, several studies on traffic safety have demonstrated the effectiveness of using spatial weight matrixes to address spatial autocorrelation (Flahaut, 2004; LaScala et al., 2000; LaScala et al., 2001).

where $\ln(A)$ is the natural log of crash frequency in each spatial unit; the (μ_i) denotes the coordinates of *i* point in space. $\beta_k(\mu_i)$ is a function of μ_i indicating the coordinates of the i^{th} point, which allows the measure to be a continuous surface and accounts for the spatial variability of the surface (Fotheringham et al., 2002). Using this approach, the author was able to obtain parameter estimates, standard errors, and some diagnostic statistics for every regression point.

In terms of the kernel type, this study chose "Adaptive" (bi-square) to specify the bandwidth used to observe the same number of data points in the local sample, which could make the standard error from each model to be comparable. In doing this, the bandwidth was determined by AIC minimization (Fotheringham et al., 2002).

To compare the performance of global models and local models, this study used the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) as the indicators. The lower the AIC and BIC are, the better is the model. The local regressions were estimated using the "GWRx3.0" package.

In terms of the modeling process, several steps were used to generate parsimonious models (Figure 10). First, bivariate analyses were used to test the relationship between all crash variables and each variable from the risk exposure, socio-demographic characteristic, and travel behavior domains. Those that were significant at the 95% level in the bivariate analyses were entered together into the *original base model* for the analysis. Second, those not significant at the 95% level in the original base model were then excluded to generate a *refined based model*. Then base multivariate models were generated for total crashes and crashes with different levels of injury severity by including control variables that had a significant bivariate correlation with at least one of the dependent variables. This step allowed models for different dependent variables (total crashes and crashes with different levels of injury severity) to have the same set of control variables, and thereby facilitated comparisons of built environmental correlates across different models. Those control variables that did not have significant bivariate correlations with any of the dependent variables were excluded. One exception was the area of each census block group, which was included in the base model regardless of its significance. This decision was made because many variables in this study were captured using count measures instead of normalized measures such as density. Therefore, the inclusion of the area measure was necessary in order to control the influence of the varying sizes of spatial units. Third, built environmental variables were individually added one by one to the *refined base model*. All significant built environmental variables in the one-by-one test were entered together into the *original final model*. Built environments that were insignificant in the original final model were excluded to generate *refined final models*. Correlation tests and variance inflation factor (VIF) were also used to detect the multicollinearity issue. This study first ran the correlation test among all control and independent variables. For those variables that were significantly correlated with each other (x1 and x2) at the 95% level, this study ran a model with both x1 and x2 and a model with just x1 or x2 to determine which variable to omit. Moreover, this study excluded those control and independent variables with the VIF greater than 10 (Aiken & West, 1991).

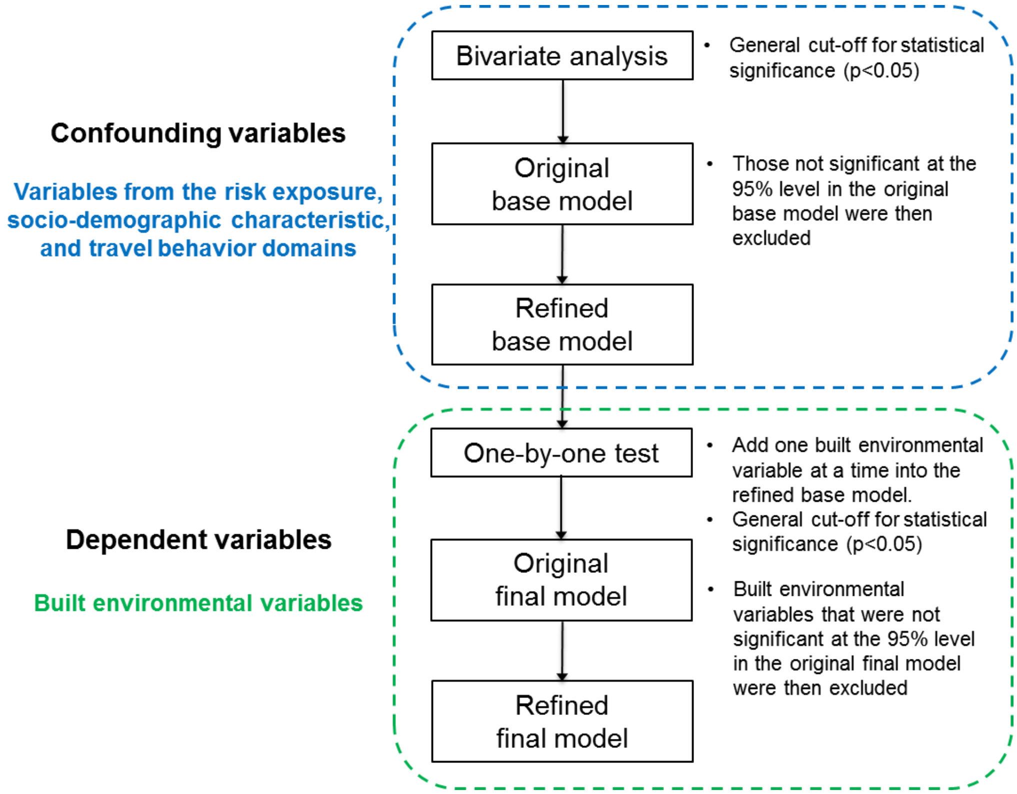


Figure 10
Modeling Process for This Study

4.3 RESULTS

4.3.1 Descriptive Statistics and Bivariate Analyses

Table 8 presents descriptive statistics of all variables and results of the bivariate analyses between each independent or control variable and each dependent variable. Each crash variable was significantly associated with the other four crash variables. Almost all independent variables had significant bivariate correlations with all dependent variables except the number of workers commuting to work by walking and biking, total miles of bike lanes, residential counts, and the number of parks.

Table 8
Descriptive Statistics and Bivariate Correlations between Each Independent or Control Variable and Dependent Variables (Unit of Analysis: Census Block Group)

	Descriptive statistics				Bivariate analysis (N=426)				
Variables					Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Mean	S.D.[a]	Min.[b]	Max.[c]	Coefficient (*p* value)				
Total crashes (#)	1017.74	1052.26	25.00	12677.00	–	0.65*** (<0.001)	0.75*** (<0.001)	0.99*** (<0.001)	0.99*** (<0.001)
Fatal injury (#)	3.75	5.31	0.00	31.00	0.65*** (<0.001)	–	0.57*** (<0.001)	0.66*** (<0.001)	0.62*** (<0.001)
Serious injury (#)	7.13	9.38	0.00	93.00	0.75*** (<0.001)	0.57*** (<0.001)	–	0.74*** (<0.001)	0.73*** (<0.001)
Minor injury (#)	556.65	554.82	4.00	5728.00	0.99*** (<0.001)	0.66*** (<0.001)	0.74*** (<0.001)	–	0.96*** (<0.001)
No injury (#)	450.20	498.08	13.00	6827.00	0.99*** (<0.001)	0.62*** (<0.001)	0.73*** (<0.001)	0.96*** (<0.001)	–
Control variables									
Risk exposures									
Traffic volume (#) (million)	254.91	305.41	22.50	3231.42	0.24*** (<0.001)	0.24*** (<0.001)	0.24*** (<0.001)	0.24*** (<0.001)	0.24*** (<0.001)
Area of the spatial unit (acres) (hundred)	181179.30	221145.10	790.00	1354017	0.07*** (<0.001)	0.09** (0.004)	0.09*** (<0.001)	0.07*** (<0.001)	0.08*** (<0.001)
Socio-demographic characteristics									
Total population (#)(thousand)	1490.80	942.92	209.71	8936.02	0.33*** (<0.001)	0.32** (0.001)	0.38*** (<0.001)	0.32*** (<0.001)	0.35*** (<0.001)
Population aged under 18 (#)(thousand)	333.33	291.12	12.00	2655.61	0.51** (0.001)	0.83** (0.005)	0.94*** (<0.001)	0.53** (0.001)	0.47** (0.001)
Non-white population (#) (thousand)	466.44	428.52	22.63	2839.31	0.72*** (<0.001)	0.93*** (<0.001)	0.99*** (<0.001)	0.74*** (<0.001)	0.68*** (<0.001)
Population less than high school (#)(thousand)	143.68	175.99	0.00	1153.96	1.42*** (<0.001)	2.35*** (<0.001)	2.05*** (<0.001)	1.53*** (<0.001)	1.27*** (<0.001)
Male population (#)(thousand)	757.46	493.38	95.08	4867.62	0.70*** (<0.001)	0.67*** (<0.001)	0.76*** (<0.001)	0.67*** (<0.001)	0.73*** (<0.001)
Household below the poverty line (#) (thousand)	269.30	277.58	2.56	2228.65	1.27*** (<0.001)	1.37*** (<0.001)	1.32*** (<0.001)	1.28*** (<0.001)	1.25*** (<0.001)
Travel behaviors									
Workers commuting by walking (#) (thousand)	21.21	39.81	0.00	455.94	7.04*** (<0.001)	4.04 (0.119)	5.66** (0.003)	6.38*** (<0.001)	7.82*** (<0.001)

[a] S.D.: Standard deviation
[b] Min.: Minimum
[c] Max.: Maximum
*: p<0.05, **: p<0.01, ***: p<0.001

Table 8 Continued

Variables	Descriptive statistics				Bivariate analysis (N=426)				
					Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Mean	S.D.[a]	Min.[b]	Max.[c]	Coefficient (p value)				
Workers commuting by public transit (#) (thousand)	43.03	52.30	0.00	496.25	6.26*** (<0.001)	4.99* (0.014)	4.42** (0.003)	6.52*** (<0.001)	5.98*** (<0.001)
Workers commuting by biking (#) (thousand)	12.37	21.13	0.00	130.73	11.50*** (<0.001)	5.58 (0.156)	6.11* (0.030)	11.04*** (<0.001)	12.18*** (<0.001)
Built environments									
Non-motorized infrastructure									
Sidewalks (miles)	9.07	5.74	0.85	41.33	–	–	–	–	–
Bike lanes (miles)	4.09	4.71	0.00	29.86	–	–	–	–	–
Street connectivity									
Three-leg street intersections (#)	22.34	13.77	0.00	83.00	–	–	–	–	–
Four-or more-leg street intersections (#)	8.47	9.14	0.00	123.00	–	–	–	–	–
Transit service									
Transit stops (#)	5.80	7.02	0.00	88.00	–	–	–	–	–
Busy roads									
Highway/freeway (miles)	0.88	1.53	0.00	11.41	–	–	–	–	–
Arterials(miles)	1.39	1.50	0.00	12.22	–	–	–	–	–
Land use types									
Residential use (#)	312.74	219.79	0.00	1491.00	–	–	–	–	–
Commercial use (#)	9.82	16.72	0.00	255.00	–	–	–	–	–
Office use (#)	5.80	18.82	0.00	300.00	–	–	–	–	–
Industrial use (#)	3.40	10.73	0.00	90.00	–	–	–	–	–
School (#)	3.01	4.57	0.00	38.00	–	–	–	–	–
Park (#)	6.00	11.49	0.00	165.00	–	–	–	–	–

[a] S.D.: Standard deviation
[b] Min.: Minimum
[c] Max.: Maximum
*: p<0.05, **: p<0.01, ***: p<0.001

4.3.2 Refined Base Models and One-by-One Tests

After including all significant control variables and the other four crash variables from bivariate tests to generate the original base models, this study checked the VIF to detect the multicollinearity issue. The VIFs of the following variables were higher than 10 and were deleted in the refined base models: total population in the fatal-injury and serious-injury models, the other four crash variables in all crash models, and the number of workers commuting to work by walking in the minor-injury and no-injury models.

Table 9 shows the result of refined base models and one-by-one tests. The refined base models showed that traffic volume and population with an education level less than high school were significantly related to all crash variables. Non-white population was a significant correlate with total, minor, and no injury crashes. The number of worker commuting to work by biking was associated with total, serious, minor, and no injury crashes.

In terms of the one-by-one tests, transit stops, highways/freeways, arterial roads, and commercial uses were significantly related to all crash variables. Total length of sidewalks and bike lanes were associated with fatal injury collisions. The number of three-leg intersections was related to total and minor injury crashes. The number of four-or-more-leg intersections was related to minor and no injury crashes. Residential use was associated with serious, minor, and no injury collisions. Office use was a significant correlate with minor and no injury crashes. School use was associated with total and no injury crashes.

Table 9
Results of Refined Base Models and One-by-One Tests between Independent Variable and Dependent Variable (Unit of Analysis: Census Block Group)

Variables	Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Coefficient (*p* value)				
Refined base model					
Traffic volume (#) (million)	0.21*** (<0.001)	0.20*** (<0.001)	0.19*** (<0.001)	0.21*** (<0.001)	0.22*** (<0.001)
Area of the spatial unit (acres) (hundred)	0.01 (0.968)	0.03 (0.353)	0.02 (0.209)	0.04 (0.795)	0.03 (0.840)
Non-white population (#)(thousand)	0.29* (0.031)	0.02 (0.951)	0.22 (0.305)	0.30* (0.041)	0.29* (0.028)
Population less than high school (#)(thousand)	0.97** (0.002)	2.35** (0.002)	1.51** (0.002)	1.07** (0.002)	0.82** (0.006)
Workers commuting by biking (#) (thousand)	10.86*** (<0.001)	6.57 (0.067)	5.43* (0.036)	10.83*** (<0.001)	10.98*** (<0.001)
One-by-one test					
Sidewalks (miles)	-0.01** (0.007)	-0.001 (0.957)	-0.02 (0.073)	-0.01 (0.196)	-0.01 (0.331)
Bike lanes (miles)	0.02* (0.016)	0.01 (0.749)	0.004 (0.698)	0.02 (0.067)	0.02 (0.060)
Three-leg street intersections (#)	-0.01* (0.016)	-0.002 (0.974)	-0.01 (0.075)	-0.01* (0.040)	-0.01 (0.049)
Four-or-more-leg street intersections (#)	0.01 (0.064)	0.01 (0.167)	0.006 (0.324)	0.01* (0.022)	0.01* (0.044)
Transit stops (#)	0.04* (0.047)	0.04* (0.034)	0.03** (0.002)	0.04*** (<0.001)	0.03*** (<0.001)
Highway/freeway (miles)	0.03*** (<0.001)	0.01*** (<0.001)	0.03* (0.032)	0.03*** (<0.001)	0.03*** (<0.001)
Arterials (miles)	0.19*** (<0.001)	0.17* (0.037)	0.14** (0.002)	0.20*** (<0.001)	0.17*** (<0.001)
Residential use (#)	-0.001 (0.074)	-0.0004 (0.236)	-0.001*** (<0.001)	-0.001*** (<0.001)	-0.001*** (<0.001)
Commercial use (#)	0.02*** (<0.001)	0.02* (0.021)	0.01* (0.018)	0.02*** (<0.001)	0.02*** (<0.001)
Office use (#)	0.01 (0.078)	0.003 (0.515)	0.01 (0.084)	0.01* (0.040)	0.01* (0.013)
Industrial use (#)	0.004 (0.166)	0.01 (0.229)	0.002 (0.663)	0.01 (0.170)	0.004 (0.185)
School (#)	0.03* (0.04)	0.02 (0.209)	0.02 (0.077)	0.03 (0.057)	0.02** (0.007)
Park (#)	0.002 (0.648)	0.004 (0.494)	0.003 (0.940)	0.002 (0.507)	0.001 (0.857)

*: p<0.05, **: p<0.01, ***: p<0.001

4.3.3 Final Negative Binomial Models

Table 10 presents the final negative binomial model results. Only traffic volume was significantly associated with all crash variables. Areas with more sidewalks were related to decreased number of total crashes. Areas with more transit stops were positively related to serious injury crashes, indicating that areas with each additional transit stop were associated with a 2.1% increase in serious injury crashes. Areas with more miles of highways/freeways (arterial roads) were significantly linked with all crash variables except serious injury crashes (fatal injury crashes).

Commercial use was a significant correlate with total, minor, and no injury crashes. Areas with each additional commercial parcel increased 1.8% of total crashes, 1.6% of minor injury crashes, and 1.4% of no injury crashes.

Table 10
Global Model Results: Final Negative Binomial Model Predicting Crashes with Different Levels of Injury Severity (Unit of Analysis: Census Block Group)

Variables	Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Coefficient (*p* value)				
Traffic volume (#) (million)	0.1149*** (<0.001)	0.1364* (0.011)	0.1153** (0.004)	0.1056*** (<0.001)	0.1087*** (<0.001)
Area of the spatial unit (acres) (hundred)	0.0033 (0.846)	0.0257 (0.391)	0.0215 (0.254)	0.0279 (0.067)	0.0184 (0.198)
Non-white population (#) (thousand)	0.2786 (0.057)	0.0804 (0.803)	0.1536 (0.482)	0.2529* (0.024)	0.2506 (0.074)
Population less than high school (#)(thousand)	0.5627* (0.045)	2.018* (0.017)	1.3094* (0.029)	0.6729 (0.078)	0.4507* (0.041)
Workers commuting by biking (#) (thousand)	6.4456* (0.027)	2.443 (0.513)	1.3298 (0.634)	5.9691** (0.001)	6.5667** (0.006)
Sidewalks (miles)	-0.0423* (0.021)				
Transit stops (#)			0.0208* (0.031)		
Highway/freeway (miles)	0.1137*** (<0.001)	0.0723* (0.031)		0.1031** (0.002)	0.1054*** (<0.001)
Arterials (miles)	0.1914*** (<0.001)		0.0933* (0.027)	0.1629*** (<0.001)	0.1404*** (<0.001)
Commercial use (#)	0.0181*** (<0.001)			0.0157*** (<0.001)	0.0144*** (<0.001)
AIC	6358.86	1905.97	2418.55	5895.20	5656.90
BIC	6407.51	1942.46	2459.09	5943.85	5705.55

*: p<0.05, **: p<0.01, ***: p<0.001

4.3.4 Final Local Models

GWPR models generated local coefficients, t-values, and p-values between all independent variables and each dependent variable for each census block group. This study presented the five-number summaries for the coefficients, including the minimum, lower quartile, median, upper quartile, and maximum values (from top to bottom in the Table 11).

Table 11 shows the results of the GWPR model (local model) for all crash variables in census block groups. For total crashes, the impacts of highways/freeways, arterial roads, and commercial counts were all positive across all census block groups. For the local coefficient for each spatial unit (Figures 11-13), some periphery areas had larger coefficients between highways/freeways and total crashes, between commercial uses and total crashes, and between arterial roads and total crashes than some downtown areas. For example, a one mile increase of highway/freeway was expected to lead to more increases in total crashes in these periphery areas than in downtown areas.

In terms of fatal injury crashes, the local coefficients of highways/freeways varied from negative to positive values in census block groups in the GWPR model. However, those negative coefficients were not significant at the 95% level (Figure 14). With regards to serious injury crashes, the local coefficients of the number of transit stops and total miles of arterial roads were all positive (Figures 15 and 16). The local coefficients between arterial roads and serious injury collisions were larger in some periphery areas than in some downtown areas.

For minor and no injury crashes (Figures 17-22), all significant variables had positive local coefficients in the GWPR model. Most periphery spatial units had larger local coefficients than some downtown areas, such as the relationships between commercial uses and minor injury crashes, between arterial roads and no injury crashes, and between commercial uses and no injury crashes.

Table 11
Local Model Results: GWPR Models Predicting Crashes with Different Levels of Injury Severity (Unit of Analysis: Census Block Group)

	GWPR model				
	Total crashes	Fatal injury	Serious injury	Minor injury	No injury
	Coefficient[a]				
Traffic volume (#) (million)	0.0012 0.0103 0.0212 0.0287 0.0351	0.0799 0.0912 0.1165 0.1396 0.1546	0.0834 0.1052 0.1211 0.1573 0.1802	0.0046 0.0259 0.0501 0.0874 0.1207	0.0021 0.0724 0.1386 0.1923 0.2831
Area of the spatial unit (acres) (hundred)	0.0002 0.0014 0.0026 0.0036 0.0044	0.0103 0.0214 0.0302 0.0397 0.0511	0.0024 0.0162 0.0275 0.0396 0.0506	0.0011 0.0173 0.0265 0.0344 0.0512	0.0044 0.0125 0.0203 0.0295 0.0386
Non-white population (#) (thousand)	0.0042 0.1065 0.2254 0.3062 0.3994	0.0502 0.0745 0.0862 0.0977 0.1124	0.1032 0.1363 0.1596 0.1703 0.1894	0.1009 0.2018 0.3034 0.4118 0.5061	0.1034 0.1612 0.2175 0.2688 0.3092
Population less than high school (#) (thousand)	0.3041 0.4287 0.5492 0.6205 0.7002	1.4224 1.7462 2.0688 2.3446 2.7031	1.1001 1.2158 1.3011 1.4015 1.5038	0.4821 0.5572 0.6892 0.7592 0.9002	0.1013 0.2046 0.3581 0.4405 0.5538
Workers commuting by biking (#) (thousand)	5.9122 6.1054 6.3398 6.4928 6.6704	1.5446 1.7836 2.1034 2.3677 2.5623	0.8477 1.0221 1.4132 1.7988 1.9546	4.0304 5.0013 5.8051 6.6567 7.1081	4.0307 5.0513 6.1419 7.2047 8.0171
Sidewalks (miles)	-0.0703 -0.0541 -0.0428 -0.0298 -0.0089				
Transit stops (#)			0.0072 0.0088 0.0124 0.0241 0.0915		
Highway/freeway (miles)	0.0015 0.0495 0.0842 0.1187 0.2415	-0.3051 -0.0119 0.0569 0.1230 0.3653		0.0141 0.0983 0.1241 0.1648 0.2815	0.0721 0.1013 0.1616 0.2004 0.5253
Arterials (miles)	0.0011 0.0024 0.1547 0.2104 0.3468		0.0263 0.1320 0.1782 0.2571 0.5966	0.0042 0.0215 0.0876 0.1582 0.2369	0.0217 0.1424 0.1986 0.2404 0.3836
Commercial use (#)	0.0024 0.0107 0.0199 0.0301 0.0583			0.0121 0.0207 0.0361 0.0511 0.0694	0.0027 0.0157 0.0227 0.0277 0.0547
AIC	3104.37	848.19	1175.04	1851.27	1396.01
BIC	3155.06	885.68	1206.28	1903.82	1445.66

[a] Coefficients are presented in the order of the minimum, the lower quartiles, the median quartiles, the upper quartiles, and the maximum values from top to bottom. All coefficients listed in the Table are siginificant at the 95% level.

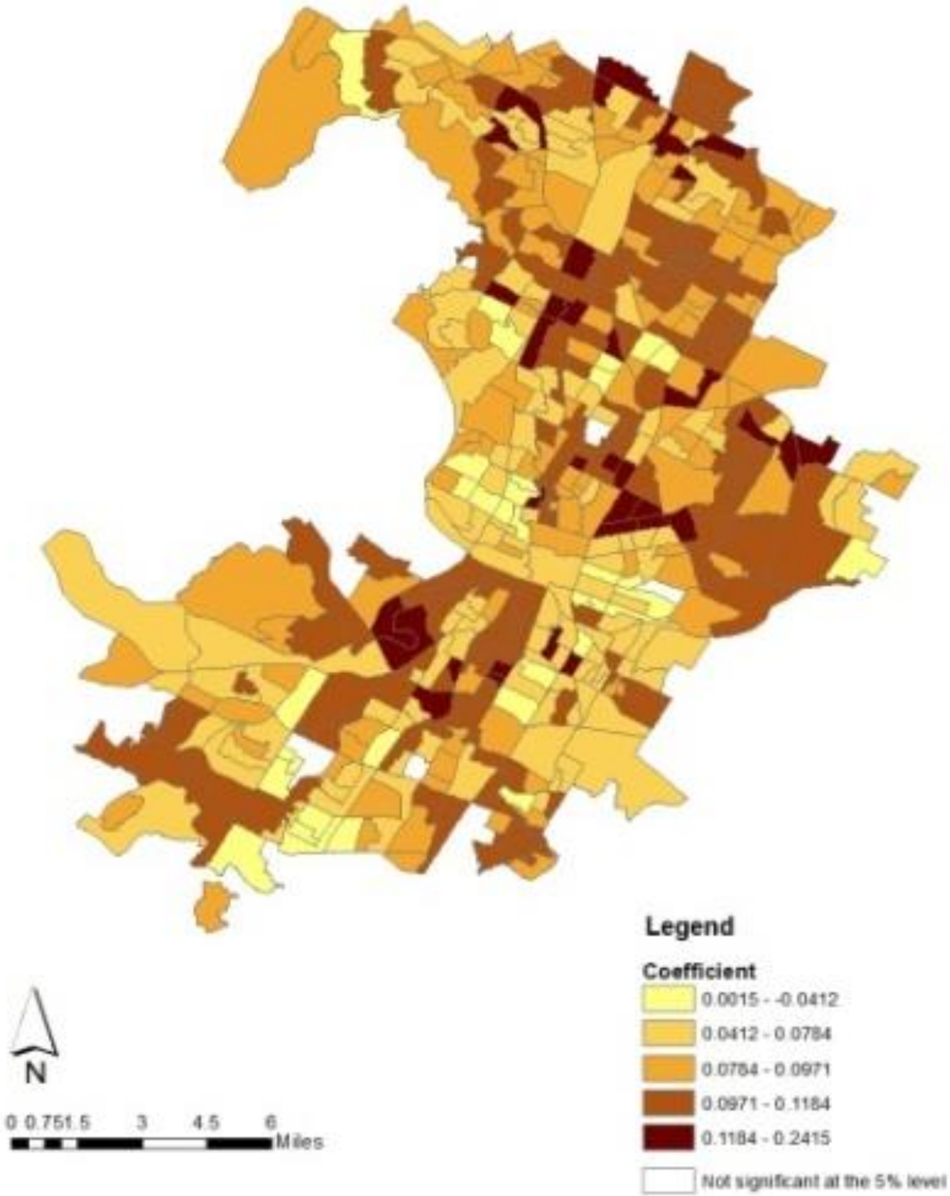


Figure 11
Coefficients between Highways/Freeways and Total Crashes in Census Block Groups

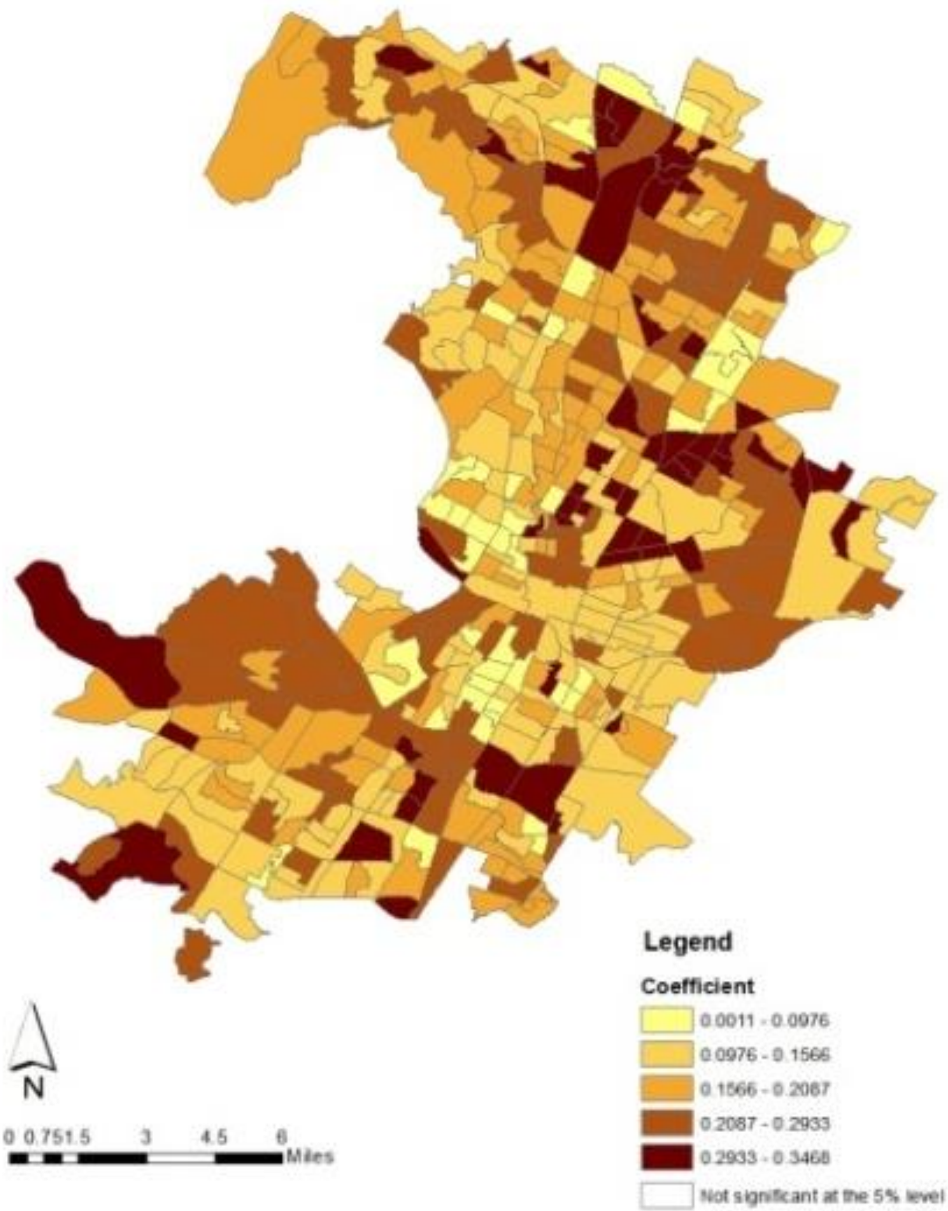


Figure 12
Coefficients between Arterial Roads and Total Crashes in Census Block Groups

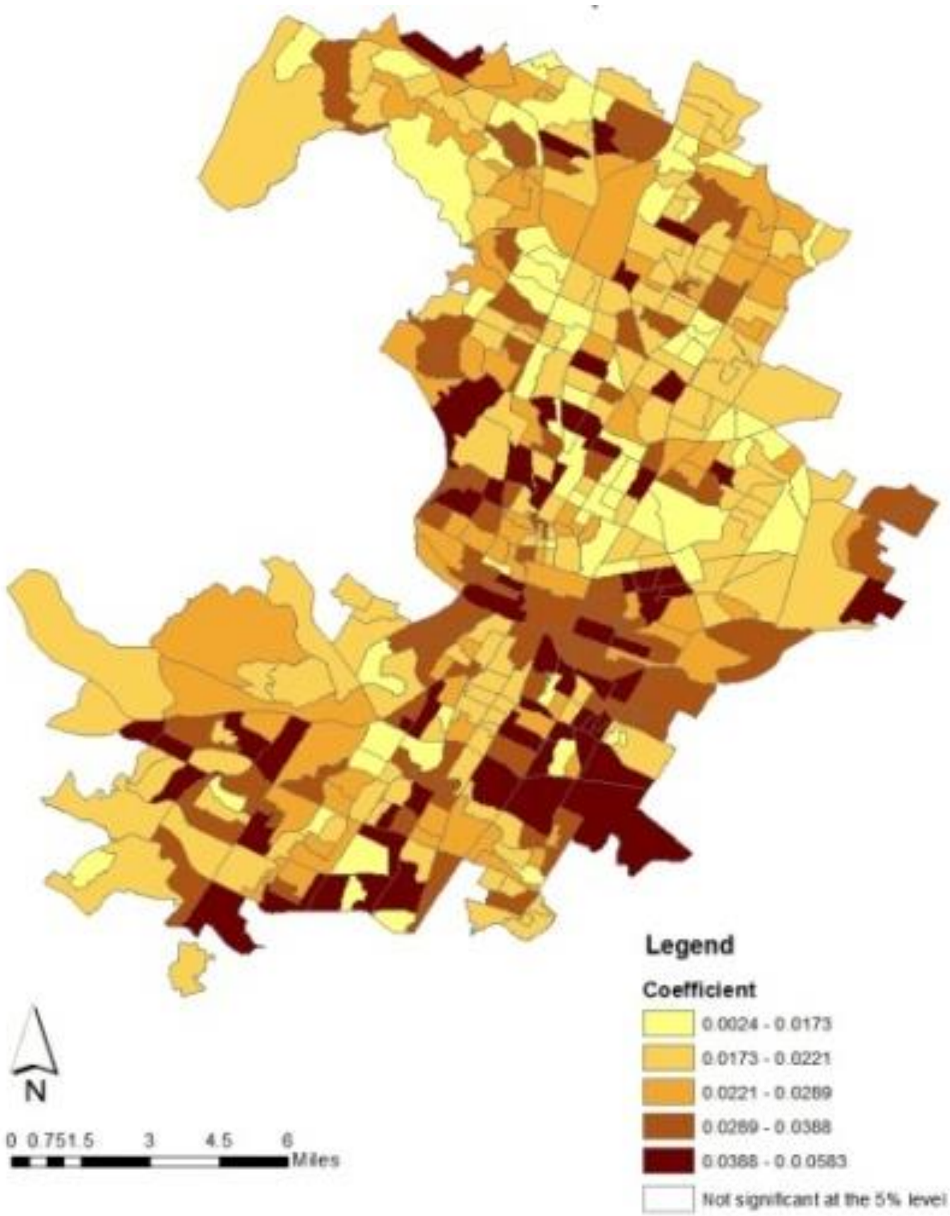


Figure 13
Coefficients between Commercial Uses and Total Crashes in Census Block Groups

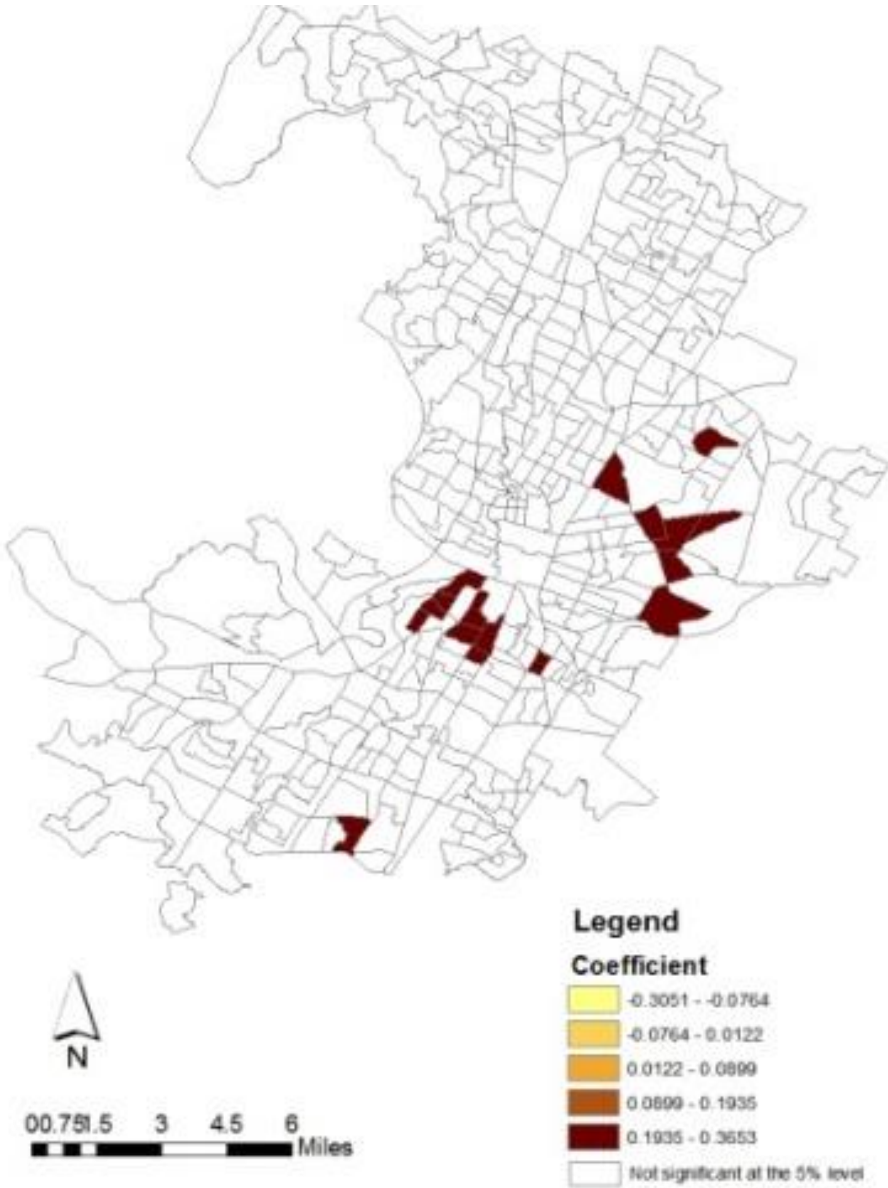


Figure 14
Coefficients between Highways/Freeways and Fatal Crashes in Census Block Groups

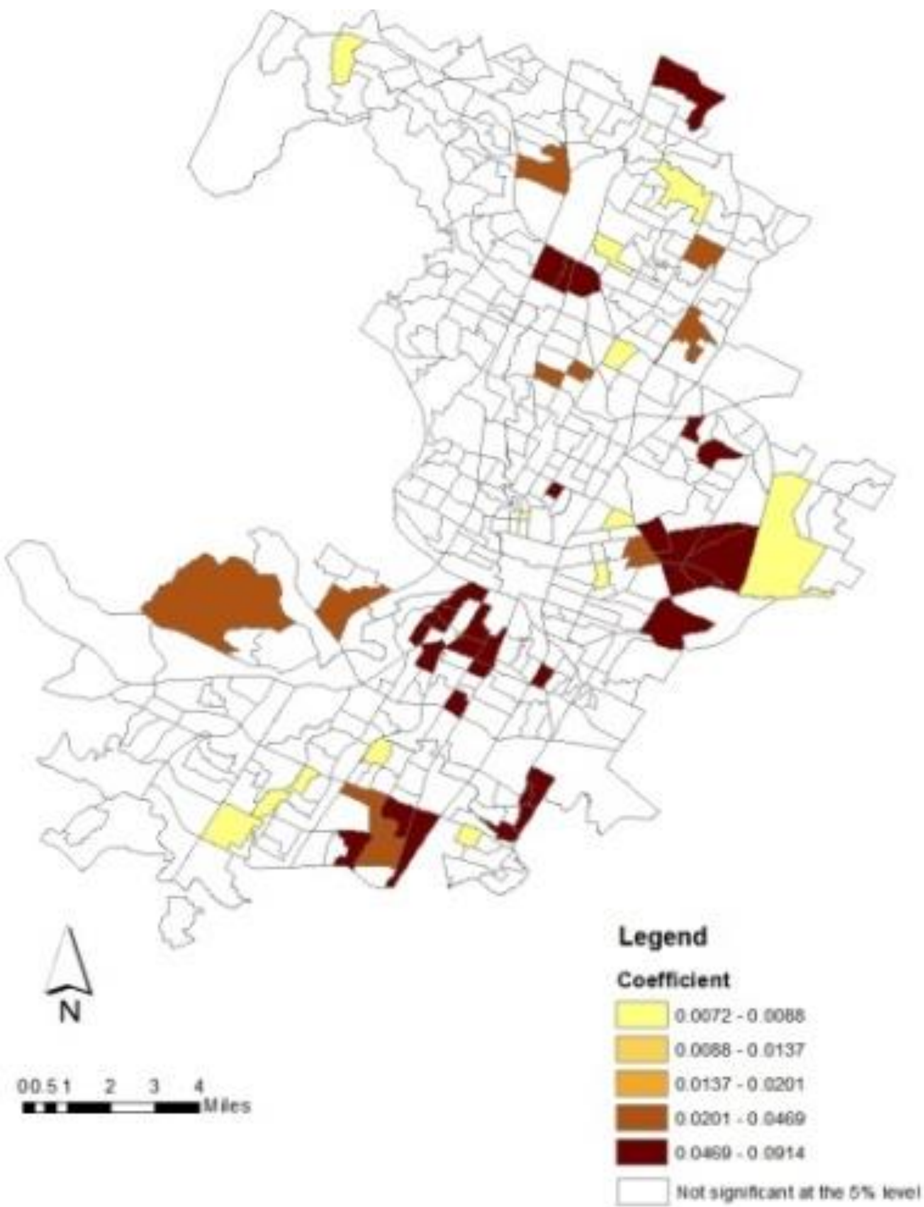


Figure 15
Coefficients between Transit Stops and Serious Crashes in Census Block Groups

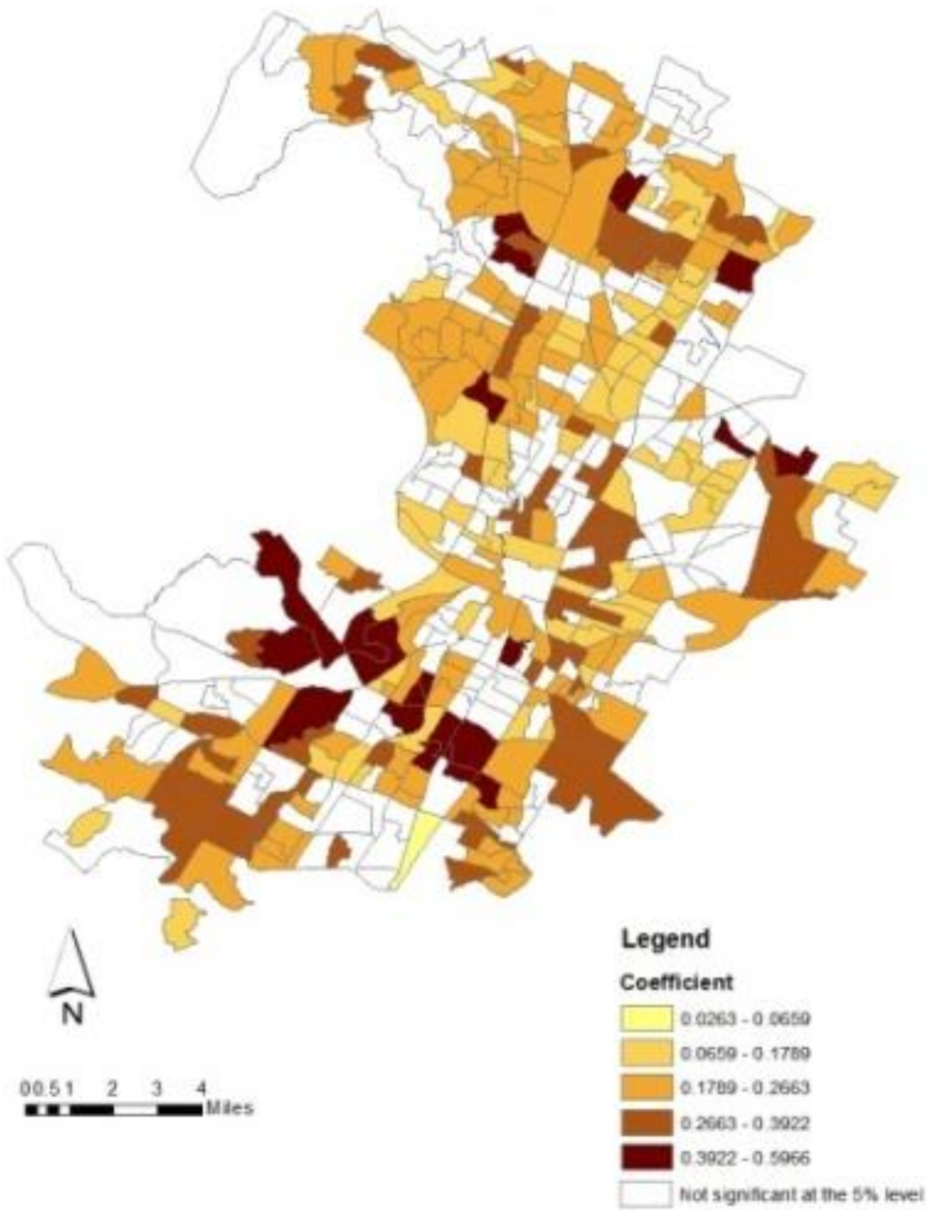


Figure 16
Coefficients between Arterial Roads and Serious Crashes in Census Block Groups

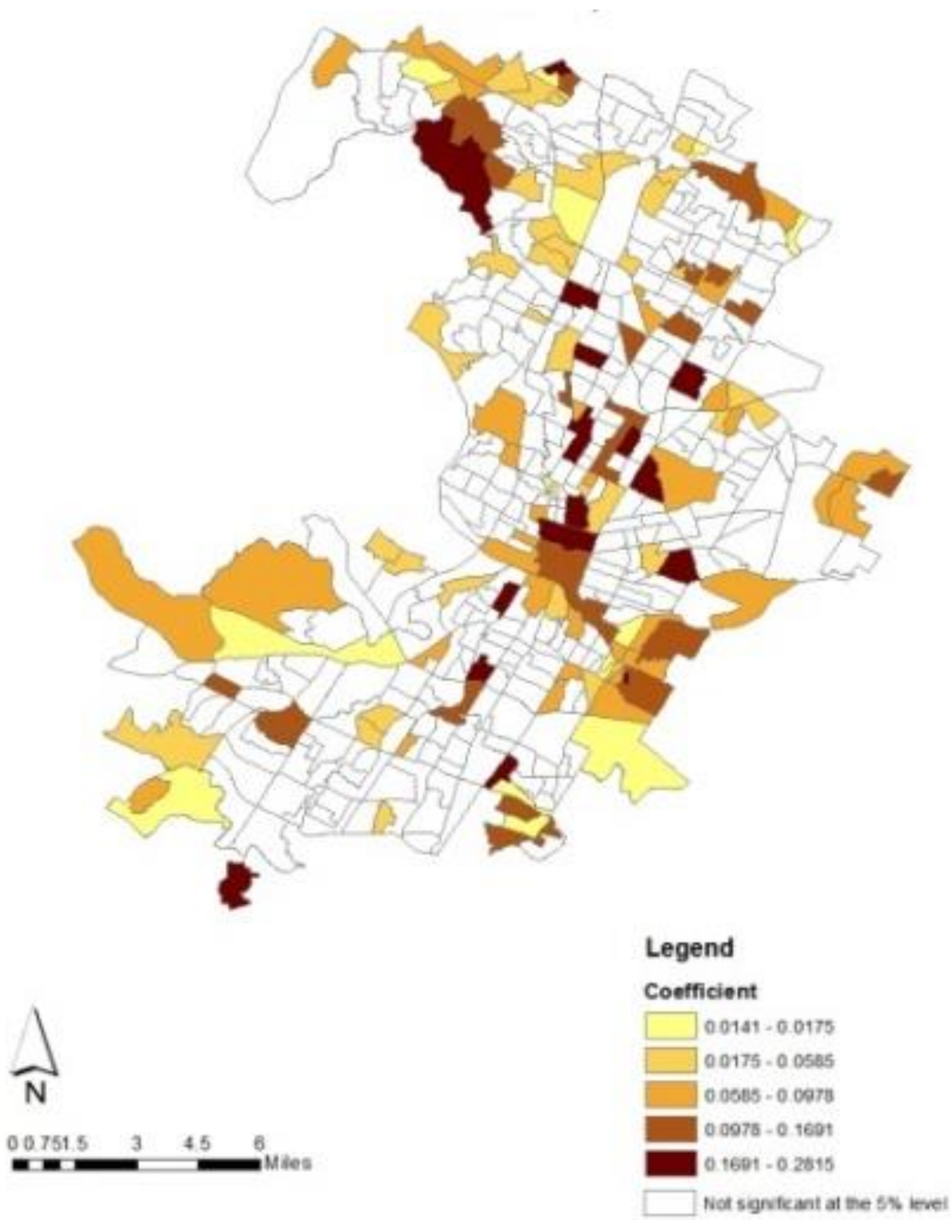


Figure 17
Coefficients between Highways/Freeways and Minor Injury Crashes in Census Block Groups

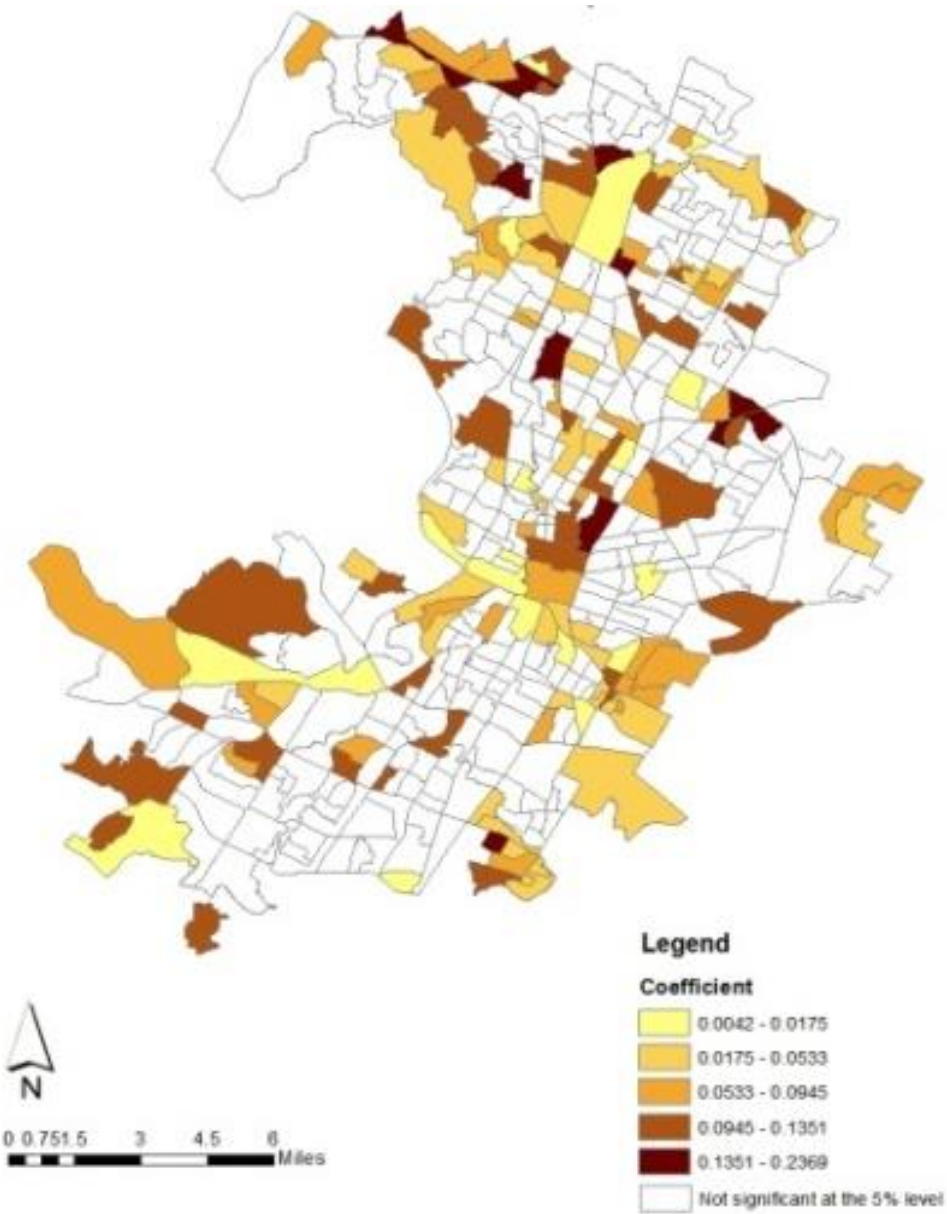


Figure 18
Coefficients between Arterial Roads and Minor Injury Crashes in Census Block Groups

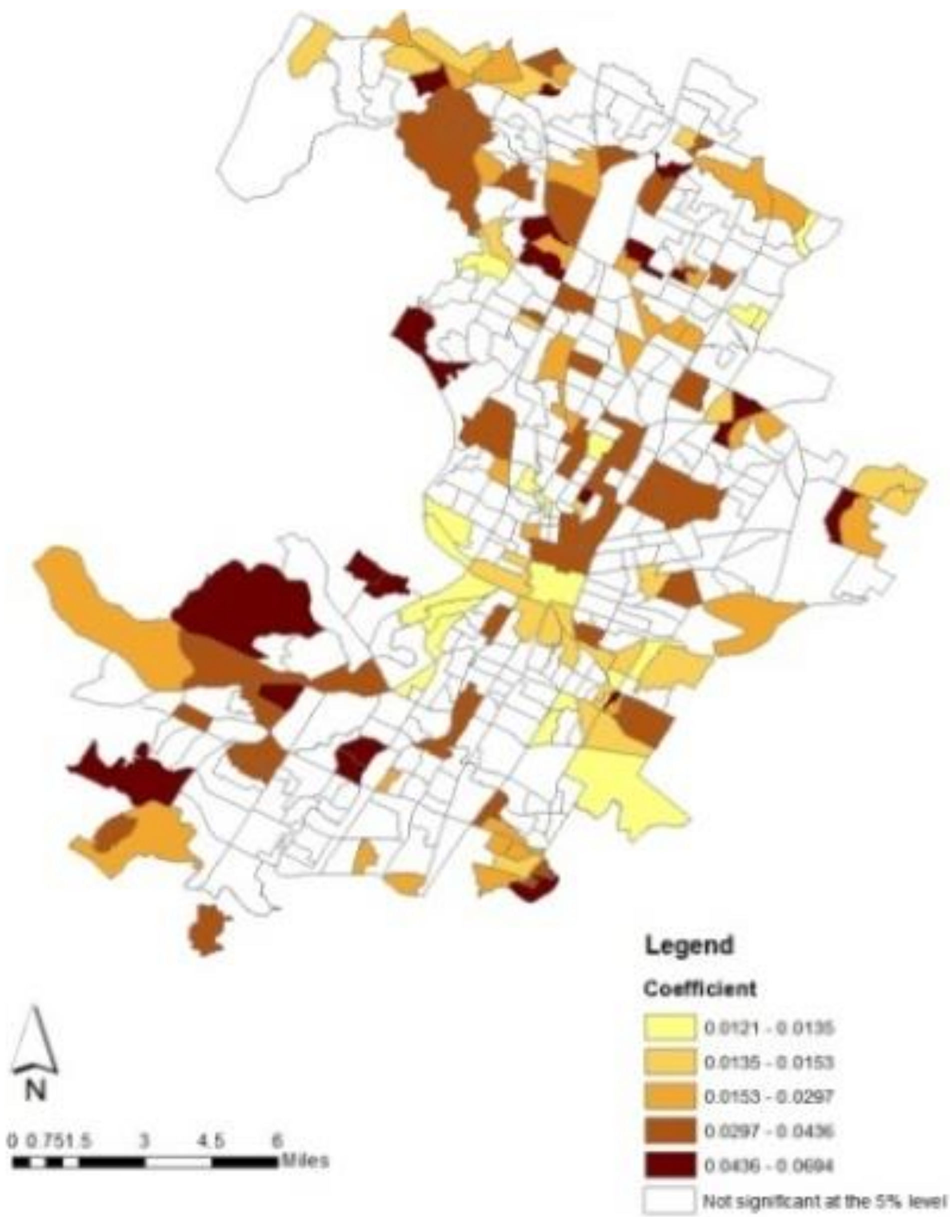


Figure 19
Coefficients between Commercial Uses and Minor Injury Crashes in Census Block Groups

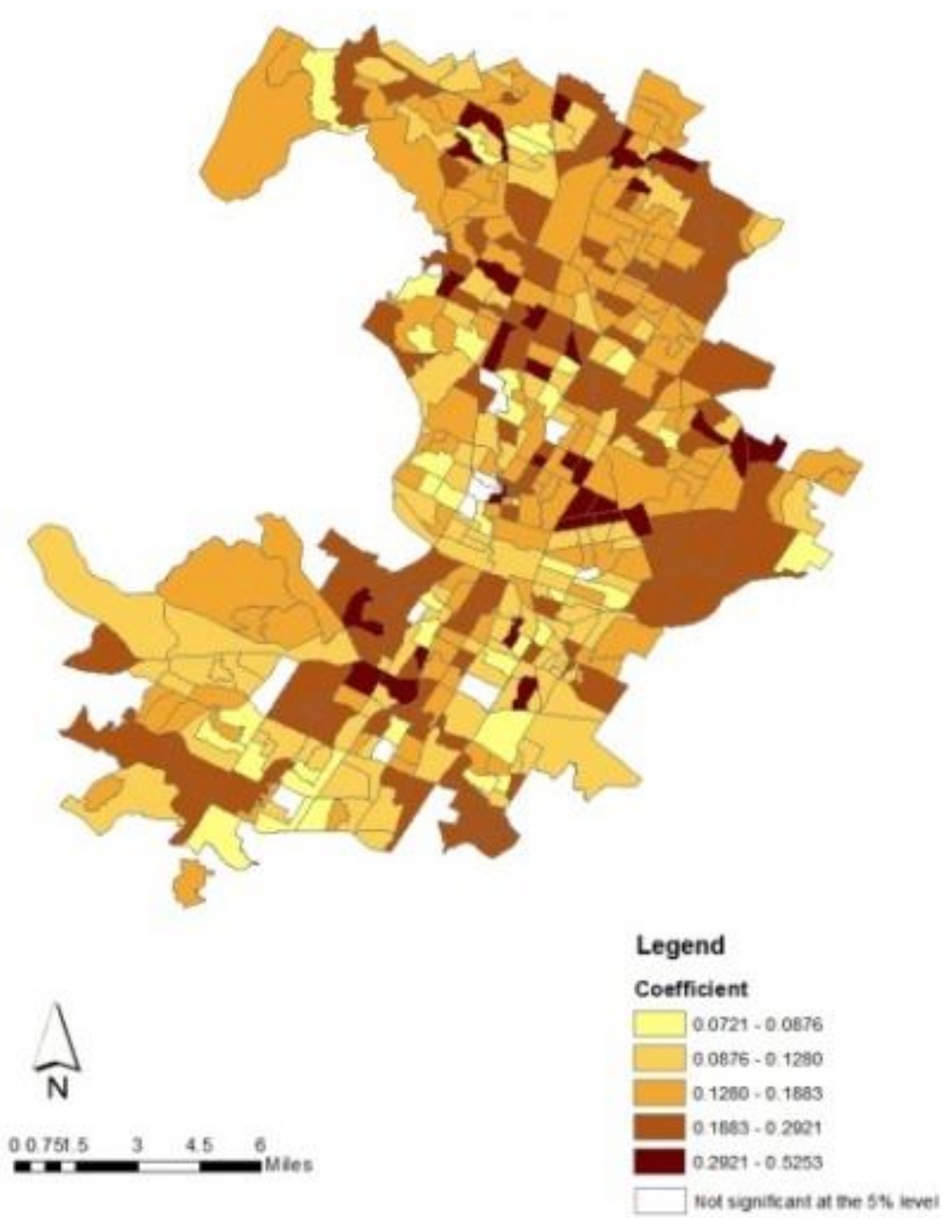


Figure 20
Coefficients between Highways/Freeways and No Injury Crashes in Census Block Groups

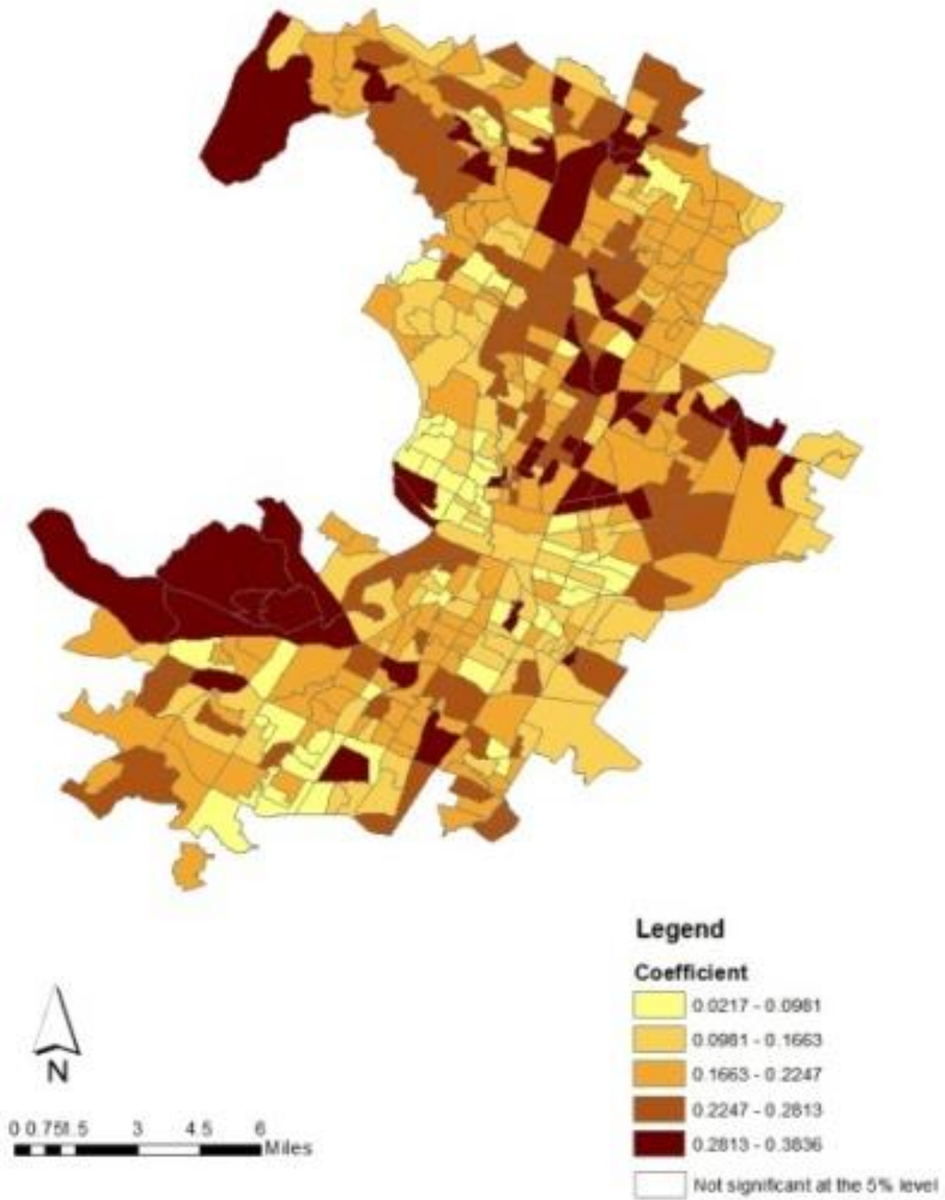


Figure 21
Coefficients between Arterial Roads and No Injury Crashes in Census Block Groups

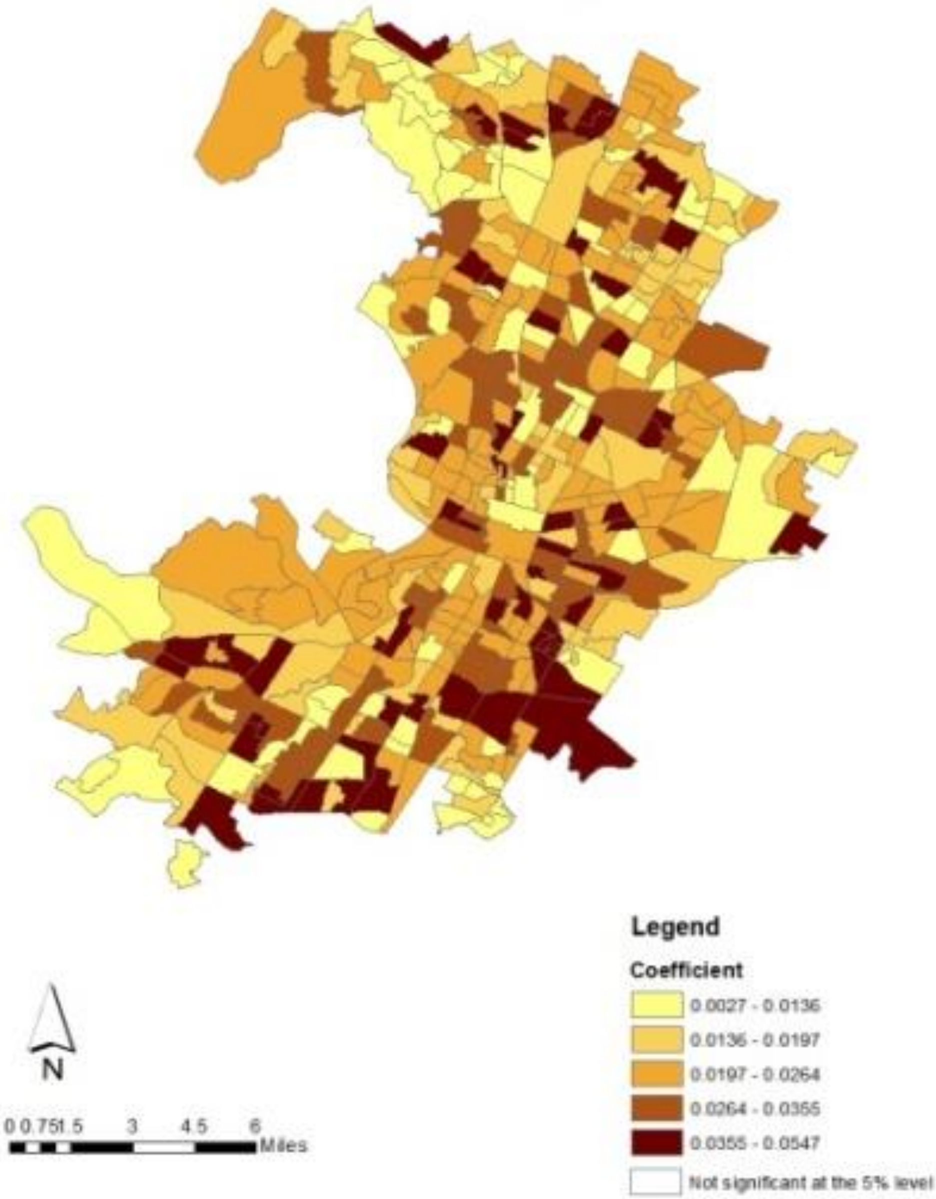


Figure 22
Coefficients between Commercial Uses and No Injury Crashes in Census Block Groups

From Tables 10 and 11, the AIC and BIC values in the GWPR models were all lower than those in the negative binomial models across all crashes in census block groups. Moreover, according to the likelihood-ratio test, all GWPR models had significantly ($p<0.05$) better performance than the negative binomial models across all crashes in census block groups, indicating improved performance of all GWPR models

4.4 DISCUSSION AND CONCLUSION

Traffic volume had consistently positive effects on all types of crashes across the three spatial units. This finding has been confirmed by previous studies (Dumbaugh & Rae, 2009) and can make it reasonable to conclude that the more traffic, the higher was the crash risk. Areas with more populations with an education level less than high school had more total crashes and more fatal, serious, and no injury crashes. Moreover, non-white populations were positively related to the number of minor injury crashes. This potential disparity issue was also found in previous studies (Graham & Glaister, 2003; Loukaitou-Sideris et al., 2007; Noland et al., 2013).

4.4.1 Local Variations between Built Environments and Traffic Safety

Various local coefficients in each spatial unit from local models implied that the degree of impact of built environments on traffic safety might differ across different spatial units in the study area. The associations could be strong (large absolute value of coefficient) in some areas and weak (small absolute value of coefficient) in others.

Highway/freeway

The results showed that areas with more highways/freeways had more total, fatal, minor, and no injury crashes. Although previous studies in New York, NY (Ukkusuri et al., 2012) and in San Antonio, TX (Dumbaugh & Rae, 2009) had consistent results, this study has added to traffic safety literature that highways/freeways had different degrees of influences on traffic safety in different spatial units. A one mile increase in highways/freeways was expected to lead to more increases in crashes in some periphery areas compared with some downtown areas. Although highways are designed for high operating travel speeds with wide and straight lanes, this high-speed design leads to traffic safety issues for almost all types of injury severity. It is possible that vehicles with high travel speeds on highways have to decelerate before they enter other types of roads (e.g., local roads). This speed difference causes traffic conflicts between vehicles traveling on highways and those on other low-speed roads, thus leading to more crashes.

In terms of local variation, the author examined whether highways were more likely to be designed to connect with low-speed roads (i.e., local roads) in some periphery areas with larger local coefficients than in some downtown areas with smaller local coefficients. The author categorized census block groups into four sub-groups based on the median values of local coefficients between highways/freeways and total crashes, highways/freeways and fatal injury crashes, highways/freeways and minor injury crashes, and highways/freeways and no injury crashes. The results showed that the percentages of highways/freeways that connected to local roads were all significantly higher in areas with larger local coefficients than those in areas with smaller local coefficients (Table 12). It indicated that areas with larger local coefficients might have more traffic conflicts between vehicles on highways and those on low-speed roads. Therefore, planners should re-examine street network systems in these areas and retrofit them into a hierarchical street pattern with more gradual decrease in travel speeds from highways.

Table 12
The Percentages of Highways/Freeways that Connected to Local Roads in Areas with Larger and Smaller Local Coefficients

	Spatial units with larger (≥ median) local coefficients	Areas with smaller (< median) local coefficients	t-test (*p*-value)
	Mean (%)	Mean (%)	
Local coefficient between highway/freeway and total crashes	55%	40%	2.14* (0.034)
Local coefficient between highway/freeway and fatal injury	58%	44%	1.99* (0.048)
Local coefficient between highway/freeway and minor injury	57%	42%	2.13* (0.035)
Local coefficient between highway/freeway and no injury	58%	44%	2.00* (0.047)

*: p<0.05, **: p<0.01, ***: p<0.001

Arterial road

Areas with more arterial roads also generated more total, serious, minor, and no injury crashes. Increased crash risk on arterial roads might be related to land use patterns along arterial roads. Perry's neighborhood unit concept suggested that traffic-generating uses (e.g., commercial and retail uses) were located along major roadways (e.g., arterial roads) in order to reduce through traffic within the neighborhood (Perry, 1929). This design may cause traffic conflicts between high-speed vehicles on arterial roads and low-speed automobiles on driveway leading to surrounding commercial uses. The author generated 100-feet buffers around arterial roads and local roads to understand the land use patterns around these roads, and the percentage of commercial use around arterial road (39%) was significantly higher than the percentage along local roads (14%). This means that arterial roads simultaneously serve the high-speed cut-through traffic and provide driveway access to surrounding commercial land uses. Multiple users (e.g., pedestrians, cyclists, drivers, etc.) interact and generate complex traffic conditions on arterial roads, which might lead to speed differences and potential conflicts, a situation that increases the crash risk (Dumbaugh & Li, 2011).

Transit stop

This study also showed a positive relationship between the number of transit stops and serious injury crashes. This result was consistent with findings from two previous studies, one in New York, NY (Ukkusuri et al., 2012) and the other in Montreal, Canada (Miranda-Moreno et al., 2011). This may be related to built environmental designs (road type and land use type) around transit stops (Figure 23). The author generated 0.25-mile buffers around transit stops in the study area and found that 60% of road types within these buffers were arterial roads. For those transit stops located in areas with larger local coefficients, the percentage of arterial roads (74%) was even higher. Although transit stops were located along arterial roads to provide great accessibility, the problem associated with this is the exposure of transit commuters to high speed traffic when pedestrians need to cross these arterial roads. Providing safe crosswalks or traffic calming devices (e.g., speed humps, speed tables, etc.) may be an effective approach to slow the through traffic and reduce the risk of serious injury crashes. Moreover, for the land use type within 0.25-mile buffers around transit stops, 61% of them were commercial uses, which might generate more pedestrian activities and attract more vehicle traffic around transit stops. Therefore, future studies should comprehensively consider built environmental designs around transit stops to promote traffic safety.

Figure 23
Built Environmental Designs around Transit Stops

Commercial use

Areas with more commercial uses experienced more total, minor, and no injury crashes. The result was consistent with previous studies in Baltimore, MD (Clifton & Kreamer-Fults, 2007), New York, NY (Ukkusuri et al., 2012), and Hawaii (I. Kim et al., 2006). One possible reason is that commercial uses lead to more traffic in the area, as implied by the significant correlation coefficient (0.259) between commercial uses and travel volume in this study, which increases the crash risk (Ukkusuri et al., 2012).

For the local variation, one parcel count increase in commercial uses was associated with a greater increase in the number of crashes in some periphery areas than in some downtown areas. The possible reason may be the different built environmental designs around commercial uses in different areas. Ossenbruggen, Pendharkar, and Ivan (2001) compared the crash performance (total crashes) of sites with urban and suburban characteristics in New Hampshire and found that sites with pedestrian-oriented roadside designs experienced fewer crashes than suburban roadways with automobile-oriented design. For example, big-box stores are more likely to feature auto-oriented designs that may be unsafe for pedestrians. A big-box store typically ranges from 20,000 to 26,000 square feet and is usually designed as a stand-alone building with a large parking lot (Evans-Cowley, 2006). The author checked the parcel sizes of commercial land uses in some periphery areas with larger local coefficients and in some downtown areas with smaller local coefficients. Results showed that periphery areas with larger coefficients had more (41%) large (>20,000 square feet) commercial parcels than those in downtown areas with smaller local coefficients (9%).

It is reasonable to expect that commercial uses in these periphery areas (areas with larger local coefficients) were more likely to be auto-oriented and be surrounded by more high-speed roads (e.g., arterial roads) (Figure 24), which might lead to more crashes than small-parcel commercial uses surrounded by low-speed roads (e.g., local roads) in some downtown areas.

Periphery Area
Auto-oriented designs (e.g., big box stores) and high-speed road design (e.g., arterial roads, highways)

Downtown Area
Pedestrian-oriented designs (e.g., landscape treatments) and low-speed road (e.g., local roads)

Figure 24
An Example of Different Commercial Designs in Periphery and Downtown Areas

Although the presence of commercial uses has been identified as a significant correlate for traffic safety, the specific design features (e.g., auto-oriented, pedestrian-oriented, etc.) of this land use may also play a crucial role. Future studies should examine the influence of commercial uses with different design features on traffic safety.

4.4.2 Limitations

Several limitations of this study need to be addressed. First, the GIS datasets have slight variations in their time frames due to their limited availability. However, these GIS data provide objective measurements for environmental variables and make it possible to directly translate study results into intervention strategies. Second, some information or data are not available for the analysis. For example, because the data for the numbers of people walking, biking, and taking public transit could not be found, this study used the proxy measures – the numbers of workers commuting to work by walking, biking, and taking public transit from the 2010 Census data. Third, this study only reported census block groups as the unit of analysis and cannot deal with the MAUP issue. Several studies have tried to explore scale and zoning effects by examining the analytic results across spatial units with different sizes and zone configurations (Fotheringham & Wong, 1991; Openshaw, 1984; Zhang & Kukadia, 2005). If the results from different scales and zones are relatively stable, there is a greater level of confidence in the interpretation of the findings. The results of using two different units of analysis – census tracts and traffic analysis zones – are given in Appendix B: Results in census tracts and traffic analysis zones. In general, the results in census tracts and traffic analysis zones are quietly consistent with census block groups. Fourth, caution is needed for generalizing study results. GWPRs serve as an effective tool for estimating non-stationary relationships between crashes and independent variables by producing local coefficients for each spatial unit in Austin. However, the results could not be spatially transferred and generalized to other areas. Different jurisdictions need to develop their own models to guide the safety planning. Last, this study's contribution in understanding the impacts of built environmental factors on crashes with different levels of injury severity is limited because all crash variables were highly correlated with each other and it is possible to model nearly the same dependent variable for each injury model.

4.4.3 Conclusion

Despite the above limitations in this study, the results of the non-stationary relationships between crashes and independent variables in each spatial unit indicated that a uniform policy may not be appropriate for the city of Austin, TX. The findings showed that it is necessary to develop tailored policies with regard to the characteristics of each area. Furthermore, crashes with different levels of injury severity were associated with different built environmental factors. The results could guide the traffic safety planning to provide a safe environment.

5. DISPARITY IN TRAFFIC SAFETY ACROSS NEIGHBORHOODS WITH DIFFERENT ECONOMIC STATUSES AND ETHNIC COMPOSITIONS

5.1 INTRODUCTION

To address the research gap mentioned in 2.5.2 “Disparity in Traffic Safety,” this study explored whether there was any disparity in crashes with different levels of injury severity across neighborhoods with different economic statuses and ethnic compositions. Moreover, this study also examined whether the built environment–traffic safety relationship differed in areas with different economic statuses and ethnic compositions

5.2 METHODS

5.2.1 Study Setting, Units of Analysis, and Variables and Measurements

Because this section also focuses on neighborhood environments, the study setting, units of analysis (census block groups), and study variables are the same as those used in Section 4. However, since the specific purpose of this study is to investigate disparity issues in crashes with different levels of injury severity, two variables – population below the poverty line[3] and non-white population – are selected to represent the neighborhoods’ economic statuses and ethnic compositions, respectively.

[3] The poverty thresholds were referred to the Census Bureau and the information was from the website: http://www.city-data.com/poverty/poverty-Austin-Texas.html.

5.2.2 Data Analysis

To explore the disparity issue in traffic safety, negative binomial models were used to predict crash counts with different levels of injury severity, with the population below the poverty line, the non-white population, and significant control and built environmental variables in the final negative binomial models estimated in Section 4.

To examine whether the relationships between built environments and crashes with different levels of injury severity differ by areas with high and low percentages of non-white populations and by areas with high and low percentages of populations below the poverty line, 426 census block groups were categorized into two sub-groups: high vs. low percentage of non-white population and high vs. low percentage of population below the poverty line. Several thresholds (mean, median, 25%, and 75%) were used to separate census block groups into the two sub-groups to test the robustness of the results. In total, twenty negative binomial models were generated. In general, the results in final negative binomial models were fairly consistent and robust across the models with the use of different thresholds (median, mean, 25%, and 75%). This study only reported the results using the median value (see Appendix D Results by using thresholds mean, 25%, and 75% values).

The modeling procedure was the same as that in Section 4 (Figure 10). To consistently compare the influence of built environments on crashes in areas with different economic statuses and ethnic compositions, this study used the same predictor variables as those identified in the final models and estimated two separate models for those census block groups with high versus low percentages of low income and minority populations. The differences in the predictors' significance of association with each crash outcome variable were examined. This study further tested interaction terms between populations below the poverty line, non-white populations, and built environmental variables. None of the interaction terms had significant associations with the crash variable and the results of these interaction terms are not reported here.

5.3 RESULTS

The results of final negative binomial models (Table 10) showed that the population below the poverty line was not significantly related to any crash variables in census block groups. The non-white population was significantly associated with minor injury crashes only.

Table 13 presents the descriptive statistics for areas with high and low percentages of non-white population and population below the poverty line. In general, high-percentage areas had higher mean of crash counts than low-percentage areas. Moreover, high-percentage areas also experienced more traffic volume and had more workers commuting by walking, biking, and transit than low-percentage areas.

Table 13
Descriptive Statistics for Control Variables and Independent Variables for Areas with High and Low Percentages of Non-White Population and Population below the Poverty Line (Threshold: Median)

Variable	High % of non-white population (N=213)	Low % of non-white population (N=213)	High % of population below poverty line (N=213)	Low % of population below poverty line (N=213)
	Mean (S.D.) Min.-Max.			
Total crash (#)	1257.34 (1237.95) 41-12677	778.13 (756.21) 25-5294	1336.63 (1238.75) 41-12677	698.84 (693.45) 25-3962
Fatal injury (#)	4.86 (6.01) 0-31	2.65 (4.24) 0-22	5.12 (6.23) 0-31	2.39 (3.74) 0-19
Serious injury (#)	9.63 (11.46) 0-93	4.64 (5.71) 0-38	9.68 (11.30) 0-93	4.59 (5.98) 0-46
Minor injury (#)	692.41 (637.77) 13-5728	420.89 (416.31) 4-2686	732.99 (634.79) 13-5728	380.31 (389.45) 4-2167
No injury (#)	550.44 (601.96) 28-6827	349.95 (338.82) 13-2548	588.85 (605.10) 28-6827	311.55 (304.25) 13-1852
Control variables				
Risk exposures				
Traffic volume (#)	208305.67 (242935.82) 3150-1298680	154052.97 (193764.21) 790-1354017	221017.68 (239022.27) 790-1161230	141340.96 (194216.86) 1560-1354017
Area of the spatial unit (acres)	316.98 (390.75) 41.30-3231.42	192.85 (162.99) 22.50-2476.61	268.51 (340.24) 22.50-3231.42	241.32 (266.19) 24.38-2476.61
Socio-demographic characteristics				
Total population (#)	1960.25 (1079.75) 537-8936	1021.35 (416.77) 210-3057	1862.70 (1054.26) 531-8936	1118.89 (626.90) 210-4643
Population aged under 18 (#)	492.94 (330.93) 49-2656	173.75 (95.99) 12-737	437.23 (335.64) 12-2656	229.46 (188.61) 35-1550
Population less than high school (#)	247.06 (196.51) 3-1154	40.31 (44.83) 0-252	694.42 (474.86) 84-2839	238.42 (195.41) 23-1487
Male population (#)	1009.33 (565.79) 232-4868	505.57 (200.99) 95-1446	237.93 (202.42) 1-1154	49.44 (57.21) 0-409
Household below poverty line	395.17 (306.75) 23-2229	143.42 (169.03) 3-1420	960.26 (556.97) 210-4868	554.64 (308.45) 95-2275
Travel behaviors				
Workers commuting by walking (#)	26.73 (50.30) 0-456	15.71 (24.24) 0-174	31.51 (52.80) 0-456	10.93 (13.36) 0-84
Workers commuting by public transit (#)	56.02 (62.54) 0-496	30.05 (35.18) 0-196	63.66 (63.50) 0-496	22.41 (24.50) 0-141

S.D.: Standard deviation
Min.: Minimum
Max.: Maximum

Table 13 Continued

Variable	High % of non-white population (N=213)	Low % of non-white population (N=213)	High % of population below poverty line (N=213)	Low % of population below poverty line (N=213)
	Mean (S.D.) Min.-Max.			
Workers commuting by biking (#)	9.79 (17.29) 0-120	14.95 (24.15) 0-131	16.84 (26.85) 0-131	7.91 (11.61) 0-77
Independent variables				
Built environments				
Non-motorized infrastructure				
Sidewalks (miles)	10.10 (6.95) 1.25-41.33	8.04 (3.97) 0.85-26.53	9.28 (6.52) 1.25-41.33	8.85 (4.85) 0.85-35.79
Bike lanes (miles)	4.48 (4.96) 0-27.30	3.69 (4.42) 0-29.86	3.98 (4.38) 0-27.30	4.19 (5.03) 0-29.86
Street connectivity				
Three-leg street intersections (#)	23.88 (15.47) 0-83	20.80 (11.65) 0-60	22.27 (14.45) 0-80	22.41 (13.08) 0-83
Four-or-more-leg street intersections (#)	9.23 (10.74) 0-123	7.72 (7.16) 0-70	9.76 (11.59) 0-123	7.19 (5.47) 0-27
Transit service				
Transit stops (#)	7.22 (8.48) 0-88	4.38 (4.78) 0-43	7.77 (8.56) 0-88	3.84 (4.20) 0-24
Busy roads				
Highway/freeway (miles)	1.10 (1.65) 0.01-9.14	0.65 (1.38) 0.02-11.41	1.06 (1.53) 0.01-6.69	0.70 (1.53) 0.02-11.41
Arterials (miles)	1.69 (1.80) 0.01-12.22	1.10 (1.05) 0.03-8.53	1.58 (1.82) 0.01-12.22	1.21 (1.06) 0.03-6.70
Land use types				
Residential use (#)	328.98 (256.45) 15-1491	296.51 (174.77) 9-895	292.06 (236.14) 15-1491	333.43 (200.55) 9-1220
Commercial use (#)	11.24 (20.96) 0-255	8.39 (10.80) 0-60	12.84 (21.38) 0-255	6.80 (9.20) 0-42
Office use (#)	6.15 (22.36) 0-300	5.45 (14.50) 0-186	7.61 (25.50) 0-300	4.00 (7.31) 0-75
Industrial use (#)	5.56 (14.48) 0-90	1.23 (3.40) 0-34	5.58 (14.49) 0-90	1.22 (3.35) 0-32
School (#)	3.75 (5.47) 0-38	2.27 (3.29) 0-25	3.87 (5.47) 0-38	2.15 (3.23) 0-25
Park (#)	6.75 (10.25) 0-82	5.25 (12.60) 0-165	5.75 (9.78) 0-82	6.26 (12.99) 0-165

S.D.: Standard deviation
Min.: Minimum
Max.: Maximum

5.3.1 Results for Areas with High and Low Percentages of Non-White Population

Table 14 presents the bivariate analysis results between control variables and all crash variables. All crash variables were significantly correlated with each other. For the areas with high percentages of non-white population, almost all control variables had significant bivariate correlations with all dependent variables except the number of workers commuting to work by walking, biking, and public transit, total population, population younger than 18 years, and male population. In terms of the areas with low percentages of non-white population, all but total population, population aged under 18, population below the poverty line, and the number of workers commuting to work by walking, biking, and public transit were significantly related with all crash variables.

Table 14
Bivariate Analysis between Control Variables and Dependent Variables for Areas with High and Low Percentages of Non-White Population in Census Block Groups (Threshold: Median)

Variable	Total crash		Fatal injury		Serious injury		Minor injury		No injury	
	High%[a]	Low %[b]	High%	Low %	High%	Low %	High%	Low %	High%	Low %
	Coefficient (*p*-value)									
Total crash (#)	–	–	0.54*** (<0.001)	0.48*** (<0.001)	0.65*** (<0.001)	0.62*** (<0.001)	0.91*** (<0.001)	0.84*** (<0.001)	0.93*** (<0.001)	0.91*** (<0.001)
Fatal injury (#)	0.54*** (<0.001)	0.48*** (<0.001)	–	–	0.52*** (<0.001)	0.47*** (<0.001)	0.61*** (<0.001)	0.63*** (<0.001)	0.62*** (<0.001)	0.68*** (<0.001)
Serious injury (#)	0.65*** (<0.001)	0.62*** (<0.001)	0.52*** (<0.001)	0.47*** (<0.001)	–	–	0.71*** (<0.001)	0.70*** (<0.001)	0.69*** (<0.001)	0.65*** (<0.001)
Minor injury (#)	0.91*** (<0.001)	0.84*** (<0.001)	0.61*** (<0.001)	0.63*** (<0.001)	0.71*** (<0.001)	0.70*** (<0.001)	–	–	0.95*** (<0.001)	0.96*** (<0.001)
No injury (#)	0.93*** (<0.001)	0.91*** (<0.001)	0.62*** (<0.001)	0.68*** (<0.001)	0.69*** (<0.001)	0.65*** (<0.001)	0.95*** (<0.001)	0.96*** (<0.001)	–	–
Risk exposures										
Traffic volume (#) (million)	0.21*** (<0.001)	0.26*** (<0.001)	0.19*** (<0.001)	0.29*** (<0.001)	0.22*** (<0.001)	0.24*** (<0.001)	0.21*** (<0.001)	0.26*** (<0.001)	0.22*** (<0.001)	0.26*** (<0.001)

[a] High % of non-white population (N=213)
[b] Low % of non-white population (N=213)
*: p<0.05, **: p<0.01, ***: p<0.001

Table 14 Continued

Variable	Total crash		Fatal injury		Serious injury		Minor injury		No injury	
	High%[a]	Low %[b]	High%	Low %	High%	Low %	High%	Low %	High%	Low %
	Coefficient (*p*-value)									
Area of the spatial unit (100 acres)	0.04* (0.019)	0.10** (0.006)	0.05 (0.115)	0.21* (0.021)	0.07** (0.003)	0.13** (0.008)	0.04* (0.032)	0.09* (0.018)	0.05* (0.014)	0.11** (0.002)
Socio-demographic characteristics										
Total population (#) (thousand)	0.20** (0.001)	0.47** (0.001)	0.13 (0.186)	0.48 (0.082)	0.22** (0.007)	0.32 (0.084)	0.17** (0.005)	0.43** (0.004)	0.23*** (<0.001)	0.53*** (<0.001)
Population aged under 18(#) (thousand)	0.14 (0.384)	0.25 (0.670)	0.38 (0.188)	0.74 (0.575)	0.47* (0.038)	0.28 (0.725)	0.15 (0.372)	0.43 (0.477)	0.12 (0.450)	0.05 (0.923)
Population less than high school (#) (thousand)	0.77*** (<0.001)	4.15*** (<0.001)	1.72** (0.001)	8.09** (0.001)	1.15** (0.004)	4.25** (0.002)	0.85** (0.003)	4.61*** (<0.001)	0.66*** (<0.001)	3.58*** (<0.001)
Male population (#) (thousand)	0.48*** (<0.001)	1.36*** (<0.001)	0.34 (0.059)	1.31* (0.028)	0.49** (0.001)	0.86* (0.024)	0.42*** (<0.001)	1.27*** (<0.001)	0.54*** (<0.001)	1.47*** (<0.001)
Household below the poverty line (#) (thousand)	0.75*** (<0.001)	2.10*** (<0.001)	0.99** (0.006)	1.22 (0.268)	0.72* (0.019)	0.92 (0.096)	0.72** (0.001)	2.19*** (<0.001)	0.78*** (<0.001)	2.03*** (<0.001)
Travel behaviors										
Workers commuting by walking(#) (thousand)	5.24*** (<0.001)	8.57** (0.001)	1.56 (0.547)	6.01 (0.256)	3.31 (0.101)	7.41* (0.037)	4.37** (0.003)	8.32** (0.003)	6.28*** (<0.001)	8.91** (0.001)
Workers commuting by public transit (#) (thousand)	3.93** (0.001)	7.21*** (<0.001)	2.42 (0.222)	5.18 (0.187)	2.06 (0.236)	1.91 (0.462)	3.84** (0.002)	7.95*** (<0.001)	4.06** (0.001)	6.39*** (<0.001)
Workers commuting by biking (#) (thousand)	14.63*** (<0.001)	11.49*** (<0.001)	8.69 (0.141)	6.59 (0.230)	10.59* (0.012)	4.24 (0.247)	13.73*** (<0.001)	11.84*** (<0.001)	15.79*** (<0.001)	11.18*** (<0.001)

[a] High % of non-white population (N=213)
[b] Low % of non-white population (N=213)
*: p<0.05, **: p<0.01, ***: p<0.001

After including all significant variables from the bivariate analyses in the original base model, VIF of each predictor variable was examined and those with VIF greater than 10 (Aiken & West, 1991), such as the other four crash variables, total population, and the number of workers commuting to work by public transit, were excluded.

Table 15 shows the results of refined base models and one-by-one tests. For the areas with high percentages of non-white population, the refined base models showed that traffic volume and population with an education level less than high school were significantly related to all crash variables. The number of workers commuting by walking was a significant correlate of total and no injury crashes. With respect to areas with low percentages of non-white population, traffic volume and population with an education level less than high school were also significant correlates of all crash variables. The number of workers commuting by walking was significantly associated with total, minor, and no injury crashes.

In terms of the one-by-one tests, bike lanes were associated with fatal, minor, and no injury collisions in areas with greater percentage of non-white population. The number of four-or-more-leg intersections was related to total, minor, and no injury crashes in both areas. Arterial roads were significantly associated with all crash variables in both areas. Residential uses were related to all crash variables except fatal injury crashes in both areas. Commercial uses were related to all crash variables in areas with greater percentage of non-white population and were associated with all crash variables except fatal injury crashes in areas with a low percentage of non-white population.

Table 15
Refined Base Models and One-by-One Tests for Areas with High and Low Percentages of Non-White Population in Census Block Groups (Threshold: Median)

Variable	Total crash		Fatal injury		Serious injury		Minor injury		No injury	
	High%[a]	Low %[b]	High%	Low %	High%	Low %	High%	Low %	High%	Low %
	Coefficient (*p*-value)									
Refined base model										
Traffic volume (#) (million)	0.20*** (<0.001)	0.27*** (<0.001)	0.17*** (<0.001)	0.28*** (<0.001)	0.19*** (<0.001)	0.22*** (<0.001)	0.19*** (<0.001)	0.28*** (<0.001)	0.20*** (<0.001)	0.26*** (<0.001)
Area of the spatial unit (100 acres)	0.01 (0.600)	0.03 (0.359)	0.02 (0.471)	0.06 (0.482)	0.03* (0.016)	0.02 (0.653)	0.01 (0.750)	0.05 (0.213)	0.01 (0.464)	0.02 (0.600)
Population less than high school (#)(thousand)	0.84*** (<0.001)	5.08*** (<0.001)	1.54** (0.003)	9.78** (0.001)	1.05** (0.007)	4.71** (0.004)	0.87** (0.001)	5.71*** (<0.001)	0.79*** (<0.001)	4.31*** (<0.001)
Workers commuting by walking (#) (thousand)	2.58* (0.012)	4.76* (0.034)	1.25 (0.574)	3.24 (0.471)	0.24 (0.879)	2.34 (0.477)	1.94 (0.073)	4.73* (0.045)	3.42** (0.001)	4.86* (0.029)
One-by-one test										
Sidewalks (miles)	-0.01 (0.802)	-0.01 (0.682)	-0.01 (0.994)	-0.03 (0.432)	-0.01 (0.344)	-0.02 (0.477)	-0.01 (0.973)	-0.01 (0.750)	-0.01 (0.563)	-0.02 (0.636)
Bike lanes (miles)	0.02* (0.019)	0.01 (0.347)	0.02 (0.405)	0.05 (0.108)	0.01 (0.774)	0.01 (0.905)	0.03* (0.019)	0.02 (0.225)	0.02* (0.026)	0.01 (0.555)
Three-leg street intersections (#)	-0.01 (0.253)	-0.03 (0.478)	-0.01 (0.998)	-0.01 (0.737)	-0.01 (0.126)	-0.01 (0.658)	-0.01 (0.193)	-0.02 (0.398)	-0.02 (0.411)	-0.02 (0.626)
Four-or-more-leg street intersections (#)	0.01* (0.012)	0.03** (0.001)	0.014 (0.155)	0.02 (0.207)	0.01 (0.142)	0.01 (0.488)	0.01* (0.025)	0.03** (0.001)	0.01** (0.006)	0.03*** (<0.001)
Transit stops (#)	0.03*** (<0.001)	0.07*** (<0.001)	0.04* (0.011)	0.05 (0.124)	0.03** (0.002)	0.03* (0.043)	0.04*** (<0.001)	0.08*** (<0.001)	0.03*** (<0.001)	0.07*** (<0.001)
Highway/freeway (miles)	0.05 (0.175)	0.02 (0.784)	0.01 (0.992)	0.03 (0.817)	0.02 (0.747)	0.03 (0.792)	0.07 (0.108)	0.01 (0.864)	0.04 (0.339)	0.05 (0.426)
Arterials (miles)	0.17*** (<0.001)	0.23*** (<0.001)	0.11* (0.018)	0.35* (0.014)	0.12* (0.020)	0.18* (0.023)	0.17*** (<0.001)	0.27*** (<0.001)	0.17*** (<0.001)	0.20** (0.001)
Residential use (#)	-0.01** (0.005)	-0.02** (0.002)	-0.01 (0.261)	-0.01 (0.381)	-0.01*** (<0.001)	-0.01*** (<0.001)	-0.01** (0.004)	-0.01*** (<0.001)	-0.01*** (<0.001)	-0.01*** (<0.001)
Commercial use (#)	0.01*** (<0.001)	0.03*** (<0.001)	0.02* (0.014)	0.02 (0.175)	0.01* (0.049)	0.02* (0.011)	0.01** (0.001)	0.03*** (<0.001)	0.01*** (<0.001)	0.03*** (<0.001)
Office use (#)	0.01* (0.037)	0.02** (0.007)	0.01 (0.236)	0.01 (0.719)	0.01 (0.071)	0.01 (0.180)	0.01 (0.053)	0.02** (0.009)	0.01* (0.032)	0.02** (0.006)
Industrial use (#)	0.01 (0.217)	0.06** (0.003)	0.01 (0.220)	0.08 (0.069)	0.01 (0.661)	0.04 (0.216)	0.01 (0.235)	0.06** (0.004)	0.01 (0.220)	0.06** (0.004)
School (#)	0.03*** (<0.001)	0.04** (0.008)	0.03 (0.174)	0.01 (0.810)	0.03* (0.035)	0.02 (0.463)	0.04*** (<0.001)	0.05** (0.006)	0.03** (0.001)	0.04* (0.015)
Park (#)	0.01 (0.397)	0.01 (0.936)	0.01 (0.557)	0.01 (0.418)	0.01 (0.183)	0.01 (0.467)	0.01 (0.302)	0.01 (0.965)	0.01 (0.584)	0.01 (0.853)

[a] High % of non-white population (N=213)
[b] Low % of non-white population (N=213)
*: p<0.05, **: p<0.01, ***: p<0.001

Table 16 presents the results of final negative binomial models for areas with high and low percentages of non-white populations. Both AIC and BIC values in areas with high percentages of non-white population were a bit higher than those in low-percentage areas. But, based on the likelihood-ratio test, there was no significant difference between high- and low-percentage areas for each injury model.

Traffic volume was significantly related to all crash variables in both types of areas, while the number of workers commuting by walking was not significant. Some built environmental variables were significantly associated with crash variables in areas with both low and high percentages of non-white population. For example, arterial roads and commercial uses were related to total crashes in both types of areas. Residential uses were significantly associated with serious injury crashes in both types of areas. However, some built environmental variables were only significantly related to crash variables in high-percentage areas but not in low-percentage areas, such as arterial roads in the fatal-injury model, school uses in the minor-injury model, and office and school uses in the no-injury model.

Table 16
Final Negative Binomial Models for Areas with High and Low Percentages of Non-White Population in Census Block Groups (Threshold: Median)

Variable	Total crash		Fatal injury		Serious injury		Minor injury		No injury	
	High%[a]	Low %[b]	High%	Low %	High%	Low %	High%	Low %	High%	Low %
	Coefficient (*p*-value)									
Traffic volume (#) (million)	0.16*** (<0.001)	0.22*** (<0.001)	0.11** (0.009)	0.21** (0.005)	0.13*** (<0.001)	0.16** (0.001)	0.15*** (<0.001)	0.20*** (<0.001)	0.15*** (<0.001)	0.19*** (<0.001)
Area of the spatial unit (100 acres)	0.03* (0.010)	0.01 (0.722)	0.01 (0.590)	0.06 (0.474)	0.04* (0.044)	0.10 (0.102)	0.02 (0.209)	0.04 (0.288)	0.01 (0.440)	0.07* (0.043)
Population less than high school (#) (thousand)	0.83*** (<0.001)	2.98** (0.003)	1.39** (0.005)	7.88** (0.007)	0.92** (0.009)	3.23 (0.050)	0.76*** (<0.001)	2.95** (0.008)	0.56** (0.004)	1.73 (0.094)
Workers commuting by walking (#)(thousand)	1.52 (0.080)	1.98 (0.300)	3.47 (0.121)	2.19 (0.627)	4.16 (0.057)	2.20 (0.515)	1.26 (0.171)	0.30 (0.872)	0.86 (0.327)	0.22 (0.907)
Arterials (miles)	0.15*** (<0.001)	0.13* (0.013)	0.01* (0.034)	0.31 (0.834)			0.17*** (<0.001)	0.13* (0.023)	0.16*** (<0.001)	0.06 (0.296)
Residential use (#)					-0.01*** (<0.001)	-0.01** (0.019)	-0.01** (0.004)	-0.02*** (<0.001)	-0.02** (0.002)	-0.03*** (<0.001)
Commercial use (#)	0.01** (0.003)	0.03*** (<0.001)					0.02** (0.008)	0.03*** (<0.001)	0.03*** (<0.001)	0.02*** (<0.001)
Office use (#)									0.02* (0.045)	0.01 (0.282)
School (#)							0.03** (0.001)	0.01 (0.715)	0.03** (0.004)	0.02 (0.896)
AIC	6301.24	6286.14	1907.41	1897.54	2404.65	2397.33	5874.56	5851.74	5641.22	5632.26
BIC	6418.54	6398.34	1934.25	1927.14	2447.22	2431.17	5904.25	4998.52	5607.24	5596.47

[a] High % of non-white population (N=213)
[b] Low % of non-white population (N=213)
*: p<0.05, **: p<0.01, ***: p<0.001

5.3.2 Results for Areas with High and Low Percentages of Population below the Poverty Line

Table 17 shows the bivariate analysis results between control variables and all crash variables. All crash variables were significantly correlated with each other. For the areas with high percentages of population below the poverty line, almost all control variables had significant bivariate correlations with all dependent variables except the number of workers commuting to work by walking, biking, and public transit. For the areas with low percentages of population below the poverty line, all but total population, population younger than 18 years, male population, and the number of workers commuting to work by walking and biking were significantly related to all crash variables.

Table 17
Bivariate Analysis between Control Variables and Dependent Variables for Areas with High and Low Percentages of Population below the Poverty Line in Census Block Groups (Threshold: Median)

Variable	Total crash		Fatal injury		Serious injury		Minor injury		No injury	
	High%[a]	Low %[b]	High%	Low %	High%	Low %	High%	Low %	High%	Low %
	Coefficient (*p*-value)									
Total crash (#)	–	–	0.52*** (<0.001)	0.45*** (<0.001)	0.61*** (<0.001)	0.63*** (<0.001)	0.93*** (<0.001)	0.87*** (<0.001)	0.92*** (<0.001)	0.90*** (<0.001)
Fatal injury (#)	0.52*** (<0.001)	0.45*** (<0.001)	–	–	0.50*** (<0.001)	0.49*** (<0.001)	0.58*** (<0.001)	0.61*** (<0.001)	0.64*** (<0.001)	0.71*** (<0.001)
Serious injury (#)	0.61*** (<0.001)	0.63*** (<0.001)	0.50*** (<0.001)	0.49*** (<0.001)	–	–	0.68*** (<0.001)	0.75*** (<0.001)	0.72*** (<0.001)	0.68*** (<0.001)
Minor injury (#)	0.93*** (<0.001)	0.87*** (<0.001)	0.58*** (<0.001)	0.61*** (<0.001)	0.68*** (<0.001)	0.75*** (<0.001)	–	–	0.93*** (<0.001)	0.91*** (<0.001)
No injury (#)	0.92*** (<0.001)	0.90*** (<0.001)	0.64*** (<0.001)	0.71*** (<0.001)	0.72*** (<0.001)	0.68*** (<0.001)	0.93*** (<0.001)	0.91*** (<0.001)	–	–
Risk exposures										
Traffic volume (#) (million)	0.23*** (<0.001)	0.25*** (<0.001)	0.23*** (<0.001)	0.25*** (<0.001)	0.22*** (<0.001)	0.27*** (<0.001)	0.23*** (<0.001)	0.25*** (<0.001)	0.24*** (<0.001)	0.25*** (<0.001)
Area of the spatial unit (100 acres)	0.21*** (<0.001)	0.08*** (<0.001)	0.26** (0.001)	0.10* (0.019)	0.19*** (<0.001)	0.11*** (<0.001)	0.20*** (<0.001)	0.07*** (<0.001)	0.22*** (<0.001)	0.08*** (<0.001)
Socio-demographic characteristics										
Total population (#) (thousand)	0.40*** (<0.001)	0.24** (0.001)	0.43** (0.001)	0.17 (0.196)	0.43*** (<0.001)	0.32** (0.001)	0.39*** (<0.001)	0.22** (0.003)	0.42*** (<0.001)	0.26*** (<0.001)
Population aged under 18 (#) (thousand)	0.54** (0.005)	0.39 (0.063)	1.09** (0.004)	0.35 (0.359)	0.93** (0.001)	0.90** (0.005)	0.59** (0.003)	0.37 (0.103)	0.47* (0.016)	0.41* (0.043)
Non-white population (#) (thousand)	0.49*** (<0.001)	0.80*** (<0.001)	0.79** (0.001)	0.81* (0.044)	0.78*** (<0.001)	1.06*** (<0.001)	0.50*** (<0.001)	0.85*** (<0.001)	0.48*** (<0.001)	0.73*** (<0.001)
Population less than high school (#)(thousand)	0.82** (0.001)	2.52** (0.001)	1.91*** (<0.001)	2.89* (0.021)	1.57*** (<0.001)	3.49** (0.001)	0.86** (0.001)	2.99*** (<0.001)	0.75** (0.004)	1.93* (0.011)
Male population (#)(thousand)	0.77*** (<0.001)	0.53*** (<0.001)	0.81*** (<0.001)	0.38 (0.142)	0.76*** (<0.001)	0.73*** (<0.001)	0.74*** (<0.001)	0.50** (0.001)	0.80*** (<0.001)	0.56*** (<0.001)
Travel behaviors										
Workers commuting by walking (#)(thousand)	5.78*** (<0.001)	6.54* (0.010)	2.62 (0.336)	3.19 (0.560)	3.87 (0.059)	7.89 (0.053)	5.02** (0.001)	5.83* (0.026)	6.68*** (<0.001)	7.36** (0.003)
Workers commuting by public transit (#) (thousand)	2.98*** (0.004)	10.81*** (<0.001)	1.40 (0.445)	9.18* (0.044)	0.72 (0.648)	9.56** (0.003)	3.07** (0.004)	11.50*** (<0.001)	2.93** (0.005)	10.06*** (<0.001)
Workers commuting by biking (#)(thousand)	7.70*** (<0.001)	10.98*** (<0.001)	0.62 (0.873)	11.90 (0.129)	1.96 (0.498)	12.33* (0.019)	6.94** (0.001)	12.30*** (<0.001)	8.78*** (<0.001)	14.63*** (<0.001)

[a] High % of population below the poverty line (N=213)
[b] Low % of population below the poverty line (N=213)
*: p<0.05, **: p<0.01, ***: p<0.001

After inclusion of all significant variables from the bivariate analyses in the original base model, VIF of each predictor variable was examined and those with VIF greater than 10, such as the other four crash variables, total population, population younger than 18 years, and the number of workers commuting to work by biking and public transit, were excluded.

Table 18 shows the results of refined base models and one-by-one tests. For the areas with high percentages of population below the poverty line, traffic volume and population with an education level less than high school were significantly related to all crash variables. The number of workers commuting by walking was a significant correlate of minor and no injury crashes. With respect to areas with low percentages of population below the poverty line, traffic volume and population with an education level less than high school were significant correlates of all crash variables. The number of workers commuting by walking was significantly associated with total and no injury crashes only.

In terms of the one-by-one tests, the number of four-or-more-leg intersections was related to total, minor, and no injury crashes in both types of areas. The number of transit stops was related to all crash variables in both types of areas except fatal injury collisions. Total miles of arterial roads were significantly associated with all crash variables in both types of areas. Residential uses were significantly correlated with all crash variables except fatal injury collisions in both types of areas. Commercial uses were related to all crash variables in areas with high percentages of population below the poverty line and were associated with all crash variables except fatal injury crashes in areas with low percentages of population below the poverty line.

Table 18
Refined Base Models and One-by-One Tests for Areas with High and Low Percentages of Population below the Poverty Line in Census Block Groups (Threshold: Median)

Variable	Total crash		Fatal injury		Serious injury		Minor injury		No injury	
	High%[a]	Low %[b]	High%	Low %	High%	Low %	High%	Low %	High%	Low %
	Coefficient (*p*-value)									
Refined base model										
Traffic volume (#) (million)	0.21*** (<0.001)	0.23*** (<0.001)	0.19*** (<0.001)	0.24*** (<0.001)	0.21*** (<0.001)	0.21*** (<0.001)	0.21*** (<0.001)	0.23*** (<0.001)	0.22*** (<0.001)	0.22*** (<0.001)
Area of the spatial unit (100 acres)	0.03 (0.371)	0.02 (0.177)	0.07 (0.365)	0.04 (0.269)	0.01 (0.858)	0.05* (0.010)	0.04 (0.286)	0.02 (0.330)	0.02 (0.535)	0.03 (0.087)
Population less than high school (#)(thousand)	0.49* (0.030)	1.92** (0.001)	1.25* (0.023)	2.77* (0.031)	1.21** (0.003)	2.17** (0.009)	0.49* (0.037)	2.43*** (<0.001)	0.47* (0.033)	1.30* (0.018)
Workers commuting by walking (#)(thousand)	1.26 (0.273)	3.55* (0.029)	1.63 (0.495)	1.25 (0.758)	1.74 (0.367)	1.99 (0.379)	0.59* (0.024)	3.13 (0.066)	2.09* (0.045)	4.09* (0.011)
One-by-one test										
Sidewalks (miles)	-0.02 (0.076)	-0.01 (0.635)	-0.04 (0.201)	-0.01 (0.684)	-0.01 (0.584)	-0.02 (0.226)	-0.02 (0.085)	-0.01 (0.526)	-0.02 (0.070)	-0.02 (0.614)
Bike lanes (miles)	0.02 (0.195)	0.02* (0.015)	0.02 (0.493)	0.02 (0.509)	0.03 (0.225)	0.01 (0.648)	0.02 (0.108)	0.03 (0.060)	0.01 (0.417)	0.02 (0.054)
Three-leg street intersections (#)	-0.01 (0.438)	-0.01 (0.156)	-0.01 (0.329)	-0.02 (0.801)	-0.02 (0.398)	-0.01 (0.693)	-0.01 (0.364)	-0.01 (0.057)	-0.01 (0.524)	-0.02 (0.457)
Four-or-more-leg street intersections (#)	0.01* (0.013)	0.03*** (<0.001)	0.02 (0.080)	0.01 (0.520)	0.01 (0.098)	0.01 (0.340)	0.01* (0.025)	0.03** (0.001)	0.01** (0.007)	0.03*** (<0.001)
Transit stops (#)	0.03*** (<0.001)	0.06*** (<0.001)	0.02 (0.116)	0.09** (0.001)	0.03* (0.010)	0.07*** (<0.001)	0.03*** (<0.001)	0.07*** (<0.001)	0.03*** (<0.001)	0.06*** (<0.001)
Highway/freeway (miles)	0.01 (0.880)	0.08 (0.102)	0.04 (0.723)	0.02 (0.627)	0.04 (0.623)	0.04 (0.559)	0.02 (0.706)	0.07 (0.182)	0.01 (0.556)	0.09 (0.050)
Arterials (miles)	0.25*** (<0.001)	0.18*** (<0.001)	0.13** (0.002)	0.28** (0.004)	0.25*** (<0.001)	0.08* (0.042)	0.25*** (<0.001)	0.20*** (<0.001)	0.24*** (<0.001)	0.16*** (<0.001)
Residential use (#)	-0.01** (0.002)	-0.01* (0.045)	-0.01 (0.404)	-0.01 (0.645)	-0.01* (0.017)	-0.02* (0.019)	-0.01** (0.003)	-0.01* (0.027)	-0.02** (0.001)	-0.01** (0.009)
Commercial use (#)	0.02*** (<0.001)	0.03*** (<0.001)	0.02* (0.024)	0.02 (0.162)	0.01* (0.046)	0.02* (0.012)	0.01*** (<0.001)	0.03*** (<0.001)	0.01*** (<0.001)	0.03*** (<0.001)
Office use (#)	0.01*** (<0.001)	0.03** (0.001)	0.01 (0.387)	0.02 (0.188)	0.01* (0.030)	0.02* (0.045)	0.01*** (<0.001)	0.03** (0.002)	0.01*** (<0.001)	0.03*** (<0.001)
Industrial use (#)	0.01 (0.340)	0.01 (0.253)	0.01 (0.133)	0.02 (0.889)	0.04 (0.481)	0.02 (0.110)	0.01 (0.399)	0.01 (0.260)	0.01 (0.285)	0.01 (0.294)
School (#)	0.02** (0.004)	0.06** (0.001)	0.02 (0.351)	0.05 (0.314)	0.03* (0.042)	0.03 (0.243)	0.03*** (<0.001)	0.06** (0.001)	0.02** (0.001)	0.05** (0.002)
Park (#)	0.01 (0.099)	0.01 (0.119)	0.01 (0.535)	0.02 (0.775)	0.01 (0.725)	0.02 (0.786)	0.01 (0.107)	0.01 (0.228)	0.02 (0.082)	0.01 (0.050)

[a] High % of population below the poverty line (N=213)
[b] Low % of population below the poverty line (N=213)
*: p<0.05, **: p<0.01, ***: p<0.001

Table 19 shows the results of final negative binomial models for areas with high and low percentages of populations below the poverty line. Following the same pattern as the results for non-white population, each injury model for areas with a low percentage of population below the poverty line had lower AIC and BIC values than the corresponding model for high-percentage areas. However, no significant difference was found between two models according to the likelihood-ratio test.

Traffic volume was a significantly positive correlate of all crash variables in both models. Population with less than high school education was significantly related to all crash variables in both models except for fatal and no injury collisions in low-percentage areas. The number of workers commuting by walking was not significantly associated with any crash variables in both models.

Most built environmental variables were significantly related to crash variables in both areas, such as arterial roads, residential uses, commercial uses, and school uses in the total-crash model, minor-injury model, and no-injury model. However, some built environment–traffic safety relationships were only significant in areas with high percentages of population below the poverty line. High-percentage areas with more office uses had more total crashes and minor injury crashes. Arterial roads had a significant association with only fatal injury collisions in high-percentage areas.

Table 19
Final Negative Binomial Models for Areas with High and Low Percentages of Population below the Poverty Line in Census Block Groups (Threshold: Median)

Variable	Total crash		Fatal injury		Serious injury		Minor injury		No injury	
	High%[a]	Low %[b]	High%	Low %	High%	Low %	High%	Low %	High%	Low %
	Coefficient (*p*-value)									
Traffic volume (#) (million)	0.19*** (<0.001)	0.17*** (<0.001)	0.14** (0.004)	0.20** (0.001)	0.18*** (<0.001)	0.18*** (<0.001)	0.19*** (<0.001)	0.17*** (<0.001)	0.19*** (<0.001)	0.17*** (<0.001)
Area of the spatial unit (100 acres)	0.05 (0.096)	0.03 (0.638)	0.03 (0.674)	0.02 (0.630)	0.06 (0.230)	0.06* (0.020)	0.05 (0.120)	0.06 (0.694)	0.05 (0.075)	0.01 (0.680)
Population less than high school (#)(thousand)	0.47* (0.019)	1.07* (0.033)	1.35* (0.015)	1.93 (0.115)	1.41*** (<0.001)	2.00* (0.017)	0.48* (0.022)	1.52** (0.007)	0.44* (0.024)	0.54 (0.255)
Workers commuting by walking (#)(thousand)	0.26 (0.596)	1.11 (0.431)	2.49 (0.294)	4.54 (0.312)	4.76 (0.061)	0.69 (0.750)	0.99 (0.336)	1.78 (0.242)	0.63 (0.521)	0.28 (0.643)
Arterials (miles)	0.23*** (<0.001)	0.14*** (<0.001)	0.05** (0.008)	0.26 (0.090)	0.24*** (<0.001)	0.09* (0.045)	0.24*** (<0.001)	0.15*** (<0.001)	0.22*** (<0.001)	0.12*** (<0.001)
Residential use (#)	-0.01** (0.004)	-0.01* (0.048)			-0.01* (0.043)	-0.02* (0.029)	-0.01** (0.006)	-0.01* (0.029)	-0.01** (0.003)	-0.01* (0.045)
Commercial use (#)	0.02*** (<0.001)	0.02*** (<0.001)					0.02*** (<0.001)	0.02*** (<0.001)	0.02*** (<0.001)	0.02** (0.001)
Office use (#)	0.01*** (<0.001)	0.01 (0.153)					0.02*** (<0.001)	0.01 (0.292)	0.01*** (<0.001)	0.01* (0.033)
School (#)	0.03** (0.006)	0.05** (0.001)					0.03*** (<0.001)	0.06** (0.001)	0.02** (0.002)	0.04** (0.003)
AIC	6360.24	6354.57	1895.68	1887.52	2398.81	2392.35	5874.14	5868.32	5648.23	5637.89
BIC	6389.68	6381.47	1931.47	1922.85	2447.22	2438.86	5931.46	5924.47	5701.13	5692.37

[a] High % of population below the poverty line (N=213)
[b] Low % of population below the poverty line (N=213)
*: p<0.05, **: p<0.01, ***: p<0.001

5.4 DISCUSSION AND CONCLUSION

The purpose of this study was to examine whether areas with more populations below the poverty line and non-white populations were related to more crashes with different levels of injury severity. The results were not definitive because other factors seemed to play stronger roles in traffic safety than populations below the poverty line and non-white populations. For example, populations below the poverty line and non-white populations were significantly related to all crash variables in the bivariate analyses in census block groups (Table 8). But after adding other control variables, populations below the poverty line were no longer significantly associated with any crash variables. Non-white populations were only related to total and minor injury crashes. After adding other built environmental variables, only the relationship between non-white populations and minor injury crashes was still significant (Table 10).

5.4.1 Built Environment–Traffic Safety Relationships in Areas with High and Low Percentages of Non-White Population and Population below the Poverty Line

The present study expanded on prior work by examining whether the built environment–traffic safety relationships differed for areas with different economic statuses (high and low percentages of population below the poverty line) and ethnic compositions (high and low percentages of non-white population). The results showed that some built environmental variables were significant in areas with both high and low percentages of non-white population and population below the poverty line. However, some built environmental variables (e.g., arterial roads, office uses, and schools) showed significant impacts on traffic safety only in areas with high percentages of non-white population and population below the poverty line and not in low-percentage areas. For example, total miles of arterial roads were associated with increased fatal injury crashes in areas with high percentages of non-white population and population below the poverty line but not in corresponding low-percentage areas. High-percentage areas with more office uses experienced more minor and no injury crashes than did low-percentage areas. School counts were related to more minor and no injury crashes in areas with high percentages of non-white population. This suggested that arterial roads, office uses, and school uses mattered more to areas with high percentages of non-white population and population below the poverty line and indicated that policies and programs related to these built environmental attributes in promoting traffic safety may bring more benefits to areas with more non-white or lower-income populations.

The different built environment–traffic safety associations among areas with different economic statuses and ethnic compositions may be attributable to different travel behaviors between non-white and white people and between low-income and high-income populations. Non-white and low-income people were less likely to own a car compared with white and high-income populations (Besser & Dannenberg, 2005). Based on the 2009 National Household Travel Survey (NHTS), the percentages of people having no vehicle decreased as incomes increased (<$15,000 income: 73.48% had no vehicle, $15,000-$34,999: 53.73%, $35,000-$69,999: 23.51%, ≥$70,000: 10.02%), and the percentage of whites having no car (29.84%) was much lower than that of African Americans (59.38%) and Hispanics (48.84%). In addition, areas with high percentages of non-white population and population below the poverty line had higher percentages of arterial roads than did corresponding low-percentage areas (high vs. low percentage of non-white population: 17% vs. 9%; high vs. low percentages of population below the poverty line: 15% vs. 8%). These minority populations with lower car ownership may have greater exposure to large traffic flows brought by arterial roads.

5.4.2 Adequate Non-Motorized Infrastructure

Providing a sufficient non-motorized infrastructure might be an effective approach and may have more benefit in promoting traffic safety in areas with high percentages of non-white and low-income people. The data in this study showed that the densities of sidewalks and bike lanes in areas with more non-white and low-income people were significantly lower than that in areas with less non-white and low-income people (non-white population: sidewalk – p=0.002, bike lane – p=0.043; population below the poverty line: sidewalk – p<0.001, bike lane – p=0.005).

5.4.3 Tailored Traffic Safety Strategies

Findings from this study implied that planning and policies related to arterial roads, office uses, and schools may not equally promote traffic safety in areas with different economic statuses and ethnic compositions. Tailored traffic safety strategies are need for areas with more non-white and low-income people. Further, a more detailed investigation of micro-level built environmental attributes would be needed to explore the mechanism regarding the built environment–traffic safety relationship in areas with more non-white and low-income people. Therefore, future studies need to address the roles of arterial roads and built environmental designs (e.g., non-motorized infrastructure, speed limit, traffic calming, etc.) around office uses and schools especially in areas with high percentages of non-white population and population below the poverty line.

5.4.4 Incorporating Perceived Traffic Safety into Traffic Safety Planning Process

Including the perspectives from non-white and low-income people in the traffic safety planning process would be an important approach (Anguelovski, 2013). Most planners and practitioners rely on prior crash data to identify possible strategies to formulate effective interventions. Recent approaches have emphasized a more proactive and comprehensive method of traffic safety planning by including planning context and perception of environments (Meyer, 2005). Perceived traffic safety has been identified as an important factor because it could explain people's behaviors and identify potential high–risk areas (Lam, 2001; Schneider, Rynznar, & Khattak, 2004). Therefore, perceived traffic safety for non-white and low-income populations would be another important dimension to help develop effective and tailored traffic safety policies and programs.

5.4.5 Limitations

This study used GIS datasets to measure built environmental attributes. However, the limited availability of GIS datasets in different time frames may cause measurement problems. The author included the same built environmental variables in each injury model to compare the results from high- and low-percentage areas. There may be estimation problems because some variables were only significant in high- or low-percentage areas. Moreover, the analysis did not control for the potential issue of spatial autocorrelation. The areas' characteristics may be affected by adjacent areas. Although the author modeled five crash variables to explore built environmental correlates of crashes with different levels of injury severity, the strong correlations among five crash variables may limit the contribution of this study, as different models might model almost the same dependent variables.

5.4.6 Conclusion

The author examined moderating effects of areas' economic statuses and ethnic compositions on the built environment–traffic safety relationship. The results showed that some built environmental factors had significant impacts only in areas with high percentages of non-white population and population below the poverty line. The findings indicated that tailored policies are necessary for areas with more non-white and low-income people.

6. ASSOCIATION BETWEEN NEIGHBORHOOD ENVIRONMENT AND CRASHES INVOLVING ELEMENTARY SCHOOL–AGED CHILDREN DURING SCHOOL TRAVEL TIME

6.1 INTRODUCTION

To address the research gap mentioned in 2.5.3 “School Travel Safety,” this study examined the relationships between built environments and school travel safety around elementary schools. The author analyzed the risk of occurrence of a collision involving elementary school–aged children during school travel time around 78 elementary schools in the Austin Independent School District (AISD), TX, by using two-level (street segment–level and school–level) binomial logistic models.

The conceptual framework for this study (Figure 25) was an extension from the general conceptual framework in this dissertation (Figure 5 in Section 3). Control variables included risk exposures (school–level) and socio-demographic characteristics (school–level), and independent variables consisted of road environments (street segment–level) and neighborhood environments around schools (school–level).

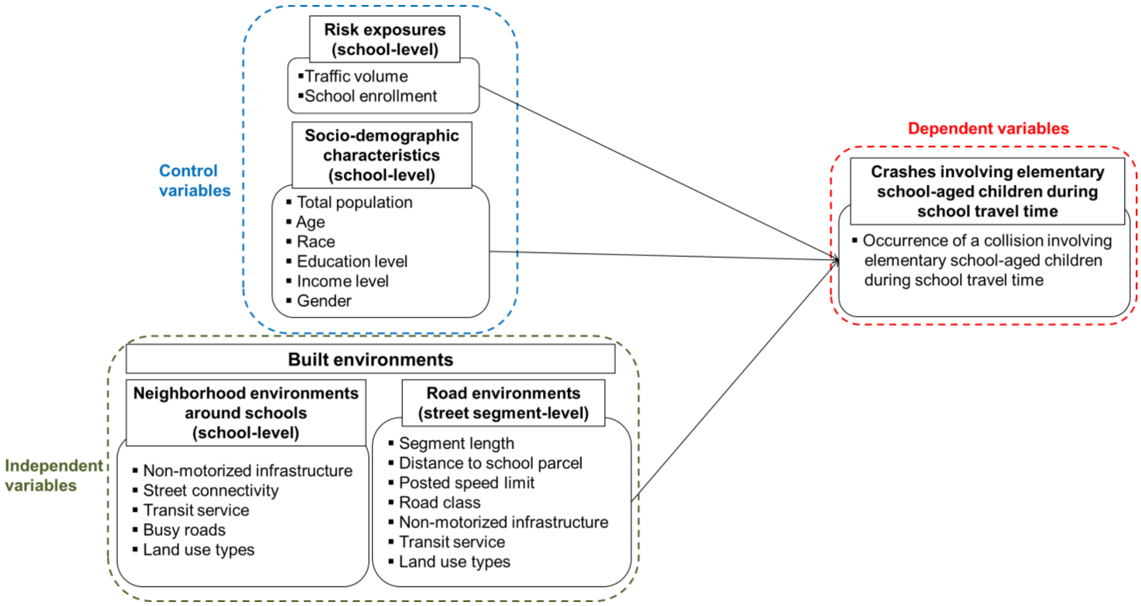


Figure 25
Conceptual Framework for School Travel Safety

6.2 METHODS

6.2.1 Study Setting

The study setting was 78 elementary schools in the AISD, TX (Figure 26). To measure the environments around schools, 0.5-mile buffers were used because 0.5 miles are considered feasible for elementary school-aged children to walk and this buffer area usually experience regular, concentrated, and congested traffic flows imposing safety threats to the surrounding areas (Abdel-Aty et al., 2007; Clifton & Kreamer-Fults, 2007; LaScala et al., 2004).

Figure 26
Crashes Involving Elementary School–Aged Children during School Travel Time Located Within Half Mile Parcel Buffers of Elementary Schools in the AISD, TX

6.2.2 Variables and Measurements

Dependent variables

The five-year (2008-2012) crash data came from the Texas Department of Transportation (TxDOT). These data provided the age of people involved in the crash and time of the crash (e.g., the day of the week, and the time of the day). This study geo-coded these collisions based on the longitude and latitude of the crash.

To identify crashes involving elementary school–aged children during school travel time, four criteria developed by Abdel-Aty et al. (2007) and McDonald et al. (2011) were used:

1. Include crashes where the age of the person involved was from 5–11 years (for schools serving grades 1–5) or 5–12 years (for schools serving grades 1–6).
2. Select crashes that occurred on weekdays (from Monday to Friday).
3. Select crashes that happened during school travel time (5–11 a.m. and 1–6 p.m.).
4. Select crashes that happened between September and May (information not available in this study's dataset).
5. Identify traffic crashes located within 0.5-mile buffers of elementary school parcels in the AISD.

Due to the unavailability of the data, this study could not consider the fourth criterion in the selection process. According to the above selection criteria, a total of 3,000 crashes were identified as crashes involving elementary school–aged children during school travel time between 2008 and 2012 within the 0.5-mile parcel buffers of 78 elementary schools in the AISD, TX (Table 20).

Table 20
Number of Crashes Involving Elementary School–Aged Children during School Travel Time within 0.5-mile Parcel Buffers from Elementary Schools in the AISD, TX

Year	Number	Percentage
2008	755	25.17%
2009	436	14.53%
2010	618	20.60%
2011	537	17.90%
2012	654	21.80%
Total	3,000	100.00%

Data Source: Texas Department of Transportation (TxDOT) 2008-2012

If each single crash point is used as the unit of analysis and a buffer around the crash is used for measuring the built environment, there will be serious spatial autocorrelation issues among the buffers. Therefore, this study used the street segment as the unit of analysis. These street segments were split at intersections and jurisdiction boundaries to ensure there was no major change in road characteristics along each segment. Since the study area was limited to the 0.5-mile buffers of elementary schools, street segments were also cut off at the buffer boundary when they intersected with the edges of the buffers.

In total, 11,178 street segments were located within 0.5-mile school parcel buffers around 78 elementary schools in the AISD, TX. Among these segments, 247 and 2,072 segments were located in three and two school parcel buffers, respectively. Because crashes that occurred on these segments were influenced by environments around the corresponding two or three schools, this study counted these segments two or three times for the analysis (i.e., repeated for each school). As a result, the final sample size was 16,063 segments.

Descriptive statistics showed that 80.28% of the street segments had no crashes between 2008 and 2012. Therefore, this study decided to use a binary outcome variable of with (1) and without (0) crashes involving elementary school–aged children during school travel time to measure the street segment's performance in terms of school travel–related safety.

Independent variables

The independent variables were identified based on previous literature and the proposed conceptual framework presented in Section 3 (Figure 5). They included four domains of factors – risk exposures, socio-demographic characteristics, travel behaviors, and built environments.

Table 21 lists the dependent and independent variables, their measurements, data sources, and units of measurement. For risk exposures, this study considered vehicle miles traveled during 5 years (2008–2012) in 0.5-mile elementary school parcel buffers and school enrollment for each school. The pedestrian volumes around the schools were not available for the study areas and therefore were not included.

Table 21
List of Variable, Their Measurements, Data Sources, Units of Measurement, and Bivariate Analyses

Variables	Measurements	Data source	Time	Unit of measurement	Descriptive statistics	Bivariate analysis
						Coefficient (*p*-value)
Dependent variable (street segment-level)						
Occurrence of a collision involving elementary school–aged children during school travel time	Yes (1), No (0)	TxDOT	2008-2012	Point	1: 3168 (19.72%) 0: 12895 (80.28%)	–
Control variables						
Risk exposures (school-level)						
School enrollment[a]	Number of students enrolled for each school / area of the school parcel buffer (acres)	Academic Excellence Indicator System	2011	Each school	Mean:2.38 S.D.[c]:0.93 Min.[d]:0.74 Max.[e]:4.69	0.01 (0.872)
Traffic volume	Vehicle miles traveled during five years in the school parcel buffer / area of the school parcel buffer (acres)	City of Austin	2006	Point	Mean:2422.17 S.D.:2412.40 Min.:9.23 Max.:9632.72	0.01*** (<0.001)
Socio-demographic characteristics[b] (school-level)						
Population density	Total population / area of the school parcel buffer (acres)	U.S. Census Bureau	2010	Census block group	Mean:6.54 S.D.:3.08 Min.:0.60 Max.:15.17	0.05** (0.003)
% of the population younger than 18 years	Population under age 18 / total population				Mean:0.23 S.D.:0.09 Min.:0.07 Max.:0.41	0.17** (0.002)
% of non-white population	Non-white population / total population				Mean:0.32 S.D.:0.17 Min.:0.07 Max.:0.73	0.13** (0.003)

[a] Downloaded from AEIS 2011-2012 (Academic Excellence Indicator System).
[b] Used 2010 census block group data and area apportionment approach to estimate.
[c] Standard deviation.
[d] Minimum.
[e] Maximum.
*: p<0.05, **: p<0.01, ***: p<0.001

Table 21 Continued

Variables	Measurements	Data source	Time	Unit of measurement	Descriptive statistics	Bivariate analysis
						Coefficient (*p*-value)
% of the population with an education level less than high school	Population with an education level less than high school / total population				Mean:0.12 S.D.[c]:0.08 Min.[d]:0.01 Max.[e]:0.29	0.31** (0.001)
% of male population	Male population / total population	U.S. Census Bureau	2010	Census block group	Mean:0.51 S.D.:0.06 Min.:0.39 Max.:0.79	0.11* (0.023)
% of the population below the poverty line	Population below the poverty line / total population				Mean:0.20 S.D.:0.10 Min.:0.02 Max.:0.55	0.22* (0.013)
Independent variables						
Road environments (street segment-level)						
Segment length	Continuous (mile)				Mean:0.08 S.D.:0.06 Min.:0.01 Max.:0.86	6.92*** (<0.001)
Distance to school parcel	Continuous (mile)				Mean:0.24 S.D.:0.20 Min.:0.01 Max.:0.48	0.45 (0.122)
Posted speed limit	Continuous (miles per hour [MPH])	City of Austin	2010	Street segment	25: 8529 (53.10%) 30: 200 (1.20%) 35:4510 (28.10%) 40: 597 (3.70%) 45:1441 (9.00%) 50:684 (4.30%) 55:11 (0.10%) 65:91 (0.60%)	0.12*** (<0.001)

[c] Standard deviation.

[d] Minimum.

[e] Maximum.

*: p<0.05, **: p<0.01, ***: p<0.001

Table 21 Continued

Variables	Measurements	Data source	Time	Unit of measurement	Descriptive statistics	Bivariate analysis
						Coefficient (*p*-value)
Road class						
Highways/interstates	1=yes; 0=no	City of Austin	2010	Street segment	122 (0.80%)	2.97*** (<0.001)
Arterials	1=yes; 0=no				2052 (12.80%)	2.06*** (<0.001)
Local roads	1=yes; 0=no				9379 (58.40%)	-1.81*** (<0.001)
City collectors	1=yes; 0=no				4235 (26.40%)	0.26** (0.002)
Ramps and turnarounds	1=yes; 0=no				275 (1.70%)	1.38*** (0.002)
Non-motorized infrastructure						
Sidewalk completeness	(Sidewalk length) / (street length × 2) in the street segment buffer	City of Austin	2008	Line	Mean:0.60 S.D.[c]:0.26 Min.[d]:0 Max.[e]:1.00	-2.47*** (<0.001)
Bike lane completeness	(Bike lane length) / (street length × 2) in street segment buffer	City of Austin	2008	Line	Mean:0.20 S.D.:0.30 Min.:0 Max.:1.00	0.24 (0.10)
Transit service						
Transit stops	# of transit stops / area of the street segment buffer (acres)	Capital Metro	2010	Point	Mean:0.11 S.D.:0.27 Min.:0 Max.:2.76	1.92*** (<0.001)
Land use types						
Residential use	Residential area / total area in the street segment buffer (acres)	City of Austin	2010	Parcel	Mean:0.62 S.D.:0.41 Min.:0.01 Max.:1.00	-1.94*** (<0.001)
Commercial use	Commercial area / total area in the street segment buffer (acres)				Mean:0.08 S.D.:0.22 Min.:0 Max.:0.95	2.35*** (<0.001)
Office use	Office area / total area in the street segment buffer (acres)				Mean:0.04 S.D.:0.15 Min.:0 Max.:0.91	2.41** (0.003)

[c] Standard deviation.

[d] Minimum.

[e] Maximum.

*: p<0.05, **: p<0.01, ***: p<0.001

Table 21 Continued

Variables	Measurements	Data source	Time	Unit of measurement	Descriptive statistics	Bivariate analysis
						Coefficient (p-value)
Industrial use	Industrial area / total area in the street segment buffer (acres)	City of Austin	2010	Parcel	Mean:0.02 S.D.[c]:0.11 Min.[d]:0 Max.[e]:0.84	1.11** (0.003)
Park	Park area / total area in the street segment buffer (acres)				Mean:0.07 S.D.:0.21 Min.:0 Max.:0.89	0.13 (0.191)
Neighborhood environments around schools (school-level)						
Non-motorized infrastructure						
Sidewalk completeness	(Sidewalk length) / (street length × 2) in the school parcel buffer	City of Austin	2008	Line	Mean:0.80 S.D.:0.14 Min.:0.28 Max.:0.99	-1.02* (0.021)
Bike lane completeness	(Bike lane length) / (street length × 2) in the school parcel buffer				Mean:0.21 S.D.:0.16 Min.:0 Max.:0.96	0.85 (0.042)
Street connectivity						
Three-leg intersection density	# of three-leg intersections / area of the school parcel buffer (acres)	City of Austin	2010	Point	Mean:0.12 S.D.:0.05 Min.:0.02 Max.:0.26	-0.61 (0.612)
Four-or-more-leg intersection density	# of four-or-more-leg intersections / area of the school parcel buffer (acres)				Mean:0.06 S.D.:0.05 Min.:0.01 Max.:0.23	2.02 (0.131)
Transit service						
Transit stops	# of transit stops / area of the school parcel buffer (acres)	Capital Metro	2010	Point	Mean:0.04 S.D.:0.03 Min.:0 Max.:0.13	-0.86** (0.009)

[c] Standard deviation.

[d] Minimum.

[e] Maximum.

*: p<0.05, **: p<0.01, ***: p<0.001

Table 21 Continued

Variables	Measurements	Data source	Time	Unit of measurement	Descriptive statistics	Bivariate analysis
						Coefficient (*p*-value)
Busy roads						
Highways/freeways	The miles of highway/freeway / total miles in the school parcel buffer	City of Austin	2010	Street segment	Mean:0.04 S.D.[c]:0.08 Min.[d]:0 Max.[e]:0.32	1.31* (0.041)
Arterials	The miles of arterial roads / total miles in the school parcel buffer				Mean:0.12 S.D.:0.10 Min.:0 Max.:0.39	1.82*** (<0.001)
Land use types						
Residential use	Residential area / total area in the school parcel buffer (acres)	City of Austin	2010	Parcel	Mean:0.53 S.D.:0.21 Min.:0.06 Max.:0.90	-0.45 (0.141)
Commercial use	Commercial area / total area in the school parcel buffer (acres)				Mean:0.07 S.D.:0.08 Min.:0 Max.:0.46	2.35*** (<0.001)
Office use	Office area / total area in the school parcel buffer (acres)				Mean:0.04 S.D.:0.08 Min.:0 Max.:0.44	2.13* (0.031)
Industrial use	Industrial area / total area in the school parcel buffer (acres)				Mean:0.04 S.D.:0.08 Min.:0 Max.:0.32	2.01* (0.012)
Park	Park area / total area in the school parcel buffer (acres)				Mean:0.12 S.D.:0.18 Min.:0 Max.:0.83	-1.18** (0.021)

[c] Standard deviation.
[d] Minimum.
[e] Maximum.
*: p<0.05, **: p<0.01, ***: p<0.001

Socio-demographic characteristics included total population density, percentage of population younger than 18 years, percentage of non-white population, percentage of the population with an education less than high school, percentage of male population, and percentage of the population below the poverty line within 0.5-mile elementary school parcel buffers. This study used socio-demographic information for 2010 census block groups and the area apportionment approach (splitting the population in the census block group into the school parcel buffer by the fraction of the area of the school parcel buffer in each census block group) to estimate the above variables.

With respect to travel behaviors, the information regarding the percentages of students walking, biking, and driven by their parents were not available and therefore were not included.

This study considered two types/levels of built environments: road environments around the street segment (level 1) and neighborhood environments around schools (level 2). The parcel–level land use, street centerline, and sidewalk data came from the city of Austin GIS datasets. With regard to road environments, this study generated 100-feet buffers around the street segment. This buffer size was determined based on several considerations. First, this study referred to the minimum requirement regarding lane width, shoulder width, and median width for different road types (i.e., freeways, arterial roads, city collectors, and local roads) from the Federal Highway Administration at the U.S. Department of Transportation (Texas Department of Transportation, 2013). For example, the minimum lane width of highways (taking the wildest road as the example) is 12 feet and each highway has at least two lanes in each direction. The widths of both the outside and the inside shoulder for highways are 4-12 feet on average. If a highway is designed with two lanes and one outside and one inside shoulder for both directions, the minimum total width would be 96 feet. Given these minimum requirements, this study chose a slightly larger buffer size of 100 feet. Second, this buffer size is wide enough to capture most of the land uses around the corresponding street segments while avoiding those along other street segments. Last, this buffer size is reasonably small/narrow to avoid excessive overlaps among the buffers which will cause serious spatial autocorrelations.

For road environments, this study included the segment length, distance to school parcel, posted speed limit, road class (highway/interstate, arterial, local road, city collector, and ramp and turnaround), non-motorized infrastructure (sidewalk and bike lane completeness), transit service density, and the percentage for land use types (residential, commercial, office, industrial, and park) in the 100-feet buffers around the street segment.

For the neighborhood environment around schools, this study included not only the aforementioned variables used in measuring road environments but also additional variables such as the three- and four-or-more-leg street intersection density and the percentage of busy roads (highways/freeways and arterial roads). The 0.5-mile buffer around each school parcel was used as the unit of analysis in order to be consistent with the crash selection criteria.

6.2.3 Data Analysis

This study developed two-level (segment-level and school-level) binomial logistic models to examine the impact of road and school environments on the occurrence of collisions involving elementary school–aged children during school travel time on street segments.

Among the various types of multilevel analysis, random-intercept models have been commonly employed in previous studies. For example, D. Kim, Lee, Washington, and Choi (2007) estimated random-intercept models to examine the probability that a type of crash will occur by using crash-level (level-1) and intersection-level (level-2) predictors. Huang, Chor, and Haque (2008) also used random-intercept models to explore driver injury severity and vehicle damage at signalized intersections. These models considered varying intercepts and assumed that slope coefficients did not vary across level-2 units. Therefore, this study also used random-intercept models to avoid the possibility of excess complexity and nonconvergence (Snijders & Bosker, 2012).

The variance of level-1 residuals for binomial logistic distribution is $\pi^2/3=3.29$, while the intercept variance of level-2 binomial logistic random-intercept model is τ_0^2 (Snijders & Bosker, 2012). The intra-class correlation coefficient (ICC) is calculated by these two variances to examine the average correlation between subjects within a group.

$$\text{ICC} = \frac{\tau_0^2}{\tau_0^2+\pi^2/3} \quad (8)$$

Maas and Hox (2005) suggests a design effect to examine whether the multilevel model is necessary. If the value of the design effect is higher than 2, the use of single–level analysis may lead to biased results.

Design effect= 1+ (average group size-1) ICC* .... (9)

A multilevel binomial logistic model is formulated as follows:

$$log\left(\frac{p_{ij}}{1-p_{ij}}\right) = \beta_{0j} + \sum_{p=1}^{P} \beta_{pj} X_{pj} \quad (10)$$

and

$$\beta_{0j} = \gamma_{00} + \sum_{q=1}^{Q} \gamma_{0q} W_{qj} + u_{0j} \quad (11)$$

$$\beta_{1j} = \gamma_{10} \quad (12)$$

.

.

$$\beta_{pj} = \gamma_{p0} \quad (13)$$

where p_{ij} is the probability of the occurrence of a collision involving elementary school-age children during school travel time on a street segment; γ_{00} is the intercept; W_{qj} is a vector of school-level variables; X_{pj} is a vector of street segment-level variables; γ_{0q} and γ_{p0} are regression coefficients of school-level variables and street segment-level variables, respectively; and u_{0j} is the random effect at level 2, where $u_{0j} \sim N(0, \tau_0^2)$.

For the modeling procedure, this study first tested bivariate correlations between all independent variables and the dependent variable. For school-level independent variables, this study considered them as the level-2 predictors when testing bivariate associations. The author included only those significant risk exposure and socio-demographic variables from the bivariate analyses at the 95% level to generate the *original base model.* The insignificant variables in the original base model were excluded to generate the *refined base model*. Second, one-by-one tests were conducted for each of the road environments and neighborhood environments variables, by adding one of those at a time to the *refined base model*. Those significant built environmental variables from the one-by-one test were added together to the refined base model to generate the *original final model*. Finally, this study removed insignificant road environments and neighborhood environment variables from the original final model to generate a *refined final model*.

Because of the potential multicollinearity issue, this study used the “grand mean center” approach for all independent variables by subtracting the grand mean of that independent variable from each observation for that variable (Aiken & West, 1991). The estimation of the models was performed by using HLM 7.0.

6.3 RESULTS

6.3.1 Descriptive Statistics and Bivariate Analyses

Table 21 summarizes the descriptive statistics and bivariate correlations between each independent variable and the dependent variable. Within 0.5-mile school parcel buffers, collisions involving elementary school–aged children had occurred in 19.72% of the street segments during school travel time between 2008 and 2012. In terms of socio-demographic characteristics in 0.5-mile school parcel buffers, the mean population density was 6.54 per acre (S.D.=3.08), the mean percentage of the population younger than 18 years was 23%, the mean percentage of non-white population was 32%, the mean percentage of the population with less than high school education was 12%, the mean percentage of male population was 51%, and the mean percentage of the population below the poverty line was 20%.

Regarding road environments, 53.10% of the street segments had the 25 miles per hour (MPH) posted speed limit; 58.40% were local roads; the mean of sidewalk and bike lane completeness around street segments was 60% and 20%, respectively; the mean transit stop density was 0.11 per acre (S.D.=0.27); and the mean percentage of residential use was 62%.

With respect to neighborhood environments around schools, the mean sidewalk and bike lane completeness was 80% and 21%, respectively; the mean density of three-leg and four-or-more-leg intersections was 0.12 per acre (S.D.=0.05) and 0.06 per acre (S.D.=0.05), respectively; and the mean percentage of highways/freeways and arterial roads was 4% and 12%, respectively. The most abundant type of land use around schools was residential use (mean percentage=53%).

In terms of bivariate analyses, traffic volume was significantly associated with school travel–related crashes at the 99% level. For socio-demographic characteristics, all variables were significant at the 95% level. With respect to road environments, all variables were significant at the 99% level except the distance to school parcel, bike lane completeness, and the percentage of parks in the street segment buffer. Regarding neighborhood environments, most of them were significant at the 95% level except the bike lane completeness, three- and four-or-more-leg intersection densities, and the percentage of residential use.

6.3.2 Refined Base Models and One-by-One Tests

The results showed that three variables (traffic volume, the percentage of population with less than high school education, and segment length) were significant at the 95% level in the refined base model (Table 22).

For the road environment, all variables were significant at the 95% level in these one-by-one tests except bike lane completeness and the percentage of parks. Concerning the neighborhood environment around schools, variables including the transit stop density, the percentage of arterials, and the percentages of commercial, office, industrial, and park land uses were significant at the 95% level.

Table 22
The Results of the Refined Base Models and One-by-One Tests

Variables	Coefficient	S.E.[a]	Odds ratio	*p*-value
Refined base model				
School enrollment (students/acre)	–	–	–	–
Traffic volume (cars/acre)	0.01**	0.004	1.0001	0.003
Population density (people/acre)	–	–	–	–
Population younger than 18 years (%)	–	–	–	–
Non-white population (%)	–	–	–	–
Population with less than high school education (%)	0.33**	0.08	1.39	0.006
Male population (%)	–	–	–	–
Population below the poverty line (%)	–	–	–	–
Segment length (mile)	1.85**	0.33	6.36	0.004
Distance to school parcel (mile)	–	–	–	–
One-by-one test				
Road environments				
Posted speed limit (MPH)	0.12***	0.003	1.13	<0.001
Highways/interstates (1=Yes, 0=No)	2.38***	0.25	10.80	<0.001
Arterials (1=Yes, 0=No)	2.09***	0.05	8.08	<0.001
Local roads (1=Yes, 0=No)	-1.82***	0.05	0.16	<0.001
City collector (1=Yes, 0=No)	0.32**	0.05	1.38	0.006
Ramps and turnarounds (1=Yes, 0=No)	1.20**	0.13	3.32	0.007
Sidewalk completeness (%)	-2.30***	0.09	0.10	<0.001
Bike lane completeness (%)	1.88	1.63	6.55	0.132
Transit stops (stops/acre)	2.03***	0.07	7.61	<0.001
Residential use (%)	-1.88***	0.06	0.15	<0.001
Commercial use (%)	2.34***	0.08	10.38	<0.001
Office use (%)	2.35**	0.13	10.49	0.006
Industrial use (%)	1.04**	0.16	2.83	0.008
Parks (%)	0.08	0.10	1.08	0.434
Neighborhood environments around schools				
Sidewalk density (%)	-0.66	0.41	0.52	0.112
Bike lane density (%)	1.02	0.34	2.77	0.121
Three-leg intersections (/acre)	-0.36	1.16	0.70	0.764
Four-or-more-leg intersections (/acre)	2.19	1.24	8.94	0.185
Transit stops (/acre)	-1.61*	0.66	0.20	0.033
Highway/freeway (%)	0.68	0.71	1.97	0.342
Arterials (%)	1.77***	0.54	5.87	<0.001
Residential use (%)	-0.55	0.29	0.58	0.191
Commercial use (%)	1.76**	0.68	5.81	0.012
Office use (%)	2.30*	0.89	9.97	0.041
Industrial use (%)	1.61*	0.71	5.00	0.037
Parks (%)	-0.88*	0.36	0.41	0.029

*: $p<0.05$, **: $p<0.01$, ***: $p<0.001$
[a] Standard error

6.3.3 Refined Final Models

Table 23 presents the final estimated results for the probability of a collision involving elementary school–aged children during school travel time on the street segment. To check whether multilevel analysis fits the dataset, this study calculated the ICC based on Eq. (8) and the design effect from Eq. (9). The ICC was 0.16, indicating that approximately 16% of the total variation was explained by between-school variations. In terms of the design effect, the average number of street segments in each school was 205.94. The value of design effect was 33.79, which was much higher than 2, suggesting that using single-level analysis for this study may lead to biased results. Therefore, the test results confirmed that the multi-level analysis was an appropriate analytical method for this study.

For control variables, traffic volume, the percentage of population with less than high school education, and the segment length were significant. In terms of road environments, posted speed limit, road classes as highways/freeways and arterial roads, transit stop density, and the percentages of commercial, office, and industrial uses around street segments were significantly positive correlates, while the road class as local roads, sidewalk completeness, and the percentage of residential uses around street segments were negatively related to crashes involving elementary school–aged children during school travel time. For neighborhood environments around schools, the percentage of arterial roads and transit stop density were significantly related to the probability of a collision involving elementary school–aged children during school travel time.

Table 23
Final Estimated Results

Variable	Coefficient	S.E.[a]	Odds ratio	95% CI[b]	*p*-value
Fixed part					
Intercept (γ_{00})	-1.86**	0.05	0.16	(0.14, 0.17)	0.001
Control variable					
Traffic volume (cars/acre)	0.03**	0.02	0.99	(0.98, 1.00)	0.007
Population less than high school (%)	0.29*	0.07	1.34	(1.15,1.53)	0.021
Segment length (mile)	1.90*	0.39	6.69	(5.98, 7.40)	0.012
Road environments (segment-level)					
Posted speed limit (MPH)	0.01**	0.004	1.01	(1.00, 1.02)	0.005
Highways/interstates (1=Yes, 0=No)	1.35***	0.28	3.86	(2.23, 6.65)	<0.001
Arterials (1=Yes, 0=No)	0.77***	0.07	2.16	(1.87, 2.51)	<0.001
Local roads (1=Yes, 0=No)	-0.83**	0.07	0.44	(0.38, 0.50)	0.003
Sidewalk completeness (%)	-1.12**	0.11	0.33	(0.26, 0.41)	0.007
Transit stops (stops/acre)	0.77**	0.08	2.16	(1.85, 2.51)	0.004
Residential use (%)	-0.57**	0.07	0.57	(0.49, 0.66)	0.009
Commercial use (%)	0.96***	0.11	2.61	(2.11, 3.22)	<0.001
Office use (%)	1.22*	0.15	3.39	(2.54, 4.57)	0.031
Industrial use (%)	0.41*	0.19	1.51	(1.05, 2.19)	0.047
Neighborhood environments around schools(school-level)					
Transit stops (stops/acre)	-3.36*	1.82	0.03	(0.001, 1.31)	0.043
Arterial roads (%)	1.08**	0.49	2.94	(1.12, 7.73)	0.003
Random part					
Between-group Intercept τ_0^2	0.61				
Within-group $\pi^2/3$	3.29				
ICC	0.16				
Design effect	33.79				

*: p<0.05, **: p<0.01, ***: p<0.001
[a] Standard error
[b] Confidence interval

6.4 DISCUSSION AND CONCLUSION

In terms of risk exposures, this study confirmed that school areas with higher traffic volumes resulted in higher probabilities of crashes involving elementary school–aged children during school travel time on the street segment. Researchers have previously identified schools as high risk crash locations that experience regular, concentrated, and congested traffic flows (Abdel-Aty et al., 2007; Clifton & Kreamer-Fults, 2007; LaScala et al., 2004).

Moreover, school areas with a greater percentage of population with low education levels (less than high school) were associated with increased likelihoods of having crashes involving elementary school–aged children during school travel time. With a 1% increase in the population with less than a high school education, there was a 34% increase in the crash risk. LaScala et al. (2000) also indicated that areas with higher percentages of people with high school or higher education experienced fewer collisions in San Francisco, CA.

The main contribution of this research is the examination of both the road environments and the neighborhood environments around schools. This study also demonstrates the multi-level model is needed due to the hierarchical structures of traffic safety data.

For road environments, highways/interstates and arterial roads had higher probabilities of school travel–related crashes, while local roads had lower likelihoods. This could be related to be the differences in traffic speeds on different road types. Highways and arterial roads are designed for high operating travel speeds with wide and straight lanes, while narrow local roads decrease vehicle speeds, reducing stopping sight distances and giving drivers more time to react to unforeseen hazards (Ewing & Dumbaugh, 2009). The influence of speed limit on each road in this study also confirmed this explanation that roads with a higher speed limit increased the probability of school travel–related crashes.

Roads with completed sidewalks decreased the likelihood of crashes involving elementary school–aged children during school travel time. It is possible that roads with completed and connected sidewalks around schools reduce the situation in which pedestrians walk on the shoulders of streets, which decrease traffic conflicts between pedestrians and vehicles (Boarnet, Anderson, Day, McMillan, & Alfonzo, 2005).

In terms of land uses along street segments, with a 1% increase in commercial, office, and industrial uses, there were 161%, 239%, and 51% increases in the probability of school travel–related crashes, respectively. These traffic-generating land uses, together with the school, lead to more vehicle and pedestrian activities and therefore increase the potential for traffic conflicts. However, for the residential use, every 1% increase was accompanied by a 43% decrease in the crash risk. A New York study also found a negative relationship between the percentage of residential uses and collisions in census tracts (Ukkusuri et al., 2012).

This study added to previous research that two contextual variables (arterial roads and transit stop) had significant influence on school travel-related collisions. A 1% increase in arterial roads around schools led to a 194% increase in the likelihood of school travel–related crashes. Previous studies also revealed that arterial roads with high operating speeds offer drivers less time to react to unexpected hazards (Eluru et al., 2008; Siddliqui et al., 2006; Sze & Wong, 2007; Wier et al., 2009).

The interesting finding is that transit stop density had different directions of association with the crash risk when captured as the road environment variable versus the neighborhood environment variable. Every density increase of transit stops in the

100-feet buffer along street segment and in the 0.5-mile buffer around school was associated with a 116% increase and a 97% decrease in the probability of school travel–related crashes, respectively. One possible explanation is that within the 0.5-mile school buffer, transit services provide personal mobility to individuals traveling to and from school and decrease the traffic volume in the school area, which in turn lowers the crash risk. However, within the 100-feet street segment buffer, transit stops act as focal points generating a lot of pedestrian activities along the segments during school travel time, increasing the conflicts between pedestrians and vehicles and the likelihood of school travel–related collisions.

The results have several implications for built environmental designs around schools and school site choice in promoting school travel safety. First, planners should plan an environment with low traffic volume and low-speed roads around the school area. Lowering traffic volume in the school area could relieve the congested and mixed traffic flows during school rush hours. One possible way to reduce traffic volume is to provide attractive and safe alternatives, such as walking, biking, and public transit (Technical Administration and City Planning Office, 2007). This study proved that offering more transit services within the school area and connected sidewalks on the routes to school decrease the crash risk. Moreover, designing a complementary network of low-speed roads (i.e., local roads) or locating schools and designating attendance areas strategically to reduce the need to travel on freeways/highways during school travel both lower the crash risk for school travel. Second, planners should consider strategies to limit non-residential uses along the streets near schools and/or locate schools within or close to residential neighborhoods. Traffic-generating uses along routes to schools generate more trips, which increase traffic volume and pedestrian activities. Last, planners should pay more attention to roads with transit services. Based on the possible explanation that transit stops produce multiple pedestrian activities at a time and lead to potential traffic conflicts, planners need to use traffic calming strategies such as the provision of buffers between transit stops and vehicle roadways to promote safety.

This study has some limitations that need to be addressed. First, the micro-level features of built environments, such as the maintenance and quality of traffic infrastructure and neighborhood facilities, were not considered in this study due to data limitations. Second, several criteria were applied to increase the possibility to identify the crashes that involved elementary school–aged children during school travel time. But this study still cannot confirm whether these crashes were actually related to school travel. Third, the results of this study may be subject to the scale effect in the MAUP issue since this study only considered one buffer size (half mile) around school parcels. Last, some information or data were not available. In the selection of crashes during school travel time, due to the lack of information regarding the exact dates of the crashes, this study could not identify crashes that happened during the school year. Moreover, the numbers of students who walk, bike, or were driven by their parents to school were not available from ISDs. The "travel behaviors" domain of control variables could not be considered.

7. CONCLUSIONS

This dissertation examined the effects of built environments on traffic safety in two different spatial scales (neighborhood-level and school-level) in Austin, TX. The results revealed the important roles of built environments on traffic safety. This study made several contributions to the existing literature on this topic, regarding local spatial variations in the impacts of built environments on collisions with different levels of injury severities, disparities in traffic safety across neighborhoods with different economic statuses and ethnic compositions, and the associations between built environments and school travel safety.

7.1 LIMITATIONS

Although this study contributes important knowledge about the impact of built environments on crash frequency at the neighborhood level and school level, several limitations need to be acknowledged. First, the GIS datasets used in this study have slight variations in their time frames due to their limited availability. These varying time frames may cause biased estimates as urban patterns would be slight changed in different years. However, the objective measurements of these GIS data for built environmental variables provide the benefit of directly translating study results into intervention strategies. Second, the generalizability of results from Aim 1-1 is limited. GWPRs provide an effective tool to estimate non-stationary relationships between crashes and independent variables by producing local coefficients for each spatial unit in Austin, TX. However, the results could not be directly transferred and generalized to other areas. Different jurisdictions need to develop their own local models to guide their planning efforts in improving traffic safety. Third, because the five crash variables (total, fatal, serious, minor, and no injury crashes) were highly correlated with each other in Aim 1-1. It is possible that each injury model may examine almost the same dependent variable. Therefore, the intended contribution of this study related to examining crashes with different injury severities might be limited. Last, some information or data are not available (e.g., the date of the crash occurred and the numbers of students who walk, bike, or driven by their parents to school) for school-level analysis (Aim 2). This omission could have introduced some biases to the perimeter estimates. In the selection of crashes during school travel, due to the lack of information regarding the dates of the crashes, this study could not identify crashes that happened during the school year. Moreover, although this dissertation applied several criteria to identify the crashes that involved elementary school–aged children during school travel time, this study still cannot confirm whether these crashes were actually related to school travel. In addition, the numbers of students who walk, bike, or driven by their parents to school were not available from the AISD. The “travel behaviors” domain of control variables could not be considered in Aim 2.

7.2 SUMMARY OF THE FINDINGS

Section 4 explored the local relationships between built environments and crashes with different levels of injury severity (fatal, serious, minor, and no injury). It also compared the performance of global models (negative binomial model) and local models (Geographically Weighted Poisson Regression). The findings illustrated that traffic volume, highways/freeways, arterial roads, and commercial uses had consistent positive associations with total, fatal-injury, serious-injury, minor-injury, and no-injury crashes in census block groups. The results also demonstrated that built environments had stronger influences in some areas but became weaker predictors in other places.

Section 5 investigated disparities in crashes with different levels of injury severities (fatal, serious, minor, and no injury) across neighborhoods with different economic statuses (population below the poverty line) and ethnic compositions (non-white population). In addition, the author also examined whether the built environment–traffic safety relationship differed in areas with different socio-demographic characteristics. The results showed that non-white population was only significantly related to minor-injury crashes in census block groups. It is likely that the impacts of other factors (e.g., traffic volume, highways/freeways, arterials, commercial uses) had stronger impacts on traffic safety than neighborhoods' economic statuses and ethnic compositions. Furthermore, some built environmental variables (e.g., arterial road, office use, and school) showed significant impacts on traffic safety only in areas with high percentages of non-white population and population below the poverty line but not in low-percentage areas.

Section 6 explored the influence of built environments (road environments and neighborhood environments around schools) on school travel safety by using two-level binomial logistic models. This study found that roads with higher posted speed limits, the road classes as highways/freeways and arterials, higher percentages of commercial, office, and industrial uses around street segments significantly increased the probability of crashes involving elementary school–aged children during school travel time. One interesting finding is that transit stop density around street segments and in the 0.5-mile school buffer had contrasting impacts on school travel safety. This suggested that built environmental factors in different spatial scales might have different influences, which were overlooked in previous studies.

7.3 DISCUSSIONS AND IMPLICATIONS FOR FUTURE RESEARCH AND PRACTICE

The "Discussion" sections in previous sections discussed the implications of study findings as related to each section's research question. This section will synthesize findings from previous sections and explore their implications for future research and practice in relevant areas.

Results from previous sections showed that some built environmental variables (e.g., highways and commercial land uses) had consistent, positive associations with crashes with different levels of injury severity and crashes involving elementary school–aged children during school travel time. Therefore, future planning and transportation efforts in improving traffic safety should pay extra attention to these specific elements.

7.3.1 Highway

Highways are designed for high operating travel speeds with wide and straight lanes. Areas with more miles and higher percentages of highways were related to more crashes. This finding was consistent with the results of previous studies conducted in New York, NY (Ukkusuri et al., 2012) and in San Antonio, TX (Dumbaugh & Rae, 2009). One possible reason is that highways could generate a large amount of vehicle traffic, and thereby increase the crash risk (Dumbaugh & Rae, 2009). Another possible explanation is the speed difference between highways and other types of roadways. Because 68% of the roads in the 0.5-mile buffer around school parcels are local roads, vehicles with high travel speeds on highways have to decelerate before they enter local roads. This deceleration may cause conflicts between vehicles exiting from highways and those on local roads, thus leading to more crashes.

Some periphery areas had larger coefficients of the relationship between highway and crashes than some downtown areas. If the speed difference between highways and surrounding low-speed roads is one of the reasons for this association as explained earlier, planners and policy makers should provide well-designed deceleration lanes to allow for safer transitions from highways to low-speed roads, especially in these periphery areas. These deceleration lanes could provide gradual accelerations and decelerations for vehicles entering and exiting highways (Transportation Research Board, 2003).

7.3.2 Commercial Use

A higher percentage of commercial uses was associated with more crashes with different levels of injury severity and crashes involving elementary school–aged children during school travel time. This finding was also consistent with results from previous studies. A Hawaiian study showed that a greater number of commercial parcels in geographic units was associated with more crashes (I. Kim et al., 2006). Ukkusuri et al. (2012) reported a positive relationship between the percentage of commercial uses and the number of crashes in census tracts in New York, NY. In addition, commercial uses also had larger coefficients in some periphery areas than in some downtown areas, which has never been discussed in prior research. One possible explanation is the auto-oriented site design used in most commercial uses. Because commercial uses are usually set back from roads and parking lots, driveway access is a potential location for conflicts among users of different transportation modes (e.g., vehicles, cycling, and walking) (Dumbaugh & Li, 2011). Therefore, the well-designed driveway access from surrounding roads to commercial uses through transportation and land use planning is needed to address traffic safety issue, especially for periphery areas with high-speed roads. Such access points may act as potential locations for conflicts among different road users (vehicles, pedestrians, and cyclists). A speed difference between vehicles on surrounding roads and those entering or leaving the commercial areas may not provide sufficient time for drivers to decelerate or accelerate and therefore increase the risk of crashes. Access management is an approach used by transportation planners to provide safe access to abutting land uses without sacrificing the flow of traffic on surrounding roads (Transportation Research Board, 2003).

Several factors should be considered in designing a safe driveway access from adequate spacing design to limiting the number of access points (Transportation Research Board, 2003). First, adequate spacing among driveways and between driveways and intersections is important. Vehicles with high operating speeds on surrounding roads require long stopping sight distances and enough room to decelerate when they enter or leave the road. Providing insufficient space may cause conflicts among vehicles with different travel speeds. Second, traffic control devices such as speed humps and speed tables on driveways may force drivers to slowdown, which decreases the safety threats. Another approach is to limit the number of driveway entering the commercial areas. If every land use parcel along roads has one driveway access, the density of driveways becomes higher, which provides insufficient space for drivers to accelerate or decelerate. The design of a shared access would be an effective strategy to reduce the number of driveways along the street segment. A shared access with a consolidated signage may help improve the ease of entering and leaving the area. Drivers may also pay greater attention to this clear driveway notification when driving through these areas.

Furthermore, the coordination between transportation planners and land use planners plays an important role in addressing these potential traffic conflicts. To provide a shared access for all stores, promoting a shopping plaza or mixed use development via flexible zoning approaches would be effective. When customers need to go to adjacent shopping plazas, these plazas could link together to avoid the need to enter or exit onto surrounding roads. Narrow-lot parcels (e.g., commercial strips) should be avoided since they have been found to increase all types of crashes (e.g., motorist, multiple-vehicle, fixed-object, parked-car, pedestrian, and cyclist crashes) in a San Antonio, TX study (Dumbaugh & Li, 2011).

Another possible reason for the positive relationship between commercial uses and crashes may be traffic conflicts between pedestrians and vehicles, as both commercial uses and schools need to be accessible by the surrounding roads. A closer examination of crash locations revealed that 65% of crashes occurred on roads where their adjacent uses included either commercial uses or schools. Figure 27 shows a school site layout, its relationships with surrounding commercial use, and the adjacent crash locations. Several school travel-related crashes occurred on the road surrounded by commercial uses and the school. Drivers cannot quickly stop for pedestrian crossing streets, even if they drive on local roads with low travel speeds. Two issues contribute to this type of accident: (1) no clear driveway notification for drivers, and (2) no crosswalks in the middle of the road for pedestrian passing. When these two elements are provided, drivers will pay greater attention when driving through these areas even if there is no visible pedestrian passing.

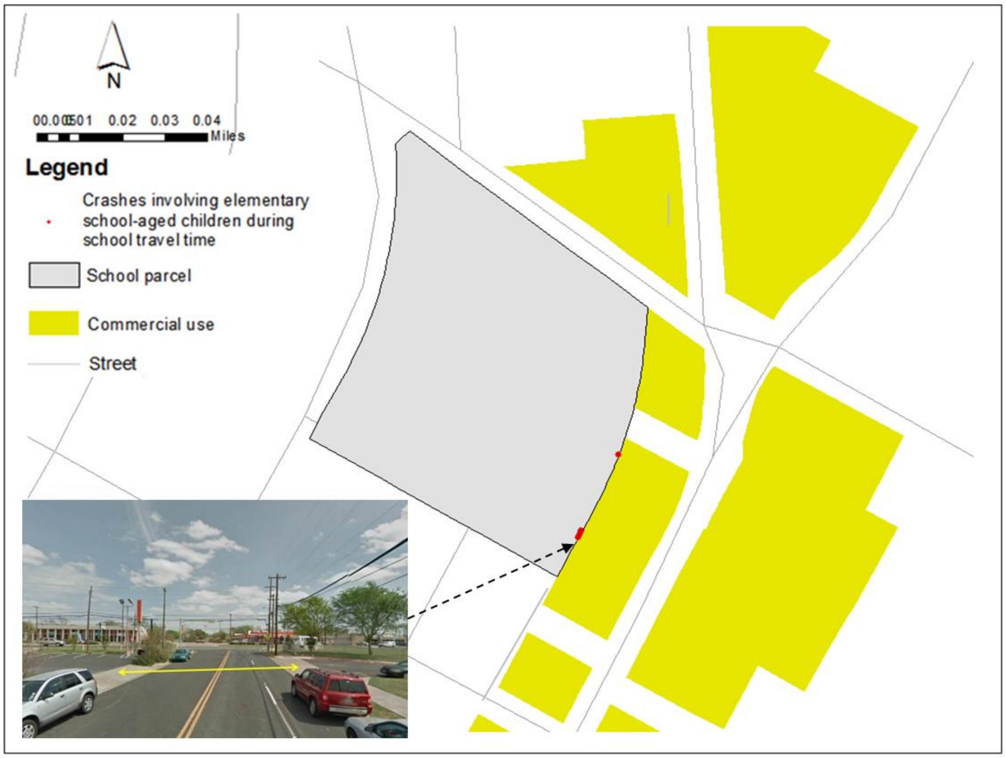


Figure 27
School Site Layout, Its Relationship with Surrounding Commercial Uses, and Relevant Crash Locations

7.3.3 Built Environmental Designs around Schools and School Site Choice

With respects to school travel safety, planners should consider strategies to limit/control the speed and volume of the traffic around schools as top priorities. One possible way to reduce traffic volume is to provide attractive and safe alternatives modes of transportation such as walking, biking, and public transit. This study found that a higher transit stop density within 0.5-mile school parcel buffers was related to lower probability of crashes involving elementary school–aged children during school travel time. Moreover, designing a complementary network of low-speed roads (i.e., local roads) in the vicinity of school areas or locating schools in low-speed environments lower the crash risk for school travel. Second, traffic-generating uses should not be located around school areas. Last, planners should pay more attention to roads with transit services. As discussed earlier, street segments with more transit stops were associated with a higher probability of crashes involving elementary school–aged children during school travel time, likely because transit stops increase pedestrian activities along the segment and lead to more traffic conflicts between pedestrians and vehicles. Planners need to use traffic calming strategies such as the provision of buffers between transit stops and vehicle roadways to promote safety along street segments with transit stops. Figure 28 provides one example of possible solutions.

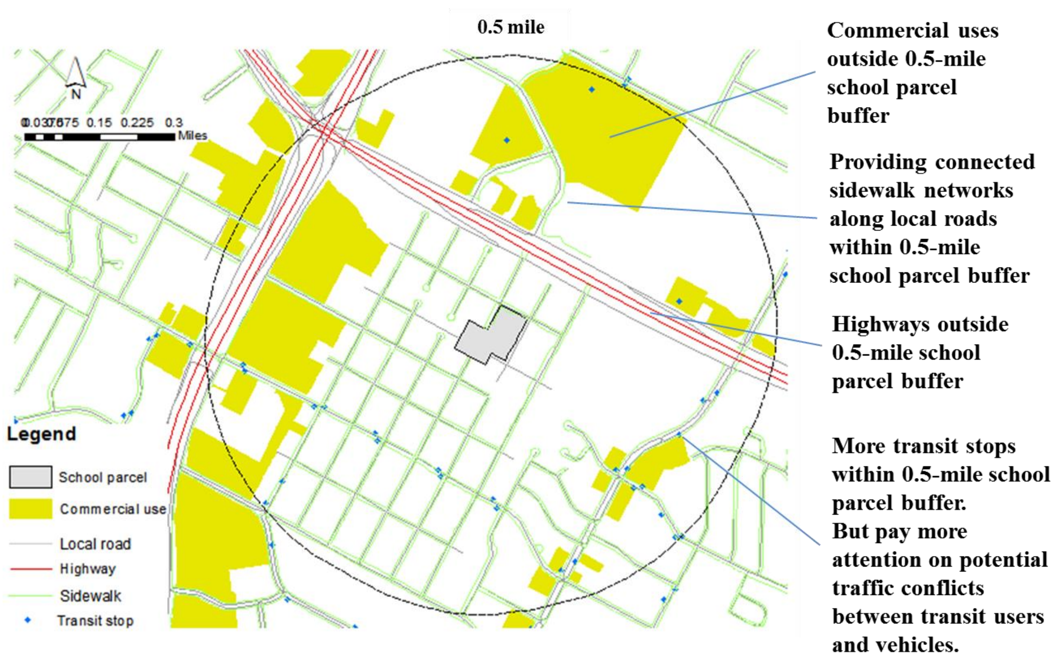


Figure 28
Suggested Built Environmental Designs within 0.5-mile School Parcel Buffers

7.3.4 Tailored Traffic Safety Planning and Policies for Areas with More Minority Populations

This study found that planning and policies related to arterial roads, office uses, and schools may not equally promote traffic safety in areas with different economic statuses and ethnic compositions. Tailored traffic safety strategies are need for areas with more non-white and low-income people. To generate tailored traffic safety planning for areas with concentrated minority populations, it is necessary to include the perspectives from non-white and low-income people into the traffic safety planning process (Anguelovski, 2013).

Most planners and practitioners depend on prior crash data to examine possible factors affecting traffic safety to formulate effective interventions. Recent researchers have emphasized a proactive and comprehensive approach by including planning context and perception of environments into the traffic safety planning (Meyer, 2005). Perceived traffic safety has been identified as an important factor because it could explain people's behaviors and identify potential high–risk areas (Lam, 2001; Schneider et al., 2004). Therefore, understanding the perceived traffic safety for those non-white and low-income people would be a feasible way to adjust and generate tailored traffic safety policies and programs.

Traffic safety has been and will continue to be an important topic for transportation engineers, urban planners, and land developers. This study provides preliminary evidence and also demonstrates the need for more detailed studies in this field.

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APPENDIX A

URBAN DEVELOPMENT CHANGE

Land Use Change (2003-2010)

Area difference: area 2010 – area 2003 (acres).

% of area difference: (area 2010 – area 2003) / area 2003.

Count difference: count 2010 – count 2003.

% of count difference: (count 2010 – count 2003) / count 2003.

Census Block Group

Land Use Change in Census Block Groups

	Area difference	% of area difference	Count difference	% of count difference
	Mean (standard deviation) Min. – Max.			
Residential use	5.62 (30.87) -266.40 – 374.40	5.16% (24.81%) -100% – 340%	17.01 (93.42) -183 – 1476	8.88% (69.61%) -100% – 945%
Commercial use	2.46 (14.93) -91.84 – 167.42	27.74% (200.69%) -100% – 3532%	0.28 (3.08) -17 – 30	11.73% (87.89%) -100% – 1400%
Office use	-0.55 (20.26) -278.62 – 143.08	18.82% (153.79%) -100% – 2276%	0.19 (2.40) -16 – 15	8.66% (59.88%) -100% – 467%
Industrial use	1.90 (18.37) -209.47 – 147.83	107.59% (10.22%) -100% – 12545%	0.22 (2.51) -9 – 30	5.19% (76.82%) -100% – 500%
School	2.49 (23.49) -26.65 – 458.91	22725% (4020.29%) -100% – 7124024%	0.19 (2.26) -39 – 10	11.86% (53.66%) -100% – 300%
Open space	7.03 (25.56) -69.87 – 220.15	1448.42% (13649.64%) -100% – 207652%	2.14 (9.24) -18 – 149	64.60% (173.66%) -100% – 1300%

Census Tract

Land Use Change in Census Tracts

	Area difference	% of area difference	Count difference	% of count difference
	Mean (standard deviation) Min. – Max.			
Residential use	15.09 (63.16) -256.74 – 396.47	5.72% (32.4%) -100% – 340%	60.56 (194.59) -246 – 1556	14.23% (99.88%) -100% – 945%
Commercial use	5.04 (22.63) -18.95 – 233.57	32.86% (95.82%) -28% – 387%	0.80 (5.69) -18 – 37	24.2% (145.07%) -100% – 1700%
Office use	-1.09 (33.11) -278.62 – 143.08	20% (122%) -100% – 900%	0.47 (4.18) -16 – 15	11.14% (65.19%) -100% – 467%
Industrial use	4.28 (25.89) -133.21 – 172.21	169% (1312.5%) -100% – 12800%	0.66 (4.32) -12 – 30	19% (95.2%) -100% – 600%
School	6.86 (39.11) -26.65 – 452.39	39% (154.1%) -100% – 1300%	0.54 (3.92) -41 – 10	18% (50.2%) -100% – 300%
Open space	27.42 (105.63) -51.21 – 1205.26	368% (1882.8%) 0% – 17500%	6.35 (19.89) -18 – 209	83% (169.7%) 0% – 1000%

Traffic Analysis Zone

Land Use Change in Traffic Analysis Zones

	Area difference	% of area difference	Count difference	% of count difference
	Mean (standard deviation) Min. – Max.			
Residential use	4.90 (26.45) -230.40 – 213.45	148.63% (2956%) -100% – 67352%	19.25 (92.81) -246 – 912	155.19% (1828.15%) -100% – 31400%
Commercial use	1.83 (11.18) -91.57 – 121.01	83.51% (1013.39%) -100% – 21235%	0.23 (2.30) -11 – 17	16.74% (97.89%) -100% – 1300%
Office use	-0.40 (17.64) -288.29 – 133.06	20.33% (120.23%) -100% – 1193%	0.15 (2.04) -18 – 13	13.06% (77.33%) -100% – 700%
Industrial use	1.34 (15.85) -267.09 – 147.83	67.89% (824.69%) -100% – 12545%	0.17 (1.88) -10 – 25	5.22% (73.83%) -100% – 500%
School	2.03 (20.12) -20.40 – 436.65	184.45% (2730.77%) -100% – 52605%	0.18 (1.74) -30 – 10	10.14% (57.71%) -100% – 400%
Open space	5.92 (28.57) -287.04 – 265.79	174851% (3299140%) -100 – 62423131%	1.89 (10.00) -18 – 208	67.99% (192.12%) -100% – 1600%

Street Mile Change (2007-2011)

Mile difference: mile 2011 – mile 2007.

% of mile difference: (mile 2011 – mile 2007) / mile 2007.

Street Mile Change in the Three Spatial Units

	Mile difference	% of mile difference
	Mean (standard deviation) Min. – Max.	
Census block group	0.10 (0.41) -0.53 – 4.41	1.45% (6.92%) -10.34% - 114.53%
Census tract	0.29 (0.67) -0.56 – 4.41	1.59% (4.15%) -6.95% - 37.77%
Traffic analysis zone	0.09 (0.34) -0.66 – 3.85	2.12% (9.51%) -9.26% - 118.12%

APPENDIX B

RESULTS IN CENSUS TRACTS AND TRAFFIC ANALYSIS ZONES

Census Tract

Descriptive Statistics and Bivariate Correlations between Each Independent or Control Variable and Dependent Variable (Unit of Analysis: Census Tract)

	Descriptive statistics				Bivariate analysis (N=144)				
Variables					Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Mean	S.D.[a]	Min.[b]	Max.[c]	Coefficient (*p* value)				
Total crash (#)	2622.22	1841.58	272	13920	–	0.72*** (<0.001)	0.78*** (<0.001)	0.99*** (<0.001)	0.99*** (<0.001)
Fatal injury (#)	9.63	9.26	0	39	0.72*** (<0.001)	–	0.64*** (<0.001)	0.73*** (<0.001)	0.67*** (<0.001)
Serious injury (#)	17.33	14.62	0	99	0.78*** (<0.001)	0.64*** (<0.001)	–	0.76*** (<0.001)	0.78*** (<0.001)
Minor injury (#)	1429.01	979.62	58	6322	0.99*** (<0.001)	0.73*** (<0.001)	0.76*** (<0.001)	–	0.95*** (<0.001)
No injury (#)	1166.26	867.07	173	7460	0.99*** (<0.001)	0.67*** (<0.001)	0.78*** (<0.001)	0.95*** (<0.001)	–
Control variables									
Risk exposures									
Traffic volume (#) (million)	653.78	381.74	118.05	2026.36	0.11*** (<0.001)	0.13*** (<0.001)	0.10*** (<0.001)	0.11*** (<0.001)	0.11*** (<0.001)
Area of the spatial unit (acres) (hundred)	440117.8 0	366679.00	30795	1727730	0.01 (0.703)	0.03 (0.180)	0.01 (0.757)	0.03 (0.832)	0.01 (0.564)
Socio-demographic characteristics									
Total population (#) (thousand)	4195.56	1568.04	584	9381	0.04 (0.259)	0.03 (0.558)	0.04 (0.314)	0.04 (0.289)	0.04 (0.238)
Population aged under 18 (#) (thousand)	931.10	597.59	12	2857	0.02 (0.828)	0.19 (0.170)	0.14 (0.197)	0.04 (0.674)	0.01 (0.934)
Non-white population (#) (thousand)	1333.26	962.29	95	4215	0.16** (0.005)	0.28** (0.003)	0.25*** (<0.001)	0.18** (0.002)	0.13* (0.018)

[a] Standard deviation
[b] Minimum
[c] Maximum
*: p<0.05, **: p<0.01, ***: p<0.001

Continued

Variables	Descriptive statistics				Bivariate analysis (N=144)				
					Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Mean	S.D.[a]	Min.[b]	Max.[c]	Coefficient (*p* value)				
Population less than high school (#) (thousand)	415.03	457.76	0	2254	0.38** (0.001)	0.77*** (<0.001)	0.64*** (<0.001)	0.42** (0.001)	0.32** (0.005)
Male population (#) (thousand)	2135.04	836.64	210	4388	0.16** (0.008)	0.15 (0.160)	0.16* (0.039)	0.15* (0.017)	0.18** (0.003)
Household below the poverty line (#) (thousand)	785.90	702.75	30	4921	0.28** (0.001)	0.37* (0.010)	0.34** (0.001)	0.29** (0.001)	0.26** (0.002)
Travel behaviors									
Workers commuting by walking (#) (thousand)	61.33	102.85	0	724	1.37* (0.041)	-0.25 (0.825)	0.70 (0.393)	1.08 (0.119)	1.73* (0.010)
Workers commuting by public transit (#) (thousand)	128.40	129.56	0	664	1.72*** (<0.001)	1.59* (0.045)	1.63** (0.006)	1.84*** (<0.001)	1.58*** (<0.001)
Workers commuting by biking (#) (thousand)	36.17	58.70	0	328	3.13** (0.002)	2.84* (0.014)	1.14 (0.391)	2.99*** (<0.001)	3.35*** (<0.001)
Independent variables									
Built environments									
Non-motorized infrastructure									
Sidewalks (miles)	24.38	10.83	1.25	55.56	-0.01 (0.294)	-0.01 (0.384)	-0.004 (0.531)	-0.004 (0.470)	-0.01 (0.148)
Bike lanes (miles)	8.16	6.17	0.51	29.86	0.01 (0.200)	0.01 (0.669)	0.01 (0.519)	0.01 (0.268)	0.01 (0.139)
Street intersections									
Three-leg street intersections (#)	61.65	28.75	7	138	-0.002* (0.021)	-0.002 (0.673)	-0.004 (0.076)	-0.003* (0.031)	-0.002* (0.020)
Four-or-more-leg street intersections (#)	24.08	18.49	0	130	0.01*** (<0.001)	0.01** (0.008)	0.01** (0.005)	0.01*** (<0.001)	0.01*** (<0.001)
Transit service									
Transit stops (#)	16.88	13.97	0	92	0.02*** (<0.001)	0.03*** (<0.001)	0.03*** (<0.001)	0.03*** (<0.001)	0.02*** (<0.001)

[a] Standard deviation
[b] Minimum
[c] Maximum
*: p<0.05, **: p<0.01, ***: p<0.001

Continued

Variables	Descriptive statistics				Bivariate analysis (N=144)				
					Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Mean	S.D.[a]	Min.[b]	Max.[c]	Coefficient (p value)				
Busy road									
Highway/freeway (miles)	2.09	2.39	0	11.41	0.09*** (<0.001)	0.15*** (<0.001)	0.10** (0.001)	0.09*** (<0.001)	0.09*** (<0.001)
Arterials (miles)	3.37	2.27	0.04	14.38	0.11*** (<0.001)	0.11** (0.006)	0.09*** (<0.001)	0.11*** (<0.001)	0.11*** (<0.001)
Land use types									
Residential use (#)	872.21	538.21	0	2891	-0.004*** (<0.001)	-0.004* (0.048)	-0.005*** (<0.001)	-0.004*** (<0.001)	-0.004*** (<0.001)
Commercial use (#)	28.04	33.29	0	266	0.01*** (<0.001)	0.01*** (<0.001)	0.01*** (<0.001)	0.01*** (<0.001)	0.01*** (<0.001)
Office use (#)	16.33	33.00	0	309	0.01*** (<0.001)	0.01 (0.064)	0.01** (0.004)	0.01** (0.001)	0.01*** (<0.001)
Industrial use (#)	8.93	20.22	0	146	0.01** (0.001)	0.01** (0.008)	0.01* (0.024)	0.01** (0.001)	0.01** (0.001)
School (#)	8.64	8.53	0	42	0.03*** (<0.001)	0.03* (0.018)	0.02* (0.025)	0.03*** (<0.001)	0.03*** (<0.001)
Park (#)	15.85	23.46	0	245	0.002 (0.610)	0.001 (0.767)	0.001 (0.738)	0.003 (0.313)	0.003 (0.912)

[a] Standard deviation
[b] Minimum
[c] Maximum
*: p<0.05, **: p<0.01, ***: p<0.001

Results of Refined Base Models and One-by-One Tests between Independent Variable and Dependent Variable (Unit of Analysis: Census Tract)

Variables	Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Coefficient (*p* value)				
Refined base model					
Traffic volume (#) (million)	0.11*** (<0.001)	0.12*** (<0.001)	0.11*** (<0.001)	0.11*** (<0.001)	0.11*** (<0.001)
Area of the spatial unit (acres) (hundred)	0.01 (0.302)	0.01 (0.778)	0.03 (0.051)	0.02 (0.247)	0.01 (0.411)
Non-white population (#)(thousand)	0.11** (0.005)	0.01 (0.928)	0.09 (0.328)	0.12** (0.003)	0.09 (0.157)
Population less than high school (#)(thousand)	0.26 (0.073)	0.77** (0.007)	0.47* (0.020)	0.27 (0.079)	0.23* (0.010)
Workers commuting by biking (#) (thousand)	3.59** (0.001)	2.36* (0.041)	1.53 (0.190)	3.54*** (<0.001)	3.69*** (<0.001)
One-by-one test					
Sidewalks (miles)	-0.003 (0.597)	-0.01 (0.572)	-0.01 (0.462)	-0.003 (0.553)	-0.002 (0.683)
Bike lanes (miles)	0.01 (0.070)	0.004 (0.799)	0.02 (0.080)	0.013 (0.069)	0.01 (0.088)
Three-leg street intersections (#)	-0.004* (0.035)	-0.001 (0.828)	-0.003 (0.202)	-0.004* (0.036)	-0.003* (0.041)
Four-or-more-leg street intersections (#)	0.01** (0.002)	0.01 (0.084)	0.01* (0.026)	0.01* (0.011)	0.01* (0.031)
Transit stops (#)	0.01* (0.041)	0.02* (0.010)	0.02*** (<0.001)	0.01* (0.041)	0.01* (0.042)
Highway/freeway (miles)	0.01*** (<0.001)	0.01*** (<0.001)	0.02* (0.048)	0.01*** (<0.001)	0.02*** (<0.001)
Arterials (miles)	0.10*** (<0.001)	0.11* (0.010)	0.12*** (<0.001)	0.11*** (<0.001)	0.009*** (<0.001)
Residential use (#)	-0.0002* (0.044)	-0.0003 (0.154)	-0.0002** (0.008)	-0.0002* (0.027)	-0.0003** (0.003)
Commercial use (#)	0.01*** (<0.001)	0.005 (0.067)	0.004* (0.021)	0.01*** (<0.001)	0.01*** (<0.001)
Office use (#)	0.004 (0.067)	0.003 (0.182)	0.004* (0.013)	0.003 (0.054)	0.004 (0.061)
Industrial use (#)	0.003 (0.228)	0.002 (0.629)	0.002 (0.625)	0.003 (0.265)	0.003 (0.195)
School (#)	0.01* (0.043)	0.01 (0.199)	0.01 (0.190)	0.01* (0.032)	0.01 (0.079)
Park (#)	0.001 (0.508)	0.001 (0.822)	0.001 (0.678)	0.002 (0.328)	0.001 (0.806)

*: p<0.05, **: p<0.01, ***: p<0.001

Results of Refined Final Negative Binomial Model when Using Census Tracts as the Unit of Analysis

Variables	Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Coefficient (*p* value)				
Traffic volume (#)(million)	0.4846** (0.004)	0.0641* (0.042)	0.0662*** (<0.001)	0.0447*** (<0.001)	0.0462*** (<0.001)
Area of the spatial unit (acres) (hundred)	0.0478 (0.084)	0.0071 (0.769)	0.0323 (0.108)	0.0549 (0.071)	0.0171 (0.196)
Non-white population (#)(thousand)	0.0405* (0.021)	0.0564 (0.653)	0.0659 (0.463)	0.0432** (0.004)	0.0122 (0.828)
Population less than high school (#)(thousand)	0.2864 (0.101)	0.6881* (0.012)	0.6336* (0.042)	0.3265 (0.102)	0.2703* (0.025)
Workers commuting by biking (#) (thousand)	2.1163** (0.004)	0.1572 (0.918)	0.1791 (0.877)	2.1517* (0.034)	2.2559** (0.001)
Transit stops (#)		0.0208* (0.044)	0.0120*** (<0.001)		
Highway/freeway (miles)	0.0765** (0.004)	0.0738** (0.007)	0.0801* (0.031)	0.0821** (0.004)	0.0571* (0.021)
Arterials (miles)	0.0511*** (<0.001)	0.0541* (0.023)	0.0734* (0.023)	0.1025*** (<0.001)	0.0744*** (<0.001)
Residential use (#)			-0.0004* (0.021)		-0.0002** (0.001)
Commercial use (#)	0.0059*** (<0.001)			0.0057*** (<0.001)	0.0062*** (<0.001)

*: p<0.05, **: p<0.01, ***: p<0.001

Traffic Analysis Zone

Descriptive Statistics and Bivariate Correlation between Each Independent or Control Variable and Dependent Variable (Unit of Analysis: Traffic Analysis Zone)

Variables	Descriptive statistics				Bivariate analysis (N=552)				
					Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Mean	S.D.[a]	Min.[b]	Max.[c]	Coefficient (*p* value)				
Total crash (#)	880.43	694.33	9	4030	–	0.53*** (<0.001)	0.66*** (<0.001)	0.99*** (<0.001)	0.98*** (<0.001)
Fatal injury (#)	3.31	4.48	0	33	0.53*** (<0.001)	–	0.44*** (<0.001)	0.54*** (<0.001)	0.49*** (<0.001)
Serious injury (#)	6.22	7.06	0	45	0.66*** (<0.001)	0.44*** (<0.001)	–	0.65*** (<0.001)	0.64*** (<0.001)
Minor injury (#)	481.58	390.06	5	2161	0.99*** (<0.001)	0.54*** (<0.001)	0.65*** (<0.001)	–	0.95*** (<0.001)
No injury (#)	389.33	306.51	2	1825	0.98*** (<0.001)	0.49*** (<0.001)	0.64*** (<0.001)	0.95*** (<0.001)	–
Control variables									
Risk exposures									
Traffic volume (#) (million)	222.57	300.66	7.38	4417.82	0.22*** (<0.001)	0.24*** (<0.001)	0.21*** (<0.001)	0.22*** (<0.001)	0.22*** (<0.001)
Area of the spatial unit (acres) (hundred)	156545.20	181809.40	1260	1278090	0.03* (0.014)	0.07** (0.007)	0.06** (0.005)	0.03* (0.016)	0.03* (0.017)
Socio-demographic characteristics									
Total population (#)(thousand)	1185.03	1100.09	43.14	7261.89	0.20*** (<0.001)	0.19** (0.003)	0.26*** (<0.001)	0.20*** (<0.001)	0.19*** (<0.001)
Population aged under 18 (#) (thousand)	270.92	305.02	3.74	2194.79	0.55*** (<0.001)	0.71** (0.002)	0.89*** (<0.001)	0.59*** (<0.001)	0.49*** (<0.001)
Non-white population (#)(thousand)	378.36	446.62	6.82	3034.73	0.54*** (<0.001)	0.71*** (<0.001)	0.79*** (<0.001)	0.58*** (<0.001)	0.48*** (<0.001)
Population less than high school (#) (thousand)	116.26	183.22	0	1559.29	1.30*** (<0.001)	1.92*** (<0.001)	1.94*** (<0.001)	1.41*** (<0.001)	1.14*** (<0.001)
Male population (#)(thousand)	607.93	565.20	23.45	3698.40	0.42*** (<0.001)	0.43** (0.001)	0.54*** (<0.001)	0.43*** (<0.001)	0.40*** (<0.001)

[a] Standard deviation
[b] Minimum
[c] Maximum
*: p<0.05, **: p<0.01, ***: p<0.001

Continued

Variables	Descriptive statistics				Bivariate analysis (N=552)				
					Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Mean	S.D.[a]	Min.[b]	Max.[c]	Coefficient (p value)				
Household below the poverty line (#)(thousand)	212.88	299.70	4.83	3111.21	0.92*** (<0.001)	0.93*** (<0.001)	1.10*** (<0.001)	0.98*** (<0.001)	0.85*** (<0.001)
Travel behaviors									
Workers commuting by walking (#)(thousand)	16.48	34.21	0	442.85	4.99*** (<0.001)	1.41 (0.542)	1.98 (0.327)	4.75** (0.001)	5.33*** (<0.001)
Workers commuting by public transit (#) (thousand)	33.96	55.11	0	617.14	5.46*** (<0.001)	3.97* (0.011)	5.24*** (<0.001)	5.84*** (<0.001)	5.01*** (<0.001)
Workers commuting by biking (#) (thousand)	9.59	19.36	0	257.51	7.25*** (<0.001)	1.17 (0.786)	1.26 (0.694)	7.23** (0.001)	7.40*** (<0.001)
Independent variables									
Built environments									
Non-motorized infrastructure									
Sidewalks (miles)	7.40	6.74	0.69	49.73	-0.01* (0.042)	-0.02* (0.035)	-0.02* (0.019)	-0.01* (0.039)	-0.01 (0.059)
Bike lanes (miles)	3.72	4.16	0	27.50	0.01 (0.144)	0.01 (0.963)	0.02 (0.065)	0.01 (0.113)	0.01 (0.217)
Street intersections									
Three-leg street intersections (#)	18.24	18.66	0	123	-0.003* (0.034)	-0.01* (0.020)	-0.01* (0.019)	-0.004* (0.037)	-0.004* (0.043)
Four-or-more-leg street intersections (#)	6.81	6.43	0	51	0.03*** (<0.001)	0.02 (0.051)	0.03** (0.001)	0.03*** (<0.001)	0.03*** (<0.001)
Transit service									
Transit stops (#)	4.62	4.04	0	27	0.07*** (<0.001)	0.06*** (<0.001)	0.09*** (<0.001)	0.08*** (<0.001)	0.07*** (<0.001)
Busy roads									
Highway/free way (miles)	0.80	1.33	0	9.82	0.21*** (<0.001)	0.28*** (<0.001)	0.24*** (<0.001)	0.21*** (<0.001)	0.20*** (<0.001)
Arterials (miles)	1.23	1.17	0	8.20	0.20*** (<0.001)	0.22*** (<0.001)	0.25*** (<0.001)	0.20*** (<0.001)	0.19*** (<0.001)
Land use types									
Residential use (#)	256.76	328.51	0	2704	-0.004 (0.635)	-0.001 (0.512)	-0.001 (0.505)	-0.002* (0.010)	-0.002* (0.012)
Commercial use (#)	7.68	9.02	0	69	0.04*** (<0.001)	0.02** (0.002)	0.03*** (<0.001)	0.04*** (<0.001)	0.04*** (<0.001)

[a] Standard deviation
[b] Minimum
[c] Maximum
*: p<0.05, **: p<0.01, ***: p<0.001

Continued

Variables	Descriptive statistics				Bivariate analysis (N=552)				
					Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Mean	S.D.[a]	Min.b	Max.[c]	Coefficient (p value)				
Office use (#)	4.51	7.24	0	65	0.02*** (<0.001)	0.01* (0.023)	0.01* (0.027)	0.02** (0.002)	0.02*** (<0.001)
Industrial use (#)	2.66	6.83	0	67	0.01** (0.005)	0.02 (0.063)	0.01 (0.076)	0.02** (0.004)	0.01* (0.012)
School (#)	2.42	3.24	0	22	0.02* (0.024)	0.02 (0.349)	0.02 (0.162)	0.03* (0.011)	0.02 (0.074)
Park (#)	5.10	12.63	0	244	0.001 (0.734)	0.005 (0.398)	0.003 (0.499)	0.001 (0.64)	0.001 (0.822)

[a] Standard deviation
[b] Minimum
[c] Maximum
*: p<0.05, **: p<0.01, ***: p<0.001

Results of Refined Base Models and One-by-One Tests between Independent Variable and Dependent Variable (Unit of Analysis: Traffic Analysis Zone)

Variables	Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Coefficient (*p* value)				
Refined base model					
Traffic volume (#) (million)	0.21*** (<0.001)	0.20*** (<0.001)	0.18*** (<0.001)	0.21*** (<0.001)	0.21*** (<0.001)
Area of the spatial unit (acres) (hundred)	0.02* (0.037)	0.03 (0.232)	0.004 (0.795)	0.02* (0.033)	0.02* (0.040)
Non-white population (#)(thousand)	0.26* (0.029)	0.04 (0.878)	0.25 (0.248)	0.27* (0.034)	0.25* (0.030)
Population less than high school (#)(thousand)	0.62* (0.027)	1.63* (0.017)	1.19* (0.016)	0.71* (0.017)	0.50* (0.035)
Workers commuting by biking (#) (thousand)	6.46* (0.011)	0.79 (0.842)	1.46 (0.616)	6.53* (0.032)	6.49* (0.037)
One-by-one test					
Sidewalks (miles)	-0.007* (0.011)	-0.01 (0.355)	-0.01 (0.540)	-0.01 (0.199)	-0.01 (0.360)
Bike lanes (miles)	0.01 (0.097)	0.01 (0.423)	0.02 (0.211)	0.01 (0.063)	0.01 (0.177)
Three-leg street intersections (#)	-0.003 (0.094)	-0.002 (0.678)	-0.002 (0.596)	-0.004 (0.066)	-0.003 (0.157)
Four-or-more-leg street intersections (#)	0.02 (0.071)	0.001 (0.916)	0.01 (0.081)	0.02 (0.094)	0.02 (0.107)
Transit stops (#)	0.06*** (<0.001)	0.04* (0.047)	0.06*** (<0.001)	0.06*** (<0.001)	0.06*** (<0.001)
Highway/freeway (miles)	0.03*** (<0.001)	0.08*** (<0.001)	0.09*** (<0.001)	0.04*** (<0.001)	0.03*** (<0.001)
Arterials (miles)	0.18*** (<0.001)	0.15*** (<0.001)	0.20*** (<0.001)	0.19*** (<0.001)	0.17*** (<0.001)
Residential use (#)	-0.0003 (0.070)	-0.0002 (0.404)	-0.0002 (0.207)	-0.0003* (0.012)	-0.0003* (0.015)
Commercial use (#)	0.03*** (<0.001)	0.01 (0.280)	0.02*** (<0.001)	0.03*** (<0.001)	0.03*** (<0.001)
Office use (#)	0.02* (0.041)	0.02* (0.031)	0.02* (0.039)	0.01* (0.015)	0.02 (0.121)
Industrial use (#)	0.001 (0.879)	0.01 (0.497)	0.001 (0.858)	0.002 (0.638)	0.001 (0.771)
School (#)	0.01 (0.125)	0.0003 (0.990)	0.002 (0.904)	0.02 (0.070)	0.01 (0.259)
Park (#)	0.004 (0.060)	0.001 (0.874)	0.002 (0.477)	0.01 (0.071)	0.004 (0.060)

*: p<0.05, **: p<0.01, ***: p<0.001

Results of Refined Final Negative Binomial Model when Using Traffic Analysis Zones as the Unit of Analysis

Variables	Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Coefficient (*p* value)				
Traffic volume (#) (million)	0.1241*** (<0.001)	0.1250* (0.017)	0.0835* (0.025)	0.1161*** (<0.001)	0.1240*** (<0.001)
Area of the spatial unit (acres) (hundred)	0.0216 (0.084)	0.013 (0.586)	0.0368 (0.059)	0.0465 (0.071)	0.0403 (0.112)
Non-white population (#) (thousand)	0.1752 (0.133)	0.2544 (0.387)	0.0142 (0.948)	0.0738* (0.048)	0.1207 (0.264)
Population less than high school (#)(thousand)	0.2811* (0.034)	1.9159* (0.039)	1.0175* (0.032)	0.4590 (0.088)	0.2197* (0.043)
Workers commuting by biking (#) (thousand)	3.8381 (0.054)	0.4631 (0.908)	1.7554 (0.537)	3.069 (0.053)	3.3132 (0.069)
Sidewalks (miles)	-0.0193* (0.023)				
Transit stops (#)	0.0345*** (<0.001)		0.0424** (0.004)	0.0208*** (<0.001)	0.0314*** (<0.001)
Highway/freeway (miles)	0.1180*** (<0.001)	0.1444** (0.021)	0.1751** (0.001)	0.1388*** (<0.001)	0.1255*** (<0.001)
Arterials (miles)	0.1844*** (<0.001)	0.1894** (0.007)	0.2063*** (<0.001)	0.1734*** (<0.001)	0.1535*** (<0.001)
Commercial use (#)	0.0254*** (<0.001)		0.0193** (0.001)	0.0041*** (<0.001)	0.0260*** (<0.001)

*: p<0.05, **: p<0.01, ***: p<0.001

APPENDIX C

DESCRIPTIVE STATISTICS OF CRASH VARIABLES FOR AIM 1-1

Aim 1-1: Examining the Impacts of Neighborhood Environments on Crashes with Different Levels of Injury Severity

Crash Counts (2004–2012) in Each Spatial Unit

		Fatal injury	Serious injury	Minor injury	None injury
Tract (n=144)	Mean	9.67	17.76	1378.34	1124.09
	Variance	86.59	235.24	982068.24	750227.68
	S. D.	9.31	15.34	990.99	866.16
	Min.	0	0	0	0
	Max.	39	99	6322	7460
	% with zero crash	16.7%	4.5%	2.6%	2.6%
Block group (n= 426)	Mean	3.93	7.23	565.04	455.78
	Variance	30.56	90.12	328231.02	255913.81
	S. D.	5.53	9.49	572.91	505.88
	Min.	0	0	0	0
	Max.	31	93	5728	6827
	% with zero crash	43.6%	22.7%	1.8%	1.8%
TAZ (n=552)	Mean	3.25	5.93	469.96	378.54
	Variance	20.42	47.77	162614.02	97595.14
	S. D.	4.52	6.91	403.25	312.40
	Min.	0	0	0	0
	Max.	33	45	2800	1828
	% with zero crash	45.2%	26.1%	1.9%	1.9%

Crash Rates (2004-2012) in Each Spatial Unit

		Fatal injury	Serious injury	Minor injury	None injury
Tract (n=144)	Mean	0.02	0.04	3.40	2.78
	Variance	0.001	0.003	13.09	9.67
	S. D.	0.03	0.05	3.62	3.11
	Min.	0	0	0.08	0.06
	Max.	0.13	0.37	28.52	21.98
Block group (n= 426)	Mean	0.02	0.05	3.89	3.16
	Variance	0.001	0.006	20.27	14.12
	S. D.	0.04	0.08	4.50	3.76
	Min.	0	0	0.02	0.02
	Max.	0.24	0.63	33.97	24.09
TAZ (n=552)	Mean	0.03	0.07	5.74	5.03
	Variance	0.005	0.018	63.3	73.98
	S. D.	0.07	0.14	7.96	8.60
	Min.	0	0	0	0
	Max.	0.57	1.34	77.50	79.48

APPENDIX D

RESULTS BY USING THRESHOLDS MEAN, 25%, AND 75% VALUES

Threshold (mean = 0.30)

Bivariate Analysis between Control Variables and Dependent Variables

Variable	High % of non-white population (N=191)					Low % of non-white population (N=235)				
	Total crash	Fatal injury	Serious injury	Minor injury	No injury	Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Coefficient (*p*-value)									
Control variables										
Risk exposures										
Traffic volume (#) (million)	0.19*** (<0.001)	0.18*** (<0.001)	0.21*** (<0.001)	0.19*** (<0.001)	0.20*** (<0.001)	0.26*** (<0.001)	0.26*** (<0.001)	0.23*** (<0.001)	0.26*** (<0.001)	0.27*** (<0.001)
Area of the spatial unit (100 acres)	0.04* (0.033)	0.05 (0.136)	0.07** (0.003)	0.04 (0.05)	0.04* (0.026)	0.09** (0.006)	0.14* (0.038)	0.09* (0.031)	0.08* (0.019)	0.10** (0.002)
Socio-demographic characteristics										
Total population (#) (thousand)	0.16* (0.014)	0.09 (0.411)	0.17* (0.035)	0.13* (0.043)	0.19** (0.003)	0.43*** (<0.001)	0.30 (0.190)	0.28 (0.079)	0.38** (0.002)	0.49*** (<0.001)
Population aged under 18 (#)(thousand)	0.08 (0.641)	0.30 (0.323)	0.36 (0.107)	0.08 (0.637)	0.06 (0.697)	0.50 (0.276)	0.61 (0.558)	0.02 (0.973)	0.62 (0.193)	0.37 (0.421)
Population less than high school (#)(thousand)	0.60* (0.039)	1.40* (0.011)	0.87* (0.035)	0.68* (0.024)	0.50 (0.087)	2.35** (0.005)	4.38* (0.018)	2.81* (0.018)	2.64** (0.003)	2.01* (0.013)
Male population (#)(thousand)	0.43*** (<0.001)	0.27 (0.152)	0.41** (0.004)	0.37** (0.001)	0.51*** (<0.001)	1.15*** (<0.001)	0.77 (0.114)	0.75* (0.019)	1.06*** (<0.001)	1.27*** (<0.001)
Household below the poverty line (#) (thousand)	0.60** (0.006)	0.72 (0.051)	0.41 (0.186)	0.55** (0.014)	0.66** (0.003)	2.13*** (<0.001)	1.48 (0.138)	1.16* (0.043)	2.20*** (<0.001)	2.07*** (<0.001)
Travel behaviors										
Workers commuting by walking (#)(thousand)	4.12** (0.003)	0.22 (0.932)	1.91 (0.323)	3.24* (0.023)	5.22*** (<0.001)	8.65*** (<0.001)	6.14 (0.163)	7.43* (0.019)	8.22** (0.001)	9.19*** (<0.001)
Workers commuting by public transit (#)(thousand)	2.28* (0.043)	0.93 (0.606)	0.45 (0.789)	2.26 (0.051)	2.35* (0.036)	8.58*** (<0.001)	6.51 (0.055)	3.69 (0.116)	9.07*** (<0.001)	8.08*** (<0.001)
Workers commuting by biking (#)(thousand)	13.45*** (<0.001)	6.48 (0.300)	8.26 (0.059)	12.37*** (<0.001)	14.86*** (<0.001)	12.03*** (<0.001)	7.64 (0.131)	6.90 (0.053)	12.22*** (<0.001)	11.88*** (<0.001)

*: p<0.05, **: p<0.01, ***: p<0.001

Base Model and One-by-One Test

Variable	High % of non-white population (N=191)					Low % of non-white population (N=235)				
	Total crash	Fatal injury	Serious injury	Minor injury	No injury	Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Coefficient (*p*-value)									
Base model										
Traffic volume (#) (million)	0.18*** (<0.001)	0.17*** (<0.001)	0.18*** (<0.001)	0.17*** (<0.001)	0.18*** (<0.001)	0.26*** (<0.001)	0.26*** (<0.001)	0.23*** (<0.001)	0.26*** (<0.001)	0.26*** (<0.001)
Area of the spatial unit (100 acres)	0.01 (0.439)	0.02 (0.421)	0.03* (0.048)	0.01 (0.570)	0.01 (0.328)	0.03 (0.146)	0.01 (0.924)	0.02 (0.707)	0.04 (0.104)	0.03 (0.240)
Population less than high school (#)(thousand)	0.64* (0.012)	1.11* (0.041)	0.74 (0.066)	0.65* (0.016)	0.62* (0.011)	2.80*** (<0.001)	5.69** (0.001)	2.83* (0.011)	3.22*** (<0.001)	2.30** (0.001)
Workers commuting by walking (#)(thousand)	1.77 (0.088)	2.88 (0.215)	1.16 (0.447)	1.16 (0.279)	2.58* (0.012)	5.31** (0.006)	3.38 (0.379)	2.67 (0.346)	5.09* (0.013)	5.64** (0.003)
One-by-one test										
Sidewalks (miles)	0.01 (0.922)	0.01 (0.938)	0.02 (0.362)	0.01 (0.930)	0.01 (0.708)	0.02 (0.863)	0.02 (0.491)	0.01 (0.552)	0.03 (0.815)	0.01 (0.827)
Bike lanes (miles)	0.02 (0.051)	0.02 (0.346)	0.01 (0.773)	0.02 (0.063)	0.02* (0.044)	0.02 (0.122)	0.04 (0.130)	0.01 (0.650)	0.02 (0.058)	0.01 (0.300)
Three-leg street intersections (#)	-0.01 (0.116)	0.01 (0.947)	-0.01* (0.047)	-0.01 (0.106)	-0.01 (0.169)	-0.01 (0.327)	-0.01 (0.985)	-0.02 (0.669)	-0.01 (0.203)	-0.02 (0.562)
Four-or-more-leg street intersections (#)	0.01* (0.022)	0.01 (0.172)	0.01 (0.097)	0.01* (0.047)	0.01* (0.010)	0.03*** (<0.001)	0.02 (0.144)	0.01 (0.384)	0.03*** (<0.001)	0.03*** (<0.001)
Transit stops (#)	0.03*** (<0.001)	0.03* (0.032)	0.03** (0.004)	0.03*** (<0.001)	0.03*** (<0.001)	0.07*** (<0.001)	0.06* (0.021)	0.04** (0.005)	0.08*** (<0.001)	0.07*** (<0.001)
Highway/freeway (miles)	0.04 (0.378)	0.02 (0.832)	0.04 (0.591)	0.05 (0.250)	0.02 (0.632)	0.02 (0.630)	0.04 (0.752)	0.03 (0.752)	0.03 (0.840)	0.05 (0.342)
Arterials (miles)	0.15*** (<0.001)	0.09* (0.016)	0.11* (0.027)	0.15*** (<0.001)	0.15*** (<0.001)	0.24*** (<0.001)	0.30* (0.047)	0.16* (0.021)	0.28*** (<0.001)	0.21*** (<0.001)
Residential use (#)	-0.01** (0.005)	0.01 (0.435)	-0.01** (0.001)	-0.01** (0.005)	-0.01* (0.010)	-0.01** (0.002)	-0.01 (0.218)	-0.02* (0.046)	-0.01** (0.003)	-0.01** (0.003)
Commercial use (#)	0.01** (0.001)	0.02* (0.038)	0.01* (0.047)	0.01** (0.003)	0.01*** (<0.001)	0.03*** (<0.001)	0.02 (0.064)	0.02** (0.008)	0.03*** (<0.001)	0.03*** (<0.001)
Office use (#)	0.01* (0.049)	0.01 (0.265)	0.01 (0.068)	0.01 (0.071)	0.01* (0.039)	0.02** (0.001)	0.01 (0.513)	0.01 (0.141)	0.02** (0.003)	0.02** (0.001)
Industrial use (#)	0.01 (0.334)	0.01 (0.341)	0.01 (0.835)	0.01 (0.361)	0.01 (0.318)	0.06*** (<0.001)	0.08* (0.025)	0.03 (0.160)	0.06*** (<0.001)	0.06*** (<0.001)
School (#)	0.03** (0.004)	0.02 (0.402)	0.03 (0.073)	0.03** (0.002)	0.02* (0.011)	0.05*** (<0.001)	0.03 (0.285)	0.03 (0.115)	0.06*** (<0.001)	0.05*** (<0.001)
Park (#)	0.01 (0.126)	0.02 (0.328)	0.02 (0.208)	0.01 (0.099)	0.02 (0.197)	0.01 (0.801)	0.01 (0.366)	0.01 (0.520)	0.02 (0.852)	0.02 (0.658)

*: p<0.05, **: p<0.01, ***: p<0.001

Final Negative Binomial Model

Variable	High % of non-white population (N=191)					Low % of non-white population (N=235)				
	Total crash	Fatal injury	Serious injury	Minor injury	No injury	Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Coefficient (*p*-value)									
Traffic volume (#) (million)	0.13*** (<0.001)	0.10* (0.039)	0.10* (0.018)	0.12*** (<0.001)	0.13*** (<0.001)	0.20*** (<0.001)	0.20** (0.001)	0.18*** (<0.001)	0.19*** (<0.001)	0.19*** (<0.001)
Area of the spatial unit (100 acres)	0.01 (0.626)	0.02 (0.414)	0.06** (0.007)	0.01 (0.689)	0.01 (0.776)	0.01 (0.784)	0.02 (0.766)	0.02 (0.671)	0.03 (0.678)	0.02 (0.489)
Population less than high school (#)(thousand)	0.48* (0.025)	1.08* (0.038)	0.73* (0.042)	0.62** (0.006)	0.43* (0.039)	1.06 (0.111)	4.35* (0.014)	1.71 (0.128)	1.64* (0.020)	0.79 (0.219)
Workers commuting by walking (#)(thousand)	0.83 (0.346)	4.57 (0.055)	4.26** (0.005)	1.54 (0.103)	0.31 (0.728)	0.09 (0.956)	0.15 (0.970)	3.02 (0.324)	3.07 (0.530)	0.18 (0.913)
Arterials (miles)	0.12** (0.002)	0.01* (0.017)		0.13** (0.001)	0.12** (0.002)	0.14** (0.001)	0.24 (0.056)		0.17*** (<0.001)	0.11* (0.012)
Residential use (#)	-0.01** (0.001)		-0.02*** (<0.001)	-0.01* (0.012)	-0.01** (0.003)	-0.01*** (<0.001)		-0.01* (0.027)	-0.02*** (<0.001)	-0.01*** (<0.001)
Commercial use (#)	0.01*** (<0.001)			0.02* (0.013)	0.02*** (<0.001)	0.02*** (<0.001)			0.02*** (<0.001)	0.02*** (<0.001)
Office use (#)					0.01** (0.009)					0.01 (0.304)
School (#)				0.03* (0.011)	0.02* (0.037)				0.02 (0.209)	0.03 (0.413)

*: p<0.05, **: p<0.01, ***: p<0.001

Threshold (25% = 0.16)

Bivariate Analysis between Control Variables and Dependent Variables

Variable	High % of non-white population (N=320)					Low % of non-white population (N=106)				
	Total crash	Fatal injury	Serious injury	Minor injury	No injury	Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Coefficient (*p*-value)									
Control variables										
Risk exposures										
Traffic volume (#) (million)	0.24*** (<0.001)	0.21*** (<0.001)	0.24*** (<0.001)	0.23*** (<0.001)	0.24*** (<0.001)	0.23*** (<0.001)	0.40*** (<0.001)	0.24*** (<0.001)	0.23*** (<0.001)	0.23*** (<0.001)
Area of the spatial unit (100 acres)	0.08*** (<0.001)	0.08* (0.019)	0.09*** (<0.001)	0.07** (0.001)	0.08*** (<0.001)	0.08* (0.025)	0.21* (0.034)	0.15** (0.006)	0.07* (0.047)	0.08* (0.015)
Socio-demographic characteristics										
Total population (#) (thousand)	0.26*** (<0.001)	0.20* (0.027)	0.29*** (<0.001)	0.24*** (<0.001)	0.28*** (<0.001)	0.72*** (<0.001)	1.28** (0.002)	0.86*** (<0.001)	0.70*** (<0.001)	0.73*** (<0.001)
Population aged under 18 (#)(thousand)	0.35* (0.021)	0.56* (0.039)	0.71** (0.001)	0.36* (0.022)	0.33* (0.029)	0.64 (0.342)	3.94 (0.063)	2.57* (0.017)	0.48 (0.492)	0.79 (0.236)
Population less than high school (#)(thousand)	1.08*** (<0.001)	1.89*** (<0.001)	1.63*** (<0.001)	1.14*** (<0.001)	0.99*** (<0.001)	7.73* (0.010)	7.18* (0.046)	9.44* (0.043)	8.39** (0.008)	6.95* (0.016)
Male population (#)(thousand)	0.57*** (<0.001)	0.48** (0.005)	0.61*** (<0.001)	0.54*** (<0.001)	0.62*** (<0.001)	1.42*** (<0.001)	2.31* (0.015)	1.72** (0.001)	1.37*** (<0.001)	1.46*** (<0.001)
Household below the poverty line (#) (thousand)	0.98*** (<0.001)	1.03** (0.002)	1.03*** (<0.001)	0.95*** (<0.001)	1.01*** (<0.001)	3.74*** (<0.001)	2.89 (0.243)	1.02 (0.463)	3.84*** (<0.001)	3.66*** (<0.001)
Travel behaviors										
Workers commuting by walking (#)(thousand)	5.55*** (<0.001)	2.62 (0.293)	4.16* (0.029)	4.79** (0.001)	6.48*** (<0.001)	6.03*** (<0.001)	9.78 (0.350)	8.74* (0.024)	10.55*** (<0.001)	10.53*** (<0.001)
Workers commuting by public transit (#)(thousand)	4.85*** (<0.001)	3.83 (0.055)	2.90 (0.064)	4.95*** (<0.001)	4.76*** (<0.001)	5.16** (0.001)	3.96 (0.875)	4.32 (0.257)	6.81** (0.001)	8.58** (0.001)
Workers commuting by biking (#)(thousand)	12.62*** (<0.001)	8.67* (0.049)	7.84* (0.015)	9.07*** (<0.001)	10.38*** (<0.001)	10.56** (0.008)	7.32 (0.438)	6.27 (0.825)	8.91* (0.010)	10.38** (0.007)

*: p<0.05, **: p<0.01, ***: p<0.001

Base Model and One-by-One Test

Variable	**High % of non-white population (N=320)**					**Low % of non-white population (N=106)**				
	Total crash	Fatal injury	Serious injury	Minor injury	No injury	Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Coefficient (*p*-value)									
Base model										
Traffic volume (#) (million)	0.22*** (<0.001)	0.18*** (<0.001)	0.20*** (<0.001)	0.22*** (<0.001)	0.22*** (<0.001)	0.21*** (<0.001)	0.39** (0.002)	0.15* (0.049)	0.20*** (<0.001)	0.21*** (<0.001)
Area of the spatial unit (100 acres)	0.01 (0.347)	0.02 (0.338)	0.03* (0.044)	0.01 (0.489)	0.02 (0.241)	0.04 (0.172)	0.01 (0.839)	0.05 (0.389)	0.04 (0.209)	0.04 (0.137)
Population less than high school (#)(thousand)	0.98*** (<0.001)	1.60** (0.001)	1.38*** (<0.001)	1.04*** (<0.001)	0.90*** (<0.001)	4.18 (0.129)	2.89 (0.191)	5.10 (0.251)	5.35 (0.073)	2.78 (0.285)
Workers commuting by walking (#)(thousand)	2.09* (0.030)	1.21 (0.567)	0.37 (0.793)	1.52 (0.127)	2.83** (0.003)	9.39* (0.010)	0.59 (0.556)	7.71 (0.144)	6.90* (0.013)	8.99** (0.008)
One-by-one test										
Sidewalks (miles)	-0.01 (0.852)	-0.01 (0.814)	-0.02 (0.157)	-0.01 (0.906)	-0.01 (0.751)	-0.02 (0.325)	-0.13 (0.064)	-0.05 (0.223)	-0.03 (0.322)	-0.02 (0.316)
Bike lanes (miles)	0.02 (0.058)	0.01 (0.812)	0.01 (0.620)	0.02 (0.052)	0.02 (0.057)	0.02 (0.377)	0.11 (0.079)	0.01 (0.675)	0.03 (0.223)	0.01 (0.642)
Three-leg street intersections (#)	-0.01 (0.124)	-0.02 (0.913)	-0.01* (0.021)	-0.01 (0.119)	-0.01 (0.168)	-0.01 (0.916)	-0.03 (0.106)	-0.02* (0.042)	-0.02 (0.745)	-0.01 (0.886)
Four-or-more-leg street intersections (#)	0.02*** (<0.001)	0.02* (0.036)	0.01 (0.085)	0.02** (0.001)	0.02*** (<0.001)	0.03 (0.090)	0.05 (0.174)	0.01 (0.835)	0.03 (0.089)	0.02 (0.106)
Transit stops (#)	0.04*** (<0.001)	0.04** (0.004)	0.03** (0.001)	0.04*** (<0.001)	0.03*** (<0.001)	0.10*** (<0.001)	0.11 (0.071)	0.06* (0.035)	0.11*** (<0.001)	0.09*** (<0.001)
Highway/freeway (miles)	0.01 (0.758)	0.02 (0.815)	0.01 (0.923)	0.02 (0.669)	0.01 (0.892)	0.19* (0.032)	0.12 (0.604)	0.18 (0.210)	0.16 (0.084)	0.21** (0.009)
Arterials (miles)	0.19*** (<0.001)	0.15* (0.016)	0.12** (0.007)	0.20*** (<0.001)	0.18*** (<0.001)	0.18* (0.042)	0.36 (0.141)	0.20 (0.115)	0.22* (0.022)	0.14 (0.106)
Residential use (#)	-0.02** (0.001)	-0.01 (0.125)	-0.01*** (<0.001)	-0.01** (0.001)	-0.01** (0.002)	-0.01* (0.046)	-0.01 (0.344)	-0.01* (0.035)	-0.01 (0.054)	-0.02* (0.020)
Commercial use (#)	0.02*** (<0.001)	0.02** (0.002)	0.01* (0.019)	0.02*** (<0.001)	0.02*** (<0.001)	0.03*** (<0.001)	0.02 (0.407)	0.02 (0.112)	0.03*** (<0.001)	0.03*** (<0.001)
Office use (#)	0.01* (0.029)	0.01 (0.183)	0.01 (0.055)	0.01* (0.040)	0.01* (0.026)	0.03** (0.001)	0.06 (0.093)	0.02 (0.117)	0.03** (0.001)	0.03** (0.001)
Industrial use (#)	0.01 (0.149)	0.01 (0.129)	0.01 (0.708)	0.01 (0.155)	0.01 (0.164)	0.03 (0.408)	0.04 (0.647)	0.01 (0.891)	0.03 (0.448)	0.03 (0.386)
School (#)	0.04*** (<0.001)	0.03 (0.097)	0.03* (0.014)	0.04*** (<0.001)	0.03*** (<0.001)	0.03 (0.292)	0.06 (0.408)	0.02 (0.571)	0.04 (0.178)	0.02 (0.526)
Park (#)	0.03 (0.353)	0.01 (0.562)	0.01 (0.808)	0.03 (0.308)	0.02 (0.414)	0.01 (0.266)	0.02 (0.524)	0.02 (0.333)	0.01 (0.373)	0.01 (0.170)

*: p<0.05, **: p<0.01, ***: p<0.001

Final Negative Binomial Model

Variable	High % of non-white population (N=320)					Low % of non-white population (N=106)				
	Total crash	Fatal injury	Serious injury	Minor injury	No injury	Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Coefficient (*p*-value)									
Traffic volume (#) (million)	0.16*** (<0.001)	0.16*** (<0.001)	0.19*** (<0.001)	0.16*** (<0.001)	0.16*** (<0.001)	0.19*** (<0.001)	0.36** (0.005)	0.15 (0.040)	0.19*** (<0.001)	0.19*** (<0.001)
Area of the spatial unit (100 acres)	0.01 (0.541)	0.01 (0.733)	0.07** (0.001)	0.01 (0.332)	0.01 (0.933)	0.01 (0.857)	0.02 (0.824)	0.04 (0.589)	0.01 (0.831)	0.01 (0.850)
Population less than high school (#)(thousand)	0.89*** (<0.001)	1.74*** (<0.001)	1.32*** (<0.001)	0.88*** (<0.001)	0.64*** (<0.001)	2.14 (0.400)	8.17 (0.277)	4.97 (0.262)	2.82 (0.303)	2.44 (0.333)
Workers commuting by walking (#)(thousand)	0.73 (0.357)	2.07 (0.330)	1.68 (0.222)	1.03 (0.237)	0.72 (0.392)	0.07 (0.987)	7.29 (0.435)	8.20 (0.127)	1.56 (0.723)	2.82 (0.534)
Arterials (miles)	0.17*** (<0.001)	0.15* (0.016)		0.16*** (<0.001)	0.16*** (<0.001)	0.08 (0.385)	0.36 (0.141)		0.10 (0.258)	0.02 (0.777)
Residential use (#)	-0.01*** (<0.001)		-0.01*** (<0.001)	-0.01*** (<0.001)	-0.01*** (<0.001)	-0.01* (0.048)		-0.03* (0.041)	-0.01* (0.030)	-0.01* (0.027)
Commercial use (#)	0.02*** (<0.001)			0.02*** (<0.001)	0.02*** (<0.001)	0.03*** (<0.001)			0.03*** (<0.001)	0.02* (0.021)
Office use (#)					0.01** (0.002)					0.02 (0.122)
School (#)				0.03*** (<0.001)	0.03*** (<0.001)				0.02 (0.438)	0.02 (0.919)

*: p<0.05, **: p<0.01, ***: p<0.001

Threshold (75% = 0.42)

Bivariate Analysis between Control Variables and Dependent Variables

Variable	High % of non-white population (N=107)					Low % of non-white population (N=319)				
	Total crash	Fatal injury	Serious injury	Minor injury	No injury	Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Coefficient (*p*-value)									
Control variables										
Risk exposures										
Traffic volume (#) (million)	0.22*** (<0.001)	0.23*** (<0.001)	0.24*** (<0.001)	0.22*** (<0.001)	0.23*** (<0.001)	0.25*** (<0.001)	0.25*** (<0.001)	0.25*** (<0.001)	0.25*** (<0.001)	0.25*** (<0.001)
Area of the spatial unit (100 acres)	0.08** (0.004)	0.13* (0.022)	0.11** (0.002)	0.08** (0.003)	0.08** (0.008)	0.07** (0.002)	0.08* (0.044)	0.09** (0.001)	0.06** (0.006)	0.08*** (<0.001)
Socio-demographic characteristics										
Total population (#) (thousand)	0.31*** (<0.001)	0.23 (0.109)	0.35** (0.004)	0.30*** (<0.001)	0.33*** (<0.001)	0.32*** (<0.001)	0.33** (0.009)	0.36*** (<0.001)	0.30*** (<0.001)	0.35*** (<0.001)
Population aged under 18 (#)(thousand)	0.63** (0.009)	0.50 (0.209)	0.84* (0.013)	0.60* (0.015)	0.68** (0.006)	0.34 (0.078)	0.61 (0.114)	0.72** (0.008)	0.34 (0.099)	0.34 (0.073)
Population less than high school (#)(thousand)	0.84** (0.006)	0.67 (0.219)	0.97* (0.027)	0.78* (0.013)	0.93** (0.003)	2.77*** (<0.001)	4.00*** (<0.001)	3.56*** (<0.001)	2.93*** (<0.001)	2.56*** (<0.001)
Male population (#)(thousand)	0.60*** (<0.001)	0.49 (0.061)	0.64** (0.003)	0.57*** (<0.001)	0.64*** (<0.001)	0.71*** (<0.001)	0.67** (0.005)	0.74*** (<0.001)	0.68*** (<0.001)	0.75*** (<0.001)
Household below the poverty line (#) (thousand)	0.67** (0.003)	0.57 (0.133)	0.63 (0.059)	0.60** (0.009)	0.75** (0.001)	1.86*** (<0.001)	1.73** (0.002)	1.62*** (<0.001)	1.88*** (<0.001)	1.84*** (<0.001)
Travel behaviors										
Workers commuting by walking (#)(thousand)	12.04** (0.004)	7.80 (0.262)	6.49 (0.283)	10.68* (0.011)	11.09** (0.001)	6.95*** (<0.001)	4.57 (0.101)	6.55** (0.001)	6.43*** (<0.001)	7.51*** (<0.001)
Workers commuting by public transit (#)(thousand)	2.21 (0.101)	0.90 (0.678)	0.70 (0.736)	1.75 (0.202)	2.86* (0.035)	8.22*** (<0.001)	6.52* (0.018)	5.53** (0.005)	8.81*** (<0.001)	7.57*** (<0.001)
Workers commuting by biking (#)(thousand)	11.78** (0.002)	12.55 (0.194)	10.10 (0.275)	11.72** (0.002)	11.17** (0.002)	12.13*** (<0.001)	7.69 (0.074)	8.28** (0.006)	11.85*** (<0.001)	12.53*** (<0.001)

*: p<0.05, **: p<0.01, ***: p<0.001

Base Model and One-by-One Test

Variable	High % of non-white population (N=107)					Low % of non-white population (N=319)				
	Total crash	Fatal injury	Serious injury	Minor injury	No injury	Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Coefficient (*p*-value)									
Base model										
Traffic volume (#) (million)	0.19*** (<0.001)	0.21** (0.001)	0.18*** (<0.001)	0.18*** (<0.001)	0.20*** (<0.001)	0.23*** (<0.001)	0.23*** (<0.001)	0.21*** (<0.001)	0.23*** (<0.001)	0.22*** (<0.001)
Area of the spatial unit (100 acres)	0.04 (0.097)	0.09 (0.100)	0.05 (0.163)	0.05 (0.072)	0.03 (0.177)	0.03 (0.786)	0.02 (0.466)	0.03 (0.063)	0.01 (0.532)	0.02 (0.798)
Population less than high school (#)(thousand)	0.15 (0.657)	0.96 (0.153)	0.20 (0.715)	0.21 (0.549)	0.06 (0.848)	2.23*** (<0.001)	3.88*** (<0.001)	2.81*** (<0.001)	2.46*** (<0.001)	1.94*** (<0.001)
Workers commuting by walking (#)(thousand)	9.65* (0.021)	8.99 (0.235)	6.72 (0.617)	8.79* (0.043)	10.02** (0.007)	3.34** (0.002)	2.68 (0.765)	1.76 (0.252)	3.02** (0.007)	3.72*** (<0.001)
One-by-one test										
Sidewalks (miles)	-0.02 (0.337)	-0.05 (0.197)	-0.02 (0.447)	-0.02 (0.282)	-0.01 (0.424)	-0.01 (0.892)	-0.01 (0.503)	-0.01 (0.373)	-0.01 (0.792)	-0.02 (0.834)
Bike lanes (miles)	0.03 (0.066)	0.08* (0.018)	0.02 (0.422)	0.04 (0.054)	0.03 (0.115)	0.02 (0.066)	0.03 (0.122)	0.01 (0.889)	0.02 (0.051)	0.01 (0.116)
Three-leg street intersections (#)	-0.01 (0.817)	-0.02 (0.105)	-0.01 (0.197)	-0.01 (0.853)	-0.01 (0.809)	-0.02 (0.454)	-0.01 (0.770)	-0.03 (0.474)	-0.03 (0.322)	-0.01 (0.681)
Four-or-more-leg street intersections (#)	0.02** (0.005)	0.03 (0.104)	0.02 (0.226)	0.02* (0.010)	0.03** (0.003)	0.02** (0.001)	0.01 (0.177)	0.01 (0.361)	0.02** (0.001)	0.02*** (<0.001)
Transit stops (#)	0.03** (0.001)	0.05* (0.014)	0.02 (0.364)	0.04** (0.002)	0.03** (0.001)	0.05*** (<0.001)	0.03 (0.080)	0.03** (0.002)	0.05*** (<0.001)	0.04*** (<0.001)
Highway/freeway (miles)	0.03 (0.669)	0.06 (0.609)	0.09 (0.386)	0.04 (0.483)	0.02 (0.566)	0.02 (0.529)	0.01 (0.934)	0.02 (0.793)	0.02 (0.720)	0.04 (0.352)
Arterials (miles)	0.19** (0.001)	0.20 (0.093)	0.26** (0.009)	0.18** (0.003)	0.20*** (<0.001)	0.18*** (<0.001)	0.14 (0.059)	0.09 (0.063)	0.20*** (<0.001)	0.17*** (<0.001)
Residential use (#)	-0.01 (0.209)	-0.01 (0.330)	-0.01 (0.055)	-0.01 (0.286)	-0.01 (0.146)	-0.01** (0.006)	-0.01 (0.320)	-0.01** (0.008)	-0.01** (0.007)	-0.01** (0.007)
Commercial use (#)	0.03*** (<0.001)	0.04** (0.002)	0.01 (0.228)	0.03*** (<0.001)	0.03*** (<0.001)	0.02*** (<0.001)	0.01 (0.081)	0.01* (0.012)	0.02*** (<0.001)	0.02*** (<0.001)
Office use (#)	0.02* (0.042)	0.01 (0.561)	0.02 (0.208)	0.02 (0.054)	0.02* (0.035)	0.01** (0.006)	0.01 (0.341)	0.01 (0.070)	0.01** (0.008)	0.01** (0.005)
Industrial use (#)	0.01 (0.595)	0.01 (0.370)	0.04 (0.543)	0.01 (0.709)	0.01 (0.454)	0.01 (0.089)	0.02 (0.252)	0.01 (0.377)	0.01 (0.099)	0.01 (0.097)
School (#)	0.02* (0.042)	0.04 (0.110)	0.01 (0.458)	0.02* (0.044)	0.02* (0.047)	0.04*** (<0.001)	0.01 (0.718)	0.03* (0.044)	0.05*** (<0.001)	0.04*** (<0.001)
Park (#)	0.01* (0.037)	0.02 (0.968)	0.01 (0.752)	0.01 (0.067)	0.01* (0.014)	0.01 (0.120)	0.02 (0.164)	0.01 (0.746)	0.01 (0.333)	0.01* (0.026)

*: p<0.05, **: p<0.01, ***: p<0.001

Final Negative Binomial Model

Variable	High % of non-white population (N=107)					Low % of non-white population (N=319)				
	Total crash	Fatal injury	Serious injury	Minor injury	No injury	Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Coefficient (*p*-value)									
Traffic volume (#) (million)	0.14*** (<0.001)	0.21** (0.001)	0.17** (0.005)	0.13*** (<0.001)	0.14*** (<0.001)	0.19*** (<0.001)	0.21*** (<0.001)	0.20*** (<0.001)	0.18*** (<0.001)	0.18*** (<0.001)
Area of the spatial unit (100 acres)	0.01 (0.983)	0.03 (0.649)	0.07 (0.051)	0.01 (0.806)	0.01 (0.749)	0.03* (0.017)	0.03 (0.892)	0.06** (0.005)	0.02 (0.226)	0.01 (0.724)
Population less than high school (#)(thousand)	0.07 (0.816)	0.65 (0.330)	0.40 (0.458)	0.05 (0.875)	0.22 (0.441)	1.67*** (<0.001)	3.88*** (<0.001)	2.71*** (<0.001)	1.78*** (<0.001)	1.21*** (<0.001)
Workers commuting by walking (#)(thousand)	8.17* (0.015)	9.48 (0.186)	4.84 (0.482)	4.41 (0.222)	6.51* (0.041)	1.87* (0.032)	0.61 (0.794)	0.63 (0.679)	0.39 (0.682)	0.89 (0.330)
Arterials (miles)	0.14** (0.008)	0.20* (0.043)		0.17** (0.003)	0.18*** (<0.001)	0.14*** (<0.001)	0.14 (0.059)		0.15*** (<0.001)	0.13*** (<0.001)
Residential use (#)			-0.01 (0.055)	-0.01* (0.014)	-0.01** (0.003)			-0.01** (0.008)	-0.01** (0.002)	-0.01** (0.001)
Commercial use (#)	0.03*** (<0.001)			0.02*** (<0.001)	0.02*** (<0.001)	0.02*** (<0.001)			0.02*** (<0.001)	0.02*** (<0.001)
School (#)				0.03* (0.025)	0.02* (0.023)				0.04*** (<0.001)	0.03** (0.001)

*: p<0.05, **: p<0.01, ***: p<0.001

Threshold (mean = 0.18)

Bivariate Analysis between Control Variables and Dependent Variables

Variable	High % of population below the poverty line (N=176)					Low % of population below the poverty line (N=250)				
	Total crash	Fatal injury	Serious injury	Minor injury	No injury	Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Coefficient (*p*-value)									
Control variables										
Risk exposures										
Traffic volume (#) (million)	0.21*** (<0.001)	0.22*** (<0.001)	0.20*** (<0.001)	0.21*** (<0.001)	0.21*** (<0.001)	0.27*** (<0.001)	0.26*** (<0.001)	0.28*** (<0.001)	0.26*** (<0.001)	0.27*** (<0.001)
Area of the spatial unit (100 acres)	0.14*** (<0.001)	0.22** (0.006)	0.13** (0.007)	0.15*** (<0.001)	0.14** (0.001)	0.09*** (<0.001)	0.10* (0.015)	0.12*** (<0.001)	0.08*** (<0.001)	0.10*** (<0.001)
Socio-demographic characteristics										
Total population (#) (thousand)	0.32*** (<0.001)	0.41** (0.002)	0.33** (0.001)	0.33*** (<0.001)	0.32*** (<0.001)	0.32*** (<0.001)	0.21 (0.102)	0.42*** (<0.001)	0.29*** (<0.001)	0.36*** (<0.001)
Population aged under 18 (#)(thousand)	0.63** (0.001)	1.22** (0.002)	0.98*** (<0.001)	0.66** (0.001)	0.58** (0.002)	0.25 (0.218)	0.23 (0.518)	0.78* (0.011)	0.23 (0.266)	0.25 (0.199)
Non-white population (#) (thousand)	0.41** (0.001)	0.76** (0.003)	0.66*** (<0.001)	0.43** (0.001)	0.38** (0.002)	0.93*** (<0.001)	0.86* (0.024)	1.23*** (<0.001)	0.93*** (<0.001)	0.91*** (<0.001)
Population less than high school (#)(thousand)	0.85** (0.001)	1.94*** (<0.001)	1.54*** (<0.001)	0.88** (0.001)	0.79** (0.001)	2.65*** (<0.001)	2.96* (0.029)	3.79*** (<0.001)	2.92*** (<0.001)	2.30** (0.001)
Male population (#)(thousand)	0.63*** (<0.001)	0.75*** (0.003)	0.57** (0.002)	0.63*** (<0.001)	0.63*** (<0.001)	0.70*** (<0.001)	0.52* (0.028)	0.88*** (<0.001)	0.64*** (<0.001)	0.76*** (<0.001)
Travel behaviors										
Workers commuting by walking (#)(thousand)	1.86 (0.248)	1.23 (0.686)	1.77 (0.465)	1.42 (0.398)	2.45 (0.119)	10.69*** (<0.001)	8.37 (0.054)	11.22*** (<0.001)	9.74*** (<0.001)	11.74*** (<0.001)
Workers commuting by public transit (#)(thousand)	2.93 (0.055)	0.87 (0.626)	0.18 (0.905)	2.94 (0.076)	2.96 (0.093)	11.36*** (<0.001)	9.76* (0.024)	10.43** (0.001)	11.75*** (<0.001)	9.92*** (<0.001)
Workers commuting by biking (#)(thousand)	3.80 (0.076)	3.20 (0.433)	4.41 (0.143)	3.77 (0.085)	4.03 (0.060)	10.68*** (<0.001)	8.63* (0.019)	9.56*** (<0.001)	10.11*** (<0.001)	11.36*** (<0.001)

*: p<0.05, **: p<0.01, ***: p<0.001

Base Model and One-by-One Test

Variable	**High % of population below the poverty line (N=176)**					**Low % of population below the poverty line (N=250)**				
	Total crash	Fatal injury	Serious injury	Minor injury	No injury	Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Coefficient (*p*-value)									
Base model										
Traffic volume (#) (million)	0.19*** (<0.001)	0.18*** (<0.001)	0.18*** (<0.001)	0.19*** (<0.001)	0.20*** (<0.001)	0.23*** (<0.001)	0.23*** (<0.001)	0.21*** (<0.001)	0.23*** (<0.001)	0.23*** (<0.001)
Area of the spatial unit (100 acres)	0.03 (0.344)	0.07 (0.335)	0.02 (0.825)	0.04 (0.254)	0.02 (0.525)	0.01 (0.390)	0.03 (0.390)	0.05* (0.015)	0.01 (0.628)	0.02 (0.211)
Population less than high school (#)(thousand)	0.52* (0.030)	1.29* (0.024)	1.16** (0.005)	0.51* (0.039)	0.54* (0.029)	1.58** (0.002)	2.37* (0.037)	2.32** (0.002)	1.99*** (<0.001)	1.04* (0.031)
Workers commuting by walking (#)(thousand)	0.53 (0.651)	2.66* (0.047)	3.24 (0.105)	0.06 (0.762)	1.26 (0.267)	4.53** (0.007)	1.03 (0.799)	2.78 (0.221)	3.97* (0.024)	5.26** (0.002)
One-by-one test										
Sidewalks (miles)	-0.03 (0.070)	-0.06 (0.079)	-0.01 (0.834)	-0.03* (0.046)	-0.03* (0.034)	-0.01 (0.542)	-0.01 (0.829)	-0.02 (0.425)	-0.01 (0.447)	-0.03 (0.704)
Bike lanes (miles)	0.02 (0.199)	0.02 (0.539)	0.03 (0.317)	0.03 (0.120)	0.01 (0.387)	0.02* (0.027)	0.02 (0.574)	0.01 (0.826)	0.02 (0.058)	0.02 (0.052)
Three-leg street intersections (#)	-0.01 (0.577)	-0.01 (0.234)	-0.02 (0.386)	-0.01 (0.495)	-0.01 (0.676)	-0.01 (0.237)	-0.01 (0.828)	-0.02 (0.647)	-0.01 (0.106)	-0.02 (0.570)
Four-or-more-leg street intersections (#)	0.02** (0.002)	0.03* (0.021)	0.01 (0.277)	0.02** (0.004)	0.02** (0.001)	0.02* (0.025)	0.03 (0.807)	0.01 (0.403)	0.02* (0.041)	0.02* (0.016)
Transit stops (#)	0.04*** (<0.001)	0.04 (0.050)	0.03* (0.041)	0.05*** (<0.001)	0.04*** (<0.001)	0.05*** (<0.001)	0.06* (0.015)	0.05** (0.001)	0.05*** (<0.001)	0.04*** (<0.001)
Highway/freeway (miles)	0.03 (0.628)	0.05 (0.637)	0.12 (0.151)	0.04 (0.470)	0.01 (0.529)	0.05 (0.263)	0.03 (0.581)	0.01 (0.951)	0.04 (0.407)	0.06 (0.142)
Arterials (miles)	0.29*** (<0.001)	0.14* (0.021)	0.27*** (<0.001)	0.29*** (<0.001)	0.28*** (<0.001)	0.15*** (<0.001)	0.22* (0.013)	0.07 (0.168)	0.17*** (<0.001)	0.14*** (<0.001)
Residential use (#)	-0.01 (0.144)	-0.02 (0.294)	-0.01* (0.014)	-0.01 (0.197)	-0.02 (0.109)	-0.01* (0.013)	-0.02 (0.330)	-0.04* (0.041)	-0.01** (0.008)	-0.02* (0.037)
Commercial use (#)	0.02*** (<0.001)	0.03** (0.003)	0.01 (0.160)	0.02*** (<0.001)	0.02*** (<0.001)	0.02*** (<0.001)	0.01 (0.292)	0.02* (0.035)	0.02*** (<0.001)	0.02*** (<0.001)
Office use (#)	0.01* (0.016)	0.01 (0.242)	0.01 (0.097)	0.01* (0.019)	0.01* (0.016)	0.01* (0.026)	0.01 (0.693)	0.01 (0.109)	0.01* (0.035)	0.01* (0.025)
Industrial use (#)	0.03 (0.563)	0.01 (0.235)	0.06 (0.187)	0.01 (0.607)	0.01 (0.516)	0.01 (0.131)	0.01 (0.495)	0.02 (0.152)	0.01 (0.163)	0.01 (0.119)
School (#)	0.02** (0.005)	0.02 (0.240)	0.03 (0.074)	0.03** (0.004)	0.02* (0.011)	0.05** (0.001)	0.02 (0.613)	0.04 (0.082)	0.06*** (<0.001)	0.04** (0.002)
Park (#)	0.07 (0.067)	0.04 (0.706)	0.05 (0.888)	0.06* (0.029)	0.08** (0.008)	0.01* (0.046)	0.01 (0.303)	0.02 (0.823)	0.01 (0.117)	0.02* (0.014)

*: p<0.05, **: p<0.01, ***: p<0.001

Final Negative Binomial Model

Variable	**High % of population below the poverty line (N=176)**					**Low % of population below the poverty line (N=250)**				
	Total crash	Fatal injury	Serious injury	Minor injury	No injury	Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Coefficient (*p*-value)									
Traffic volume (#) (million)	0.17*** (<0.001)	0.17*** (0.001)	0.18*** (<0.001)	0.17*** (<0.001)	0.18*** (<0.001)	0.17*** (<0.001)	0.21 (<0.001)	0.18*** (<0.001)	0.17*** (<0.001)	0.17*** (<0.001)
Area of the spatial unit (100 acres)	0.05 (0.068)	0.01 (0.954)	0.07 (0.148)	0.05 (0.106)	0.06* (0.038)	0.01 (0.714)	0.01 (0.753)	0.05* (0.024)	0.01 (0.956)	0.01 (0.510)
Population less than high school (#)(thousand)	0.60** (0.003)	1.55* (0.010)	1.43*** (<0.001)	0.60** (0.005)	0.58** (0.003)	1.13* (0.014)	1.91 (0.084)	2.28** (0.002)	1.55** (0.002)	0.63 (0.152)
Workers commuting by walking (#)(thousand)	0.37 (0.697)	3.21 (0.182)	5.05** (0.008)	1.05 (0.303)	0.43 (0.642)	0.49 (0.749)	1.22 (0.767)	1.02 (0.636)	1.32 (0.408)	0.57 (0.708)
Arterials (miles)	0.23*** (<0.001)	0.14* (0.041)	0.28*** (<0.001)	0.24*** (<0.001)	0.23*** (<0.001)	0.13*** (<0.001)	0.22 (0.063)	0.08 (0.132)	0.14*** (<0.001)	0.11** (0.001)
Residential use (#)	-0.01* (0.017)		-0.01* (0.013)	-0.01* (0.023)	-0.01* (0.018)	-0.01** (0.001)		-0.01* (0.033)	-0.01** (0.001)	-0.01** (0.005)
Commercial use (#)	0.02*** (<0.001)			0.02*** (<0.001)	0.02*** (<0.001)	0.02*** (<0.001)			0.02*** (<0.001)	0.02*** (<0.001)
Office use (#)										
School (#)	0.02** (0.007)			0.02** (0.005)	0.02* (0.014)	0.05** (0.001)			0.05** (0.001)	0.04** (0.006)

*: p<0.05, **: p<0.01, ***: p<0.001

Threshold (25% = 0.09)

Bivariate Analysis between Control Variables and Dependent Variables

Variable	High % of population below the poverty line (N=319)					Low % of population below the poverty line (N=107)				
	Total crash	Fatal injury	Serious injury	Minor injury	No injury	Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Coefficient (*p*-value)									
Control variables										
Risk exposures										
Traffic volume (#) (million)	0.22*** (<0.001)	0.20*** (<0.001)	0.21*** (<0.001)	0.21*** (<0.001)	0.23*** (<0.001)	0.31*** (<0.001)	0.40*** (<0.001)	0.37*** (<0.001)	0.31*** (<0.001)	0.30*** (<0.001)
Area of the spatial unit (100 acres)	0.15*** (<0.001)	0.19*** (0.001)	0.14*** (<0.001)	0.15*** (<0.001)	0.16*** (<0.001)	0.10*** (<0.001)	0.16** (0.008)	0.13*** (<0.001)	0.10*** (<0.001)	0.10*** (<0.001)
Socio-demographic characteristics										
Total population (#) (thousand)	0.34*** (<0.001)	0.34** (0.002)	0.39*** (<0.001)	0.33*** (<0.001)	0.36*** (<0.001)	0.37*** (<0.001)	0.36 (0.077)	0.41** (0.002)	0.36*** (<0.001)	0.37*** (<0.001)
Population aged under 18 (#)(thousand)	0.50** (0.003)	0.86** (0.008)	0.96*** (<0.001)	0.54** (0.002)	0.45** (0.008)	0.67* (0.020)	0.90 (0.139)	0.97* (0.019)	0.65* (0.036)	0.69* (0.013)
Non-white population (#) (thousand)	0.52*** (<0.001)	0.74** (0.001)	0.82*** (<0.001)	0.53*** (<0.001)	0.49*** (<0.001)	0.86** (0.001)	0.75 (0.178)	1.13** (0.001)	0.86** (0.002)	0.86** (0.001)
Population less than high school (#) (thousand)	0.89*** (<0.001)	1.76*** (<0.001)	1.69*** (<0.001)	0.95*** (<0.001)	0.80** (0.001)	8.83*** (<0.001)	10.42 (0.135)	11.28** (0.001)	9.64*** (<0.001)	7.90*** (<0.001)
Male population (#) (thousand)	0.71*** (<0.001)	0.68*** (0.001)	0.76*** (<0.001)	0.68*** (<0.001)	0.75*** (<0.001)	0.64*** (<0.001)	0.63 (0.102)	0.76** (0.003)	0.63** (0.001)	0.65*** (<0.001)
Travel behaviors										
Workers commuting by walking (#)(thousand)	5.06*** (<0.001)	1.79 (0.440)	3.37* (0.049)	4.30** (0.001)	5.98*** (<0.001)	5.30*** (<0.001)	3.88* (0.046)	3.40*** (<0.001)	5.52*** (<0.001)	4.90*** (<0.001)
Workers commuting by public transit (#)(thousand)	3.87*** (<0.001)	2.23 (0.207)	2.15 (0.150)	3.85*** (<0.001)	3.92*** (<0.001)	4.89** (0.001)	5.52 (0.450)	3.19* (0.036)	6.41** (0.001)	3.29** (0.002)
Workers commuting by biking (#)(thousand)	9.19*** (<0.001)	2.52 (0.486)	4.48 (0.100)	8.49*** (<0.001)	10.17*** (<0.001)	13.50 (0.333)	7.85 (0.803)	4.96 (0.824)	3.57 (0.377)	4.06 (0.299)

*: p<0.05, **: p<0.01, ***: p<0.001

Base Model and One-by-One Test

Variable	High % of population below the poverty line (N=319)					Low % of population below the poverty line (N=107)				
	Total crash	Fatal injury	Serious injury	Minor injury	No injury	Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Coefficient (*p*-value)									
Base model										
Traffic volume (#) (million)	0.20*** (<0.001)	0.18*** (<0.001)	0.18*** (<0.001)	0.19*** (<0.001)	0.20*** (<0.001)	0.25*** (<0.001)	0.34** (0.001)	0.22*** (<0.001)	0.25*** (<0.001)	0.24*** (<0.001)
Area of the spatial unit (100 acres)	0.03 (0.131)	0.06 (0.207)	0.03 (0.223)	0.03 (0.118)	0.03 (0.176)	0.02 (0.299)	0.08 (0.095)	0.04 (0.124)	0.02 (0.441)	0.02 (0.208)
Population less than high school (#)(thousand)	0.67** (0.001)	1.33** (0.004)	1.37*** (<0.001)	0.71** (0.001)	0.61** (0.002)	4.16* (0.028)	3.59 (0.494)	4.14 (0.186)	5.12* (0.018)	3.14 (0.072)
Workers commuting by walking (#)(thousand)	2.01* (0.030)	1.67 (0.411)	0.14 (0.920)	1.44 (0.127)	2.76** (0.003)	5.11 (0.350)	8.98 (0.432)	4.22 (0.651)	4.81 (0.429)	5.37 (0.302)
One-by-one test										
Sidewalks (miles)	-0.01 (0.253)	-0.02 (0.449)	-0.02 (0.853)	-0.01 (0.260)	-0.01 (0.250)	-0.02 (0.848)	-0.06 (0.081)	-0.03 (0.385)	-0.01 (0.721)	-0.01 (0.978)
Bike lanes (miles)	0.01 (0.203)	0.01 (0.826)	0.02 (0.276)	0.02 (0.125)	0.01 (0.382)	0.03* (0.030)	0.06 (0.078)	0.02 (0.500)	0.03* (0.037)	0.03* (0.029)
Three-leg street intersections (#)	-0.03 (0.926)	-0.01 (0.397)	-0.02 (0.674)	-0.01 (0.950)	-0.01 (0.877)	-0.01 (0.240)	-0.01 (0.504)	-0.01 (0.343)	-0.01 (0.157)	-0.02 (0.436)
Four-or-more-leg street intersections (#)	0.02** (0.001)	0.02 (0.076)	0.01 (0.081)	0.02** (0.002)	0.02*** (<0.001)	0.03** (0.009)	0.04 (0.153)	0.01 (0.540)	0.03* (0.025)	0.03** (0.004)
Transit stops (#)	0.04*** (<0.001)	0.03** (0.009)	0.03** (0.002)	0.04*** (<0.001)	0.04*** (<0.001)	0.05** (0.006)	0.04* (0.037)	0.07* (0.013)	0.06** (0.007)	0.04* (0.013)
Highway/freeway (miles)	0.01 (0.834)	0.05 (0.943)	0.03 (0.646)	0.02 (0.683)	0.02 (0.942)	0.14* (0.039)	0.06 (0.692)	0.05 (0.633)	0.11 (0.137)	0.17** (0.008)
Arterials (miles)	0.23*** (<0.001)	0.20** (0.008)	0.23*** (<0.001)	0.23*** (<0.001)	0.22*** (<0.001)	0.15* (0.010)	0.17* (0.015)	0.03 (0.806)	0.18** (0.006)	0.12* (0.030)
Residential use (#)	-0.01** (0.001)	-0.01 (0.157)	-0.01** (0.003)	-0.01** (0.001)	-0.01*** (<0.001)	-0.01** (0.009)	-0.01 (0.121)	-0.01* (0.030)	-0.01* (0.016)	-0.01* (0.030)
Commercial use (#)	0.02*** (<0.001)	0.02** (0.009)	0.01* (0.015)	0.02*** (<0.001)	0.02*** (<0.001)	0.03*** (<0.001)	0.02* (0.030)	0.02 (0.158)	0.03*** (<0.001)	0.02** (0.006)
Office use (#)	0.01** (0.005)	0.01 (0.175)	0.01* (0.032)	0.01** (0.009)	0.01** (0.004)	0.01 (0.251)	0.01 (0.710)	0.01 (0.386)	0.01 (0.326)	0.01 (0.212)
Industrial use (#)	0.01 (0.112)	0.01 (0.111)	0.01 (0.935)	0.01 (0.136)	0.01 (0.100)	0.01 (0.897)	0.01 (0.959)	0.02 (0.400)	0.01 (0.906)	0.01 (0.860)
School (#)	0.03*** (<0.001)	0.02 (0.230)	0.03* (0.020)	0.04*** (<0.001)	0.03*** (<0.001)	0.02 (0.426)	0.07 (0.400)	0.04 (0.415)	0.03 (0.347)	0.02 (0.604)
Park (#)	0.02 (0.510)	0.01 (0.389)	0.02 (0.624)	0.02 (0.471)	0.02 (0.519)	0.02 (0.060)	0.01 (0.614)	0.02 (0.300)	0.02 (0.122)	0.02* (0.026)

*: p<0.05, **: p<0.01, ***: p<0.001

Final Negative Binomial Model

Variable	High % of population below the poverty line (N=319)					Low % of population below the poverty line (N=107)				
	Total crash	Fatal injury	Serious injury	Minor injury	No injury	Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Coefficient (*p*-value)									
Traffic volume (#) (million)	0.16*** (<0.001)	0.16*** (<0.001)	0.16*** (<0.001)	0.16*** (<0.001)	0.16*** (<0.001)	0.21*** (<0.001)	0.35** (0.001)	0.21* (0.010)	0.22*** (<0.001)	0.21*** (<0.001)
Area of the spatial unit (100 acres)	0.05* (0.035)	0.03 (0.532)	0.05 (0.185)	0.05* (0.045)	0.05* (0.029)	0.02 (0.472)	0.06 (0.223)	0.07 (0.066)	0.01 (0.545)	0.02 (0.461)
Population less than high school (#)(thousand)	0.65*** (<0.001)	1.66*** (<0.001)	1.61*** (<0.001)	0.69*** (<0.001)	0.58** (0.001)	0.13 (0.944)	2.24 (0.663)	3.91 (0.243)	0.28 (0.891)	0.45 (0.802)
Workers commuting by walking (#)(thousand)	0.38 (0.632)	2.93 (0.151)	2.19 (0.090)	1.04 (0.210)	0.43 (0.593)	5.31 (0.338)	3.61 (0.303)	1.08 (0.912)	7.75 (0.198)	2.76 (0.616)
Arterials (miles)	0.20*** (<0.001)	0.20** (0.008)	0.23*** (<0.001)	0.20*** (<0.001)	0.19*** (<0.001)	0.13* (0.013)	0.17 (0.195)	0.01 (0.894)	0.16** (0.005)	0.10* (0.045)
Residential use (#)	-0.01*** (<0.001)		-0.01** (0.002)	-0.01*** (<0.001)	-0.01*** (<0.001)	-0.01* (0.017)		-0.01* (0.042)	-0.01* (0.040)	-0.01* (0.039)
Commercial use (#)	0.02*** (<0.001)			0.02*** (<0.001)	0.02*** (<0.001)	0.02** (0.001)			0.03*** (<0.001)	0.02* (0.016)
Office use (#)	0.01** (0.001)			0.01** (0.001)	0.01** (0.002)	0.01 (0.202)			0.01 (0.301)	0.01 (0.154)
School (#)	0.03*** (<0.001)			0.04*** (<0.001)	0.03*** (<0.001)	0.02 (0.558)			0.02 (0.436)	0.01 (0.761)

*: p<0.05, **: p<0.01, ***: p<0.001

Threshold (75% = 0.24)

Bivariate Analysis between Control Variables and Dependent Variables

Variable	High % of population below the poverty line (N=110)					Low % of population below the poverty line (N=316)				
	Total crash	Fatal injury	Serious injury	Minor injury	No injury	Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Coefficient (*p*-value)									
Control variables										
Risk exposures										
Traffic volume (#) (million)	0.19*** (<0.001)	0.17** (0.004)	0.15*** (<0.001)	0.19*** (<0.001)	0.19*** (<0.001)	0.27*** (<0.001)	0.28*** (<0.001)	0.29*** (<0.001)	0.26*** (<0.001)	0.27*** (<0.001)
Area of the spatial unit (100 acres)	0.20*** (<0.001)	0.34** (0.005)	0.16* (0.022)	0.21*** (<0.001)	0.20*** (<0.001)	0.08*** (<0.001)	0.09** (0.006)	0.11*** (<0.001)	0.07*** (<0.001)	0.08*** (<0.001)
Socio-demographic characteristics										
Total population (#) (thousand)	0.27** (0.001)	0.38* (0.031)	0.21 (0.061)	0.27** (0.002)	0.28** (0.001)	0.34*** (<0.001)	0.25* (0.026)	0.45*** (<0.001)	0.32*** (<0.001)	0.36*** (<0.001)
Population aged under 18 (#)(thousand)	0.58** (0.008)	1.29* (0.012)	0.82** (0.009)	0.59** (0.009)	0.56* (0.010)	0.38* (0.046)	0.40 (0.211)	0.92** (0.001)	0.40* (0.045)	0.34 (0.061)
Non-white population (#) (thousand)	0.34* (0.024)	0.75* (0.030)	0.44 (0.052)	0.34* (0.029)	0.34* (0.025)	0.86*** (<0.001)	0.80** (0.004)	1.16*** (<0.001)	0.89*** (<0.001)	0.82*** (<0.001)
Population less than high school (#)(thousand)	0.76** (0.007)	1.79** (0.009)	1.32** (0.002)	0.76** (0.009)	0.74** (0.008)	1.98*** (<0.001)	2.32** (0.003)	2.62*** (<0.001)	2.19*** (<0.001)	1.71*** (<0.001)
Male population (#)(thousand)	0.58*** (<0.001)	0.73* (0.034)	0.37 (0.096)	0.56** (0.001)	0.62*** (<0.001)	0.70*** (<0.001)	0.55** (0.006)	0.88*** (<0.001)	0.67*** (<0.001)	0.73*** (<0.001)
Travel behaviors										
Workers commuting by walking (#)(thousand)	0.14 (0.926)	2.98 (0.371)	4.08 (0.074)	0.48 (0.764)	0.94 (0.540)	11.42*** (<0.001)	7.26 (0.057)	11.31*** (<0.001)	10.69*** (<0.001)	12.27*** (<0.001)
Workers commuting by public transit (#)(thousand)	1.68 (0.118)	0.30 (0.881)	0.45 (0.781)	1.58 (0.155)	1.84 (0.083)	9.53*** (<0.001)	7.10* (0.014)	7.22** (0.001)	9.91*** (<0.001)	9.10*** (<0.001)
Workers commuting by biking (#)(thousand)	2.96 (0.192)	5.39 (0.232)	4.84 (0.120)	2.93 (0.206)	3.21 (0.161)	10.84*** (<0.001)	11.55* (0.013)	10.45** (0.001)	11.18*** (<0.001)	10.68*** (<0.001)

*: p<0.05, **: p<0.01, ***: p<0.001

Base Model and One-by-One Test

Variable	High % of population below the poverty line (N=110)					Low % of population below the poverty line (N=316)				
	Total crash	Fatal injury	Serious injury	Minor injury	No injury	Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Coefficient (*p*-value)									
Base model										
Traffic volume (#) (million)	0.17*** (<0.001)	0.13* (0.026)	0.16*** (<0.001)	0.17*** (<0.001)	0.17*** (<0.001)	0.23*** (<0.001)	0.25*** (<0.001)	0.22*** (<0.001)	0.23*** (<0.001)	0.23*** (<0.001)
Area of the spatial unit (100 acres)	0.07 (0.174)	0.20 (0.082)	0.03 (0.687)	0.08 (0.119)	0.05 (0.292)	0.02 (0.848)	0.02 (0.482)	0.04* (0.026)	0.01 (0.946)	0.01 (0.659)
Population less than high school (#)(thousand)	0.45 (0.084)	0.85 (0.243)	0.99* (0.022)	0.39 (0.146)	0.51* (0.048)	1.56*** (<0.001)	2.06** (0.003)	1.88*** (<0.001)	1.83*** (<0.001)	1.23*** (<0.001)
Workers commuting by walking (#)(thousand)	0.43 (0.695)	3.96 (0.148)	5.04* (0.011)	1.21 (0.289)	0.54 (0.617)	5.40** (0.002)	0.28 (0.935)	3.62 (0.131)	4.88** (0.009)	6.06** (0.001)
One-by-one test										
Sidewalks (miles)	-0.06 (0.051)	-0.08 (0.055)	-0.04 (0.112)	-0.06** (0.001)	-0.06** (0.001)	-0.01 (0.356)	-0.03 (0.867)	-0.02 (0.162)	-0.01 (0.308)	-0.01 (0.454)
Bike lanes (miles)	0.02 (0.260)	0.01 (0.897)	0.03 (0.302)	0.03 (0.187)	0.02 (0.394)	0.02* (0.045)	0.01 (0.554)	0.02 (0.818)	0.02* (0.034)	0.02 (0.076)
Three-leg street intersections (#)	-0.01 (0.075)	-0.02 (0.138)	-0.01 (0.517)	-0.01 (0.050)	-0.01 (0.130)	-0.01 (0.069)	-0.01 (0.963)	-0.01 (0.286)	-0.01* (0.032)	-0.01 (0.187)
Four-or-more-leg street intersections (#)	0.02** (0.001)	0.02 (0.122)	0.02 (0.098)	0.02** (0.003)	0.02** (0.001)	0.02** (0.003)	0.01 (0.281)	0.01 (0.396)	0.02** (0.007)	0.02** (0.002)
Transit stops (#)	0.04*** (<0.001)	0.02 (0.333)	0.03* (0.028)	0.04*** (<0.001)	0.04*** (<0.001)	0.05*** (<0.001)	0.05** (0.007)	0.05*** (<0.001)	0.06*** (<0.001)	0.05*** (<0.001)
Highway/freeway (miles)	0.01 (0.935)	0.07 (0.646)	0.06 (0.525)	0.02 (0.692)	0.02 (0.703)	0.04 (0.370)	0.03 (0.717)	0.02 (0.805)	0.03 (0.495)	0.05 (0.255)
Arterials (miles)	0.25*** (<0.001)	0.11* (0.015)	0.26** (0.001)	0.24*** (<0.001)	0.25*** (<0.001)	0.19*** (<0.001)	0.20** (0.008)	0.11* (0.027)	0.20*** (<0.001)	0.17*** (<0.001)
Residential use (#)	-0.01 (0.647)	-0.03 (0.689)	-0.01 (0.165)	-0.01 (0.786)	-0.01 (0.518)	-0.01** (0.002)	-0.01 (0.332)	-0.01* (0.011)	-0.01** (0.002)	-0.01** (0.005)
Commercial use (#)	0.02*** (<0.001)	0.03* (0.012)	0.01 (0.102)	0.02*** (<0.001)	0.02*** (<0.001)	0.02*** (<0.001)	0.01 (0.091)	0.01* (0.034)	0.02*** (<0.001)	0.02*** (<0.001)
Office use (#)	0.01* (0.020)	0.01 (0.321)	0.01* (0.027)	0.01* (0.025)	0.01* (0.020)	0.01* (0.013)	0.03 (0.639)	0.01 (0.151)	0.01* (0.016)	0.01* (0.014)
Industrial use (#)	0.02 (0.589)	0.01 (0.306)	0.01 (0.502)	0.02 (0.665)	0.03 (0.517)	0.01 (0.135)	0.01 (0.539)	0.01 (0.354)	0.01 (0.143)	0.01 (0.146)
School (#)	0.02* (0.026)	0.01 (0.890)	0.03 (0.072)	0.02* (0.015)	0.02* (0.037)	0.06*** (<0.001)	0.04 (0.157)	0.04* (0.029)	0.06*** (<0.001)	0.05*** (<0.001)
Park (#)	0.01 (0.379)	0.03 (0.494)	0.02 (0.891)	0.01 (0.446)	0.01 (0.286)	0.01 (0.993)	0.01 (0.309)	0.01 (0.759)	0.01 (0.877)	0.01 (0.849)

*: p<0.05, **: p<0.01, ***: p<0.001

Final Negative Binomial Model

Variable	High % of population below the poverty line (N=110)					Low % of population below the poverty line (N=316)				
	Total crash	Fatal injury	Serious injury	Minor injury	No injury	Total crash	Fatal injury	Serious injury	Minor injury	No injury
	Coefficient (*p*-value)									
Traffic volume (#) (million)	0.15*** (<0.001)	0.12 (0.040)	0.15*** (<0.001)	0.15*** (<0.001)	0.15*** (<0.001)	0.18*** (<0.001)	0.23*** (<0.001)	0.19*** (<0.001)	0.17*** (<0.001)	0.18*** (<0.001)
Area of the spatial unit (100 acres)	0.06 (0.194)	0.13 (0.372)	0.14 (0.091)	0.06 (0.277)	0.07 (0.124)	0.01 (0.774)	0.02 (0.527)	0.04 (0.056)	0.01 (0.531)	0.01 (0.954)
Population less than high school (#)(thousand)	0.62* (0.010)	1.13 (0.155)	1.52** (0.001)	0.56* (0.028)	0.67** (0.004)	1.07*** (<0.001)	1.93** (0.004)	1.63** (0.001)	1.32*** (<0.001)	0.76** (0.007)
Workers commuting by walking (#)(thousand)	0.81 (0.395)	4.31 (0.114)	6.04** (0.002)	1.68 (0.092)	0.25 (0.793)	0.10 (0.947)	1.68 (0.638)	1.20 (0.583)	0.55 (0.720)	0.92 (0.537)
Arterials (miles)	0.22*** (<0.001)	0.11* (0.023)	0.25** (0.002)	0.21*** (<0.001)	0.22*** (<0.001)	0.15*** (<0.001)	0.20** (0.008)	0.12* (0.019)	0.16*** (<0.001)	0.13*** (<0.001)
Residential use (#)	-0.01 (0.549)		-0.01 (0.319)	-0.01 (0.603)	-0.01 (0.543)	-0.01*** (<0.001)		-0.01** (0.008)	-0.01*** (<0.001)	-0.01*** (<0.001)
Commercial use (#)	0.02** (0.001)			0.02** (0.001)	0.02*** (<0.001)	0.02*** (<0.001)			0.02*** (<0.001)	0.02*** (<0.001)
Office use (#)										
School (#)	0.02* (0.045)			0.02* (0.027)	0.01* (0.048)	0.04*** (<0.001)			0.05*** (<0.001)	0.04** (0.001)

*: p<0.05, **: p<0.01, ***: p<0.001