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Environmental Characteristics around Hotspots of Pedestrian-Automobile Collision in the City of Austin

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Environmental Characteristics around Hotspots of Pedestrian-Automobile Collision in the City of Austin

by

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Dedication

To my sweet parents, auntie and grandmother in China.

No one would have been more proud of me.

Acknowledgements

Thanks to all the friends, faculties and colleagues who technically and mentally supported me through this process. In addition, I would like to express my gratitude to Yuanshen Ji and Haitao Yu for offering me free rides to conduct the field survey around hotspots during Texas summer days.

Abstract

Environmental Characteristics around Hotspots of Pedestrian-Automobile Collision in the City of Austin

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The increasingly serious pedestrian safety issue in the City of Austin aroused the concern. Other than conducting quantitative analysis at aggregate level via collecting and examining the secondary data extracted from the existing datasets, the authors shifted towards the disaggregate level analysis, focusing on twenty-six hotspots of pedestrian collisions via mixed method research. Qualitative data was collected in the field survey to precisely capture the contextual features of collision locations, and was interpreted and coded as explanatory variables for the quantitative analysis. Instead of the frequency of pedestrian collision, crash rate measured by incident count per million pedestrians was the dependent variable to identify the factors truly influencing the pedestrian safety issue, not just the total number of walkers. The stepwise bivariate analysis and negative binomial regression examined the association between pedestrian collision rate and independent variables. Finally, the average block length, speed limit posted, sidewalk

condition, and the degree of proximity to major pedestrian attractors were statistically significant factors correlating with the pedestrian collision risk.

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Chapter One: Introduction

Accidents of crashing into pedestrians are on the rise in Texas. Texas Department of Transportation (TxDOT) reported that 5,000 pedestrians were hit in 2012, resulting in nearly 3,000 serious injuries and 481 deaths, which indicated 13.2 percent higher than the death rate of 2011. In the United States, one pedestrian is killed every 119 minutes, while one was injured every eight minutes in 2012[1].

The City of Austin experienced 78 traffic fatalities in 2012. 26 auto-pedestrian deaths accounted for 33% of the total, which increased 18 percent compared to 2011[2]. From 2008 to 2012, there has been 91 pedestrian fatalities occurring in the city during five-year period of time[3]. The increasingly growing fatal pedestrian collisions raise the concern. Pedestrian safety issue has been identified as one of three priorities for discussion in the 2012 Transportation Safety Summit held by City of Austin Transportation Department and CAMPO.

In many auto-dominant cities in Texas, the design of transportation system has the long-term tradition favoring auto users. Yet the pedestrian interests, such as safety, accessibility and mobility, are always unequally undervalued. To enhance the pedestrian safety and improve the walking environment in the City of Austin, this paper identified the locations where the pedestrian crashes more frequently occurred and the factors of

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[1] Austin Local News, TxDOT: Pedestrian, Bicyclist accidents on the rise. http://www.kvue.com/news/local/TxDOT-Pedestrians-and-bicyclist-accidents-jump-13-and-19-percent-respectively-220240291.html

[2] City of Austin 2012 Traffic Fatality Report

[3] Pedestrian and bicycle deaths in Austin, http://www.statesman.com/interactive/traffic/pedestrian-fatalities/

environment associated with the pedestrian-auto collision risk. The conclusion can provide implications for the policies of transportation, land use, and pedestrian facility improvement in the City of Austin.

Chapter Two: Literature Review

The primary theory shedding the light upon the traffic safety research is Haddon Matrix (Catherine Cubbin, 2002). It identified three broad contributors accounting for the crashes, human, agent (vehicle), and built environmental factors in pre-event, accident, and post-event phases. Similarly, four contributing factors that increase the likelihood of a pedestrian collision were concluded as (1) pedestrian/ driver factors; (2) vehicle factors; (3) traffic and roadway factors; and (4) land use, social, and physical factors (B. J. Campbell, 2004). Campbell et al. also pointed out that pedestrian or driver factors accounted for only 15 percent of collisions, and vehicle factors contributed 12 percent to the cases. Therefore, there has been more and more traffic safety studies investigating the impacts of environmental features on the pedestrian risks, instead of individual-level errors. In this paper, environmental features are broadly categorized into traffic condition, roadway design including pedestrian facilities, and land use factors.

2.1 TRAFFIC AND ROADWAY DESIGN

2.1.1 Traffic Condition

As mentioned previously, researches on correlates of pedestrian-vehicle collisions showed that traffic volume was a significant predictor. Higher pedestrian average daily traffic (ADT) and higher traffic ADT had effects on the occurrence of pedestrian crashes (Junfeng Jiao A. V., 2013; Roberts, 1995; Levine N. K., 1995a; Levine N. K., 1995b; Robert J. Schneider, 2004). The association between the traffic volume and pedestrian crash risk can be sustained by “no safety in numbers” concept: areas where there were more pedestrians also have more vehicular traffic, leading to more collisions (Rajiv Bhatia, 2011).

Injury severity was largely determined by vehicle speed. At the individual level, hit by a vehicle traveling 40 miles per hour (mph), the chance of a pedestrian being killed was 85 percent, while the fatality rate dropped to 5 percent at 20 mph (Charles V. Zegeer C. S., 2002; U.K. Department for Transport, 1997). For contextual concern, Campbell pointed out that most pedestrian crashes occurred where speed limits posted were low to moderate ranging from 40 to 56 km/h (B. J. Campbell, 2004). It was primarily because most pedestrians generally walked in higher density area where high speed was not encouraged.

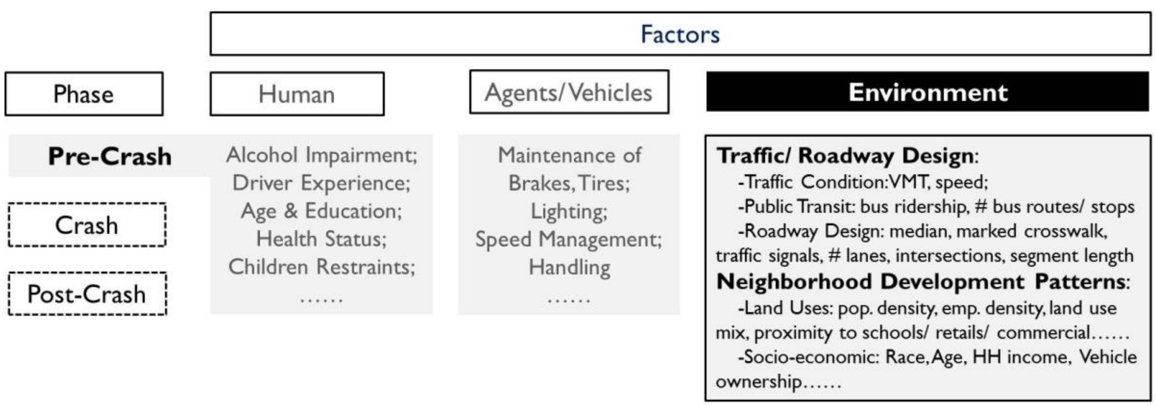


Figure 1: Body of Literature Related to Pedestrian Safety

2.1.2 Roadway Design

Roadway design elements have been carefully examined in the micro-level environment. The earlier studies indicated the presence of pedestrian signal at roadway junctions had mixed effects upon pedestrian behaviors (Jil Mead, 2013). Providing raised median could substantially reduce pedestrian crash rate on multi-lane roads (B. J.

Campbell, 2004). Zegeer et al. found that the presence of marked crosswalks was significantly associated with lower pedestrian crash risk only on multilane roads with ADT greater than 10,000 accidents (Charles V. Zegeer J. R., 2002). The density of intersections was also associated with increased pedestrian crashes (Eric Dumbaugh, 2011; Reid Ewing K. K., 2012; Junfeng Jiao A. V., 2013; Chowdhury Siddiqui, 2012). Roadway segment length, number of roadway lanes, the presence of traffic signals were also the common predictors of pedestrian collision risk (Robert J. Schneider, 2004; B. J. Campbell, 2004).

2.1.3 Public Transit

Public transit was a safer alternative and generated less traffic volume at corridor level. Yet in micro-level environment, transit stop was always considered as an important pedestrian attractor which would bring more pedestrian volumes and collisions. Careful placement of bus stops, number of bus stops, and bus ridership can affect pedestrian safety (Junfeng Jiao A. V., 2013; Paul Mitchell Hess, 2004; Robert J. Schneider, 2004). Use of bus stops on the far side of an intersection and at locations with a good sight distance and alignment was important (B. J. Campbell, 2004; Junfeng Jiao A. V., 2013).

2.2 NEIGHBORHOOD DEVELOPMENT

2.2.1 Land Use Characteristic

Land use factors played the role of activity generator as well as pedestrian attractor. Thus, they can be primarily viewed as the proxy measure of pedestrian volume. Many studies have examined that pedestrian collision risk increased with higher population or employment density (Eric Dumbaugh, 2011; Anastasia Loukaitou-Sideris, 2007; Chowdhury Siddiqui, 2012; Robert J. Schneider, 2004). Campbell summarized that the pedestrian collisions more frequently took place in residential and commercial areas where most pedestrian exposure occurred. Loukaitou-Sideris et al. also observed a higher density of incidents in neighborhoods with higher percent of commercial and retail uses and high-density residential uses (Anastasia Loukaitou-Sideris, 2007). The positive association between pedestrian-vehicle collisions and the presence of strip commercial use, big box stores, neighborhood commercial center, and schools were also noted in the previous studies (Eric Dumbaugh, 2011; Junfeng Jiao A. V., 2013; Levine N. K., 1995b).

2.2.2 Socio-economic Status

Age, race, neighborhood poverty, and vehicle ownership were found as the proxy of socio-economic status associated with pedestrian collision risks. Researchers have found the relationship between pedestrian collisions and an area's social deprivation as well as lack of affluence (B. J. Campbell, 2004). Studies conducted in California pointed out that Hispanic and African American children living in the disadvantaged neighborhoods under the poverty level were disproportionately represented among all pedestrian injuries related to their shares of the population (Anastasia Loukaitou-Sideris, 2007; Megan Wier, 2009). It was assumed that vulnerable groups were more likely to walk, ride, or take public transit because they cannot afford the private vehicles, which resulted in a greater exposure to dangers of the streets.

2.3 LIMITATIONS

In sum, there have already been many studies investigating the relations between pedestrian collision risk and environmental features. Environmental features were broadly grouped into traffic and roadway predictors and neighborhood development factors. It was evident that more efforts were spent on examining factors of traffic condition and roadway design elements than the land use. The positive association between the pedestrian-vehicle collisions and traffic volume as well as vehicle speed has been carefully modeled and well interpreted. Other roadway design elements at the micro- and macro-level environment were also identified and examined, yet the correlations varied case by case. However, the land use factors characterizing neighborhood development patterns, a direct determinant of traffic volume, pedestrian exposure, and roadway design characteristic were comparatively under studied. Therefore, the author's study focused on the built environment of neighborhood including land use patterns and the degree of proximity to major attractors.

Although some built environmental factors have been justified by now, most traffic safety studies depended upon the context. There were few relevant researches specifically conducted within Texas context. As the travel behavior and environmental features of Texas are fairly different from other places across the nation, whether these site- or context-sensitive predictors also have effects on the pedestrian collision in Austin requires further investigation. Therefore, authors tried to identify and examine the factors accounting for pedestrian safety issue in the local context.

Another critical issue with previous researches was that most of them just demonstrated the factors encouraging or discouraging people from walking, not the contributing factors exactly accounting for pedestrian unsafety. Chowdhury Siddiqui et al. grouped the safety researches into two broad categories. One branch of safety studies investigated pedestrian collision by micro-level roadway entities. While the other branch of analysis calculated crash frequency by aggregating crash data over specific geographic entity, such as census blocks, census tracts, TAZs, or grid cells. By now, researches around pedestrian safety were almost aggregate level analysis due to the availability of in-depth data. However, the aggregated spatial data always faced the issue of Modifiable Areal Unit Problem (MAUP) (Junfeng Jiao A. V., 2013), where analysis units of different sizes or shapes can result in different model conclusion. Therefore, the predictor variables, which should have indicated meaningful associations at micro level, were also examined in the aggregate studies, resulting in unexpected correlates that can hardly be interpreted by the known theories and principles. For example, it was assumed that the presence of crosswalk at junction in micro-level analysis had positive effect on pedestrian behavior. However， at the aggregate level, intersections equipped with marked crosswalks were associated with higher pedestrian crash frequency (Junfeng Jiao A. V., 2008; Megan Wier, 2009). Similar inconsistency also happened to the predictors of neighborhood land uses, transit route and stop, and traffic signals. Safety benefits (or impacts) of some predictors at disaggregate level can be opposite when being accumulated to the macro-level environment. The reason was that most of those explanatory variables in aggregate-level studies only demonstrated what attracted more walkers rather than the reasons for unsafe walking. Although more collisions were expected to occur in places where there were more pedestrians, few studies have accounted for the underlying effects of pedestrian volume on collision risk. Therefore, in-depth explanatory variables at disaggregate level, not limited to roadway entities, are expected to be identified. What's more, a more valid measure of pedestrian collision risk should also be proposed and examined. In this way, the study can find out the factors which truly influence the pedestrian safety, not the total number of people walking.

Thus, this paper not only identified the contextual features of higher pedestrian crash locations in a broad sense, but also specifically analyzed the built environmental characteristics at disaggregate level to truly reflect pedestrian safety issue. The roadway design elements and land use characteristics around the hotspots of pedestrian collisions were fully examined through mixed research method. The first section at macro level can inform the policy maker where the safety improvement programs should direct to. The latter part can indicate the pedestrian safety countermeasures in micro environment design.

Chapter Three: Research Questions and Goals

3.1 SPATIAL DISTRIBUTION OF PEDESTRIAN CRASH

The study identified high frequency auto-pedestrian crash locations in Austin. As many previous studies suggested, the pedestrian-vehicle crashes were disproportionately distributed throughout the region: some particular areas have higher densities of pedestrian injuries than others. At first, this paper responded the first question as following:

1. Where did automobile-pedestrian crashes frequently occur in the City of Austin during recent years? And, where were higher density crash locations in the City?

3.2 TYPOLOGIES OF BUILT ENVIRONMENT

Having acquired the spatial distribution of collisions involving pedestrians in the City, the field surveys including observation, photographic documentation, and field check and rating were then employed to help create the typologies of built environment surrounding the hotspots. The goal was to identify the common issues faced by the hotspots of pedestrian collision in the perspectives of roadway feature, pedestrian facilities, and land use characteristics. It helped to identify explantory variables for further statistical analysis in the next step. Therefore, the second research question was shown as following:

2. In the micro-level environment, what common ground do these locations with higher-density pedestrian crashes share in the aspects of roadway design elements and land uses?

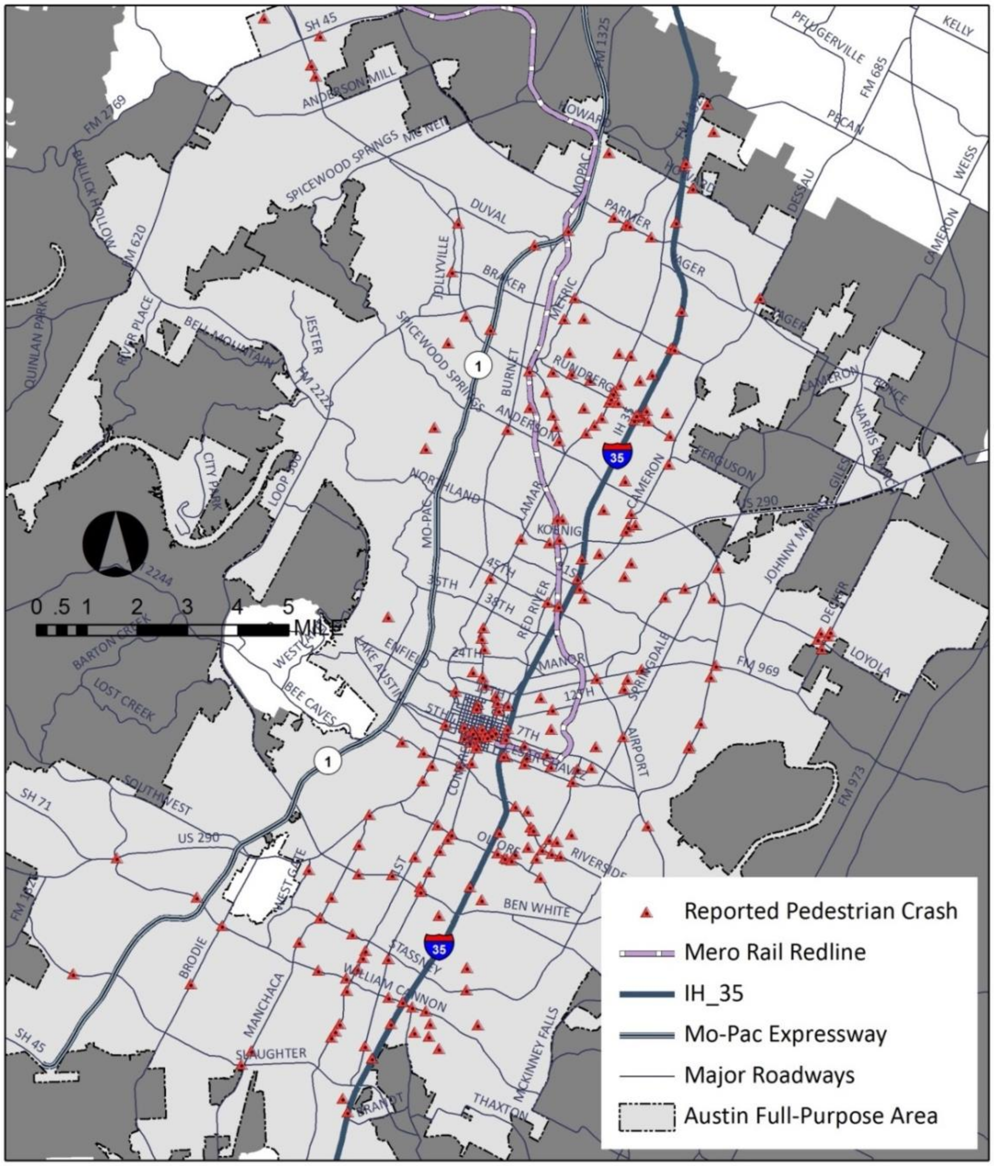
3.3 EXAMINATION OF ENVIRONMENTAL FACTORS

On top of spatial analysis and qualitative study of collisions involving pedestrians in Austin, the quantitative analysis examined built environmental factors and how these factors affected the risk of pedestrian crashes. The associations can help the City of Austin understand the environmental factors influencing the pedestrian collision risk. They can optimize the facility improvement programs and transportation projects by providing the targeted pedestrian safety countermeasures. Finally, the last research question was:

3. What environmental factors of hotspot locations where pedestrian collisions more frequently occurred were significantly associated with the risk of pedestrian crashes? And how these environmental factors affect the risk of pedestrian collision in Austin?

Chapter Four: Research Method and Data

4.1 CRASH DATA



Projection Coordinate System: NAD_1983_StatePlane_Texas_Central_FIPS_4203_Feet
Data Source: Austin Police Department (ADP) Annual Incident Extract 2008-2012, Jan.-May 2014

Figure 2: Reported Pedestrian Crashes in Austin, 2008-2012, Jan.-May 2014

As this paper tried to disclose the environmental factors accounting for the collisions involving pedestrians in the urban areas, research only focused on the geography of the full-purpose jurisdiction of Austin, neither extraterritorial jurisdictions (ETJ) nor limited-purpose areas were included. Pedestrian-vehicle collision was “rare” event, which requires long-term recording over multiple years in order to obtain a sufficient number of observations (Junfeng Jiao A. V., 2013). Given by the confidentiality of crash datasets under the protection by the federal and state laws, author failed to request the full crash datasets for the most recent years from the Texas Department of Transportation (TxDOT) and the Capital Area Metropolitan Planning Organization (CAMPO) as an individual graduate researcher. The only accessible datasets was Open Government Data provided by the City of Austin[4]. Through searching “Crash” then filtered by the crime type of “PED-AUTO Crash/Collision”, 257 reported crashes from 2008 through 2012 and from January to May 2014 were successfully extracted from Austin Police Department (ADP) Annual Incident Extract[5]. However, crash records collected in this way were roughly one-third of total collision record released by CAMPO during the same period[6]. The reason for this issue was unknown, though one CAMPO planner confirmed that the crash datasets of both APD and CAMPO followed the same statewide data scheme. To complete the study in time after several unsuccessful requests, these 257 crashes involving pedestrians were finally geocoded in ArcGIS to proceed. CAMPO Online Interactive Map[7] was used to check against and to confirm the hotspot selection. To correct the shortage of deficient

[4] City of Austin’s Open Datasets, https://data.austintexas.gov/
[5] https://data.austintexas.gov/browse?limitTo=datasets&utf8=%E2%9C%93&q=crash&sortBy=relevance
[6] Pedestrian Crash 2008-2010, CAMPO Region: http://campotexas.wpengine.com/wp-content/uploads/2013/10/Pedestrian-Crashes-2008-to-2010-5County.pdf
[7] CAMPO Interactive Map: http://www.austintexas.gov/GIS/CAMPOInteractiveMap/

data, the research method was specifically designed to deal with the issue in order to improve the validity as well as the reliability of the research. Figure 2 above shows the spatial distribution of the reported collision involving pedestrians in the City of Austin.

4.2 MIXED METHOD RESEARCH

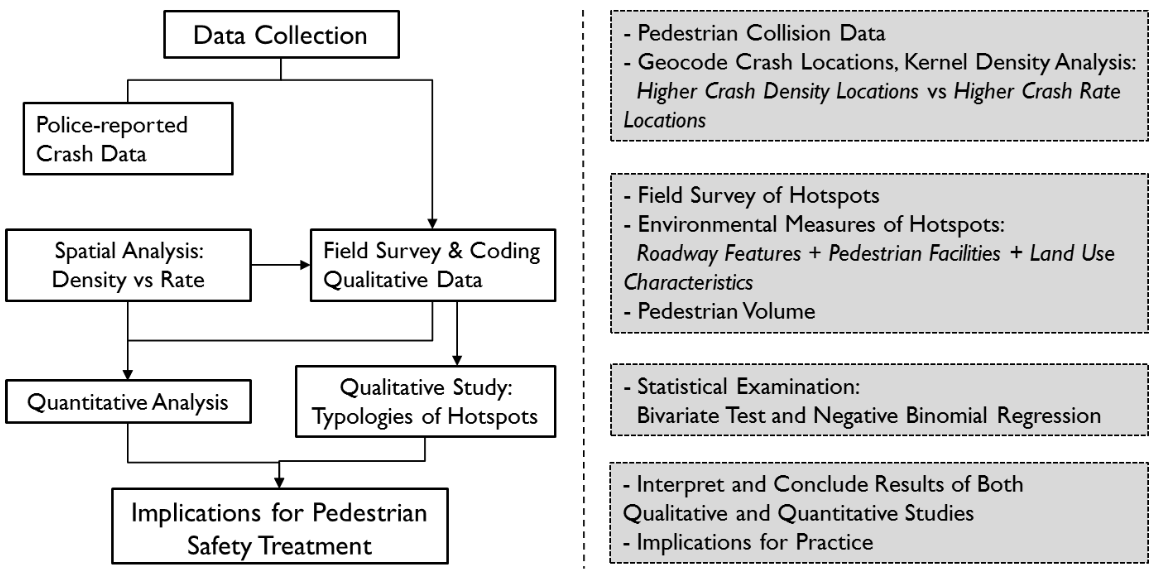


Figure 3: Structure of Mixed Method Research

Given by the issue of inadequate data, quantitative analysis alone focusing upon the full City's geography cannot validly produce any generalized conclusions. Therefore, compromising the generalizability, this paper shifted toward the thorough analysis of contextual features of higher-density collision locations. Additionally, pedestrian safety can be considered as a contextual-dependent issue. If this paper only employed the quantitative method examining the factors identified by earlier works, some unexpected associations which would be only specific to Austin context would be veiled. The field survey including direct observation, photographic documentation, and field check can induct the possible built environmental factors on the ground. Therefore the qualitative method was necessarily incorporated to correct the issue of data shortage as well as the limitation of the quantitative method in nature.

Specifically, author employed the mixed method research that consisted of three closely sequential parts. At first, the collisions involving pedestrians were geocoded via Arc GIS in order to present the spatial distribution of auto-pedestrian crashes in the city. Then higher incident density locations were identified as hotspots for the sample. In the next stage of qualitative study, the field survey was conducted around the selected hotspots where the crash risk arose to varying degrees. Each hotspot location of pedestrian collision was surveyed and evaluated by measures of roadway features, pedestrian facilities, and land use characteristics. Aerial photography provided by Google Earth and field photographic documentation by author were also used to assist with evaluating each hotspot of pedestrian collision in the sample. After analyzing the qualitative data collected in the field survey, typologies of hotspots were created, and factors which might affect the risk of pedestrian collision were identified as independent variables for further statistical examination. Then, qualitative data collected from the field survey were coded and quantitated as inputs for the following statistical analysis. In the last phase of quantitative analysis, bivariate analysis and negative binomial regression model examined the potential the association between pedestrian collision risk and independent variables measuring the built environment patterns. In sum, the sequential mixed method involved collecting data in a process whereby the data gathered in one phase contributes to the data examined in the next. The application of mixed method approach ensured that two data gathering method complemented to each other. Quantitative method can estimate the relationship between outcomes and contributing factors, while qualitative analysis can precisely provide the contextual information and facilitate understanding and interpretation of the quantitative results.

4.3 SPATIAL ANALYSIS BY KERNEL DENSITY

Kernel density estimation was used to represent the spatial distribution of collisions involving pedestrians in the city, as the technique can precisely identify the location, spatial extent and intensity of the incidents at a broad, regional view. Kernel density estimation involves placing a symmetrical surface defined by the searching radius around each crash point, evaluating the surface value primarily determined by distance from the incident point to the reference cell based on the quartic function, and summing the values of all Kernel surfaces where they overlays the grid cell. Thus, each reference cell has a different density estimates as different number of the collisions fall within the search area of the grid cell (Levine N. , 2013).

Kernel Density estimation was implemented in Arc GIS in author's study. The spatial analysis tool in ArcGIS visually presented Kernel estimates: areas with higher densities of pedestrian collisions were shown in darker tones, while those with lower densities were shown in lighter tones. The 100 by 100 meter (roughly equals to 328 feet) reference grid cell was laid over the entire City's jurisdiction. The cell size was determined by the estimated block length on average in the downtown core area. The relatively smaller size of grid cell can help precisely show the hotspots of auto-pedestrian collisions in the city. The searching radius which determined the Kernel surface was defined as half a mile, 1,320 feet. As the sample size was smaller due to the missing crash record, a larger searching radius was selected in order to avoid finding false hotspots: some hotspots may be nothing more than random variation. Half-mile distance is also the maximum accepted walking distance for the people.

From the spatial analysis, a profile of overall pedestrian collision in the City was expected to be outlined. Roadway features and location types of collision points were examined in order to see the common issues of built environment contributing to incidents. Then twenty-six areas with higher densities of pedestrian-auto collisions were expected to be found out in the City. These higher crash density areas where the contiguous grid cells in darker tones clustered were considered as the hotspots of pedestrian crash. The study area was defined as the union of quarter-mile buffer area from the pedestrian-auto crash points of each hotspot. Measures representing environmental characteristics of hotspots in the following study were almost at the analysis unit of study area, except the ones for which data should be collected from U.S. census estimations.

4.4 FIELD SURVEY AND QUALITATIVE ANALYSIS

As mentioned in the section of literature review, the most predictor variables from earlier studies at aggregate level merely indicated the factors that attracted a number of pedestrian activities, such as the density of population, number of intersections and percent of commercial and retail uses, rather than the factors that exactly contributed pedestrian safety issue. Even in a neighborhood where any parts of it almost shared some broad-scale features in development types, property value and density, the pedestrian crashes always more frequently occurred at some certain locations because the closely adjacent built environment of these incident points directly accounted for the risk of pedestrian collisions. Moreover, the data of measures in the aggregate-level studies were almost the secondary numerical value, which are too rough and abstract to exactly characterize the environment context. Therefore, instead collecting quantitative data of macro-level measures from the existing datasets, direct observation and field check at study area level and urban block scale for each hotspot were necessarily employed in author’s study to collect the primary descriptive data. Measures of qualitative study at disaggregate level can more concretely characterize the environments of unsafe walk. At last but not the least, another major reason for the necessity of qualitative study was to correct the shortage of crash data: the limited data made it challenging to bring out the generalized theory, while the study can shift towards representing the real context.

Therefore, after identifying twenty-six top hotspots of pedestrian incident in the first phase, qualitative methods were used to collect and analyze data. Following the data collection instrument shown in Table 1, the direct observation, field check and rating, photographic documentation, and exploration on Google Map together were employed to evaluate the built environment surrounding the hotspots of incidents. Then original data were interpreted and coded in order to identify the causing factors and to create typologies of built environment around twenty-six hotspots. The coding also helped introduce the interpreted qualitative data into the subsequent quantitative study.

4.4.1 Justification of Measures

Measures used in qualitative study were categorized into four groups, volume of pedestrian activity, pedestrian facilities, roadway features, and land use characteristics, in order to fully capture the characteristics of built environment around hotspots. There's no safety in numbers, simply, pedestrian crash are more likely to occur where there are a number of pedestrian activities. However, previous studies where frequency of collision served as the dependent variable only examined the factors influencing the total number of people walking. Therefore, pedestrian count in five minutes during the peak hour was necessarily introduced to estimate the average daily pedestrian volume of hotspots. The objective data came from direct observation and counting in person by the author.

Pedestrian facilities were grouped by the location type: signalized intersections, uncontrolled intersections or mid-blocks, and corridor. The earlier studies indicated the installation of pedestrian signal had mixed effects on pedestrian behaviors and unclear influences on motorist behaviors, while the impact of pedestrian countdown signals on pedestrian-automobile collisions should be further examined. Previous studies already demonstrated positive effects on both pedestrians and motorists behaviors responding to the highly-visible crosswalks or leading pedestrian intervals, though the association between crosswalk and pedestrian crash rate was still debatable. Zegger et al. found that the presence of crossing island or raised median can provide the pedestrians with statistically significant safety benefits on multi-lane roads (Jil Mead, 2013). Whether one of the treatments including pedestrian signal, crosswalk, and raised median, or any combination of them installed at different locations would have different safety impacts on the incidents required more analysis. Sidewalks in good condition was suggested to encourage more walking, while whether the condition of sidewalk can be significantly associated with the walking safety remained unknown. Sidewalk condition was examined from the width, continuity, ramps, tree canopy, and street-oriented buildings. The report of Best Practice for Walking and Bicycling in Michigan and City of Austin Sidewalk Master Plan[8] were the important reference for the justification of countermeasures of pedestrian facilities. Objective data on pedestrian facilities within the study areas of hotspots all came from field survey.

On-street parking can serve as the buffer area separating pedestrian from the heavy traffic flow, while sometimes it also yielded conflicts between pedestrians and motors. Its safety impacts on the different types of roadway and location should be further examined. The other measures evaluating roadway features, such as roadway type, number of lane, and speed limit, were primarily selected from the Federal Highway Administration's (FHWA) overview of pedestrian crash countermeasures and safety programs and literature review of researches of pedestrian-related roadway measures (Jil Mead, 2013). Meanwhile author also considered the content in PEDSAFE website[9], North Carolina Pedestrian and Bicycle Crash Data Tool website[10] when selecting the potential measures of roadway features. Objective data of roadway features came from the direct observation, field check, and Austin transportation GIS database.

To review the land use characteristics within the study area, the study citied the checklists from pedestrian-oriented guidelines developed by Reid Ewing (Reid Ewing K. B., 2013) and common characteristics of pedestrian-friendly communities for Washington

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[8] http://www.austintexas.gov/sites/default/files/files/Public_Works/Sidewalk_Master_Plan.pdf
[9] Pedestrian Safety Guide and Countermeasure Selection System, http://www.pedbikesafe.org/PEDSAFE/countermeasures.cfm
[10] Pedestrian Crash Data, http://www.pedbikeinfo.org/pbcat_nc/_ped.cfm

State (Washington State Department of Transportation, 1997). Almost 60 percent of U.S. urban pedestrian crashes occurred at places other than intersections pursuant to the review of national safety research. Midblock dart out and midblock dash were major pedestrian behaviors accounting for the collision occurred in urban area, and pedestrians were judged at fault most of the time (B. J. Campbell, 2004). Pedestrians would dash into the traffic when they felt a detour around destinations if the next safe crossings were far away. Hence the average block length of study area should be one variable, and data was drawn from the Austin geodatabase. Proximity to major attractors to the varying degrees might be an important variable as pedestrians were potentially exposed to more traffic conflicts around these uses. Driveways interruption adjacent to hotspots without any safety control might also present conflicts between walking and driving. Compared to the auto-dominant environment, whether the pedestrian-friendly neighborhood can also offer the safety benefits remained to be further demonstrated. The land use patterns was rated from extremely car dependent to walker's paradise upon the checklist of mix of uses, densities, street network, street-oriented and human-scale buildings, and well-designed street furnishings. The criteria for evaluating land use pattern cited aforementioned guidelines of pedestrian-oriented design, but excluded measures related to the pedestrian facilities and transit facilities in order to avoid the repetitive measuring, more importantly, to avoid the multi-collinearity in the following regression analysis. The communities accommodating higher income households were assumed to offer better public service through maintaining and improving the public goods including roadway and pedestrian facilities. Therefore median household income was also selected as a proxy of community social-economic status, and data was collected from the most recent five-year U.S. census estimates. Measures category, unit of analysis, and data collection method are shown in the following Table 1 with more details.

4.4.2 Coding the Qualitative Data

After acquiring the primary data of environment context in field survey, the author interpreted and categorized the qualitative information responding to each measure. For each non-cardinal measure used in field survey, codes were applied to the relevant contents, and similar condition was systematically marked with the same code name. The process of coding briefly identified the spatial pattern adjacent to the crash locations. Then typologies of built environment were created to characterize the hotspots of pedestrian collision, and suggested predictor variables of pedestrian facilities, roadway features, and neighborhood development for further quantitative analysis.

After coding the qualitative data, there were seven binary measures, six continuous measures, and five categorical measures. Continuous variables included traffic volume, median of household income, residential density, average block length, average speed limits posted, and number of roadway lane. Binary measures checked the presence of facilities and uses or not. The categorical measures included land use patterns, sidewalk conditions, degree of the proximity to pedestrian attractors, crash location types, and roadway classification. The following coding manual in Table 1 shows more details of interpreting data and identifying environment attributes.

Factors		No.	Measures Definition	Measurement	Unit of Analysis	Data Collection Method
Pedestrian Activity		1	Pedestrian Volume	Number of pedestrians passing through the observation point in 5 minutes during the peak hour	Most Frequently Incident Location of Each Hotspots	Observation and Count in Person
Pedestrian Facilities	Signalized Intersection	2(a)	Pedestrian Countdown Signal	Absence ; Presence	Study Area	Field Check, Photography, Google Map
		3(a)	Leading Pedestrian Interval, and/or Crossing Refuge Island	Absence; Presence	Study Area	Field Check, Photography, Google Map
		4(a)	Yield Marking or Stop Bar	Absence; Presence	Study Area	Field Check, Photography
	Mid-Block or Uncontrolled Crossing	2(b)	Pedestrian Sign, Flash Signal, or Stop Bar	Absence; Presence	Study Area	Field Check, Photography
		3(b)	Marked Crosswalk	Absence; Presence	Study Area	Field Check, Photography, Google Map
		4(b)	Pedestrian Refuge	Absence; Presence	Study Area	Field Check, Photography
	Corridor	5	Sidewalk Conditions	Graded from 0=None to 5=Best Sidewalk Condition: Absence = 0; Continuity = +1; Reasonable Width without Overgrowth = +1; Available Ramps = +1; Tree Canopy = +1; Street-Oriented Buildings = +1.	Study Area	Field Check, Photography
		6	Raised Median	Absence; Presence	Study Area	Field Check, Google Map
Roadway Features		7	Location Features	Mid-Block; Intersection; Underpass and Overpass; Others (including Traffic circle, Railroad Crossing; Bridge Junction, etc.)	Most Frequently Incident Location of Each Hotspots	Field Check, Photography, Google Map
		8	Roadway Type	Interstate Highway, Expressway, or Toll road; US and/or State Highway; Major Arterial; Minor Arterial; Local City/County Street; City collector; Ramps and Turn Arounds	Roadways where the Collisions Occurred	Field Check, Google Map, Austin GIS data
		9	On-Street Parking	Absence; Presence	Along Roadways where the Collisions Occurred	Field Check
		10	Roadway Lanes	Number of roadway lanes on average	Roadways where the Collisions Occurred	Field Check, Google Map, Austin GIS data
		11	Speed limits Posted	Measured in miles per hour (mph) on average	Roadways where the Collisions Occurred	Field Check, CAMPO database

Table 1: Data Collection Instrument and Coding Manual

Factors	No.	Measures Definition	Measurement	Unit of Analysis	Data Collection Method
Land Use Characteristics	12	Average Block Length	Measured in feet	Block Group where the Study Area Overlaid	Austin GIS Database
	13	Residnetial Use	Predominant Residential Use; Not Predominant Residential Use.	Study Area	Austin GIS Database
	14	Proximity to Attractors	Graded from 0=None to 5=Most Pedestrian Volume as well as Conflicts: None of Attractors = 0; Proximate to Transit hubs or stops = +1; Proximate to Gas station with Grocery stores = +1; Proximate to Schools = +1; Proximate to Employers = +1; Big-box Retailers, Auto Services, or Community Centers with Surface Parking Lots = +1.	Study Area	Field Check, Austin GIS data, Travis Central Appraisal District, Google Map
	15	Driveway Interruption	Presence of Driveways within 150 feet of most frequent crash location of hotspot; Absence of Driveways	50-feet Buffer Area from the Most Frequent Crash Location of Hotspot	Field Check, Google Map, Austin GIS data
	16	Land Use Patterns	Graded from 0=Car-oriented to 5=Pedestrian-oriented Land Use: Vacant, Undeveloped, and/or Gas Station Only = 0; Hihger-density (≥7 Dwelling Units per Acre) = +1; Mix of Land uses = +1; Well-connected & Grid-like street network = +1; Human-scale Buidings and Signage = +1; Adequate & Well-designed Street Furnishings = +1	Study Area	Field Check, Google Map
	17	Household Density	Number of household per acre (Households refered to the ones within the block group where the study area overlaid)	Block Group where the Study Area Overlaid	Census Data 2012 5-year estimates
	18	Neighborhood Social Status	Median Income of census tract where the study area overlaid	Block Group where the Study Area Overlaid	Census Data 2012 5-year estimates

Table 1 Cont.: Data Collection Instrument and Coding Manual

4.5 QUANTITATIVE ANALYSIS

Dependent Variables		Data Source
Pedestrian-Automobile Crash Rate (Daily Pedestrian Collision Counts per Million Pedestrians)		ADP Annual Incident Extract, Field Survey Count, CAMPO Interactive Map
Independent Variables		**Data Source**
Roadway Condition	Speed Limits Posted	Field Survey; City of Austin Geodatabase, CAMPO dataset
Pedestrian Facilities	Sidewalk Conditions	Coding after Field Survey
	Advanced Yield Markings or Pedestrian Caution Sign	Field Check
Neighborhood Development	Proximity to Major Attractors	Coding after Field Survey
	Land Use Pattern	
	Household Density	City of Austin Geodatabase, U.S. Census Estimates
	Block Length	

Table 2: Variables in Negative Binomial Regression

4.5.1 Dependent Variable

As mentioned before, the area where more pedestrians walk was more likely to witness more collisions involving walkers occurred if other factors were equally controlled. Therefore, frequency or density of incident aggregated into geographic unit, as dependent variable, didn’t validly measure the collision risk faced by pedestrians, as it failed to isolate the influence of pedestrian volume on incidents. To figure out factors exactly accounting for unsafety issue, the dependent variable of quantitative analysis in this paper was collision rate of each hotspot location measured by annual average daily pedestrian crash count per million pedestrians. The counts of annual average daily collisions were estimated by five-year incident number of hotspots, and daily pedestrian volume was estimated by the pedestrian counts in five minute during the peak hour. Then twenty-six hotspots were categorized by the pedestrian collision risk into three groups: high collision risk, medium collision risk, and low collision risk locations. The results might be greatly different from the category of crash density after accounting for the total pedestrian volume. The risk category of hotspot was used in the further bivariate analysis of categorical and binary variables.

4.5.2 Independent Variables

Independent variables in the first-round quantitative examination almost came from the coded and quantitated measurements in last phase qualitative study. Roadway features, pedestrian facilities, and land use characteristics were measured by cardinal, categorical, and binary variables. Besides those ones, the traffic volume measured by annual average daily traffic counts was introduced as the proxy of pedestrian exposure, which has been justified as a theoretically important variable in many of earlier studies.

Then independent variable should be selected after receiving tests of statistical significance one by one before the final regression modeling. Bivariate analysis with the dependent variables employed correlation test for continuous variables including block length, speed limit, AADT, household density, and etc. Categorical and binary variables received the Fisher’s test as well as one-way ANOVA to examine the association (or contingency) between explanatory and response variables. The variables that were shown statistically correlated were finally modeled by negative binomial regression to examine the potential association between pedestrian crash risk and environmental characteristics.

Chapter Five: Spatial Analysis of Pedestrian Collisions

5.1 PEDESTRIAN COLLISION DENSITY

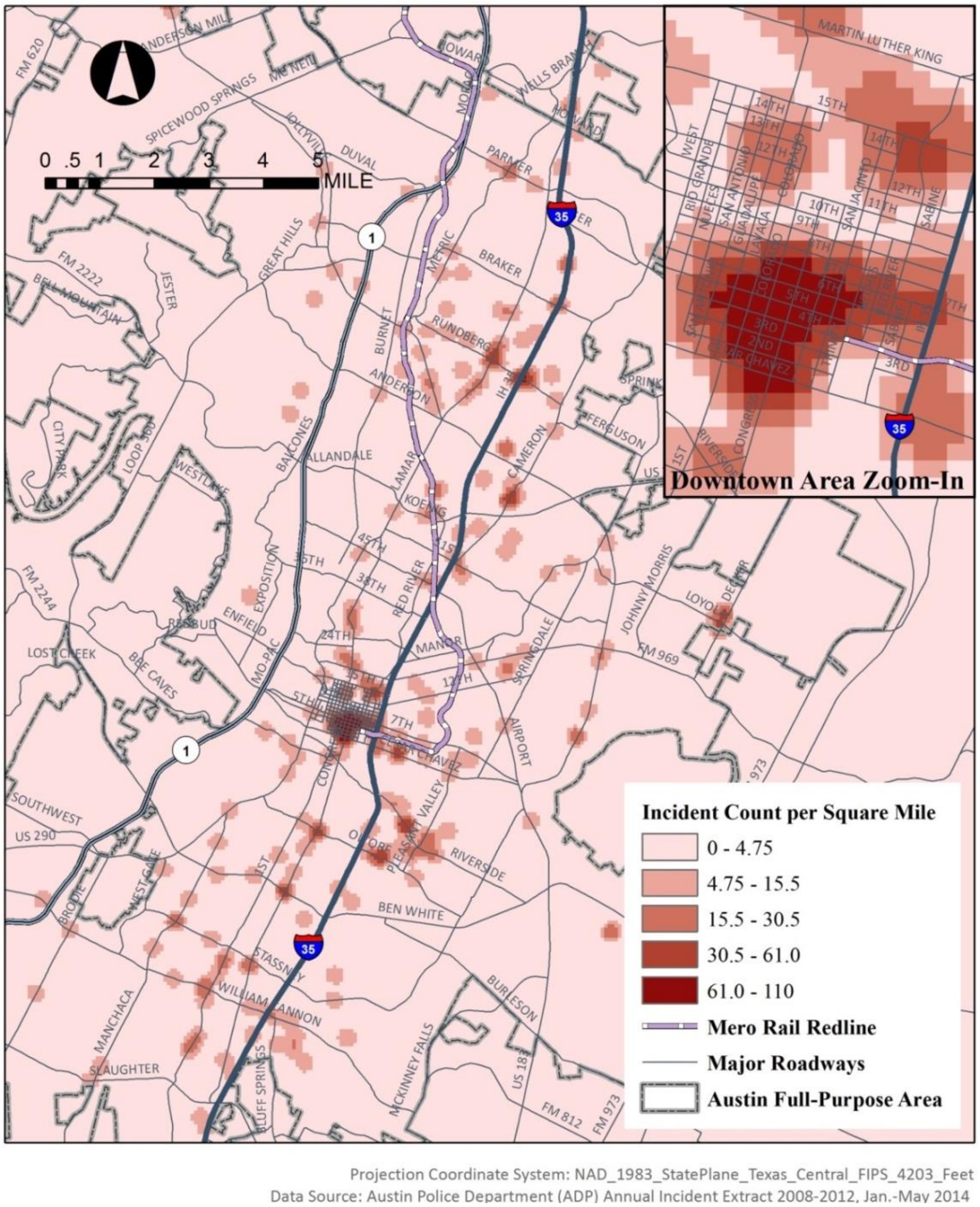

Figure 4: Hotspots of Pedestrian-Automobile Collisions in the City of Austin

Where did pedestrian collisions frequently occur? Kernel density analysis in

ArcGIS helped present the spatial concentration of pedestrian-vehicle collisions. The crashes were not evenly distributed across the City of Austin. As shown in Figure 4, there were many clusters of darker-tone grid cells which represent the higher-density of crashes occurred. The density map indicated that pedestrian collisions during the last six years more densely occurred in the Austin downtown area bounded on the north by 6^{th} Street, on the south by E Cesar Chavez Street, on the west by Lavaca Street, and on the east by Trinity Street. Other higher crash density areas were found around the intersection of N Lamar Blvd and Rundberg Lane, the crossing of N Interstate 35 and Rundberg Lane, and the junction of Loyola Lane and Decker Lane. Two paralleling segments from S Interstate 35 to S Pleasant Valley Road of both E Riverside Drive and E Oltorf Street had also experienced higher-density pedestrian crashes than the surroundings. Other locations with higher incident densities were situated around the intersection of E St. Johns Avenue and Cameron Road, crossing of S Congress Avenue and E Ben White Boulevard, and junction of S Congress Avenue and W Oltorf Street. More details of spatial concentration of pedestrian-automobile collisions are displayed in Figure 4 above.

To select the typical areas where pedestrian crashes more densely occurred for the further study, the clusters with the highest density over 15.5 incidents per square mile were identified as the hotspots. Then the clusters with the collision densities ranging from 15.5 to 30.5 incidents per square mile were defined as low-crash hotspots, clusters with the densities falling within the range from 30.5 to 61.0 collisions per unit area were defined as medium-crash hotspots, and clusters with the densities over 61.0 collisions per unit area were the high-crash hotspots. The category of hotspots based on the collision density of cluster was prepared for the further analysis. To balance the full coverage the typologies of three groups of hotspots and accessibility to these hotspots by the author, there were 26 hotspots were finally included in the sample for field survey. As the concern of inadequate data arose, higher crash density locations illustrated on the online interactive map developed by CAMPO was then used to check against and to confirm the hotspot selection. There were four out of twenty-six samples identified as high-density hotspots, and they were areas neighboring the junction of N Interstate 35 and Rundberg Lane, the segment of Congress Avenue from E Cesar Chavez Street to E 2nd Street, the cluster around Congress Avenue bounded from 4th Street to 6th Street, and areas around intersection of E Riverside Drive and S Pleasant Valley Road. Eight of them were medium-density ones, and the remaining were low-density samples. The category of pedestrian crash density of top twenty-six hotspots is listed in Table 3.

5.2 OVERVIEW OF COLLISION CHARACTERISTICS IN AUSTIN

5.2.1 Location Feature

Among nearly 260 pedestrian-vehicle collisions, there were 66 of total incidents occurred at intersections, while the remaining crashes all occurred at mid-blocks. Though the study failed to fully extract all the incident record of the City, what the limited data indicated also embraced the national tendency that mid-block location in the absence of safety treatment presented more potential threats to pedestrians.

No.	Location Description of Hotspots	Density Hierarchy
1	12600 - 12900 N Interstate 35	Low
2	1700 W Parmer Ln - W Parmer Ln & Metric Blvd - 2000 W Parmer Ln	Low
3	12100 N Interstate 35	Low
4	700 - 800 E Braker Ln	Low
5	1000 N Meadows DR - 10600 N Lamar Blvd	Low
6	8000 - 8400 N Research Blvd	Low
7	**9200 - 9600 N Lamar Blvd - 300 W Rundberg Ln**	**Medium**
8	N Lamar Blvd & Thurmond St - 8700-8900 N Lamar Blvd	Low
9	**Interstate 35 & E Rundberg Ln - 9200-9300 N Interstate 35 - 800-1000 E Rundberg Ln**	**High**
10	**7000 Cameron Rd - E St. Johns Ave & Cameron Rd**	**Medium**
11	W Highland Mall Blvd & Airport Blvd - 100 E Highland Mall Blvd	Low
12	**6500-7000 Decker Lane - 8400 Loyola Ln**	**Medium**
13	W 27th St & Guadalupe St - 3100 Guadalupe St	Low
14	400 W 21st St - 2200 Rio Grande St	Low
15	**600 E 15th St - E 15th St & San Jacinto Blvd**	**Medium**
16	**100 W 4th St & S Congress Ave - W 5th St & Lavaca St - 6th & S Congress Ave**	**High**
17	**E Cesar Chavez St & Congress Ave - E 2nd St & Congress Ave**	**High**
18	**1600 E Cesar Chavez St - 300 Comal Street**	**Medium**
19	**2400-2500 E Riverside DR - 1700 S Pleasant Valley Rd - E Riverside DR & S Pleasant Valley Rd**	**High**
20	**1900 E Oltorf St - E Oltorf St & Burton DR**	**Medium**
21	**100 E Oltorf St - S Congress Ave & W Oltorf St - 2500 S Congress Ave**	**Medium**
22	**S Congress Ave & E Ben White Blvd - 200 W Ben White Blvd**	**Medium**
23	5600 Manchaca Rd - 2000 W Stassney Ln	Low
24	5800 S Congress Ave	Low
25	7700 - 8300 S 1st St	Low
26	700 W William Cannon DR	Low

Table 3: Location Descriptions of Hotspots and Density Category

5.2.2 Roadway and Corridor with High Crash Frequency

To examine if the pedestrian safety treatment should be specifically targeted towards the certain corridors or certain roadway types, the study then examined features of roadways where the pedestrian collisions more frequently occurred. Every segment of streets where the incident points laid on was selected, and then the collision frequency of the street was summed up. If pedestrian-vehicle crash occurred at junctions, all segments of intersecting roadways were individually counted with one time. There were in total 411 segments of streets involving pedestrian collisions in the Full-Purpose Jurisdiction of Austin during the last six years.

Road Classification	**Ped-Auto Collision Count**
Interstate Highway, Expressway or Toll road	1
US or and State Highway	9
Major Arterial	**173**
Minor Arterial	34
Local City/County Street	76
City Collector	**115**
Ramps and Turn Arounds	3

Table 4: Pedestrian-Automobile Collision Classified by Roadway Type

According to the generalized U.S. census bureau standards, urban roadways involved incident segments were grouped into: 1), Interstate Highway, Expressway, or Toll road, 2), US and/or State Highway, 4), Major Arterial, 5), Minor Arterial, 6), Local City/County Street, 8), City collector, and 10), Ramps and Turn Arounds. The analysis result shown in Table 4 indicated that 42 percent of total pedestrian-vehicle collisions occurred on Major Arterial, and nearly 28 percent of pedestrians were hit by automobiles on city's collectors.

Subsequently, the analysis of pedestrian collision by roadway corridor illustrated that S 1st Street, N Lamar Boulevard, N Interstate 35 SVRD, and S Congress Avenue with over ten times crashes were ranked as top four corridors where pedestrian-vehicle crashes most frequently happened during the last six years. In addition, corridors along Airport Boulevard, E 6th Street, E Cesar Chavez Street, E Oltorf Street, Guadalupe Street, and Research Boulevard SVRD were also considered unsafe for pedestrians. Among 17 highest crash frequency roadways with no less than five times collision, 64.7 percent of them were north-south direction corridors.

Ped-Auto Crash Ranking	Full Name of Roadway Segment Where Collision Occurred	Ped-Auto Collision Count
1	**S 1st St.**	**13**
2	**N Lamar Blvd**	**12**
3	**N Interstate 35 SVRD SB**	**10**
4	**S Congress Ave**	**10**
5	**E 6th St.**	**8**
6	Airport Blvd	7
7	E Cesar Chavez St.	7
8	E Oltorf St.	7
9	Guadalupe St.	7
10	Manchaca Rd.	7
11	Research Blvd Svrd SB	7
12	Congress Ave	6
13	E Riverside DR	6
14	S Interstate 35 SVRD SB	6
15	Metric Blvd	5
16	Trinity St.	5
17	W Parmer Ln	5

Table 5: Names of Streets with Higher Crash Frequency

5.2.3 Pedestrian Collision by Speed Limit

Speed of roadway was proven to be an important explanatory variable of pedestrian safety in the previous researches. Therefore author summarized the speed limits of roadways involved pedestrian-vehicle collisions. The result indicated that, unlike the aforementioned conclusion by previous studies, incidents occurred more on moderate-to-high speed streets. 78 percent of total pedestrian crashes were on the roadways where speed limits posted ranging from 35 mph to 45 mph. Among these roadways, the streets on which 45 mph speed limit was posted saw the most pedestrian collisions, and then the streets on which 35 mph speed limit applied ranked second according to crash frequency. More details can be found in the following Table 6.

Speed Limit of Roadway	**Ped-Auto Collision Count**
25 mph	40
30 mph	1
35 mph	**116**
40 mph	40
45 mph	**166**
50 mph	40
55 mph	2
60 mph	2
65 mph	3

Table 6: Pedestrian-Automobile Crash Classified by Speed Limit

5.2.4 Adjacent Land Use

In the previous studies conducted at aggregate level, many of them demonstrated that pedestrian crashes prominently took place in residential and commercial areas where most pedestrian exposure occurred. As land use played the role of activity generator as well as pedestrian attractors, the author also made a profile representing the adjacent land uses around the crash locations to identify which uses predominantly occupied the parcels. The parcels located within the one-eighth mile buffer zone from each collision points were included, and the area of each use occurred within the buffers were then aggregated for study. There were totally 12-thousand-acre parcels involved, and nearly 30 percent of them were occupied by residential uses. Commercial uses, public open space, and manufacture & warehouse were the other major uses within the adjacent areas of collision points.

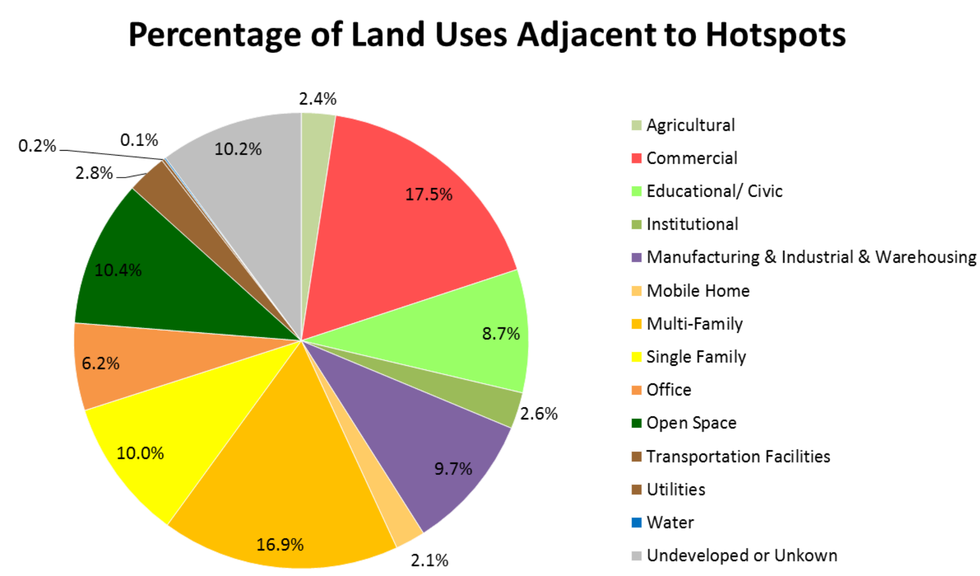

Figure 5: Adjacent Land Uses within Study Areas of Hotspots

5.3 CONCLUSION

Analysis which was built upon the limited reported data showed that Austin downtown areas around the junction of N Interstate 35 and Rundberg Lane, and segments from S Interstate 35 to S Pleasant Valley Road of E Riverside Drive were higher collision density areas. The pedestrian collision more likely to happen at midblock locations instead of controlled intersections, and it confirmed the result of previous studies in the nation. Moderate-to-high speed (35 to 45 mph) roadways with multiple lanes, such as major arterials and city collector streets, were subject to more frequent pedestrian-vehicle crashes than other types of streets. S 1st Street, N Lamar Boulevard, N Interstate 35 SVRD, and S Congress Avenue were top four corridors of high pedestrian collision density. In Austin, similar to other cities, pedestrian collisions predominantly occurred around the residential and commercial uses.

Chapter Six: Field Survey and Qualitative Analysis of Hotspots

6.1 PEDESTRIAN VOLUME

Daily pedestrian volume of each hotspot was significantly necessary in author's research to normalize the number of pedestrian collisions occurred around each hotspot. Daily data was estimated by the number of pedestrians passing through the observation point in five minutes during the peak hours (4:00 pm to 6:00 pm) on weekdays. After counting and estimation, nearly 5,000 pedestrians per day were assumed to appear around the junction of 6th Street and Congress Avenue. The intersections of E Cesar Chavez Street and Congress Avenue and hotspots adjacent to UT Austin campus were also expected to encourage a large number of pedestrians. The observation points of 12900 N Interstate 35, 12100 N Interstate 35, and 6500 Decker Lane attracted the least walkers, less than 50 pedestrians per day. The expected value of estimated pedestrian volume among twenty-six hotspots was 760, while 19 out of all hotspots saw less than 760 pedestrians daily. The standard deviation (SD) of the sample was nearly 1097. The descriptive statistics suggested that the distribution of estimated daily pedestrian volume in the sample was skewed and over-dispersed.

6.2 PEDESTRIAN FACILITIES

Among the sample consisting of twenty-six hotspots, there were twelve midblock locations, twelve junctions, and two of them were located around underpass or overpass. For fourteen non-block locations, there were four hotspots without pedestrian countdown signals. Marked crosswalk or pedestrian leading intervals were not installed or worn off around half of these intersections. Only two junctions didn't have advanced yield marking or stop bar. For twelve hotspots at midblock, two-third of them didn't install any pedestrian caution sign, flash light or yield markings, five of them didn't have marked crosswalk of leading intervals for pedestrians, and only two of them had pedestrian refuge islands for protection. The sample indicated that high crash density locations at midblock lacked necessary pedestrian safety treatment, while the condition of marked crosswalk at intersections required improvement and maintenance.

Sidewalk conditions within the study areas of twenty-six hotspots ranged from the extremely poor to the best after checking continuity, width, ramps, tree canopy and adjacent buildings. Sidewalks in the study areas of twelve hotspots were evaluated as fair as they just met the criteria of continuity, reasonable width, and availability of ramps. Sidewalks in downtown areas were in the best condition, while sidewalks along Guadalupe Street around UT Austin campus were also well maintained. Segments from 6500 to 7000 Decker lane, 9200 to 9600 N Lamar Blvd, and 8000 to 8400 N Research Blvd didn't install sidewalks at all or only had discontinuous and narrow sidewalks.

Number of Lane	Absence of Raised Median	Presence of Raised Median	**Sum**
2 Lanes	0	2	2
3 to 4 Lanes	13	6	19
5 or More Lanes	1	4	5
Sum	14	12	26

Table 7: Presence of Raised Median by Number of Lane

Raised median along multi-lane roadways can't only separate two-way traffic, but also serve as the pedestrian safety refuge when traffic control device is absent. Among the sample, 80 percent roadways with five lanes or more were equipped with raised median, while nearly two-third of three-lane and four-lane roadways didn't install raised median. There's no raised median on two-lane streets. Its safety impacts should be further examined in the next phase.

6.3 ROADWAY FEATURE

In the sample including twenty-six hotspots, pedestrian collisions occurred more on moderate-to-high speed roadways. Average speed limit posted on the roadways around 18 hotspots ranged from 35 to 55 mph. Seven hotspots were closely adjacent to the roadways with speed limit ranging from 20 to 30 mph. In the sample, the roadways passing through the hotspots were almost three-lane and four-lane streets. Around twenty-six hotspots, nearly 66 percent of roadways were major arterials, 17 percent were city local streets, and 10 percent were city collectors. On-street parking only occurred along Guadalupe Street in campus area and Congress Avenue in downtown core.

6.4 LAND USE CHARACTERISTIC

In author's sample, the expected value of average length of blocks where the study areas of hotspots overlapped was 1,915 feet. Hotspots in downtown and campus areas had the shortest block length, less than 400 feet, on average. The block where the hotspot of 12100 N Interstate overlaid had the longest length of 7,350 feet. Twelve hotspots were located at the urban blocks with lengths less than one-quarter mile, while five hotspots were situated at the blocks with lengths over a half mile.

The degree of proximity to major attractors including grocery stores, community center, big-box retailers, employers, schools, and transit stops was used to measure how much potential traffic conflicts the pedestrians were exposed to. All hotspots were at least proximate to one type of major attractors. Twenty-two hotspots were immediately adjacent to bus or transit stops. In the sample, a half of twenty-six hotspots were commonly close to both bus stops and gas station with grocery stores. 15 hotspots adjacent to any three of these attractors were considered at the fair level of exposure to conflicts. Hotspots around UT Austin campus and 700 W William Cannon Drive were proximate to the most attractors. Though sidewalks along segments of 9200 to 9600 N Lamar Blvd and 8000 to 8400 N Research Blvd were discontinuous or lacking, these two hotspots were closely adjacent to more attractors than others. Because there were many major attractors closely proximate to hotspots, the driveways built for these attractors also largely interrupted walking.

The land use was graded from car dependent to pedestrian-oriented after examining the mix of use, density, street network, building scale and design, and street furnishings. Study areas around hotspots in downtown and near UT Austin campus were the most desirable environment for pedestrians. Only eight hotspots were located in the walkable environment, while ten hotspots of incident were situated in car-dependent surroundings. It strongly suggested that land use pattern around hotspots might be an important predictor of collision risk.

In the sample, household median income of census tract where the hotspot overlaid ranged from $8,500 to $ 86,000, and the expected value of the household median income was $41,500 by the year of 2012. If seven household per acre[11] can be considered as higher

[11] The value borrowed the number of dwelling unit per acre which can just support the local bus service.

density area, only four hotspot surroundings met this benchmark. Nearly half of hotspots were located in lower-density neighborhood ranging from 2 to 4 households per acre. Among twenty-six hotspots, hotspots around UT campus had the densest households in the neighborhood.

6.5 CONCLUSION

Among twenty-six hotspots in the sample, crash locations at midblock commonly lacked of necessary pedestrian safety treatment, while crash locations at junctions needed improvement and better maintenance of crosswalk. Sidewalks around hotspots were generally in the fair condition: they are continuous and reasonably wide with available ramps. There was no sidewalk available around three hotspot locations, even some of them were closely adjacent many attractors. Most collisions involving pedestrians in the sample occurred along the moderate-to-high speed, and three-lane or four-lane roadways. Major arterials passing through hotspots saw the most collision. On average, the block length around twenty-six hotspots in sample was nearly 2,000 feet. Downtown area and campus area had grid-like street network with the average length less than 400 feet. Hotspots were generally located within the car-dependent environment, though they almost have mixed uses and were closely adjacent to community service, transit, or employers.

Chapter Seven: Quantitative Analysis

Twenty-six hotspots where the highest density of crash was more than15.5 incidents per square mile were included in the samples (n=26). The dependent variable prepared for the final statistical analysis was pedestrian collision rate of each hotspot measured by daily count[12] of incidents per million pedestrians. There were totally 18 independent variables in the first-round quantitative examination. Most of explanatory variables were transformed from measures of qualitative study. Measurements of roadway features, pedestrian facilities, and land use characteristics were coded and quantitated for the statistical analysis. Besides, the traffic volume measured by annual average daily traffic (AADT) counts was introduced as the proxy of exposure, which has been justified as a theoretically important variable in many of earlier studies.

7.1 COLLISION RATE AS DENPENDENT VARIABLE

After correction and estimation, pedestrian collision rates of twenty-six hotspots in the sample ranged from 1.6 to 79.9 crashes per million pedestrians. The expected value of incident rate was 16.26, and variance of collision rate in the sample 395.8. The greater variance than the mean of counts of item favored the negative binomial model. Each model coefficient reported the percentage change in the dependent variable associated with one unit of change in the independent variable.

Furthermore, twenty-six hotspots were assigned to high- (0-7.00 incidents per million pedestrians), medium- (7.01-14.00 incidents per million pedestrians), and

[12] To more precisely estimate the collision risk, the count of pedestrian crash of each hotspot was checked against CAMPO Interactive Map and was corrected in order to be close to the valid official data.

low-risks (14.01-80.00 incidents per million pedestrians) based on their collision rate. The result of risk category greatly differed from the classification of hotspot by crash density, which demonstrated the necessity of normalization by pedestrian volume. There were seven hotspots considered as high risk collision locations which were almost located on the outskirts of town. The category by collision rate was used for contingency test of categorical variables in the next bivariate analysis.

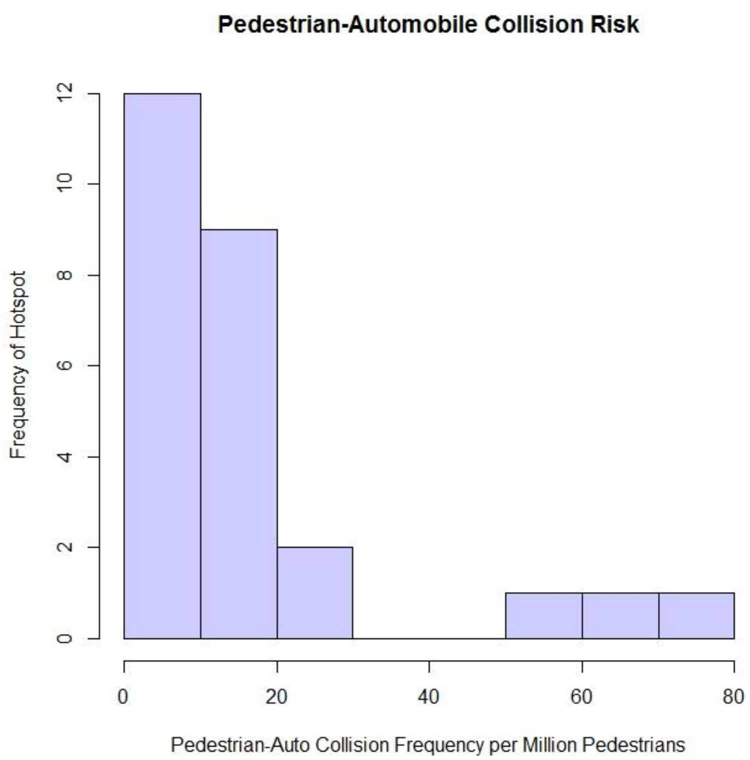

Figure 6: Distribution of Pedestrian-Auto Collision Rate of Twenty-six Hotspots

No. Hotspot	Location Description of Hotspots	Crash Rate Per Million Pedestrian	Risk Category
1	**12600 - 12900 N Interstate 35**	39.95	**High**
2	**1700 W Parmer Ln - W Parmer Ln & Metric Blvd - 2000 W Parmer Ln**	11.42	**High**
3	**12100 N Interstate 35**	11.42	**High**
4	**700 - 800 E Braker Ln**	8.56	**High**
5	1000 N Meadows DR - 10600 N Lamar Blvd	3.81	**Medium**
6	8000 - 8400 N Research Blvd	1.71	**Low**
7	9200 - 9600 N Lamar Blvd - 300 W Rundberg Ln	5.35	**Medium**
8	**N Lamar Blvd & Thurmond St - 8700-8900 N Lamar Blvd**	25.68	**High**
9	Interstate 35 & E Rundberg Ln - 9200-9300 N Interstate 35 - 800-1000 E Rundberg Ln	4.39	**Medium**
10	7000 Cameron Rd - E St. Johns Ave & Cameron Rd	5.33	**Medium**
11	W Highland Mall Blvd & Airport Blvd - 100 E Highland Mall Blvd	2.38	**Low**
12	**6500-7000 Decker Lane - 8400 Loyola Ln**	34.25	**High**
13	W 27th St & Guadalupe St - 3100 Guadalupe St	1.45	**Low**
14	400 W 21st St - 2200 Rio Grande St	1.29	**Low**
15	600 E 15th St - E 15th St & San Jacinto Blvd	2.85	**Low**
16	100 W 4th St & S Congress Ave - W 5th St & Lavaca St - 6th & S Congress Ave	6.56	**Medium**
17	E Cesar Chavez St & Congress Ave - E 2nd St & Congress Ave	0.79	**Low**
18	1600 E Cesar Chavez St - 300 Comal Street	6.52	**Medium**
19	2400-2500 E Riverside DR - 1700 S Pleasant Valley Rd - E Riverside DR & S Pleasant Valley Rd	2.01	**Low**
20	1900 E Oltorf St - E Oltorf St & Burton DR	3.00	**Medium**
21	100 E Oltorf St - S Congress Ave & W Oltorf St - 2500 S Congress Ave	1.90	**Low**
22	S Congress Ave & E Ben White Blvd - 200 W Ben White Blvd	6.52	**Medium**
23	**5600 Manchaca Rd - 2000 W Stassney Ln**	9.99	**High**
24	5800 S Congress Ave	5.71	**Medium**
25	7700 - 8300 S 1st St	5.71	**Medium**
26	700 W William Cannon DR	2.85	**Low**

Table 8: Category of Hotspots by Pedestrian Collision Rate

7.2 BIVARIATE ANALYSIS

In the first-round analysis of total 18 independent variables, there were in total five categorical variables, seven binary variables, and six continuous variables. The data of pedestrian collision rate was transformed into natural logarithm values for Pearson product-moment correlation test of continuous dependent variables, such as AADT, speed limit, average block length, household density and household median income. After coding the categorical and binary measurements into dummy variables, they were subject to the Fisher's test as well as one-way ANOVA to examine the correlation with the category of collision rate. The independent variables of exposure, pedestrian facilities, roadway features, and land use characteristics were finally selected if they were statistically significant in the bivariate analysis at least at 90 percent confident level (p-value < 0.1). As a result, three continuous variables including speed limits posted (mean=36.25, SD=8.91), average block length (mean=1915, SD=1670.91), and household density (mean=4.32, SD=2.86), and three categorical variables including sidewalk conditions, degree of proximity to major attractors, and land use patterns were selected for the final model construction. The descriptive statistics of independent variables and correlation test results are shown in the Table 9 with more details.

No.	Measures Definition	Measurement Level	Measurement
0	Collision Frequency per Million Pedestrians	Continuous Variable	Natural log value of COL_RATE; Min: 0.79, Max: 39.95, Mean:8.13, Standard Deviation (sd): 9.95
0.cat	Collision Rate Category	Categorical Variable	Coded by Collision Rate: 0-3.0=Low risk: 10, 3.01-6.59=Medium risk: 9, 6.60-40.0=High risk: 7

Table 9: Bivariate Analysis Results of Independent Variables

No.	Measures Definition	Measurement Level	Measurement	Correlation Test	Significance
1	Annual Average Daily Traffic	Continuous Variable	Original value; Min: 4250, Max: 41830, Mean: 22390, sd: 10519.2	Pearson correlation; Linear regression on transformed value	No
2(a)	Pedestrian Countdown Signal	Binary Variable	Coding upon Presence: 0=Absence: 4, 1=Presence: 10	Fisher test, one-way ANOVA	No
3(a)	Leading Pedestrian Interval, and/or Crossing Refuge Island	Binary Variable	Coding upon Presence: 0=Absence: 7, 1=Presence: 7	Fisher test, one-way ANOVA	No
4(a)	Yield Marking or Stop Bar (*)	Binary Variable	Coding upon Presence: 0=Absence: 2, 1=Presence: 12	Fisher test	p-value = 0.03297 (*)
2(b)	Pedestrian Sign, Flash Signal, or Stop Bar	Binary Variable	Coding upon Presence: 0=Absence: 8, 1=Presence: 4	Fisher test, one-way ANOVA	No
3(b)	Marked Crosswalk	Binary Variable	Coding upon Presence: 0=Absence: 5, 1=Presence: 7	Fisher test, one-way ANOVA	No
4(b)	Pedestrian Refuge	Binary Variable	Coding upon Presence: 0=Absence: 10, 1=Presence: 2	Fisher test, one-way ANOVA	No
5	Sidewalk Conditions	Categorical Variable	Coding upon Conditions: 0=None: 2, 1=Extremely Poor: 1, 2=Poor: 4, 3=Fair: 12, 4=Good: 3, 5=Best: 4	Fisher test one-way ANOVA	p-value = 0.06868 (.) Pr(>F) = 0.052 (.)
6	Raised Median	Binary Variable	Coding upon Presence: 0=Absence: 16, 1=Presence: 10	Fisher test	No
7	Location Features	Categorical Variable	Coding upon Types: 1=MidBlock: 12, 2=Intersection: 12, 3=Underpass, Overpass, Bridge: 2	Fisher test	No
8	Roadway Type	Categorical Variable	Coding upon Types: 4=Major Arterial: 17, 5=Minor Arterial: 2, 6=Local Street:5, 8=Collector: 2	Fisher test	No

Table 9 Cont.: Bivariate Analysis Results of Independent Variables

No.	Measures Definition	Measurement Level	Measurement	Correlation Test	Significance
9	On-Street Parking	Binary Variable	Coding upon Presence: 0=Absence: 23, 1=Presence: 3	Fisher test	No
10	Roadway Lanes	Continuous Variable	Original value in count; Min: 2.0, Max: 6.0, Mean: 3.94, sd: 1.04	Pearson correlation; Linear regression on transformed value	No
11	Speed limits Posted	Continuous Variable	Original value in mph; Min: 20.0, Max: 55.0, Mean: 36.25, sd: 8.91	Pearson correlation	p-value = 0.01374 (*)
12	Average Block Length	Continuous Variable	Original value in feet; Min: 360, Max: 7350, Mean: 1915, sd: 1670.91	Pearson correlation	p-value = 0.00174 (*)
13	Residnetial Use	Binary Variable	Predominant Residential Use=1: 20, Not Predominant Residential Use=0: 6	Fisher test	No
14	Proximity to Attractors	Categorical Variable	Coding upon Degree of Proximity (Traffic Conflicts and Exposure): 0=None: 0, 1=Least : 1, 2=Less: 5, 3=Fair: 15, 4=More: 4, 5=Most: 1	Fisher test	No
				one-way ANOVA	Pr(>F) = 0.00329 (**)
15	Driveway Interruption	Binary Variable	Coding upon Presence: 0=No: 1, 1=Yes: 25	Fisher test	No
16	Land Use Patterns	Categorical Variable	Coding upon Land Use Pattern: 0=Extremely Car-dependent: 4, 1=Car-dependent: 6, 2=Somewhat Walkable: 8, 3=Walkable: 3, 4=Very Walkable: 3, 5=Walker's Paradise: 2	Fisher test	p-value = 0.0661 (.)
				one-way ANOVA	Pr(>F) = 0.0015 (**)
17	Household Density	Continuous Variable	Original value in Household per Acre; Min: 0.66, Max: 12.74, Mean: 4.32, sd: 2.86	Pearson correlation	p-value = 0.0925 (.)
18	Neighborhood Social Status	Continuous Variable	Original value in Dollar; Min: $8,490, Max: $86,364, Mean: $41,507, sd: $18,421	Pearson correlation; Linear regression on transformed value	No

Table 9 Cont.: Bivariate Analysis Results of Independent Variables

7.3 NEGATIVE BINOMIAL REGRESSION

Given by the short list of independent variables, four of six variables represented land use characteristics. Thus the final model started from the regression analysis on all variables measuring the land characteristics including household density, land use pattern, proximity to major attractors, and average block length. Then, as shown in Table 12, two variables of household density and land use patterns were excluded from the model as the former one was not statistically significant at all, while the latter one were only significant at 10 percent confident level (p-value= 0.0605). The base model (2 log likelihood value = -171.283, and pseudo R^2 = 0.640) containing degree of proximity to major attractors and average block length remained for adding other independent variables for further stepwise regression analysis.

Domain	Independent Variables	Coefficient	Exp. (Coefficient)	Significant Level (p-value)		95% Confident Interval (Exp.)
Land Use Characteristic	**Average Block Length** (Mile)	**0.00043**	**1.00**	**0.0005**	*******	**1.0002 - 1.0007**
	Proximity to Atrractors (1-5 Levels)					
	proximity to 2 types	**2.58**	**13.17**	**0.0029**	******	**2.2563 - 76.2648**
	proximity to 3 types	**1.89**	**6.62**	**0.0455**	*****	**0.9751 - 41.9754**
	proximity to 4 types	1.09	2.96	0.2600	×	0.4013 - 20.6749
	proximity to 5 types	1.48	4.41	0.2568	×	0.3112 - 58.0452
	Land Use Patterns (0-5 Levels)					
	Car-Dependent	-0.61	0.54	0.1198	×	0.2471 - 1.1543
	Somewhat Walkable	-0.40	0.67	0.2851	×	0.3007 - 1.4347
	Walkable	-0.46	0.63	0.3657	×	0.2285 - 1.7332
	Very Walkable	-1.32	0.27	0.0605	·	0.0632 - 1.0930
	Walker's Paradise	-0.26	0.77	0.6405	×	0.2479 - 2.4446
	Household Density	0.09	1.09	0.1394	×	0.9648 - 1.2442
Intercept		-0.09	0.91	0.9306		
N = 26	2 × Log Likelihood = -165.977		pseudo R-squared = 0.7112			

Table 10: Initial Negative Binomial Analysis on Variables of Land Use Characteristics

Then variable of sidewalk condition after coding was added into base model. The regression result (2 log likelihood value = -162.74, pseudo R^2 = 0.748) showed that even the presence of a poor sidewalk compared to the absence of sidewalk was significantly correlated to the decline of pedestrian rate (p-value = 0.0113), and provision of the sidewalk in above the fair condition was also correlated to the decline of collision risk (p-value = 0.0692). Keeping the variable of sidewalk condition, variable of average speed limit posted was then added in. The last regression model (2 log likelihood value = -159.01, pseudo R^2 = 0.7867) showed that speed limit posted was also a significant variable with pedestrian collision risk. Finally the average block length (p-value = 0.0062), average speed limit posted (p-value = 0.0477), presence of the sidewalk (p-value = 0.0201), and proximity to two types of major attractors (p-value = 0.0089) were confirmed as the significantly correlated variables accounting for the change of pedestrian collision rate.

Domain	Independent Variables	Coefficient	Exp. (Coefficient)	Significant Level (p-value)		95% Confident Interval (Exp.)
Land Use Characteristic	**Average Block Length** (Mile)	**2.15**	**8.56**	**0.000052**	***	**2.8339 - 28.5317**
	Proximity to Atrractors (1-5 Levels)					
	proximity to 2 types	**2.28**	**9.77**	**0.0040**	**	**1.7503 - 51.1848**
	proximity to 3 types	**1.65**	**5.20**	**0.0478**	*	**0.8862 - 28.0546**
	proximity to 4 types	0.91	2.48	0.3001	×	0.3797 - 15.1604
	proximity to 5 types	0.69	1.99	0.5656	×	0.1651 - 22.7119
Intercept		0.14	1.16	0.8778		
N = 26	2 × Log Likelihood = -171.283		pseudo R-squared = 0.6403			

Table 11: Base Model with Statistically Significant Variables of Land Use Features

The output of exponential values of coefficient estimates of significantly correlated variables showed how the explanatory factors influence the collision rate in sample. The average block length, degree of proximity to major attractors, and average speed limit posted were variables positively accounting for the increase of collision rate. The percentage change of pedestrian collision rate was assumed to be a nearly 3.8 percent increase for every unit increase in average block length (measure by mile). Each mile per hour increase in speed limit posted of surrounding roadways was expected to account for 1.03 percent increase of collision rate. The incident rate for proximity to any two types of attractors was 6.45 times of the incident rate for the reference group (proximity to only one type of major attractor) holding the other variables constant. The sidewalk condition was expected to be negatively associated with the increasing collision rate. The presence of sidewalk, even in the poor condition, was assumed to lower down the collision rate by nearly 80 percent than the reference group (absence of sidewalk at all).

Domain	**Independent Variables**	**Coefficient**	**Exp. (Coefficient)**	**Significant Level (p-value)**		**95% Confident Interval** (Exp.)
Land Use Characteristic	**Average Block Length** (Mile)	**1.33**	**3.77**	**0.0062**	**	**1.3632 - 11.0374**
	Proximity to Atrractors (1-5 Levels)					
	proximity to 2 types	**1.86**	**6.45**	**0.0089**	**	**1.4355 - 30.3854**
	proximity to 3 types	1.18	3.26	0.1207	×	0.6718 - 15.6433
	proximity to 4 types	0.48	1.62	0.5507	×	0.3031 - 8.5856
	proximity to 5 types	1.48	4.39	0.2276	×	0.3555 - 51.3108
Pedestrian Facilities	**Sidewalk Conditions** (0-5 Levels)					
	presence of sidewalk at least	**-1.49**	**0.23**	**0.0201**	*	**0.0647 - 0.7795**
	presence of poor sidewalk	-0.10	0.91	0.8494	×	0.3361 - 2.4400
	presence of fair sidewalk	0.25	1.29	0.5614	×	0.5291 - 3.0912
	presence of good sidewalk	-0.77	0.46	0.2226	×	0.1229 - 1.6743
	presence of best sidewalk	-0.09	0.92	0.8662	×	0.3189 - 2.6487
Roadway Features	**Average Speed Limits Posted** (MPH)	**0.03**	**1.03**	**0.0477**	*	**1.0010 - 1.0680**
Intercept		-0.46	0.63	0.71858		
N = 26	2 × Log Likelihood = -159. 014		pseudo R-squared = 0.7867			

Table 12: Final Negative Binomial Regression Model of Pedestrian Collision Risk

Chapter Eight: Discussions

8.1 COLLISION RATE OR COLLISION DENSITY

Unlike previous studies, the collision risk was not measured by collision density (number of pedestrian crash per unit area) in this paper. Instead of collision rate, the amount count of pedestrian collision normalized by pedestrian volume was applied to truly measure the collision risk of hotspot locations. The primary reason was that collision density or frequency was not a valid measure of collision risk as it inherently failed to exclude the effect of the number of pedestrians. This assumption can be supported by the facts that incident occurrence was significantly associated with surrounding development density in the previous studies. What's more, many factors which were proven to be associated with pedestrian collision just indicated the environment features with which walkers were more likely to occur. Therefore, compared to density of incident, collision rate was expected to be more appropriate measure of incident risk. The change of dependent variable can be justified by the difference between hotspot ranking by collision density and by incident rate: the higher crash density hotspots were greatly distinct from the higher crash rate hotspots. Moreover, the statistical examination also reinforced that household density, a proxy of development density, was not correlated with collision risk after accounting for the impact by pedestrian volume. Though incident risk was justified as a more valid measure, it heavily depended on the availability of valid data of pedestrian volume. As author failed to find data of pedestrian counts of all the twenty-six hotspots from CAMPO or TxDOT, this data was roughly estimated by the 5-minute number during the peak hour.

8.2 MIDBLOCK AND BLOCK LENGTH

Embracing the fact of the United States that more than half of the urban pedestrian crashes occurred at midblock locations, nearly three quarters of 257 reported crash locations were situated at places other than junctions. In the author's sample, nearly half of twenty-six high-incident-density hotspots also occurred at midblock. Midblock dart out and midblock dash were major pedestrian behaviors, thus assumption that longer blocks would result in higher collision risk was proposed. In the sample of hotspots, the average block length ranged from 360 feet to 7,350 feet, and its expected value of was 1,915 feet. On average, four hotspots in downtown and campus areas had the smaller-size blocks, in contrast, five hotspots were situated at the blocks with lengths over a half mile. For the top high incident density locations, the blocks were generally longer than the comfortable walking distance, namely one-quarter mile. The final regression suggested that longer block length was significantly correlated with the increase of pedestrian collision rate. Given by the greater incident risk, however, two-third of midblock hotspot didn't install any pedestrian caution sign, flash light or yield markings, and only two of them had pedestrian refuge islands for protection. The sample indicated that the existing high-risk midblock locations lacked necessary pedestrian safety treatments. Therefore, for the existing longer blocks where pedestrian collisions frequently occurred, the installation of advanced pedestrian caution sign, flash light or yield markings should be considered at midblock locations. For the new development or redevelopment project, shortening the block length to one-quarter mile is highly recommended in order to create a safe walking as well as pedestrian-friendly environment.

8.3 PROXIMITY TO ATTRACTORS

All hotspots were at least proximate to one type of major attractors.15 hotspots were adjacent to three types of major attractors at the fair level of exposure to conflicts. Specifically, in the sample, a half of twenty-six hotspots were characterized by the close proximity to both bus stops and gas station with grocery stores. Twenty-two hotspots were immediately adjacent to bus or transit stops. The final regression suggested that incident rate of the proximity to two types of attractors was 6.45 times of the incident rate of proximity to one type attractor. The negative binomial regression also indicated that proximity to more than two types of attractors didn't account for the increased collision rate. Given by the context information, author inferred that the proximity to both gas station with grocery stores and bus stops was expected to account for the higher collision risks among the selected hotspots. Bus stops attracted a large number of pedestrian approaching, while gas stations with grocery stores were built for autos. If hotspot location was simultaneously adjacent to these two kinds of attractors, the conflicts between pedestrian and automobiles were expected. Driveways of gas station and car-oriented grocery stores also interrupted the sidewalks. The inference should be further confirmed by the statistical examination after recoding the measurements of proximity in the future.

8.4 SIDEWALK CONDITION

Sidewalks around hotspots were evaluated as fair when they just met the criteria of continuity, reasonable width, and availability of ramps, and twelve of them were in fair condition. Segments from 6500 to 7000 Decker lane, 9200 to 9600 N Lamar Blvd, and 8000 to 8400 N Research Blvd didn't install any sidewalk at all or only had discontinuous and narrow sidewalks, even they ranked as higher risk locations and were proximate to many important attractors. The regression showed that even the presence of poor sidewalk would effectively lower down the collision rate by nearly 80 percent than the absence of sidewalk. Better sidewalk condition, such in downtown and UT campus areas, wasn't significantly correlated with further decline of collision rate. The conclusion came out that the presence of sidewalk makes more sense than the improvement of its condition. For those locations where higher rate of collision arose, the installation of continuous, reasonably wide sidewalks with ramps is necessary to reduce the pedestrian crash risk.

8.5 SPEED LIMIT

The average speed limit posted on the roadways around 18 hotspots ranged from 35 to 55 mph. Compared to the previous conclusion that pedestrian collisions were more likely to occur on the low-to-moderate speed roadways in the United States, the moderate-to-high speed streets presented higher incident risk to walkers after the effect of total number of pedestrians. Each mile per hour increase in speed limit of roadways was expected to result in 1 percent increase of collision rate. It was assumed that drivers on the higher speed roadways did not have enough time to brake the cars in response to the potential traffic conflict. Higher speed streets did not appear to make drivers yield to other street users either. Therefore, advanced caution signs of lowering down the speed or flash light before the pedestrian attractors were necessary to ensure enough reaction and stopping distance for these medium-to-high speed streets. Meanwhile, many higher speed streets lacked the accessibility by city collectors to ensure the mobility. Thus, blocks along these higher speed streets were always longer. The speed limits and the average block length might correlate with each other. The further examination to explore such correlation was expected in the future.

Chapter Nine: Conclusion

Instead of reaching a generalized conclusion of the overall pedestrian crashes in Austin, the author conducted mixed-method research around higher-incident-density locations. After combining spatial analysis, field survey, and statistical test, four predictor variables were suggested to be associated with higher pedestrian collision risk around the hotspot locations. They were the average speed limits posted on the roadway where the collision occurred, the degree of proximity to major pedestrian attractors within the study areas of hotspots, the average block length of the block group where the hotspot overlaid, and the condition of sidewalks within the study areas. Unlike the results of previous studies, the moderate-to-high speed roadways were expected to present higher pedestrian risk than lower speed streets after isolating the influence of pedestrian volume. Proximity to both bus stops and grocery stores being built at gas station at the same time was the most common condition found around hotspots, which would bring higher collision risks to the surrounding pedestrians. The provision of sidewalks around higher collision density locations were expected to effectively lower down the crash rate. However, the improvement of sidewalk condition would not account for any further decline of collision risk. The most important finding of this paper was that pedestrian collision risk was positively associated with the increasing of block length. More grid-like street network encompassing smaller-size block should be on the agenda to improve the pedestrian safety in Austin.

Appendix A: Original Data Collected in the Field Survey

Hotspots	PED_COUNT	HH_DEN	P_SIGNAL_I	P_CROSSWALK_I	P_MARKING_I	P_PEDSIGN_M	P_CROSSWALK_M	P_PEDISLAND_M	SIDEWALK	P_MEDIAN	TYPE_LOCATION	TYPE_ROADWAY
1	1	2.64	Absence	Absence	Absence	Absence	Absence	Absence	continuous; Width; Ramps	Presence	Midblock	6
2	2	2.01	Presence	Absence	Presence	Absence	Presence	Absence	continuous; Width; Ramps	Presence	Intersection	4
3	1	0.73	Absence	Absence	Absence	Absence	Absence	Absence	Continuous; Ramps	Absence	Midblock	6
4	2	3.41	Presence	Absence	Presence	Absence	Absence	Absence	Continuous; Ramps	Presence	Intersection	4
5	3	2.32	Absence	Absence	Presence	Absence	Presence	Absence	Ramps	Absence	Midblock	4
6	10	3.41	Presence	Absence	Presence	Absence	Absence	Absence	None	Absence	Midblock	6
7	16	6.07	Presence	Presence	Presence	Presence	Presence	Absence	continuous; Width; Ramps	Presence	Midblock	4
8	2	5.99	Presence	Presence	Presence	Absence	Presence	Absence	continuous; Width; Ramps	Absence	Intersection	4
9	13	3.35	Presence	Presence	Presence	Absence	Presence	Absence	continuous; Width; Ramps	Presence	Underpass or Overpass	4 (Rundberg), 6 (I-35)
10	15	10.08	Presence	Presence	Presence	Presence	Presence	Presence	continuous; Width; Ramps	Presence	Intersection	4 (Cameron)
11	12	0.66	Presence	Absence	Presence	Absence	Absence	Presence	continuous; Width; Ramps	Presence	Midblock	8 (Highland Mall)
12	1	1.95	Presence	Presence	Presence	Absence	Absence	Absence	None	Absence	Midblock	4
13	55	8.16	Presence	Presence	Presence	Presence	Presence	Absence	continuous; Width; Ramps; S	Absence	Intersection	4
14	31	12.74	Presence	Presence	Presence	Absence	Presence	Absence	continuous; Width; Ramps; S	Absence	Intersection	8
15	6	1.79	Presence	Absence	Presence	Absence	Absence	Absence	continuous; Width; Ramps	Presence	Intersection	4
16	101	3.19	Presence	Absence	Presence	Absence	Absence	Absence	continuous; Width; Ramps; S	Absence	Intersection	4
17	58	3.19	Presence	Absence	Presence	Absence	Presence	Absence	continuous; Width; Ramps; S	Absence	Intersection	4
18	7	2.01	Presence	Presence	Presence	Absence	Absence	Absence	continuous; Ramps; Street-o	Absence	Intersection	5 (Cesar Chavez), 8 (Comal)
19	17	4.60	Presence	Presence	Presence	Presence	Presence	Absence	continuous; Width; Ramps; T	Absence	Midblock	4
20	19	8.24	Absence	Absence	Presence	Absence	Presence	Absence	continuous; Ramps	Absence	Midblock	4 (E Oltorf), 8 (Burton)
21	15	4.94	Presence	Presence	Presence	Presence	Absence	Absence	continuous; Width; Ramps; S	Absence	Intersection	4
22	7	3.91	Presence	Absence	Presence	Absence	Presence	Absence	continuous; Width; Ramps	Absence	Underpass or Overpass	6 (Ben White); 4 (S Cong.)
23	4	3.56	Presence	Presence	Presence	Presence	Presence	Presence	continuous; Width; Ramps	Presence	Intersection	4
24	3	4.11	Presence	Presence	Presence	Absence	Absence	Absence	Width; Ramps	Absence	Midblock	4
25	3	3.70	Presence	Presence	Presence	Presence	Presence	Absence	Width; Ramps; Street-oriente	Absence	Midblock	5
26	8	5.61	Presence	Presence	Presence	Absence	Absence	Absence	continuous; Width; Ramps; S	Presence	Midblock	4

Table 13: Original Qualitative Data Collected in Field Survey

Hotspots	P_STPARKING	NUM_LANE	SPEED	BLOCK_LENGTH	RES_DUMMY	ATT_PROXIMITY	P_DRIVEWAY	CAR_TO_PED	M_HH_INCOME
1	Absence	3.0	50.0	6,050	Non-Res	Gas Station; Big-box	Yes	Mixed Use	$ 42,426
2	Absence	6.0	35.0	3,320	Res	Bus Stop; Elementary school; Community center plaza	Yes	Mixed Use	$ 73,482
3	Absence	3.0	55.0	7,350	Non-Res	Employers	Yes	None	$ 51,307
4	Absence	4.0	35.0	1,000	Res	Bus Stops; Gas Station; Community center plaza	Yes	Mixed Use	$ 36,058
5	Absence	4.0	45.0	2,450	Res	Bus Stops; Auto services	Yes	Mixed Use; Grid Street Network	$ 20,798
6	Absence	3.0	45.0	2,960	Res	Grocery Store; Auto Services; Elementary School; Bus Stops	Yes	Mixed Use	$ 35,791
7	Absence	4.0	45.0	1,950	Res	Gas Station & Grocery Store; Bus Stops; School; Neighborhoo	Yes	Mixed Use; Higher Density; Grid Street Network	$ 31,829
8	Absence	4.0	45.0	2,350	Res	Gas Station & Grocery Stores; Bus Stops; Schools	Yes	Mixed Use; Higher Density; Grid Street Network	$ 31,866
9	Absence	3.0	45.0	782	Res	Gas Station; Bus Stops; Neighborhood Center	Yes	Mixed Use; Grid Street Network	$ 46,226
10	Absence	5.0	30.0	1,200	Res	Grocery Store; Bus Stops; High School	Yes	Mixed Use; Higher Density; Grid Street Network	$ 29,688
11	Absence	4.0	35.0	1,320	Non-Res	Bus Stops; Employers; Big Box	Yes	Mixed Use	$ 48,594
12	Absence	4.0	55.0	2,496	Res	Gas Station & Grocery Store; Colony Park	Yes	None	$ 31,925
13	Presence	4.0	20.0	598	Res	Gas Station & Grocery Stores; Bus Stops; UT Campus; Emplo	Yes	Hihger-densities; Mix of Land uses; Well-connec	$ 15,856
14	Absence	2.0	30.0	385	Res	Bus Stops; Grocery Stores; UT campus; Student Housing	Yes	Hihger-densities; Mix of Land uses; Well-connec	$ 8,490
15	Absence	6.0	35.0	625	Non-Res	Bus Stops; Employers; UT Campus	No	Well-connected street network	$ 33,542
16	Presence	4.0	37.5	394	Non-Res	Bus Stops; Employers; Urban Center with Surface Parking Lot	Yes	Hihger-densities; Mix of Land uses; Well-connec	$ 86,364
17	Presence	4.0	40.0	360	Non-Res	Bus Stops; Employer; Open Space	Yes	Hihger-densities; Mix of Land uses; Well-connec	$ 86,364
18	Absence	2.0	28.3	457	Res	Bus Stops; Community Center;	Yes	Mixed Use; Well-connected street network; Hum	$ 26,339
19	Absence	5.0	40.0	1,826	Res	Bus Stops; Big Box w/ parking; Gas Station	Yes	Mixed Use	$ 37,730
20	Absence	3.0	35.0	1,235	Res	Bus Stops; Grocery Stores w/ Surface Parkings; Student Hous	Yes	Hihger-densities; Mix of Land uses	$ 30,603
21	Absence	4.0	27.5	870	Res	School;Grocery Stores w/ Surface Parkings; Community Cent	Yes	Mixed Use; Well-connected street network; Hum	$ 40,285
22	Absence	3.5	45.0	2,219	Res	Transit Hub; Gas Station w/ grocery stores; Employers	Yes	Mixed Use	$ 42,420
23	Absence	4.0	27.5	3,065	Res	Transit Stop; Community center; School	Yes	Mixed Use	$ 44,400
24	Absence	4.0	37.5	1,810	Res	Transit stops; Auto Service; Gas station	Yes	None	$ 46,927
25	Absence	4.0	26.7	1,592	Res	Gas Stataion w/ grocery stores; Bus stops; School	Yes	None	$ 50,489
26	Absence	6.0	33.3	1,137	Res	Gas Station w/ grocery store; Big Box; School; Bus stops	Yes	Well-connected street network; Human-scale bu	$ 49,375

Table 13 Cont.: Original Qualitative Data Collected in Field Survey

Appendix B: Data Summary of the Sample

Measure No.	Measures Definition	Measure ID	Description of Data	
			Category	Count
0.cat	Collision Rate Category	COL_RATE_Cat.	1=High	7
			2=Medium	10
			3=Low	9
2(a)	Pedestrian Countdown Signal	P_SIGNAL_I	0=Abcense	4
			1=Presence	10
3(a)	Leading Pedestrian Interval, and/or Crossing Refuge	P_CROSSWALK_I	0=Abcense	7
			1=Presence	7
4(a)	Yield Marking or Stop Bar	P_MARKING_I	0=Abcense	2
			1=Presence	12
2(b)	Pedestrian Sign, Flash Signal, or Stop Bar	P_PEDSIGN_M	0=Abcense	8
			1=Presence	4
3(b)	Marked Crosswalk	P_CROSSWALK_M	0=Abcense	5
			1=Presence	7
4(b)	Pedestrian Refuge	P_PEDISLAND_M	0=Abcense	10
			1=Presence	2
5	Sidewalk Conditions	SIDEWALK	0=None	2
			1=Extremely Poor	1
			2=Poor	4
			3=Fair	12
			4=Good	3
			5=Best	4
6	Raised Median	P_MEDIAN	0=Abcense	16
			1=Presence	10
7	Location Features	TYPE_LOCATION	1=Midblock	12
			2=Intersection	12
			3=Underpass	2
8	Roadway Type	TYPE_ROADWAY	4=Major Arterial	17
			5=Minor Arterial	2
			6=Local Street	5
			8=City Collector	2
9	On-Street Parking	P_STPARKING	0=Abcense	23
			1=Presence	3
13	Residnetial Use	RES_DUMMY	0=Non-Res	6
			1=Res	20
14	Proximity to Attractors	ATT_PROXIMITY	1=Least	1
			2=Less	5
			3=Fair	15
			4=More	4
			5=Most	1
15	Driveway Interruption	P_DRIVEWAY	0=No	1
			1=Yes	25
16	Land Use Patterns	CAR_TO_PED	0=Extremely Car-Dependent	4
			1=Car-Dependent	6
			2=Somewhat Walkable	8
			3=Walkable	3
			4=Very Walkable	3
			5=Walker's Paradise	2

Table 14: Data Summary of Non-Continuous Variables

Measure No.	Measure Definition	Measure ID	Descriptive Statistics of Sample			
			Min	Max	Mean	Standard Deviation
0	Collision Frequency per Million Pedestrians	COL_RATE	1	40	8	9.95
1	Annual Average Daily Traffic	ADDT	4,250	41,830	22,390	10,519.20
10	Roadway Lanes	NUM_LANE	2.0	6.0	3.94	1.04
11	Speed limits Posted	SPEED	20.0	55.0	36.25	8.91
12	Average Block Length	BLOCK_LENGTH_FT	360	7,350	1,915.00	1,670.91
17	Household Density	HH_DEN	0.66	12.74	4.32	2.86
18	Neighborhood Social Status	M_HH_INCOME	$ 8,490	$ 86,364	$ 41,507	$ 18,421

Table 15: Descriptive Statistics of Continuous Variables

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