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A Spatial Analysis of the Relationship between Pedestrian Crash Events and Features of the Built Environment in Downtown Atlanta

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B.A. Sociology, B.A. Anthropology

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A Spatial Analysis of the Relationship between Pedestrian Crash Events and Features of the Built Environment in Downtown Atlanta

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The faculty and staff of the Institute of Public Health.

In loving memory of my father,

Arturo Peter Taquechel

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CHAPTER I
INTRODUCTION

1.1 Background

Pedestrian injury due to motor vehicle crash is a serious public health problem. Every year, an estimated 4600 to 4900 pedestrians are killed by motorists, and 80,000 to 120,000 more are injured. Pedestrian fatalities account for approximately 11% of all traffic related deaths, and this percentage climbs to 35% percent in cities with a population over one million (*Traffic Safety Facts*, 2002). While these numbers have declined in the past few decades, it still remains a problem in need of applied public health intervention.

Urban environments, though rich with many unique resources and opportunities, are often ground zero for motor vehicle and pedestrian crashes and injury. The nature of urban design lends towards highly condensed and heavily trafficked areas, as they are usually the business centers of the surrounding area, as well as hubs for entertainment centers and areas of residence. Downtown Atlanta is no different. Between the years 2000 and 2006, metro Atlanta has seen a growth rate of 16.8% (U.S. Census Bureau), however, the Center for Disease Control (CDC) has ranked Atlanta as one of the most dangerous metropolitan areas in the United States for pedestrians (NHTSA, 2003). This equation adds up to more pedestrians being put at risk of getting injured or killed by a motorist, and public health measures are called upon to reduce this risk.

Urban university campuses face unique challenges when dealing with pedestrian safety issues. In fall 2007, a Georgia State University student was struck and by a moving vehicle and killed while crossing one of the arterial streets that run through the campus. This is only one of hundreds of pedestrian injuries and fatalities that have occurred in the last several years in downtown Atlanta. Approximately 25,000 GSU students, staff, and faculty are forced to navigate around the fast-moving, high-volume traffic of downtown Atlanta every day (Georgia State University, 2009). They are required to cross busy streets as they go to classes from residences, dormitories, public transit stations, and parking facilities. There are many hazards associated with crossing campus streets- motor vehicle traffic volume, speed, and street design. Grady Memorial Hospital also brings numerous pedestrians (including disabled, pediatric, and elderly patients) and is a destination for emergency medical services vehicles responding to life-threatening injuries. Nearby MARTA rail stations, State Capitol, and other government buildings result in large volumes of pedestrian traffic along those streets. Tourist attractions such as the Georgia Aquarium, Centennial Park, and the World of Coca-Cola bring even more pedestrians, many who are not aware of the traffic volume, intersection signals and road signage. This presents a unique challenge for pedestrians and public health officials alike. While pedestrians must find ways to navigate the deadly hazards of the many one way, multi-lane, high speed streets of Atlanta, compounded by the high traffic volume that travels these streets, public health officials must finds ways to intervene that will prevent crashes from occurring in such an environment. This study will examine the impact that features of the built environment, specifically those related to pedestrian travel, has on pedestrian safety.

1.2 Purpose of Study

The purpose of this study is to identify modifiable physical environment characteristics that might increase the risk of pedestrian injury through the utilization of Geographic Information Systems (GIS). Owing to the dangerous combination of heavy traffic volume and heavy pedestrian volume packed into a relatively small area in Downtown Atlanta, there is an increased risk of pedestrian injury and even death. One of the missions of public health is to identify and seek ways to reduce these risks, therefore preventing the likelihood of injury or death. Risk is often increased when environmental factors are not conducive to safe pedestrian travel (Cho et al, 2009). An objective of this study is to identify these factors in the hopes that future policy, armed with this knowledge, will be able to create safer pedestrian environments. By distributing the data geospatially, this study hopes to be able to determine if there are any spatial relationships between the urban campus environment and the occurrence of a pedestrian crash.

1.3 Research Questions

This study attempts to answer several research questions that might provide better insight into the role of the built environment with pedestrian safety, as well as the importance of GIS for spatial analysis.

1) What features of the built environment show a spatial relationship with pedestrian crashes at intersections?

    a) What is the relationship between the corner radius' and pedestrian crashes?

    b) What is the relationship between public transit and pedestrian crashes?

c) What is the relationship between pedestrian signals, crosswalk signs, and pedestrian crashes?

d) What is the relationship between location branding signs and pedestrian crashes?

e) What is the relationship between vehicle instruction signs and pedestrian crashes?

2) What features of the built environment show a spatial relationship with pedestrian crashes at road segments?

a) What is the relationship between street width and pedestrian crashes?

b) What is the relationship between street condition and pedestrian crashes?

c) What is the relationship between one way streets and pedestrian crashes?

d) What is the relationship between the presence of a furniture zone and pedestrian crashes?

e) What is the relationship between street furniture and pedestrian crashes?

f) What is the relationship between number of driveways and pedestrian crashes?

g) What is the relationship between street lighting and pedestrian crashes?

3) How are Geographic Information Systems (GIS) utilized to create a visual representation of the distribution of pedestrian crash events on the Georgia State campus?

CHAPTER II

REVIEW OF THE LITERATURE

2.1 Environmental risk factors for pedestrian crashes

Understanding the influence of the built environment on pedestrians is imperative to understanding pedestrian crashes and what accounts for increased risk in urban environments. Pedestrian infrastructure in urban areas contributes to the overall walking environment and safety of pedestrians in many ways. First, it can provide buffers between pedestrians and motorists, such as furniture zones and refuge islands, which reduce the risk of pedestrian injury due to motor vehicle crashes. Second, it can encourage motorists to keep a safe speed through the inclusion of traffic calming measures, such as speed humps, traffic circles, and road narrowing. Third, it can provide pedestrian more visibility through the inclusion of such features as crosswalks, signs, and lighting. Finally, it can encourage pedestrian travel through the inclusion of aesthetic features, such as tree-lined streets, inviting building frontage, and accommodating street furniture. However, while these features may often be seen as protective factors, they can also contribute to pedestrian injury risk (Loukaitou-Sideris et al, 2007). One study found that some of their pedestrian injury “hotspots” contained flora that were considered intrusive. They also found that street parking, which could be interpreted as a buffer between pedestrians and motorists, actually contributed to increased occurrence of pedestrian crash (Schuurman et al, 2009).

The absence of certain features of the built environment and road infrastructure that are viewed as protective factors can contribute to a higher rate of pedestrian crashes. One study found that an absence of traffic signals can increase risk (Lee et al, 2005). Lighting is an important feature for pedestrian visibility, and one study found that over the majority of their high risk intersections were lacking sufficient lighting (Loukaitou-Sideris et al, 2007). The type of street, as well as the width, can have an influence on pedestrian safety as well. Some studies found a concentration of crashes on major arterial streets, which tend to be wider and have a higher level of traffic density than small, narrower streets, thus putting the pedestrian at greater risk for a longer period of time while crossing the road (Morency et al, 2006; Schuurman et al, 2009), however another study found that the majority of midblock crashes occurred in streets less than 35 feet in width, while the majority of intersection crashes occurred on streets greater than 70 feet in width (Lightstone et al, 2001). These conflicting results suggest that there are confounding factors that might affect crash patterns at certain sites, for instance, block length and presence of crosswalks and signals. One study found that for both midblock and intersection crash locations, long block length was a contributing factor (Schuurman et al, 2009).

While the street and sidewalk infrastructure are important factors in pedestrian injury risk, equally as important are the types of land use that inhabit these urban environments. Retail density can often play an influential role in pedestrian density, as well as pedestrian injury risk (Schuurman, 2009; Loukaitou-Sideris et al, 2007; Clifton et al, 2007; Cho et al, 2009). Low neighborhood and retail density have been linked to reduced risk for both pedestrian and bicyclist injury as a result of behavioral changes due to high perceived risk in these areas (Cho et al, 2009). Built environment features linked with commercial and retail districts, such as surface parking lots (Loukaitou-Sideris et al, 2007) and the presence of driveways (Clifton, 2007; Loukaitou-Sideris et al, 2007) have also been shown to increase the risk of pedestrian crashes.

2.2 Haddon's Matrix as a Theoretical Framework

This study attempts to understand the relationship of the built environment with occurrences of pedestrian crashes through the theoretical lens of Haddon's matrix for injury prevention. Haddon's conceptual framework for injury prevention was created as an extension of the host, agent, and environment matrix. Haddon theorized that the crash and injury process could be divided into three temporal stages which contained pre-event (i.e. before the incident), event (i.e. moment of the incident), and post-event (i.e. after the incident) attributes, and four different factors with included host (i.e. person who is injured), agent (i.e. vehicle), physical environment (i.e. road and sidewalk infrastructure), and the social environment (i.e. pedestrian's behaviors, crossing norms and rules). By creating a matrix that incorporates all of these components engaged in a synergistic relationship with one another, researchers are able to identify the causes of injury on a multi-level scale, which can introduce the third dimension of this theory – intervention (Lett et al, 2002). Table 2.1 presents the Haddon Matrix as applied to the problem of motor vehicle crashes.

Table 2.1 Haddon Matrix Applied to the Problem of Motor Vehicle Crashes (adapted from Christoffel and Gallagher, 1999)

	Factors			
Phases	**Host**	**Agent/Vehicle**	**Physical Environment**	**Social Environment**
Pre-event *(before crash occurs)*	• Driver Vision • Alcohol impairment • Driver ability / experience	• Maintenance of brakes/tires • Speed of travel • Load characteristics	• Adequate roadway markings • Divided highways • Roadway lighting • Hazardous intersections • Road curvature • Adequate roadway shoulders	• Public attitudes on drinking and driving • Impaired driving laws • Graduated licensing laws • Speed limits • Support for injury prevention efforts
Event *(during the crash)*	• Spread out energy in time and space with seat belt and or airbag use • Child restraint use	• Vehicle size • Crashworthiness of vehicle—'crush space', integrity of passenger compartment, overall safety rating • Padded dashboards, steering wheels, etc.	• Guard rails, median barriers • Presence of fixed objects near roadway • Roadside embankments	• Adequate seat belt and child restraint laws • Enforcement of occupant restraint laws • Motorcycle helmet laws
Post-event *(after the crash)*	• Crash victim's general health status • Age of victims	• Gas tanks designed to maintain integrity during a crash to minimize fires	• Availability of effective EMS systems • Distance to quality trauma care • Rehabilitation programs in place	• Public support for trauma care and rehabilitation • EMS training

Haddon identifies ten categories of countermeasures to help prevent injury: 1) Prevent the creation of the hazard, 2) Reduce the amount of hazard brought into being, 3) Prevent the release of the hazard, 4) Modify the rate of release of the hazard from its source, 5) Separate the hazard from that which is to be protected by time and space, 6) Separate the hazard from that which is to be protected by a physical barrier, 7) Modify relevant basic qualities of the hazard, 8) Make what is to be protected more resistant to the damage from the hazard, 9) Begin to counter damage done by the hazard, and 10) Stabilize, repair, and rehabilitate the object of damage. These countermeasures are vital to the prevention of accidental injury, and provide a compass for those who wish to participate in intervention (Runyan, 2003).

2.3 Haddon's Matrix Applied to the Built Environment

This study's primary focus is on the physical environment's effect on host and agent during the pre-event stages of the incident, although it is important to include the other factors as they remain influenced by one another. One crucial step for injury prevention is to identify features of the physical environment that could be contributing factors to pedestrian crash risk. Once identified, they should be modified to reduce their impact on this risk. The physical environment influences the behaviors of both the host and agent, and therefore can increase risk of a crash. By identifying these risks related to the physical environment and categorized in the pre-event stages, the feasibility of creating appropriate interventions is improved.

Specific countermeasures can be applied to the pre-event physical environment by using Haddon's conceptual framework. Modifying the rate of release of the hazard from its source can be created through an exclusive pedestrian signal phase at a signalized intersection, which would allow pedestrians to cross the intersection in all directions. One study showed that the incidences of pedestrian injury due to crash at intersections with such signalization were approximately half that of intersections without the signalization (Zegeer et al, 1982). Modifying relevant basic qualities of the hazard can be accomplished through the use of traffic calming devices, such as installing a roundabout. One study in the Netherlands found that the conversion of 181 intersections into roundabouts reduces pedestrian crashes by 73 percent (Schoon et al, 1994). Lastly, separating the hazard from that which is to be protected by a physical barrier can be accomplished through the inclusion of a refuge island, which provides a buffer between motorists and pedestrians and allows pedestrians to cross a street in stages instead of all at once. One particular study in Sweden collected data from roughly 115 urban intersections with variable features and found that the risk of pedestrian-vehicle conflicts decreased by two-thirds at intersections with refuge islands (Garder, 1989). Through the identification of those physical features that contribute the most to pedestrian crash risk, the aforementioned countermeasures can be tailored to the specific environment, in this case Georgia State University, and thus have the most profound effect on reducing the occurrence of pedestrian crash events.

2.4 Geographic Information Systems and injury research

Geographic Information Systems (GIS) are integrated software that allow for data to be geospatially distributed over a map of a particular area. This process of data organization and distribution is imperative for injury epidemiology because it allows for a visual representation of the geographical distribution of disease. Furthermore, it gives the researcher the opportunity to visually relate certain incidences to others as a way of identifying the geographical significance of the distribution of disease (Edelman, 2007). This can to bring us closer to a real understanding of the environmental causes of pedestrian crashes that might have been less apparent without this type of analysis. Table 2.2 presents the rationale for using GIS in injury research.

Table 2.2: Potential Implications for the use of GIS in Injury Research (adapted from Edelman, 2007)

Potential Implications for the use of GIS in Injury Research
Descriptions of injuries by geographic location and overlaying environmental and population demographic characteristics
Description of populations at increased risk for injury and the identification of characteristics that might contribute to risk
Allocation of health care resources including health care workers, hospitals, and emergency medical services
Spatial temporal assessment of injury prevention program effectiveness
Provide information that influences national policy and finding initiatives to improve the safety environment and to establish prevention programs targeted toward populations most in need

Even though GIS technology is an underused tool in the field of injury epidemiology (Bell, 2009), several studies have utilized it in ways that have improved the research of disease distribution dramatically. One such study, similar to this study, evaluated measures of pedestrian walkability in localized areas using a walkability audit, a household survey, and GIS for spatial analysis. Of particular interest to this study were the maps that were generated as a result of data collected with the walkability audits (Ackerson, 2005).

These maps, using contrasting colors to represent variables, create a simple, yet effective method for displaying the spatial distribution of these features. The viewer is presented with a comprehensive picture of the distribution of these environmental features within the neighborhood from these maps. By displaying the maps of each neighborhood within a cluster, side-by-side comparisons can easily be made, which further supports the usefulness of these maps for descriptive analysis. The overall goal was to assess the walkability of each neighborhood surrounding a school to determine the influence of certain pedestrian amenities to the travel behaviors of the students attending those schools (Ackerson, 2005). While much of the research using GIS evaluates conditions on large-scale areas, such as census blocks, counties, and states, this study, like ours, examines these features on a neighborhood level, which provides a more unique and localized perspective to the ways in which micro-environments affect pedestrian behavior and safety.

In addition to the creating visual representations of walking environments as they relate to pedestrian injury risk, GIS technologies are being utilized to facilitate planning models such as the Ped INDEX, a tool that is used to identify key areas for pedestrian infrastructure and design improvements. This tool uses two indices for measurement, as shown in figure 2.3.

Figure 2.1 Two indices used in the Ped INDEX methodology to identify high-priority areas (City of Sacramento, n.d.)

These indices approach pedestrian infrastructure design from a more comprehensive viewpoint by identifying two different indices: improvements that need to be made to the built environment and factors that will facilitate more motivation for walking. These indices account for infrastructural deficiencies such as broken sidewalks, lack of crosswalks, and poor street lighting, as well as factors that will encourage pedestrian travel, such as pleasant streetscape, street connectivity and close proximity to destinations (City of Sacramento, n.d.).

After the inventory is completed, maps are created in order to visually convey the areas that are in most need of improvements. A composite score of both infrastructure deficiencies and pedestrian potential are compiled to determine pedestrian improvement need. The final process consists of prioritizing individual projects based on factors such as cost/benefit ratio, level of community support, and possible sources of funding. Through this process, improvement projects that can most feasibly be carried out will take priority over those without the same level of potential (City of Sacramento, n.d.). This process exemplifies the ways in which GIS can be used not only to assess the distribution of risk, but to assist in the creation of an action plan for actual improvement. Table 2.3 displays the strengths and limitations of using GIS in injury research.

Table 2.3: Strengths and Limitations of Geographic Information Systems (adapted from Edelman, 2007)

Strengths	Limitations
Linking of spatial data with demographic attributes	The use of secondary data from multiple sources
Creation of overlay maps that allow visualization of injury events and underlying population characteristics	Paucity of individual injury and socioeconomic status data resulting in a dependence on group data
Identification of injury clusters not bound by artificial boundaries such as counties	Injury rates in areas with small numbers of injuries may be over-estimated
Spatial statistic techniques that determine the true relationship of injury events with other environmental or population characteristics	Confounders and covariates may erroneously influence the injury rates in adjoining areas

Although utilization of GIS presents some limitations, the strengths outweigh the drawbacks, thus helping to bridge the gap between research and project implementation.

Chapter III

METHODOLOGY

3.1 Data Sources

Built environment data for the study area was collected through environmental audits over the course of three months in the summer of 2009. Two separate audit forms were created, one for segments (indicating the portion of road between two intersections) and one for intersections. Each intersection and its adjoining segments within the study area were given both objective and subjective measures for several variables pertaining to the road infrastructure, pedestrian infrastructure, and streetscape. Additionally, measurements on traffic and pedestrian signals were collected for timing and condition. The Atlanta street networks shapefile was obtained from the Environmental Systems Research Institute (ESRI) and utilized as the base for all maps in the analysis. Pedestrian crash data from the years 2006 and 2007 were obtained from the Georgia Department of Transportation. This data includes both pedestrian injury and fatality; however, for the purposes of this study, each incident falls into the same category, identified as pedestrian crash, as the primary goal of the study is to compare the incidence of a crash to features of the built environment.

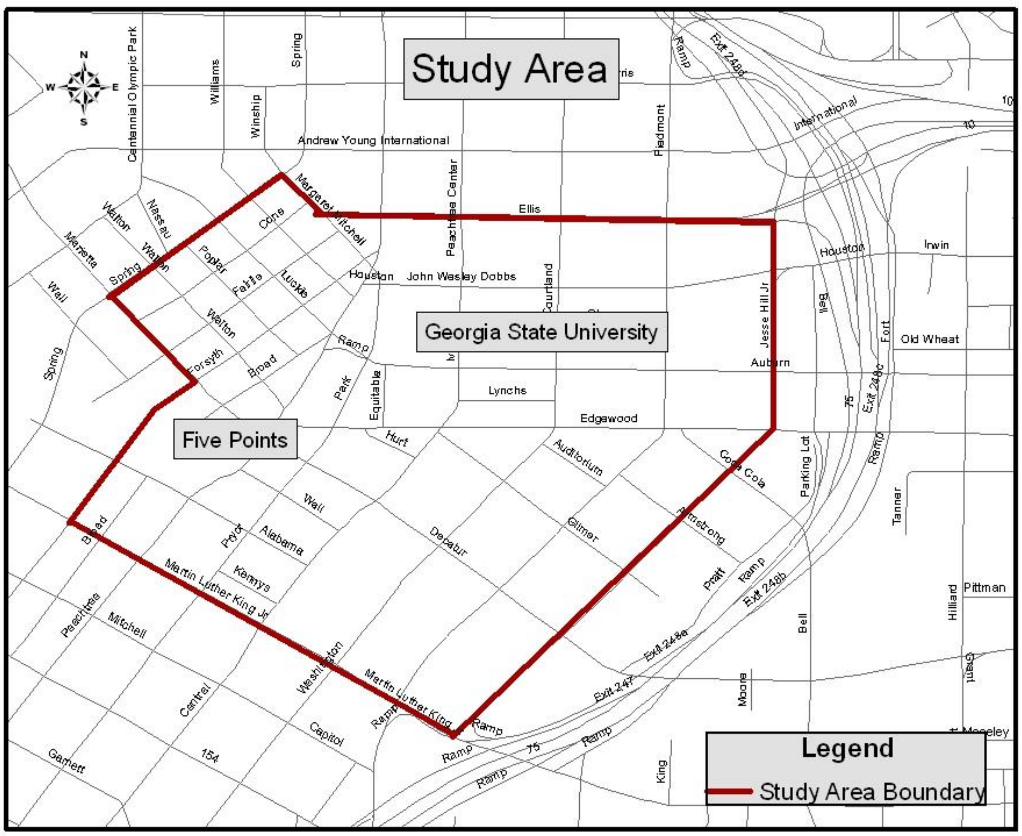
3.2 Study Area

The study area was selected by the research team based on what constituted the GSU campus and any peripheral area where students would be likely to traverse for University-related activities. The area was then divided into four separate zones, based on the estimated density of student activity in each. Zone 1 consisted of the University's main campus, bordered by Edgewood Ave. to the north, Jesse Hill Jr. Dr. to the southeast, Martin Luther King Jr. Dr. to the southwest, and Central Ave. to the northwest. Zone 2 consisted primarily of the Fairlie-Poplar district, which accommodates several University buildings, including Aderhold Learning Center, Rialto Center for the Arts, and the Robinson College of Business. This area is bordered by Spring St. to the northwest, Carnegie Way to the northeast, Peachtree St. to the southeast, and Marietta St. to the southwest. Zone 3 consisted of the area directly north of main campus, housing the University Commons and the Lofts. This area is bordered by Ellis St. to the north, Jesse Hill Jr. Dr. to the east, Edgewood Ave. to the south, and Peachtree St. to the west. Finally, Zone 4 consisted of the area west of main campus and south of the Fairlie-Poplar District. This area includes Five Points and Underground Atlanta, and is bordered by Forsyth St. to the northwest, Decatur St. to the northeast, Central Ave. to the southeast, and Martin Luther King Jr. Dr. to the southwest.

3.3 Study Measures

Intersection audits included measures in four categories: lanes, corners, signage, and signals. Lanes were measured for width, type, material, condition, and total crossing distance. Additionally, the presence and type of crosswalk was recorded, as well as the presence or absence of a median and stop bar. Variables that fell under the category of corner measurements included waiting capacity (defined as the number of people who could comfortably stand on the corner without obstructing the passersby on the sidewalk), the ADA compliance of ramps and corner radius.

Figure 3.1: Georgia State University Campus and Surrounding Area Included in Study



Additionally, the presence or absence of obstructions, curb extension, a channelized turn lane, and a turn lane crosswalk were recorded. The variables for signage at each intersection included a count for speed limit signs, street name signs, vehicle instructions, pedestrian instructions, location branding signs, way-finding signs (defined as any sign that gives directional instructions to either vehicles or pedestrians) and crosswalk signs. Pedestrian and vehicle signals were timed for appropriate synchronization. Additionally, pedestrian signals were inspected for condition and the presence or absence of automation, an activation button, an audible signal, and a numeric countdown. The condition and timing mechanism (pre-timed or actuated) were recorded for vehicle signals as well. Lastly, the presence or absence and type of public transit available at the intersection were recorded. Coordinates for all intersections were collected and recorded using a Garmin handheld Global Positioning Systems (GPS) device.

Segment audits included measures in five categories: lanes, sidewalks, environment, signage, and streetscape. Each segment is defined as the discrete section of road in between two adjacent intersections. Lanes were measures for type, width, and condition. Sidewalks were measured for width, material, condition, as well as furniture zone width and material. Several variables were measured in the environment category, including number of driveways, building height, use, and frontage, presence and type of parking facility (i.e. garage, lot), presence of absence of a sidewalk closure (defined as an obstruction that prevents a pedestrian from using the sidewalk), and presence or absence of any other obstructions. The variables for signage included counts of speed limit signs, vehicle instructions, pedestrian instructions, location branding signs, way-finding signs, crosswalk signs, and the presence or absence of a midblock crosswalk. The streetscape of each segment was rated for overall condition, degree of ornamentation, furniture, lighting, litter, vacant or boarded lots or buildings, mature trees, shrubs or small trees, and flowers or grass. Lastly, the presence or absence of a median and public transit facilities were also recorded.

For the purpose of this study, specific features were selected from each audit to be used for spatial analysis. These features were selected based on their degree of influence to the pedestrian experience based on previous studies examining the contributions of these features to the walking environment. Additionally, a few features that have shown relevance to pedestrian safety were left out of the study due to their ubiquitous presence or absence within the study area. For instance, crosswalks, although a crucial design component shown to increase pedestrian safety, were present at virtually every intersection in the study area, therefore they would not make a significant contribution to the analysis. Conversely, speed limit signs are an important feature within a streetscape in order to encourage motorists to maintain the appropriate speed and decrease the risk of crash, however there were no observed speed limit signs in the study area. Decatur St, which falls within the study area, was largely excluded from the study due to the construction that was present during the time of data collection; however, some data was collected on one intersection on this street. If data was included in the analysis for this intersection it will be present on the appropriate maps.

3.4 Spatial Analysis

All spatial analysis was conducted through ArcMap Verson 9.3. The base map was a shapefile of Atlanta streets obtained from the Environmental Systems Research Institute (ESRI) that was used as a reference map for all built environment and crash data. All data was geocoded using Geographic Coordinate System GCS_North_American_1983, Datum D_North_American_1983, and Projected Coordinate System USA_Contiguous_Lambert_Conformal_Conic. Thirteen separate maps were created for built environment data. A few of the maps represented data collected at intersections, which included corner radius, presence and type of transit, presence of pedestrian signal, presence of crosswalk sign, number of location branding signs, and number of vehicle instruction signs. Other maps contained street infrastructure data, which included street widths, street conditions, and one-way versus two-way streets. Additionally, the rest of the maps contained data on pedestrian infrastructure, such as number of driveways, presence of a furniture zone, presence of street furniture, and lighting. Each variable was saved as a separate shapefile. The Georgia Department of Transportation crash data was geocoded using latitude and longitude coordinates and projected onto built environment data maps for purposes of comparison. Categories for each variable were separated using natural breaks (Jenks) method, which is used to reflect natural clusters in the data. Descriptive analysis was conducted through the overlay of pedestrian crash events on each of these maps. Each event, represented by a star, was characterized by the built environment features that were present at the location of the incident. The total incidences for each environmental variable were recorded, and the percentage of each incident with a particular environmental feature was calculated. Finally, a kernel density map was created to determine high risk areas for pedestrian crashes.

Chapter IV

RESULTS

Numerous studies have shown that features of the built environment have effects on pedestrian crash occurrences. The data displayed on these maps supports much of this evidence. Each of the research questions that were presented in the Chapter I are addressed here with a series of maps depicting the spatial distribution of specific features of the built environment with a pedestrian crash overlay, with the intent of visually illustrating the relationship between the two categories. Along with the map, a brief statistical summary will be provided. Tables 4.1 and 4.2 present overall prevalence rates for environmental variables at intersections and street segments, respectively.

The total number of pedestrian crashes that occurred in the study area was 26. Eighteen of these crashes occurred at intersections, which is 69 percent of the total. Likewise, eight of the crashes occurred in road segments, which is 31 percent of the total. The percentages for figures 4.1 through 4.5 are based on the total crashes that occurred at intersections (n=18), whereas figures 4.6 through 4.12 will be based all crashes that occurred within the entire study area (n=26). Finally, figure 4.13 displays the kernel density estimation for the entire study area. Prevalence rates were calculated for each feature by dividing the number of pedestrian crash locations with a particular built environment feature by the total number of locations in the study area associated with that particular feature. This method was chosen as a way to eliminate the bias of some features being either overrepresented or underrepresented within the study area.

Table 4.1 Overall Prevalence Rates for Environmental Variables at Intersections

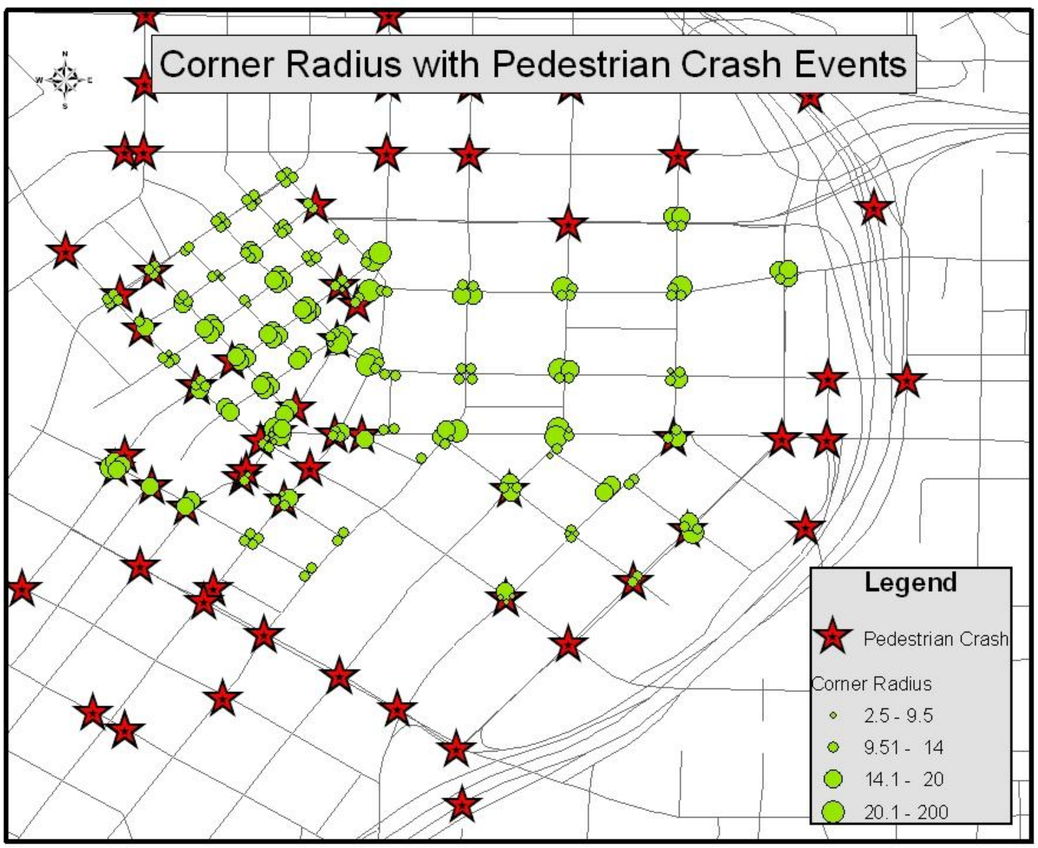
Variables	Total number of locations with feature present	Number of features associated with pedestrian crash	Prevalence Rate
Crosswalk Signs	13	8	0.615384615
Pedestrian Signals	40	17	0.425
Transit	28	11	0.392857143
Location Branding Signs			
many	17	10	0.588235294
few	33	8	0.242424242
none	14	4	0.285714286
Vehicle Instruction Signs			
0-2	6	1	0.166666667
3-4	18	5	0.277777778
5-6	14	7	0.5
7-9	22	6	0.272727273
10-12	5	3	0.6
Corner Radius (feet)			
2.5-9.5	17	6	0.352941176
9.51-14	46	14	0.304347826
14.1-20	28	13	0.464285714
20.1-200	12	3	0.25

Table 4.2 Overall Prevalence Rates for Street Segment Variables

Variables		Total number of locations with feature present	Number of features associated with pedestrian crash	Prevalence Rate
Street Width (feet)				
	10-12	3	0	0
	13-18	5	0	0
	19-20	13	4	0.307692308
	21-25	4	1	0.25
	26-28	1	0	0
	29-35	11	6	0.545454545
	36-40	53	24	0.452830189
	41-60	11	4	0.363636364
	61-80	3	2	0.666666667
One Way Streets		58	12	0.206896552
Two Way Streets		49	21	0.428571429
Street Condition				
	good	32	12	0.375
	fair	67	22	0.328358209
	poor	8	1	0.125
Furniture Zone				
	yes	73	24	0.328767123
	no	28	8	0.285714286
Street Furniture				
	many	58	18	0.310344828
	few	70	23	0.328571429
	none	5	0	0
Driveways				
	0	69	25	0.362318841
	1	37	11	0.297297297
	2	32	8	0.25
	3-4	14	3	0.214285714
	5-6	4	0	0
Street Lighting				
many		69	23	0.333333333
few		62	20	0.322580645
none		10	2	0.2

4.1 Each research question and the subsequent answer will be presented in the following section. The first research question asked 'What is the relationship between corner radius and pedestrian crashes?'. Figure 4.1 displays the corner radius and pedestrian crash event map.

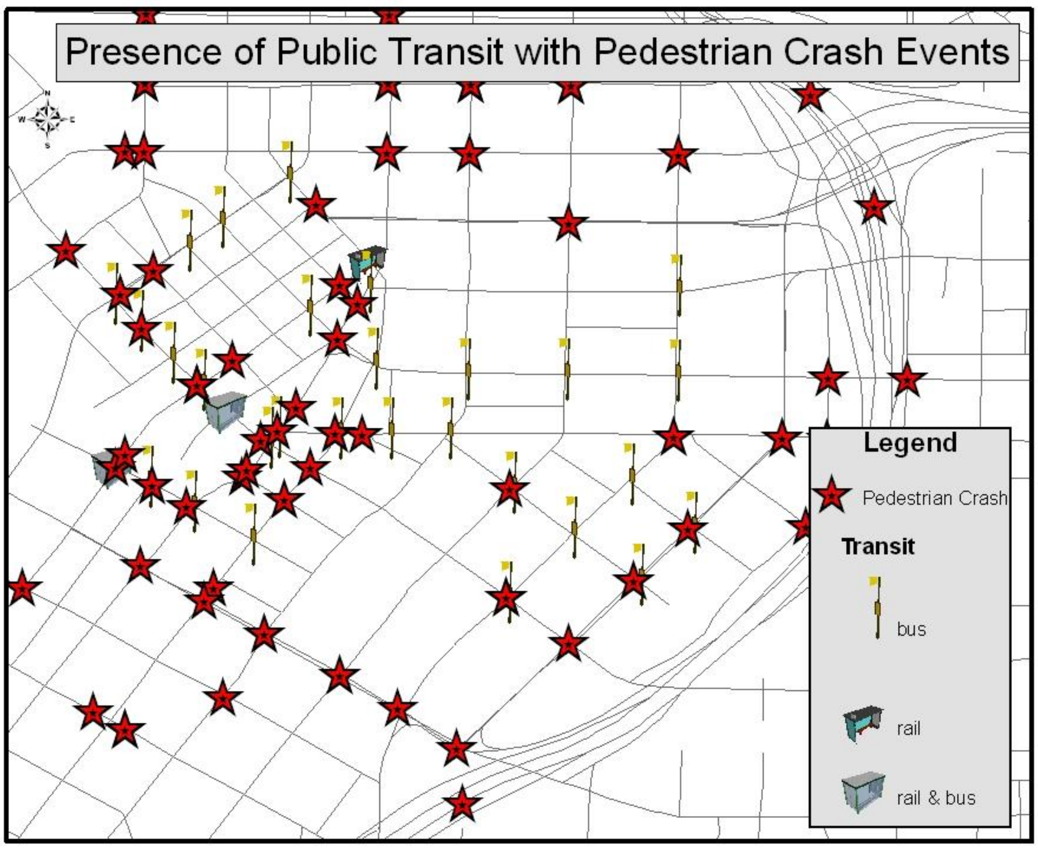
Figure 4.1: Relationship of Corner Radius to Pedestrian Crashes



The prevalence of pedestrian crashes that occurred at intersections with at least one corner with a radius smaller than 9.51 feet was 35 percent (n=17). Additionally, the prevalence of pedestrian crashes that occurred at intersections with at least one corner with a radius between 9.51 and 14 feet was 30 percent (n=46), compared with the prevalence of pedestrian crashes that occurred at intersections with at least one corner with a radius between 14.1 and 20 feet at 46 percent (n=28). Lastly, the prevalence of pedestrian crashes that occurred at intersections with at least one corner with a radius higher than 20 feet was 25 percent (n=12).

4.2 What is the relationship between public transit and pedestrian crashes?

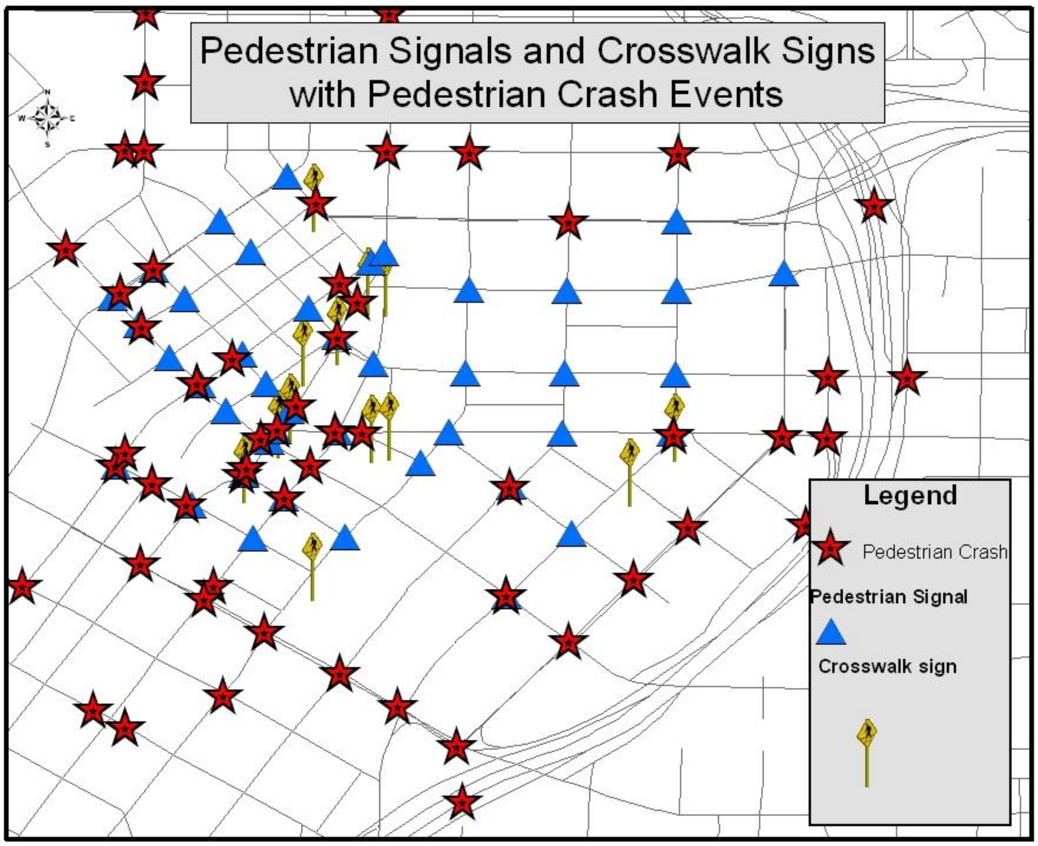
Figure 4.2: Relationship of Public Transit to Pedestrian Crashes



The prevalence of pedestrian crashes that occurred at intersections with the presence of a MARTA bus station was 39 percent (n=28).

4.3 What is the relationship between pedestrian signals, crosswalk signs, and pedestrian crashes?

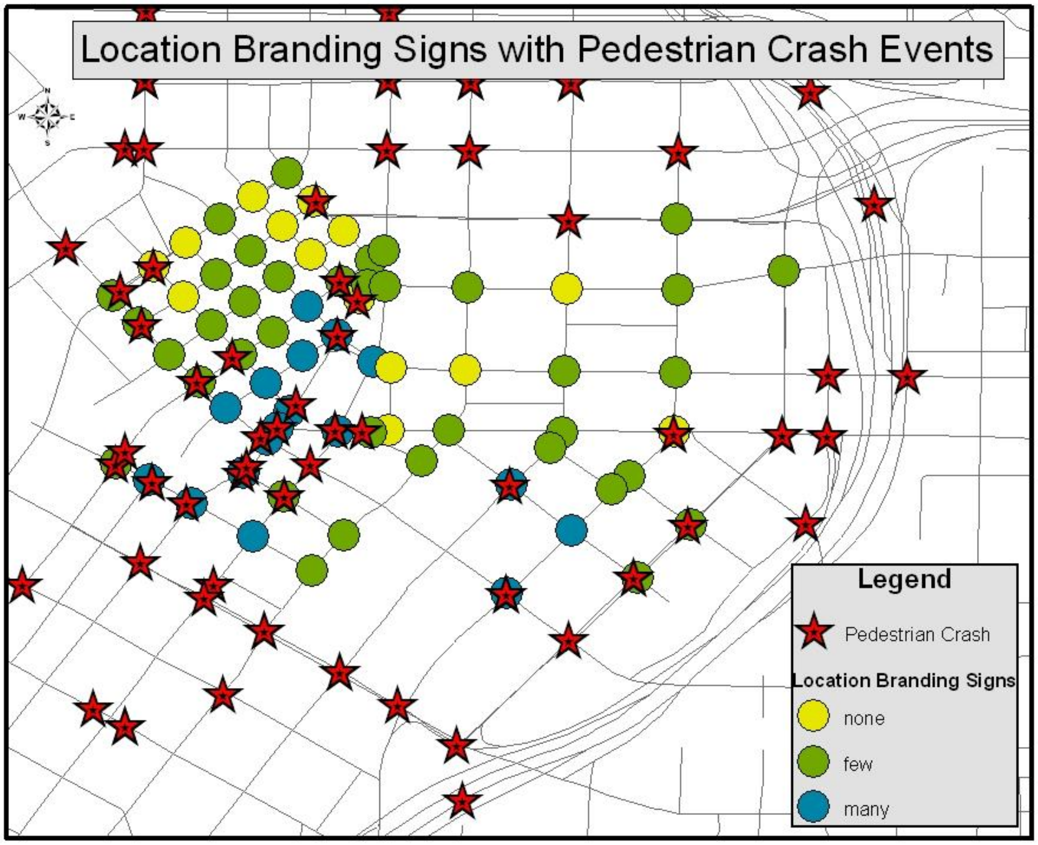
Figure 4.3: Relationship of Pedestrian Signals and Crosswalk Signs to Pedestrian Crashes



The prevalence of pedestrian crashes that occurred at intersections with a pedestrian signal was 43 percent (n=40). Additionally, the prevalence of pedestrian crashes that occurred at intersections with a crosswalk sign was 62 percent (n=13).

4.4 What is the relationship between location branding signs and pedestrian crashes?

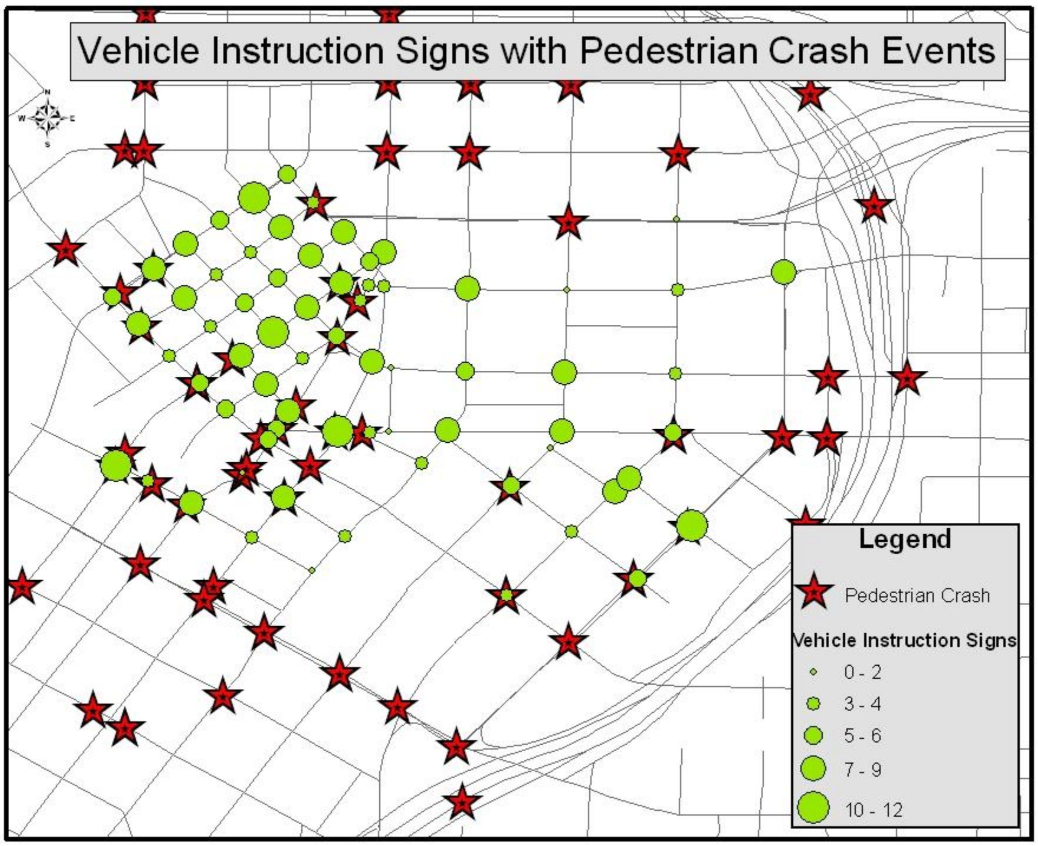
Figure 4.4: Relationship of Location Branding Signs to Pedestrian Crashes



The prevalence of pedestrian crashes that occurred at intersections with no location branding signs was 29 percent (n=14), while the prevalence of pedestrian crashes that occurred at intersections with few location branding signs was 24 percent (n=33). Lastly, the prevalence of pedestrian crashes that occurred at intersections with many location branding signs was 59 percent (n=17). No data was collected for the intersection on Decatur St. with a pedestrian crash due to construction occurring at the time of data collection.

4.5 What is the relationship between vehicle instruction signs and pedestrian crashes?

Figure 4.5: Relationship of Vehicle Instruction Signs to Pedestrian Crashes

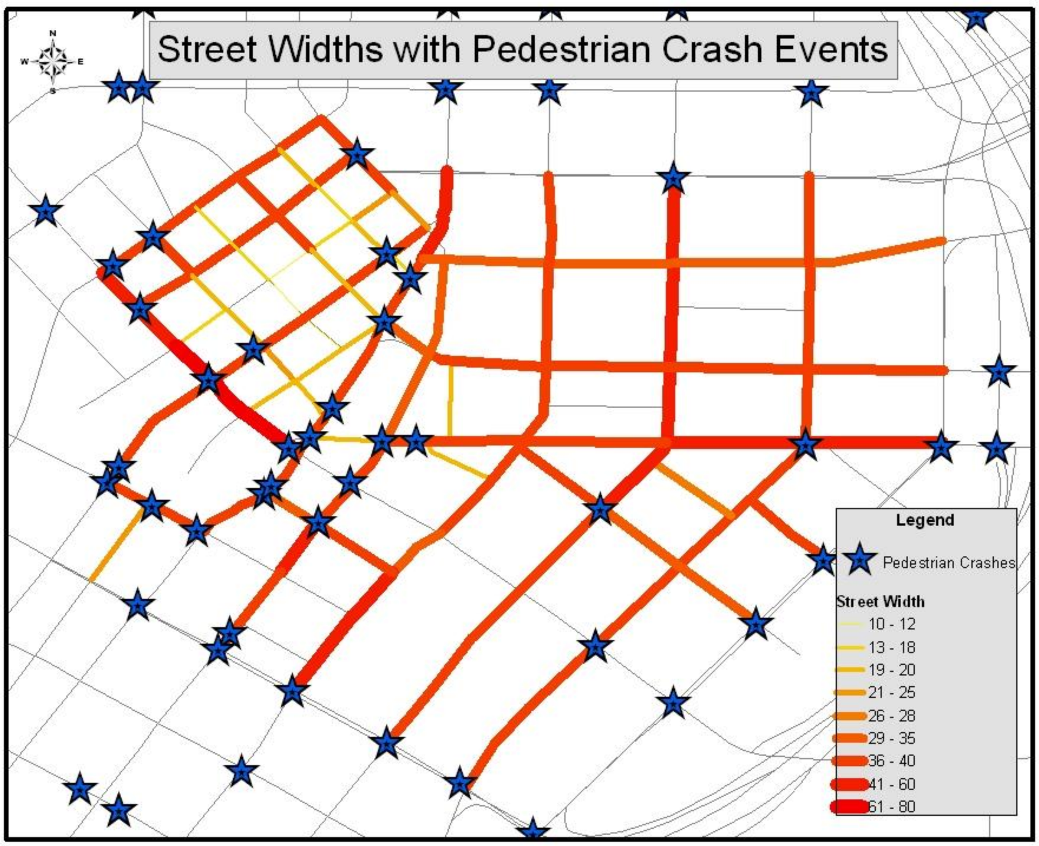


The prevalence of pedestrian crashes that occurred at intersections with 0-2 vehicle instruction signs was 17 percent (n=6) while the prevalence of pedestrian crashes that occurred at intersections with 3-4 vehicle instruction signs was 28 percent (n=18). Additionally, the prevalence of pedestrian crashes that occurred at intersections with 5-6 vehicle instruction signs was 50 percent (n=14) compared with 27 percent (n=22) for intersections with 7-9 vehicle instruction signs was 27 percent (n=22). Lastly, the prevalence of pedestrian crashes that occurred at intersections with 10-12 vehicle instruction signs was 60 percent (n=5).

For the following results, the term “location” is used to refer to both intersection and road segment sites, as these results include both.

4.6 What is the relationship between street width and pedestrian crashes?

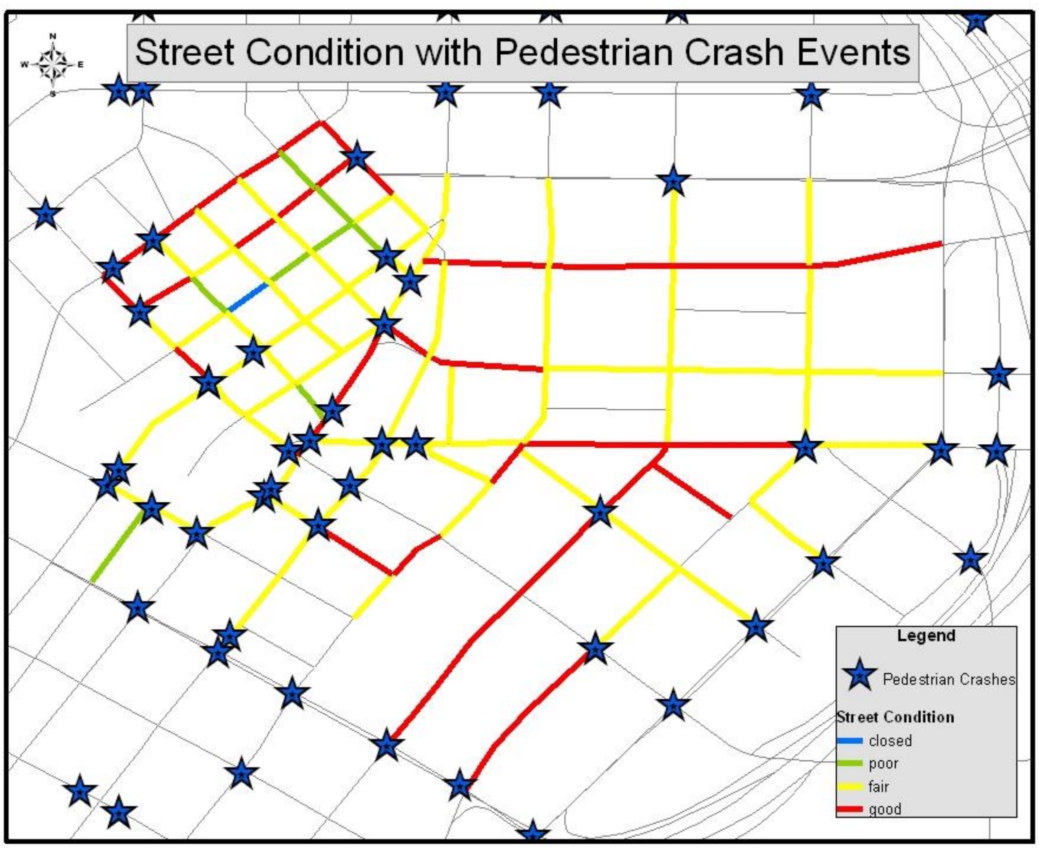
Figure 4.6: Relationship of Street Width to Pedestrian Crashes



There were no pedestrian crashes that occurred at a location with a street width 18 feet or less. The prevalence of pedestrian crashes that occurred at a location with a street width between 19 and 20 feet was 31 percent (n=13), while 25 percent (n=4) of locations with a street width between 21 and 25 feet had a pedestrian crash event. No pedestrian crashes occurred at a location with a street width between 26 and 28 feet. The prevalence of pedestrian crashes that occurred at a location with a street width between 29 and 35 feet was 55 percent (n=11). Likewise, the prevalence of pedestrian crashes that occurred at a location with a street width between 36 and 40 feet was 45 percent (n=53), and 36 percent (n=11) of locations with a street width between 41 and 60 feet had a pedestrian crash event. Lastly, the prevalence of pedestrian crashes that occurred at a location with at least one street width between 61 and 80 feet was 67 percent (n=3).

4.7 What is the relationship between road condition and pedestrian crashes?

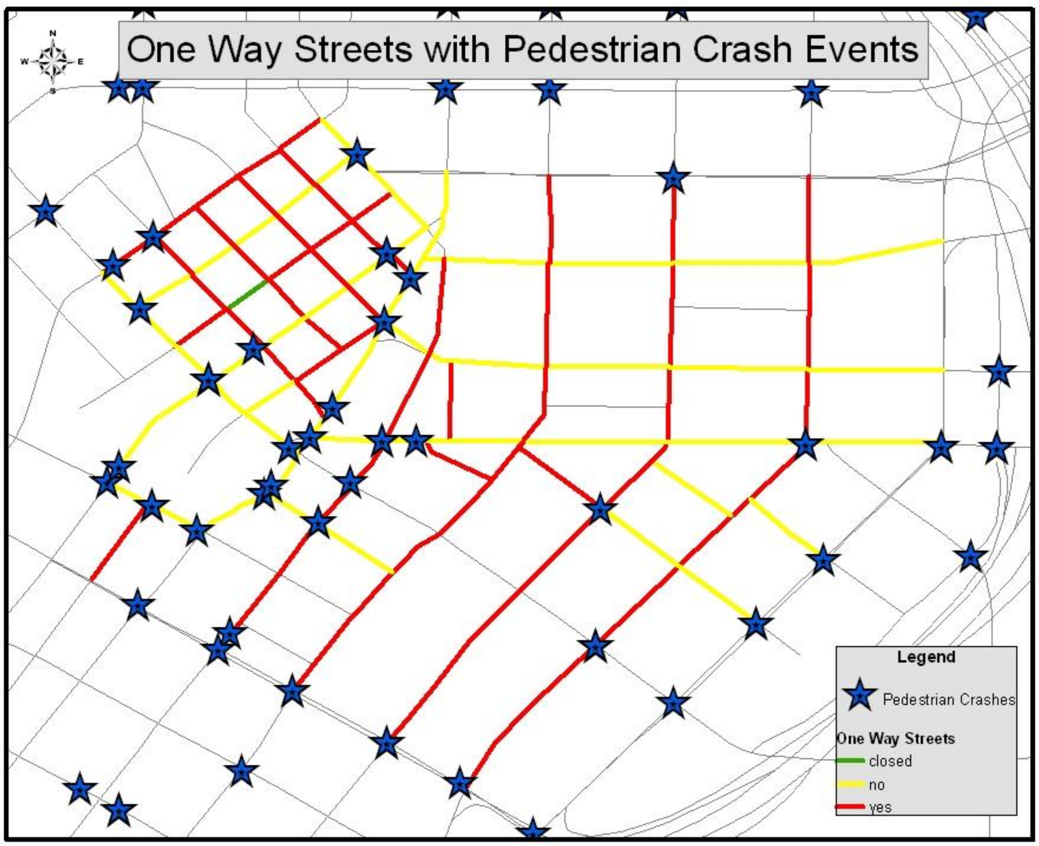
Figure 4.7: Relationship of Street Condition to Pedestrian Crashes



The prevalence of pedestrian crashes that occurred at a location with a street in poor condition was 13 percent (n=8), while 33 percent (n=67) of locations with fair street conditions had pedestrian crash events. Finally, the percentage of pedestrian crashes that occurred at a location with at least one street in good condition was 38 percent (n=32).

4.8 What is the relationship between one way streets and pedestrian crashes?

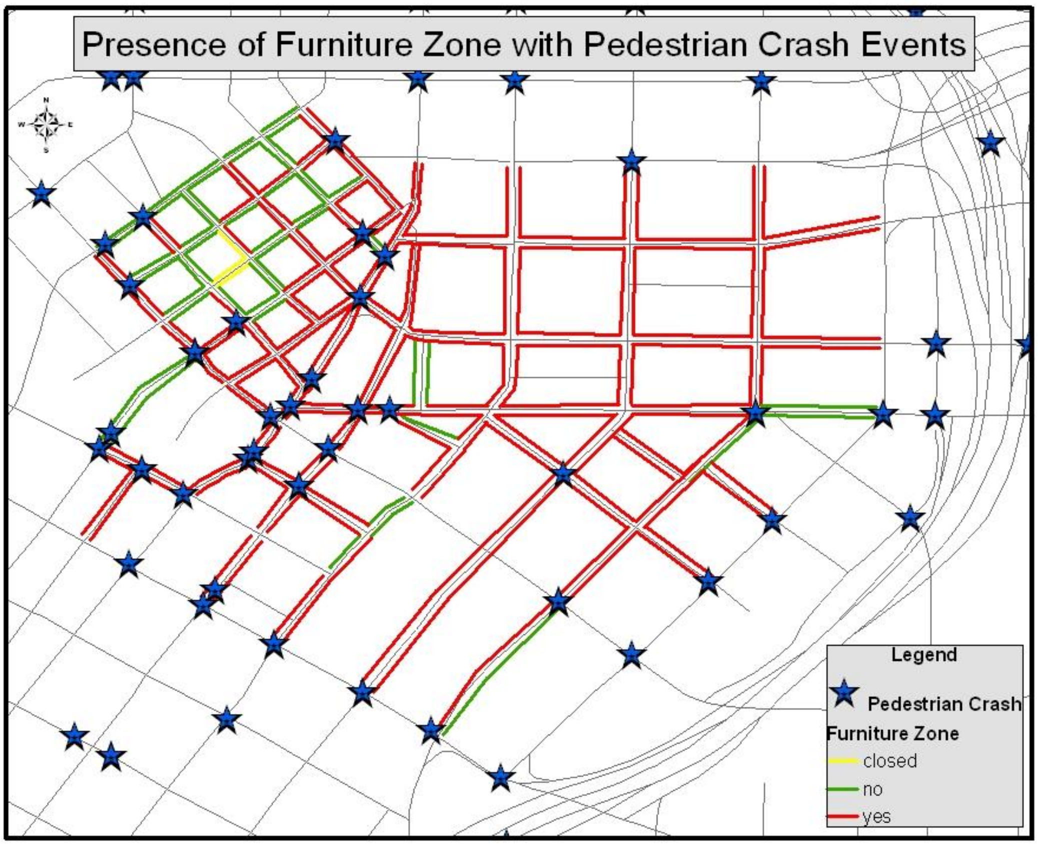
Figure 4.8: Relationship of One Way Streets to Pedestrian Crashes



The prevalence of pedestrian crashes that occurred at a location with a one-way street was 21 percent (n=58). Likewise, the prevalence of pedestrian crashes that occurred at a location with a two-way street was 43 percent (n=49).

4.9 What is the relationship between the presence of a furniture zone and pedestrian crashes?

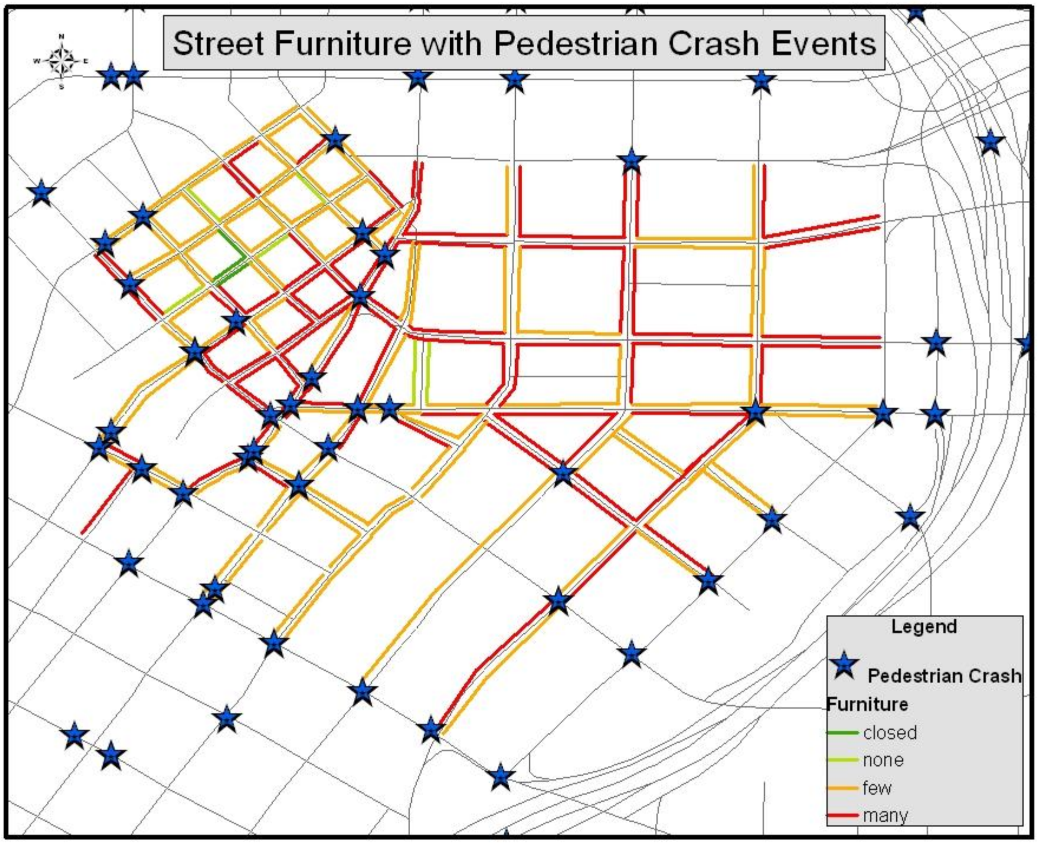
Figure 4.9: Relationship of Furniture Zone to Pedestrian Crashes



The prevalence of pedestrian crashes that occurred at a location with a sidewalk that contained a furniture zone was 33 percent (n=73), whereas the prevalence of pedestrian crashes that occurred at a location with a sidewalk that did not contain a furniture zone was 29 percent (n=28).

4.10 What is the relationship between street furniture and pedestrian crashes?

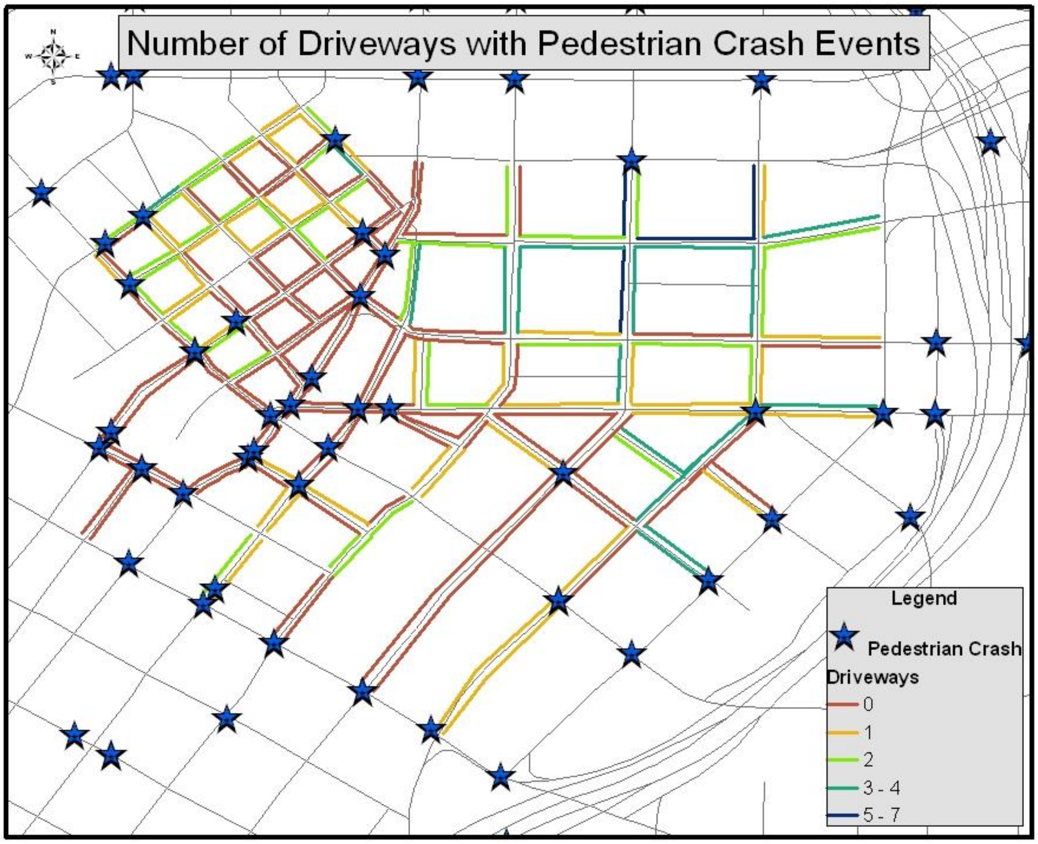
Figure 4.10: Relationship to Street Furniture to Pedestrian Crashes



There were no pedestrian crashes that occurred at a location without any street furniture. Likewise, 33 percent (n=70) of locations with a sidewalk that contained a small amount of street furniture had pedestrian crash events, compared with 31 percent (n=58) at locations with a sidewalk that contained a good amount of street furniture.

4.11 What is the relationship between number of driveways and pedestrian crashes?

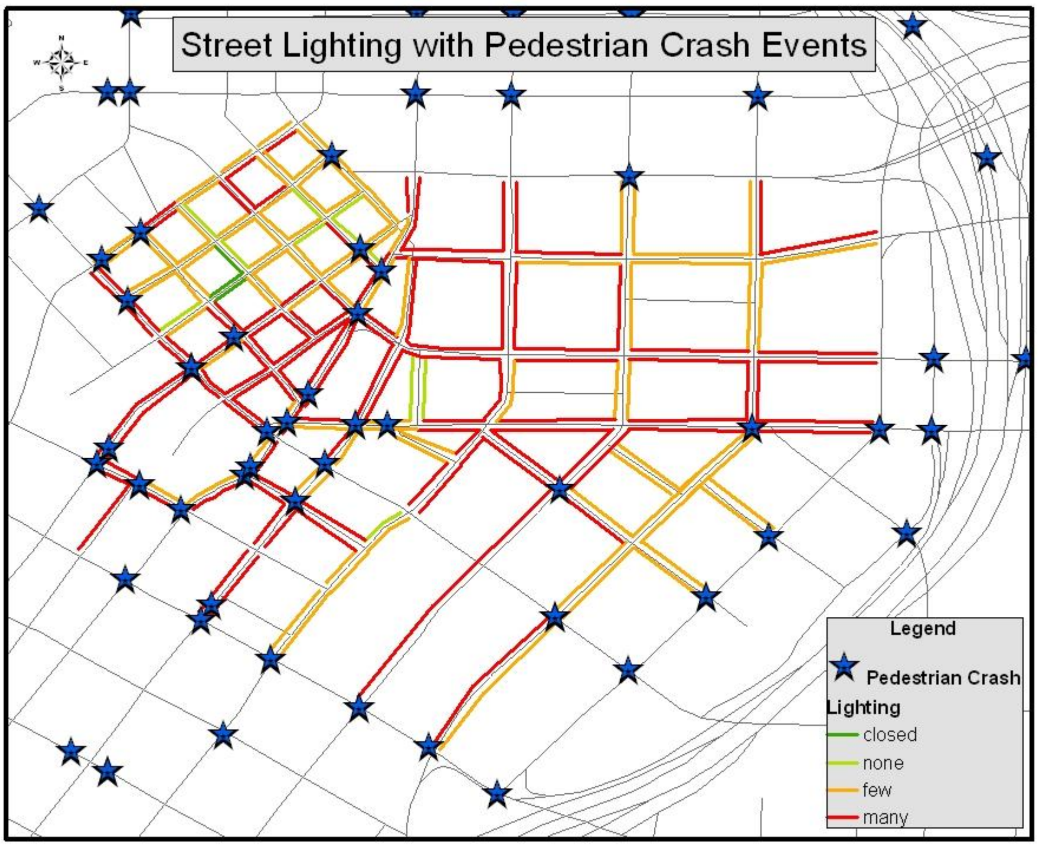
Figure 4.11: Relationship of Number of Driveways to Pedestrian Crashes



The prevalence of pedestrian crashes that occurred at a location with a sidewalk containing no driveways was 36 percent (n=69). Additionally, 30 percent (n=37) of locations with a sidewalk containing one driveway had a pedestrian crash event, compared with 25 percent (n=32) of locations with a sidewalk containing two driveways. The prevalence of pedestrian crashes that occurred at location with a sidewalk containing three or four driveways was 21 percent (n=14), and there were no pedestrian injuries that occurred at locations with a sidewalk containing five or more driveways.

4.12 What is the relationship between street lighting and pedestrian crashes?

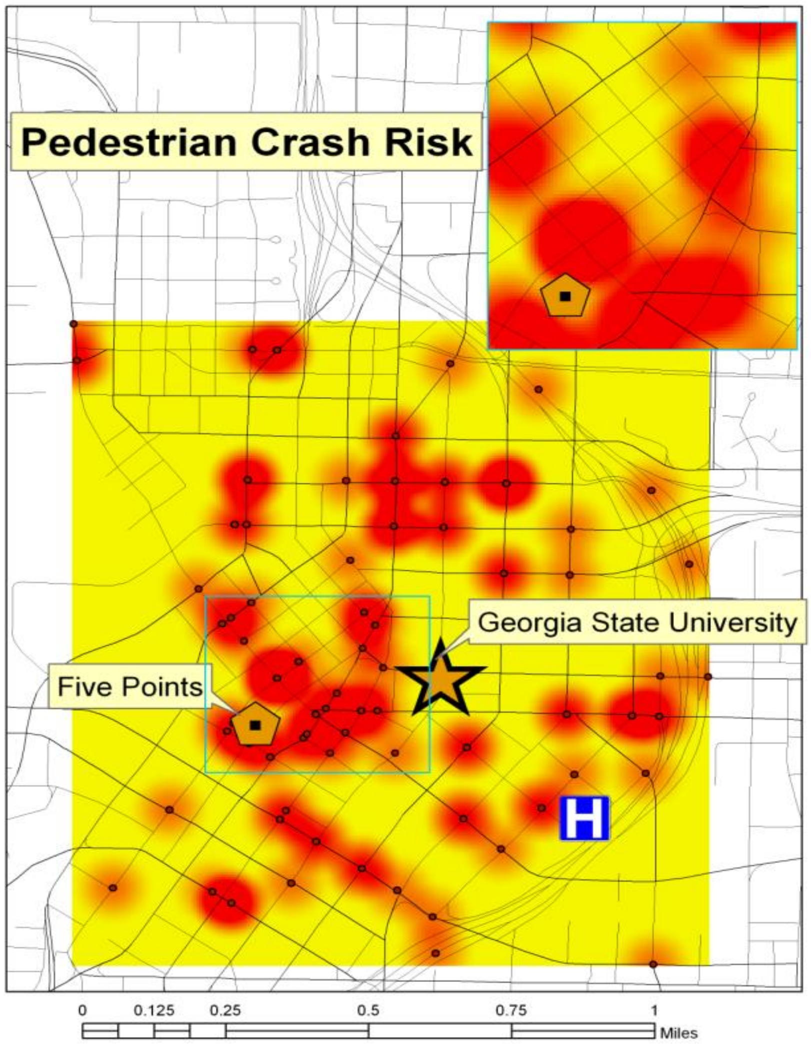
Figure 4.12: Relationship to Street Lighting to Pedestrian Crashes



The prevalence of pedestrian crashes that occurred at locations with a sidewalk containing no street lighting was 20 percent (n=10). Likewise, the prevalence of pedestrian crashes that occurred at a location with a sidewalk containing a small amount of street lighting was 32 percent (n=62). Finally, the prevalence of pedestrian crashes that occurred at a location with a sidewalk containing a good amount of street lighting was 33 percent (n=69).

4.13 How are Geographic Information Systems (GIS) utilized to create a visual representation of the distribution of pedestrian crash events on the Georgia State campus?

Figure 4.13: Kernel Density Clustering of Pedestrian Crash Sites



These maps show an estimation of high risk areas for pedestrian injuries using kernel density clustering. The kernel density function is used to calculate the magnitude of risk per unit area given the frequency of the events within that area, and thus can provide a visual representation of crash distribution over a geographic area. From these maps, it is apparent that clustering occurs predominately in the Five Points area and the surrounding business district which indicates these as high risk areas for pedestrian crashes.

Chapter V

DISCUSSION AND CONCLUSION

5.1 Discussion

Several inferences can be made from the preliminary results shown in Chapter IV. Descriptive analysis for environmental data at intersections exposes certain correlations. For instance, pedestrian crashes were more likely to occur at intersections with five or more vehicle instruction signs and several location branding signs, indicating that motorists might be affected by too many visual stimuli on the road (Dixon, 1998). In addition, the crosswalk signs map illustrates that pedestrian crashes occurred on nearly all of the intersections with crosswalk signs present, with a prevalence rate of 62 percent. This is contrary evidence to some studies that show the presence of crosswalk signs increases the motorists' awareness of pedestrians and are therefore less likely to hit a pedestrian crossing at the crosswalk (Van Houten, 1992). It should be mentioned that some signage can be a protective factors for pedestrian risk such as speed limit signs. The environmental audits contained a count for speed limit signs at each intersection and road segment, however there were no observed signs in the study area. This is important to note when examining factors such as the speed the motorist was traveling prior to a crash.

Additionally, the data shows that the lowest prevalence of pedestrian crashes occurred at intersections where at least one corner radius was 20 or more feet; however it was impossible to infer from the police reports which corner the pedestrian exited in order to enter the road, so conclusions are indecisive. Wider corner radiuses, however, provide pedestrians with more visibility and range of motion therefore can be a protective factor when crossing the street. This could suggest the importance of wider corners for greater pedestrian visibility at intersections.

Descriptive analyses of the maps that depict road infrastructure are important to analyze as well. For instance, street widths show a positive correlation with pedestrian crash risk. Street width is the main indicator for crossing distance, which is directly tied to pedestrian crash risk. These findings are consistent with the literature ((Lightstone et al, 2001; Morency et al, 2006; Schuurman et al, 2009). The majority of the crashes in our study area are clustered around Peachtree St, Marietta St., and Pryor St., which all have streets widths over 35 feet. Conversely, the streets that are the narrowest show very few pedestrian crashes. This most likely occurs because pedestrians crossing wider streets are in the road for a longer period of time, thus increasing their risk of being hit by a motorist. This risk can be mediated by such features as a refuge island or signs indicating pedestrian crossing (Garder, 1989), however, this study and others show conflicting results as to whether these features are protective factors or not (Harrel, 1994; Van Houten, 1992). For instance, this study demonstrates how crosswalk signs at intersections are not necessarily protective factors on their own; however, future research should examine the combined effect of multiple features at one site to reduce pedestrian risk.

In addition, fair and good road conditions are shown to be linked to a greater number of crashes, with a prevalence rate of 33 percent and 38 percent respectively. This could be attributed to the fact that the fewer potholes and defects a road has, the more likely the motorist will travel at a higher speed, which makes them less likely to have a timely response to a pedestrian crossing the street. Lastly, the data shows that the majority of pedestrian crashes occurred on two-way roads. This can be contributed also to the fact that these roads are wider than most others in our study area. Additionally, two way roads tend to be more difficult for pedestrians to navigate as they must cross against two directions of traffic. The addition of a refuge island could help mediate the risk of crossing these multi-lane, high speed roads (Garder, 1989).

Street furniture and furniture zones are linked to the reduction of pedestrian crash and the improvement of pedestrian streetscapes, which encourage pedestrian travel (Ridgeway, 1986). They can serve functional purposes by creating a physical barrier that protects pedestrians from motorists who might jump the curb during a crash. They also serve an aesthetic function as they contribute to the overall walking environment (Ridgeway, 1986). The results show the majority of pedestrian crashes occurred at locations with street furniture; however there were only five locations that did not have any street furniture. Likewise, the majority of pedestrian crashes occurred at locations with furniture zones, with a prevalence rate of 33 percent, yet this percentage is not high enough to make any sound conclusions. One explanation for this percentage is that the locations where pedestrian crashes are clustered tend to have furniture zones and more street furniture because they are more heavily populated and therefore more resources are invested in these areas. Less populated areas show a lower frequency of these features as well as a lower frequency of pedestrian crashes.

The amount of street lighting had been shown to be directly related to pedestrian risk. The better lit the area, the more visibility provided to both the pedestrian and the motorist (Loukaitou-Sideris et al, 2007). The results of this study, however, show that the areas with good lighting have the highest prevalence of pedestrian crashes at 33 percent. This conflicts with the results of previous studies. One explanation for this is the fact that the denser areas in downtown Atlanta tend to be well lit due to heavy pedestrian and vehicle traffic, and these areas have the highest events of pedestrian crash. It should also be noted that the majority of pedestrian crashes in the study area occurred during daylight hours when lighting would not have been an important factor. It is impossible to know, however, if lighting was a factor during the dawn and dusk hours when the degree of sunlight changes at different times of the year. These hours might have been classified as daylight hours on the police reports, however street lighting might have a more significant effect during fall and winter months compared to the same hours in the spring and summer months.

The kernel density map displays the clustering of pedestrian crash incidences within certain areas. This is useful for the identification of high risk areas due to frequency. From this map, it is apparent that high risk areas include Five Points and the surrounding business district. These areas have higher retail density and street compactness, which supports the findings in the literature which show that areas with high retail density, neighborhood compactness, greater land use mix, and higher employment density increase pedestrian risk (Morency et al, 2006; Schuurman et al, 2009; Loukaitou-Sideris et al, 2007). This map also draws attention to some areas outside of the study area, specifically around Martin Luther King Jr. Dr. There appears to be a high density of crashes in this area, which points towards future research that should expand beyond the Georgia State University campus.

Limitations to the kernel density estimation affect the significance of the results however. The first limitation is the fact that the kernel density function uses raw numbers instead of rates in its estimations. The second limitation is the inability of the available software to create kernel density estimations along street networks, therefore the estimations provided here include everything within a circular radius of the point features. This detracts from the strength of the analysis because the circular radius includes off-street as well as on-street locations; however this study is only interested in the density of on-street locations. These limitations are important to emphasize when discussing the results presented here.

This study, in addition to examining the correlations between built environment and pedestrian crash events, seeks to promote the utility of Geographic Information Systems as an important tool for assessing this relationship within a visual format. It is imperative with injury research to understand the role that geography plays. Geography can be an important indicator of disease, and is used in public health research to link disease to specific spatially-related variables. As is the case with this research, it can link the risk of crash to specific small-scale environmental variables and provides a visual snapshot of this relationship. This research has attempted to show different ways that GIS can be used to visually represent the data on a map in a manner that lends towards future analysis of the relationships between the built environment and pedestrian crash events. While the results from this study are preliminary and difficult to extrapolate to more expansive areas, they do start a conversation about the ways in which the urban environment can have both a positive and negative influence on pedestrian safety.

5.2 Study Limitations

One limitation to this study was the small number of pedestrian crash events that were recorded and used for analysis. Related to this was the limited time period in which the data was collected. Two years of pedestrian crash data are not sufficient to make conclusive associations with the built environment; however some important observations were recorded in this study that will plant the seed for future research. Additionally, there was no way to account for the severity of pedestrian injury due to crash, which could have contributed to this research. Furthermore, there is no way to account for any changes that might have occurred to the pedestrian environment over the course of the years that have passed between the when the pedestrian crash data was collected and when the built environment data was collected, given the limited time allowance and resources of this project. Future studies of the built environment's relationship to pedestrian crash events in this study area should take a longitudinal approach to collecting and analyzing data in order to account for these changes. This could provide a more in-depth and comprehensive understanding of the way subtleties in the physical environment can affect behavior and risk.

Another limitation was the exclusion of traffic and pedestrian density data from the study. The inclusion of this data would have provided a better understanding of the clustering of incidences in certain areas as opposed to others. While this study looked primarily at built environment variables, often there are other factors that have a large influence on pedestrian crash events. Future research could benefit from examining these factors in order to capture a better understanding of elements associated with pedestrian crashes.

A third limitation with this research is the small study area, which makes it difficult to extract conclusive results. Future research should cover the entire downtown Atlanta area so that analysis will have more statistical power. Additionally, the exclusion of data on Decatur St., a major arterial street on campus, detracted from the comprehensiveness of the study. Because of the ongoing infrastructural changes that were taking place during the time the audits were being carried out, data was not collected and therefore the majority of Decatur St. was excluded from the study. Future research should be inclusive of all streets in the area, and take into account the possible accommodation of construction.

A fourth limitation to this study was the exclusion of certain built environment features in the mapping process, largely due to time constraints. This exclusion resulted in the absence of a comprehensive picture of the built environment in our study area. The environmental audit tools were created to capture a detailed picture of the infrastructural features and conditions, however, the involvement of the mapping process required us to filter out certain variables, and thus only include those that were deemed most relevant for the study.

Finally, one more notable limitation was the inability to account for the direction in which a pedestrian was travelling during the event of the accident. This makes it difficult to assess the specific environmental features that might have played a role in the accident. For example, knowing which corner a pedestrian was leaving when they were struck would allow for a more accurate description of the relationship between corner radius and crash events.

5.3 Recommendations

This study was designed as a springboard for future research interested in the role GIS, the built environment, and pedestrian safety play in downtown Atlanta. There are many directions that this research can take. One suggestion is to expand the study area to incorporate all of downtown Atlanta. While this study's main focuses was Georgia State University, the results shown here can only be strengthened through the expansion of the study area. Another suggestion would be to include other modifiable factors in the analysis, both environmental and behavioral. Several studies have looked at the link between behaviors and pedestrian crashes, and it would be useful to combine both types of factors to see if they influence one another in this particular region. Finally, including traffic and pedestrian counts in the analysis would establish a more grounded and conclusive association between pedestrian crashes and other factors.

5.4 Conclusion

Pedestrian crashes place a huge burden on public health in the United States; however they can be prevented through careful research and appropriate interventions. One way to prevent the occurrence of pedestrian injury due to motor vehicle crash is to identify and modify features of the built environment that might contribute to this risk. This study focuses primarily on the physical environment in an urban setting, given that pedestrian injuries are often clustered in urban environments where both motorist and pedestrian traffic are high. The main purpose of this study is to offer up a new way of presenting data in a visual format that provides insight into the spatial distribution of built environment variables as they relate to pedestrian crashes, and to create a springboard for future research that aims to expand the associations between the built environment and pedestrian crash events. Through the inclusion of these results into the larger matrix of injury prevention, appropriate countermeasures on all levels can be applied to the problem of pedestrian injury and death as a result of motor vehicle crashes.

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Appendix. Data Collection Forms: Intersection Audit

Use this form with the instructions. Use one form per evaluation area. Obtain area ID and side designations from master map. .							
Area ID:		Date:		Time:		Surveyor:	

Graph the intersection.

Lanes	Side 1	Side 2	Side 3	Side 4	Side 5
Travel lanes (#)					
Parking lanes (#)					
Turn lanes (#)					
Other lanes (#)					
Lane width (min/max)					
Roadway material	S P U O	S P U O	S P U O	S P U O	S P U O
Roadway condition	I F P	I F P	I F P	I F P	I F P
Total crossing dist					
Median (Y/N)					
Stop bar (Y/N)					
Crosswalk type	s c l z d p u	s c l z d p u	s c l z d p u	s c l z d p u	s c l z d p u

Corners	Corner 1	Corner 2	Corner 3	Corner 4	Corner 5
Waiting capacity					
Ramps	C NC A	C NC A	C NC A	C NC A	C NC A
Obstructions (Y/N)					
Temp. obstruct (Y/N)					
Corner radius					
Channel turn (Y/N)					
Turn crosswalk(Y/N)					
Curb (Y/N)					

Signage	
Speed limit (#)	
Street name (#)	
Vehicle instruction (#)	
Pedestrian instruction (#)	
Way finding (#)	
Location branding signs	Many Few None
In-street crosswalk signs (#)	
Other_____________________	

Diagram Intersection

Pedestrian Signal	← *[Only for intersection with traffic signal]* →									
	a	b	c	d	e	f	g	h	i	j
Automation (Y/B/N)										
Button (Y/B/N)										
Audible (Y/B/N)										
Countdown (Y/B/N)										
Condition (I/F/P)										

Vehicle Signal					
Control	Light	Pt stop	All stop	Merge	Other
Signal Timing	Pretimed	Actuated			
Condition	Ideal	Fair	Poor		
Other_____________					

Transit			
Service	Rail	Bus	None

Appendix. Data Collection Forms: Road Segment Audit

Use this form with the instructions. Use one form per evaluation area. Obtain area ID and side designations from master map.

Area ID:		Date:		Time:		Surveyor:	

Graph the segment.

Lanes		
Travel lanes (#)		
Parking lanes (#)		
Turn lanes (#)		
Other lanes (#)		
Lane width	min	max
Roadway material	Solid Paved	Unpaved Other
Roadway cond.	Ideal Fair Poor	

Sidewalks	Side 1	Side 2
Sidewalk width	variable	variable
Sidewalk material	S P U O	S P U O
Fur zone width		
Fur zone material	S P U O	S P U O

Environment	Side 1	Side 2
Driveways (#)		
Building height	Short Med Tall	Short Med Tall
Building use	Comm. Res. Mix	Comm. Res. Mix
Building frontage	Ideal Fair Poor	Ideal Fair Poor
Parking facilities	Gar Lot None	Gar Lot None
Sidewalk Closure	Yes No	Yes No
Obstructions	Many Few None	Many Few None
Sidewalk condition	Ideal Fair Poor	Ideal Fair Poor
ADA compliance	Ideal Fair Poor	Ideal Fair Poor

Record measured speeds in ranges --->

Transit			
Service	Rail	Bus	None

Signage	Side 1	Side 2
Speed limit (#)		
Vehicle instruction (#)		
Pedestrian instruction (#)		
Wayfinding signs (#)		
Location branding signs	ManyFewNone	ManyFewNone
Crosswalk sign (#)		
Midblock crosswalk	Yes	No
Other_______________________________		

Streetscape	Side 1	Side 2
Streetscape condition	Ideal Fair Poor	Ideal Fair Poor
Ornamentation	Good Min None	Good Min None
Furniture	Many Few None	Many Few None
Lighting	Many Few None	Many Few None
Litter/damage	Many Few None	Many Few None
Vacant/boarded	Many Few None	Many Few None
Mature trees	Many Few None	Many Few None
Shrubs/small tree	Many Few None	Many Few None
Flowers/grass	Many Few None	Many Few None
Median	Physical Painted	None
Other_______________		

Speed				
Posted Speed			MPH	N/A