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# Determining the Influence of the Built Environment on Pedestrian-Vehicle Crashes in Dekalb County, Georgia Using Geographic Information Systems

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DETERMINING THE INFLUENCE OF THE BUILT ENVIRONMENT ON PEDESTRIAN-VEHICLE  
CRASHES IN DEKALB COUNTY, GEORGIA USING GEOGRAPHIC INFORMATION SYSTEMS

by

DEREK JAWORSKI

Under the Direction of Dajun Dai

ABSTRACT

This study aimed to examine how the characteristics of the road network and the built environment influence the frequency of pedestrian-vehicle crashes. Pedestrian crashes (2000 – 2007) on major roads in DeKalb County of Georgia were obtained from Georgia Department of Transportation. Hotspot analysis was performed on locations with frequent pedestrian incidents to determine their built environment characteristics. Using Geographic Information Systems, the built environment was characterized using road grade, curvature, population density, the amount stores and restaurants, bars, and public transit stops nearby. A negative binomial regression model was used to examine the influence of the built environment characteristics on pedestrian crashes. The results showed that all the variables except for road grade were positively associated with increased number of pedestrian crashes. Findings provided insights into the influence of built environment characteristics which is important for injury prevention to improve pedestrian safety.

INDEX WORDS: Pedestrian incidents, Geographic Information Systems, Built environment

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CRASHES IN DEKALB COUNTY, GEORGIA USING GEOGRAPHIC INFORMATION SYSTEMS

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DEREK JAWORSKI

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Arts

in the College of Arts and Sciences

Georgia State University

2012

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2012

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December 2012

**DEDICATION**

This thesis is dedicated to my parents and family. They have been a constant source of inspiration and support throughout my life.

## **ACKNOWLEDGEMENTS**

I'd like to express my thanks to my advisor Dr. Dai who has been a great source of guidance in developing this thesis. I'd also like to acknowledge my committee members Dr. Kiage and Dr. Diem for their help and support in developing this thesis.

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## 1. INTRODUCTION

Designing a neighborhood that accommodates those who walk should be considered a valuable goal for planners. The risk of being hit by a car when walking is a major issue as evidenced by the more than 4,600 pedestrian fatalities in the United States in 2007 (Jones et al. 2010). Creating safe and walkable communities is an important goal to strive for, because automobile oriented transportation infrastructure often restricts access based on age and income. With 1,047 pedestrian incidents on major roads in DeKalb County from the years 2000 to 2007, according to the Georgia Department of Transportation (GDOT), safety for walkers is a major concern. Although other methods such as pedestrian education can have minor benefits to increasing pedestrian safety, making travel safer for pedestrians is best achieved by designing a road network and built environment that aims to reduce automobile collisions (Retting et al. 2003).

Creating a safe road network for both automobiles and pedestrians involves understanding the impact that road geometry and design have on incident frequency. If a road is dangerous for drivers and pedestrians then frequent incidents will be mostly unavoidable. The two aspects of road geometry that were studied are a road's gradient and curvature. These aspects of the road network may create dangerous situations to both pedestrians and automobiles.

In addition, understanding the built environment and the land use of a neighborhood may provide insights into the degree of safety an area has for pedestrians. This subject was studied because understanding the impact that the design of a road has is important, but one will not get a complete picture of what is causing pedestrian incidents if they ignore the conditions of the surrounding built environment. For example, having locations where pedestrians frequently travel may determine where an incident might occur. This study attempts to understand how the amount of bars, stores and restaurants, and bus stops around a road may affect pedestrian incident counts. Population density was

also studied in order to see how it affects pedestrian incident frequency. Locations of stores and restaurants provided insight into how areas with a high density of commercial development might affect pedestrian-automobile crash frequency. Locations classified as bars were studied separately from stores and restaurants due to their potential to increase the likelihood of intoxication in drivers and pedestrians. Understanding how bus stops affect pedestrian incident frequency is valuable because transit availability may potentially be a determinant of crash frequency. Finally, population density is valuable because it provides insights into how the amount of nearby housing and pedestrian traffic may affect crash frequency. With these insights it may be possible to better understand what areas should be addressed to improve pedestrian safety in order to make targeted modifications to the road design and the built environment.

## **2. LITERATURE REVIEW**

### **2.1 Significance of Problem**

Pedestrian-automobile crashes present a significant safety and public health concern in the United States. According to the US Department of Transportation (2012), twelve percent of all fatalities among road users involve pedestrians. The Center for Disease Control and Prevention (CDC 2010) has estimated that 80,000 to 120,000 pedestrians are injured in motor vehicle crashes in the United States each year. In high-income countries worldwide, pedestrians have a higher fatality rate per kilometer traveled than those who travel in a car (World Report on Road Traffic Injury Prevention 2004).

Pedestrians are extremely vulnerable to serious injuries when involved in an incident. In city traffic, pedestrians are the most vulnerable road users due to not being protected from vehicle impacts (Yang and Otte 2007). Pedestrians are 1.5 times more likely than passengers in an automobile to be killed in a car crash each trip (CDC 2010). In Britain, pedestrian injuries are twice as likely to be fatal as injuries to occupants of an automobile (Crandall et al. 2002). When an automobile hits a pedestrian at speeds

greater than forty miles per hour the fatality rate is eighty-five percent (Moudon et al. 2011). Chidester and Isenberg (2001)'s study found that only 3% of pedestrians involved in a crash were not injured.

Children and older adults are especially vulnerable to injury when hit by an automobile. Between 1997 and 2006, children made up twenty-three percent of pedestrian incident deaths and pedestrians over the age of seventy made up sixteen percent of deaths (Zegeer and Bushell 2012). In fact, one in four pedestrian incidents involving children are fatal (Kendrick 1993). Similarly, a study found that elderly persons had the highest mortality rate in pedestrian incidents (Peng and Bongard 1999).

The amount of pedestrian incidents in the Atlanta area has been increasing. Although pedestrian fatality rates declined in the United States from their levels in the 1990s, this decline was not felt in Atlanta (National Pedestrian Crash Report 2008). The four core counties of Atlanta (Gwinnett, Fulton, DeKalb, and Cobb) saw an increase in pedestrian fatalities between 2000 and 2004 (Beck et al. 2007). Although the reason for this trend is not certain, Beck et al. (2007) believes that the increase in pedestrian incidents may be due to an increase in developments of suburban sprawl and the rapid urbanization of Atlanta. In general, sprawled areas such as Atlanta are categorized as having higher pedestrian risk. This is potentially due to the large amount of multi-lane high speed roads which are dangerous to pedestrians (Paulozzi 2006; Beck et al. 2007).

Georgia as a whole has also shown a drastic increase in the percentage of pedestrian fatalities. In 2010 there were 168 pedestrian fatalities, which accounted for 13.5 percent of the 1,244 traffic fatalities (National Highway Traffic Safety Administration 2012). This is a drastic increase from a study done in 2000 when there were 146 pedestrian deaths with a total of 9 percent of all fatal incidents. According to the National Highway Traffic Safety Administration (2012), Georgia has 1.73 pedestrian fatalities per 100,000 people, which is higher than the national average of 1.38. This follows a larger trend showing that pedestrian fatalities rates are at a higher rate in Sun Belt states such as Georgia

(Paulozzi 2006). Paulozzi's study found that of the 14 states that fell into the highest quartile of incidents (greater than 1.83 per 100,000), ten were located along the Sun Belt (Paulozzi 2006).

## **2.2 Potential Influences of Pedestrian Incidents**

There are many different factors that potentially determine the frequency of pedestrian incidents. An understanding of what potentially affects pedestrian safety is necessary in order to increase safety. Factors that may potentially influence crash frequency include the design of the road network, the population demographics, the surrounding built environment, and the behavior of both drivers and pedestrians in an area.

Many roadway geometry and design features have been found to influence pedestrian incident frequency. One geometric change that can be made includes converting un-signalized intersections to roundabouts (Zegeer and Bushell 2012). Reducing roads to a single lane is a roadway design factor that can lower crash rates (Retting et al. 2003; Zeeger and Bushell 2012). It has also been found that creating paved shoulders helps to reduce pedestrian-crash rates (Thomson et al. 2006; Zeeger and Bushell 2012). The speed limit of a road also affects injury rates for pedestrians (Joly et al. 1991; Retting et al. 2003).

Two factors of road geometry that may have a negative effect on driver behavior are road curvature and road grade. One of the main reasons road curvature and road grade can potentially lead to incidents is that they have the ability to affect a driver's visual perception of the road which may lead to errors in judgment (Dragomanovits and Kanellaidis 2009). Both the vertical and the horizontal road curvature affect the sight distance of a driver and cause misleading visual cues that are dangerous (Staplin et al. 1997). Geometric factors such as horizontal and vertical curvature can affect overall sight distance, which could prevent one from seeing potential hazards.

Some studies have found that horizontal curvature can negatively affect driving behavior. This is because drivers often have trouble navigating through curved roads. This can be due to the driver not

giving a curvy road the proper attention, poor lane positioning, and misperception of speed (Charlton 2007). These factors make it more difficult to drive on a curved road than a straight one. A roadway's curvature also has been found to highly affect a driver's perception of safety (Kanellaidis et al. 2000). When guardrails are present on roads, studies have found that drivers slightly over correct for them in a right curve and under correct for them in a left curve (Ben-Bassat and Shinar 2011). These factors would suggest that driving around a horizontal curve is more dangerous than a straight road.

There has been limited research that mentions curvature potentially affecting pedestrian incident frequency, but there have not been many conclusive results. Retting et al. (2003) notes that an adjustment to a road's curvature is a potential measure that can be made to reduce pedestrian-vehicle crashes. Findings in a study on rural highways showed that pedestrian incidents are more common on parts of the road that are curvy (Hall et al. 2004). There have been no studies that have found how pedestrian incident frequency might be affected by curvature on urban or suburban roads.

Some studies have shown that a curvy road can lead to an elevated risk of an automobile incident. One reason for this is because there is a greater stopping distance on roads with bends than there is on straight roads (Sétra 2007). Abdel-Atyused and Radwan (2000) used negative binomial regression to look at incidents and found that the sharpness of a road's curvature had a positive effect on automobile crash rates. Joshua and Garber (1990)'s study found that the horizontal curvature was statistically related to the likelihood of truck incidents. Result have also found that there is a strong correlation between the radius of horizontal curves and frequency of incidents, because a small radius creates a sharp curve (Milton and Mannering 1998).

Other studies have shown that road curvature can act as a protective measure from automobile incidents. Joly et al. (1991)'s study of traffic incidents among children found that ninety percent of traffic incidents occurred on straight sections of road. Haynes et al. (2007)'s study found at a district scale in England and Wales that increasing the curvature of a road is a protective measure against

incidents. Jones et al. (2012) found that individual bends may potentially be hazardous, but if a road has many frequent bends, it might reduce automobile incidents. Another study found that long straight roads with a low amount of bending were more dangerous than gently winding roads with a bendiness of 40 degrees per kilometer (Fu et al. 2011). Anastasopoulos et al. (2008)'s findings on rural Tennessee roads reported that the higher degree of horizontal curvature the fewer the amount of incidents.

Although few conclusive results have been made on how pedestrian incident frequency is affected by road gradient, some studies have mentioned the impact it may have. DiMaggio and Durkin (2002)'s study of child pedestrian injuries in New York concluded that road gradient contributed to a few individual cases but the overall impact that this variable had was not certain. One study found that pedestrian incident rates on rural highways are higher in areas with sharp downgrades (Hall et al. 2004).

Steep road grades can lead to hazardous driving which may influence automobile incident frequency. Steeper road grades produce a variation in speeds between lighter vehicles and heavier vehicles. This variation produces the possibility of higher rear end and head on collision rates (Wong 2005). For example, it would take much longer for a large truck to slow down than a small compact vehicle. Because of the speed variations between lighter and heavy vehicles, higher queuing and overtaking rates occur on hilly roads (Wong 2005). These driving behaviors could potentially lead to dangerous traffic conditions. Hong et al. (2001)'s findings showed that small road slopes (maximum magnitude of 3 percent) were "large enough to cause significant errors in mass estimation of a passenger vehicle" (Hong et al. 2001: page 17).

Previous studies have shown that automobile incidents can be influenced by road grade. Fu et al.'s study (2011) found that road incident rate increases with vertical gradient exponentially. Gradients with lengths of two and three kilometers were found to have the highest correlation with incident rates (Fu et al. 2011). Chang (2005) found that severe uphill grades or descent grades on freeways increased incident likelihood and flat sections decrease incident likelihood. It was also found that severe hill grade

(greater than 3%) or descent grades increase the likelihood of incidents in mountain roads (Chang 2005). These findings mostly occurred on freeways and mountainous roads, so there is potential that these results may be much different in an urban setting. There is also the potential for the results to be different when pedestrian are involved in the incidents. The lack of information on how road gradient affects pedestrian-crash frequency is something that requires further study.

Gaps in the literature dealing with curvature and gradient's influence on pedestrian incident frequency demonstrate the need for further study. Although there has been extensive research on how gradient and curvature affects automobile incidents, how these factors affect incidents when pedestrians are involved is uncertain. In addition, many of the studies did not take place in urban or suburban areas but instead took place on major highways in rural areas. Further research to how curvature and slope affect pedestrian safety in an urban or suburban setting would be a valuable addition to current literature on the subject.

One factor that can determine the risk for pedestrian incidents is the volume of pedestrian traffic in an area. Pedestrian density is associated with increased frequency of walking which leads to an increased amount of pedestrians that can potentially be injured (Kuhlmann et al. 2009). The increased risk associated with higher pedestrian volumes explains why findings have shown that an increase in population density also leads to an increase in pedestrian incident rates (LaScala et al. 2000). Population density is a factor that influences pedestrian incidents because it can potentially act as a proxy for pedestrian traffic volumes (Dumbaugh and Li 2010). Other methods that have been used to measure pedestrian volume include total employment and the number of transit stops nearby (Miranda-Moreno et al. 2011).

Population demographics other than population density have also shown to potentially influence pedestrian incident rates. Pedestrian injuries have been found to be more common in areas with lower proportions of children ages 0-15 (LaScala et al. 2000). Areas with greater unemployment

and less educated residents were found to have higher rates of pedestrian-automobile crashes (LaScala et al. 2000). In addition, minorities have found to be more frequent victims in pedestrian-automobile incidents (Ryb et al. 2007). Finally, pedestrians who do not possess a driver's license are statistically more likely to be involved in a pedestrian incident (Ryb et al. 2007). One potential reason for the increased risk in these groups is that environment justice areas have a higher transit availability index which has been found to have a relationship to pedestrian incidents (Cottrill and Thakuria 2010). These results may also be due to lower-income areas having had less infrastructure investments and amenities available that would make walking safer (Ryb et al. 2007). The potential for the built environment to be influencing unequal distribution of pedestrian incidents reinforces the importance of better understanding which aspects of the built environment are dangerous.

The land use characteristics of an area may also be a predictor of the amount of pedestrian incidents that occur. Wedagama and Bird (2006) found that an increase in retail and community-driven land use led to an increase in pedestrian incidents. This is likely because land use that increases the population density will lead to an increase in pedestrian traffic (Miranda-Moreno et al. 2011). Ukkusuri et al. (2012) found that census tracts with a greater percentage of industrial, commercial, or open land use had more pedestrian incidents, while census tracts with more residential land use had fewer incidents. Miranda-Moreno et al. (2011) conclude that there is a complex relationship between dense land use and pedestrian incidents. Increasing density will lead to increased pedestrian incidents unless supplementary safety measures in the built environment also come with density increase (Miranda-Moreno et al. 2011). Further research into this subject would be beneficial to better understand the effect that land use has on incidents.

Land use characteristics typical of suburban sprawl have been found to be dangerous for pedestrians. Ewing et al. (2009)'s study found that urban sprawl is directly related to traffic fatalities and pedestrian fatalities. Each big box store present in area is associated with an 8.7% increase in



pedestrian incidents and strip commercial land use caused a 3% increase in pedestrian incidents (Dumbaugh and Li 2010). This was likely due to the fact that these types of land uses result in an increase in interaction between pedestrians and automobiles (Dumbaugh and Li 2010).

Having a large amount of walkable destinations is a potential predictor of pedestrian incident frequency. This is because the presence of certain common destinations may be determinants of higher pedestrian activity. These types of destinations can include retail destinations as well as public transit stops. Ukkusuri et al. (2012) found that greater numbers of subway stops in an area will lead to increased fatal pedestrian incidents. In addition to transit stations, the amount of nearby retail also influences pedestrian crash frequency. In their study of Washington State, Hess et al. (2004) found that for each increase of 100,000 square feet of retail, there was a 1.5 times greater chance of a pedestrian incident. These results provide some insight into potential locations where pedestrians might be most likely to get hit by an automobile.

The size of the road has an effect on how frequently pedestrian incidents occur. Joly et al. (1991) found that two thirds of incidents occurred in areas where traffic was moving in both directions. Gitelman et al. (2012)'s study of pedestrians echoed these findings when they discovered that 80% of sites in Israel with high amounts of pedestrian-automobile incidents were on multi-lane, high capacity urban roads. Indeed, it was found that each additional mile of arterial road was associated with a 9.3% increase in pedestrian-motor vehicle incidents in Dumbaugh and Li (2010)'s study of San Antonio-Bexar County in Texas.

Intoxication due to the consumption of drugs and alcohol may affect pedestrian incident frequency. Intoxication leads to increased incident rates and increased severity of injuries (LaScala et al. 2000). It was found that in Northern Sweden from 1977 to 1995 nineteen percent of pedestrian fatalities occurred when blood alcohol was detected in the victim (Öström and Eriksson 2001). In the United States, forty-six percent of pedestrian fatalities involved intoxication in either the driver or the

pedestrian that was hit (National Pedestrian Crash Report 2008). Although not as common as alcohol, victims of pedestrian-automobile crashes also may be under the influence of other drugs. A study of fatally injured drivers and pedestrians in Ontario found that alcohol was present in the victim at twice the rate as all other substances combined (Cimbura et al. 1980). The higher pedestrian-automobile crash rates occur because intoxicated pedestrians are more likely to act recklessly and cross the street in an unsafe manner such as crossing the street away from crosswalks (Dultz et al. 2011).

Crossing the street away from a crosswalk is a behavioral pattern in walkers that leads to an increase in incidents. Jaywalking can often be due to the need to save time or because of the lack of locations to safely cross the road on a person's walking route (Hess et al. 2004). The National Highway Traffic Safety Administration (2008) found that 27 percent of pedestrian deaths in the United States were due to pedestrians choosing to cross roadways improperly (LaScala et al. 2000). This is significant because many pedestrian incidents have been found to be at locations away from crosswalks. A study in Israel found that forty-nine percent of pedestrian fatalities occurred away from crosswalks (Gitelman et al. 2012). Dai (2012) found that crossing away from crosswalks, darting into traffic and playing or standing in the road were significantly higher risk factors for a pedestrian incident than crossing at crosswalks,

Distracted behavior by pedestrians increases their likelihood of being involved in a pedestrian-automobile incident. In a study on college campuses, Schwebel et al. (2012) found that pedestrians were more likely to be involved in an incident if they were listening to music, talking on the phone, or texting. This is because these tasks cause the person walking to pay less attention to the road (Schwebel et al. 2012). Another study (Bungum et al. 2005) showed that pedestrians distracted by activities such as talking on a phone, eating, listening to head phones or smoking are less likely to exhibit caution, to look both ways before crossing the street, and to enter a cross walk when there is a crossing signal

Conversely, pedestrians that exhibit cautious behavior are less likely to be involved in traffic incidents. Responsible pedestrians that give prompts to oncoming automobiles such as raised hands and extended arms lead to motor vehicles more frequently yielding (Crowley-Koch et al.2011). Looking both ways while crossing the street and not running when crossing the street are other types of behavior that increase pedestrian safety (Miller et al. 2004).

Urban design and safety measures that are implemented into the built environment can increase safety and decrease incident frequency. Having an adequate amount of lighting in an area can reduce pedestrian incidents because darkness increases a pedestrian's fatality risk sevenfold (Sullivan and Flannagan 2011). Traffic-calming interventions such as speed bumps, roundabouts and one way streets have been shown to reduce pedestrian injuries and fatalities (Quistberg et al. 2010). Having pedestrian countdown signals at cross-walks also leads to a decrease in pedestrian crashes (Pulugurtha et al. 2010). Engineering measures that separate pedestrians and vehicles such as overpasses and underpasses, sidewalks, and pedestrian islands also improve safety (Retting, et al. 2003).

### **3. RESEARCH QUESTIONS AND OBJECTIVES**

#### **3.1 Significance of Study**

As mentioned in the literature review, many aspects of the road network have been studied extensively for their influence on pedestrian incidents. However, road curvature and road grade's impacts on pedestrian incidents are still mostly uncertain. Multiple studies in the past have inquired about road curvature and road grade's impact on automobile aspects, but little research has been done about their impact on pedestrian incidents. In addition most of the research on road slopes and road curvature has not taken place in specifically urban areas.

Although previous studies have measured the impact of land use and the built environment on pedestrian incidents, the methods used in this study will allow for an increased understanding of how

the density of potential destinations that pedestrians frequent might affect incident frequency. Instead of using variables such as land cover data, this study will present count data on the amount of specific points located nearby. This will allow for a better idea of how the density of stores/restaurants, bus stops, and bars might affect pedestrian incidents frequency.

The potential benefits for this research include:

- An increased understanding of road curvature and road grade's impact on the incident frequency between pedestrians and automobiles.
- An increased understanding on how the built environment affects pedestrian incidents along major roads.
- The creation of a method that will allow one to use GIS to measure these factors.
- Potential insights on how to design roads and neighborhoods to limit the amount of incidents between pedestrians and automobiles.
- Understanding of where the hotspots of pedestrian incidents are located within DeKalb County, Georgia.
- An understanding of the characteristics of the road network and built environment at pedestrian incident hotspots in DeKalb County.

### **3.2 Research Questions**

This study aimed to investigate the relationship between pedestrian incident frequency and the characteristics of the road network and the surrounding built environment. A pedestrian incident can be defined as an event where an automobile hit a pedestrian. The project achieves these goals through the use of Geographic Information Science, regression analysis and hotspot analysis.

The two aspects of the road network's geometry that will be studied include the road's slope and the road's curvature. The aspects of the built environment that will be studied include the

population density of the block group surrounding each road segment, the amount of bars within .8047 kilometers of the road segment, the amount of commercial destinations within a half mile of the road segment, and the amount of transit stops within .8047 kilometers (i.e, 0.5 miles) of the road segment. This research took place within DeKalb County, Georgia from 2000 to 2007. The main questions that will be addressed in this study are “How can Geographic Information Science be used to adequately measure these variables?”, and “How can regression analysis determine whether or not these features have statistically significant influence on pedestrian incidents?”

In addition, this study attempts to understand how analysis of hotspots of pedestrian can help identify characteristics of the road environment and the built environment that are dangerous. The study will investigate how GIS can help identify the locations of pedestrian hotspots in DeKalb County.

## **4. METHODOLOGY**

### **4.1 Study Area**

The area that was chosen for this research is one of the major counties in the Atlanta Metropolitan Area: DeKalb County. As of the 2010 census, the population of the county is 691,893. It is a predominantly urban county. It contains part of the city of Atlanta as well as the cities of Avondale Estates, Decatur, Doraville, Chamblee, Clarkston, Pine Lake, Dunwoody, Doraville, Lithonia, Tucker, and Stone Mountain. A map of the location of DeKalb County can be seen in Figure 1.

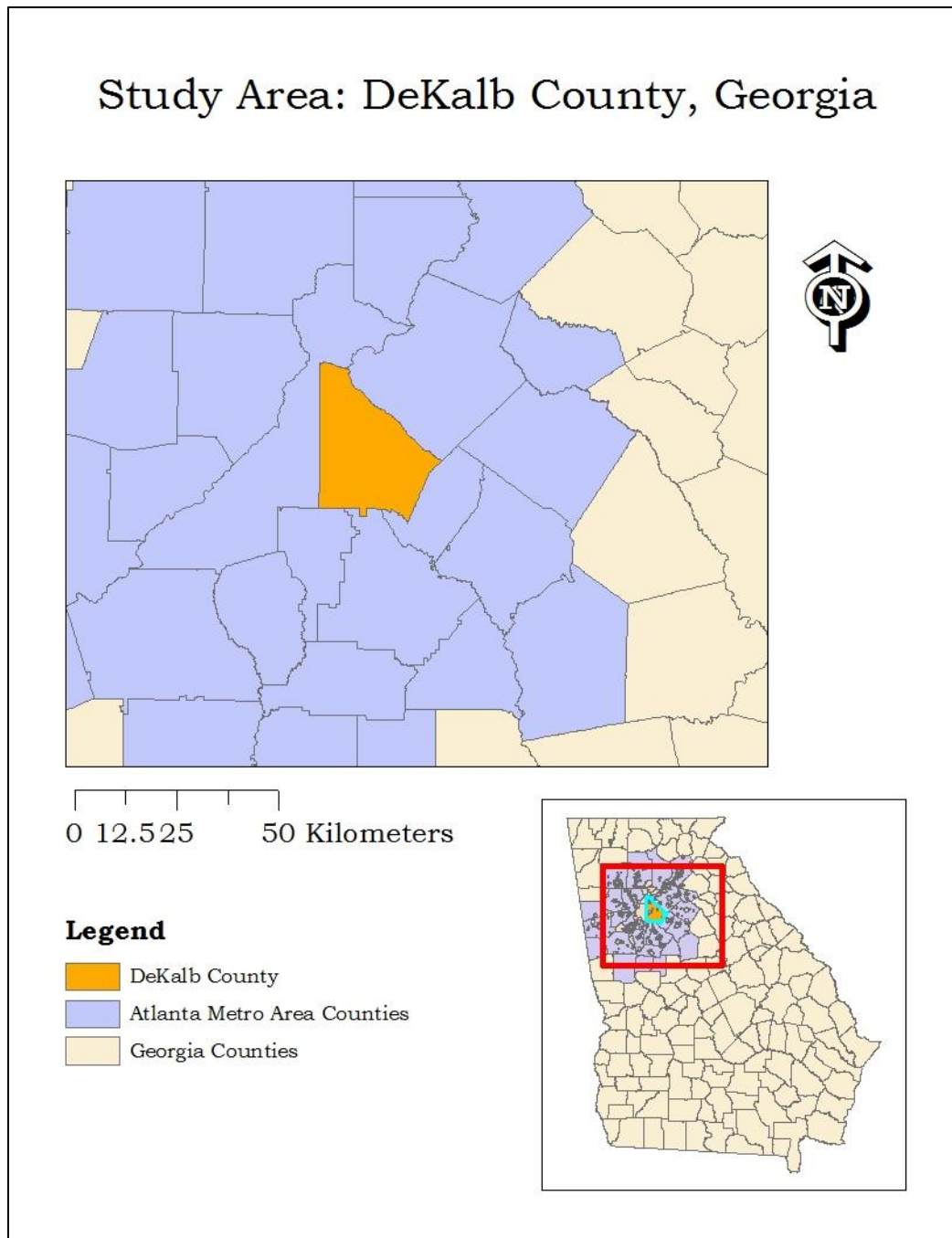


Figure 1 Map of Study Area

The road network studied included all of the major roads in DeKalb County, Georgia. The classification of major roads is designated by the Georgia Department of Transportation (GDOT) and includes major city streets, county roads and state highways. Major roads do not include interstate

highways as there is no pedestrian traffic on these roads. In total, 89 major roads were used in this study.

DeKalb County was chosen for multiple reasons. First, it contains a high volume of pedestrian incidents, which will allow for the study to have a large sample size. Dai (2012) found that there existed spatiotemporal clustering of pedestrian crashes in part of DeKalb County on Buford Highway. Out of all the counties that make up the Atlanta Metro area, the four most populous counties: Cobb, Fulton, DeKalb, and Gwinnett had pedestrian incident rates nearly twice that of other surrounding counties (Beck, Paulozzi, and Davidson 2007). Second, it contains areas with a large degree of elevation change. This allowed a better understanding of how hilly roads might affect pedestrian incidents. These hilly roads will provide a large enough variety in the sample size of road gradients to adequately measure road grade. Finally, unlike the other major counties of Atlanta, the built environment in DeKalb County is much more uniform and has a higher proportion of people who walk. For example, Fulton County has a diverse built environment that includes dense urban areas in downtown Atlanta, rural farmland in the southern part of the county and large stretches of suburban land in the northern part of the county. Most of the rest of the counties in Atlanta also are completely car dominated suburban areas which would result in less data to study the interaction between pedestrians and automobiles. DeKalb County on the other hand has many pedestrians and people who use transit.

#### **4.2 Data Sources**

Pedestrian incident data was acquired from the GDOT. The pedestrian incident data contains point data of every incident from the beginning of 2000 to the end of 2007. Incident data provides point locations of all pedestrian incidents during that time period as well as descriptive data about the nature of the incident.

Major roads in DeKalb County used to study road geometry variables were obtained from the Atlanta Regional Commission (<http://www.atlantaregional.com/info-center/gis-data-maps>). Roads used

for this study are only the major roads in DeKalb County. Population density for Census Block Groups was also obtained from the Atlanta Regional Commission. The Atlanta Regional Commission compiled population data from the US 2000 Census for the Atlanta metro area. The 2000 Census was used instead of the 2010 census because the study period starts in the year 2000 and ends in the year 2007.

Locations of bus stops were taken from the Atlanta Regional Commission. Each bus stop location is a specific point feature in GIS. All of the bus stops located in DeKalb County are part of the Metropolitan Atlanta Rapid Transit Authority (MARTA) system.

Elevation data needed to quantify road grade was obtained from the USGS National Elevation Data set (<http://ned.usgs.gov/>). The USGS National Elevation Data set presents data in 1/9 Arc Second resolution (3 meters). The National Elevation Dataset data is from the year 2009. The 1/9 Arc Second High Resolution data was obtained from LIDAR and digital photogrammetry (Evans 2012). The vertical accuracy of the data expressed as the root mean square error (RMSE) is 2.44 meters for USGS NED data (Evans 2012).

Point data that is used for determining the count data for commercial destination buffers was gathered from the Reference USA Database (<http://www.referenceusa.com>). The Reference USA database provides the name, address, and type of business for each location. A point was classified as a commercial location in this study if it was under one of the following categories in the Reference USA database: Food Stores, Restaurant, or Retail. Locations of all bars within DeKalb County were also taken from the Reference USA database. A point was classified as a bar in this study if it was located under the "Drinking Places" category in the Reference USA database.

### **4.3 Methods:**

To test if road curvature, road slope, population density, and proximity to walking destinations affected the amount of pedestrian incidents in DeKalb County, a combination of hotspot and regression analysis was used. Hotspot analysis was completed on the locations with the highest pedestrian incident



frequency to determine their characteristics. In the regression analysis, each of the independent variables was applied to 50, 100, and 150 meter road segments. Only major roads were selected so that the traffic volumes and road conditions of the study were mostly uniform.

#### **4.3.1 Kernel Density Mapping**

In order to illustrate the locations with the highest pedestrian-automobile crash frequency, Kernel Density Mapping was performed. Kernel Density Estimation (KDE) involves creating a surface that calculates the density of events within a search area (Truong and Somenahalli 2011). Previous studies of pedestrian incidents hotspots have used KDE to identify hotspot locations. (Schuurman et al. 2009; Thomas et al. 2009). In a study of pedestrian crashes in Vancouver, Schuurman et al. (2009) found that Kernel Density Mapping was an effective tool for both illustrating and locating incident hotspots.

Because typical planar Kernel Density Mapping does not effectively map on roads, a Network Kernel Density Method was used. The major problem with using planar Kernel Density is that pedestrian-automobile crashes take place on a road network, while planar KDE hotspots creates a surface over the entire study area (Truong and Somenahalli 2011). This causes planar KDE to create estimations in locations where streets are not present (Dai et al. 2010). Because of this, studies have found that a model that determines that Kernel Density over a network space is more accurate (Truong and Somenahalli 2011).

Network Kernel Density Mapping was completed in order to identify areas with highest pedestrian incident frequency. The Network Kernel Density was completed using the Kernel Density Estimation tool from the SANET toolbox version 4.1 Beta for ArcGIS 10 (Okabe et al. 2012). This tool estimates the density of points located on a network. A search radius of 100 meters was chosen because it has been found to be an accurate distance to highlight individual incidents (Dai et al. 2010; Schuurman et al. 2009). The cell size for the study was 3 meters.

#### **4.3.2 Identification of Pedestrian Hotspots**

The results of the Kernel Density Mapping were used to identify ten hot spots of pedestrian incidents in DeKalb County. The locations of the hotspots were based on the pedestrian crash density values from the Network KDE analysis. The locations with the ten highest pedestrian crash density values were selected as hotspots that would be further analyzed.

#### **4.3.3 Analysis of Pedestrian Hotspots**

An environmental scan of the hotspot locations was completed for the ten hotspots. This scan was performed in order to compare the regression results with the environmental features of each of the hotspots at the street level. The analysis of hotspots was based on the methods used in a pedestrian environment audit. This method involved scanning elements of the built environment in respect to pedestrian activity and recording findings using a pen and paper (Clifton et al. 2007).

The factors assessed in the environmental audit of hotspots included all of the values measured in the regression analysis. The road for each hotspot was analyzed to determine whether it was straight, had a slight curve, or was a curvy road. The elevation of the road was examined to determine whether it was flat, had a slight hill, or was hilly. The hotspot was scanned to see how many bus stops were located within sight distance. The hotspot was also examined to see if there were any stores and restaurants or bars located within sight distance. In addition, the housing characteristics nearby were assessed. Housing characteristics were examined because they provided a variable that could be compared with population density. If apartment complexes or single family homes were located within sight distance of a hotspot, then they were noted.

In addition to the variables measured in the regression analysis, factors dealing with road design were also analyzed at each hotspot. Pedestrian safety measures including medians, crosswalks and sidewalks were measured. Finally, the speed limit and the number of lanes for each hot spot were measured. Pictures of each hotspot location were taken to provide visual evidence illustrating the

environment of the hotspot. In addition, satellite imagery by Bing Maps ([www.bing.com/maps](http://www.bing.com/maps)) in ArcGIS was used to provide an aerial view of each hotspot.

#### **4.3.4 Hotspot Pedestrian Counts**

Pedestrian counts were completed in order to estimate the amount of pedestrian traffic at each hotspot. It has been found that pedestrian counts are a simple, inexpensive, and easily replicable way to measure the volume of pedestrian traffic at a location (Emmons 1965; Harding and Powell 2011). The combination of the pedestrian traffic counts and the nearby housing audits were used to compare the results at individual hotspots with the population density in the regression analysis.

In order to measure pedestrian traffic levels in hotspots, pedestrian counts were performed. Pedestrian counts were done for ten minutes at each hot spot location. The time of pedestrian counts was based on Lindsey and Lindsey (2004)'s findings which showed ten minutes to produce accurate estimations of pedestrian traffic levels. Pedestrian counts were done manually with a sheet of paper. The total amount of people that were observed walking in a hotspot location was used as the pedestrian count value. All pedestrian counts took place between 2 and 5 PM on weekday afternoons.

#### **4.3.5 Road Segment Division**

To create a model that revealed the relationship between pedestrian incidents and the independent variables being tested at a high resolution, major roads in DeKalb County were broken up into 50, 100, and 150 meter segments. These distances for the road segments were chosen because they allowed one to better account for how aspects of the road network and its built environment potentially affected an individual incident event. If segment sizes were too large then there was the possibility that the features of the road network that were far away from a crash would be shown as having an impact. Three different segment lengths were chosen to determine how differing segment

sizes may influence the results. The roads were divided into segments using the polyline dicer tool in ArcGIS.

#### **4.3.6 *Joining Pedestrian Incident Data to Road Segments***

Every pedestrian incident location within DeKalb County was joined to the 50, 100 or 150 meter road segment that it fell in. This allowed for each road segment to have a pedestrian incident count value which was used as the dependent variable in the regression model. Pedestrian incident points were joined to road network polylines in ArcGIS by using the Spatial Join tool in the ArcToolbox.

#### **4.3.7 *Measuring Curvature***

Previous studies on road curvature and automobile incidents have identified multiple methods to measure curvature in GIS. The first way of measuring curvature is a method called the “bend density”. This method is completed by calculating the number of vertices that are not nodes and dividing it by the total length of the road segment (Haynes et al. 2007; Jones et al. 2012). Bends are defined as the number of changes in road direction that don't include junctions. The major problem with this method is that one cannot accurately account for how sharp each of the bends taking places actually is. A line segment could have many minor bends that makes it seem like the road is very curvy when it actually it is not.

The second curvature measurement method is the “detour ratio”. This is calculated by taking the ratio between the length of a road segment and the straight line distance between the start and end points of the road segment (Haynes et al. 2007). Jones et al. (2008) used the detour ratio to look at every road section between two junctions. Junctions were defined as nodes in GIS. Roads were selected and the road distance and straight line distance were measured. The sum of the total distance between junctions and the sum of the total distance of straight lines was compared (Jones et al. 2008). A potential limitation is that if used on longer sections of road, one may not be able to accurately capture

the geometry of the road. For example, a section of road could have a very high detour ratio but only part of the road segment might actually be curvy. One half of the road section may be straight and one half may be extremely curvy, but the detour ratio simply shows it as having a high curvature value.

The third calculation is the “straightness index”. This method attempts to capture locations of long straight sections of a road in a road network. The “straightness index” method was used in Jones et al. (2008)’s study in order to measure the frequency of long straight stretches in road. Road arcs with a detour ratio of 1.0 were selected and their total length was divided by the total length of all road arcs in a district. Haynes et al. (2008)’s study in New Zealand did not find this method adequate to measure curvature. This was due to large stretches of rural roads in the study which were often misidentified as having low scores on the straightness index even though visual inspection suggested otherwise (Haynes et al. 2008). This method may be considered valuable for looking at curvature in an area wide scale. Because this method is intended for use over large areas of road in district level studies, it is not as valuable for looking at curvature for individual road segments. In addition, Haynes et al. (2008)'s findings that showed it misrepresenting a road network make it seem like not the best choice for curvature measurement.

Cumulative angle index measures the total angle difference of a road per kilometer along a stretch of road. All changes in direction along a road are calculated as angles in degrees. The sum of every angle was then divided by the road length (Haynes et al. 2007). In Fröhlich and Fonfara (2004)'s assessment, cumulative angle index is measured by taking each vertex on a polyline and measuring the total angle between them. The sum of the angle difference between the points is calculated and added together (Fröhlich and Fonfara 2004). In Jones et al. (2008)’s study, cumulative angle per kilometer was compared to the roads in each district. The sum of all the angles was divided by the road length (Jones et al. 2008). This method is potentially valuable but the main issue is difficulty of calculating angle in ArcGIS because there are no add-ons available that compute this measurement.

The method chosen to measure road curvature in this study is the “detour ratio”. The detour ratio was selected because it is a superior method for measuring curvature for road segments in GIS compared to the bend density and the straightness index. Although there may potentially be limitations dealing with detour ratio, these limitations only apply to longer road segments. With 150 meters as the longest segment length being tested, this was not as big of an issue in this study.

This curvature method was completed using ArcGIS 10.0. For each separate line segment, the detour ratio was calculated by determining the ratio between the network distance of the line and the Euclidean distance. The Euclidean distance was obtained by taking the distance between XY coordinates of the start of each line and the XY coordinates of the end of each line. The Euclidean distance was calculated in ArcGIS in the Field Calculator using the following formula

$$\sqrt{(x_1 - x_2)^2 - (y_1 - y_2)^2}$$

Where  $x_1$  value is the coordinates for the start of the line on the x axis, the  $x_2$  value is the coordinates for the end of the line on the x axis, the  $y_1$  value is the coordinates for the start of the line on the y axis and the  $y_2$  is the coordinates for the end of the line on the y axis.

The higher the detour ratio value a line segment had, the higher the degree of curvature it had. For example, roads that are perfectly straight had a detour ratio of 1.00 because the network distance is equal to the Euclidean distance. An example illustrating two curvature values for road segments can be seen in Figure 2 and 3.



Figure 2 Road with a Curvature Value of 1.0



Figure 3 Road with Curvature Value of 1.006473

#### **4.3.8 Measuring Road Slope**

A method that has been used to map the gradient of a road is mapping the elevation contours and attaching the contour data to the road. Wong (2005)'s study involved mapping contours on a road and then calculating the change in elevation of the road as it passed through each individual contour. The formula for the road grade calculation was the change in elevation divided by the distance multiplied by 100 (Wong 2005). A potential disadvantage with this method is that acquiring contour data that has enough vertical accuracy to be able to show the difference in slope on a road over a short distance would be difficult.

Data from remotely sensed imagery such as LIDAR has also been used to determine the grade of roads. Smadi (2004) used LIDAR imagery to determine the slope of the study area, and then selected



only the pixels that were located on the road. Zhang and Frey also used LIDAR imagery to determine road grade (Zhang and Frey 2006). They then used an ArcObject macro to place LIDAR points on the road network. The formula used a buffer around the road network line based on the width of the road and then placed DEM points onto the road network (Zhang and Frey 2006).

After reviewing previous methods of measuring slope on road networks, using a digital elevation model that obtains its data from remotely sensed imagery appears to be the ideal method. Based on the results in previous studies, this method seems ideal because the points can be easily joined to the road network and they will be accurate as long as the vertical accuracy for the elevation dataset is high enough.

GIS was used to calculate the gradient of the road network. Mapping slope values on each road segment were done using ArcGIS 10.0. Using USGS elevation data, the slope values of the entire DeKalb County area were mapped. This was done using the "Slope" tool found in ArcToolBox in ArcGIS. This tool determined the slope value in degrees for each pixel in the study area. A three meter buffer was then placed around each road segment feature. Using the Zonal Statistics as table tool in the Arc Toolbox in ArcGIS, the standard deviation of the slope value of every pixel along each road segment was calculated. Using the standard deviation allowed for an accurate representation of what the general gradient of the road is along each road segment. It accounted for any road segments that potentially may have a sharp slope in one part of the segment while being relatively flat in another section. Standard Deviation of the slope also allows one to see the overall degree of changes in slope that occurred, which was thought to potentially affect the ability of a driver to navigate the road safely.

#### **4.3.9 Test of Elevation Data**

In order to determine if the digital elevation model that was used in this study had accurate data, the DEM values were compared to the elevation obtained from a GPS device. Sixteen GPS points

were taken in the study area in DeKalb Count. The elevation data from the GPS device was then compared to determine if the DEM was accurate.

#### **4.3.10 *Density of Surrounding Stores and Restaurants***

The amount of surrounding business and retail locations were determined using a buffer. This excluded bars, clubs and drinking locations, which were assessed separately. Using this variable is valuable because it can be used both as a proxy for commercial land use in an area, and to measure the amount of destinations that a person would frequently walk to. Point locations for each commercial business were added to the map by geocoding the address locations provided by Reference USA using ArcGIS 10. After every point was geocoded, the amount of commercial business locations that were within a .8047 kilometer (half-mile) buffer zone around each road segment was determined. This was done by using the “Spatial Join” tool in ArcTool Box and setting the join distance to .8047 meters. This distance was chosen because of literature citing a half-mile as a reasonable walking distance for most people (Cervero 1995). The overall count value of the number of businesses was used as an independent variable. This determined if the number of businesses within walking distance of a road segment affected the amount of pedestrian incidents on a segment.

#### **4.3.11 *Density of Surrounding Bars***

Similar to the number of retail locations, a count value of bars located within .8047 kilometers of each road segment was determined. This factor was assessed due to the literature explaining the potential for alcohol consumption to cause pedestrian incidents (Öström and Eriksson 2001; Dultz et al. 2011). An example illustrating the buffering technique can be seen in Figure 4.

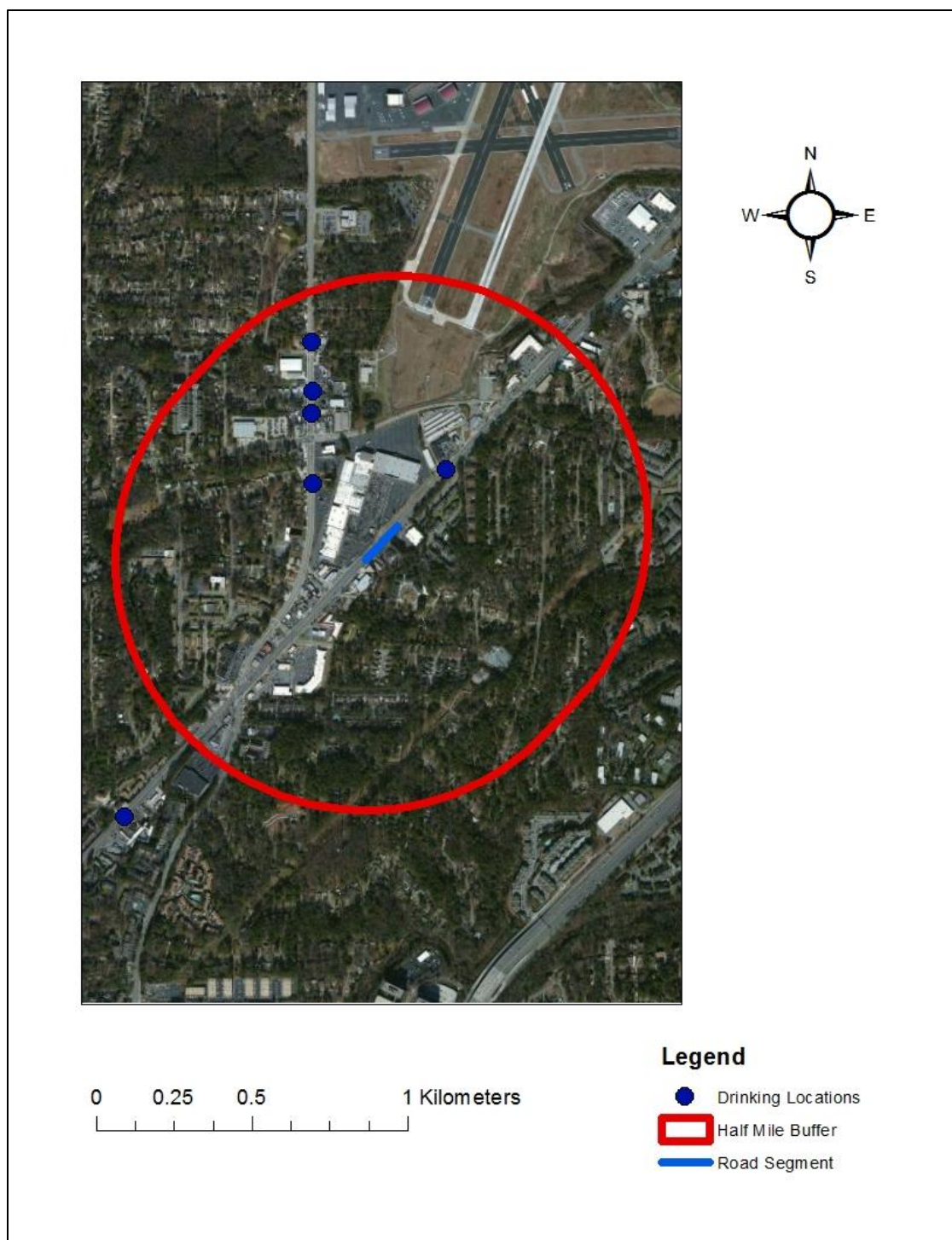


Figure 4 Example of Buffer Method used for Bars

#### **4.3.12 Density of Surrounding Bus Stops**

The final land use points that were tested to see if they affected the amount of pedestrian incidents were the amount of bus stops located near each segment. As mentioned in the literature review, an increased amount of transit may lead to increased amounts of pedestrian incidents (Miranda-Moreno et al. 2011; Cottrill and Thakuria 2010). Once again a .8047 kilometer buffer value was used around each bus stop.

#### **4.3.13 Measuring Population Density**

Finally, population density was also tested to see if it affected the amount of pedestrian incidents. Population density was used because it can potentially be seen as a determinant for pedestrian activity. The population density was taken from the 2000 Census at the Census Block Group Level. The population density value of the census block groups that bordered the road segment were assigned as the value. Population Density was calculated by finding the total population per acre for each census block. If multiple census block groups bordered a road segment then the mean value of the census blocks were taken. Data for Census Block Group was added using the Spatial Join function in ArcGIS 10.

#### **4.3.14 Omission of Road Segments**

Some road segments within the study area had to be omitted from the model. Because elevation data was taken from the National Elevation Dataset which is a digital elevation model, the slopes of roads were not accurate for locations that were on bridges. This is because the method of gathering the slope takes the elevation of the ground and not the elevation of the elevated road. For this reason, all road segments that were located on, or partially on, bridges were omitted from the study. The bridge data was taken from the Georgia GIS Clearinghouse (<https://data.georgiaspatial.org/>).

The data was created by the State Base Map of Georgia. There were 533 bridges in total located in DeKalb County, Georgia.

Because the roads were broken up into segments based on distances, there were some segments that were smaller than the given segment length. Segments that were located at the end of each individual road were often a value smaller than the segment size used for the study. To determine the effect that each variable was having on pedestrian incidents, it may be valuable to have each segment be the exact same length. Because of this, the models were run twice. The first time the model was run, all road segments that were smaller than the given segment length for the regression model (50, 100, or 150) were omitted. This method resulted in a small under-sampling of road segments near intersections as these locations often are located at the ends of roads. The second time the regression model was run, every road segment was included.

#### **4.3.15 Quartiles**

In addition to regression analysis, the results for each individual variable were divided up into quartiles. This was done in order to better understand how an increase in value for each independent variable affected pedestrian incident count values. Incident rates per road segment were taken at four percentile levels. For example the lowest twenty five percent of curvature values were the first quartile and the incident rate for this level was taken. It was then compared with each subsequent level. Quartile analysis was done for 50, 100, and 150 meter segments.

#### **4.3.16 Regression Analysis**

When modeling pedestrian and automobile incidents the most common regression models use are the Poisson and/or Negative Binomial regression models. These models are often used because crash data typically is not normally distributed and has large amounts of zeros which results in a long tail (Lord and Geedipally 2011). This is because in studies of crash events, in the vast majority of locations

there are zero incidents (Lord and Geedipally 2011). Shankar et al. (1995) demonstrates that multiple researchers have found the Poisson Regression and Negative Binomial model to be valuable in modeling incident frequency. The Poisson regression is:

$$Prob(n_i) = \frac{\lambda_i^{n_i} \exp(-\lambda_i)}{n_i!}$$

$$\lambda_i = \exp(\beta x_i)$$

Where  $n_i$  is the amount of pedestrian incidents on a road segment  $i$ .  $\lambda_i$  is the expected mean number of pedestrian incidents.  $x$  represents all of the independent variables for road segment  $i$ .  $\beta$  represents the parameter to be estimated (Hashimoto 2005).

Typically, the flaw with the Poisson Regression is that it assumes that the variance of events equals the mean. This often results in overdispersion where the variance is greater than the mean (Miaou and Lum 1993). In the case of vehicle incidents the results usually tend to be over-dispersed (Chang 2005). Miaou and Lum (1993) noted multiple factors that may cause over-dispersion in incident models including omitted variables, sampling errors, and non-homogenous study areas. If overdispersion occurs, then typically negative binomial regression will then be used. Negative binomial regression allows for the variance to exceed the value of the mean (Miaou & Lum, 1993). The negative binomial regression model specifies that:

$$\lambda_i = \exp(\beta x_i + \varepsilon_i)$$

Where  $\lambda_i$  is the expected mean amount of pedestrian incidents on road segment.  $\beta$  is the parameter to be estimated.  $x_i$  represents the independent variables for road section  $i$ .  $\varepsilon_i$  is the error term (Hashimoto 2005). This results in the probability distribution as.

$$Prob\left(\frac{n_i}{\varepsilon}\right) = \frac{\exp[-\lambda_i \exp(\varepsilon_i)] [\lambda_i \exp(\varepsilon_i)]^{n_i}}{n_i!}$$

These methods were used because the data being analyzed were incident count data that were not normally distributed. The regression analysis was performed using SPSS software. The dependent

variable in this model was the number of pedestrian incidents per road segment. This was derived using the count data of pedestrian incidents from the years 2000 to 2007.

#### **4.3.17 Test for Overdispersion**

The variables were tested for overdispersion in order to determine if negative binomial regression should be used. Because Poisson regression cannot be used if the variable is overdispersed, the dependent variable had to be tested. If overdispersion existed due to the variance being greater than the mean, then negative binomial regression was performed.

#### **4.3.18 Multicollinearity Test**

A test was done in order to make sure that multicollinearity did not exist between the independent variables. Multicollinearity is an issue that occurs when an independent variable is highly correlated with one or more other independent variables (Blalock 1963). The Variance Inflation Factor (VIF) statistic is calculated in order to detect if multicollinearity exists. It has been found that if the VIF is greater than 10 then significant multicollinearity exists (Meyers et al. 2005). Multicollinearity is also possible if the tolerance value of less than .1 (Meyers et al. 2005).

Multicollinearity testing was calculated using SPSS by running separate regression analysis for each individual independent variable. In the regression model the predictor variable became the dependent variable. Each variable was predicted by the remaining independent variables. The VIF and tolerance value for each independent variable was then calculated to determine if multicollinearity existed.

## 5. RESULTS

### 5.1 Pedestrian Incident Statistics

A total of 1,047 incidents took place along major roads in DeKalb County between 2000 and 2007. Demographics and statistics detailing those involved in pedestrian incidents, as well the conditions at the time of the incident, can be seen in Figure 5 and Tables 1, 2, 3, and 4

Table 1 Pedestrian Incidents and Road Condition

Road Condition	Icy	Rainy	Snowy	Clear	Other
Number of Incidents	3	155	2	885	1

Table 2 Pedestrian Injury Severity on DeKalb County Major Road

Pedestrian Injury Type	Not Injured	Compliant	Visibly Injured	Seriously Injured	Fatally Injured
Number of Incidents	90	351	394	138	74

Table 3 Pedestrian Incident Victims by Gender

Gender	Male	Female
Number of Incidents	675	372

Table 4 Pedestrian Incidents and Light Condition

Light Condition	Daylight	Dusk	Dawn	Dark-Lighted	Dark- Not Lighted
Number of Incidents	525	20	20	306	176



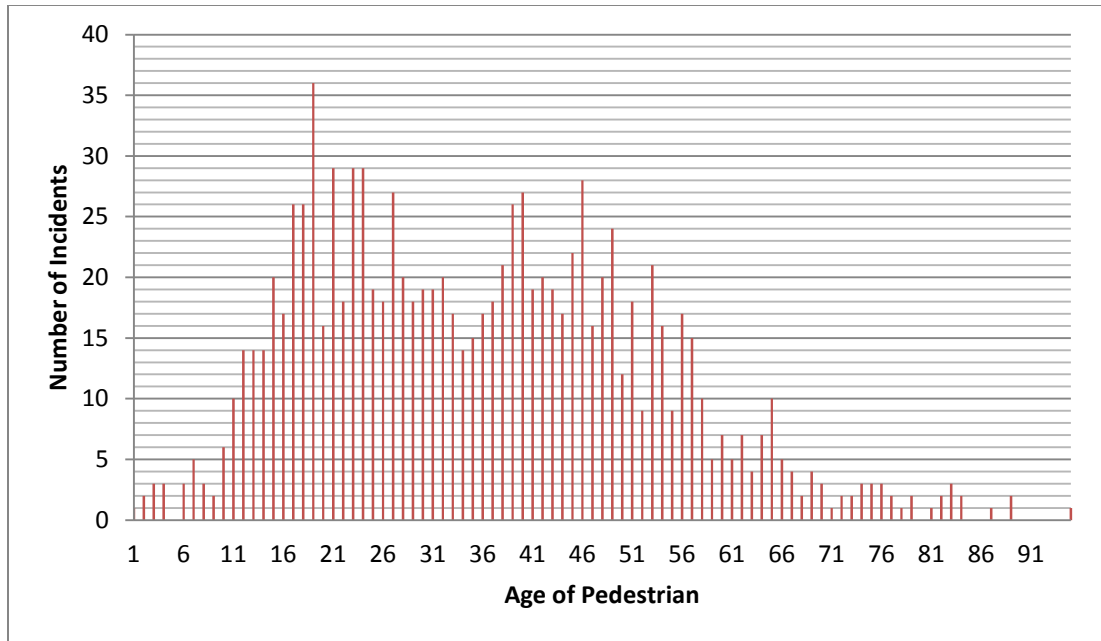


Figure 5 Pedestrian Incidents by Age

## 5.2 Kernel Density Results

The network KDE results found that incidents were the most common in certain areas of the county. There were many pedestrian incidents located along Buford Highway between the intersections of North Druid Hills Road and Clairmont Road. Pedestrian incident volumes were high along Candler Road near the intersection of Rainbow Drive as well as near the intersections with Flat Shoals Parkway and Panthersville Road. Pedestrian incidents were common on Glenwood Road between Covington Highway and Candler Road. Finally, incidents were also common on Buford Highway near the intersections with Shallowford Road and Chamblee-Dunwoody Road.

Meanwhile, certain areas of the county had minimal amounts of pedestrian incidents. The eastern section of the county had very small incident count numbers. The southeast and northern sections of the county also contained lower amounts of pedestrian incidents. A map showing the Kernel Density distribution of pedestrian incidents can be seen in Figure 6.

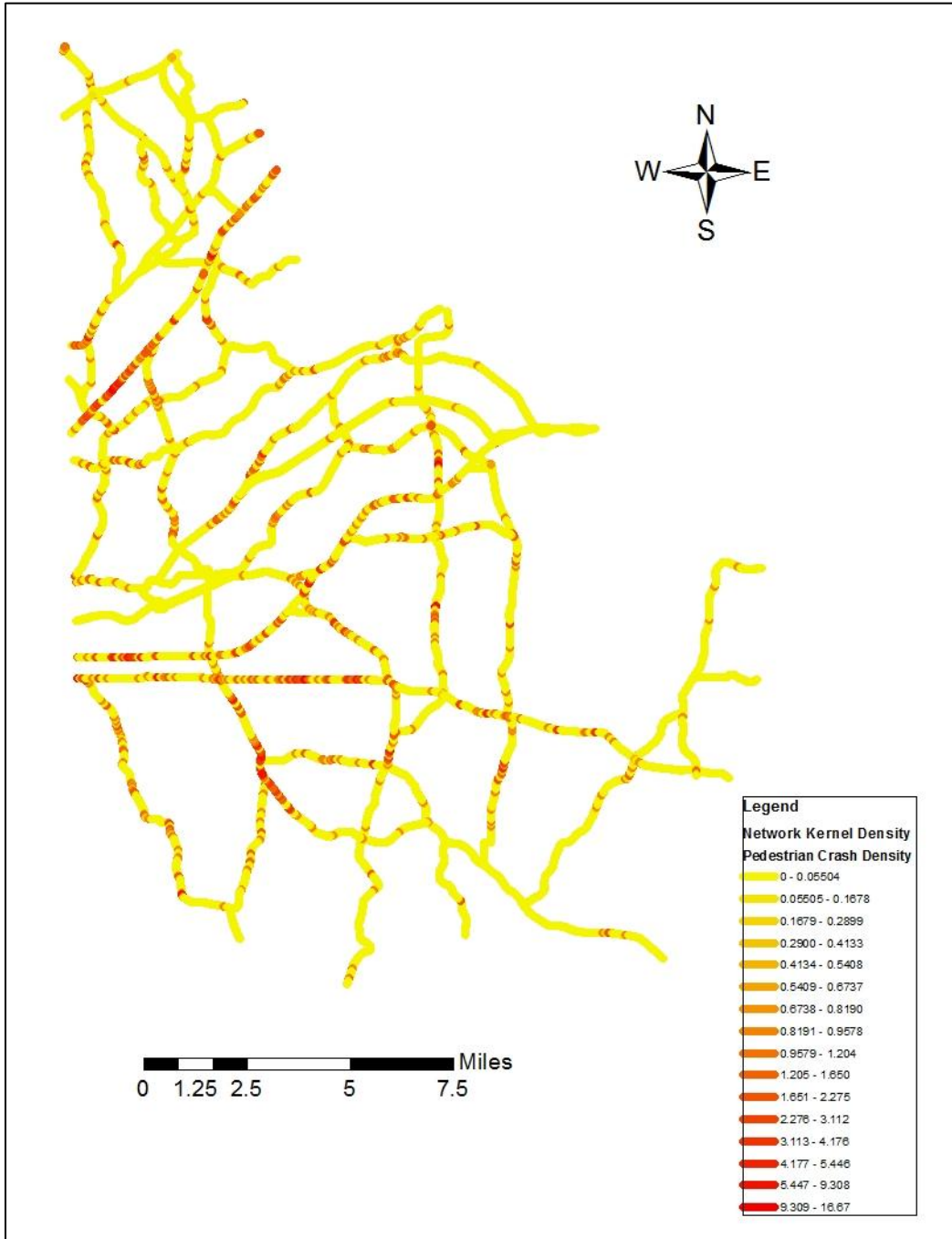


Figure 6 Network Kernel Density Map of Pedestrian Incidents

### 5.3 Hotspot Selection

The locations with the ten highest Network Kernel Density values from the analysis with 100 meter bands and 3 meter cells were used for the hotspot analysis. All ten locations that were used in the

hotspot analysis had a Pedestrian Crash Density from the analysis greater than 7. A section of Buford Highway at the intersection of Cliff Valley Way had the highest Pedestrian Crash density with a value of 16.721. The segment with the second highest Pedestrian Crash Density was located on Glenwood Avenue near the intersection of Brownwood Park Road. This hotspot had a Crash Density of 13.0429. A map showing the locations of the ten hotspots can be seen in Figure 7. A chart showing details on the ten hotspots can be seen in Table 5.

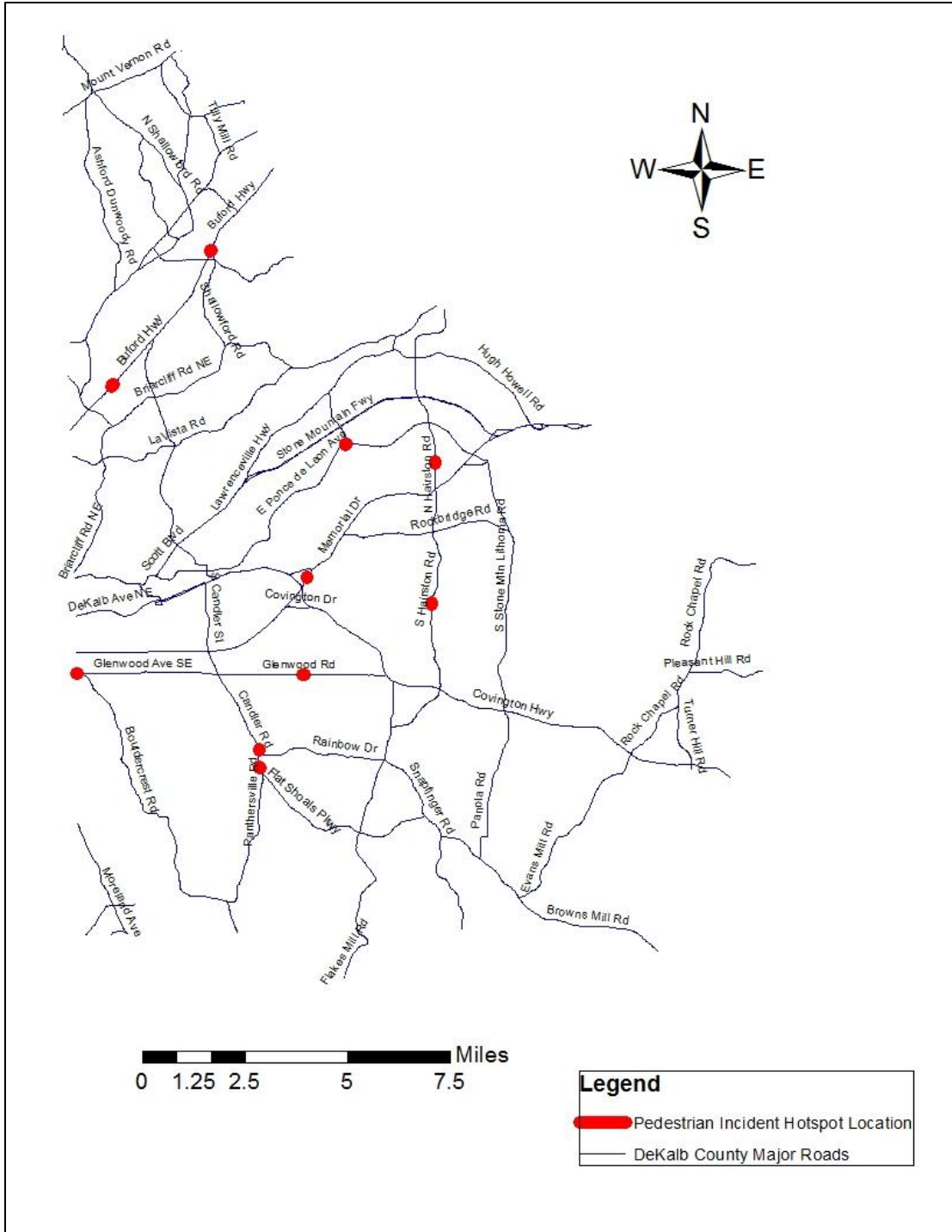


Figure 7 Hotspot Locations

Table 5 Hotspots Selected for Analysis

Hotspot Number	Road	Pedestrian Crash Density	Coordinates	Nearest Cross Street
1	Buford Highway	16.6721	33.842168,- 84.329644	Cliff Valley Way
2	Glenwood Avenue	13.0429	33.74019,- 84.347819	Brownwood Park Avenue
3	North Hairston Road	11.9754	33.811824,- 84.193721	Central Drive
4	Glenwood Rd	10.4799	33.737936,- 84.251757	Columbia Drive
5	South Hairston Road	9.6781	33.761966,- 84.196543	Redan Road
6	Buford Hwy	8.1051	33.888734,- 84.286541	Chamblee-Dunwoody Road
7	Memorial Drive	8.097175	33.771601,- 84.249742	Kensington Road
8	E Ponce de Leon Ave	7.877169	33.819013,- 84.230768	Brockett Road
9	Candler Rd	7.8286	33.711769,- 84.271652	HF Shepard Road
10	Candler Rd	7.3773	33.705383,- 84.271448	Flat Shoals Road

#### 5.4 Hotspot Analysis

The results for the hotspot analysis found a wide variety of characteristics at each of ten hotspots.

The results for the hotspot analysis can be found in Tables 6 and 7.

Table 6 Hotspot Results

Hotspot Number	Number of Visible Bus Stops	Visible Bars?	Visible Stores and Restaurants?	Single Family Housing?	Apartments?	Curvature	Slope
1	4	Yes	Yes	No	Yes	Straight	Hilly
2	3	Yes	Yes	Yes	Yes	Straight	Flat
3	3	Yes	Yes	No	Yes	Straight	Slight
4	6	No	Yes	No	Yes	Straight	Slight
5	2	Yes	Yes	No	Yes	Straight	Slight
6	3	No	Yes	Yes	No	Straight	Mild
7	3	No	No	No	Yes	Straight	Slight
8	3	Yes	Yes	No	Yes	Curvy	Slight
9	3	No	Yes	No	No	Curvy	Slight
10	2	No	Yes	No	Yes	Mild Curve	Slight

Table 7 Hotspot Results

Hotspot Number	Sidewalks	Maximum # of Lanes	Minimum # of Lanes	Crosswalk	Speed Limit	Median
1	Yes – Both Sides of the street	7	7	Yes	45	No
2	Yes – Both Sides	2	2	No	35	No
3	Yes – Both Sides	5	5	Yes	40	Yes
4	Yes – Both Sides	5	4	Yes	40	No
5	Yes – Both Sides	5	5	Yes	40	Yes
6	Yes – Both Sides	7	7	Yes	45	No
7	Yes – Both Sides	7	7	Yes	45	No
8	Yes – One Side	4	3	Yes	45	No
9	Yes – Both Sides	6	5	Yes	45	No
10	Yes – Both Sides`	5	4	Yes	45	No

#### 5.4.1 Hotspot 1

This location contained four bus stops within sight distance. The bus stops were highly used by pedestrians. The bus stops were used both for public transportation from MARTA and for transportation from private shuttle companies that traveled on Buford Highway. There was a large degree of commercial development located at this location. The shopping center “Northeast Plaza” was located adjacent to this hotspot. There was a high density of apartments located on Cliff Valley Way. There was one bar located at this location called “Cream”. The slope on this road section varied. Half of the hotspot was located on a hill and the other hand was located on flat terrain. The road was straight with no curves located at this hotspot.

This location contained 7 lanes with no median located in the middle of the road. The speed limit for this location was 45 miles per hour. There were four crosswalks located in this section at the intersection of with Cliff Valley Way. Sidewalks that were in good condition were located on both sides of the road at this location.

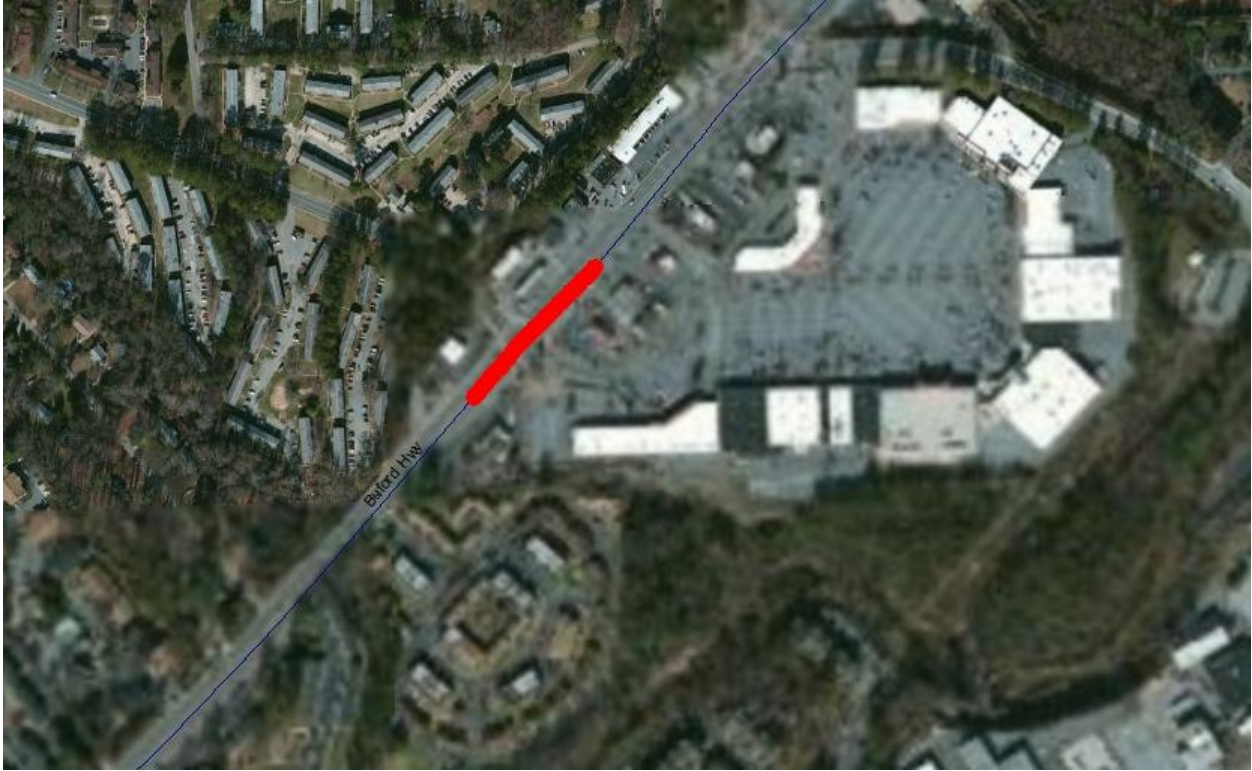


Figure 8 Satellite View of Hotspot 1



Figure 9 View of Hotspot 1



Figure 10 Apartment Housing Located near Hotspot 1



#### 5.4.2 Hotspot 2

This location contained three bus stops within sight distance. The bus stops were lightly used. There was some commercial development in this area. Most of the development came in the form of small restaurants and shops. The commercial development had parking lots located behind the building and away from the street. There were multiple bars located within sight distance of this location including “The Glenwood”, “The Graveyard Tavern”, and “Mary’s”. There was one high rise retirement community located adjacent to the hotspot location. Many single family houses were located nearby. The road located here was straight and contained minimal gradient.

This location contained two lanes with no median located in the middle of the road. The speed limit for this location was 35 miles per hour. Sidewalks that were in good condition were located on both sides of the road. There were no crosswalks located at this hotspot.

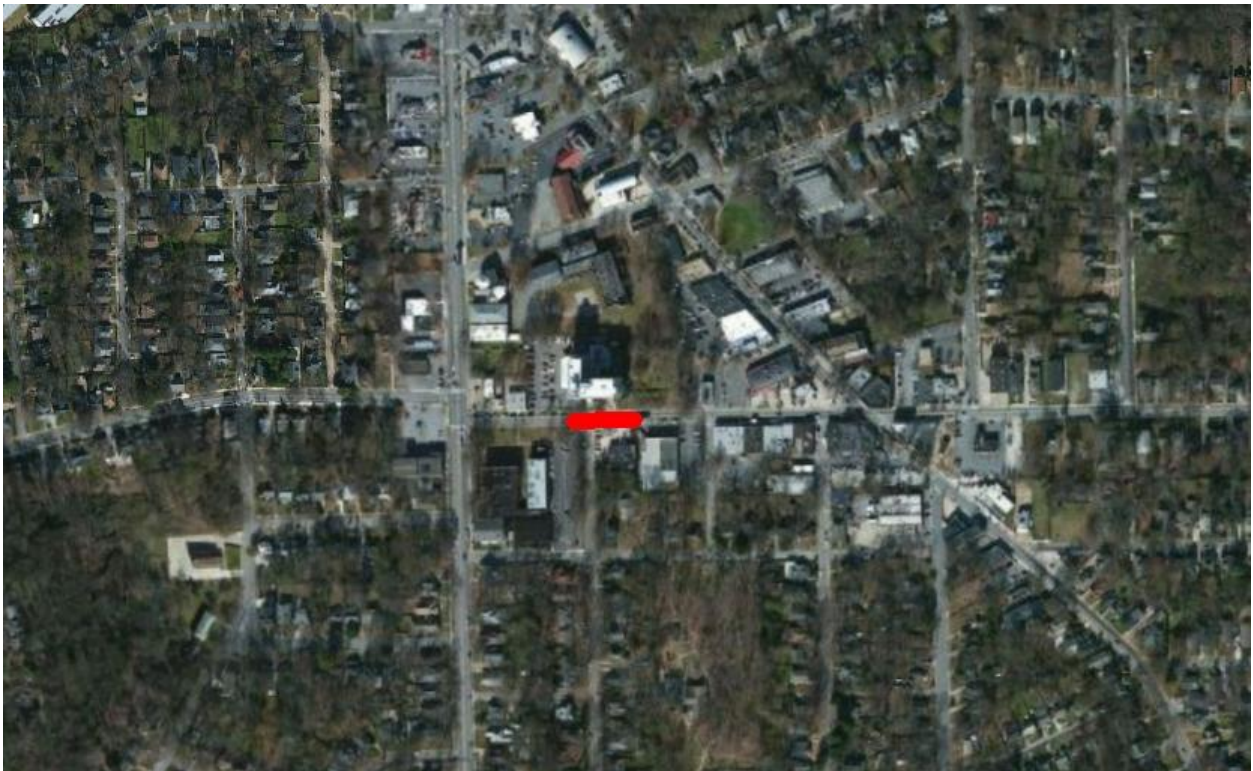


Figure 11 Satellite View of Hotspot 2



Figure 12 View of Hotspot 2



Figure 13 Housing located near Hotspot 2

### 5.4.3 Hotspot 3

This location contained three bus stops within sight distance. They were heavily used bus stops located along North Hairston Road. There was some commercial development located on this road. There was a CVS, Gas Stations, and multiple corner stores located here. There were no bars located within sight distance of this location. The area contained a high degree of housing located within this location. Multiple apartment complexes were located within walking distance of this hotspot. The road was straight and contained a slight hill.

The location contained five lanes with a median separating traffic. The speed limit for this location was 40 miles per hour. Sidewalks were in good condition and located on both sides of the road. There were crosswalks located on the intersection of North Hairston Road and Central Drive.

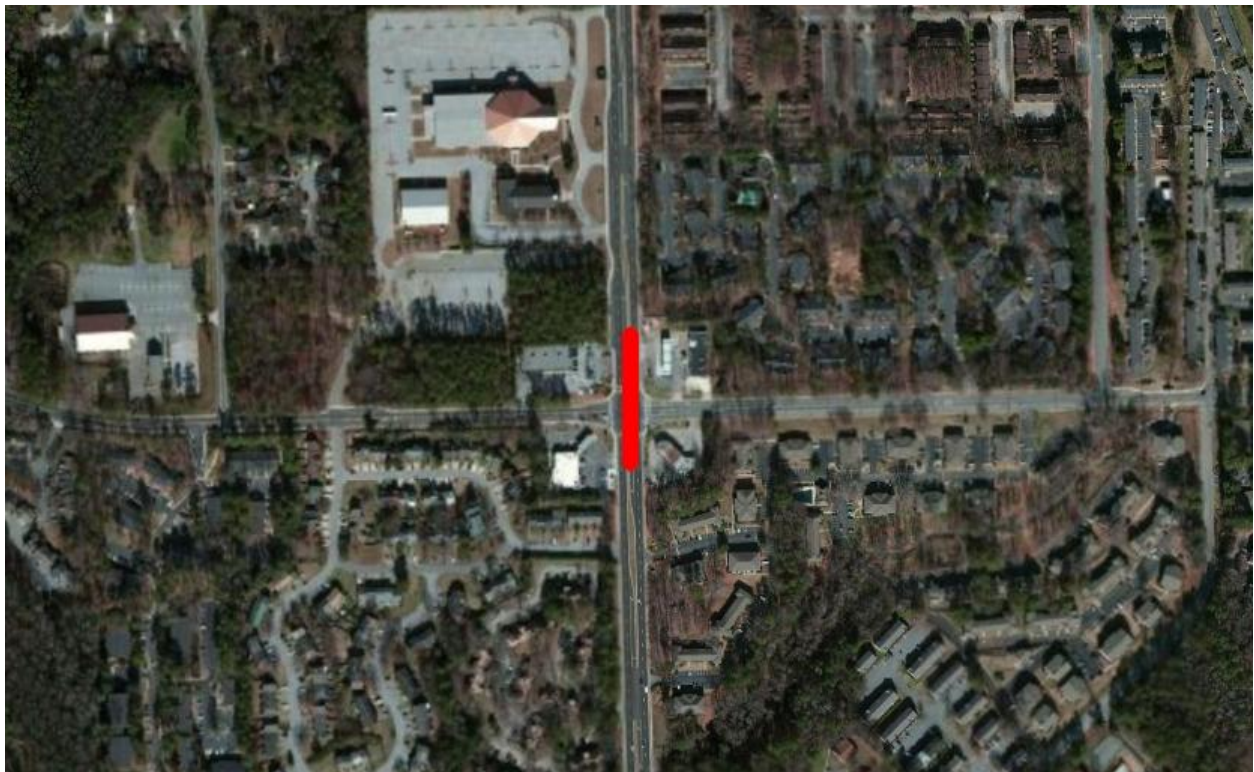


Figure 14 Satellite View of Hotspot 3



Figure 15 View of Hotspot 3

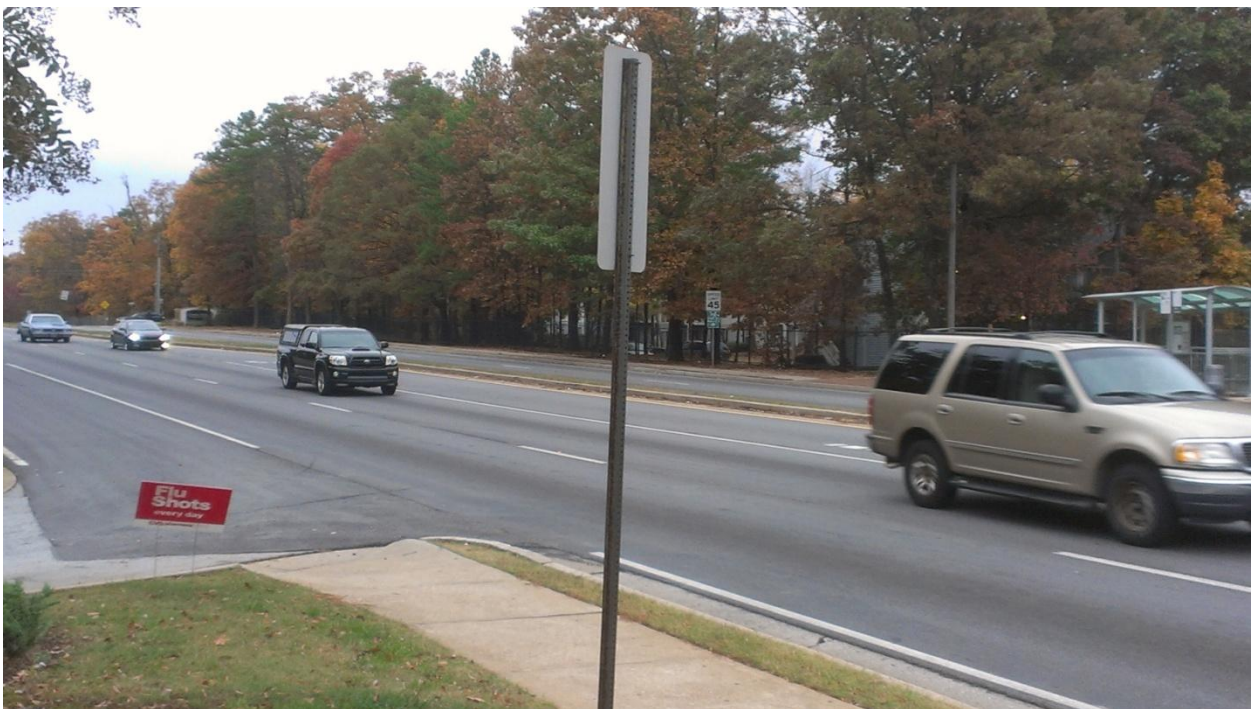


Figure 16 View of Hotspot 3

#### 5.4.4 Hotspot 4

This location contained six visible bus stops. The bus stops located at the intersection of Glenwood Road and Columbia Drive was highly used with many people waiting. There were no visible bars located at this hotspot. There was visible commercial development including a CVS, a Family Dollar, and the Columbia Plaza shopping center. There was one bar located adjacent to the hotspot called “The Tanqueray Lounge”. There were apartments visible on the eastern half of the segment. The road was straight with a slight hill.

There were sidewalks located on both sides of the road. The sidewalks, however, were incomplete and in poor condition. The maximum number of lanes on this segment was five and the minimum was four. There were crosswalks located at the intersection of Columbia Drive and Glenwood Road. The speed limit for this segment was 40 miles per hour. There was not a median in this road.



Figure 17 Satellite View of Hotspot



Figure 18 View of Hotspot 4



Figure 19 View of Hotspot 4

#### 5.4.5 Hotspot 5

The number of visible bus stops for this segment was two. However, the bus stops were fairly highly used. There were two visible bars within this segment including "Echelon 3000" and "Jay's Place". The vast majority of the land use was commercial and there were many different stores and restaurants. Some of the commercial development at this location included the Redan Village Shopping Center, a Walgreens Pharmacy, and Kroger Supermarket. There was some apartment housing visible near the southern extent of the hotspot. The road was straight with a mild slope.

There were sidewalks located on both sides of the road. The road contained five lanes with a median at this hotspot. There were crosswalks located at the intersection of South Hairston Road and Redan Road. The speed limit for this segment was 40 miles per hour.

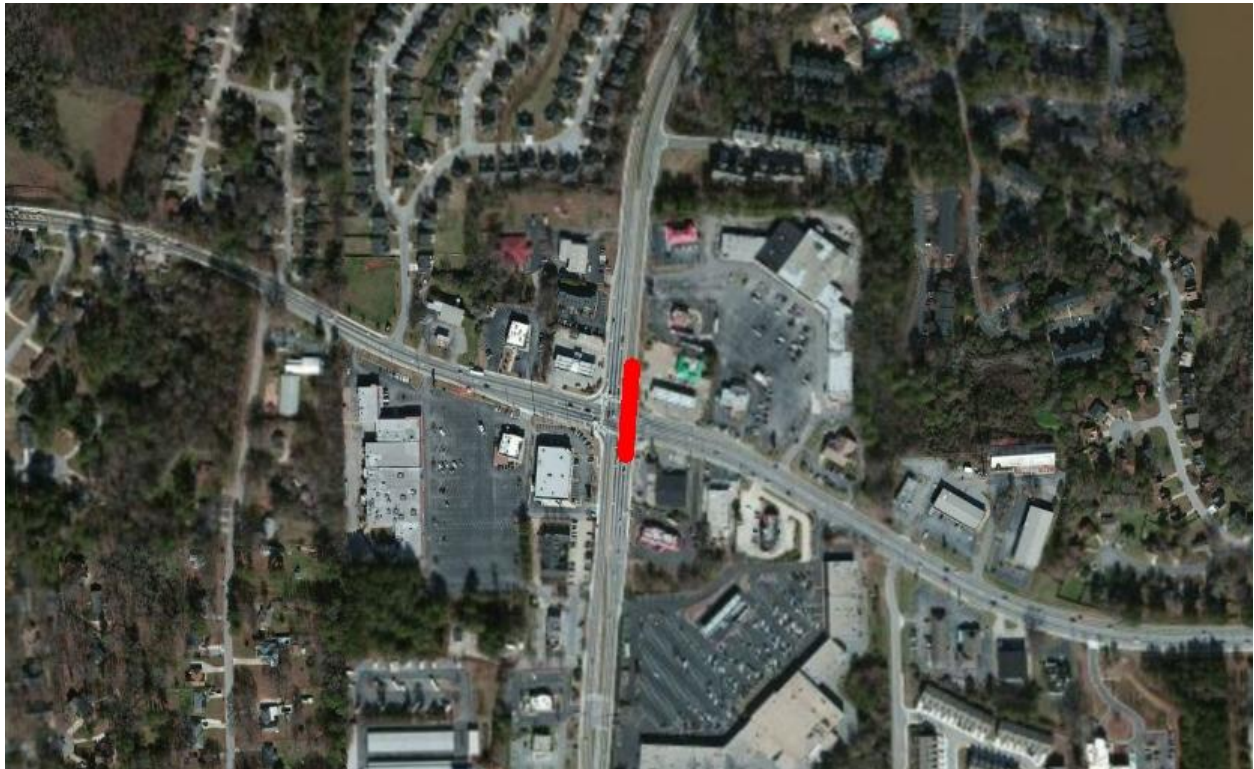


Figure 20 Satellite View of Hotspot 5



Figure 21 View of Hotspot 5



Figure 22 View of Hotspot 5



#### 5.4.6 Hotspot 6

There were three bus stops located at this segment. They were fairly highly used bus stops. There were stores and restaurants located around this segment, but not as many as other hotspots. The major store located at this hotspot was the Buford Highway Flea Market. Slightly farther to the northeast, down Buford Highway, the shopping center “Northwoods Plaza” is located. This shopping center can be seen in Figure 24. The vast majority of the land use nearby was commercial. The only housing located within sight distance was single family housing. The road was straight with a mostly flat surface.

There were sidewalks located on both sides of the street in this segment. The sidewalks for this road were complete and in good condition. There were crosswalks on this segment located at the intersection of Buford Highway & Chamblee Dunwoody Road. The speed limit for this hotspot was 45 miles per hour. The road was seven lanes with no median.



Figure 23 Satellite View of Hotspot 6



Figure 24 View of Hotspot 6



Figure 25 View of Hotspot 6

#### 5.4.7 Hotspot 7

There were 3 visible bus stops located at this hotspot. In addition to the bus stops, the pedestrian entrance to the Kensington MARTA train station was located at this hotspot. The bus stops were not very highly used, but the Kensington MARTA station was a main destination for most of the people walking on this segment. There were no visible bars at this location. There were also no visible stores or restaurants at this location. There was an apartment complex located nearby called “Kensington Station” which was the source of the majority of the pedestrian traffic. A picture of the entrance of Kensington Station can be seen in Figure 27. The road had a slight hill and was straight.

There were sidewalks located on both sides of the road that were in good condition. There were 7 lanes on this road with no median. There were crosswalks located at the intersection of Memorial Drive and Kensington Road. The speed limit at this hotspot was 45 miles per hour.



Figure 26 Satellite View of Hotspot 7



Figure 27 View of Hotspot 7



Figure 28 View of Hotspot 7

#### 5.4.8 Hotspot 8

There were three visible bus stops on this segment. There was one bar located at this segment named the "Brockett Pub House". There was many stores and restaurants located on the north side of this segment in the Tahoe Village Shopping Center. The southern side of the segment only contained railroad tracks. There were apartments located near the southeastern section of this hotspot. The entire section of this road was curvy with a slight hill.

There were sidewalks located on one side of the road that were in fair condition. The road contained a maximum of four lanes and a minimum of three lanes. There were crosswalks located at the intersection of East Ponce de Leon Avenue and Brockett Way. The speed limit for this hotspot was 45 miles per hour. There was no median on this road.

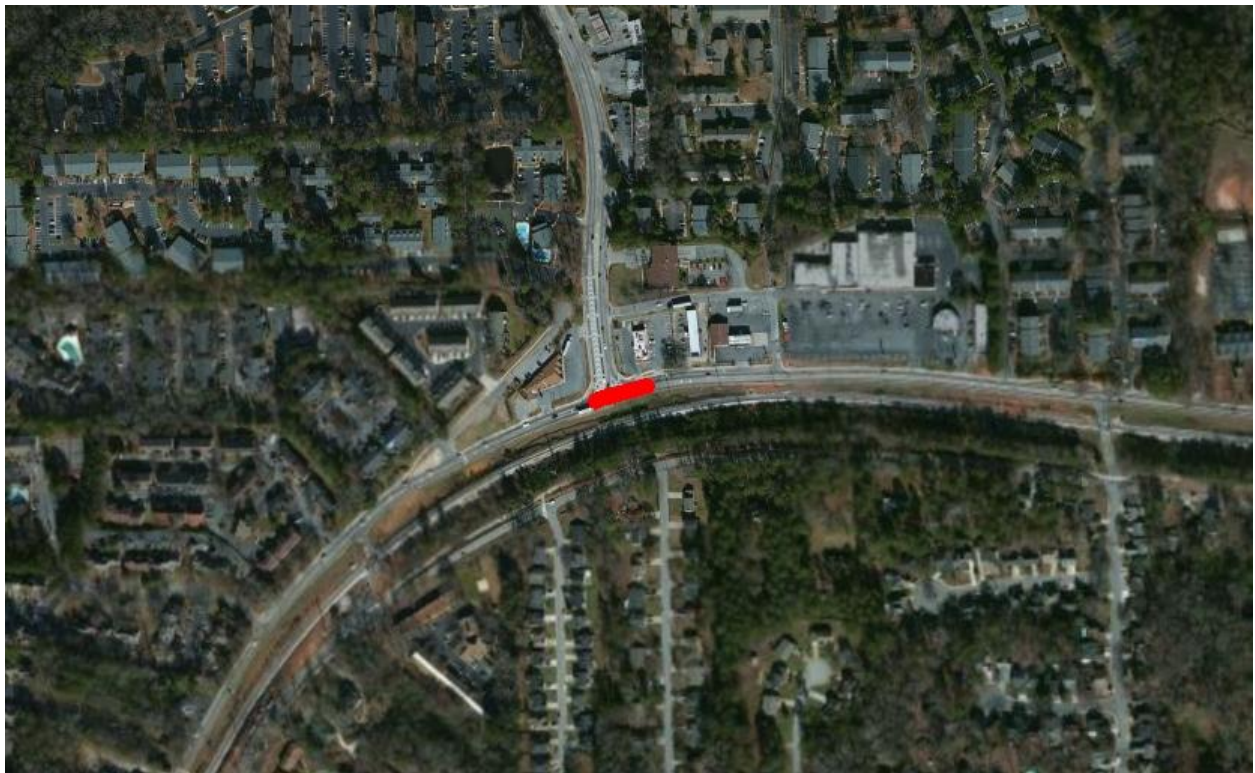


Figure 29 Satellite View of Hotspot 8



Figure 30 View of Hotspot 8



Figure 31 View of Hotspot 8

#### 5.4.9 Hotspot 9

There were three visible bus stops on this segment. The bus stop located at the intersection of Candler Drive and HF Shepard Drive was highly used. There were many restaurants and stores located near this hotspot including a shopping center with a Kroger as the anchor, and South DeKalb Mall. There was no visible housing located at this hotspot. There were no visible bars at this hotspot. The road was hilly and had a horizontal curve.

There were sidewalks located on both sides of the road. The sidewalks were complete and in good condition. The road had a maximum of 6 lanes and a minimum of 5 lanes. There was no median on this road. There were crosswalks located at the intersection of Candler Road and HF Shepard Drive.

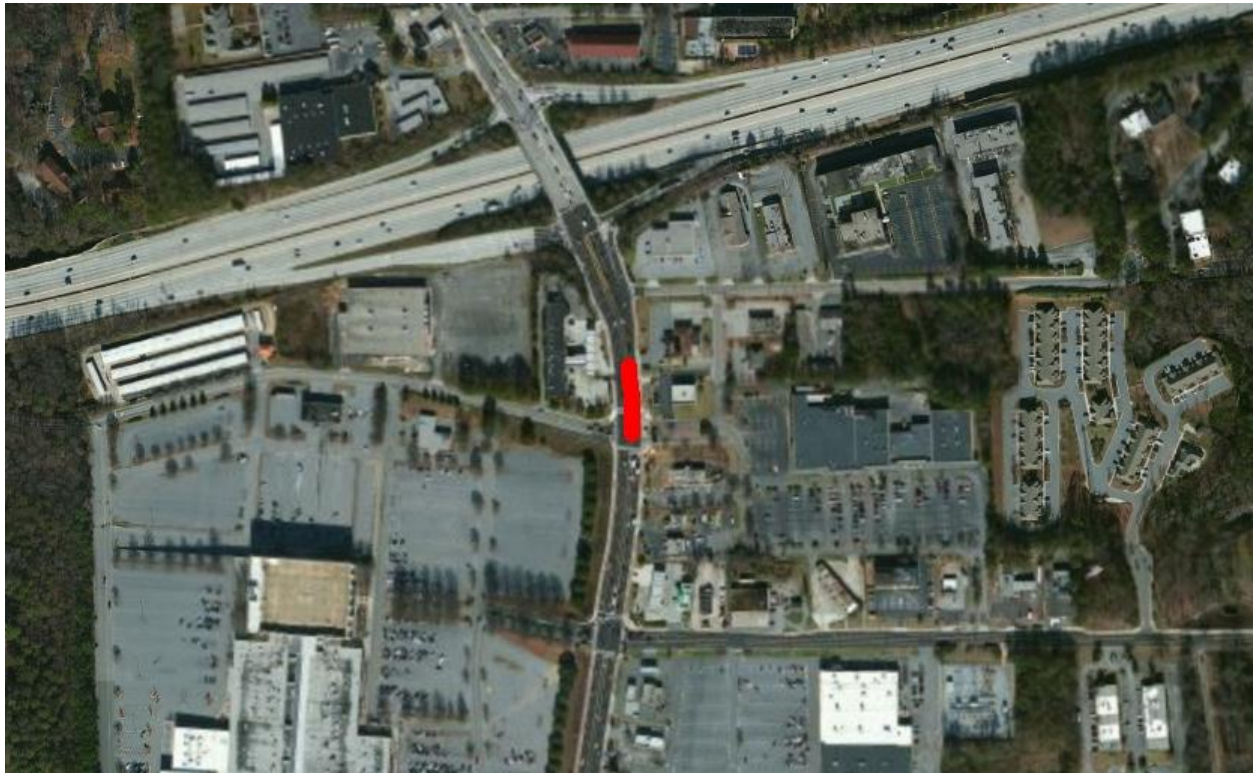


Figure 32 Satellite View of Hotspot 8



Figure 33 View of Hotspot 9



Figure 34 View of Hotspot 9



#### **5.4.10 Hotspot 10**

There were two visible bus stops at this hotspot. There was only a mild amount of usage for the bus stops. There were no visible bars on this segment. There was only minimal commercial usage at this hotspot with Checker's, McDonald's and Texaco being the major commercial developments. There were many nearby apartments located to the west of the hotspot. The road had a mild hill and a horizontal curve.

There were sidewalks located on both sides of the road. The road had a maximum number of five lanes and minimum number of four lanes. There was no median in this road. There were crosswalks at the intersection of Candler Road and Flat Shoals Road. The speed limit for this hotspot was 45 miles per hour.

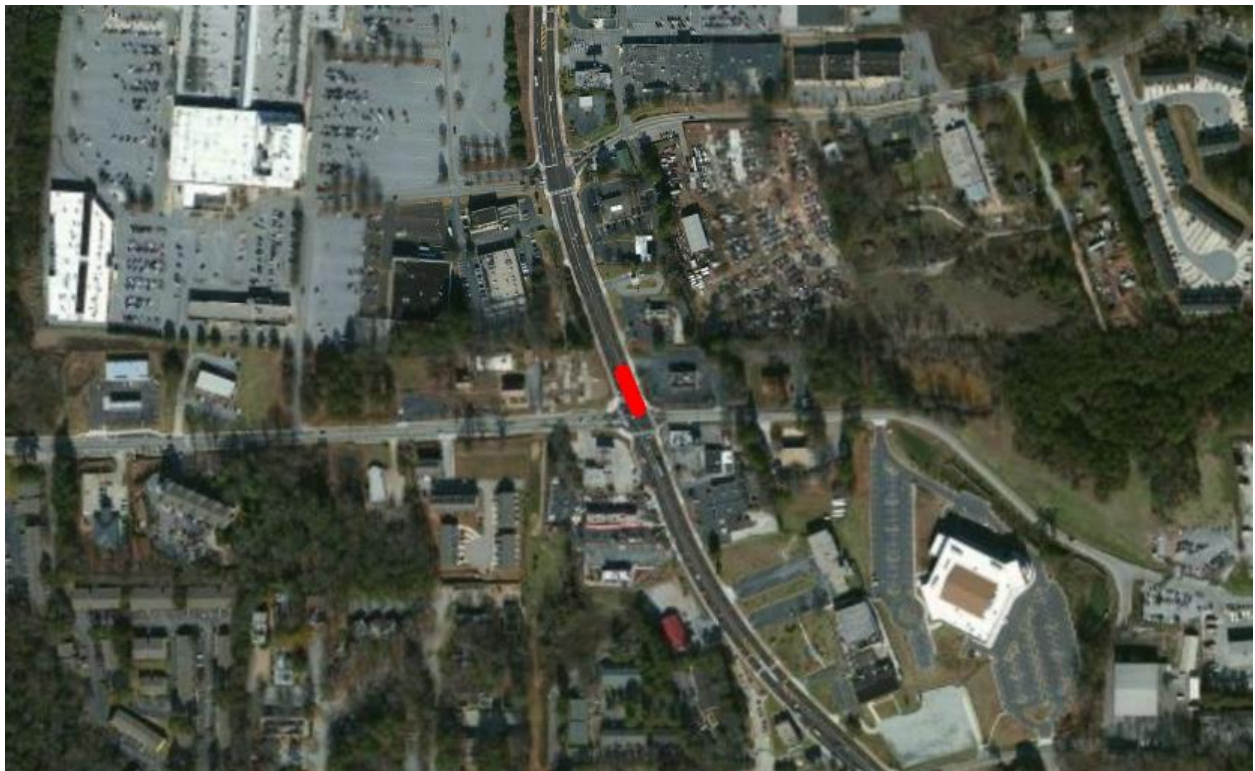


Figure 35 Satellite View of Hotspot 10



Figure 36 View of Hotspot 10

## 5.5 Pedestrian Count Results

The pedestrian count revealed the locations with the highest pedestrian traffic volumes. The location with the highest pedestrian count was Hotspot 1 at the intersection of Buford Highway and Cliff Valley Road with 32 pedestrians counted in 10 minutes. The location with the second highest pedestrian count was Hotspot 3 at North Hairston Road & Central drive with 26. The location with the lowest pedestrian count was Hotspot 8 with 13 pedestrians counted. The results for the pedestrian count can be seen in Table 8.

Table 8 Pedestrian Count Results

Hotspot Number	Pedestrian Count	Pedestrian Count Date	Pedestrian Count Time
1	32	11/06/2012	16:30
2	19	11/08/2012	15:45
3	26	11/06/2012	15:45
4	17	11/08/2012	16:15

5	16	11/06/2012	16:45
6	14	11/08/2012	16:00
7	14	11/06/2012	15:00
8	13	11/06/2012	16:15
9	23	11/07/2012	15:45
10	17	11/07/2012	16:15

## 5.6 Omission of Segments

The omission of road segments resulted in a small decline of the number of road segments for the regression analysis. The total amount of road segments when the road was broken up into 50 meter segments was 8,126. With the 50 meter road segments, 237 segments were omitted. The total amount of road segments that were broken up into 100 meter segments was 3978. With the 100 meter segments, 294 segments were omitted. The total amount of road segments that were broken up into 150 meter segments was 2596. With the 150 segments, 271 segments were omitted. A table showing the segment omission results can be seen in Table 9.

Table 9 Segment Omissions in Regression Models

Segment Lengths	50	100	150
Segments Omitted	237	294	271
Incidents Omitted	16	52	45
Total Amount of Segments after Omissions	8127	3978	2596

## 5.7 Accuracy Test for Digital Elevation Model

The GPS points and the elevation data were similar enough to determine that the DEM elevation data was accurate. Most of the elevation data for each location was less than a meter different. Results for the accuracy test of the DEM can be seen in Table 10.

Table 10 GPS Accuracy Test Results

GPS Point Number	Coordinates (in Decimal Degrees)	GPS Elevation (meters)	DEM Elevation (meters)
1	-84.303557, 33.889755	311.81	311.6591
2	-84.300672, 33.893265	312.74	312.4540
3	-84.304872, 33.889096	313.94	308.4485
4	-84.266823, 33.917985	311.22	309.6768
5	-84.267128, 33.918315	310.90	310.0265
6	-84.267390, 33.918463	310.29	308.9296
7	-84.267629, 33.918730	308.76	308.1507
8	-84.267885, 33.918839	307.84	307.2261
9	-84.268096, 33.918994	306.02	306.4207
10	-84.268094, 33.919000	304.80	304.8582
11	-84.269049, 33.919535	302.36	302.8693
12	-84.269575, 33.919991	300.53	301.6494
13	-84.269781, 33.920457	301.14	302.0049
14	-84.270050, 33.921357	304.19	306.9153
15	-84.270090, 33.921815	306.02	309.4256
16	-84.272379, 33.878457	296.57	293.8166

## 5.8 Quartile Analysis

### 5.8.1 Quartile Analysis: Curvature

The quartile results for curvature yielded different results depending on the segment length. For the 50 meter segments, there was a noticeable increase in incidents from the quartile with the lowest curvature levels to the second, third and fourth quartiles. The third quartile was found to have the highest incident rates for 50 meter segments. On the other hand, the results for the quartiles of the 100 and 150 meter segments yielded results that were less concrete. The 100 meter segments saw a growth in incident rates from the quartile with the lowest curvature values to the second and third quartiles. However, the quartile with the highest curvature values actually had the lowest incident rates. In the 150 meter segment quartiles, there actually was a slight overall decline of incident rates as curvature value increased.

Table 11 Quartile Results for Curvature without Short Segments Included in the Model

	Incident Rate per Segment 1 <sup>st</sup> Quartile	Average Curvature value 1 <sup>st</sup> Quartile	Incident Rate per Segment 2 <sup>nd</sup> Quartile	Average Curvature Value 2 <sup>nd</sup> Quartile	Incident Rate per Segment 3 <sup>rd</sup> Quartile	Average Curvature Value 3 <sup>rd</sup> Quartile	Incident Rate per Segment 4 <sup>th</sup> Quartile	Average Curvature 4 <sup>th</sup> Quartile
50 meter Segments	0.11 incidents per segment	1	0.14	1.000009	0.15	1.0001	0.12	1.004
100 meter Segments	0.22	1	0.33	1.00004	0.25	1.0005	0.19	1.0132
150 meter segments	0.46	1	0.43	1.0001	0.35	1.001	0.30	1.020

Table 12 Quartile Results for Curvature with Short Segments Included

	Incident Rate per Segment 1 <sup>st</sup> Quartile	Average Curvature value 1 <sup>st</sup> Quartile	Incident Rate per Segment 2 <sup>nd</sup> Quartile	Average Curvature Value 2 <sup>nd</sup> Quartile	Incident Rate per Segment 3 <sup>rd</sup> Quartile	Average Curvature Value 3 <sup>rd</sup> Quartile	Incident Rate per Segment 4 <sup>th</sup> Quartile	Average Curvature 4 <sup>th</sup> Quartile
50 meter segments	0.11	1	0.14	1	0.15	1.0001	0.11	1.004
100 meter segments	0.21	1	0.34	1.00004	0.25	1.0005	0.20	1.009
150 meter segments	.40	1	0.45	1.0001	0.37	1.001	0.29	1.02

### 5.8.2 Quartile Results: Slope

The results for the standard deviation of the slope quartiles showed a decline in incident rates as slope values increased for all three segment lengths. These results are consistent with the results from the regression analysis which showed slope having a negative influence on incident rates. There was one exception where the 2<sup>nd</sup> quartile had a slightly higher incident rate than the 1<sup>st</sup> quartile in the 150 meter

segments. Otherwise for the rest of the segments, an increase in quartile level led to a decrease in incident rates.

Table 13 Quartile Results for Slope without Short Segments Included in the Model

	Incident Rate per Segment 1 <sup>st</sup> Quartile	Average Std. of Slope of 1 <sup>st</sup> Quartile	Incident Rate per Segment 2 <sup>nd</sup> Quartile	Average Std. of Slope of 2 <sup>nd</sup> Quartile	Incident Rate per Segment 3 <sup>rd</sup> Quartile	Average Std. of Slope of 3 <sup>rd</sup> Quartile	Incident Rate per Segment 4 <sup>th</sup> Quartile	Average Std. of Slope of 4 <sup>th</sup> Quartile
50 meter segments	0.17	.2357	0.16	0.4141	0.13	0.6074	0.05	1.6135
100 meter segments	0.36	.3441	0.27	.5557	0.27	.8301	0.10	2.1557
150 meter segments	0.51	.3961	0.53	.6649	0.32	1.0069	0.18	2.5336

Table 14 Quartile Results for Slope with Short Segments Included

	Incident Rate per Segment 1 <sup>st</sup> Quartile	Average Std. of Slope of 1 <sup>st</sup> Quartile	Incident Rate per Segment 2 <sup>nd</sup> Quartile	Average Std. of Slope of 2 <sup>nd</sup> Quartile	Incident Rate per Segment 3 <sup>rd</sup> Quartile	Average Std. of Slope of 3 <sup>rd</sup> Quartile	Incident Rate per Segment 4 <sup>th</sup> Quartile	Average Std. of Slope of 4 <sup>th</sup> Quartile
50 meter segments	0.19	0.2912	0.15	0.4747	0.12	0.7299	0.04	2.1031
100 meter segments	0.35	0.3472	0.29	0.5557	0.26	0.8301	0.09	2.1556
150 meter segments	0.52	0.3910	0.53	0.6433	0.29	1.0054	0.17	2.5318

### 5.8.3 Quartile Analysis: Population Density per Acre

The density quartiles showed that for all three segment lengths an increase in population density by census block groups leads to an increase in pedestrian incidents. These results were consistent with the regression results dealing with population density. For all three segment lengths, an

increase in quartile level lead to an increase in incident rates. The 4<sup>th</sup> quartile representing the top 25 percent of density segments had the highest incident values for all three segment lengths.

Table 15 Quartile Results for Density without Short Segments Included in the Model

	Incident Rate per Segment 1 <sup>st</sup> Quartile	Average Density of 1 <sup>st</sup> Quartile	Incident Rate per Segment 2 <sup>nd</sup> Quartile	Average Density of 2 <sup>nd</sup> Quartile	Incident Rate per Segment 3 <sup>rd</sup> Quartile	Average Density of 3 <sup>rd</sup> Quartile	Incident Rate per Segment 4 <sup>th</sup> Quartile	Average Density of 4 <sup>th</sup> Quartile
50 meter segments	0.04	1.31	0.09	3.31	0.18	4.8294	0.2	8.45599
100 meter segments	0.07	1.39	0.18	3.32	0.34	4.835	0.4	8.388
150 meter segments	0.12	1.31	0.31	3.33	0.53	4.868	0.61	8.467

Table 16 Quartile Results for Density Analysis with Short Segments Included

	Incident Rate per Segment 1 <sup>st</sup> Quartile	Average Density of 1 <sup>st</sup> Quartile	Incident Rate per Segment 2 <sup>nd</sup> Quartile	Average Density of 2 <sup>nd</sup> Quartile	Incident Rate per Segment 3 <sup>rd</sup> Quartile	Average Density of 3 <sup>rd</sup> Quartile	Incident Rate per Segment 4 <sup>th</sup> Quartile	Average Density of 4 <sup>th</sup> Quartile
50 meter segments	0.04	1.30	0.10	3.31	0.11	4.83	0.21	8.46
100 meter segments	.07	1.31	.17	3.32	.33	4.84	.41	8.45
150 meter segments	.11	1.31	.26	3.34	.52	4.87	.61	8.46

#### 5.8.4 Quartile Results: Bar Count

The bar location quartiles showed that for all three segment lengths, an increase in number of bars within .8047 kilometers of a road segment led to an increase in pedestrian incidents. For the bar count, the first two quartiles were combined because over half of the road segments did not have at least one bar within a .8047 kilometers. Incident rates for quartiles three and four were higher than the first two quartiles with zero bars.

Table 17 Quartile Results for Bar Counts with Short Segments Not Included

	Incident Rate per Segment 1 <sup>st</sup> Quartile	Average Bar Count of 1 <sup>st</sup> Quartile	Incident Rate per Segment 2 <sup>nd</sup> Quartile	Average Bar Count of 2 <sup>nd</sup> Quartile	Incident Rate per Segment 3 <sup>rd</sup> Quartile	Average Bar Count of 3 <sup>rd</sup> Quartile	Incident Rate per Segment 4 <sup>th</sup> Quartile	Average Bar Count of 4 <sup>th</sup> Quartile
50 meter segments	0.09	0	0.09	0	0.12	1	0.27	3.08
100 meter segments	0.17	0	0.17	0	0.25	1	0.52	3.11
150 meter segments	.21	0	0.21	0	0.39	1	0.78	3.12

Table 18 Quartile Results for Bar Counts with Short Segments Included

	Incident Rate per Segment 1 <sup>st</sup> Quartile	Average Bar Count of 1 <sup>st</sup> Quartile	Incident Rate per Segment 2 <sup>nd</sup> Quartile	Average Bar Count of 2 <sup>nd</sup> Quartile	Incident Rate per Segment 3 <sup>rd</sup> Quartile	Average Bar Count of 3 <sup>rd</sup> Quartile	Incident Rate per Segment 4 <sup>th</sup> Quartile	Average Bar Count of 4 <sup>th</sup> Quartile
50 meter segments	0.09	0	0.09	0	0.12	1	0.27	3.17
100 meter segments	0.17	0	0.17	0	.25	1	0.45	3.17
150 meter segments	.27	0	.27	0	.38	1	.745	3.12

### 5.8.5 Quartile Results: Stores/Restaurant Count

The quartile results showed that an increase in the amount of stores and restaurants within .8047 kilometers of a road segment corresponded to an increase in incident counts. For all three segment lengths, an increase quartile level meant an increase in the incident count. The 4<sup>th</sup> quartile which represented the top 25 percent of store/restaurant counts had the highest incident values and the 1<sup>st</sup> quartile had the lowest values.



Table 19 Quartile Results for Commercial Locations with Short Segments not Included

	Incident Rate per Segment 1 <sup>st</sup> Quartile	Average Commercial Count of 1 <sup>st</sup> Quartile	Incident Rate per Segment 2 <sup>nd</sup> Quartile	Average Commercial Count of 2 <sup>nd</sup> Quartile	Incident Rate per Segment 3 <sup>rd</sup> Quartile	Average Commercial Count of 3 <sup>rd</sup> Quartile	Incident Rate per Segment 4 <sup>th</sup> Quartile	Average Commercial Count of 4 <sup>th</sup> Quartile
50 meter segments	0.04	1.35	0.08	7.23	0.16	17.54	0.23	44.63
100 meter segments	0.07	1.355	0.17	7.83	0.3	18.29	0.45	44.95
150 meter segments	0.11	1.354	0.26	7.87	0.47	19.05	0.69	47.07

Table 20 Quartile Results for Commercial Locations with Short Segments Included

	Incident Rate per Segment 1 <sup>st</sup> Quartile	Average Commercial Count of 1 <sup>st</sup> Quartile	Incident Rate per Segment 2 <sup>nd</sup> Quartile	Average Commercial Count of 2 <sup>nd</sup> Quartile	Incident Rate per Segment 3 <sup>rd</sup> Quartile	Average Commercial Count of 3 <sup>rd</sup> Quartile	Incident Rate per Segment 4 <sup>th</sup> Quartile	Average Commercial Count of 4 <sup>th</sup> Quartile
50 meter segments	0.04	1.34	0.02	7.25	0.16	17.56	.23	44.70
100 meter segments	.007	1.355	.1729	7.831	.30	18.29	.45	44.97
150 meter segments	.1089	1.35	.26	7.87	.46	19.05	.68	47.00

### 5.8.6 Quartile Results: Bus Stop Count

The quartile results for bus stops showed that incident counts were greater for higher quartile values in all three segment lengths. These results were consistent with regression results that showed a

positive association between the amount of bus stops within .8047 kilometers of a road segment and the incident count. For all three segment lengths, an increase in quartile level for bus stop counts meant an increase in the incident count.

Table 21 Quartile Results for Bus Counts with Short Segments Removed

	Incident Rate per Segment 1 <sup>st</sup> Quartile	Average Bus Count of 1 <sup>st</sup> Quartile	Incident Rate per Segment 2 <sup>nd</sup> Quartile	Average Bus Count of 2 <sup>nd</sup> Quartile	Incident Rate per Segment 3 <sup>rd</sup> Quartile	Average Bus Count of 3 <sup>rd</sup> Quartile	Incident Rate per Segment 4 <sup>th</sup> Quartile	Average Bus Count of 4 <sup>th</sup> Quartile
50 meter segments	0.03	0.1199	0.08	8.90	.16	18.20	0.25	32.97
100 meter segments	0.02	.1057	0.2	8.90	0.31	18.62	0.35	34.06
150 meter segments	0.09	0.1	0.22	9.48	0.48	19.65	0.76	35.24

Table 22 Quartile Results for Bus Stops with Short Segments Included

	Incident Rate per Segment 1 <sup>st</sup> Quartile	Average Bus Count of 1 <sup>st</sup> Quartile	Incident Rate per Segment 2 <sup>nd</sup> Quartile	Average Bus Count of 2 <sup>nd</sup> Quartile	Incident Rate per Segment 3 <sup>rd</sup> Quartile	Average Bus Count of 3 <sup>rd</sup> Quartile	Incident Rate per Segment 4 <sup>th</sup> Quartile	Average Bus Count of 4 <sup>th</sup> Quartile
50 meter segments	0.03	.03	0.08	8.60	.16	18.19	0.25	32.94
100 meter segments	.055	.11	.135	8.90	.32	18.63	.47	34.07
150 meter segments	.009	.1042	.2251	9.49	.47	19.66	.74	36.23

## 5.9 Test for Overdispersion

The models were tested to see if the variance for number of Incidents per road segment was greater than the mean. This was in attempt to see if the Poisson or negative binomial regression model should be used. In all six regression models for the different segment lengths, the variance was found to be greater than the mean. These results suggest overdispersion in all models. Because of this, negative

binomial regression was then performed. A comparison of the variance and the mean can be found in Table 23 below.

Table 23 Overdispersion Test Results

	50 Meter Segments without short segments	50 Meter Segments with short segments	100 meter Segments	100 Meter Segments with short segments	150 meter segments	150 meter segments with short segments
Variance	0.31	0.30	0.72	0.7	.39	.38
Mean	0.13	0.12	0.25	0.25	.25	.21

### 5.10 Test for Multicollinearity

The test found that multicollinearity did not exist between any of the independent variables. All of the Tolerance Values were above .1. In addition, the VIF value for all variables was below 10. The results for the multicollinearity test can be seen in Table 24.

Table 24 Multicollinearity Test Results

Dependent Variable	Independent Variable	Tolerance	VIF
Curvature	Std of Slope	.968	1.033
	Population Density per Acre	.748	1.337
	Bus Stop Count	.569	1.758
	Store Count	.582	1.717
	Bar Count	.712	1.405
Std. of Slope	Curvature	1.000	1.000
	PopDenAcre	.748	1.337
	Bus Stop Count	.573	1.746
	Bar Count	.712	1.405
Population Density per Acre	Store Count	.585	1.709
	Curvature	1.000	1.000
	Std. of Slope	.969	1.032
	Store Count	.588	1.699
	Bar Count	.736	1.358
Bus Count	Bus Count	.682	1.467
	Curvature	.728	1.374
	Std. of Slope	.957	1.026
	PopDenAcre	.896	1.116
Store Count	Store Count	.728	1.374
	Bar Count	.712	1.404

Store Count	Curvature	1.000	1.000
	Std. of Slope	.973	1.028
	PopDenAcre	.848	1.324
	Bus Count	.711	1.407
	Bar Count	.848	1.179
Bus Count	Curvature	.999	1.001
	Std. of Slope	.975	1.026
	PopDenAcre	.896	1.116
	Store Count	.728	1.374
	Bar Count	.712	1.374

## 5.11 Regression Results

### 5.11.1 Results of 50 Meter Segments

In the regression analysis, 8,126 50 meter road segments were used. The road segment with the most of incidents contained 12 incidents. The majority of the road segments contained zero incidents. The mean incident count was .13. The standard deviation for the incident counts was .533. The results showed that 61 road segments contained three or more incidents and that 642 road segments contained at least one incident. The histogram skewed greatly to the right with the vast majority of road segments containing zero incidents.

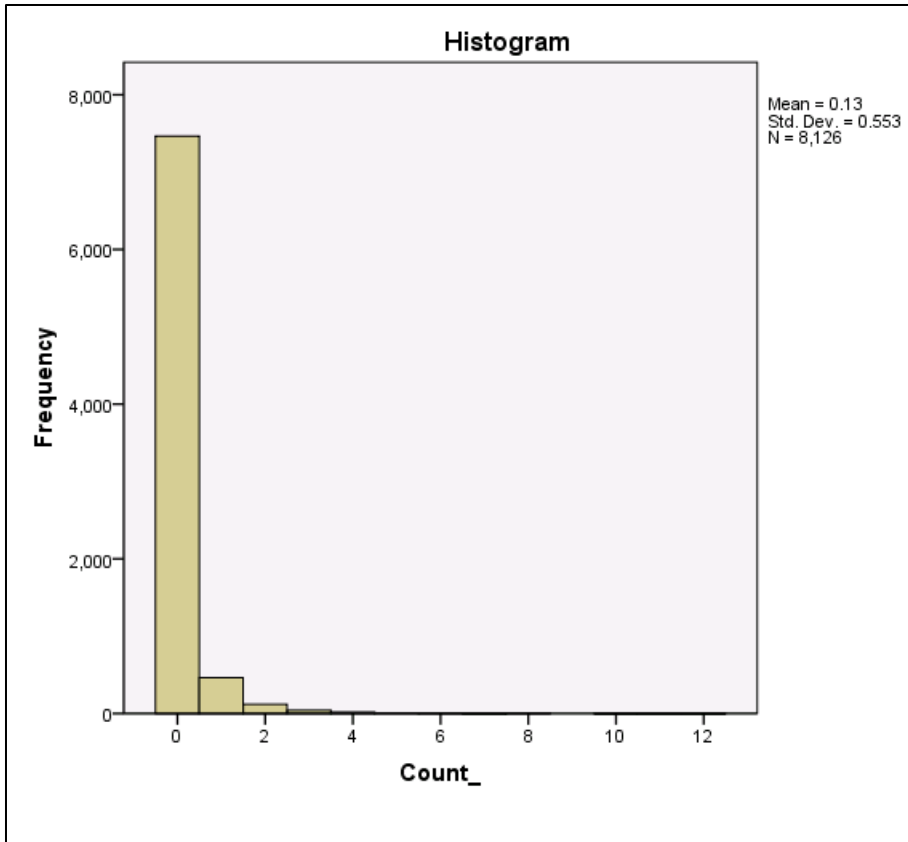


Figure 37 Histogram for 50 Meter Segments

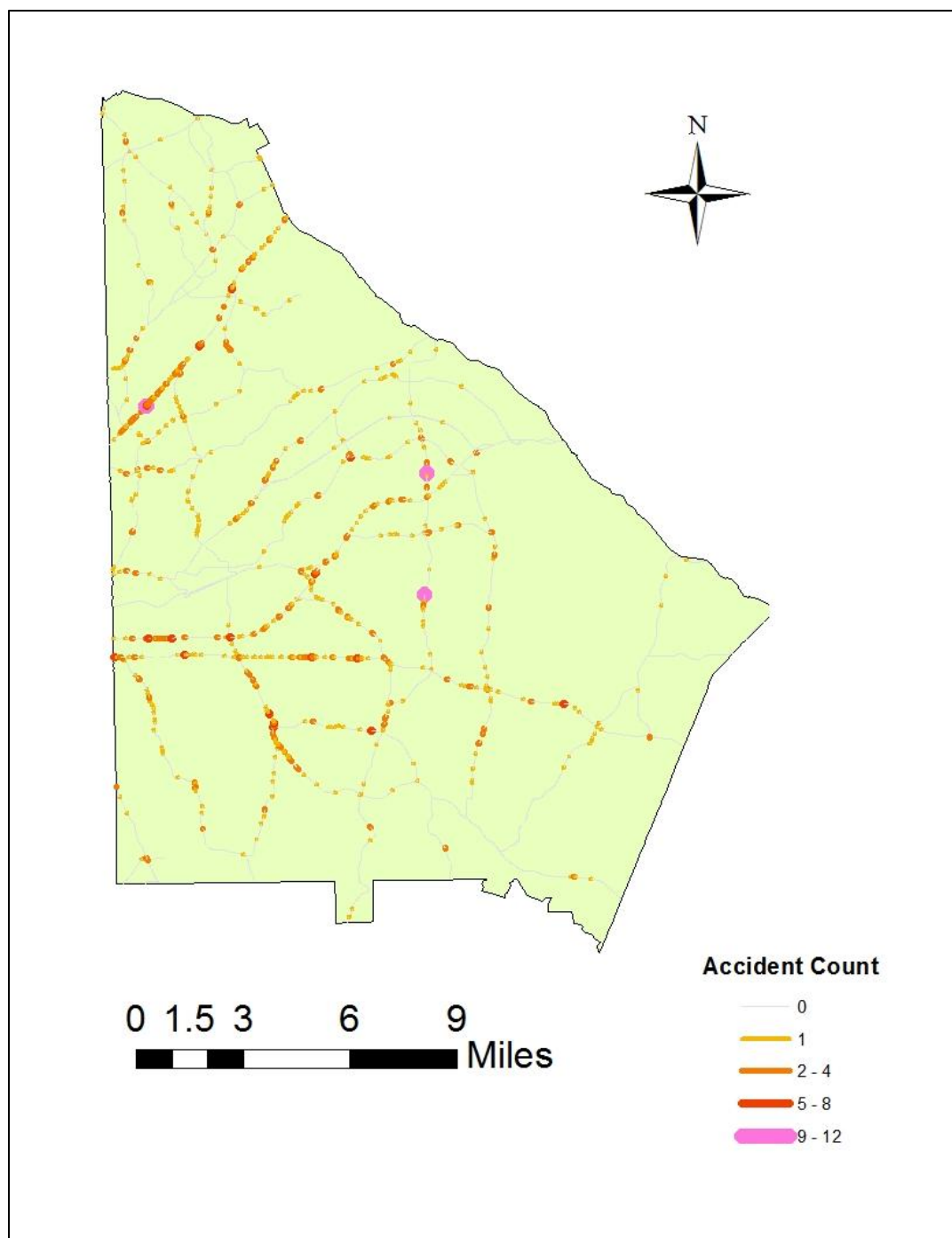


Figure 38 Incidents per Segment. 50 Meter Segments

### 5.11.2 Regression Results of 50 Meter Segments with Short Segments Omitted

The Omni-Bus test showed that the entire model was statistically significant compared to the intercept-only model at the .05 level with a significance value less than .001. This result points to the entire model being statistically significant meaning that the results are reliable. This allows one to be able to interpret the different individual pieces of the regression model. The results table shows that every variable was found to be statistically significant at the .05 level. All values in this study were found to have a positive influence on pedestrian incidents except for the standard deviation of the slope variable. The standard deviation of the slope was found to be negatively associated with pedestrian incidents. Regression results can be found in tables 25 and 26.

Table 25 Omnibus Test for Regression Mode with 50 Meter Segments

Likelihood Ratio Chi-Square	Degrees of Freedom	Sig.
593.075	6	.000

Table 26 Regression Results for 50 Meter Segments with Short Segments Omitted

Independent variables	B Value	Exp(B)	Standard Error	P value
(Intercept)	-6.381	.014	1.0941	.000
Curvature	3.173	23.875	1.0846	.003
Standard Deviation of Slope	-.407	.665	.0795	.000
Pop Density per Acre	.108	1.114	.0096	.000
Bars within buffer distance	.049	1.051	.049	.040
Store/Restaurant count within buffer distance	.006	1.006	.0020	.005
Bus Count within a buffer distance	.032	1.032	.0030	.000

### 5.11.3 Regression Results for 50 Meter Segments with Short Segments Included

The Omni-Bus Test showed that the entire model was statistically significant compared to the intercept-only model at the .05 level with a significance values less than .001. These results mean that the entire model being statistically significant with results that are reliable and the individual pieces of the model can be interpreted. The result table shows that every variable was found to be statistically significant at the .05 level. All values in this model were found to have a positive influence on pedestrian

incidents except for the standard deviation of the slope variable. The standard deviation of the slope was found to be negatively associated with pedestrian incident frequency. Results for the regression analysis can be found in figures 27 and 28.

Table 27 Omnibus Test for 50 Meter Segments with Short Segments Included

Likelihood Ratio Chi-Square	Degrees of Freedom	Sig.
593.075	6	.000

Table 28 Regression Results for 50 Meter Segments with Short Segments Included

Independent variables	B Value	Exp(B)	Standard Error	P value
(Intercept)	-6.174	.002	.0980	.000
Curvature	3.002	20.121	1.0875	.000
Standard Deviation of Slope	-.390	.667	.0630	.000
Pop Density per Acre	.108	1.114	.0096	.000
Bars within buffer distance	.048	1.050	.0240	.044
Store/Restaurant count within buffer distance	.005	1.005	.0020	.013
Bus Count within buffer distance	.032	1.032	.0030	.000

#### **5.11.4 Results of 100 Meter Segments:**

In the analysis of 100 meter segments, 3,978 road segments were used. The distribution of incidents was mostly similar to 50 meter segment results. The road segment with the most of incidents contained 12 incidents. Similar to the 50 meter segments, the majority of the road segments contained zero incidents. The mean incident count was approximately double that of 50 meter with a mean of .25. The standard deviation for the incident counts was .846. The results found that 32 road segments contained three or more incidents and 642 road segments contained at least one incident. The histogram skewed greatly to the right with the vast majority of road segments containing 0 incidents.



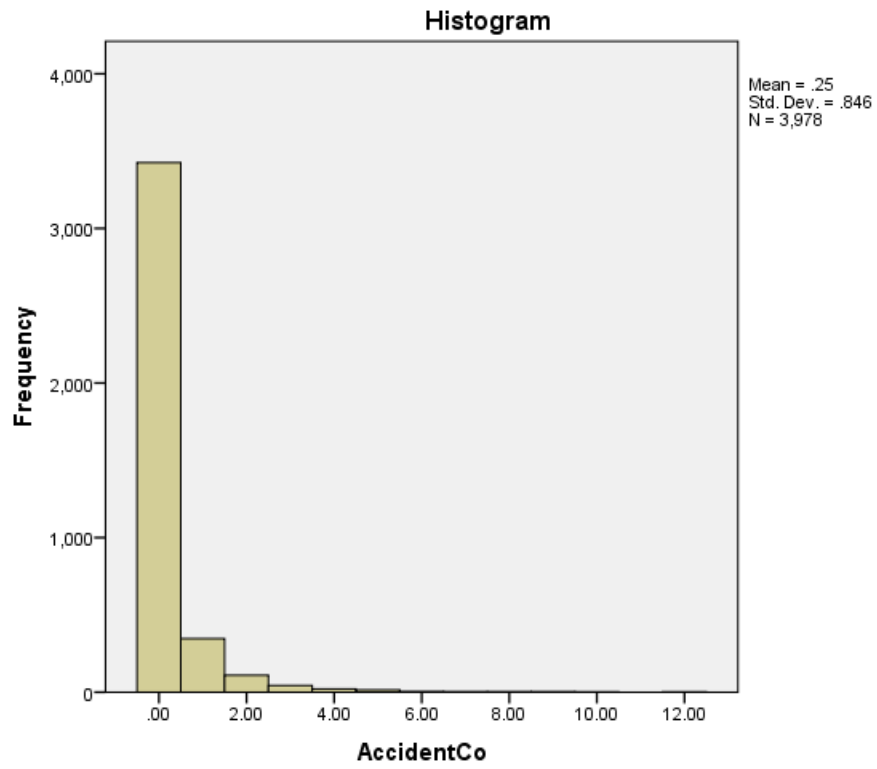


Figure 39 Histogram of Incidents for 100 Meter Segments

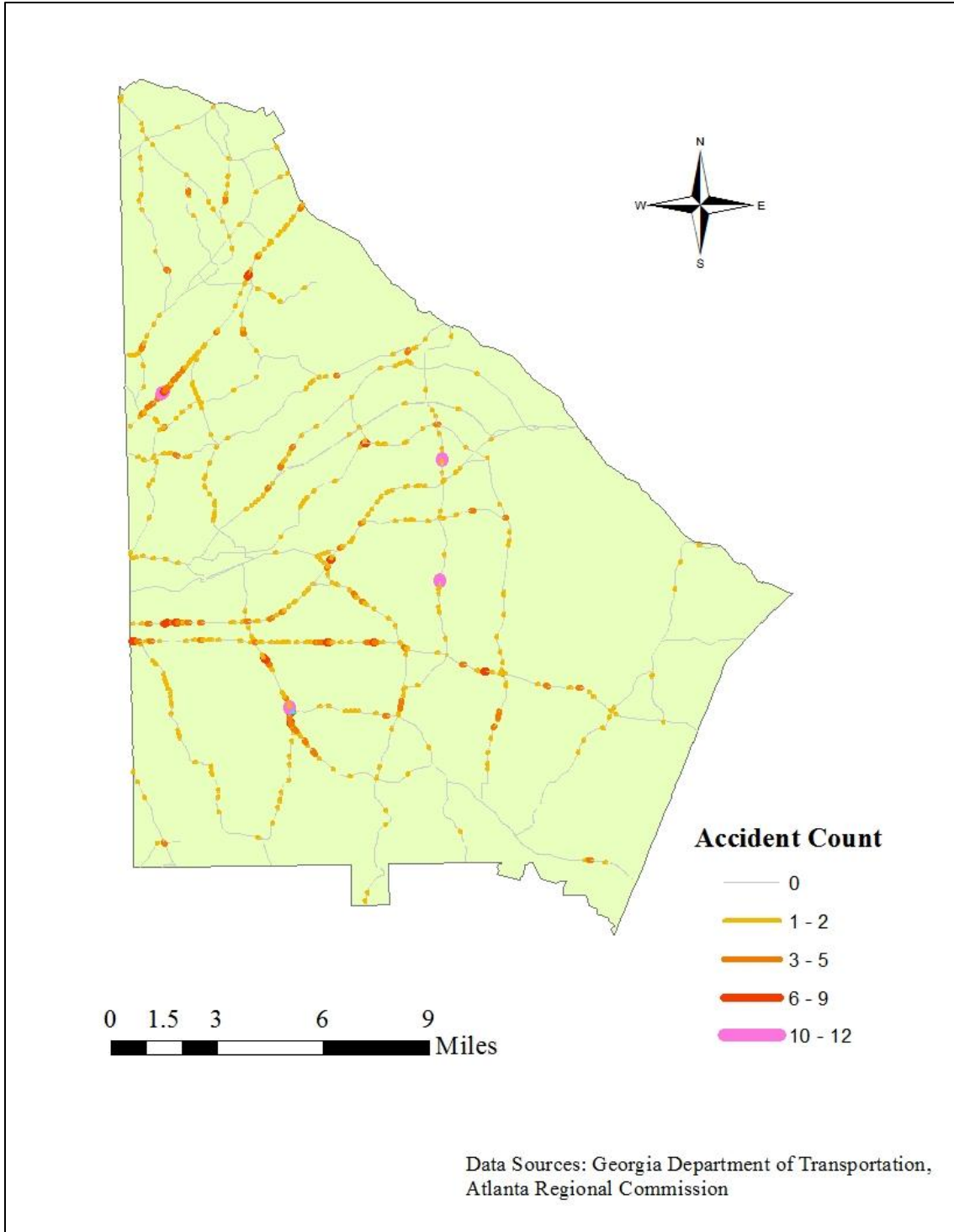


Figure 40 Incidents Count per Road Segment: 100 Meter Segments

### 5.11.5 Regression Results of 100 Meter Segments

The Omni-Bus Test level was found to be statistically significant with a significance value less than .001. These results means that the entire model can be relied upon and individual pieces of the model can be interpreted. The results table shows that every variable was found to be statistically significant at the .05 level except for the curvature which had a significance value of .064. Similar to the 50 meter segments, all values were shown to have a positive impact on incidents frequency except for standard deviation of slope. The standard deviation of the slope was found to be negatively associated with pedestrian incident frequency. Regression results can be found in Tables 29 and 30.

Table 29 Omnibus Test for 100 Meter Segments with Short Segments Omitted

Likelihood Ratio Chi-Square	Degrees of Freedom	Sig.
537.495	6	.000

Table 30 Regression Results for 100 Meter Segments with Short Segments Omitted

Independent variables	B Value	Exp(B)	Standard Error	P value
(Intercept)	-3.402	.033	.4941	.000
Curvature	.884	2.421	.4771	.064
Standard Deviation of Slope	-.377	.686	.0691	.000
Pop Density per Acre	.110	1.117	.0112	.000
Bars within buffer distance	.058	1.060	.0269	.031
Store/Restaurants count within buffer distance	.005	1.006	.0022	.020
Bus Count within buffer distance	.032	1,032	.0032	.000

### 5.11.6 Regression Results of 100 Meter Segments with Short Segments Included

The Omni-Bus Test level was found to be statistically significant with a significance value less than .001. These results means that the entire model is can be relied upon and individual pieces of the model can be interpreted. Similar to the other models, these results can be interpreted as meaning that

the entire model is statistically significant and can be relied upon. The test of model effects table shows that every variable was found to be statistically significant at the .05 level. All of the values were shown to have a positive impact on incidents frequency except for standard deviation of slope. The standard deviation of the slope was found to be negatively associated with pedestrian incident frequency. Regression results can be found in Tables 31 and 32.

Table 31 Omnibus Test for 100 Meter Segments with Short Segments Included

Likelihood Ratio Chi-Square	Degrees of Freedom	Sig.
540.018	6	.000

Table 32 Regression Results for 100 Meter Segments with Short Segments Included

Independent variables	B Value	Exp(B)	Standard Error	P value
(Intercept)	-3.359	.035	.4935	.000
Curvature	.877	2.403	.4770	.066
Standard Deviation of Slope	-.393	.675	.0689	.000
Pop Density per Acre	.108	1.114	.0109	.000
Bars within buffer distance	.049	1.050	.0266	.065
Store/Restaurant count within buffer distance	.005	1.005	.0022	.019
Bus Count within buffer distance	.032	1.032	.0032	.000

#### **5.11.7 Results for 150 Meter Segments**

The regression analysis for 150 meter segments used 2,596 road segments. The road segment with the most incidents contained 14. Similar to the other segment lengths, the majority of the road segments contained zero incidents. The mean incident count for 150 meter segments was .39. The standard deviation for the incident counts was 1.12. The results found that 107 road segments contained three or more incidents and 505 road segments contained at least one incident. The histogram skewed greatly to the right with the vast majority of road segments containing zero incidents.

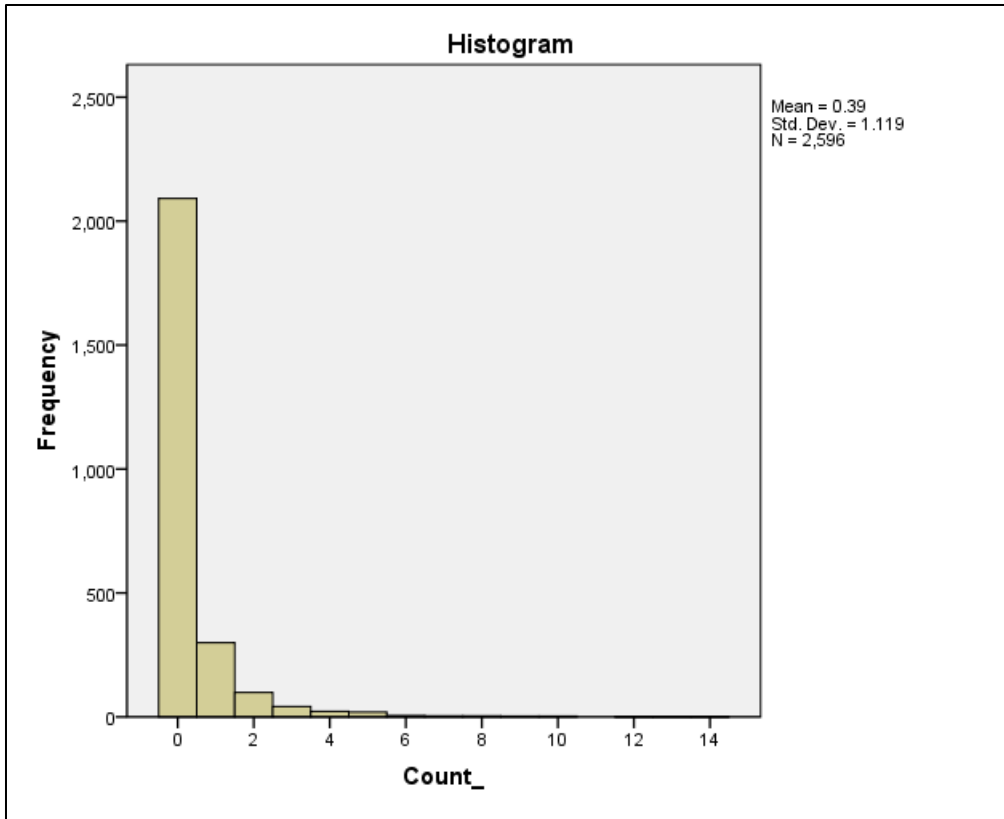


Figure 41 Histogram Results 150 Segments

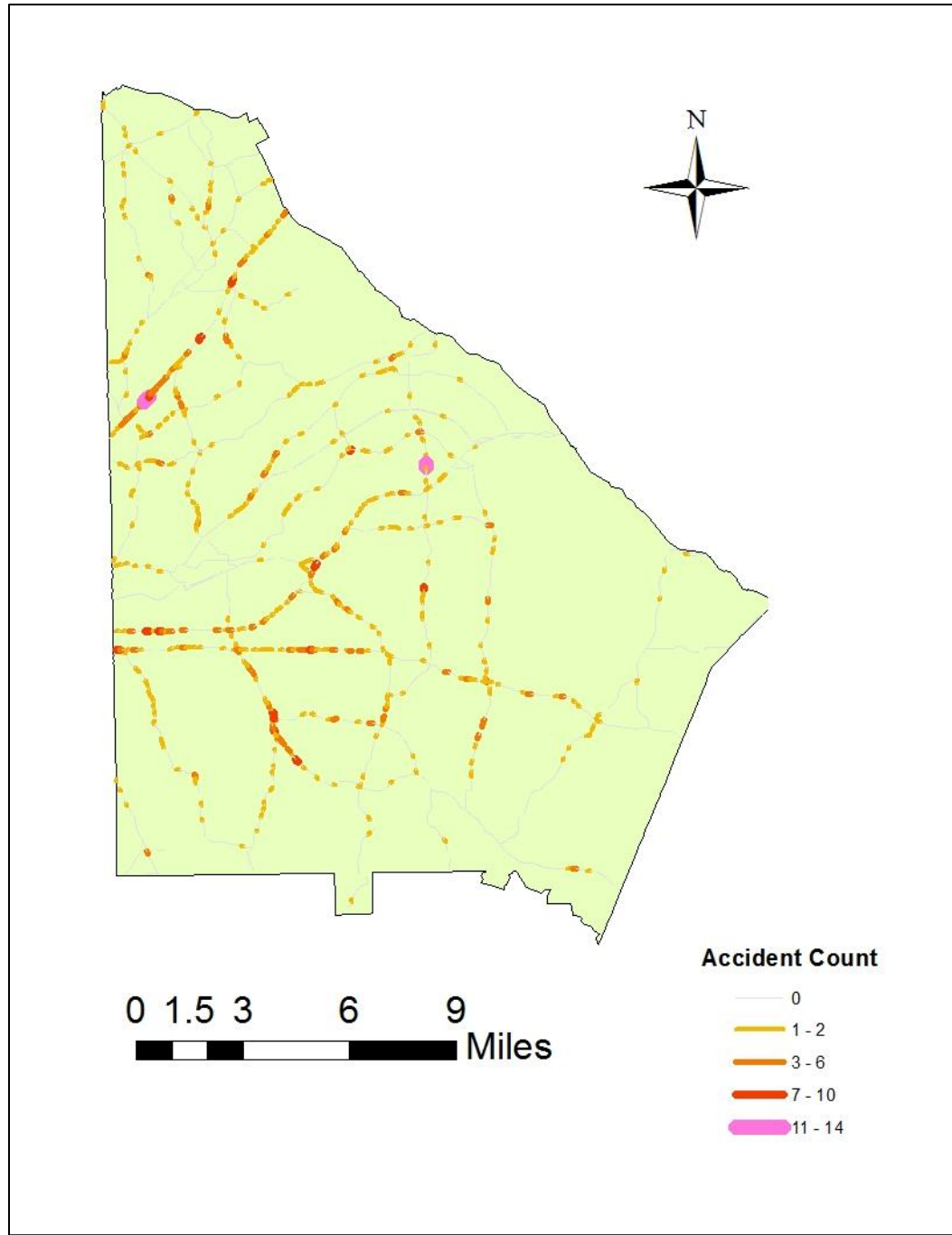


Figure 42 Pedestrian Incident Distribution for 150 Meter Segments

### 5.7.1 Regression Results for 150 Meter Segments

The Omni-Bus Test showed that the entire model was statistically significant compared to the intercept-only model at the .05 level with a significance value less than .001. These results mean that

the entire model is statistically significant and can be relied upon. The test of model effects table shows that every variable was found to be statistically significant at the .05 level except curvature and the drinking location count value. Curvature had a significance value of .289 and drinking locations had a significance value of .140. Similarly to the other two models, all values were shown to have a positive effect on pedestrian incident levels except for the standard deviation of the slope. Regression results can be found Tables 33 and 34

Table 33 Omnibus Test for 150 Meter Segments with Short Segments Omitted

Likelihood Ratio Chi-Square	Degrees of Freedom	Sig.
475.424	6	.000

Table 34 Regression Results for 150 Meter Segments with Short Segments Omitted

	B Value	Exp(B)	Standard Error	P value
(Intercept)	2.436	.087	.3413	.000
Curvature	.336	1.400	.3176	.289
Standard Deviation of Slope	-.367	.692	.0699	.000
Pop Density per Acre	.109	1.115	.0123	.000
Bars within buffer distance	.043	1.044	.0291	.140
Store/Restaurant count within buffer distance	.006	1.006	.0023	.009
Bus Count within buffer distance	.032	1.032	.0034	.000

#### **5.11.8 Regression Results for 150 Meter Segments Where Short Segments were not Omitted**

The Omni-Bus Test shows that the entire model was statistically significant compared to the intercept-only model at the .05 level with a significance value less than .001. Similar to the other regression models, these results mean that the entire model is statistically significant and can be relied upon to interpret individual factors. The test of model effects table shows that every variable was found to be statistically significant at the .05 level except curvature and the amount of drinking places within .8047 kilometers. Curvature had a significance value of .209 and bars within a .8047 kilometers distance had a significance value of .167. Similarly to the other two models, all values were shown to

have a positive effect on pedestrian incident levels except for the standard deviation of the slope.

Regression Results can be seen in Tables 35 and 36.

Table 35 Omnibus Test for 150 Meter Segments with Short Segments Included

Likelihood Ratio Chi-Square	Degrees of Freedom	Sig.
475.424	6	.000

Table 36 Regression Results for 150 Meter Segments with Short Segments Included

Independent variables	B Value	Exp(B)	Standard Error	P value
(Intercept)	2.439	.087	.3380	.000
Curvature	.398	1.490	.3171	.209
Standard Deviation of Slope	-.346	.707	.0572	.000
Pop Density per Acre	.105	1.111	.0121	.000
Bars within buffer distance	.039	1.040	.0284	.167
Store/Restaurant count within buffer distance	.005	1.005	.0023	.032
Bus Count within buffer distance	.032	1.032	.0033	.000

### 5.12 Differences between Regression Results for Different Models

For all of the regression models, the standard deviation of the slope, the population density per acre, the store/restaurant count within the buffer radius, and the bus count within the buffer radius were found to be statistically significant. Curvature was only statistically significant with 50 meter segments. Curvature's significance value for the 150 meter segment with short segments omitted was very high with value of .523. The amount of bars within a .8047 kilometer radius was found to not be statistically significant for 150 meter segments. These results point to how differences in the scale used for variables can influence the outcome.

### 5.13 Differences in Regression Results when Segments were not Omitted

There were not many major differences between the models when small segments were, and were not, omitted. One of the major differences is that curvature significance values were lower for 100 and 150 meter segments. The drinking places count value was found to not be statistically significant in



the 100 meter segments for the models that included the short segment, but was statistically significant when short segments were omitted.

## 6. DISCUSSION

### 6.1 Hotspot Analysis Discussion

#### 6.1.1 Hotspot 1

The assessment of the road and the built environment provided many potential factors that were contributing to this location having the highest pedestrian incident frequency. There was a high amount of transit usage at this hotspot. Many people used the bus stop at the intersection of Buford Highway and North Cliff Valley Way. The bus stop was used to wait for transit from MARTA buses and from private shuttle companies.

The area had the highest degree of pedestrian traffic of any of the hotspots. There were a total of 32 pedestrians counted within a ten minute span. This was likely due to the large amount of apartment homes located near the hotspot on North Cliff Valley Way. The location also had a high amount of commercial destinations that many pedestrians traveled to in the Northeast Plaza shopping center. This likely resulted in a high volume of pedestrians crossing the road as the apartments and the shopping center were located on opposite sides of the road.

The design of the road may also create potentially dangerous situations for pedestrians. Of the ten hotspots, this hotspot was one of the only locations that had seven lanes of traffic. The large amount of lanes at this location presents a more dangerous situation for pedestrians crossing the road. In addition, this location also was one of the six locations that had a speed limit of 45 mile per hour. The large amount of lanes, and the high speed limit of this location, may prompt people to drive quickly down this road and not be aware of pedestrians that may be crossing the streets. However, the

presence of sidewalks on each side of the road, and the crosswalk at intersections, does add some safety for pedestrians traveling at this location.

### **6.1.2 Hotspot 2**

This hotspot did not contain many of the features that were common in other hotspots. The commercial development was not as prevalent as other hotspot locations. There were restaurants located at this segment and some stores. However, there were no large scales commercial developments such as shopping centers or supermarkets located at this location.

Although the pedestrian traffic level was not as high other locations, there was evidence that this location is a place where people frequently walk. The high rise retirement home located at the hotspot likely results in some pedestrian travel. In addition, many single family homes located near the hotspot are likely a source of pedestrian travel.

One of the reasons that this area likely had such a high pedestrian incident frequency was due to the area being more oriented to late night entertainment. The pedestrian traffic volume was fairly high, but there is the possibility that the traffic volume would be much higher at night. Many of the businesses near the hotspot were not open yet when the assessment was completed in the middle of the afternoon. Many of the bars and restaurants did not close until well after midnight. This would result in many pedestrians walking around after dark when visibility is decreased. This may be problematic because decreased visibility may increase the likelihood that a car could hit a pedestrian.

The density of bars provides the most obvious explanation as to why the pedestrian incident frequency is was so high here. There were three bars located within sight distance of the hotspot and many other bars located nearby location. This increases the likelihood of intoxicated pedestrians, which are likely to get hit by a car. In addition, the density of bars may influence the amount of people who are

out after dark. This means that there would be a greater amount of pedestrians that would be walking in dangerous conditions where there is little light on the roadway.

The road design characteristics were much different than other hotspot locations. This road only contained two lanes and a speed limit of 35 miles per hour. This was the lowest speed limit and the lowest amount of lanes out of the ten hotspots. This made the road seem much less automobile-oriented than other major road hotspots. However, unlike the other hotspots, this location did not contain any crosswalks. This was likely due to there not being a major intersection located at this hotspot.

### **6.1.3 Hotspot 3**

A major factor that may have determined the high pedestrian incident numbers at this hotspot was the high density of housing located nearby. Unlike many of the hotspots, the commercial development in this location was not very dense. There were only a few corner stores, a gas station, and a pharmacy located at this hotspot. However, the amount of housing located at this location was far greater than most of the hotspots. The amount of nearby apartments accounted for many people walking in this area. The high density of population manifested itself in the high pedestrian count value that was recorded.

The presence of transit at this location also likely influenced pedestrian incident frequency. There were three bus stops that were visible from this hotspot. A bus stop located on the north side of the intersection of North Hairston and Central Drive was a frequent destination of pedestrians. Many pedestrians who lived nearby walked to this bus stop in order to travel.

The road design at this location made it likely dangerous to pedestrians. The road contained five lanes with a speed limit of 40 miles per hour. This creates a dangerous situation for the many pedestrians that travel at this location trying to cross the road. The median does add minor safety as a

refuge in the middle of the road, but the median is not large enough to be considered a pedestrian island. However, the presence of sidewalks and crosswalks does add some safety for pedestrians traveling on this road.

#### **6.1.4 Hotspot 4**

This section of road was characterized by its high degree of commercial development. There were many gas stations, stores and restaurants located at this hotspot location. Most of the commercial development is car oriented even though there was a high degree of pedestrian traffic.

Transit was also heavily used at this location. There were many bus stops located within sight distance of this hotspot with traffic. The hotspot was situated in between two major bus corridors located on Glenwood Road and Columbia Drive. The high volume of pedestrians that use transit at this location may potentially put many people in a dangerous situation when they are crossing this street to get to their bus stop.

The road environment contained many potentially hazardous conditions. The roads were very automobile-oriented with multiple lanes of traffic with no median to help pedestrians cross the road. The speed limit was 40 miles per hour. There were sidewalks located on this road but they were in poor condition and incomplete in some places. This may make walking for pedestrians more dangerous in this area.

#### **6.1.5 Hotspot 5**

This hotspot located on South Hairston road is also characterized by a high degree of commercial development. There were grocery stores, restaurants, and gas stations located all throughout this. These locations all provided many locations for pedestrians to travel to. Almost all of the commercial development was car oriented with large parking lots even though there was a high

amount of pedestrian traffic. Despite dominance of car-oriented development, many pedestrians were traveling to locations in this hotspot. Pedestrian traffic counts found 16 people traveling at this location.

Transit was fairly highly used at this segment. There were multiple bus stops within sight distance with multiple people waiting for the bus to arrive. Many people walked to these bus stops.

The road environment at this location presented potentially dangerous conditions. The high speed limit and five lanes made this road unsafe for pedestrians to cross. Similar to the North Hairston Road hotspot, there was a median in the middle of the road. This median was not large enough to be safely used as a pedestrian island when crossing the street. There were two positive aspects of the roadway design. The sidewalks and crosswalks allowed for pedestrians to travel throughout the area more safely which may have potentially reduced risks for pedestrians.

#### **6.1.6 Hotspot 6**

The characteristics of the road network were very similar to Hotspot 1 because they were both located on Buford Highway. The road was seven lanes wide with 45 miles per hour speed limit which likely presents a dangerous situation for anyone who attempts to cross the street. This was one of the three hotspots that contained seven lanes of traffic and a speed limit of 45 miles per hour. These characteristics make it dangerous for pedestrians to cross the road. The positive aspects of the road design were that sidewalks and crosswalks were both in place which may help to make walking here safer.

Housing was not as dense at this location as other places. There was a single family housing community located nearby, but no dense housing that was expected to be common with areas of high incident frequency. The pedestrian traffic was not as high as other locations. The pedestrian count for this location was 14.

Stores, restaurants, and other types of commercial development were located on this segment. The two major commercial destination located nearby included a shopping center and flea market. The

commercial development and the multiple bus stops located on this stretch of road provided many destinations for pedestrians to travel to.

### **6.1.7 Hotspot 7**

One of the major factors that likely made this area a hotspot for pedestrian incidents was the predominance of public transit at this location. The Kensington MARTA train station was located adjacent to this hotspot. The Kensington station seemed to be the most frequent destination for pedestrians traveling in this area. Many pedestrians crossed Memorial Drive to get to the Kensington MARTA station. The high volume of people crossing this road to get to the MARTA station may have been why there were so many pedestrian incidents at this location. There was also a MARTA bus line that ran down Memorial Drive at this hot spot.

The high density of pedestrian traffic was due to the nearby housing at this hotspot. Most of the people walking on this segment came from an apartment complex called Kensington Station. Many of the people who lived there walked to the MARTA station and other destinations. This location provided another example of how high nearby population density may be influencing pedestrian incident frequency.

Unlike other hotspots, this location had no commercial development. There were no stores, restaurants, or gas stations located at this hotspot. The only development located at this hotspot was the MARTA station, office buildings, and housing. This location seemed to be the only exception, because all other hotspots had large amounts of commercial development located nearby.

The road design in this segment had many characteristics that could potentially be dangerous to pedestrians. The first dangerous factor of this road was the amount of lanes. It was one of the three hotspots that contained seven lanes with no median in the middle. This, combined with a speed limit of 45 miles per hour, makes it a dangerous road for pedestrians to cross. The two positive aspects of the

roadway design were that there were sidewalks on both sides of the road and there were crosswalks at this hotspot.

### **6.1.8 Hotspot 8**

Public transit was available at this hotspot but was not as highly used as other hotspots. Unlike other hotspots where there was a high density of pedestrian traffic that used public transit, this hotspot had only a mild amount of people waiting at the bus stop for travel. There were multiple bus stops located within sight distance, so the availability of transit likely played a factor in the pedestrian incident frequency, but potentially not as major of a factor as other hotspots.

The presence of a bar adjacent to the hotspot offers a potential explanation for the high pedestrian incident frequency at this location. This location may influence a greater amount of intoxicated pedestrians and drivers. It also may influence a higher amount of pedestrians that are walking at night when here is limited visibility.

Unlike the majority of hotspot locations, this hotspot was located on a road with a higher degree of curvature. Based on the regression results showing that curvature was positively associated with incident frequency, this higher degree of curvature may have been one of the factors that influenced pedestrian incident frequency at this location. This would make sense because the road did not seem to be extremely dangerous based on the other factors of the road design and built environment.

The road design did not appear to present the same amount of danger as other hotspots did. The hotspot only contained three to four lanes of traffic. There was a sidewalk but only on one side of the road which may have made the road more dangerous. There were crosswalks located at the intersection which allowed pedestrians to safely cross the road.

### **6.1.9 Hotspot 9**

This hotspot had an extremely high degree of commercial development that was frequently used by pedestrians. There were many stores and restaurants located at this road segment. The Rainbow Village Shopping Center was a destination that many pedestrians traveled to. Many pedestrians were observed walking from the Kroger grocery store to the bus stop located at this hotspot. South DeKalb Mall was also located here which contained many stores and restaurants as well. The commercial development located at this hotspot was mostly car oriented but attracted a high degree of pedestrian traffic.

The hotspot was also located on a curvy road which may have made it more dangerous for pedestrians. Candler Road in this section is winding and contained many bends which may make it more difficult for cars to navigate. This may have potentially increased the likelihood of a pedestrian-automobile crash.

There was an extremely high use of public transit in this location. The bus stop at the corner of Candler Road and HF Shepard Road had many people waiting for the MARTA bus to arrive. There were also other bus stops located on Candler Road that were used. The high amount of transit may also be a potential reason for the high incident frequency at this location. Many pedestrians had to travel across the road in order to reach the bus stop.

Unlike most segments, however, there was no housing located near this segment. In the regression analysis it was found that high population density was associated with increased pedestrian incident frequency. This location seems to be an exception to these findings as there was no housing at this location.

Similar to other road segments, this location had high speeds and many lanes. The speed limit at this location was 45 miles per hour with 5 to 6 lanes of traffic. This may have increased the danger to



pedestrians. However, the sidewalks and crosswalks located at intersections may also aid to increase pedestrian safety.

#### **6.1.10 Hotspot 10**

This hotspot contained less commercial development than other road segments. There were some stores and restaurants located at this segment but not nearly as many other pedestrian incident hotspots. Commercial development around this hotspot included a Checker's, and a McDonalds. However, there were other stores and restaurants located farther north on Candler Road within walking distance.

There was housing located nearby this area which likely affected pedestrian safety. Apartment complexes were located off of Flat Shoals Road near the intersection where the hotspot was located. This likely influenced pedestrian traffic which has been associated with increased pedestrian incidents.

The road also contained a mild degree of curvature which may have made it more dangerous for drivers. This road segment was one of the few hotspots that were on a straight road. The bendiness of this road may have influenced the high density of pedestrian-automobile crashes in this location.

Similar to the other section on Candler Road, the road design was not friendly to pedestrians. The speed limit at this section was 45 miles per hour with 4 to 5 lanes of traffic. These conditions may have made it dangerous for pedestrians to cross.

## **6.2 Evaluation of Different Regression Models**

As mentioned, three different segment lengths were used in order to evaluate which segment length would be the most effective for determining the effect of road geometry and the built environment on pedestrian incidents counts. When it comes to the built environment factors, the length

of the segments probably has little impact on the end result. If the segment lengths were drastically different from one another then there might be differences, but differences between 50 meter increments was minimal. For the .8047 kilometers buffers, an increase in segment length only slightly altered the count values for bus stops, stores, and bars. The population density values unsurprisingly did not change much either. This is because the length of the segment would not alter which census block group a road segment falls in. These findings point to the conclusion that any of the three segment lengths is applicable to measuring these built environment factors.

The different segment lengths were essential, however, when evaluating the horizontal curvature of the roads. Longer road segment lengths may mask the effects that individual curves have. With 50 meter segments (and to a lesser extent 100 meter segments), one can more easily see the effect that one individual sharp curve in the road may have on an incident. Conversely, with 150 meter and longer segments, there is the possibility that if there was a sharp curve in the road at one place and then a straight road segment afterward. This could cause the detour ratio values to not be extremely high even though the road actually presents a real danger. This is especially important because Jones (2012) explained that there is the possibility that a single sharp curve in a road is more dangerous than a road with multiple curves in a row. This may potentially explain why curvature's significance levels decreased as the segment lengths got larger.

### **6.3 Evaluation of Whether or Not to Include Short Road Segments in Model.**

Because there was an issue of whether or not short segments should be included in the model, the decision was made to run all of the models twice. The first time the model was run, road segments that had a distance shorter than the given segment length for the model (50, 100, and 150) were omitted. During the second time, when the model was run, they were not. For most of the variables, there was little change in outcome regardless of whether the shorter segments were included. Because

there was little difference in outcomes, for those variables either method seems sufficient for future studies.

There were two major differences between the models where short segments were omitted and where they were not. The first difference was in the significance values for curvature. They were found to be lower in all model lengths when short segments were included. The second major difference was that the bar counts were found to be statistically significant in 100 meter segments only when the short segments were omitted.

In order to see what may be causing the changes in outcome, the average bar count and curvature values for only the segments that were omitted were compared to the rates for the rest of the road segments in the model. It was found that for the entire 100 meter road segments in DeKalb County, the average curvature value was 1.0035. This was compared to the average curvature value of 1.0016 for the segments that were omitted. This means that the average curvature value for the omitted segments were lower than the rest of the road segments in the model. It was found that for all 100 meter road segments in DeKalb Count the average bar count was .751 bars per segment. The average bar count per segment was higher for omitted segments with an average of .912. Because of these differences, it is likely better to include the shorter segments into the model. In both cases there was a noticeable difference between the average values of the segments omitted and the average values of the rest of the segments in the model. Omitting the road segments may cause the entire study area's road geometry and built environment to be misrepresented.

#### **6.4 Regression Results vs. Hotspots**

Only three of the road hotspots contained curvy roads. Since it was found that curvature was positively associated with pedestrian incident frequency it was surprising to find that most of the incident hot spots hotspots were on straight roads. However, three of the hotspots were located on curvy sections of road. The pedestrian incident hotspot at the intersection of E Ponce de Leon Avenue

and Brockett had fewer characteristics that would make it seem dangerous compared to other hotspots. Even with the decreased transit usage, fewer lanes, and less commercial development than most hotspots, it still was a dangerous location. This could potentially mean that high degree of horizontal curvature at this location was making the road dangerous for pedestrians.

The hotspot analysis did show that some locations were located on hills. This differed slightly from the regression analysis which showed slope to be negatively associated with pedestrian incident frequency. The location that had the greatest degree of elevation change was at Buford Highway and Cliff Valley Way. Half of the road section was hilly and half of the road section was mostly flat terrain. Although some of these locations were located on hills, the hills where these hotspots were located were much smaller than some of the hills on roads in DeKalb County. There were no pedestrian incident hotspots that were located on locations with major changes in elevation.

The results from the hotspot audit and the pedestrian counts support the impact that population density had on pedestrian incident frequency. The majority of the locations with pedestrian hotspots had high density housing located nearby. These results support the findings from the regression results which showed that areas with high population density were positively associated with pedestrian incident frequency. The hotspot at Buford Highway & Cliff Valley Way had a large amount of pedestrians that walked from a nearby apartment complex. This was also found at North Hairston Road where many pedestrians traveled to the hotspot from many nearby apartments. Also, multiple hotspots all had high pedestrian traffic volumes which points to high nearby population density as well.

Similar to the regression results, areas with high commercial density seemed to be associated with locations where pedestrian incidents occur. The majority of the pedestrian incident hotspots contained a high density of stores and restaurants. These results confirmed the findings from the regression analysis which found that pedestrian incidents were positively associated with the amount of nearby stores and restaurants.

The hotspot analysis showed that transit use seemed to affect pedestrian incidents. All of the pedestrian hotspots had multiple bus stops located nearby. In addition, many of the bus stops located at pedestrian-automobile crash hotspots were highly used by pedestrians. The hotspot at the intersection of Buford Highway and Cliff Valley Way had the highest amount of people using transit and it contained the highest pedestrian crash density. These findings confirm the regression results that the amount of bus stops near a road segment was positively associated with pedestrian incident frequency.

The findings from the hotspot analysis reinforce the effect that nearby bars may be having on pedestrian incident frequency. Although many of the pedestrian hotspots did not have bars located within sight distance, the findings from a few locations pointed to the effect they may be having. The pedestrian incident hotspot located on Glenwood Avenue near the intersection of Brownwood Park Avenue had a high density of bars located nearby. Other than the high density of bars, this location did not have many other features that would point to this location being a dangerous area. The location at the intersection of E Ponce de Leon Avenue and Brockett did not have many of the characteristics of a dangerous road, but contained a bar on the corner as well. Other hotspots including at Buford Highway & Cliff Valley Way, and South Hairston Road & Redan Road, also contained bars. These results support the regression results that showed bars having a positive effect on pedestrian incident frequency.

## **6.5 The Effects of Curvature**

The results point to curvature potentially having an impact on pedestrian incident frequency. Because the results on curvature were not statistically significant with the 100 and 150 meter segment in both models, there is less certainty on its impact. Incidents being significant for 50 meter segments may be due to the fact that curvature's effect on incidents might only be noticeable in one single small curve. This would be consistent with Jones et al.(2012)'s findings in the literature review which saw curvature as having a positive impact on incidents when looking at roads with one single sharp curve, but not from long curvy roads. The findings from the hotspot analysis did not provide enough support to

be certain of the effect that curvature has. Only three of the ten hotspots were located on curvy roads. It would be of value to continue researching the impact of curvature pedestrian incident. Still, these results do point to the need to be somewhat aware of the curvature of the road when planning for pedestrian safety.

Because of these results, it may be valuable to implement some measures into the built environment to plan for roads with curves in them. One measure would be to make sure that adequate signage is in place for vehicles on all roads with sharp curves. In addition when building future roads, it may be valuable to avoid sudden sharp curves. This will ensure that even if an automobile is not driving safely on a road with a curve, there won't be any pedestrians nearby to get hit. It is also essential to have adequate lighting at night for both pedestrians and for automobiles, so they can see as much as possible on curvy roads. Reduced speed limits on curvy roads are another measure that could be implemented to increase safety.

## **6.6 The Effect of Road Slope**

The regression analysis results for the standard deviation of the road slope were contrary to expectations. Based on the results in previous literature, it was assumed that more hilly roads would lead to increased incident frequency (Fu et al. 2011; Chang 2005). Instead, more hilly roads seem to act as protective measure against pedestrian incidents. These results were consistent in all three models.

The results from the hotspot analysis provided a mild amount of support to the regression results on the effect that slopes are having on pedestrian incidents. Some of the hotspots were located on roads that were hilly. Based on the regression results, it was expected that the hotspots would be located on places that were mostly flat. However, none of the hotspots were located at locations that contained major changes in elevation.

There may be a few possible explanations for these results. One possible explanation is that drivers and pedestrians act more cautiously on hilly roads which lead to a reduction in incidents. When

it comes to driver behavior, they may be paying greater attention to the road when driving on a hilly road which would allow them to see pedestrian more easily and avoid collisions. It is also possible that pedestrians avoid traveling near hilly roads altogether because of the dangers and the limited sight distance at these locations. Finally, it is possible that pedestrians avoid hilly roads altogether because they are more tiresome to traverse. There is the potential that pedestrian route selection might include choosing paths to their destination that avoid hilly roads and paths.

## **6.7 The Effects of Population Density**

All three segment lengths showed that the population density was positively associated with pedestrian incidents. These results were statistically significant in all regression models. The results from the regression analysis were supported by the hotspot analysis which found that the majority of the hotspots were located in areas with high amounts of housing and pedestrian traffic. These results are consistent with previous literature (Dumbaugh and Li 2010) on the effect that population density has on pedestrian incidents. These results lead to a few conclusions. First as Dumbaugh and Li (2010) stated, population density may potentially be used as a proxy for pedestrian traffic. Areas with higher population density are likely to have higher amounts of pedestrian traffic because there are more people around. This would mean that there are more pedestrians walking around that could potentially be involved in an incident. These results also give some insights into the types of residential locations that likely are located near areas with high pedestrian incident frequency. In DeKalb County, areas with higher population density typically are areas with many single-family households. These areas are likely car-dominated communities with low speed limits. The built environment in these areas often physically separates residential and commercial areas much more so than high population density locations. These conditions make it so there are little amounts of pedestrian traffic and when cars and pedestrians come in contact with each other, there is little risk of a collision.

Conversely, areas of high population density typically are located in areas with incident potential with automobiles. Areas with high population density often have housing consisting of apartment complexes located on long sections of major roads. This is consistent with the fact the areas with high population density are also the same areas with high commercial development.

## **6.8 The Effects of Bus Stops**

The findings show that the number of bus stops within a .8047 kilometer distance of a road segment is positively associated with pedestrian incidents. These findings were statistically significant in all regression models. The hotspots analysis also found that locations with high pedestrian crash density had multiple bus stops and high transit ridership. These results are likely because as previous literature explained, transit stops can be a predictor of the amount of pedestrian traffic (Miranda-Moreno et al. 2011) . This is because bus stops are a frequent destination of pedestrians. The riders of buses are pedestrians immediately before and after each bus trip. It is possible that having large amounts of bus stops in an area can potentially act as a predictor for pedestrian travel because it is likely that most of the people that use the bus are more likely walk. It also echoes findings that higher transit availability is linked to less pedestrian safety (Cottrill and Thakuria 2010).

The findings linking bus stops and pedestrian incidents prompt the need to investigate the safety of bus stop locations. Having the built environment improvements around bus stops could potentially increase safety which may help to lessen these associations. Adding crosswalks and sidewalks near bus stops would be a beneficial measure that could be made. Setting aside a large space on the side of the road for those waiting for the bus may be potential additions to the built environment that could lessen this association. The area around a bus stop should also have adequate lighting that will allow for both pedestrians and automobiles to see the surrounding environment well. This will allow for people to wait for the bus safely without the risk of getting hit by an automobile.



## 6.9 The Effects of Bars and Drinking Locations

Another variable that had a positive association with pedestrian incidents at all segment levels was the number of bars and drinking locations within a .8047 kilometer distance of a road segment. The findings in the hotspot analysis support these results. Multiple hotspots contained bars. The hotspot located on Glenwood Avenue also contained an extremely high density of bars nearby. These findings echo research found in the literature which shows that when pedestrians are intoxicated the incident volumes are higher (Dultz et al. 2011; LaScala et al. 2000).

The results showing the relationship between the number of bars and incidents point to the need for additional safety methods near bars to protect pedestrians. As Dultz et al. (2011) explained, pedestrians are more likely to ignore crosswalks and cross the street in an unsafe matter when intoxicated. Because of this, adding additional crosswalks may only provide limited benefit. A potential solution to this problem would be to place traffic calming devices for automobiles in areas where there are a clustering of bars. Examples of traffic calming devices could be more frequent speed bumps and lower speed limits. This would force cars to drive slower and be more aware. This would allow them to act more defensively if a pedestrian might cut in front of them while intoxicated.

Results from the regression results give credence to the high volume of incidents in areas with high amounts of bars. Specific examples of areas with high amounts of bars that also contained high incident numbers include areas near the intersection of Glenwood and Flat Shoals, and on Buford Highway near the intersection Dresden Dr. A road section near intersection of Glenwood and Flat Shoals had seven incidents and seven bars within a .8047 kilometer distance. A road section on Buford Highway near the intersection of North Druid Hills had seven incidents and six bars within a .8047 kilometer distance.

### **6.10 The Effects of Stores and Restaurants**

The count of the number of stores and restaurants was found to have a statistically significant influence on incident count for all segment lengths. There was a positive association between the number of commercial locations and the number of pedestrian incidents. The hotspot analysis supported these findings. The majority of pedestrian-automobile crash hotspots contained a high density of stores and restaurants located nearby. These results are consistent with previous literature's findings which showed that increased commercial land use leads to higher pedestrian incident rates (Wedagama et al. 2006; Ukkusuri et al. 2012). These results point to the fact that pedestrian incident frequency is higher in a built environment that has more of a commercial land use. There are multiple interpretations that one may get from this data. The results speak to the fact that more pedestrians are likely going to be in the area when there are more places such as restaurants, grocery stores, and clothing stores.

One can take away from these results the need to plan for pedestrian safety in areas with large commercial areas. Designing commercial areas that are pedestrian friendly would be an obvious solution. Currently many commercial destinations in DeKalb County and in America as a whole are designed with the automobile in mind with large parking lots and little pedestrian amenities. If major retail districts had amenities such as sidewalks, crosswalks, and less parking lots then pedestrian safety could be increased.

### **6.11 Limitations**

One of the major limitations in this study is that it could not take into account aspects of the built environment that are specifically designed to improve pedestrian safety. Some of these aspects include sidewalks, pedestrian islands, lighting, crossing signals, and traffic calming devices. DeKalb County is not uniform when it comes to the planning that takes place to protect pedestrians. Although along most major roads in DeKalb County there is little safety provided for pedestrians, there are some

areas that have actively taken initiatives to make their neighborhoods safer and more walkable. The effect that such devices have on safety cannot be adequately measured in this study. The main reason for the lack data on built environment measures is because there is little way to measure these factors at a County Level scale. Up-to-date data on the built environment on a county-wide level is not available in GIS.

Another limitation is that many of the road segments had to be omitted from the study. Ideally the study would have used LIDAR data that supplied accurate elevations of bridges, but no data was available for DeKalb County that was able to calculate the elevation of bridges. Because of this all bridges in the county had to be omitted. Other road segments had to be deleted because the segment lengths were too short. Unfortunately, when dividing roads into segments based on a given length there will be some segments. These limitations made it so not every road segment could be captured.

This study could not analyze how the variables analyzed affected pedestrians of different age groups. There is the possibility that certain variables may affect incident frequency differently depending on the age group of the pedestrian. For example, the factors of the built environment that are dangerous to children might be much different than those of the elderly. Running separate regression analyses for age groups was considered, but it was determined that the sample size would be too small if pedestrians were separated by age group.

It may be valuable to do a regression model that only examines the locations where pedestrian incidents have occurred. The vast majority of the road segments contained in the regression had a pedestrian incident value of zero, but the results may have been different if all zero values were omitted. Omitting zero values may result in different outcomes in terms of which variables are influencing pedestrian incident frequency. A regression analysis that only analyzes count values of locations where incidents have occurred may be valuable in future studies.

Finally, another limitation of this study is that the data is dated. This study was conducted in 2012, but the data is from the years 2000 to 2007. More recent data on pedestrian incidents may yield slightly different results. This is especially true as studies have been showing that pedestrian incidents are increasing in the Atlanta area.

## 7. CONCLUSION

The findings from this study provide many insights into the effect that the built environment and the road design has on pedestrian incident frequency. These results came with the aid of geographic information science and regression analysis. Using regression analysis on 50, 100, and 150 meter road segments with the number of pedestrian incidents on each segment being the dependent variable, an increased understanding of what influences pedestrian incidents was gained. The hotspot analysis also provided details on the environment surrounding the locations with the highest density of pedestrian-automobile crashes. Analysis also discovered details about the demographics of the victims in pedestrian incidents on major roads in DeKalb County.

The study found that increasing curvature leads to an increase in pedestrian incident frequency. However, this result was only found to be statistically significant on the 50 meter road segments. These results provided new insights into curvature's effect on incident frequency. Prior to this study, little research had been done on the effect curvature had on pedestrian incident. Studies had only shown that curvature influenced automobile-only incident levels.

The results showed that the slope of the road acts as a protective measure from pedestrian incidents. These results were found to be statistically significant on all segment lengths. These results were contrary to expectations based on previous literature. Other studies had shown that increasing the slope of a road lead to increased automobile-only incidents. This is possibly because increasing the

slope of the road causes both pedestrians and drivers to be more cautious. These results provide new insights into road slope's effect on incident frequency because this factor had not been studied before.

It was also found that the population density for a census block group was positively associated with pedestrian incident frequency. This was found to be statistically significant on all three segment lengths. Locations in DeKalb County with higher population densities also had higher pedestrian incident frequency. These results were consistent with previous literature which had found that increase population density was associated with increased pedestrian incident frequency.

The study found that an increase in the amount of bars located within a .8047 kilometer buffer of a road segment was positively associated with pedestrian incident frequency. These results were found to be statistically significant on all segment levels. These findings supported previous literature which found that intoxicated drivers and pedestrians were more likely to get into incidents. This study provided a new method of measuring bars impact on pedestrian incident by measuring the count value of bars located within a .8047 kilometer buffer of a road segment.

The amount of bus stops located within .8047 kilometers of road segments was found to be positively associated with pedestrian incidents. These results were statistically significant on all three segment lengths. This is likely due to the fact that bus stops influence pedestrian activity levels. The findings support previous literature showing that bus stops are a destination that might influence pedestrian incident levels.

Finally, the amount of stores, restaurants, and retail stores within .8047 kilometers of road segments was found to be positively associated with pedestrian incidents. These results were statistically significant for 50, 100 and 150 meter segments. This is likely due to the fact that these locations are destinations that pedestrians will frequently walk to. The findings support previous literature that found that commercial land use had higher pedestrian incident volumes.

Knowing that these factors lead to an increased amount of pedestrian incident counts, allows us to have a better understanding of what areas in DeKalb County are most vulnerable. The study found hotspots with high pedestrian incident counts. Having pedestrian friendly infrastructure should be seen as a priority in areas with high population densities, areas near transit stops, areas near large quantities of bars, and areas near commercial destinations. In addition in places where the road has a high degree of curvature, efforts should be taken to add built environment measures that can mitigate the risk that curvy roads produce. Reduced speed limits, warning signs and infrastructure that protects pedestrians should be placed a long curvy roads. These areas should be seen as priority locations for targeted measures to improve the built environment

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