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Final Report

Application of Demographic Analysis to Pedestrian Safety

April 2017

PREPARED FOR
Florida Department of Transportation

Center for Urban Transportation Research
University of South Florida
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Final Report

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DISCLAIMER

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation.

UNIT CONVERSION TABLE

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
AREA				
in^2	squareinches	645.2	square millimeters	mm^2
ft^2	squarefeet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

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16. Abstract

In recent years, many departments of transportation in the US have invested additional resources to enhance pedestrian safety. However, there is still a need to effectively and systematically address the pedestrian experience in low-income areas. A *Governing* analysis of pedestrian crashes found that pedestrians are fatally injured at disproportionately higher rates in the nation's poorer neighborhoods, and in metro areas, low-income tracts record pedestrian fatality rates approximately twice those of more affluent neighborhoods. Low-income areas often are sectioned by high volume/high speed arterials, which compounds the problem. This research developed a demographics-based methodology that identifies the quantitative relationships between dependent variables such as pedestrian crashes and severe injury crashes and independent variables including demographic and social factors, road environmental factors, neighborhood land use attributes, and individual characteristics in low-income areas. For demographic and social factors, major influential variables include proportions of older adults, commuters using public transit or biking, people with a low education level, and zero-car ownership. For road environmental factors, major influential variables include number of traffic signals per census block group, number of bus stops per mile, and proportion of higher-speed roads in a census block group. For neighborhood land use attributes, major influential variables include densities of discount stores, convenience stores, and fast-food restaurants. Additionally, dark–not lighted condition is the most influential variable for severe injury in pedestrian crashes. The number of impaired pedestrians and aggressive drivers also greatly increases the probability of severe injury. Based on the demographics-based analysis and results, this study makes specific recommendations for both engineering countermeasures and pedestrian safety education/outreach plans that resonate with a given area's demographics to effectively improve pedestrian safety in low-income areas.

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EXECUTIVE SUMMARY

State departments of transportation (DOTs) are investing significantly more resources to enhance pedestrian safety. However, there is still a need to effectively and systematically address the experiences of pedestrians in low-income areas. A *Governing* analysis of pedestrian crashes occurring in 2008–2012 found that pedestrians were killed at disproportionately higher rates in the nation's poorer neighborhoods and that within metro areas, low-income tracts recorded pedestrian fatality rates approximately twice those of more affluent neighborhoods. Examining Census tract poverty rates yielded a similar pattern—the country's poorest neighborhoods have the highest per-capita pedestrian fatalities.

Low-income areas generally contain a problematic mix of politically-underrepresented populations and pedestrians with little driving experience to inform their decision-making in traffic environments. These low-income areas are often sectioned by high volume/high speed arterials, which compounds the problem. To develop proactive and effective countermeasures for pedestrian safety in low-income areas, it is important to investigate and understand major contributing causes and a combination of the "pre-conditions" for pedestrian crash frequency and its resulting injury severities.

Section 1 of this final report details the project background and objectives. Realizing the challenges of pedestrian safety in low-income areas, the objectives of this research project are to (1) develop a demographics-based methodology that identifies low-income areas that possess a combination of "pre-conditions" for greater pedestrian hazard, (2) identify major factors associated with pedestrian crash frequency and injury severity and quantify their relationships, and (3) produce recommendations for both engineering countermeasures and pedestrian safety education or outreach plans that will resonate with a given area's demographics.

Section 2 addresses the first task of this project and includes a comprehensive literature review that identifies variables associated with pedestrian crash frequency and injury severity, methodologies for pedestrian crashes analysis, and existing GIS databases and tools. This section also includes input and feedback regarding the variables, outputs, and outcomes for pedestrian safety analysis from key Florida Department of Transportation (FDOT) representatives to support the objectives of this project.

Section 3 addresses a methodological flowchart and a brief description regarding the major steps for the demographic-based approaches to dealing with pedestrian safety in low-income areas. The technical approach flowchart consists of three key components: inputs, outputs, and outcomes. The variables (inputs) identified in Section 2 should be used in geographic analysis and statistical modeling (both crash frequency modeling and injury severity modeling) to generate outputs, and those outputs can be used to produce recommendations (outcomes) for engineering and education countermeasures.

Section 4 provides details of the methodology test, including testing the methodological flowchart developed in Section 3 for demographic analysis, providing the analysis results and findings for FDOT District 4 to demonstrate the kind of outputs and outcomes to be generated by following the developed methodology, and verifying that the methodology is implementable by using available datasets such as FDOT GIS databases, Census data, and other easily-available data sources. The following summarizes the major findings in methodology test:

- **Pedestrian crashes are more frequent in low-income block groups (BGs) that have more population, a smaller proportion of older adults, are minority-dominated, have zero-car ownership neighborhoods, and are among populations with a low education level.**
  - Average marginal effects indicate that the top four influential demographic variables are the proportion of older adults (negative effect), proportion of commuters using public transit or biking, proportion of people with a low education level (less than high school), and proportion of zero-car ownership.
- **Pedestrian crashes are more frequent in low-income BGs with more intersections, traffic signals, and bus stops and a larger proportion of roads with higher speed limits.**
  - Average marginal effects indicate that the most influential roadway factor is the number of traffic signals per BG, followed by the number of bus stop per mile. The third most influential variable is the proportion of lower-speed roads (negative effect); an increase in the proportion of lower-speed roads in a low-income BG can help decrease pedestrian crashes.
- **Pedestrian crashes occur more frequently in low-income BGs with the presence of a Walmart store and with greater densities of discount department stores, fast-food restaurants, convenience stores, grocery stores, and barber shops.**
  - Average marginal effects indicate that the most influential variable related to land use types is density of discount stores, followed by density of convenience stores and density of fast-food restaurants.
- **Individual characteristics, including the involvement of older pedestrians, non-crosswalk locations of pedestrians, improper pedestrian action (dart/dash), impaired pedestrians, and aggressive drivers, have positive effects on severe injuries in pedestrian crashes.**
  - Average marginal effects indicate that alcohol or drug involvement of a pedestrian is the most influential variable for severe injury in a pedestrian crash, followed by the involvement of aggressive drivers and older pedestrians.
- **Environmental factors including lighting conditions, roadway speed limits, and the presence of traffic control devices have significant effects on the injury severity of a pedestrian crash.**
  - Average marginal effects indicate that a dark–not lighted condition is the most influential variable for severe injury in pedestrian crashes, followed closely by dark–lighted condition. The third most influential variable is higher speed limit. A dark–

lighted condition seems to indicate that various lighting levels could have different impacts on injury severity in a pedestrian crash.

- **Pedestrian crashes are more frequent in segments in which the average number of fast-food restaurants, department stores, and banks is higher than average for the corridor.**
- **Pedestrian crashes are more frequent in segments in which the average number of bus stops and intersections is higher than average for the corridor.**
- **A proximity analysis illustrated that impaired pedestrian crashes tend to be more frequent in alcohol availability buffers (near the location of bars and alcohol retail) in low-income areas.**

Section 5 illustrates how the outcomes provided in the methodology developed in Section 3 and tested in Section 4 connect with the target area demographics. Engineering countermeasures are recommended based on crash analysis and types of existing facilities, and education/outreach countermeasures are recommended based on demographics, land use, and other data. This section also provides strategies for implementation of the countermeasures in a systematic approach.

Section 6 summarizes the conclusions and recommendations of this research project and includes a summary of identified related databases, the proposed and tested methodological flowchart, and the major findings to recommend implementation strategies for pedestrian safety. The recommended engineering countermeasures include the following:

- **Roadway lighting and lighting levels** – presence of lighting, adequate lighting level and uniformity, proper pedestrian lighting placement
- **Treatments at non-intersection locations** – midblock pedestrian crossing signals (High-Intensity Activated Crosswalk [HAWK] and Rectangular Rapid Flashing Beacon [RRFB]), high-visibility crosswalks, medians and crossing islands, appropriate landscaping
- **Bus stop improvements** – bus stop reallocation, transit stop request lights
- **Speed reduction treatments** – slow speed zones, road diets, roundabouts, traffic calming on residential streets
- **Road Safety Audits (RSA)**

The recommended education and outreach plan includes the following:

- **WalkWise safety education**
- **Distribution of education tip cards**
- **Social media outreach**
- **Community networking**
- **Business sweeps**

- **Law enforcement role call training**
- **Public-private partnerships**

The implementation of an education and outreach plan along with targeted High-Visibility Enforcement (HVE) has great potential in reducing both crash and injury frequency and severity. The combined engineering, education, and enforcement approach could produce the most benefits in reducing pedestrian fatalities, injuries, and crashes with a given area’s demographics.

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1. INTRODUCTION

1.1 Background

State departments of transportation (DOTs) are investing significantly more resources to enhance pedestrian safety. However, there is still a need to effectively and systematically address the pedestrian experience in low-income areas. A *Governing* analysis of pedestrian crashes occurring in 2008–2012 found that pedestrians were fatally injured at disproportionately higher rates in the poorer neighborhoods of the US, as presented in Table 1 (*Governing*, 2014). For many localities, the disparity was particularly large. For example, low-income tracts in Broward County, Florida, had pedestrian fatality rates more than double that of high-income tracts.

Table 1. Pedestrian Fatality Rates for all Census Tracts within Metro Areas

Census Tract per-Capita Income	2008–2012 Fatalities per 100K
High Income ($31,356+)	5
Middle Income ($21,559–$31,355)	6.5
Low Income (< $21,559)	**10.4**

Census Tract Poverty Rate	2008–2012 Fatalities per 100K
≤ 5%	3.8
>5–10%	5.5
>10–15%	7
>15–20%	8.3
>20–25%	9.9
>25–30%	11.2
>30%	**12.6**

Source: Governing, 2014

Dangerous by Design 2016, the fourth report since 2009, was released by Smart Growth America and the National Complete Streets Coalition in January 2017. According to the Pedestrian Danger Index (PDI) developed in this series of studies, Florida tops the “most dangerous” list for walking for the fourth consecutive time. Although Florida is still the most dangerous state for walking in the US, its statewide PDI has declined by 5.8 points since 2011 due to statewide safety efforts such as the Complete Streets Policy and Implementation Plan (Smart Growth America, 2016). The most notable Florida metro areas with a decrease in their PDI since 2011 include Miami-Fort Lauderdale (-22.8), Tampa-St. Petersburg (-20.7), and Orlando-Kissimmee (-20.7), as shown in Table 2.

Table 2. Change in Large Metro Areas PDIs in Florida

Metropolitan Area	2011 PDI	2014 PDI	2016 PDI	Change since 2011
Miami-Fort Lauderdale-Pompano Beach	167.9	145.3	145.1	-22.8
Tampa-St. Petersburg-Clearwater	212.7	190.1	192.0	-20.7
Orlando-Kissimmee	255.4	244.3	234.7	-20.7

Florida’s culture has traditionally relied on motorized transportation, and the rapid spread of low-density neighborhoods has created a vehicle-centric transportation system with wider streets and higher speeds to connect homes, offices, shops, and schools—roads that tend to be more dangerous for people walking and bicycling. One of Florida's highest priorities is creating a safer, better-connected bicycling and walking environment for its communities. The Florida Department of Transportation (FDOT) has established strategic alliances with local partners and safety advocates and has provided training and direction to assist with implementation at every level.

Although every region has its share of pedestrian accidents, fatalities are generally most common in poor and low-income areas (*Governing*, 2014). In general, poorer neighborhoods were found to have higher numbers of pedestrians fatally injured per capita than other areas within the same jurisdictions. For many localities, the disparity is particularly large. For example, low-income tracts in Broward County had pedestrian fatality rates more than double that of high-income tracts.

Table 3 lists the Florida metro areas in the top 10 metro areas ranked by five-year per-capita death rates in the poorest neighborhoods (with poverty rates greater than 25%). Poverty rates obtained from the American Community Survey (ACS) as categorized by *Governing* are:

- Poorest neighborhoods – poverty rates greater than 25%
- Poor neighborhoods – poverty rates between 15–25%
- Below national poverty rate – poverty rates less than 15%

Table 3. Florida Pedestrian Death Rates for High Poverty Tracts by Metro Area

Rank for High Poverty Tracts	Metro Area	Total 5-Year Death Rate	Poverty Rates >25% 5-Year Death Rate	Poverty Rates 15–25% 5-Year Death Rate	Poverty Rates <15% 5-Year Death Rate
1	Deltona-Daytona Beach-Ormond Beach	18.3	**26.4**	21.6	14.3
2	Tampa-St. Petersburg-Clearwater	14.5	**24.9**	17.7	10.4
3	Jacksonville	12	**24**	15.2	8.3
6	Miami-Fort Lauderdale-West Palm Beach	12.6	**20.9**	14.7	8.6
7	Orlando-Kissimmee-Sanford	13.5	**20.7**	17.5	9.8

The top 10 areas include 5 metro areas in Florida with the high pedestrian fatality rates. All recorded higher per-capita pedestrian death rates for their poorest neighborhoods (with poverty rates greater than 25%) and poor neighborhoods (with poverty rates 15–25%) than their metro area total.

A variety of factors contribute to pedestrian crashes in low-income areas. For example, Census data suggest that many residents of low-income areas are at greater risk because they walk to work or to public transportation stops more often than residents of affluent communities. Other research suggests that low-income areas typically are served by more limited infrastructure. A program by the Robert Wood Johnson Foundation conducted field research measuring the presence of sidewalks, lighting, crosswalks, and traffic calming devices in 154 communities and found that such infrastructure was more common in high-income communities (Robert Wood Johnson Foundation, 2012). Another report examined motor vehicle traffic-related pedestrian deaths data from 2001–2010 and found that racial and ethnic minorities recorded higher annualized fatality rates; people ages 75 and older also had significantly higher fatality rates in the study (CDC, 2013).

Florida's wide roadways and high volumes compound great challenges and risks for pedestrians in low-income areas. It is typical that broad, multi-lane roadways stretch for miles with few pedestrian crosswalks except for potentially dangerous intersections interacting with high-speed vehicles. They increase motorist speeds and increase the possibilities of lane-changing and of vehicles and pedestrians being hidden from one another. When these challenges are combined with a lack of a median refuge and/or effective street lighting and the lack of safety culture and knowledge, crash risks increase even more. Figure 1 illustrates the representative threats to pedestrians on wide roadways in low-income areas.

Source: Naples News FL

Source: Chip Litherland for the New York Times

Figure 1. Representative threats to pedestrians on wide roadways in low-income area

Vehicle speeds present the greatest threat to pedestrians. As vehicle speeds increase above 35 miles per hour (mph), the chance of a pedestrian or bicyclist fatality in an accident increases exponentially. Traffic calming is an important component of safety for all users of the roadway, along with providing sidewalks, crosswalks, and bike lanes.

Added to these roadway characteristics, Florida is a state with an aging population, low population density, and diverse cultures. *Dangerous by Design* (Smart Growth America, 2016) delves into demographic variables by looking at race and age in relation to pedestrian deaths and concludes that people of color and older adults are overrepresented among pedestrian deaths. The community context also plays an important role in pedestrian and bicyclist hazards in Florida. As shown in Table 4, diverse populations are present in counties with the high pedestrian and bicyclist hazards in Florida.

Table 4. Florida Counties with High Pedestrian and Bicyclist Hazard by Demographic

County	Race				Language Spoken at Home			Median Household Income
	White	*African American*	*Asian*	*Hispanic/ Latino*	*Spanish*	*English*	*Haitian Creole*	
Miami-Dade	16.3	19.2	1.7	64.3	63.77	28.07	4.22	$43,605
Orange	63.6	20.8	4.9	26.9	16.6	75.43	1.93	$50,138
Broward	41.9	27.9	3.5	29.5	22.22	63.44	5.42	$51,694
Hillsborough	71.8	16.68	2.2	24.95	22	73	0.02	$49,536
Pinellas	82.1	10.3	3	8	5	85	0.01	$45,258
Palm Beach	58.7	18.2	20.1	2.6	15.69	73.13	4.03	$53,242
Duval	60.9	29.5	4.2	7.9	5.7	87.4	Tagalog 2.8	$49,463
Volusia	86.11	9.29	1	6.57	8.92	86.2		$44,400
Lee	87.69	6.59	0.77	9.54	8.7	86.7	German 1.1	$50,014
Brevard	84.81	10.4	4.5	4.61	0.4	76	0.01	$49,523
Polk	79.58	13.54	0.93	9.49	7	79.9	0.01	$43,946
Pasco	93.7	2.07	0.94	5.69	8.66	84.36		$44,228
Escambia	68.9	22.9	2.7	4.7	4.31	90.17		$43,573
Sarasota	92.65	4.18	0.77	4.34	4.4	89.7	1	$49,388
Marion	84.16	11.55	0.7	6.03	11.6	83.1	1.6	$40,339
Statewide	78.1	16.7	2.7	23.6	19.54	73.36	1.84	$47,661

Source: 2010 Census and Wikipedia

1.2 Project Objectives

In response to the challenges of pedestrian safety in low-income areas, the objectives of this research project were to:

1. Develop a demographics-based methodology that identifies low-income areas that possess a combination of "pre-conditions" for greater pedestrian hazard.
2. Identify major factors associated with pedestrian crash frequency and injury severity and quantify their relationships.
3. Develop recommendations for engineering countermeasures (e.g., roadway lighting, signalized crosswalks, etc.) and pedestrian safety education/outreach plans that will resonate with a given area's demographics.

1.3 Report Organization

This final report is organized into six sections along with references and appendices:

1. Introduction
2. Literature Review and Interview
3. Draft Methodology
4. Methodology Test
5. Implementation Strategies
6. Conclusions and Recommendations

2. LITERATURE REVIEW AND INTERVIEW

For developing demographic-based approaches dealing with pedestrian safety, the research team conducted a comprehensive literature review to collect all related documents, including technical reports, scholarly papers, data tools, and database guidelines from the national transportation library, Google Scholar, FDOT GIS and crash database websites, US Census database, other GIS data sources, etc.

The research team reviewed different variables or pre-conditions associated with high pedestrian crash rates, including an in-depth review of methodologies used to implement a proactive approach to prevent pedestrian crashes. Currently-existing GIS databases and tools were identified as well as how these might be used or improved to support project objectives.

2.1 Variables Associated with Pedestrian Crashes

A comprehensive review was conducted to identify the variables or pre-conditions associated with high pedestrian crash rates. Accumulating evidence from previous studies revealed the following five categories of major factors related to pedestrian crashes:

1. Demographic and Social Factors
2. Road Environment Factors
3. Neighborhood Land Use Attributes
4. Individual Characteristics
5. Other (e.g., Safety Law/Regulation/Education)

Figure 2 illustrates the categories of potential factors associated with pedestrian crashes. A variety of causal factors contribute to pedestrian crashes, and previous studies have indicated that certain factors relating to the socio-demographics and the built environment may heighten the risk of pedestrian crashes (Cottrill et al., 2010; Ukkusuri et al., 2012; Zegeer et al., 2012; Yu, 2015). Details (rationale and evidence from previous studies) of the potential variables associated with pedestrian crashes were systematically reviewed by category, as explained in the following subsections.

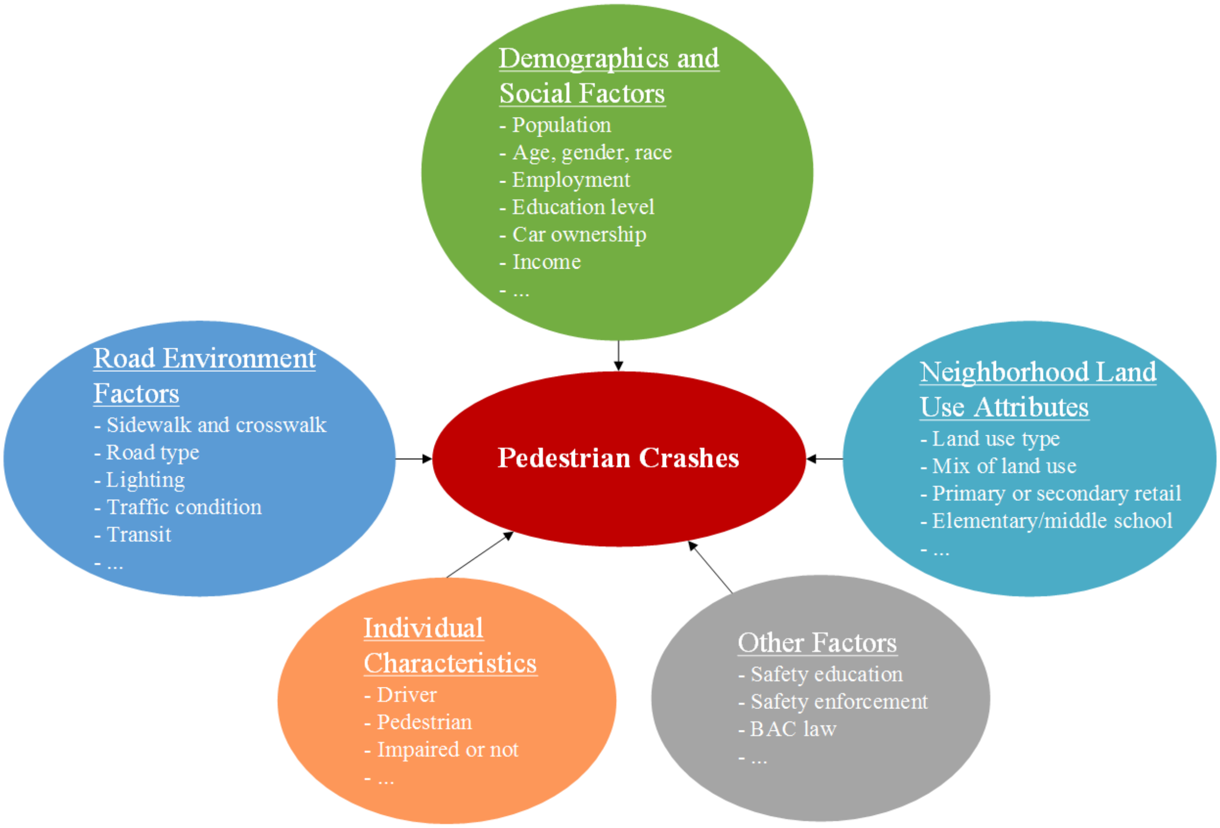


Figure 2. Potential factors associated with pedestrian crashes

Demographic and Social Factors

Based on the reviewed literature, demographic and social factors greatly affect pedestrian crash rates. Evaluated studies suggest that pedestrian crashes are more frequent in poor, densely-populated, minority-dominated neighborhoods and among populations with high unemployment rates ((LaScala et al., 2000, 2004; Siddiqui et al, 2012; Chimba et al., 2014). Some studies have identified why pedestrians may be at greater risk of crashes in low-income areas. Rivara and Barber (1985) explained that the "crowding of individual housing units," which will result in more time spent outside, is likely to be the underlying cause for the high rates of pedestrian injuries in the low-income neighborhoods. Low education level (less than high school) and little or no English-speaking ability are considered significant factors for higher pedestrian crashes according to a few studies (Cottrill, 2010; Chakravarthy, 2012; Dissanayake et al. 2009). Neighborhoods with high numbers of households without vehicles are considered at greater risk because the residents walk to work or to public transportation stops (Musinguzi et al. 2015; Chimba et al., 2014; Chakravarthy et al., 2010; Cottrill et al., 2010).

In short, the variables related to demographic and social factors from the literature review include:

- Population density
- Age group

- Gender
- Race/minority groups
- Poverty
- Income
- Household size
- Employment
- Education level
- Car ownership
- English language fluency
- Household with at least one retired person
- Commute mode (car, public transit, other)
- Travel time to work

Road Environment Factors

Road environment factors also play important roles in pedestrian crashes, mainly because individual behaviors, perceptions, and attentiveness are affected by the environment through which people travel (Moudon et al., 2011). Road environment factors include both road inventory characteristics, such as infrastructure, and traffic conditions, such as traffic volume (Wier et al., 2009; Miranda-Moreno et al., 2011). It has been commonly recognized in previous studies that wider roads with higher posted speed limits are positively related to pedestrian injury severity (Noland & Quddus, 2004; Siddliqui et al., 2006; Lee et al., 2005). Pedestrian crashes are also found to be highly correlated with lighting conditions and crossing locations (Siddiqui et al., 2006; Dumbaugh et al., 2012). For example, studies found that the probability of a pedestrian being fatally injured increases at least three times when the person is involved in a nighttime crash compared with a daytime crash (Sullivan & Flannagan, 2002). Some studies found that low-income areas typically are served by more limited infrastructure. A program by the Robert Wood Johnson Foundation conducted field research measuring the presence of sidewalks, lighting, crosswalks, and traffic calming devices in 154 communities and found such infrastructure was more common in high-income communities (Robert Wood Johnson Foundation, 2012).

Another set of road environment factors that previous studies often have linked with pedestrian crashes is transit access (e.g., transit routes and bus stops). On one hand, the higher availability of transit service may be related to higher pedestrian exposure activities and positively associated with the number of pedestrian crashes. For example, several studies found that high-collision locations were highly correlated within a certain buffer of bus stops (Miranda-Moreno et al., 2011). On the other hand, despite its influence on crash frequency, transit access was found to be negatively associated with sustaining more severe injuries (Clifton et al., 2009). Pedestrians are more likely to be in greater numbers in locations with more pedestrian activities, but the likelihood of less severe injuries may result from attributes that support their activity, such as slower vehicle speeds, better lighting, more crosswalks, and pedestrian signals.

In short, the variables related to road environment from the literature review include:

- Roadway length
- Road type (e.g., highway, arterial, local, rural)
- Intersections
- Roundabouts
- Sidewalk density
- Crosswalk density
- Light condition
- Road surface
- Posted speed limit (or density of low speed streets)
- Traffic volume (Annual Average Daily Traffic [AADT] or maximum traffic volume)
- Transit routes and bus stops (or transit availability index)

Neighborhood Land Use Attributes

According to previous studies, there is a correlation between land use patterns and pedestrian crashes (Hess et al., 2004; Moudon, et al., 2011; Dissanayake, 2009; Dumbaugh, 2011, 2012, 2013; Amoh-Gyimah et al. 2016). There is no clear consensus what land use type is more associated with a high number of pedestrian crashes. Researchers frequently associate industrial, commercial, and open land uses with high number of pedestrian crushes; however, they suggest that neighborhoods close to schools and transit stops are associated with a greater number of crashes as well (Ukkusuri et al., 2012; Braseth, 2012). Many studies point to mixed land use as highly correlated with the number of pedestrian crashes (Amoh-Gyimah et al., 2016, Miranda, 2011; Wang, 2013; Blazquez, 2016; Amoh-Gyimah, 2016). Dumbaugh (2012) suggests that strip commercial uses and big–box stores are major risk factors for older adults. Conversely, neighborhoods with a high proportion or residential land use have a lower likelihood of pedestrian crashes (Ukkusuri et al., 2012).

In short, the variables related to neighborhood land use attributes from the literature review include:

- Mixed land use
- Public schools
- Forest, park, and recreational areas
- Semi-public
- Residential
- Malls
- Bars
- Industrial
- Agricultural
- Big box stores
- Recreation

Individual Characteristics

The impact of individual characteristics on pedestrian crashes has been examined in previous studies (Moudon et al., 2011; Ha et al., 2011; Yu, 2015), many of which showed that older pedestrians are more likely to be severely or fatally injured in pedestrian crashes (Lee et al., 2005; Siddliqui et al., 2006; Clifton et al., 2009, Moudon et al., 2011; CDC, 2013). Several studies found that male pedestrians are more likely to be severely injured, probably because they take more risks than females (Lee et al., 2005). Young and male drivers, being typically more aggressive, are more likely to be involved in severe pedestrian crashes (Siddliqui, et al., 2006). Another report examined motor vehicle traffic-related pedestrian deaths data from 2001–2010 and found that racial and ethnic minorities recorded higher annualized fatality rates (CDC, 2013).

Moreover, drivers and pedestrians under the influence of drugs or alcohol have a greater fatality risk in pedestrian crashes (Moudon et al., 2011; Yu, 2015). A study by Ha et al. (2011) suggested that another common cause of crashes, inferred by investigating police officers, is human fault, either driver or pedestrian actions. This may indicate that crash frequency could be reduced by the following of traffic rules, such as yielding the right-of-way. In addition, vehicle maneuver action and vehicle type were found to be correlated with injury severity. For example, Moudon et al. (2011) found that vehicles moving straight along roadways increase the likelihood of pedestrian injury severity, whereas turning vehicles with low speeds result in lower probability of pedestrian injury severity.

In short, the variables related to individual characteristics in a crash from the literature review include:

- Pedestrian characteristics (age, gender, race)
- Driver characteristics (age, gender, race)
- Driver action
- Pedestrian action
- Impaired or not (under the influence of drugs or alcohol)
- Vehicle maneuver action (straight ahead, turning left, turning right)
- Vehicle type

2.2 Identified Methodologies for Pedestrian Crash Analysis

The literature review also focused on different methodologies that can be used to implement a proactive approach to prevent pedestrian crashes. The identified methodologies for pedestrian crash analysis include geographic analysis and statistical modeling for pedestrian crashes and crash frequency modeling and crash severity modeling.

As illustrated in Figure 3, the ArcGIS platform is typically used to visualize different data by different layers. Spatiotemporal techniques (e.g., mapping cluster analysis, kernel density, etc.) have been used to identify low-income areas or hotspot crash locations in previous studies (Prasannakumar et al., 2011). To analyze the associated variables (e.g., demographics), different statistical models (e.g., generalized logic, spatial autoregressive, multilevel, random parameter, Bayesian, etc.) are investigated to identify how the explanatory variables are correlated with the pedestrian crash rates. The result of the analysis of these variables is explained and discussed. Some literature also made further recommendations (outcomes such as engineering and education countermeasures) to improve pedestrian safety.

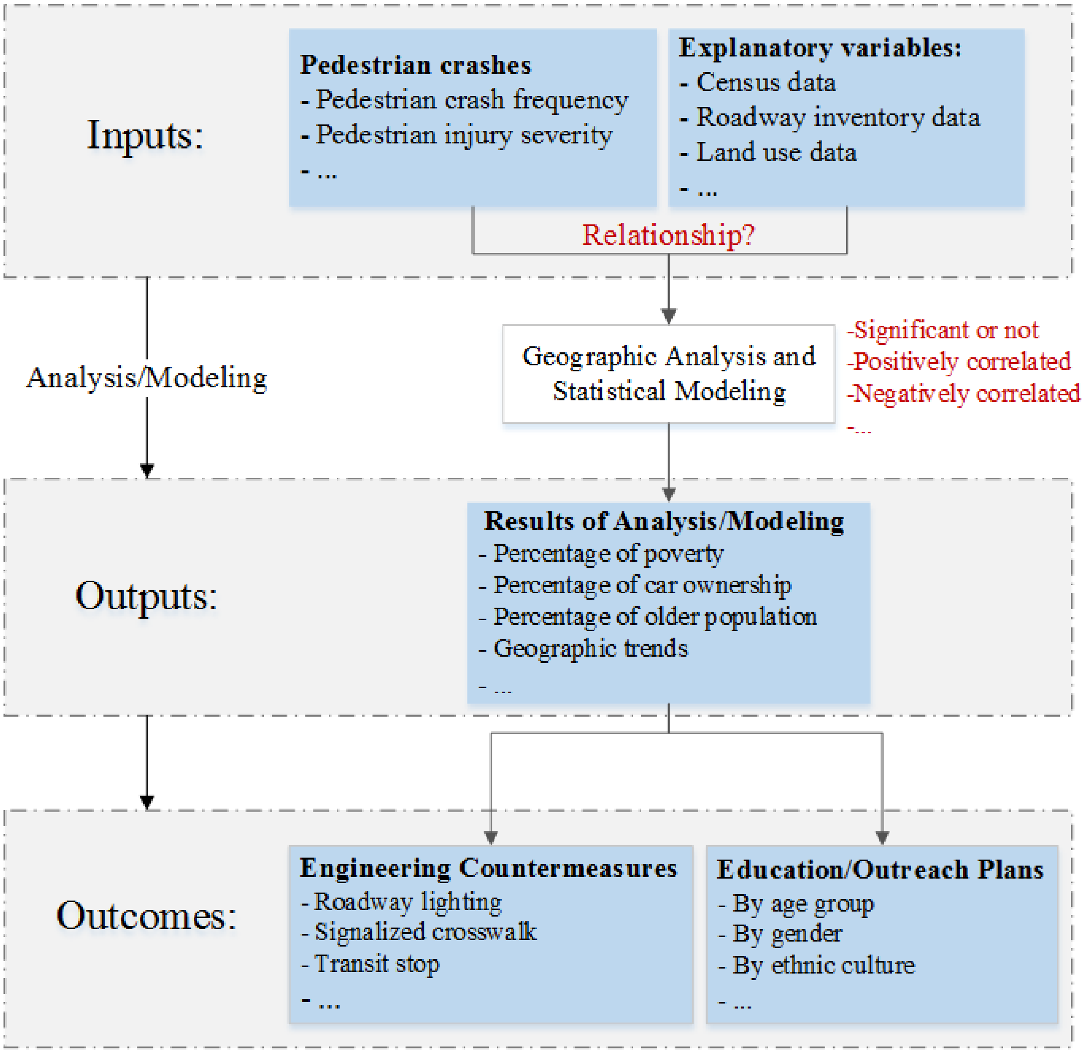


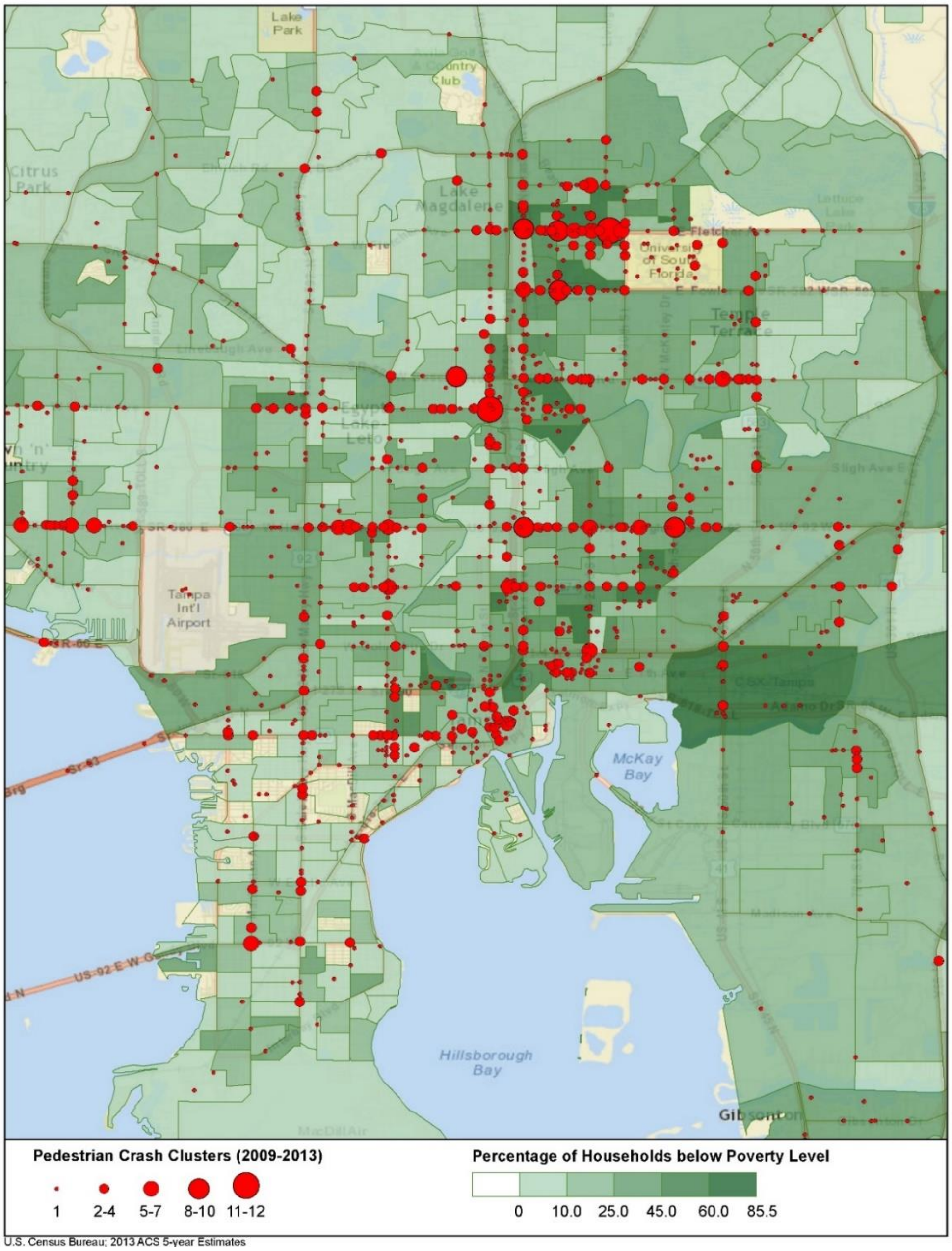
Figure 3. Methodologies for pedestrian crash analysis

GIS Visualization and Analysis

Development and application of Geographic Information System (GIS) has made for more accessible and convenient spatial analysis of various factors by integrating all variables from demographic factors to roadway characteristics into the system.

Using census data, a poverty distribution map can be constructed on an ArcGIS platform and for mapping cluster analysis for transportation inventory, traffic crash data, and other inputs. Figure 4 shows an example of the pedestrian crash clusters in the Tampa Bay Region from 2009–2013.

The larger red circles indicate higher pedestrian crash rates and the darker shaded areas indicate low-income areas (i.e., higher percentage of households below the poverty level).



U.S. Census Bureau; 2013 ACS 5-year Estimates

Figure 4. Example GIS map of poverty distribution and five-year pedestrian crash clusters

Spatial analysis tools and techniques, such as spatial autocorrelation, hot spot analysis, kernel density estimation, and similar features recognition, have been used to understand the spatial and temporal distribution of pedestrian crashes and other variables in previous studies (Plus et al., 2011; Prasannakumar et al., 2011; Lassarre et al., 2012). For instance, given the transportation inventory and crash data, Anselin Local Moran's statistics and Getis-Ord Gi Statistics were used to identify statistically-significant hot spots. With these powerful analysis tools and techniques in a GIS platform such as ArcGIS, spatial visualization and analysis helps to identify the patterns and suggest reasons for the pattern characteristics for various data layers.

Statistical Modeling

Crash analysis is often termed “aggregate” or “macro-level” when crashes are being aggregated at the level of geographical/spatial units (Siddiqui & Abdel-Aty, 2012). For statistical modeling, all demographics and environment characteristics at the unit level (e.g., census tracts) can then be associated with pedestrian crashes that occurred within that unit (e.g., census tracts). Different spatial units of analysis have been selected or defined in previous safety studies, including block groups (BGs) and census tracts, as shown in Table 5. To capture information occurring on the boundaries of the spatial units, the user-defined buffers around each unit have also been considered in previous studies (Dumbaugh &Li, 2011; Dumbaugh et al., 2012; Miranda-Moreno et al., 2011; Siddiqui & Abdel-Aty, 2012).

Table 5. Spatial Units in Previous Pedestrian Crash Studies

Spatial Units	References
Block groups (BGs)	Hashimoto, 2005; Clifton et al., 2007; Dumbaugh & Li, 2011; Dumbaugh et al., 2012; Dumbaugh & Zhang, 2013; Musinguzi & Chimaba, 2015
Census tracts	LaScale et al., 2000; Wier et al., 2009; Cottrill & Thakuriah, 2010; Ukkururi et al., 2012; Braseth, 2012; Chakravarth et al., 2010 & 2012; Wang & Kockelman, 2013; Aziz et al., 2013; Narayanamoorth et al., 2013; Chimba, 2014; Yu, 2015
Traffic analysis zones (TAZs)	Siddiqui et al., 2012; Blazquez, et al., 2016
User-defined	LaScale et al., 2004; Wang et al., 2013

In statistical modeling, demographic factors can be handled by both dependent variables (e.g., pedestrian crash frequency by pedestrian age group or gender) and explanatory variables (e.g., population size by age group, gender or race in spatial units in low-income areas). Based on the reviewed literature, statistical modeling approaches have been used to:

- Identify pedestrian crash patterns by location, severity, time, age groups, and other factors
- Identify and quantify the factors/causes contributing to pedestrian crash occurrence
- Identify and quantify the factors/causes associated with RCI contributing to pedestrian crash injury-severity
- Identify and quantify the factors/causes associated with demographics contributing to pedestrian crash injury-severity

2.3 Identified Existing GIS Databases and Tools

The growth in GIS-based governmental agencies has produced extensive demographic data that can be collected and used to improve urban areas. The analysis and presentation of this information is facilitated by GIS common to DOTs and other governmental agencies. Noting the value of GIS databases and tools, the research team examined the availability of existing GIS databases and tools that suited the objectives of this project. The details are explained in the following subsections.

FDOT Crash Analysis Reporting System (CARS)

Pedestrian crash data can be derived from Florida Long Form crashes provided by the Department of Highway Safety and Motor Vehicles (DHSMV) and maintained in the FDOT Crash Analysis Reporting System (CARS). DHSMV is the official custodian of these data; all reported crashes with a fatality, injury, or high property damage occurring on State roads are included in this database. In CARS, the variables are classified into four categories, as shown in Table 6.

Table 6. Variables in CARS by Category

No.	CAR Category	Number of Variables	Database File
1	Crash	192	RDWTBL_50
2	Vehicle	57	RDWTBL_51
3	Person	31	RDWTBL_52
4	Citation	8	RDWTBL_53

Originating from CARS, the following FDOT GIS Crash Databases (2005–2014) are available:

- On-System Crashes file – mapped crash locations for Long-Form-reported crashes within Florida and on or involving the State Highway System (SHS)
- On-System Occupants file – pedestrians, drivers and passengers involved in Long-Form-reported crashes on Florida's SHS
- On-System Vehicles file – vehicles involved in Long-Form-reported crashes on Florida's SHS
- Off-System Crashes file – mapped crash locations for Long-Form-reported crashes on Florida's local roadways
- Off-System Occupants file – pedestrians, drivers and passengers involved in Long-Form-reported crashes on Florida's local roadways
- Off-System Vehicles file – vehicles involved in Long-Form-reported crashes on Florida's local roadways

FDOT's GIS crash databases served as the major data source for pedestrian crash analysis in this project, including GIS visualization, statistical analysis, and modeling.

US Census Databases

In US Census databases, extensive tabulations for the 1970–2010 decennial censuses are available:

- Population size by sex, age, race, Hispanic origin, education status, employment status, occupation, and industry

- Median income, rent, and housing unit value
- Tabulations of other population and housing characteristics

These tabulations are presented at many levels of observation, including regions, states, counties, metropolitan areas, places, county subdivisions, census tracts/block numbering areas, block groups, and blocks. The core TIGER/Line® files and shapefiles do not include demographic data, but they do contain geographic entity codes (GEOIDs) that can be linked to the Census Bureau's demographic data available on American FactFinder at factfinder.census.gov/. Moreover, the Longitudinal Employer–Household Dynamics (LEHD) datasets, part of the Center for Economic Studies at the US Census Bureau, are also available at http://lehd.ces.census.gov/.

FDOT Road and Traffic Information Databases

FDOT's Transportation Statistics Office (TranStat) created and maintains the official FDOT basemap of all roads in the Roadway Characteristics Inventory (RCI). The statewide GIS layers (shapefiles and geodatabases) for roads, road data, traffic data, bicycle, and pedestrian data are available at http://www.dot.state.fl.us/planning/statistics/gis/. More FDOT GIS data can be found at GIS@FDOT, the portal for FDOT's organizational account for ArcGIS Online.

For the RCI database, TranStat has produced handbooks to provide a comprehensive description of the roadway data stored in the Department's RCI database and explain how to retrieve data from the database.

For traffic information, there are two web-based mapping applications:

- Florida Traffic Online – traffic count site locations and historical traffic count data
- Real-Time Traffic Information – real-time traffic count information

Moreover, the Florida Transportation Information (FTI) DVD is available for users to locate, identify, and access the information from thousands of traffic count sites monitored and thousands of miles of roadway inventoried. The FTI tool contains a graphical interface to access highway and traffic data collected for the SHS and for selected off-system roads. It allows users to view either traffic or highway characteristics by visually locating a traffic site or Roadway ID on the interactive map of Florida and then selecting the information to be displayed on the map from the View menu.

Land Use, Transit and Other Databases

Land use data are available from the University of Florida GeoPlan Center at http://www.geoplan.ufl.edu/fgdl_source_links.htm. Parcel-level land use data were originally acquired from the State Department of Revenue (DOR). GeoPlan generalized 99 land use classes into 15 classes. Another land use database identified is the HERE Navigation data from the FDOT Unified Base Map Repository at https://www3.dot.state.fl.us/unifiedbasemaprepository/.

Transit data (transit routes and bus stops) usually are available in General Transit Feed Specification (GTFS) at http://www.gtfs-data-exchange.com/agency/ for some counties (e.g., Broward, Palm Beach, and Hillsborough). For counties that are not listed in GTFS (e.g., Martin, St. Lucie, Indian River), transit data can be obtained directly from the transit agencies.

In addition, other datasets may be considered as well:

- National Household Travel Survey (NHTS) – http://nhts.ornl.gov/tools.shtml
- Aerial images – http://www.labins.org/index.cfm
- Florida Geographic Data Library (FGDL) houses data from a number of federal, state, and local sources – http://www.fgdl.org/metadataexplorer/explorer.jsp

The identified existing databases and tools are summarized in Table 7.

Table 7. Identified Existing Databases and Tools

Major Existing Databases and Tools	Links
FDOT CARS – on-system and off-system crashes	www.dot.state.fl.us/safety/11A-SafetyEngineering/SafetyEngineering1.shtm
US Census Databases – demographic data	factfinder.census.gov/
FDOT TranStat GIS – RIC and traffic counts	www.dot.state.fl.us/planning/statistics/gis/.
GTFS data – transit routes and bus stops	www.gtfs-data-exchange.com/agency/
Florida Geographic Data Library – land use data	www.geoplan.ufl.edu/fgdl_source_links.htm

2.4 Input from Key Department Representatives

Input from key staff of metropolitan planning organizations (MPOs) and other local governments, as identified by FDOT, was essential to meet the objectives of this project. Thus, after identifying common variables related to demographic analysis of pedestrian safety in the literature, the project team set up interviews with key staff to discuss the findings before development of methodology. The objective of this interview was to brainstorm and identify the following:

- Inputs (variables)
- Outputs (results of analysis and modeling)
- Outcomes (engineering and education countermeasures)

For the interviews, the project team developed and presented a short PowerPoint presentation that included findings from the literature. Interviewees then provided feedback and input regarding the variables, outputs, and outcomes for demographic analysis to pedestrian safety. The input provided was used as a tool to prepare a draft methodology. Table 8 summarizes the variables for data preparation from the literature review. Presentation slides about the findings from the literature review can be found in Appendix A.

Table 8. Summary of Variables for Data Preparation from Literature

Category and Source	Variables/Factors	Frequency in Literature
Demographic & Social Factors *Source:* *US Census*	Population density	Very frequently
	Age groups	Very frequently
	Gender	Frequently
	Race/minority groups	Frequently
	Poverty by Household	Frequently
	Income	Frequently
	Work status (employment)	Frequently
	Education level	Frequently
	Car ownership	Frequently
	Marital status	LaScala, 2000&2004
	English language fluency	Cottrill, 2010; Chakravarthy, 2012
	Commute mode	Narayanamoorthy, 2013; Amoh-Gyimah, 2016
	Travel time to work	Wang, 2013
Road Environment Factors *Sources:* *FDOT RCI* *FTI* *GTFS* *Transit Agencies*	Roadway length	Frequently
	Road type	Frequently
	Intersections	Frequently
	Roundabouts	Noland, 2004
	Sidewalk density	Wang, 2013; Lassarre, 2012
	Crosswalk density	Lassarre, 2012
	Light condition	Aziz, 2013
	Posted speed limit	Dumbaugh, 2013
	Road surface	Aziz, 2013
	Traffic volume	Frequently
	Transit access	Frequently
Neighborhood Land Use Factors *Source:* *GeoPlan Center*	Land use type	Frequently
	Mixed land use	Miranda, 2011; Wang, 2013; Blazquez, 2016; Amoh-Gyimah, 2016
	Primary or secondary retail	Hess, 2014; Dissanayake, 2009
	Big box stores	Dumbaugh, 2011, 2012, 2013
	Elementary/middle school	Braseth, 2012
Individual Characteristics *Source:* *CARS*	Pedestrian age, gender, race	Frequently
	Driver age, gender, race	Frequently
	Driver action	Ha et al., 2011
	Pedestrian action	Ha et al., 2011
	Impaired or not	Moudon, 2011; Yu, 2015
	Vehicles maneuver action	Moudon, 2011; Yu, 2015
	Vehicle types	Moudon, 2011; Yu, 2015

A GoToMeeting session with key representatives was set up and conducted to obtain support and input from engineers and/or managers on application of demographic analysis to pedestrian safety. The project team coordinated the meeting and documented the discussions. Table 9 lists the attendees at this GoToMeeting.

Table 9. Attendees at GoToMeeting

Organization	Attendees
FDOT	Mark Plass, Thomas Miller. Maria Anaya de Yeats, Steven Bolyard, Yujing Xie
CUTR	Pei-Sung Lin, Rui Guo, Achilleas Kourtellis, Richard Hartman, Kristin Larsson

Guidelines for Discussion

Three major interview questions were asked in the discussion session:

- Inputs – what variables do you think are important or need to be considered for pedestrian crash analysis?
- Outputs – what are the potential outputs that you are expecting from the demographic analysis to pedestrian safety?
- Outcomes – what kind of potential outcomes are you seeking or expecting to improve pedestrian safety (e.g. education and engineering countermeasures)?

Demographic and Social Factors Discussion

Key FDOT Representative:

- For inputs/variables, there are a limited number of databases that can be used together in the GIS environment.
- What data are readily available or relatively easily available? What are the established databases that can be easily pulled out for use? For example, the variables of marital status or English language fluency may be relatively hard to obtain.
- The inputs (variables) can be filtered by what types of data that is readily-available to the department; the department then can decide the variables that are important for pedestrian crash analysis.
- The ultimate goal is to create a methodology that can be implemented statewide.

CUTR Project Team:

- The project team will notate which datasets are easily available. Ultimately, the inputs that have the highest correlation should be the ones for recommendation.

Road Environment Factors Discussion

Key FDOT Representative:

- Locations of bus stops, not only transit accessibility, are important as inputs for analysis. Many people jaywalk near bus stops (e.g., running and trying to get on the bus before it leaves), which may cause safety issues.

CUTR Project Team:

- The project team will include the bus stop location as the variable and test its correlation with pedestrian crashes.

Neighborhood Land Use Attributes Discussion

Key FDOT Representative:

- Land use type variables need to include specific locations such as check-cashing stores, convenience stores, beauty supply stores, street malls, etc.
- In a preliminary review of pedestrian-involved crashes in Broward County, there was a correlation between check-cashing stores and pedestrian-involved crashes.
- FDOT is interested in learning which land use categories are highly related to greater pedestrian hazard.

CUTR Project Team:

- The project team noted a higher pedestrian hazard near specific land use types such as big-box stores (e.g., Walmart) and fast-food restaurants. The more detailed land use categories in the commercial development land use type will be included and tested.
- The existing educational outreach projects conducted by CUTR found a high correlation between pedestrian crashes, Walmart locations, and crime rates. The crime rates and pedestrian crashes may be both highly related to lighting conditions. The project team will exam the correlated variables (e.g., lighting conditions and crime rates) and recommend those that can better represent the pre-conditions for greater pedestrian hazard.

Other Discussion:

- It is important to include a practical perspective into this project. For example, the datasets need to be readily- and easily-available for all FDOT Districts. The outcomes from the analysis need to be efficient and implementable to better allocate resources for pedestrian safety improvements.

From the interviews, several important input variables were identified, such as location of bus stops, detailed land use categories (specific locations such as check-cashing stores, convenience stores, beauty supply stores, street malls, etc.). Interviewed FDOT staff and the project team agreed that it is important to include the practical perspective in this project. For input variables, there should be datasets readily available for all FDOT District, and research outcomes should be efficient and implementable.

Moreover, an additional land use database (i.e., Licensee Files of Public Records from the Florida Department of Business & Professional Regulations) was identified to supplement the two land use databases identified by the project team (i.e., Property Appraiser data and HERE Navigation data from the FDOT Unified database). Specific retailers that key FDOT staff recognized include Walmart, gas stations, barber shops, convenience stores, liquor stores, pawn shops, check-cashing stores, and Social Security offices. In addition, it was suggested to show roadway segment analysis and examine surrounding stores near high-crash clusters for 2–3 high pedestrian-crash corridors in low-income areas for countermeasure development.

3. DRAFT METHODOLOGY

3.1 Methodological Flowchart

Based on the interviews, the research team developed demographic-based approaches to dealing with pedestrian safety in low-income areas. Demographic variables (inputs) that should be included in the methodology were determined, as were how these variables would be analyzed to produce the results of the analysis of these variables (outputs) and how those outputs could be implemented to produce the desired recommendations (outcomes) for engineering countermeasures and pedestrian safety education/outreach plans.

Figure 5 illustrates the methodological flowchart for the demographic analysis of pedestrian safety, which consists of six steps:

Step 1. Data Collection and Compilation
Step 2. Data Preparation by Analysis Unit
Step 3. GIS Visualization and Spatial Analysis
Step 4. Statistical Tests and Modeling
Step 5. Discussion of Results of Data Analysis
Step 6. Education and Engineering Countermeasures

Step 1. Data Collection and Compilation

Pedestrian crash, census, roadway environment, and land use data were collected from different sources. The datasets developed for this project were collected and compiled from the following five major sources:

- FDOT GIS Crash Data – on-system and off-system crashes
- US Census Geodatabases – demographic data
- FDOT TranStat GIS – Roadway Characteristics Inventory (RCI) and traffic counts
- GTFS data – transit routes and bus stops
- Florida Geographic Data Library (FGDL) – parcel-level land use data

Step 2. Data Preparation by Analysis Unit

Based on the compiled data, the ArcGIS platform was used to visualize different data by different layers. Low-income areas were identified through mapping cluster analysis based on poverty-related data. All candidate variables were prepared by analysis unit, which include:

- Aggregated at census tract level
- Aggregated at census block group level
- Disaggregated at crash level (with crash buffer)

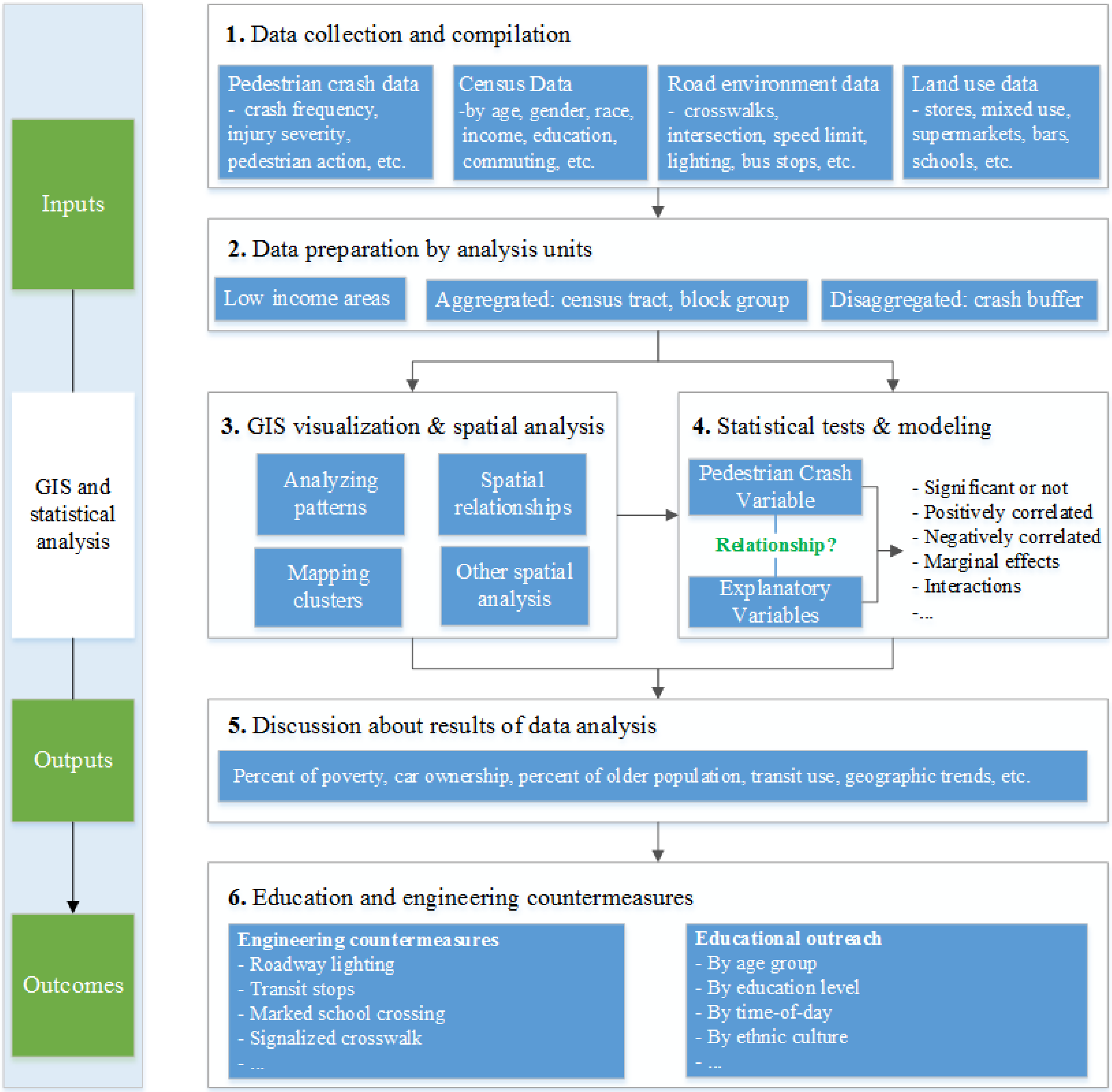


Figure 5. Methodological flowchart

Step 3. GIS Visualization and Spatial Analysis

A GIS environment was used to generate and process data from available sources and analyze spatial patterns, clustering, and the relationship of the variables that were selected based on the previous comprehensive literature review. Demographic, land use, and road inventory data were mapped, and their pattern, clusters, and spatial relationship with pedestrian crash data were analyzed. Global Moran’s I spatial autocorrelation analysis was used to describe spatial patters of pedestrian crashes. Hot Spot analysis was used to detect clusters among pedestrian crashes, Proximity analysis was implemented to explore the relationship between location of various land uses and pedestrian clashes, and kernel density function aided data visualization. The data generated in the GIS environment served as an input to the statistical testing and modeling. Details about GIS analysis can be found in Appendix B.

Step 4. Statistical Tests and Modeling

Through statistical tests and modeling, demographic and other variables and how they are correlated to pedestrian crash rates were identified. Statistical analysis was used to:

- Identify pedestrian crash patterns by location, severity, time, pedestrian age group, and other factors.
- Identify and quantify factors contributing to pedestrian crash occurrence (especially for fatal crashes) in low-income areas.
- Identify and quantify factors associated with RCI contributing to pedestrian crash injury-severity in low-income areas.
- Identify and quantify factors associated with demographics contributing to pedestrian crash injury-severity in low-income areas.

In statistical modeling, demographic factors can be handled by both the dependent variables (e.g., pedestrian crash frequency by pedestrian age group or pedestrian gender) and the explanatory variables (e.g., population size by age group, gender or race in spatial units in low-income areas). The best combination of various variables can be examined through a methodology test. Details about statistical tests and modeling can be found in Appendix C and Appendix D, respectively.

Step 5. Discussion of Results of Data Analysis

The geographic analysis and statistical modeling of the identified variables (inputs) will produce results (outputs) such as percentage of poverty, percentage or level of car ownership, percentage of older population, percentage of transit use, marginal effects of child size, marginal effects of sidewalk, geographic trends, and so on.

Step 6. Education and Engineering Countermeasures

Informed by the outputs, the outcomes for both engineering countermeasures (e.g., roadway lighting, signalized crosswalks, etc.) and education/outreach plans (e.g., by age group or ethnic culture, etc.) will be recommended for implementation.

3.2 Statistical Methodology

Pedestrian Crash Frequency: Negative Binomial Regression Model

A wide range of statistical methodologies has been developed to describe the relationship between crash frequency and a set of explanatory variables. These methodologies were reviewed and are discussed in Appendix D. In this project, the negative binomial (Poisson-Gamma) regression model was used to quantify the factors that affect the occurrence of pedestrian crashes.

Poisson regression model and negative binominal regression model are two of most commonly-used models in traffic crash frequency modeling, as the distribution of Poisson distribution and negative binominal distribution can well simulate that of count data. However, the assumptions of equal mean and variance of events in the Poisson distribution sometimes make it unsuitable for real-life situations, as there is a possibility of under-dispersion and over-dispersion. In such cases, the negative binomial distribution was proposed as a generalization of the Poisson distribution since it has the same mean structure as Poisson regression and has an extra parameter to model the over-dispersion. Different from the most common relationship between explanatory variables and the Poisson parameter as shown in Equation (1):

$$\lambda_i = EXP\ (\beta X_i) \text{ Or, equivalently } LN\ (\lambda_i) = \beta X_i \tag{1}$$

The negative binomial regression model is derived by introducing a disturbance term ε_i, for each observation i, as shown in Equation (2),

$$\lambda_i = EXP\ (\beta X_i + \varepsilon_i) \tag{2}$$

where X_i is a vector of explanatory variables, β is a vector of estimable parameters and $EXP(\varepsilon_i)$ is a Gamma-distributed disturbance term with mean 1 and variance α. The addition of this term allows the variance to differ from the mean as shown in Equation (3),

$$VAR[y_i] = E[y_i][1 + \alpha E[y_i] = E[y_i] + \alpha E[y_i]^2 \tag{3}$$

The Poisson regression model is regarded as a limiting model of the Negative Binominal regression model as α approaches zero, which means that the selection between these two models is dependent upon the value of α. The parameter α is often referred to as the over-dispersion parameter. The probability density function for the negative binomial distribution can be expressed as Equation (4),

$$P_r(y_i) = \frac{\Gamma(y_i+1/\alpha)}{\Gamma(1/\alpha)y_i!}\left(\frac{\alpha\lambda_i}{1+\alpha\lambda_i}\right)^{y_i}\left(\frac{1}{1+\alpha\lambda_i}\right)^{1/\alpha} \tag{4}$$

In this way, the Poisson regression model is nested within the negative binomial regression and statistical tests for $\alpha = 0$ can be used to evaluate the significant presence or amount of over-dispersion in the data. If the conditional distribution of the outcome variable is over-dispersed, the confidence intervals for negative binomial regression are likely to be narrower as compared to those from a Poisson regression.

Pedestrian Crash Injury Severity: Logistic Regression Model

Logistic regression (or logit model) is a regression model in which the dependent variable is categorical. Logistic regression can be regarded as a special case of a generalized linear regression model. It measures the relationship between categorical dependent variables and one or more independent variables by estimating probabilities using a logit function as the link function, which is a cumulative logistic distribution. For logistic regression, the dependent is the population proportion or probability (P) that the resulting outcome indicates the presence of a condition—usually denoted using a binary indicator variable coded as 1 or 0. In developing the logistic regression equation, the LN of the odds represents a logit transformation, there the logit is a function of covariates such that

$$Y_i = logit\ (P_i) = LN\ \left(\frac{P_i}{1 - P_i}\right) = \beta_0 + \beta_1 X_{1,i} + \beta_2 X_{2,i} + \cdots + \beta_k X_{k,i} \quad (5)$$

where β_0 is the model constant and the $\beta_1 \cdots \beta_k$ are the unknown parameters corresponding with the explanatory variables $(X_k, k = 1, \cdots, k\ the\ set\ of\ independent\ variables)$. In Equation 1, the unknown binominal probabilities are a function of explanatory variables (which may include both continuous and discrete variables).

Although analogous to linear regression, the model of logistic regression is based on different assumptions. First, the conditional distribution of a dependent variable based on an explanatory variable is Bernoulli distribution rather than normal distribution. In addition, the distribution of errors for logit models is assumed to be standard logistic distribution. In addition, logistic regression predicts the probability of particular outcomes through logistic function. Therefore, the predicted values are restricted between 0 and 1.

According to the characteristics of dependent variables, logistic regression can be grouped into three basic categories: binary logistic regression, multinomial logistic regression, and ordered logistic regression. A binary logit model deals with a situation in which there are only two categories of dependent variables, whereas in multinomial logit regression, there are more than two categories of discrete outcomes. Ordered logistic regression is a regression model for ordinal dependent variables that can be applied to dichotomous dependent variables while allowing for more than two ordered response categories.

In addition, some basic principles are useful in the development and interpretation of these models: odds, odds ratio, and the log of odds ratios, or log (odds). Odds are related to probability but are conceptually and numerically different. Odds describe likelihood of events. Odds are related to probability such that O = P/ (1-P). Odds ratios are useful for comparing the likelihood of two events. It can be presented as O_1/O_2. For analytical convenience the odds ratio is often scaled using a natural logarithmic transform, which gives the log of the odds ratio.

4. METHODOLOGY TEST

In this section, the following subtasks were completed in the methodology test: (a) tested the methodological flowchart developed (Figure 5) for demographic analysis; (b) provided the analysis results and findings for FDOT District 4 to demonstrate the kind of outputs and outcomes to be generated by following the developed methodology; and (c) verified that the methodology is implementable by using available datasets such as FOOT GIS databases, Census data, and other easily-available data sources. The details of each subtask are described in the following sections.

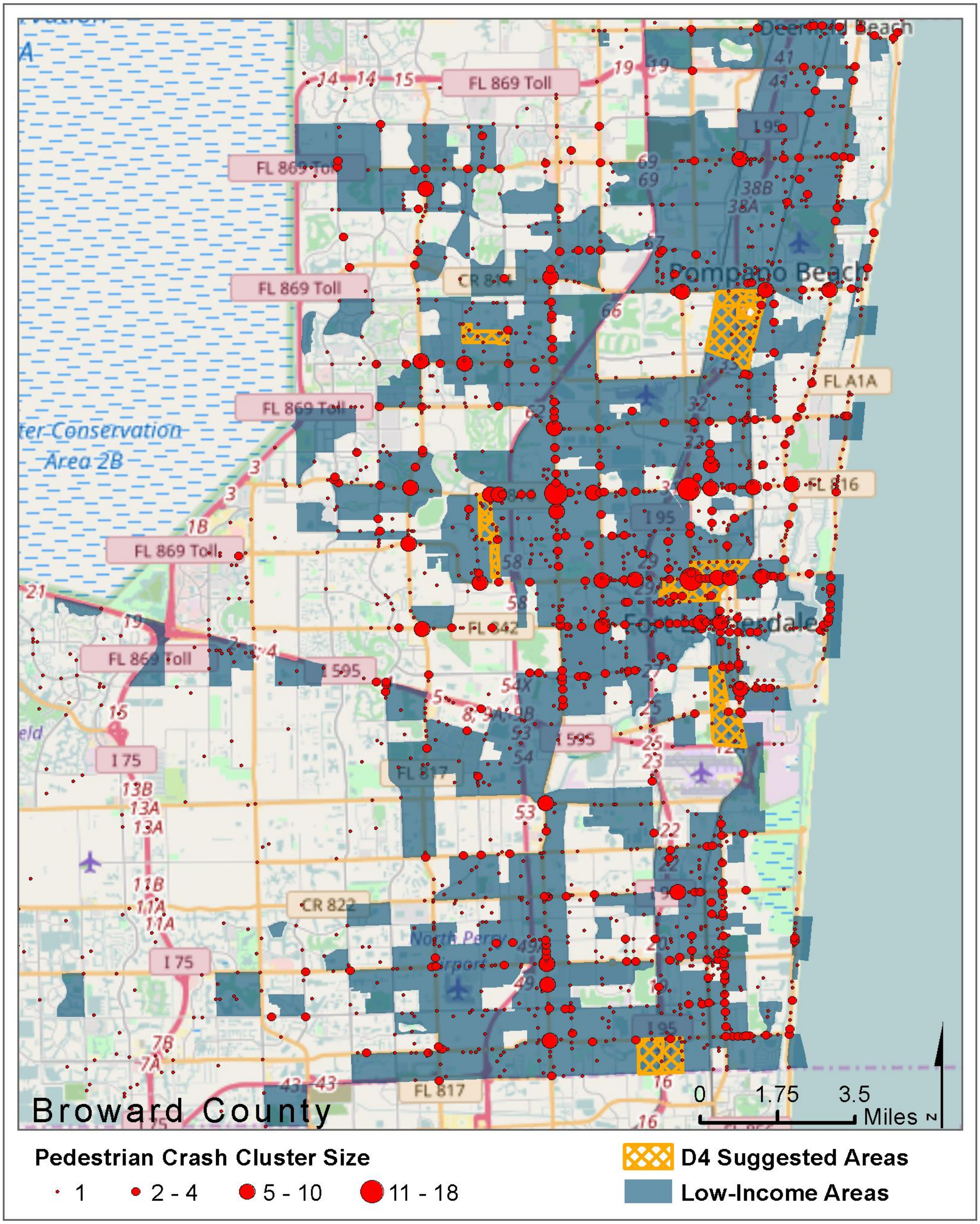
4.1 Definition/Identification of Low-income Area

To explore the correlations between pedestrian crash frequency and a set of pre-conditions such as demographic factors and land use types, geographical/spatial units are needed to aggregate crashes and different variables. The commonly-used spatial units for crash frequency analysis are census BGs and tracts. For this project, census BGs, the smallest geographical unit for which the bureau publishes sample data, were selected for pedestrian crash analysis because they can provide relatively less variations in their internal community design characteristics.

Based on "America's Poor Neighborhoods Plagued by Pedestrian Deaths" (*Governing*, 2014), low-income areas and poor neighborhoods are defined based on per-capita income and poverty rates in a census area, as shown previously in Table 1. Accordingly, in this project, poverty rates (percent of households below poverty level in a census area) and per-capita income, obtained from the American Community Survey (ACS), were used to categorize census BGs into low-income BGs and higher-income BGs:

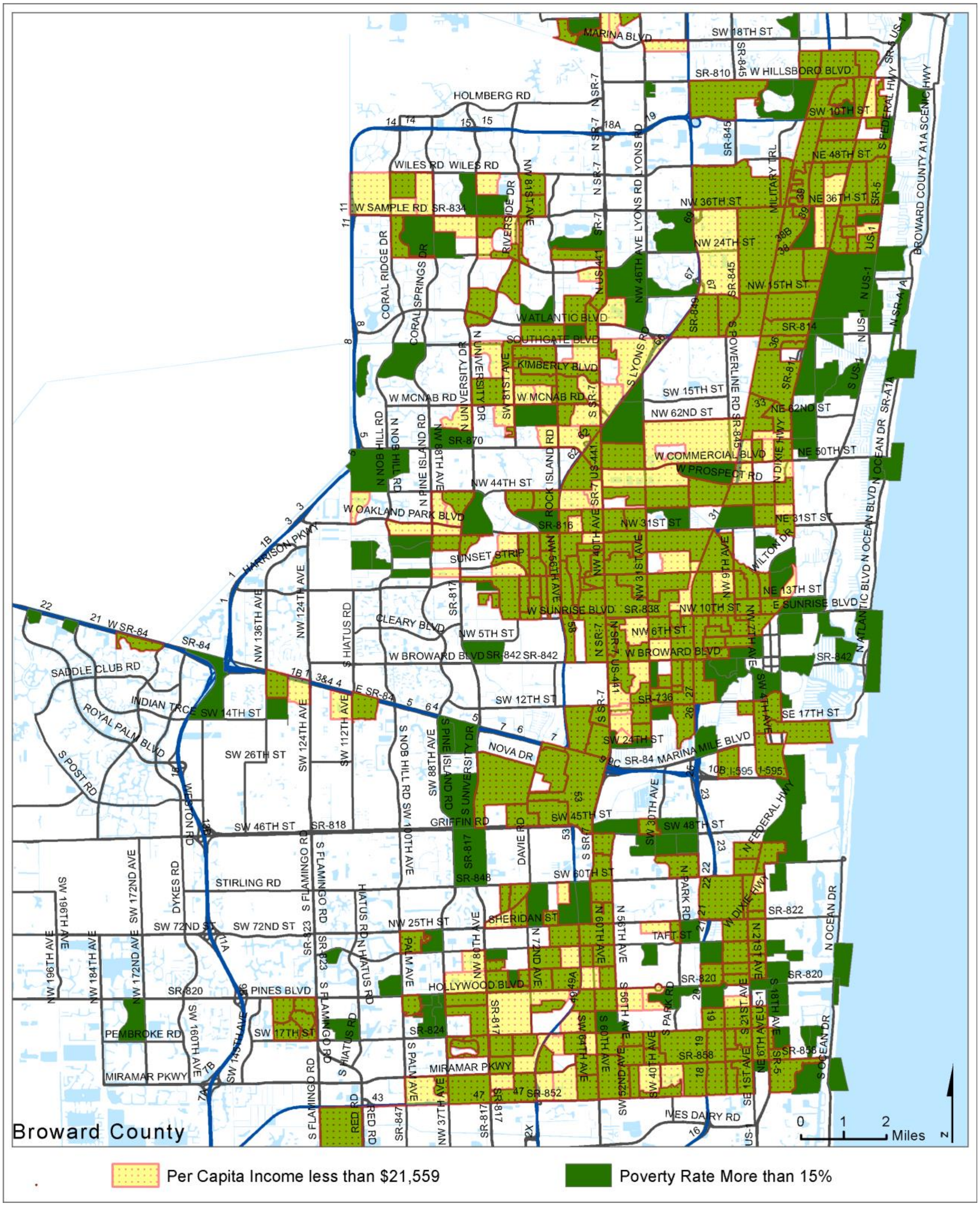
- Low-income BGs – poverty rates >15% or per-capita income < $21,559
- Higher-income BGs – poverty rates ≤ 15% or per-capita income ≥ $21,559

Based on the definition of low-income areas, 475 census BGs of a total of 939 were identified as low-income areas in Broward County, as illustrated in Figure 6(a). Similarly, 337 census BGs of 876 were identified as low-income areas in Palm Beach County, as illustrated in Figure 7(a). As shown in Figure 6(b) and Figure 7(b), the BGs with poverty rates larger than 15% do not always overlap the BGs with per-capita income less than $21,559. For example, a few BGs along A1A in Broward County were identified as low-income BGs due to poverty rates, but the per-capita income in those BGs is actually higher than the income thresholds. As determined by the Census Bureau, the poverty thresholds vary by size of family and age of members (e.g., number of children). As pointed out by the Census Bureau, although the thresholds, in some sense, reflect a family's needs, they are intended for use as a statistical yardstick, not as a complete description of what people and families need to live.



(a) Identified low-income block groups in Broward County
(*Note:* Either poverty rates >15% or per-capita income < $21,559 for low-income BGs)

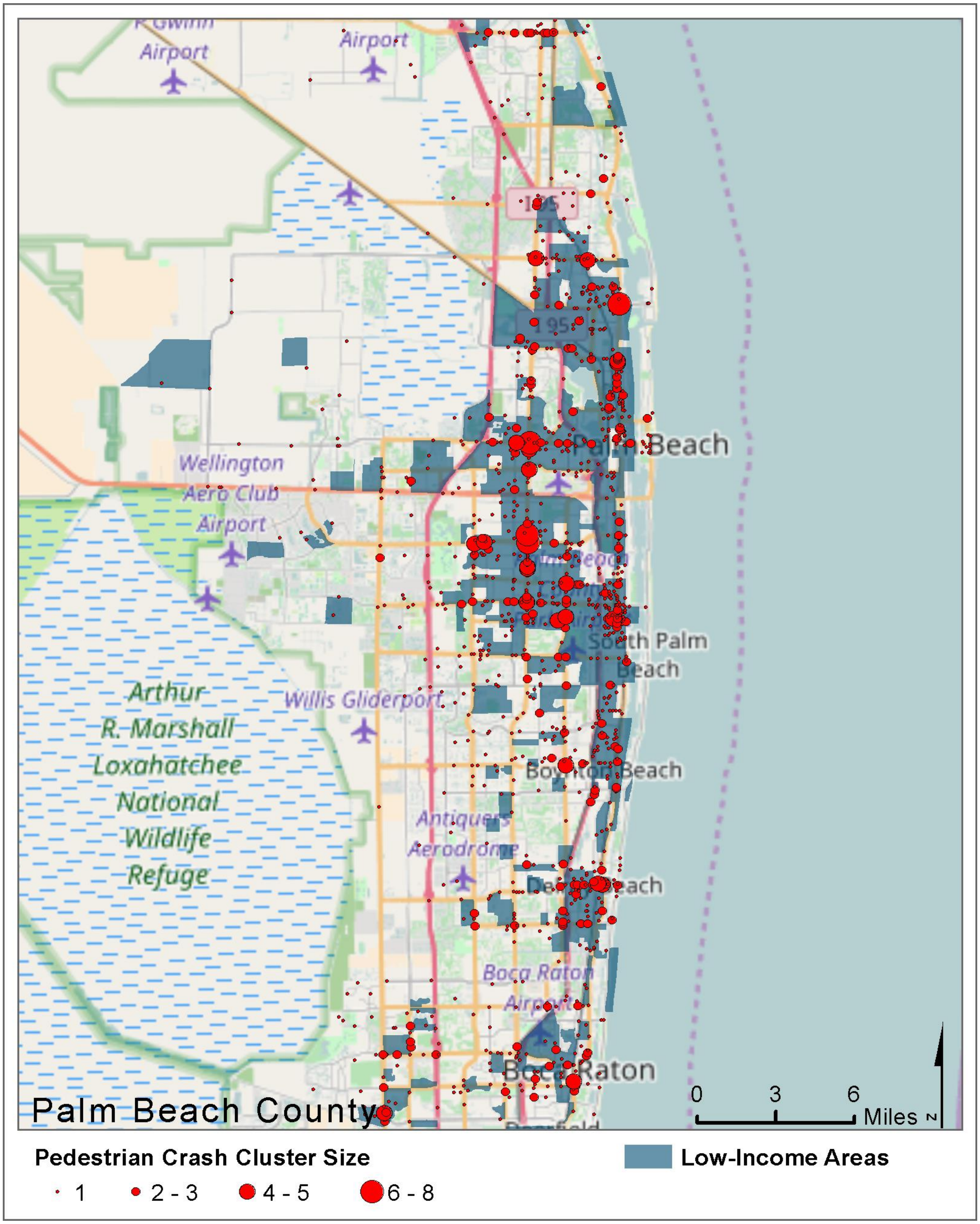
Figure 6. Identified low-income area in Broward County



🟨 Per Capita Income less than $21,559 🟩 Poverty Rate More than 15%

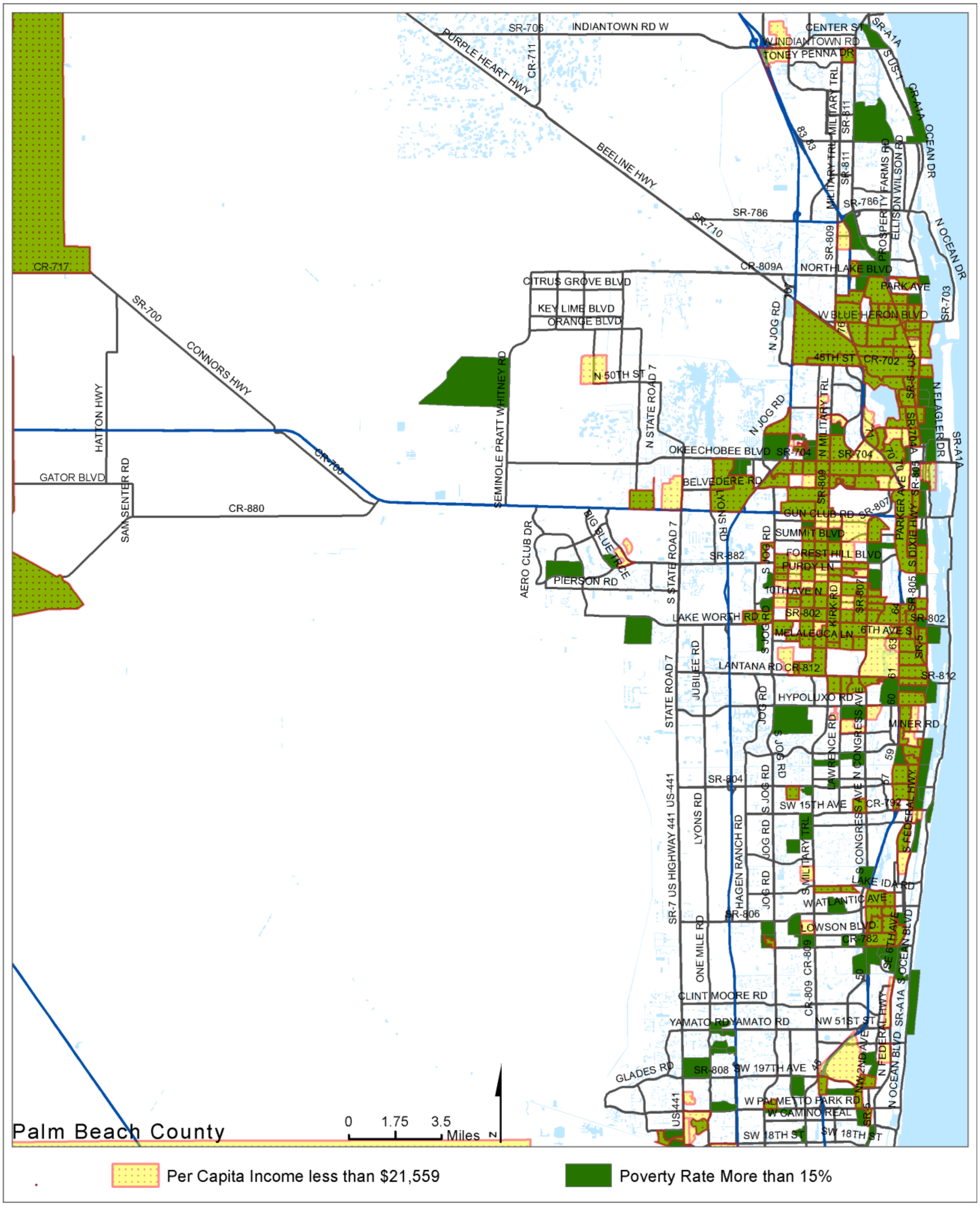
(b) Block group poverty rate and per capita income in Broward County

Figure 6. Identified low-income area in Broward County (*cont*).



(a) Identified low-income block groups in Palm Beach County
(*Note:* Either poverty rates >15% or per-capita income < $21,559 for low-income BGs)

Figure 7. Identified low-income Block Groups in Palm Beach County



(b) Block group poverty rate and per capita income in Palm Beach County

Figure 7. Identified low-income Block Groups in Palm Beach County (*cont.*)

4.2 Analysis of Pedestrian Crash Frequency (Aggregated Analysis)

For the analysis of pedestrian crash frequency, pedestrian crashes, demographic factors, road environment, and land use attributes were aggregated at geographical/spatial units (i.e., census BGs in this study) to test and model their spatial correlations. Two counties in FDOT District 4, Broward and Palm Beach, were used for this study to show the analysis results. By removing the BGs with no population, 812 were identified as valid low-income BGs based on the definition above.

Pedestrian Crash Data

Geo-located pedestrian crashes occurring between 2011 and 2014 were derived from the FDOT CARS in Broward and Palm Beach counties.

To capture the information occurring on the boundaries of the spatial units, the approach in previous literature was followed, and a 100-ft buffer was developed around each block group, as shown in Figure 7. Crash information can be assigned within the BG itself as well as within the buffer area along its edges. For example, there were 28, 19, 14, and 32 pedestrian crashes in BGs A, B, C, and D, respectively, as shown in Figure 8.

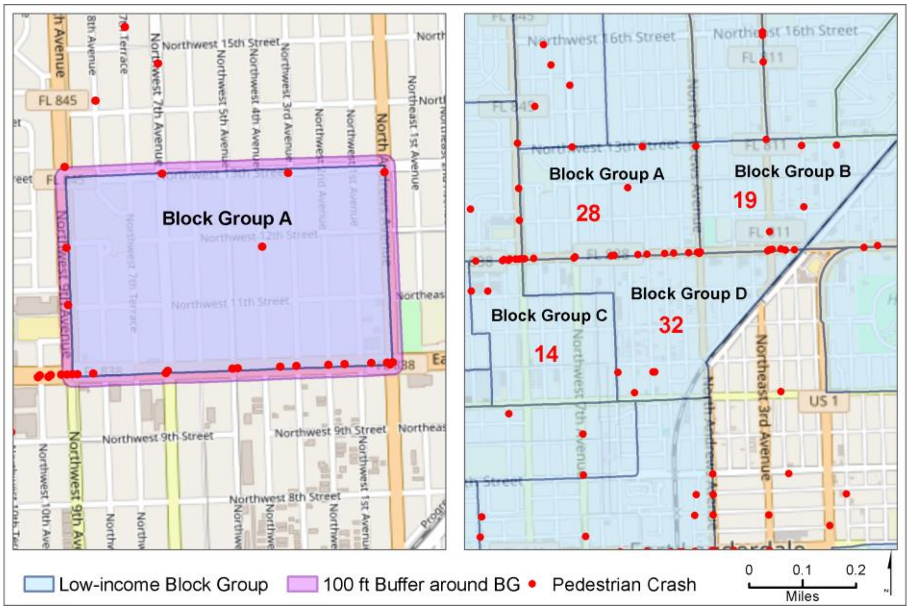


Figure 8. Illustrative census block groups and buffer

To explore the relationship between pedestrian crashes and explanatory variables by following the flowchart in Figure 5, the dependent variables can be processed in different ways, as shown in Table 10. In this study, two dependent variables, pedestrian crash frequency and severe injury pedestrian crash frequency, were tested, and other dependent variables can follow the same approach. “All pedestrian crash frequency” is the most commonly-used dependent variable in a frequency analysis, and severe injury pedestrian crashes are the major concern or interest related to pedestrian crashes for most people. Severe injury pedestrian crashes are the highest crash severity, fatality, or incapacitating injury. As defined in CARS, there are five levels of crash injury severity: 1 – No injury, 2 – Possible injury, 3 – Non-incapacitating injury, 4 – Incapacitating injury, and 5 – Fatality (within 30 days).

Table 10. Descriptive Statistics of Prepared Crash Frequency Data

(Number of low-income block groups: 812)

Dependent Variables	Variable Description	Low-income Block Groups		
		Mean	*Min*	*Max*
All pedestrian crashes	Pedestrian crash frequency	6.28	0	44
Severe injury crashes	Severe injury pedestrian crash frequency	1.65	0	17
Daytime	Daytime pedestrian crash frequency	3.42	0	22
Non-daytime	Non-daytime pedestrian crash frequency	2.81	0	26
Male pedestrian	Male pedestrian crash frequency	2.86	0	29
Female pedestrian	Female pedestrian crash frequency	1.62	0	13

Demographic and Social Factors

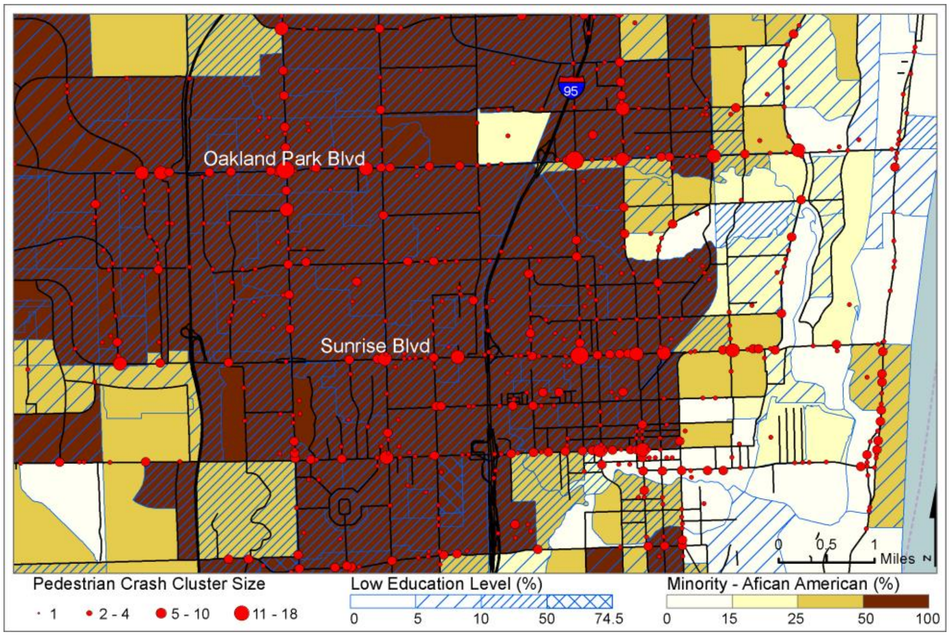
To account for the effects that demographic and social factors may have on pedestrian crash frequency, demographic data were obtained for 2010–2014 from the US Census Bureau's TIGER/Line® with Selected Demographic and Economic Data, which incorporates geography from the 2014 TIGER/Line® shapefiles and data from the 2010–2014 ACS Five-year Estimates. Based on the findings from literature review and interview, the identified variables related to demographic and social factors were tested in data analysis, as shown in Table 11.

Table 11. Descriptive Statistics of Prepared Demographic Data

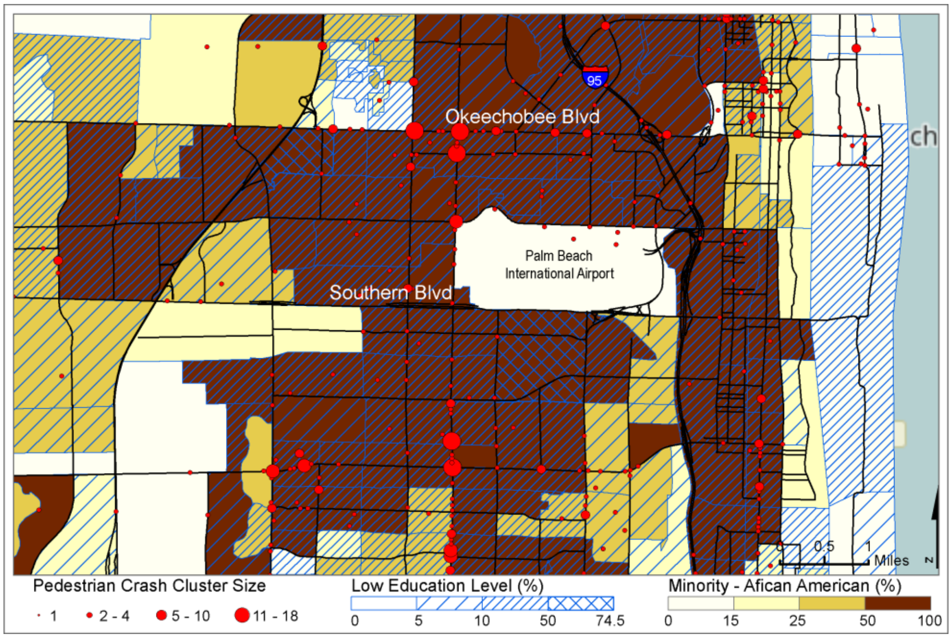
(Number of low-income block groups: 812)

Demographic & Social Factors	Variable Description	Low-income Block Groups
		Mean
Population	Population in thousands	1.70
Age & gender	Proportion of children (ages 5–14) (%)	11.60
	Proportion of older adults ($\geq$ age 65) (%)	16.71
Minority groups	Proportion of African American population (%)	34.14
	Proportion of Hispanic population (%)	25.80
Poverty & income	Proportion of households below poverty level (%)	23.06
	Income per capita	$20,090.73
Employment	Proportion of unemployed people (%)	14.79
Commuting mode	Proportion of commuters using public transit or biking (%)	5.51
Car ownership	Proportion of households with zero car (%)	11.00
Education	Proportion of population less than high school (%)	20.13
English fluency	Proportion of limited English speaking households (%)	12.06

As shown in Figure 9, higher pedestrian crashes appear to be correlated with higher proportions of minority and low-education-level population areas. Similar trends were observed for commuters using public transit and zero-car ownership neighborhoods. To test these hypotheses, the statistical model (negative binomial model) was used. For the highly-correlated variables indicated in the correlation test (e.g., proportion of children and proportion of older adults), only one was used in the model.



(a) Demographics and pedestrian crashes in Broward County



(b) Demographics and pedestrian crashes in Palm Beach County

Figure 9. Illustrative correlation between demographics and pedestrian crashes

Based on the results of the statistical modeling, it was validated that pedestrian crashes are more frequent in BGs that have low-income populations and a smaller proportion of older adults, are minority-dominated and zero-car ownership neighborhoods, and are among populations with low education levels, as shown Table 12. In addition to the analysis for all pedestrian crashes, severe injury pedestrian crash frequency was tested. The statistical modeling results showed that severe injury pedestrian crashes are more frequent in low-income BGs with more population, a smaller proportion of older adults, have a higher proportion of households without a car, and are among populations with a low education level. Total and minority population and commuting modes did not show significant correlation with severe injury pedestrian crash frequency. The details of the modeling results can be found in Table 28 in Appendix E.

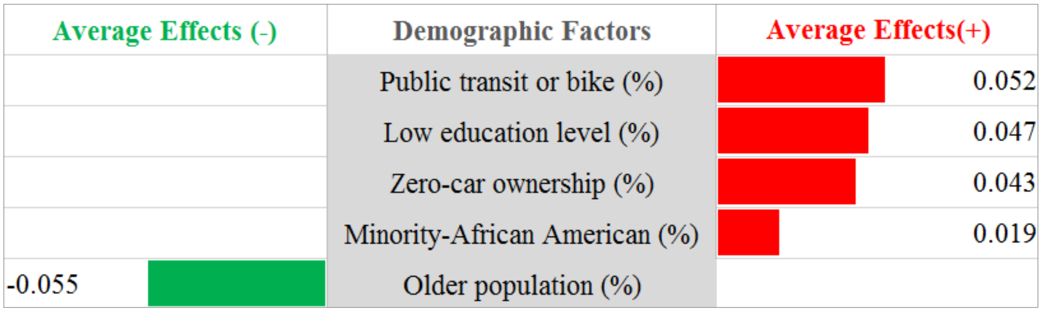
Table 12. Correlation between Pedestrian Crash Frequency and Demographic Factors

Demographic & Social Factors *(Source: US Census)*	**Pedestrian Crash Frequency in Low-income Block Groups**	**Severe Injury Pedestrian Crash Frequency in Low-income Block Groups**
Population in thousands	⊕ Positive correlation	⊕ Positive correlation
Older adult population (%)	⊖ Negative correlation	⊖ Negative correlation
African American (%)	⊕ Positive correlation	No significant correlation
Hispanic (%)	No significant correlation	No significant correlation
Employment (%)	No significant correlation	No significant correlation
Public transit or bike to work (%)	⊕ Positive correlation	No significant correlation
Walk to work (%)	No significant correlation	No significant correlation
Zero-car ownership (%)	⊕ Positive correlation	⊕ Positive correlation
Low education level (%)	⊕ Positive correlation	⊕ Positive correlation

Specifically, the following demographic factors are significantly correlated with pedestrian crash frequency. Figure 10 illustrates the effects of these demographic factors on pedestrian crash frequency.

- **Population** – Population in BGs is positively correlated with pedestrian crash frequency. On average, an increase of 1,000 in population results in an average increase of 0.910 pedestrian crashes in 4 years in a low-income BG. ⊕
- **Older adult population** – The proportion of older adult population is negatively correlated with pedestrian crash frequency. On average, a 1% increase in older adult population results in an average decrease of 0.055 pedestrian crashes in 4 years in a low-income BG. ⊖
- **Minority** – Pedestrian crashes are more frequent in BGs with a higher proportion of African American population. On average, a 1% increase in minority and African American population results in an average increase of 0.019 pedestrian crashes in 4 years in a low-income BG. ⊕

- **Public transit or biking to work** – BGs with a higher proportion of commuters using public transit or biking are more likely to be associated with a higher number of pedestrian crashes. On average, a 1% increase in commuters using public transit or biking results in an average increase of 0.052 pedestrian crashes in 4 years in low-income BGs. ⊕
- **Zero-car ownership** – BGs with a higher proportion of households without vehicles are more likely to have a higher number of pedestrian crashes. This mostly likely is because residents rely on public transportation or walk to work and, consequently, gain more pedestrian exposure time on roads. On average, a 1% increase in zero-car households results in an average increase of 0.043 pedestrian crashes in 4 years in a low-income BG. ⊕
- **Low education** – The proportion of people with a low education level (less than high school) is a significant factor for a higher number of pedestrian crashes. On average, a 1% increase in low education-level population results in an average increase of 0.047 pedestrian crashes in 4 years in a low-income BG. ⊕



Average Effects (-)	Demographic Factors	Average Effects(+)
	Public transit or bike (%)	0.052
	Low education level (%)	0.047
	Zero-car ownership (%)	0.043
	Minority-African American (%)	0.019
-0.055	Older population (%)	

Figure 10. Effects of demographic factors on pedestrian crash frequency

The average marginal effects on pedestrian crash frequency indicate that the top four influential variables related to demographic characteristics are the proportion of older adults (negative effect), the proportion of commuters using public transit or biking, the proportion of people with a low education level (less than high school), and the proportion of zero-car ownership.

Road Environment Factors

Road environment data were acquired from FDOT TranStat GIS shapefiles and geodatabases, and bus stop location data were collected from GTFS or obtained directly from transit agencies. Based on the findings from the literature review and interviews, the variables related to road environment factors, as shown in Table 13, were tested in data analysis.

Table 13. Descriptive Statistics of Prepared Road Environment Data

(Number of low-income block groups: 812)

Road Factors	Variable Description	Low-income Block Groups
		Mean
Intersections	Count of intersections	25.30
Traffic signals	Count of traffic signals	2.31
Sidewalk density	Proportion of sidewalks (%)	25.14
Bike lane density	Proportion of bike lanes (%)	5.68
Bus stop locations	Number of bus stops per mile	5.30
Lower-speed roads	Proportion of lower-speed roads (%)	42.95

As shown in Figure 11, higher pedestrian crashes appeared to be correlated with a higher density of bus stop locations. Similar trends were observed for other roadway factors such as intersections and traffic signals. To test these hypotheses, roadway factors were also included in the statistical model. To include all related roadway information in the analysis, a 100-ft buffer around each BG was used when processing the road environment data.

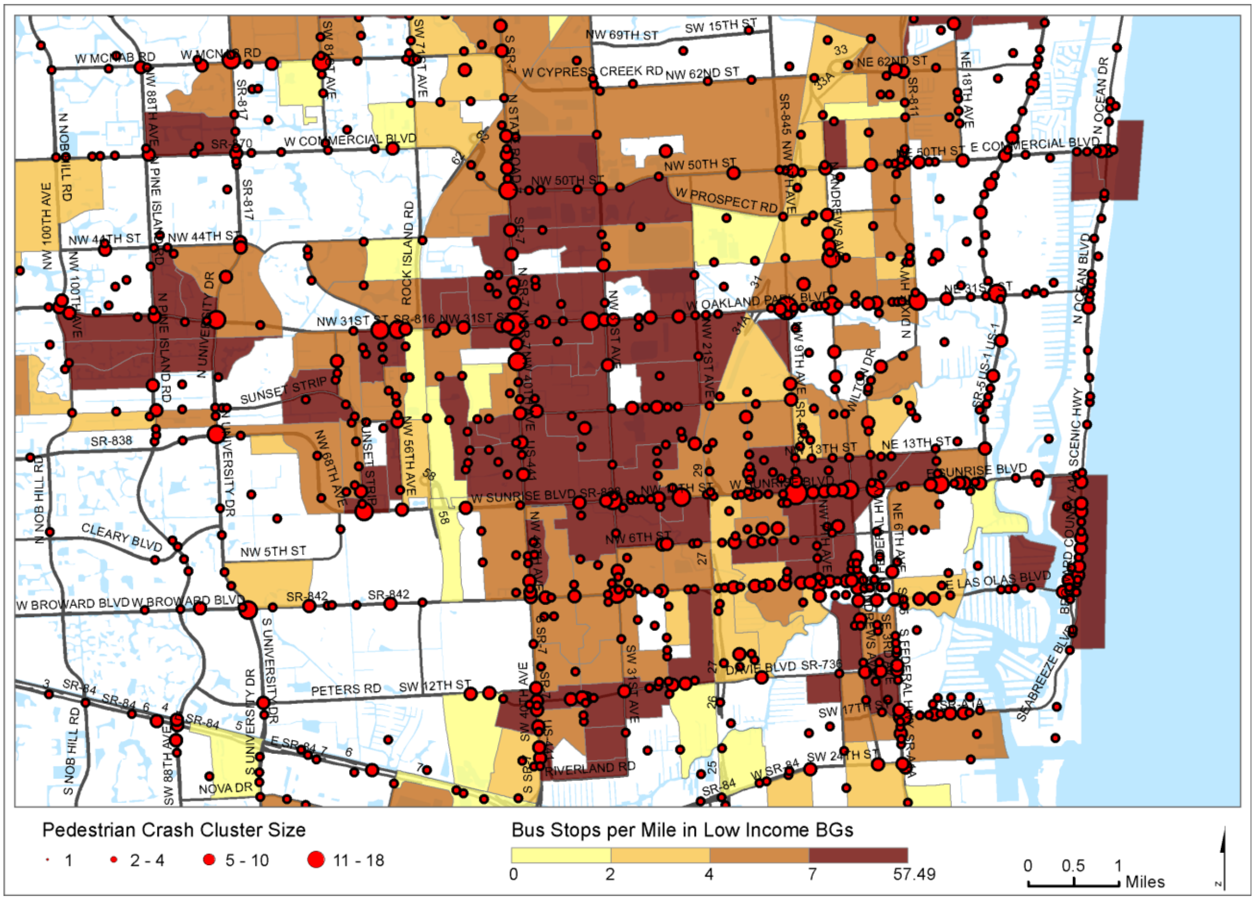


Figure 11. Illustrative correlation between bus stops and pedestrian crashes

As shown in Table 14, both total pedestrian crashes and severe injury pedestrian crashes occurred more frequently in neighborhoods with more intersections, traffic signals, bus stops, and roads with higher speed limits. As indicated in the FDOT TranStat GIS website, roadway information was compiled from the most accurate source data from the FDOT Statistics Office. However, the roadway GIS data is for reference purposes only and is not to be construed as a legal document or survey instrument. For instance, the information related to sidewalk and bike lane may be incomplete, especially for the off-State-system roads. Thus, the test of roadway factors is inconclusive at best. (See detailed results in Table 28 of Appendix E.)

Table 14. Correlation between Pedestrian Crash Frequency and Roadway Factors

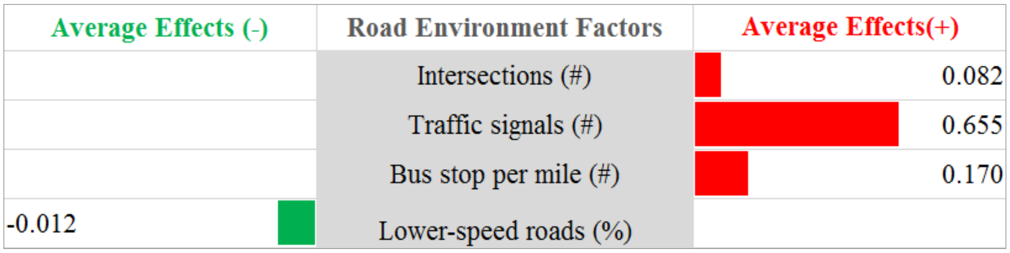
Road Environment Factors *(Sources: FDOT RCI GTFS, Transit Agencies)*	**Pedestrian Crash Frequency in Low-income Block Groups**	**Severe Injury Pedestrian Crash Frequency in Low-income Block Groups**
Intersections	⊕ Positive correlation	⊕ Positive correlation
Traffic signals	⊕ Positive correlation	⊕ Positive correlation
Sidewalk density	*No significant correlation	*No significant correlation
Bike lane density	*No significant correlation	*No significant correlation
Bus stop locations	⊕ Positive correlation	⊕ Positive correlation
Lower-speed roads	⊖ Negative correlation	⊖ Negative correlation

**Note that the test is inconclusive at best due to the concern of possibly missing data on the off State system roads and the potential random effects of these variables on the pedestrian crash occurrences.*

Specifically, the following road factors are significantly correlated with pedestrian crash frequency. Figure 12 illustrates the effects of these road factors on the pedestrian crash frequency.

- **Intersections** – The count of intersections per BG is a significant factor to heighten pedestrian crash frequency. It can be explained by possible conflicts between crossing pedestrians and turning vehicles and the complexities of traffic conditions around intersections. On average, an increase of 1 intersection results in an average increase of 0.082 pedestrian crashes in 4 years in a low-income BG. ⊕
- **Traffic signals** – The number of traffic signals per BG is positively correlated with pedestrian crash frequency. On average, an increase of 1 traffic signal results in an average increase of 0.655 pedestrian crash in 4 years in a low-income BG. ⊕
- **Bus stops** – The number of bus stops per mile in low-income BGs is positively correlated with pedestrian crash frequency. On average, an increase of 1 bus stop per mile results in an average increase of 0.17 pedestrian crashes in 4 years in a low-income BG. ⊕
- **Lower-speed roads** – The proportion of local roads and collectors is negatively correlated with pedestrian crash frequency. Local and collector roads typically are designed for speeds between 20 and 35 mph, and lower speed limits can reduce stopping

sight distances and allow drivers to brake quickly should they encounter a pedestrian. On average, a 1% increase in the proportion of lower-speed roads results in an average decrease of 0.012 pedestrian crashes in 4 years in a low-income BG. ⊖



Average Effects (-)	Road Environment Factors	Average Effects(+)
	Intersections (#)	0.082
	Traffic signals (#)	0.655
	Bus stop per mile (#)	0.170
-0.012	Lower-speed roads (%)	

Figure 12. Effects of road environment factors on pedestrian crash frequency

Average marginal effects on pedestrian crash frequency indicate that the most influential variable related to roadway factors is the number of traffic signals per BG, followed by the number of bus stops per mile. The third most influential variable is the proportion of lower-speed road (negative effect). The increase on the proportion of lower-speed roads in a low-income BG can help decrease pedestrian crashes.

Neighborhood Land Use Attributes

Different land use types may have different effects on pedestrian crash frequency because some land use types are major trip attractors to pedestrians and some are not. Due to the difficulty of obtaining all the land use types from a single data source, three different data sources were used to download parcel-level land use data:

- Property Appraiser data from the Florida Geographic Data Library (e.g., Walmart stores, schools, bars, hotels, churches, shopping centers)
- HERE Navigation data from FDOT Unified database (e.g., grocery stores, convenience stores, discount stores, fast-food restaurants)
- Licensee Files of Public Records from the Florida Department of Business & Professional Regulations (e.g., barber shops, beauty salons)

Based on the findings from the literature review and interviews, the variables related to neighborhood land use attributes were tested in data analysis, as shown in Table 15.

As shown in Figure 13, pedestrian crash hot spots appeared to be correlated with the presence or counts of some land use types such as fast-food restaurants, convenience stores, Walmart stores, and discount stores. To exam these hypotheses, different land use types were included in the statistical model.

Table 15. Descriptive Statistics of Prepared Land Use Data

(Number of low-income block groups: 812)

Land Use Types	Variable Description	Low-income Block Groups
		Mean
Walmart stores	Presence of Walmart stores in low-income block group	0.02
Discount stores	Number of discount department stores per sq. mi.	0.76
Convenience stores	Number of convenience stores per sq. mi.	5.40
Fast-food restaurants	Number of fast-food restaurants per sq. mi.	7.14
Grocery stores	Number of grocery stores per sq. mi.	3.52
Barber shops	Number of barber shops per sq. mi.	2.35
Beauty salons	Number of beauty salons per sq. mi.	7.39
Bars	Number of bars per sq. mi.	0.72
Schools	Number of public schools per sq. mi.	1.19
Churches	Number of churches per sq. mi.	7.83
Hotels	Number of hotels and motels per sq. mi.	2.74
Shopping centers	Presence of shopping centers in low-income block group	0.17

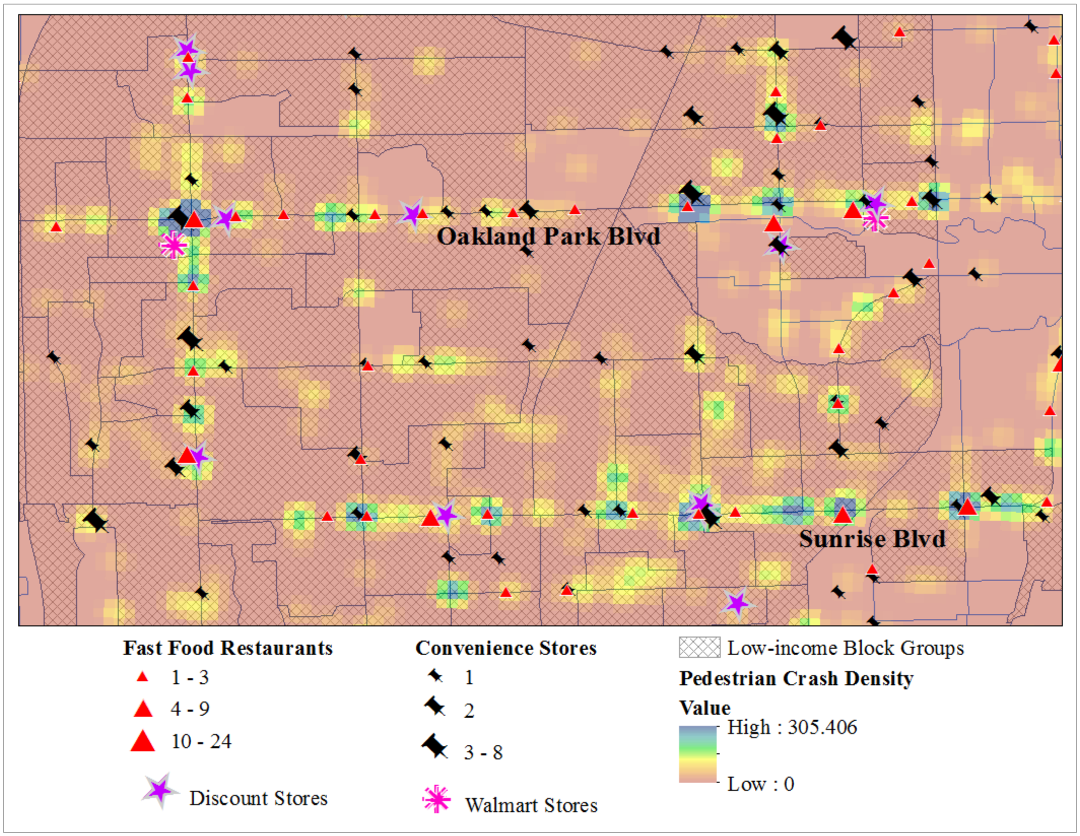


Figure 13. Illustrative correlation between land use types and pedestrian crashes

As shown in Table 16, pedestrian crashes occurred more frequently in low-income neighborhoods with a Walmart store and with greater densities of discount department stores, fast-food restaurants, convenience stores, grocery stores, and barber shops. In addition to the analysis for all pedestrian crashes, severe injury pedestrian crash frequency was tested. The statistical modeling results showed that severe injury pedestrian crashes are more frequent in neighborhoods with greater densities of discount department stores and fast-food restaurants. The presence of a Walmart store, convenience stores, grocery stores, or barber shops did not show significant correlation with severe injury pedestrian crash frequency. Other land use types that showed no significant correlation with pedestrian crash frequency or severe injury pedestrian crash frequency include beauty salons, bars, schools, churches, hotels, and shopping centers. (See detailed results in Table 28 of Appendix E.)

Table 16. Correlation between Pedestrian Crash Frequency and Land Use Types

Land Use Factors *(Source: FGDL; HERE; License)*	**Pedestrian Crash Frequency in Low-income Block Groups**	**Severe Injury Pedestrian Crash Frequency in Low-income Block Groups**
Walmart stores	⊕ Positive correlation	No significant correlation
Convenience stores	⊕ Positive correlation	No significant correlation
Fast-food restaurants	⊕ Positive correlation	⊕ Positive correlation
Grocery stores	⊕ Positive correlation	No significant correlation
Discount stores	⊕ Positive correlation	⊕ Positive correlation
Barber shops	⊕ Positive correlation	No significant correlation
Beauty salons	No significant correlation	No significant correlation
Bars	No significant correlation	No significant correlation
Schools	No significant correlation	No significant correlation
Churches	No significant correlation	No significant correlation
Hotels	No significant correlation	No significant correlation
Shopping centers	No significant correlation	No significant correlation

Specifically, the following land use factors are significantly correlated with pedestrian crash frequency. Figure 14 illustrates the effects of these land use types on pedestrian crash frequency.

- **Walmart stores** – The presence of a Walmart store is likely to increase the pedestrian crash frequency in a low-income BG when compared to one without a Walmart store. On average, the presence of a Walmart store in a low-income BG results in an average increase of 1.803 pedestrian crashes in 4 years. ⊕
- **Discount stores** – The density of discount department stores (e.g., Family Dollar, Dollar Tree, Dollar General, Kmart, Big Lots) is positively correlated with pedestrian crash frequency. On average, an increase of 1 discount store per square mile results in an average increase of 0.226 pedestrian crashes in 4 years in a low-income BG. ⊕
- **Convenience stores** – The density of convenience stores (e.g., 7-Eleven, Chevron Food Mart, Farm Stores, Kwik Stop, Shell Shop) is positively correlated with pedestrian crash

frequency. On average, an increase of 1 convenience store per square mile results in an average increase of 0.071 pedestrian crashes in 4 years in a low-income BG. ⊕

- **Fast-food restaurants** – The density of fast-food restaurants (e.g., Burger King, Checkers, China Wok, Domino's Pizza, KFC, McDonald's, Taco Bell) is positively correlated with pedestrian crash frequency. On average, an increase of 1 fast-food restaurant per square mile results in an average increase of 0.069 pedestrian crashes in 4 years in a low-income BG. ⊕
- **Grocery stores** – The density of grocery stores (e.g., Publix, Winn-Dixie, Food Market, Aldi) is positively correlated with pedestrian crash frequency. On average, an increase of 1 grocery store per square mile results in an average increase of 0.057 pedestrian crashes in 4 years in a low-income BG. ⊕
- **Barber shops** – The density of barber shops is positively correlated with pedestrian crash frequency. On average, an increase of 1 barber shop per square mile results in an average increase of 0.049 pedestrian crashes in 4 years in a low-income BG. ⊕

Average Effects (-)	Land Use Types	Average Effects(+)
	Discount stores (#/mi^2)	0.226
	Convenience stores (#/mi^2)	0.071
	Fast food restaurants (#/mi^2)	0.069
	Grocery stores (#/mi^2)	0.057
	Barber shops (#/mi^2)	0.049

Figure 14. Effects of land use types on pedestrian crash frequency

The average marginal effects on pedestrian crash frequency indicate that the most influential variable related to land use types is the density of discount stores followed by the density of convenience stores, and the density of fast-food restaurants.

4.3 Analysis of Pedestrian Crash Injury Severity (Disaggregated Analysis)

For the analysis of pedestrian crash injury severity, injury severity and associated individual and environmental characteristics for each crash (i.e., disaggregated at crash-level) were used to test and model their statistical correlations. Individual characteristics were included in the geo-located crash data from FDOT. Based on the findings from literature review and interviews, the variables related to individual characteristics (pedestrian age, pedestrian action and location, driver behavior, alcohol/drug impairment) and environmental factors (lighting condition, roadway speed limits) were tested in crash-level data analysis. In this study, injury severity was described as a binary variable (1 – severe injury, including fatality or incapacitating injury; 0 – others). The observations with missing data in variables used in the model were omitted.

As shown in Figure 15 (see details in Table 30 of Appendix E), individual characteristics such as the involvement of older pedestrians, impaired pedestrians, and aggressive drivers have significant effects on the injury severity of a pedestrian crash. Specifically, the following individual characteristics are significantly correlated with pedestrian crash injury severity:

- **Older pedestrian** – Older pedestrians (($\geq$ 65 years) involved in a pedestrian crash are more likely to experience severe injuries, which can be explained by their physical condition (e.g., slow walking speed when crossing, delay in reaction time) as well as their reduced injury tolerance. On average, older pedestrians tend to increase the probability of sustaining severe injury in crashes by 11.61%.⊕
- **Pedestrian in travel lane other than crosswalk** – The location of pedestrians in travel lanes other than crosswalks significantly increases the probability of severe injury by 11.20% compared to other pedestrian locations (e.g., intersection, midblock crosswalk, sidewalk etc.). ⊕
- **Pedestrian darting/dashing** –Darting/dashing is a major improper pedestrian action that captures pedestrians' inherent unsafe awareness, increases the probability of severe injury by 4.91%. ⊕
- **Impaired pedestrian** – Alcohol or drug involvement, which impairs pedestrian perception and increases inherent risk-taking tendencies, increases the probability of severe injuries for pedestrian crashes by 70.32%. ⊕
- **Aggressive driver** – Aggressive drivers increase the probability of severe injury by 19.64%, as they are more likely to take risky behaviors (e.g., driving at higher speed), which is more dangerous for vulnerable road users. ⊕

Average marginal effects on pedestrian crash injury severity indicate that alcohol or drug involvement of a pedestrian is the most influential variable for severe injury of a pedestrian crash, followed by the involvement of aggressive drivers and older pedestrians in a pedestrian crash.

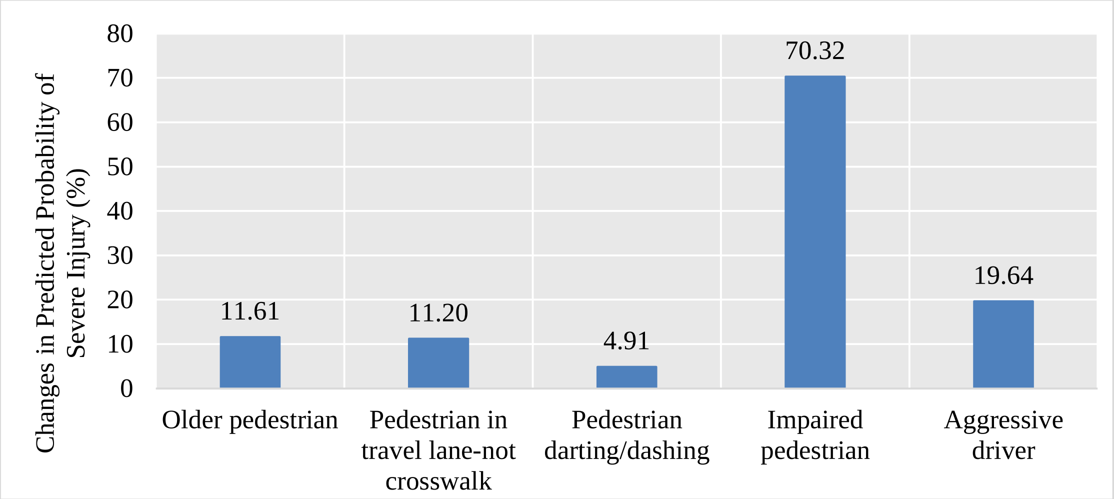


Figure 15. Effects of individual characteristics on injury severity

As shown in Figure 16 (see details in Table 30 of Appendix E), environmental factors such as lighting conditions and roadway speed limits have the significant effects on the injury severity of a pedestrian crash. Specifically, the following environmental factors are significantly correlated with pedestrian crash injury severity:

- **Dark conditions** – Relative to non-dark conditions (daylight, dusk, and dawn), dark–not lighted and dark–lighted conditions increase the average probability of severe injuries in pedestrian crashes by 21.56% and 18.82%, respectively. This finding makes intuitive sense because street lighting mitigates pedestrian injury involved in a crash due to improved sight distance. ⊕
- **Inclement weather condition** – Inclement weather (rain, fog, smoke, clouds) increases the average probability of severe injuries in pedestrian crashes by 6.33%. The possible reason is that inclement weather relative to clear weather decreases the visibility of pedestrians and increases the braking distance of vehicles, which leads to higher impact on pedestrians at the time of a crash. ⊕
- **Lower speed limit** – The most important factor that directly determines the injury severity of a pedestrian is the speed of the vehicle upon striking the pedestrian (impact speed). Empirically, the posted speed limit is highly related to impact speed. Based on the modeling results, a lower speed limit is likely to decrease the probability of severe injuries in pedestrian crashes, and the marginal effect of a lower speed limit (<40mph) denotes that the lower speed limit is likely to decrease the probability of severe injuries by 11.19%. ⊖
- **Traffic control devices** – The presence of a traffic control device (e.g., signal, STOP sign, YIELD sign, school zone device, flashing signal) at the location of a crash is likely to decrease the probability of higher injury severity in pedestrian crashes by 6.84%. Traffic control devices help to reduce traffic conflicts for road users or warn motorists to be cautious of vulnerable road users and to yield the right-of-way. Thus, traffic control devices may force drivers to slow down and, as a result, can decrease the probability of severe crash injuries. ⊖

The average marginal effects on pedestrian crash injury severity indicate that the dark–not lighted condition is the most influential variable for severe injury pedestrian crash, followed closely by the dark–lighted condition. The third most influential variable is higher speed limit. A dark-lighted condition seems indicate that various lighting levels could have different impacts on the injury severity of a pedestrian crash.

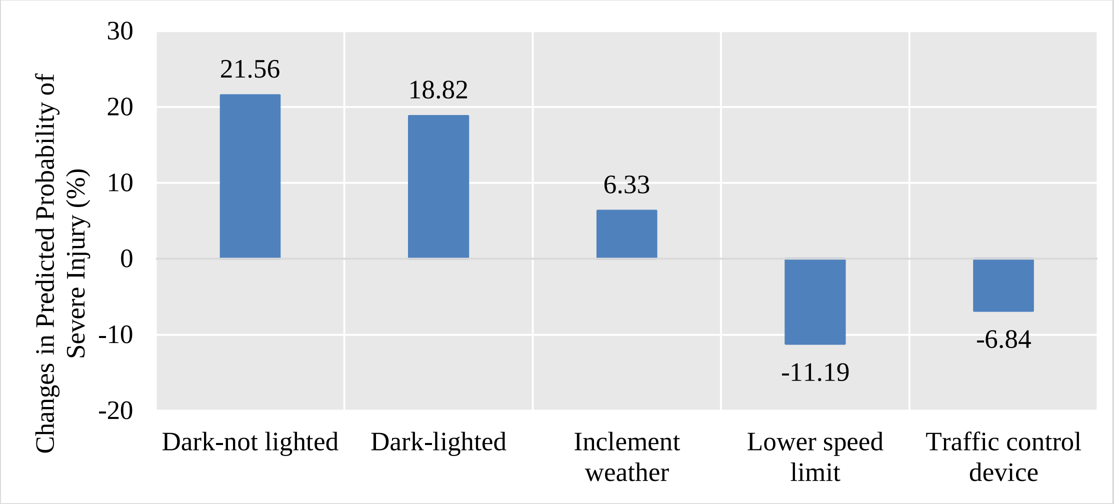


Figure 16. Effects of environmental factors on injury severity

4.4 Additional Analysis of High-Crash Corridors and Impaired Crashes

Analysis of High-Crash Corridors

Representative on-State-system and off-State-system roads in low-income areas were selected for a detailed corridor analysis, such as Oakland Park Boulevard and NW-SW 31st Avenue in Broward County (Figure 17). The Oakland Park Boulevard corridor begins at NW 68th Avenue and ends at N Ocean Boulevard (approx. 8.8 mi). The NW–SW 31st Avenue corridor starts at W Sunrise Boulevard and ends at Davie Boulevard (approx. 2.2 mi). The corridors were selected based on the high number of pedestrian crashes in the Oakland Park corridor and the off-State-road system (31st Avenue). For this study, the crosswalk locations were digitized using Google Maps.

To identify the patterns or correlations of the spatial data, the appropriate polygon or zone was needed to count the frequency of data points in each analysis zone. The analysis zone could be the existing geographic zone (e.g., census BGs in previous sections) and the user-defined polygon cells (e.g., a fishnet polygon mesh). In this study, the user-defined polygon mesh was used for detailed analysis at the corridor level. The selected corridors were divided into 820 ft × 820 ft segments, and a thorough analysis of the land use types within the segments was conducted. The mean, minimum, and maximum number of pedestrian crashes for the corridors is presented in Table 17.

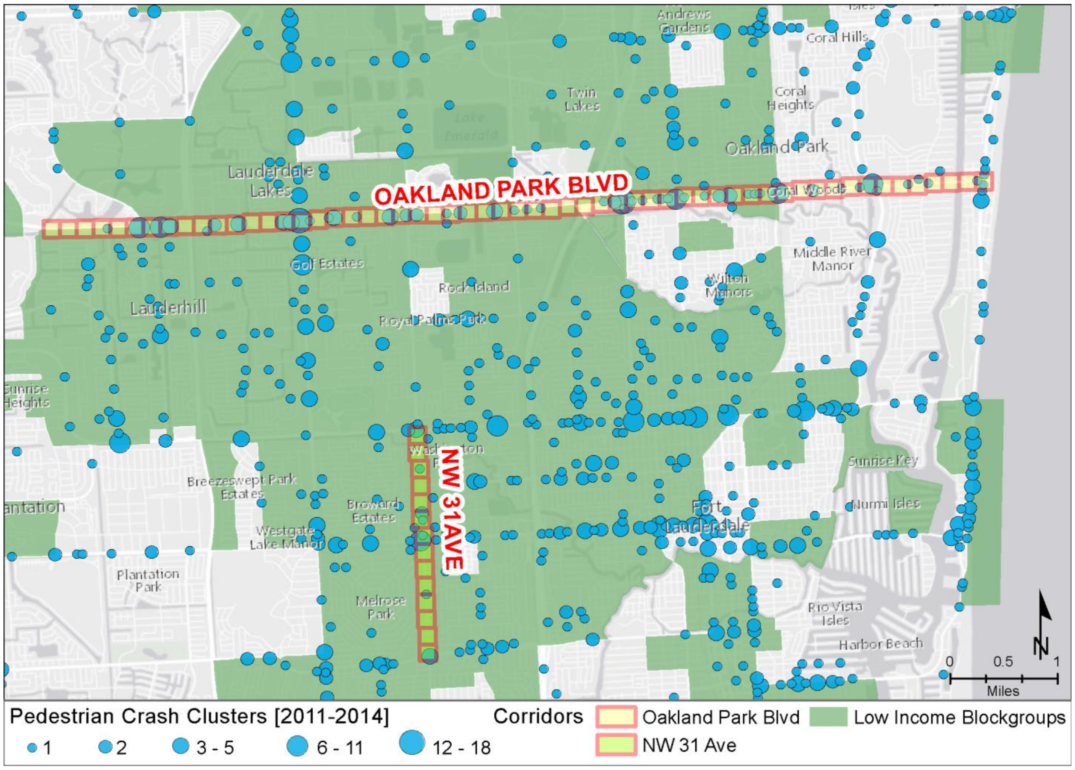


Figure 17. Example location of corridors

Table 17. Descriptive Statistics of Selected Corridors

Corridor Name	# of Segments	Total # of Pedestrian Crashes	# of Segments with Pedestrian Crashes		# of Pedestrian Crashes in Segment		
			Number	*%*	*Mean*	*Min*	*Max*
Oakland Park Blvd	57	139	40	70	2.44	1	19
31st Ave	14	21	6	42.9	1.5	1	7

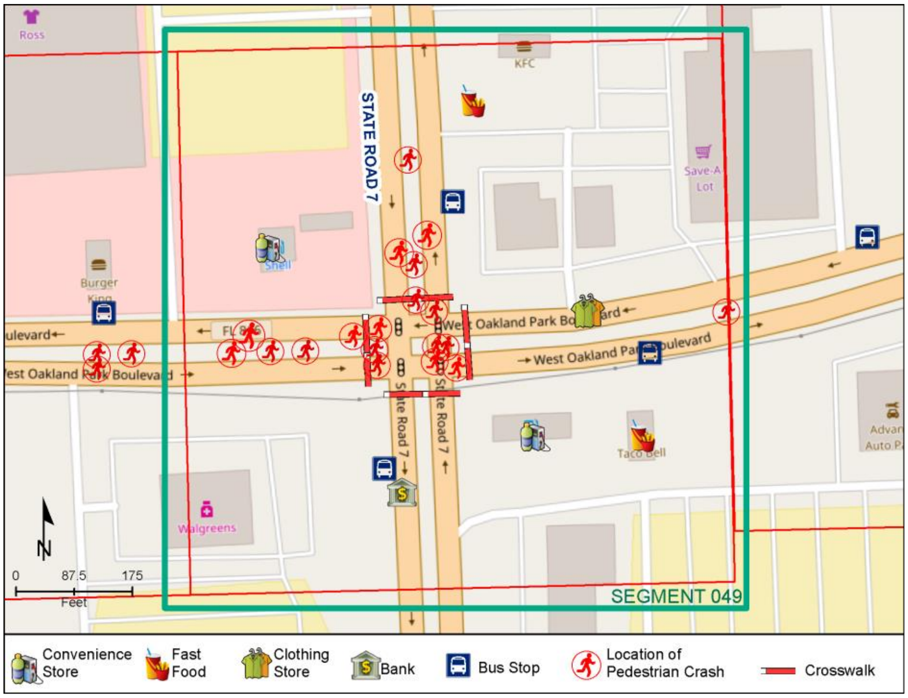
On-State System Roads

The results of the Oakland Park Boulevard corridor analysis indicate that the segments in which pedestrian crashes occurred have a higher average number of convenience stores, fast-food and dine-in restaurants, bars, and banks. The average number of bus stops, intersections, and crosswalks is higher within the segments with pedestrian crashes than the average within the segments in which pedestrian crashes did not occur (Table 18).

Table 18. Descriptive Statistics for Land Use and Road data in Oakland Corridor

Factors	**Average Number**		
	All Segments	***Segments with Pedestrian Crash***	***Segments without Pedestrian Crash***
Land Use Types			
Convenience stores	0.32	0.46	0
Fast-food	0.71	0.85	0.41
Restaurants	0.86	1.05	0.41
Grocery stores	0.18	0.18	0.18
Barber shops	0.28	0.28	0.28
Beauty salons	1	0.28	0.59
Bars	0.15	0.41	0.12
Churches	0.32	0.28	0.41
Hotels	0.09	0.1	0.06
Banks	0.68	0.87	0.29
Discount Stores	0.05	0.03	0.12
Department Stores	0.07	0.1	0
Road Environment Factors			
Bus stop	2.12	2.45	1.35
Intersection	2.98	3.35	2.12
Crosswalk	3.04	3.43	2.12

The Oakland Park Boulevard corridor analysis in Broward County indicates that the location of stores and institutions plays an important role in whether a crash occurs within a segment or not. Figure 18(a) represents a segment with 19 pedestrian crashes; the land use for this segment is represented by fast-food restaurants, convenience stores (gas station), a retail store (Payless Shoes), and a bank. Figure 18(b) shows the land use within a segment with five pedestrian crashes; the land use includes fast-food restaurants, convenience stores, beauty salons, bars, and retail stores.



(a) W Oakland Park Blvd and SR 7

(b) E Oakland Park Blvd and Andrews Ave

Figure 18. Examples of land use and pedestrian crashes in Broward County

Similarly, for the Military Trail corridor analysis in Palm Beach County, a segment with 10 pedestrian crashes corresponds to the land use types such as restaurants, bus stops, and a clothing store (Figure 19a). Figure 19(b) shows a segment with six pedestrian crashes; land use includes fast-food restaurants, bus stops, a clothing store, beauty salons, and restaurants.

(a) Okeechobee Blvd and North Military Trail

(b) Forest Hill Blvd and South Military Trail

Figure 19. Examples of land use and pedestrian crashes in Palm Beach County

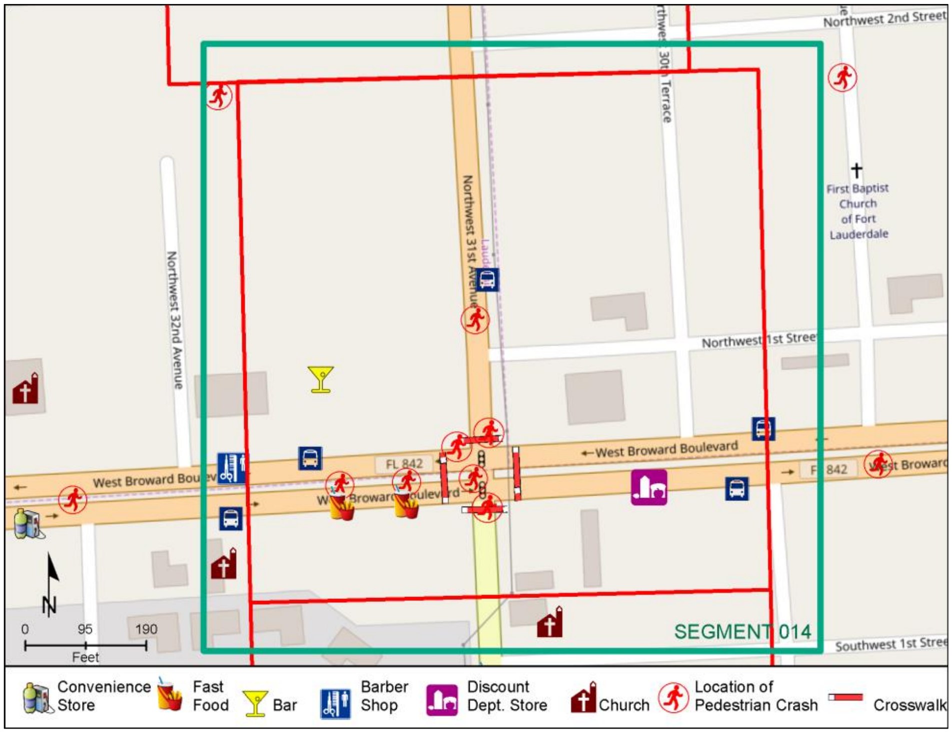
Off-State System Roads

The results of the 31st Avenue corridor analysis indicate that the segments in which pedestrian crashes occurred have a higher average number of fast-food and dine-in restaurants, beauty salons, bars, discount department stores, and banks. The average number of bus stops and intersections is higher than the average within segments in which a pedestrian crash did not occur. However, the average number of crosswalks within segments with pedestrian crashes is lower than within those in which a crash did not occur (Table 19).

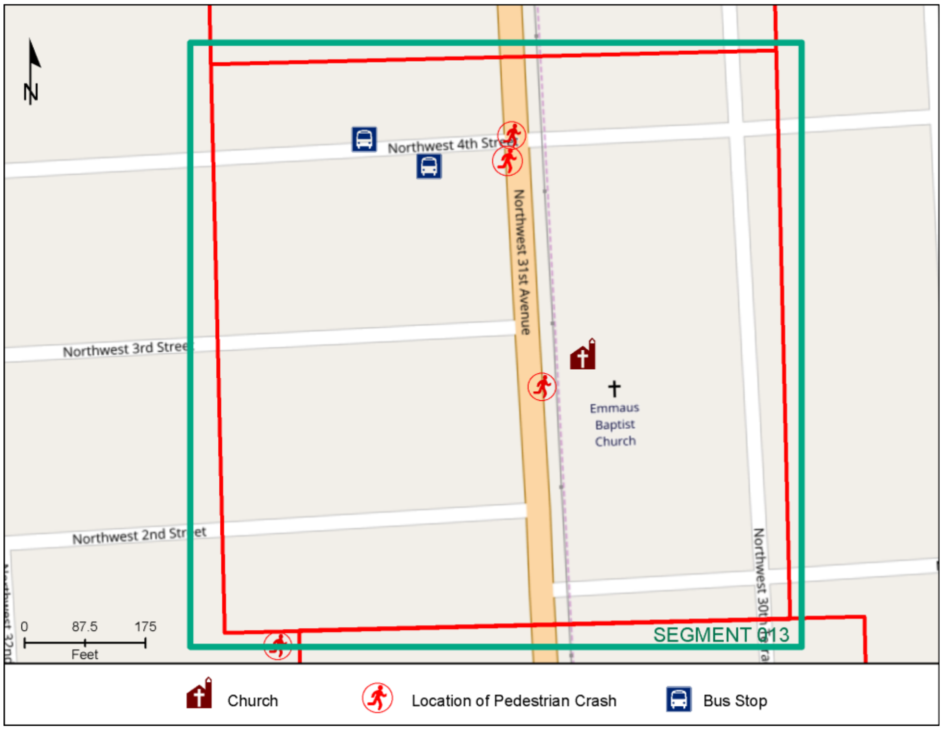
Table 19. Descriptive Statistics for Land Use and Road Data in 31st Ave Corridor

Factors	**Average Number**		
	All Segments	***Segments with Pedestrian Crash***	***Segments without Pedestrian Crash***
Land Use Types			
Convenience stores	0.21	0.5	0
Fast-food	0.29	0.5	0.13
Restaurants	0.07	0.17	0
Grocery stores	0.14	0.17	0.13
Barber shops	0	0	0
Beauty salons	0.14	0.33	0
Bars	0.08	0.17	0
Churches	0.26	0.14	0.37
Hotels	0	0	0
Banks	0.14	0.33	0
Discount dept. stores	0.07	0.17	0
Road Environment Factors			
Bus stop	1.79	2.83	1
Intersection	3.86	4.33	3.5
Crosswalk	1.29	2.17	6.25

Analysis of the 31st Avenue corridor shows that the segments with the highest number of pedestrian crashes are located close to the intersections with W Sunrise Boulevard, W Broward Boulevard, and Davie Boulevard. Figure 20(a) shows a segment with nine pedestrian crashes. The land uses include fast-food restaurants, a discount department store (Dollar Store), and a bar. A barber shop and churches are within close vicinity to the segment. Figure 20(b) shows the segment with three pedestrian crashes. The land use types are quite limited, with only two bus stops and a church.



(a) 31st Ave and W Broward Blvd



(b) 31st Ave and NW 4th St

Figure 20. Examples of land use and pedestrian crashes in Broward County

Similarly, for the corridor analysis for off-State-system roads in Palm Beach County, a segment with five pedestrian crashes corresponds to the land use types such as several restaurants, bus stops, beauty stores and a discount department store, as shown in Figure21(a). Figure 21(b) shows a segment with two pedestrian crashes. Although the land use types include restaurants, a convenience store, beauty stores and a barber shop, there is no bus stop in this segment.

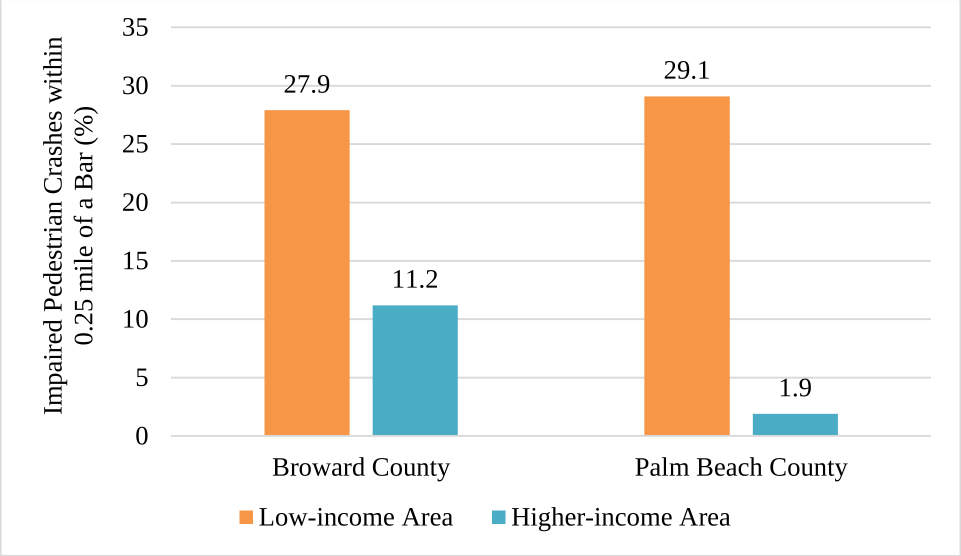
(a) Gateway Blvd and N Congress Ave

(b) Jog Rd and 10th Ave North

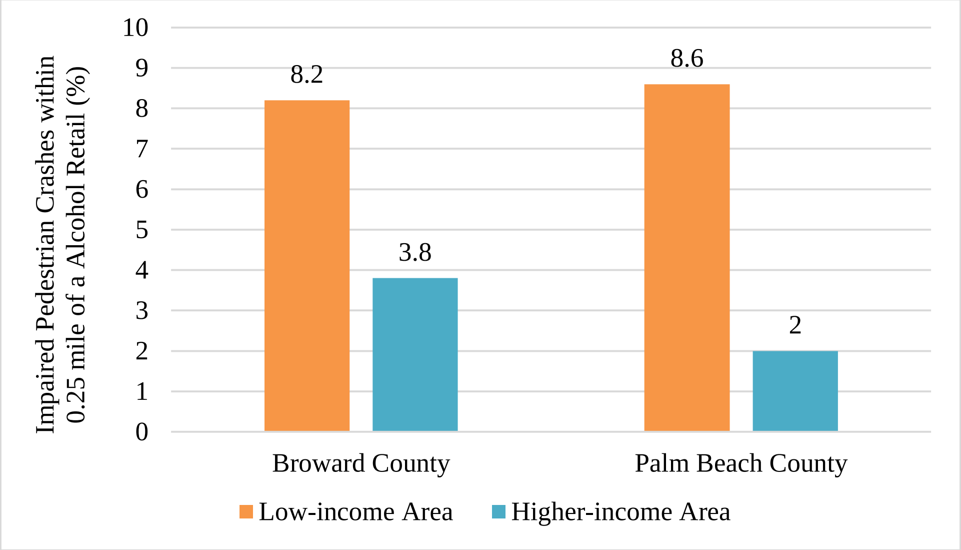
Figure 21. Examples of land use and pedestrian crashes in Palm Beach County

Proximity Analysis for Impaired Pedestrian Crashes

Proximity analysis was used to identify the relationship between location of impaired pedestrian crashes and stores where alcohol is sold and consumed. A 0.25-mile buffer was constructed around bar or alcohol retail locations, and frequency of impaired pedestrian crashes in low- and higher-income areas was calculated. Both results showed that there are more impaired pedestrian crashes within the alcohol availability buffer in low-income areas than those in higher-income areas in Broward and Palm Beach counties (Figure 22). The locations of the proximity of the highest clusters of impaired pedestrian crashes to bars are illustrated in Figure 23.

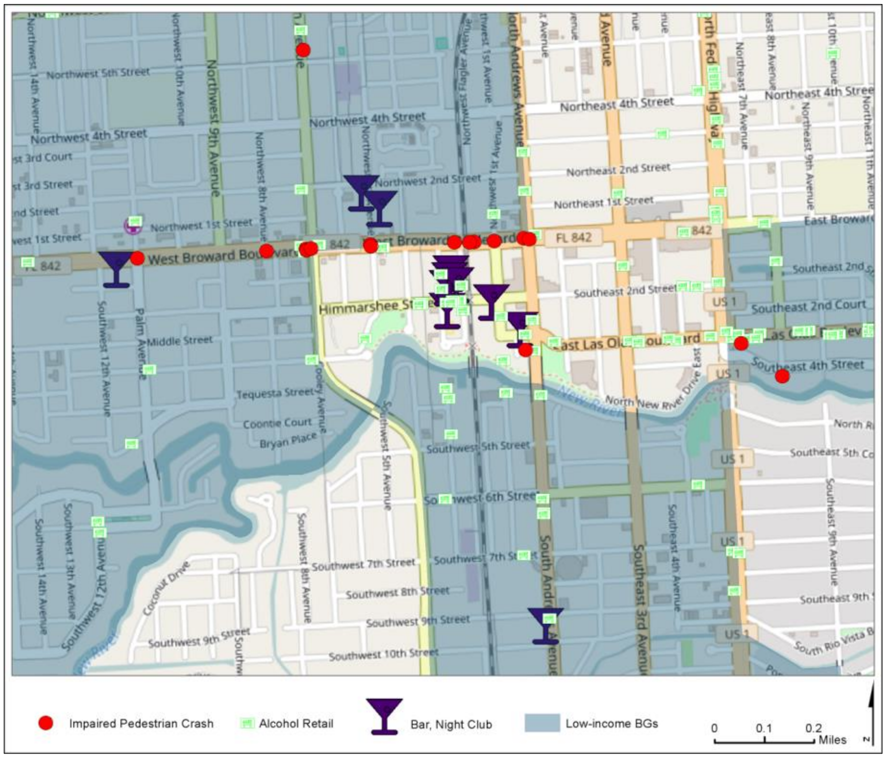


(a) Impaired pedestrian crashes and locations of bars

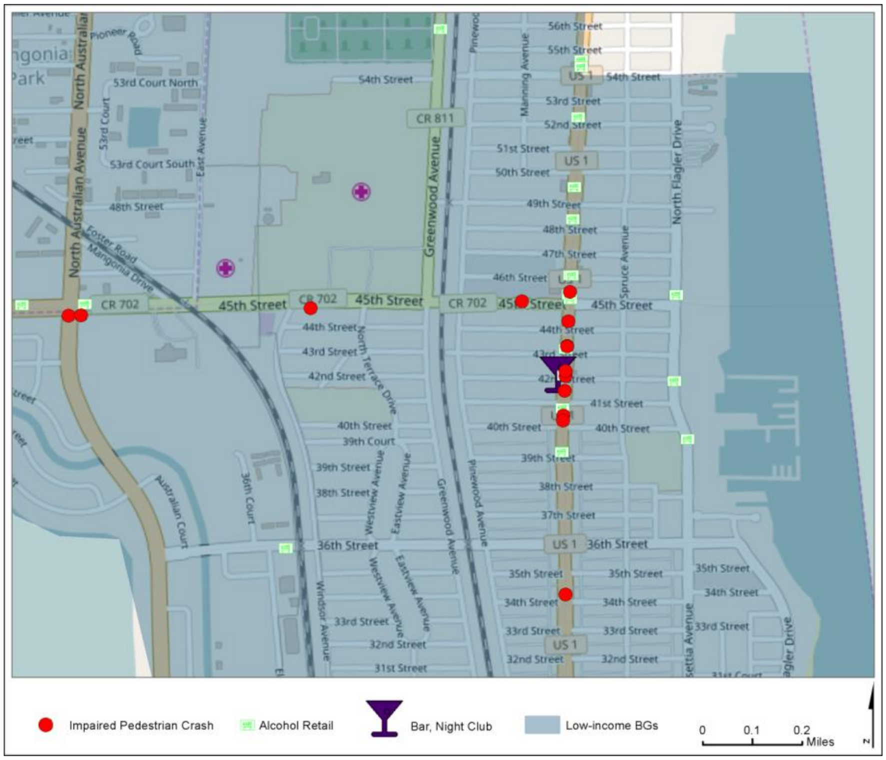


(b) Impaired pedestrian crashes and locations of alcohol retail

Figure 22. Impaired pedestrian crashes and locations of bars and alcohol retail



(a) W Broward Blvd in Broward County



(b) US 1 in Palm Beach County

Figure 23. Illustrative correlation between impaired pedestrian crashes and location of bars and alcohol retail

In sum, the corridor analysis results show that for segments with pedestrian crashes, the mean number of crosswalks differs for off- and on-State-system roads. For off-State-system roads, pedestrian crashes were more frequent (the average number of crosswalks was lower), and for on-State-system roads, pedestrian crashes were more frequent (the average number of crosswalks was higher than the average for a corridor). Since the corridor analysis was conducted for a few roads only, and the number of segments for corridors was not equal, it is premature to draw a conclusion that the results apply to all on and off State system roads. However, these test results imply the importance of corridor analysis. Moreover, the proximity analysis illustrated that impaired pedestrian crashes tend to be more frequent in alcohol availability buffer in low-income areas.

4.5 Summary of Methodology Test

The following summarizes the major findings in methodology test:

- **Pedestrian crashes are more frequent in low-income BGs that have more population, a smaller proportion of older adults, are minority-dominated, have zero-car ownership neighborhoods, and are among populations with a low education level.**
  - Average marginal effects on pedestrian crash frequency indicate that the top four influential variables related to demographic characteristics are the proportion of older adults (negative effect), the proportion of commuters using public transit or biking, the proportion of people with a low education level (less than high school), and the proportion of zero-car ownership.
- **Pedestrian crashes are more frequent in low-income BGs with more intersections, traffic signals, and bus stops and a larger proportion of roads with higher speed limits.**
  - Average marginal effects on pedestrian crash frequency indicate that the most influential variable related to roadway factors is the number of traffic signals per BG, followed by the number of bus stop per mile. The third most influential variable is the proportion of lower-speed road (negative effect). The increase on the proportion of lower-speed roads in a low-income BG can help decrease pedestrian crashes.
- **Pedestrian crashes occurred more frequently in low-income BGs with the presence of a Walmart store and with greater densities of discount department stores, fast-food restaurants, convenience stores, grocery stores, and barber shops.**
  - Average marginal effects on pedestrian crash frequency indicate that the most influential variable related to land use types is the density of discount stores, followed by density of convenience stores and density of fast-food restaurants.
- **Individual characteristics including the involvement of older pedestrians, non-crosswalk locations of pedestrians, improper pedestrian action (dart/dash),**

impaired pedestrians, and aggressive drivers have positive effects on the severe injury of a pedestrian crash.
  - Average marginal effects on pedestrian crash injury severity indicate that alcohol or drug involvement of a pedestrian is the most influential variable for severe injury of a pedestrian crash, followed by the involvement of aggressive driver and older pedestrians in a pedestrian crash.

- **Environmental factors including lighting conditions, roadway speed limits, and presence of traffic control devices have significant effects on the injury severity of a pedestrian crash.**
  - Average marginal effects on pedestrian crash injury severity indicate that the dark–not lighted condition is the most influential variable for severe injury pedestrian crash, followed closely by the dark–lighted condition. The third most influential variable is higher speed limit. The dark–lighted condition seems to indicate that various lighting levels could have different impacts on the injury severity of a pedestrian crash.
- **Pedestrian crashes are more frequent in segments in which the average number of fast-food restaurants, department stores, and banks is higher than average for the corridor.**
- **Pedestrian crashes are more frequent in segments in which the average number of bus stops and intersections is higher than average for the corridor.**
- **Proximity analysis illustrated that impaired pedestrian crashes tend to be more frequent in the alcohol availability buffer (near the location of bars and alcohol retail) in low-income areas.**

5. IMPLEMENTATION STRATEGIES

This section illustrates how the outcomes provided in the methodology developed in Section 3 and tested in Section 4 connect with the target area demographics. Engineering countermeasures are recommended based on crash analysis and types of existing facilities, and education/outreach countermeasures are recommended based on demographics, land use, and other data. This section also provides strategies for implementation of the countermeasures in a systematic approach. To support the development of implementation strategies for pedestrian safety, the previous sections developed a thorough understanding of the factors that affect the likelihood of a crash occurrence and the characteristics that may exacerbate or mitigate the degree of injury sustained by crash-involved road users when a crash has occurred. The safety-oriented engineering countermeasures serve two functions: (1) prevent pedestrian crash occurrences (i.e., reduce crash frequency) and (2) minimize the consequences when a pedestrian crash does occur (i.e., reduce the severity of an injury in the event of a crash). The goal of the education and outreach plans is to increase the knowledge level of safety actions for pedestrians and drivers in selected high-crash emphasis areas and to increase compliance with existing laws. The desired outcome of the educational outreach effort is to decrease pedestrian crashes and fatalities in coordination with local law enforcement and engineering efforts and to document an increase in knowledge.

5.1 Identified Low-income Areas with Higher Pedestrian Hazards

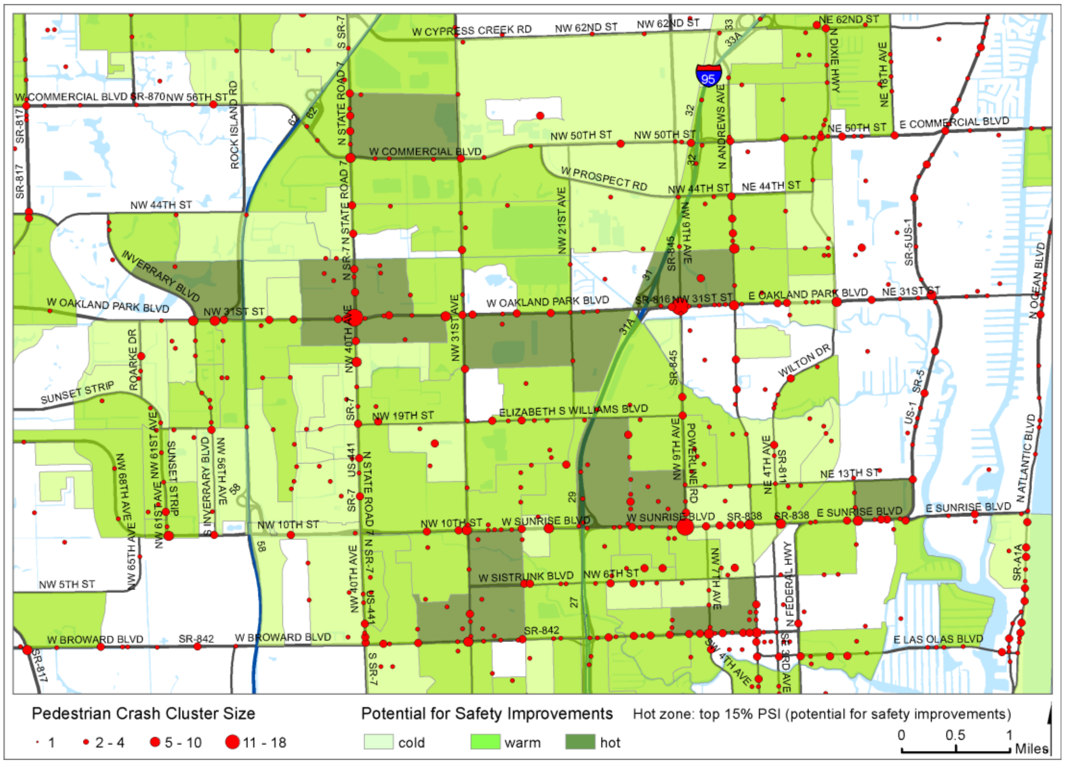
In Section 4, several demographic and social factors that influence pedestrian crash likelihood were reported. It was found that pedestrian crashes are more frequent in low-income BGs that have more population and a smaller proportion of older adults, are minority-dominated, have zero-car ownership neighborhoods, and are among populations with a low education level. Table 20 summarizes the results of modeling the pedestrian crash frequency from the methodology test. These findings are important for prioritizing neighborhoods for the development of effective pedestrian safety countermeasures, especially in Broward and Palm Beach counties in FDOT District 4.

To identify hot zones for pedestrian crashes, the empirical Bayes (EB) approach was used (Hauer et al., 2002; El-Basyouny and Sayed, 2006; Montella, 2010). Then, the potential for safety improvements (PSI) and excess crash frequency was calculated to show if a zone is experiencing more or fewer crashes compared to other zones with similar characteristics (Lee et al., 2015). PSI is the difference between the expected (or adjusted observed) and the predicted number of crashes. If the PSI is positive in an area, the area is experiencing more crashes than other areas with similar features. In contrast, if the area is experiencing fewer crashes compared to other similar areas, its PSI is negative (Montella, 2010; Lee et al., 2015).

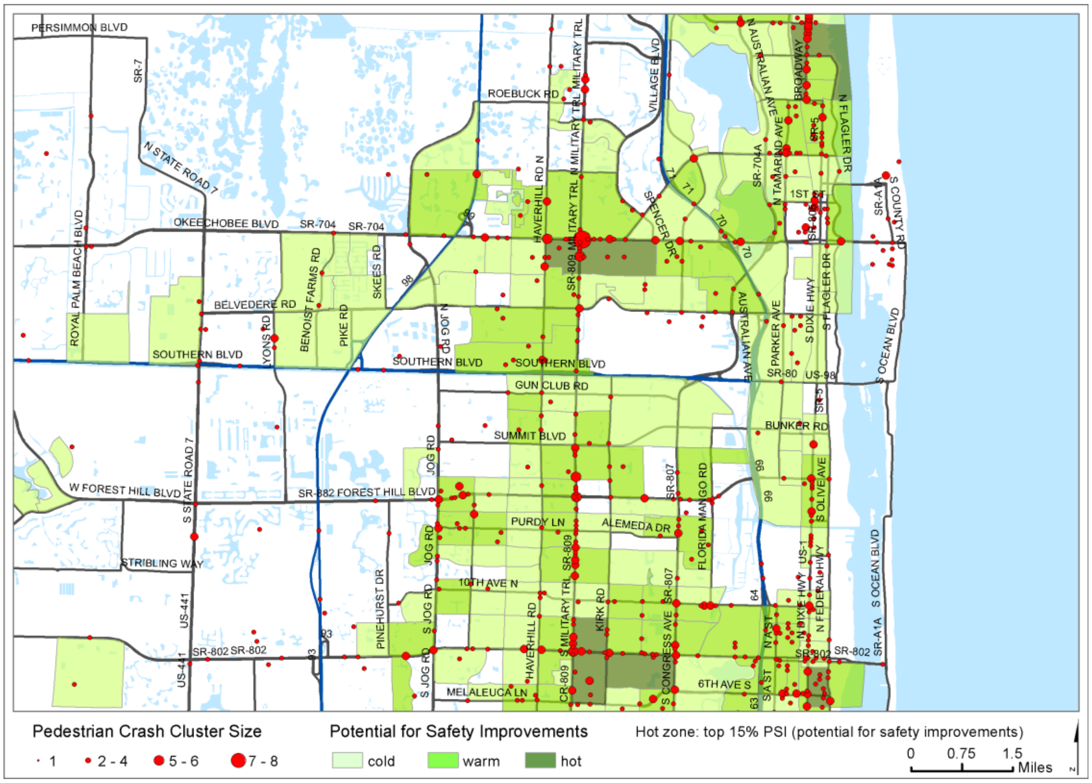
Table 20. Summary of Results of Modeling Pedestrian Crash Frequency

Factors/Explanatory Variables	Pedestrian Crash Frequency in Low-income Block Groups	Severe Injury Pedestrian Crash Frequency in Low-income Block Groups
Demographic & Social Factors *(Source: US Census)*		
Population in thousands	⊕ Positive correlation	⊕ Positive correlation
Older adult population (%)	⊖ Negative correlation	⊖ Negative correlation
African American (%)	⊕ Positive correlation	No significant correlation
Public transit or bike to work (%)	⊕ Positive correlation	No significant correlation
Zero-car ownership (%)	⊕ Positive correlation	⊕ Positive correlation
Low education level (%)	⊕ Positive correlation	⊕ Positive correlation
Road Environment Factors *(Sources: FDOT RCI, GTFS, Transit Agencies)*		
Intersections	⊕ Positive correlation	⊕ Positive correlation
Traffic signals	⊕ Positive correlation	⊕ Positive correlation
Bus stop locations	⊕ Positive correlation	⊕ Positive correlation
Lower-speed roads	⊖ Negative correlation	⊖ Negative correlation
Land Use Factors *(Source: FGDL; HERE; License)*		
Walmart stores	⊕ Positive correlation	No significant correlation
Convenience stores	⊕ Positive correlation	No significant correlation
Fast-food restaurants	⊕ Positive correlation	⊕ Positive correlation
Grocery stores	⊕ Positive correlation	No significant correlation
Discount stores	⊕ Positive correlation	⊕ Positive correlation
Barber shops	⊕ Positive correlation	No significant correlation

All low-income BGs in Broward and Palm Beach counties were classified into three zones based on the calculated PSI values—hot, warm, and cold—as shown in Figure 24 and Table 21. Hot zones are defined as BGs with a top 15% PSI (resulting in 27 BGs in the study area), cold zones refer to BGs with a PSI less than 0, and warm zones are BGs with a PSI between 0 and the top 15%). Hot zones are high-risk BGs for pedestrian safety because there are many more pedestrian crashes than other BGs with similar characteristics. In warm zones, pedestrian hazards are not as serious as in hot zones, but still there is a need for pedestrian crash reduction (PSI higher than 0). Cold zones are relatively safe for pedestrians given the zonal characteristics compared to other similar BGs. Note that a threshold of 15% used for hot zone is flexible; there is no so-called "optimal" threshold, even in the *Highway Safety Manual* (HSM, 2010). The rule of thumb is to increase the hot zone threshold for addressing more areas with higher pedestrian crash risk if the target resources for safety improvements allow.



(a) Broward County



(b) Palm Beach County

Figure 24. Identified hot zones in low-income areas for improving pedestrian safety

Table 21. Example of Screening Results – Pedestrian Crashes per Census Block Group

Census Block Group	Rank	PSI	Percent	Category
15000US120110416001	1	14.0	0.9%	Hot
15000US120110507012	2	13.6	1.9%	Hot
15000US120110503061	3	13.5	2.8%	Hot
…	…	…	…	…
15000US120990067001	74	2.9	27.0%	Warm
…	…	…	…	…
15000US120990081013	812	-33.5	100.0%	Cold

5.2 Engineering Countermeasures

Engineering countermeasures are safety treatments and programs from an engineering perspective that have demonstrated success in preventing or reducing pedestrian crash frequency or injury severities. In the methodology test, identified factors related to roadway and environmental characteristics include lighting conditions, crossing locations, traffic control devices, intersection design, bus stops, and vehicle speed. The following subsections provide the corresponding engineering countermeasures to address pedestrian safety in identified low-income areas with higher pedestrian hazards.

Roadway Lighting and Lighting Levels

In the methodology test, geo-located pedestrian crashes occurring between 2011 and 2014 were derived from the FDOT CARS in Broward and Palm Beach counties in District 4. The major outputs and findings related to lighting conditions were the following:

- A total of 72% of pedestrian fatalities occurred at night (relative to daylight, dusk, or dawn).
- A total of 22% of nighttime fatalities occurred on streets without lighting.
- Dark–not lighted conditions, relative to non-dark conditions (daylight, dusk, dawn), increased the average probability of severe injuries (fatality or incapacitating injury) in pedestrian crashes by 21.56%.
- Dark–lighted conditions, relative to non-dark conditions (daylight, dusk, dawn), increased the average probability of severe injuries (fatality or incapacitating injury) in pedestrian crashes by 18.82%.

These findings indicate that better lighting conditions can mitigate pedestrian injury severity in a crash, especially for fatal crashes. Pedestrians often assume that motorists can see them at night and are deceived by their own ability to see the oncoming headlights. In fact, without sufficient overhead lighting, motorists may not be able to see pedestrians in time to stop. Further investigations with additional lighting measurement data in other studies found that not only the presence of lighting but also the lighting levels and the appropriate placement of lighting can provide additional visibility and significantly improve visibility and sight distance for pedestrian detection and makes pedestrians more noticeable to drivers. Several examples related to lighting and lighting level improvements are presented as follows. More information about the safety effects of lighting and illumination can be found on the PEDSAFE website at http://www.pedbikeinfo.org/data/library/details.cfm?id=10 and PBIC (2014).

- **Presence of lighting** – According to a study by MetroPlan Orlando (2016), drivers normally cannot see a pedestrian at night for more than 200 ft, and lighting the road is the only way for motorists to see pedestrians in time to avoid a collision. According to Orlando officials, 400 ft (a little more than a football field) is the distance needed to safely stop for pedestrians when a motorist is traveling at 45 mph. The study also found a 70% increase in crashes on a 6-lane road with a median and no lighting compared with the same road with lighting. In addition, it was found that 41% of nighttime fatalities occurred on streets without lighting. Recently, new lighting improved the stretch of SR 436 between Colonial Drive and Old Cheney Highway, an area that is infamous for pedestrian accidents. In 2017, FDOT will begin work on installing raised medians on the stretch of SR 436 and soon will vote to approve five similar projects across Central Florida that will significantly improve roadway lighting.
- **Adequate lighting levels and uniformity** – A study conducted by CUTR found that various street lighting levels can have different impacts on the nighttime crashes (Wang et al., 2016). Figure 25 shows an example of collecting and matching illuminance data for a selected roadway segment, using the Advanced Lighting Measurement System (ALMS). A before-after study was conducted on CR 54 in Tampa Bay, as illustrated in Figure 26, and determined that light-emitting diodes (LED) improve both average lighting levels and uniformity. Adequate lighting levels and their uniformities are essential.

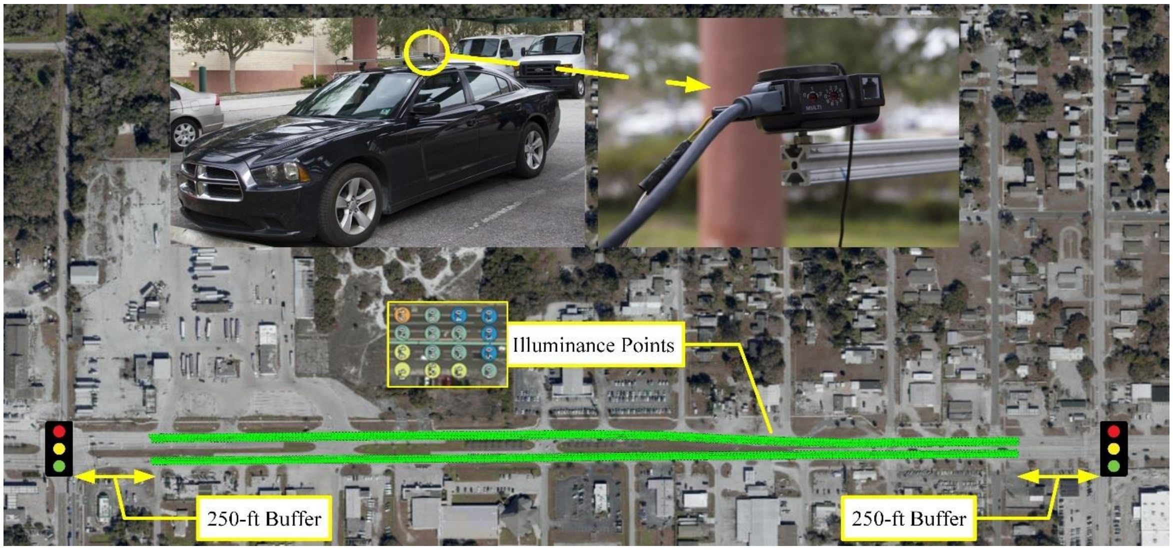
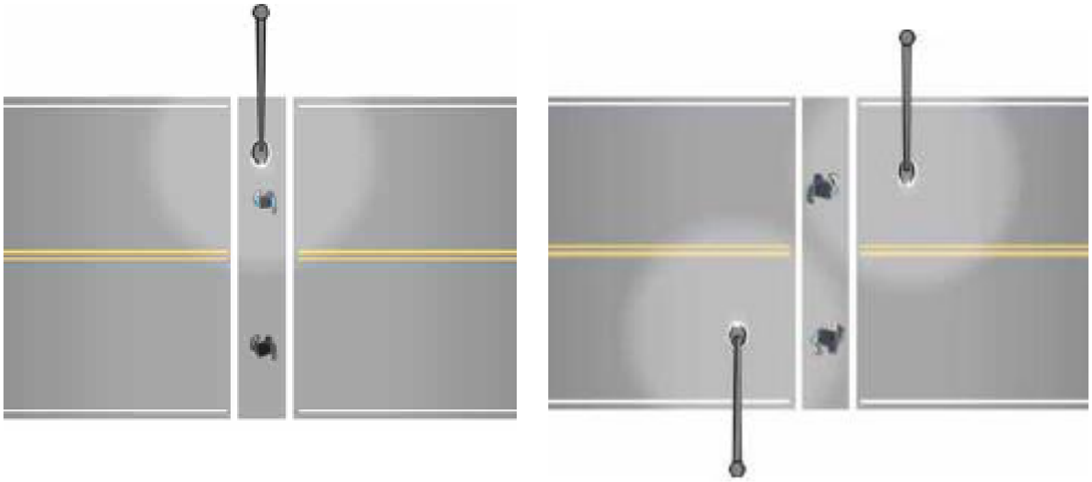


Figure 25. ALMS, illuminance data, and segment study area

(a) Before: High pressure sodium (HPS) (b) After: Light-emitting diode (LED)

Figure 26. Before-and-after comparison of lighting levels

- **Pedestrian lighting placement** – A 2008 report by Gibbons et al. of the Virginia Tech Transportation Institute (VTTI) tested drivers yielding to pedestrians at midblock crossings using static and dynamic experiments, which included lamp type, vertical illuminance level, color of pedestrian clothing, position of pedestrians in crosswalk, and glare as experimental variables. A Probeam luminaire and ground-installed LEDs also were examined. The report concluded that vertical illuminance of 20 lx at the height of 5 ft over the crosswalk created reasonable detection distances in most examples (Gibbons et al., 2008). Figure 27(a) shows traditional crosswalk lighting design in which a lamp is placed directly over the crosswalk and Figure 27(b) shows a more effective system in which a lamp is installed in front of the crosswalk on each side, increasing visibility distance.



(a) Traditional lighting layout (b) New design of lighting layout

Figure 27. Two types of pedestrian lighting placement

Source: Gibbons et al., 2008

Treatments at Non-intersection Locations

For pedestrians, it can be daunting and dangerous to walk or cross a roadway without proper pedestrian features such as a crosswalk or pedestrian-friendly traffic control devices. In the methodology test, the major outputs and findings related to pedestrian crash locations were the following:

- A total of 57% of pedestrian crashes occurred outside of intersections.
- A total of 65% of pedestrian fatalities occurred outside of intersections.
- The location indicator of pedestrians in travel lanes other than crosswalks significantly increases the probability of severe injury by 11.20% compared to other pedestrian locations (e.g., intersection, midblock crosswalk, sidewalk, etc.).
- The presence of a traffic control device (e.g., signal, STOP sign, YIELD sign, school zone device, flashing signal) at the location of a crash is likely to decrease the probability of higher injury severity in pedestrian crashes by 6.84%.

Several proven safety countermeasures related to treatments at non-intersection locations are presented as follows.

Midblock Pedestrian Crossing Signals

Traffic signals at midblock crossings are helpful or essential under the conditions such as (a) on higher volume roadways, (b) where gaps are infrequent, (c) in school zones, (d) where older adults or pedestrians with disabilities cross, and (e) where speeds are high (FHWA-HRT-05-107). On roads with six or more lanes, signalization is necessary because streets with this many lanes create a complex condition for pedestrians trying to cross the street. In addition to the traditional midblock traffic signal, two types of midblock signals have been studied, the High-Intensity Activated Crosswalk (HAWK) and the Rectangular Rapid Flashing Beacon (RRFB). The HAWK beacon, officially known as a Pedestrian Hybrid Beacon (PHB), uses traditional traffic and pedestrian signal heads but in a different configuration. It includes a sign instructing motorists to “STOP ON RED” and a “PEDESTRIAN CROSSING” overhead sign. A study released by FHWA found that vehicle-pedestrian crashes were reduced by 69% after a HAWK signal was installed (Fitzpatrick & Park, 2010).

A yellow RRFB has two rapidly- and alternatively-flashing rectangular yellow indications attached to supplement a pedestrian warning sign or school crossing sign at a crosswalk. Figure 28 illustrates an RRFB at SE Third Avenue and SE First Street in downtown Fort Lauderdale (installed in 2014). According to studies on RRFBs (FHWA, 2010; FHWA, 2014), there is an increase from 16% yielding compliance for a standard yellow overhead beacon to 78% yielding compliance with the installation of an RRFB (Report FHWA-HRT-10-043), and a driver is 3.7 times more likely to yield when the beacon is activated than when not activated (Report FHWA-HRT-15-044). A recent study for the Virginia Department of Transportation (Report VCTIR 15-R22) provides the criteria for considering the installation of RRFBs, including the posted speed limit (≤35 mph) (Dougald, 2015). Therefore, it is recommended to consider the following for wider roads:

- HAWKs or traditional midblock pedestrian signal – for speed limits ≥ 40mph
- RRFBs – for speed limits ≤ 35 mph

Figure 28. RRFB at SE Third Ave and SE First St in Fort Lauderdale
Source: Sun Sentinel, Carline Jean

High-visibility Crosswalk

Crosswalk markings provide guidance for pedestrians crossing roadways by defining the appropriate paths. Although basic crosswalk markings consist of two transverse lines, an FHWA study (Fitzpatrick et al., 2011) found that continental markings were detected at about twice the distance upstream as the transverse markings during daytime conditions. The increased distance meant that drivers traveling at 30 mph had eight additional seconds of awareness of crossing pedestrians.

(a) Bar pair markings
(b) A triple-four crosswalk pattern

Figure 29. Examples of high-visibility crosswalk
Source: PBIC

Medians and Crossing Islands

Medians and crossing islands (also known as refuge islands or center islands) allow pedestrians to cross a street in two stages and significantly reduce the distance a pedestrian must cross at one time. After crossing to the center island, pedestrians wait for motorists to stop or for an adequate gap in traffic before crossing the second half of the street. The use of raised median islands to simplify crossing maneuvers has proven to be an effective technique to improve pedestrian safety, especially on multi-lane arterials with traffic volumes greater than 10,000 vehicles per day (MnDOT, 2013). Raised medians or pedestrian crossing islands are a proven safety countermeasure and have demonstrated a 46% reduction in pedestrian crashes (FHWA, 2016). Figure 30 shows an example of pedestrian channelization barriers, which can help guide pedestrians to crosswalk locations.

Figure 30. Example of pedestrian channelization barrier

Appropriate Landscaping

The careful use of landscaping along a street can provide separation between motorists and pedestrians. Landscaping is also helpful in calming traffic by creating a visual narrowing of the roadway, and its use can provide a more pleasant street environment for all. Appropriate use of landscaping in roadway medians can also prevent pedestrians from crossing, as shown in Figure 31. The following guidelines should be considered:

- Plants should be adapted to the local climate and fit the character of the surrounding area; they should survive without protection or intensive irrigation.
- Maintenance must be considered and agreed to up-front.
- Plant growth patterns should not obscure signs or pedestrian and motorist views of each other.

(a) Before using landscaping barrier (b) After using landscaping barrier

Figure 31. Using landscaping barrier to prevent pedestrians from crossing

Bus Stop Improvements

Bus stops are critical connection points between modes of transportation (walking, bicycling, public transportation). In the methodology test, the major outputs and findings related to public transit and bus stop locations were the following:

- Census BGs with a higher proportion of commuters using public transit or biking are more likely to be associated with a higher number of pedestrian crashes.
- An increase of 1 bus stop per mile results in an average increase of 0.17 pedestrian crashes in 4 years in a low-income BG.

Pedestrian crashes are more likely to occur in greater numbers at locations with more pedestrian activities (e.g., bus stop locations). However, not all bus stop locations share attributes that are dangerous to pedestrians. For example, some bus stop locations are accompanied by infrastructure such as warning signs, crosswalks, or better lighting, which helps to increase pedestrian visibility or slow vehicle speed. Thus, further investigation with a detailed inventory are needed to systematically identify the need for effective countermeasures for bus stop improvements (e.g., relocating bus stops, installing curb ramps, adding or extending sidewalks, installing crosswalks and island cut-through).

- **Bus stop reallocation** – Repositioning of a bus stop is recommended if the following issues exist: (a) inadequate sight distance or sight distance obstruction; (b) excessive congestion or conflicts caused by the bus, or (c) frequent vehicle conflicts with non-motorists such as pedestrian crossings. A far-side bus stop location typically is preferred for improved intersection visibility and vehicle operation. Pedestrians should be encouraged to cross behind the bus. In addition, suitable access to and from the new transit stop location needs to be provided in accordance with the Americans with Disabilities Act (ADA).

- **Transit stop request light** – One example related to the transit stop request light to improve pedestrian safety is in Seattle. King County Metro installed solar-powered beacon pole lights at existing and new bus stops to reduce the number of people passed by and not picked up due to low light levels and poor visibility. They focused on installing these systems at locations that were especially dark or where roadway speeds were 35 mph or higher. The beacon pole light system allows passengers to activate a light that alerts bus drivers that someone is waiting at the stop. The system not only lights up the stop, but also lights up the roadway that is a common crossing location at a transit stop. There has been positive feedback from Metro bus drivers because the lights allow them to make planned, smooth transitions to the stop. This has reduced last-minute braking, which often occurs when visibility is poor (FHWA, 2016).

Figure 32. Transit stop light in Seattle

Speed Reduction Treatments

For both stopping distances and crash severity, speed matters. If a driver is traveling at 40 mph and suddenly spots a pedestrian in the road 100 ft ahead and begins to stop, he will, on average, still be traveling 38 mph on impact. If the driver is traveling at 25 mph in the same situation, the driver will be able to stop before the pedestrian is struck. As motor vehicle speeds increase, motorist visual fields and peripheral vision also are reduced. In the methodology test, the major outputs and findings related to speed and speed limit were the following:

- The proportion of local roads and collectors is negatively correlated with pedestrian crash frequency. Local and collector roads typically are designed for speeds between 20 and 35 mph, and lower speed limits can reduce stopping sight distances and allow drivers to brake quickly should they encounter a pedestrian. On average, a 1% increase in the proportion of lower-speed roads results in an average decrease of 0.012 pedestrian crashes in 4 years in a low-income BG.
- Based on modeling results, a lower speed limit is likely to decrease the probability of severe injuries in pedestrian crashes, and the marginal effect of a lower speed limit (< 40

mph) denotes that the lower speed limit is likely to decrease the probability of severe injuries by 11.19%.

The risks of pedestrian crash occurrences and serious injury or fatality for pedestrians are increased at higher speeds. The strategies or treatments to reduce the travel speeds include, but are not limited to the following:

- **Slow speed zones** – A slow speed zone is a portion of a road with certain traffic control strategies (e.g., speed limit or signal progression) to slow vehicular speeds for safety. Grundy et al. (2009) examined the effect of implementing 20 mph zones throughout London based on 20 years of collisions data. Results of the statistical analysis indicated a decrease of 32.4% for all pedestrian injuries and a decrease of 34.8% for fatal and severe injuries with the 20 mph zone. In Hillsborough County, the first "senior zone" (35 mph) was created in 2006 on Fletcher Avenue from Magnolia Drive to N 42nd Street near the John Knox Village retirement community. According to the traffic program manager for Hillsborough Country Traffic Services, crashes near John Knox Village have decreased 30% compared to before the zone was installed. Speeds on the busy roads of the senior zones on Fletcher Avenue and Waters Avenue have decreased 15% (TBT, 2009).

  Another strategy to create self-enforcing, slower speeds is through signal progression along signalized corridors (FHWA, 2016). As a part of New York City's Vision Zero initiative, the Arterial Slow Zone Program focuses on reducing speeds along corridors with high crash rates. On the 25 corridors selected as Arterial Slow Zones, signals were retimed for 25 mph speed progression. Slow Zone branding signs similar to the City's Neighborhood Slow Zones program were added to the corridor. In addition, police provide focused enforcement along these zones for speeding, failure to obey traffic signals, and failure to yield to pedestrians.

(a) Senior Zone, Tampa, FL (b) Arterial Slow Zone, New York City, NY

Figure 33. Examples of slow speed zone

- **Road diets** – Road diets refer to the reconfiguration of one or more travel lanes to calm traffic and provide space for bicycle lanes, turn lanes, streetscapes, wider sidewalks, and other purposes (FHWA, 2016). The safety benefits of road diets include crash reduction, reduced pedestrian crossing distance, and space for standard or separated bike lanes. Minor arterials and collectors with traffic volumes under 18,000 vehicles per day are considered candidates for conversion (MnDOT, 2013). More information can be found in the design topic on road diets and traffic analysis (FHWA-HEP-16-055) and the FHWA Crash Modification Factors Clearinghouse website.

- **Roundabouts** – Modern roundabouts are designed to control the flow of traffic at intersections without the use of traffic signals or stop signs. The characteristics of roundabouts present a number of advantages for pedestrians and bicyclists—reduced vehicle operating speed, reduced delays, and median refuge islands on all approaches, which result in having to cross only a single direction of traffic at one time (MnDOT, 2013).
- **Traffic calming on residential streets** – Traffic calming uses physical measures to slow motor vehicle speeds and encourages desired behaviors to maximize safety (e.g., yielding to pedestrians and bicyclists). Typical traffic calming measures include cross-section measures (e.g., landscaping, street trees, narrower lanes, on-street parking) and periodic measures (e.g., curb extensions, speed tables, chicanes). Elvik (2001) conducted a meta-analysis of 33 studies of traffic calming and found that area-wide traffic calming schemes reduced the number of injury collisions for all road users by about 15%, with greater effects on residential streets (a reduction of about 25%) than main roads (about 10%).

Road Safety Audits (RSA)

The identified low-income areas with higher pedestrian hazards will require an accompanying Road Safety Audit (RSA) report to determine eligibility for safety improvements. An RSA is the formal safety performance examination of an existing or future road or intersection by an independent, multidisciplinary team (http://safety.fhwa.dot.gov/rsa/). An RSA team qualitatively identifies road safety issues and opportunities for safety improvements for all road users. The aim of an RSA is to answer the following questions: (a) What elements of the road may present a safety concern—to what extent, to which road users, and under what circumstances? (b) What opportunities exist to eliminate or mitigate identified safety concerns?

As historical pedestrian crash data do not always help in determining emerging operational trends or safety issues at a location, site visits by an RSA team are of high importance to provide a more accurate assessment of the level of safety on a road. RSAs are proactive, as they can identify where crashes likely will occur and what their resultant severity will be (FHWA, 2006).

Table 22 summarizes the engineering countermeasures to improve pedestrian safety.

Table 22. Summary of Engineering Countermeasures

Outputs	Outcomes: Engineering Countermeasures	
• 72% of pedestrian fatalities occurred at night (relative to daylight, dusk or dawn). • 22% of nighttime fatalities occurred on streets without lighting. • Dark–not lighted conditions, relative to non-dark conditions (daylight, dusk, dawn), increased the average probability of severe injuries (fatality or incapacitating injury) in pedestrian crashes by 21.56%. • Dark–lighted conditions, relative to non-dark conditions (daylight, dusk, dawn), increased the average probability of severe injuries (fatality or incapacitating injury) in pedestrian crashes by 18.82%. • Better lighting conditions can mitigate pedestrian injury severity involved in a crash, especially for fatal crashes.	Roadway Lighting and Lighting Levels	a. Presence of Lighting
		b. Adequate Lighting Level and Uniformity
		c. Proper Pedestrian Lighting Placement
• 57% of pedestrian crashes occurred outside of intersections. • 65% of pedestrian fatalities occurred outside of intersections. • The location indicator of pedestrians in travel lanes other than crosswalks significantly increases the probability of severe injury by 11.20% compared to other pedestrian locations (e.g., intersection, midblock crosswalk, sidewalk, etc.). • The presence of a traffic control device (e.g., signal, STOP sign, YIELD sign, school zone device, or flashing signal) at the location of a crash is likely to decrease the probability of higher injury severity in pedestrian crashes by 6.84%. • More pedestrian crashes/ fatalities occur outside of intersections; non-crosswalk locations and lack of traffic control devices increase injury severity.	Treatments at Non-intersection Locations	a. Midblock Pedestrian Crossing Signals (HAWKs, RRFBs)
		b. High-Visibility Crosswalk
		c. Medians and Crossing Islands
		d. Appropriate Landscaping
• Census Block Groups (BGs) with a higher proportion of commuters using public transit or biking are more likely to be associated with a higher number of pedestrian crashes. • An increase of 1 bus stop per mile results in an average increase of 0.17 pedestrian crashes in 4 years in a low-income BG. • Higher pedestrian crashes are correlated with higher density of bus stop locations.	Bus Stop Improvement	a. Bus stop Reallocation
		b. Transit Stop Request Lights
• The proportion of local roads and collectors is negatively correlated with pedestrian crash frequency. • On average, a 1% increase in the proportion of lower-speed roads results in an average decrease of 0.012 pedestrian crashes in 4 years in a low-income BG. • Based on modeling results, a lower speed limit is likely to decrease the probability of severe injuries in pedestrian crashes, and the marginal effect of a lower speed limit (< 40mph) denotes that the lower speed limit is likely to decrease the probability of severe injuries by 11.19%. • Risks of pedestrian crash occurrences and serious injury or fatality for pedestrians are increased at higher speeds.	Speed Reduction Treatments	a. Slow Speed Zones
		b. Road Diets
		c. Roundabouts
		d. Traffic Calming on Residential Streets
• Beyond historical crash data— importance of site visits.	Road Safety Audit (RSA)	

5.3 Education and Outreach Plan

From the education perspective, the relationship of pedestrian crashes and demographic variables with respect to age, gender, and community context can help FDOT and local traffic agencies develop educational outreach/campaigns to focus on specific demographics of pedestrians to improve their safety in low-income areas. In the methodology test, the major outputs and findings related to demographics and land use types were the following:

- Pedestrian crashes are more frequent in low-income BGs that have more population and a smaller proportion of older adults, are minority-dominated, have zero-car ownership neighborhoods, and are among populations with a low education level.
- Pedestrian crashes occur more frequently in low-income BGs with the presence of a Walmart store and with greater densities of discount department stores, fast-food restaurants, convenience stores, grocery stores, and barber shops.
- Impaired pedestrian crashes tend to be correlated with locations of bars and alcohol retail.
- Individual characteristics, including the involvement of older pedestrians, pedestrians crossing streets at non-crosswalk locations, improper pedestrian action (dart/dash), impaired pedestrians, and aggressive drivers, have positive effects on the severe injury of a pedestrian crash.

An education and outreach plan aims to teach drivers, walkers, and bicyclists to improve their safety knowledge and awareness and encourages gradual cultural change towards improved pedestrian safety. An education and outreach plan can be implemented according to locations, approaches, contents, and audiences, as listed in Table 23.

The implementation of an education and outreach plan along with targeted High-Visibility Enforcement (HVE) has great potential in reducing both crash and injury frequency and severity. The combined engineering, education, and enforcement approach could produce the most benefits in reducing pedestrian fatalities, injuries, and crashes with a given area’s demographics.

The following subsections provide the more detailed information of the education countermeasures (Table 23) to improve pedestrian safety.

Table 23. Education and Outreach Plan

Education and Outreach Plan	Items/Targets
1. Locations (*where*)	- Hot zones in low-income area (e.g., Figure 24) - High-crash corridors or intersections (e.g., around W Oakland Blvd and US 441) - Stores: discount stores, fast-food restaurants, convenience stores - Location of bars and alcohol retail (to reduce impaired driving and walking)
2. Approaches (*how*)	- Grassroots safety education (e.g., WalkWise Florida) - Business sweeps along high-crash corridors - Public-private partnership (e.g., partnership with Walmart) - High visibility enforcement (three-stage: education -> education + warning -> education + warning + citation) with education as main focus
3. Contents (*what*)	- Safety tips for pedestrians and drivers at nighttime - Florida pedestrian laws - Improving visibility of pedestrian (e.g., reflective clothing at nighttime) - Educating road users to make safer choices - Avoiding improper pedestrian actions such as dart/dash - Avoiding distractions while walking (e.g., texting, checking emails, talking on cell phone, listening to music) - Public information supporting enforcement for aggressive driving (NHTSA, 2015) - Communication and interventions for impaired pedestrians (NHTSA, 2015) - Education about following rules, yielding right-of-way, RRFBs, etc.
4. Audiences (*who*)	- Residents in low-income communities - Commuters using public transit or bike - Adults with low-education level (e.g., less than high school) - Minority groups (e.g., African and Hispanic Americans) - Older adult populations
5. Time (*when*)	- Sooner the better - Depending on each agency (needs, resources, efforts, etc.)

WalkWise Safety Education

WalkWise is a grassroots initiative providing interactive presentations and safety information to the public to increase knowledge of appropriate pedestrian safety measures as identified by FDOT. A WalkWise presentation is an original concept developed by FDOT District 7 for adult audiences and provides a unique interactive format. In an effort to build on the program’s success in District 7, the FDOT Central Office funded the initiation of a statewide effort to expand the program through other District offices.

Figure 34. WalkWise Florida grassroots education

The WalkWise presentation was designed to work in a flexible format to add to a meeting agenda or as a stand-alone presentation. The presentation is customized based on specific requests from the group organizer, and the length is adjusted as needed. Participants are provided the option to sign an attendance sheet and agree to have their name added as a WalkWise Ambassador to the WalkWise Florida website.

A larger portion of time is invested in scheduling WalkWise presentations in and around high-crash corridors. Investigating high-crash corridors and making the necessary connections with local representatives of a community are key to scheduling presentations. Many low-income BGs represent a large population who travel by foot, bicycle, and transit. One strategy to connecting with representatives in low-income communities is to reach out to community centers, neighborhood associations, schools, and other non-profit organizations. A partnership with a local non-profit organization may be a key component to initiating your program their resources and their contacts.

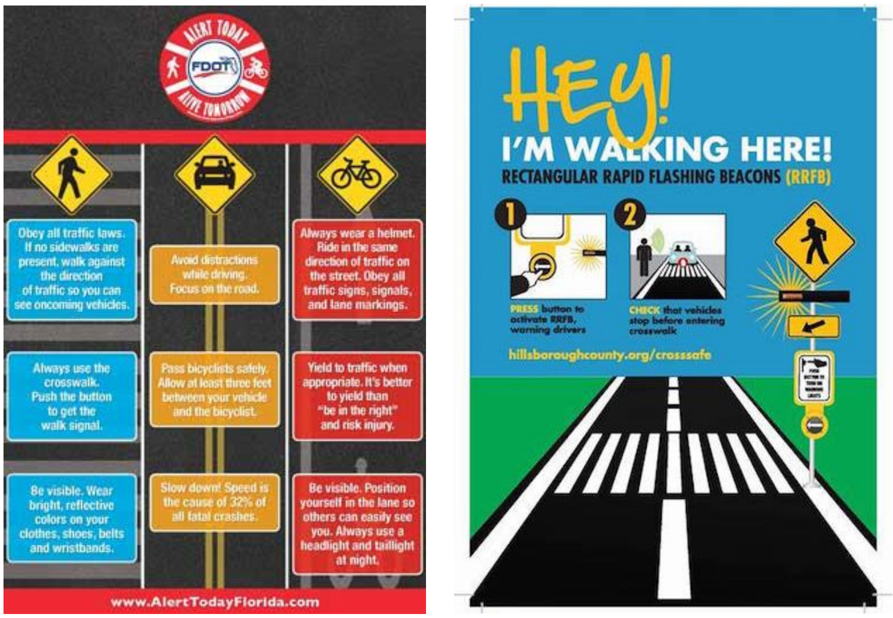
The WalkWise interactive presentation allows an opportunity for the audience to participate through an Audience Response System (ARS). Participant data are collected through the ARS to determine safety knowledge retention through pre- and post-data collection. Questions are asked to the audience and answers are revealed for instant knowledge gained. Discussion points and audience participation questions may help enhance the safety information attainment. Data are then saved and stored for future analysis that includes an aggregate measure of participation and knowledge retention within the respective cities and counties. At the end of the presentation, participants are asked to spread the word about pedestrian safety to their friends, neighbors, and coworkers and to make referrals for future presentations.

Part of the success WalkWise is presenting to an audience who is intereseted in the subject and willing to learn from the safety information. Facilitating a discussion with the audience and answering questions may help the presenter gain attention and support from the audience. Accumulated WalkWise data collected show that more than 70% of an audience agree to being alert and was the most important takeaway of the presentation. Although being alert as a pedestrian is vital, presenters stress that being seen with reflective materials or lights complements the efforts of pedestrian awareness.

Distribution of Education Tip Cards

Pedestrian and bicycle safety education tip cards can be distributed throughout multiple agencies for local distribution. Law enforcement can provide safety education tip cards for drivers to bring more awareness of pedestrian and bicycle education from a driver perspective. WalkWise presentations use tip cards as an active promotion for the program before, during, and after each presentation. Tip cards also may be distributed to businesses during high-crash corridor sweeps and are often left on business counters for customers to pick up. Whereas pedestrian and bicycle safety education tip cards encourage travel safety tips, an infrastructure education tip card can help educate the public on proper procedures for using new pedestrian and bicycle infrastructure with adequate distribution. These distributions rely on the same strategies as business sweeps.

Figures 35 and 36 show examples of safety and infrastructure education tip cards. More education tip cards can be found on the "Alert Today Alive Tomorrow" website at [http://www.alerttodayflorida.com/education.html.](http://www.alerttodayflorida.com/education.html)



(a) Safety Education (b) Infrastructure Education

Figure 35. Examples of safety and infrastructure education tip cards

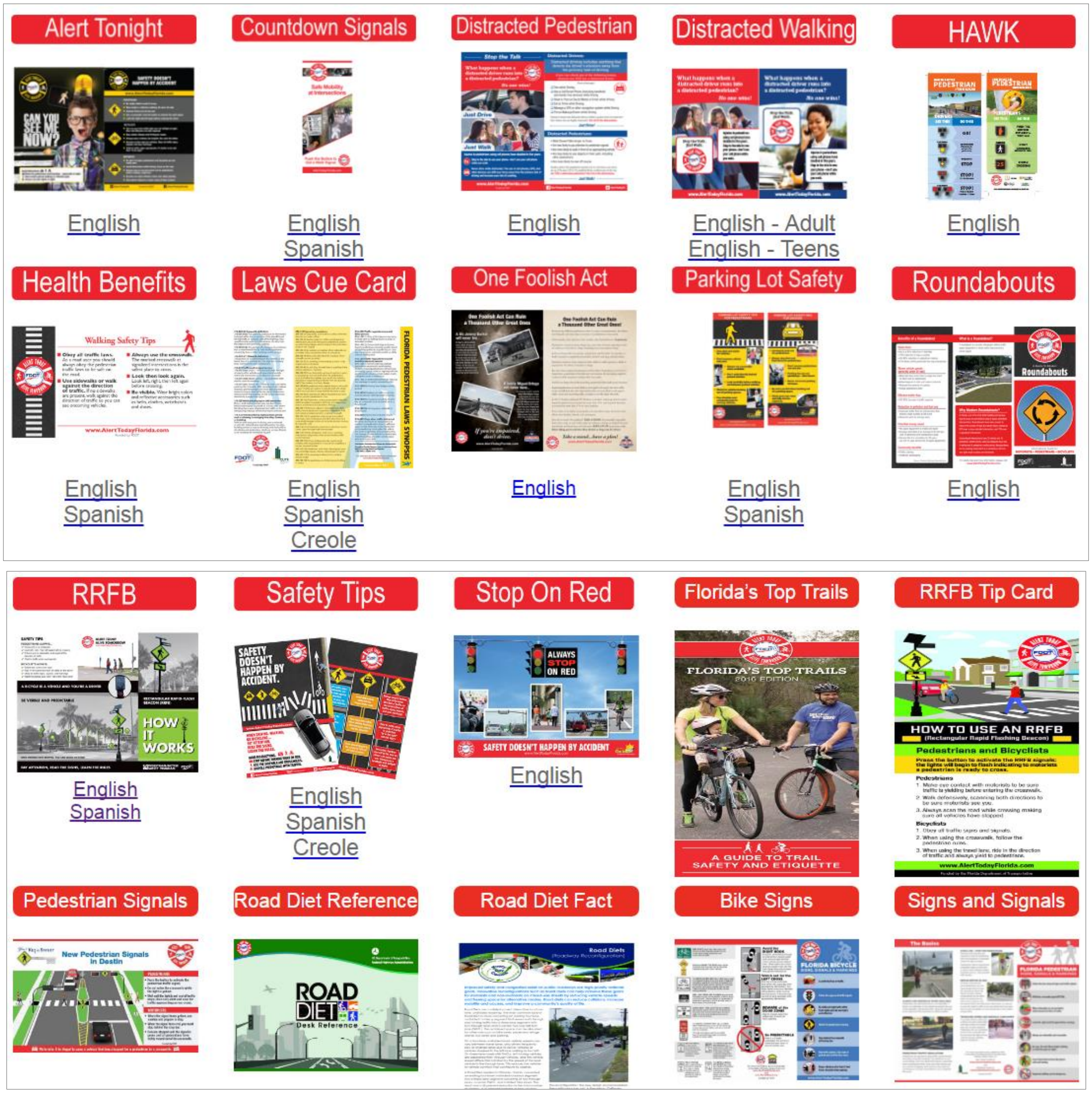
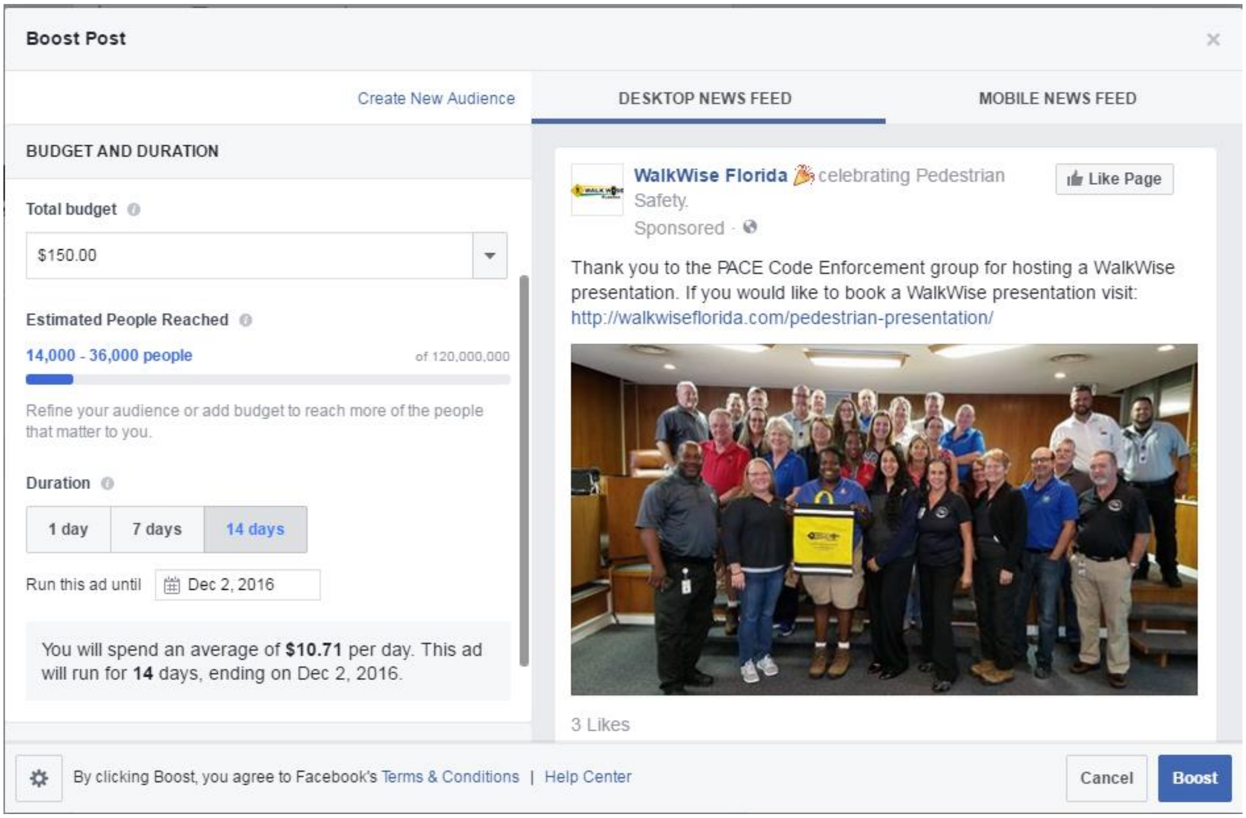


Figure 36. Education tip cards

Social Media Outreach

Social media outreach, when planned and executed well, can be an excellent means of generating leads and demand. Facebook is an effective social media platform to promote events, provide safety information, and connect with local partners and residents. Facebook allows a program such as WalkWise to personalize a message for a particular community. To help boost participation and educational posts, social media providers such as Facebook provide options to market a program and information to a targeting community and demographic. For example, Facebook advertisement can help reach your message out to a specific demographic through geolocation options. This option could help prepare a community for new local infrastructure updates and education safety.



Total budget: $150.00

Estimated People Reached: 14,000 - 36,000 people of 120,000,000

Refine your audience or add budget to reach more of the people that matter to you.

Duration: 1 day | 7 days | **14 days**

Run this ad until: Dec 2, 2016

You will spend an average of **$10.71** per day. This ad will run for **14** days, ending on Dec 2, 2016.

WalkWise Florida celebrating Pedestrian Safety.
Sponsored

Thank you to the PACE Code Enforcement group for hosting a WalkWise presentation. If you would like to book a WalkWise presentation visit: http://walkwiseflorida.com/pedestrian-presentation/

3 Likes

By clicking Boost, you agree to Facebook's Terms & Conditions | Help Center

Figure 37. Example of social media outreach

Community Networking

Attending meetings of Community Traffic Safety Teams (CTSTs), neighborhood associations, civic clubs (such as Rotary), and university gatherings and exhibiting at community events will help build partnerships and connect the safety initiative and message out to the community. Often, these partnerships lead to more safety presentations and outreach for an audience that represents more of pedestrian and bicycle crashes. Local non-profit organizations working within the high crash and low-income areas are good leads to help integrate the WalkWise presentation, as well as other safety information in the community.

Business Sweeps

WalkWise also helps form partnerships with businesses along high-crash corridors through the use of “sweeps,” with the purpose of reaching employees and customers in the immediate area. During a sweep, staff walk into a business and speak to available front-line employees. Safety information including tip cards and brochures are left at each location for distribution to customers and employees. If appropriate, a presentation is provided to the front-line employees using a hard copy of the presentation. A referral card is left with the employees to pass along to a manager for approval for a full WalkWise presentation at the location. Sweeps are a quick installment of safety outreach to areas that may have had a recent crash, nearby infrastructure installment, or presentation inquiries along a crash corridor. The best approach for conducting a sweep is to locate a high-crash corridor and visit adjoining businesses; gas stations, plazas, churches, and big box stores are good targets for reaching residents, customers, and employees. Speaking with a manager or owner prior to soliciting information is a good practice for a successful sweep.

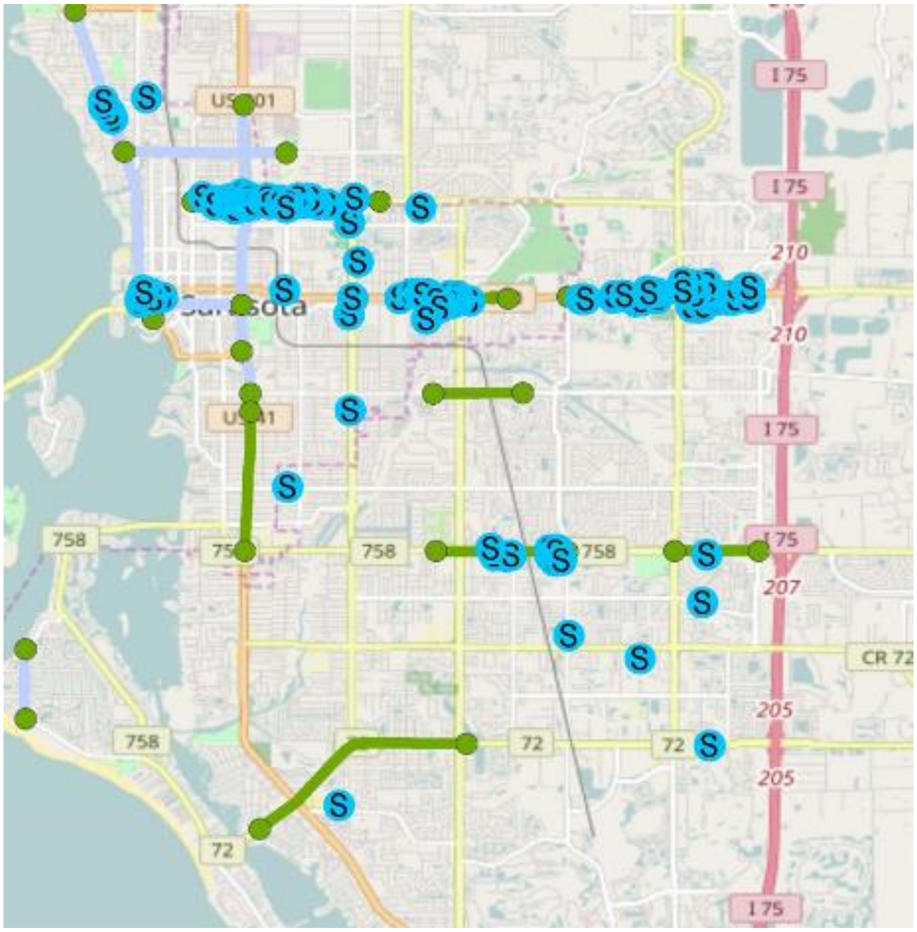
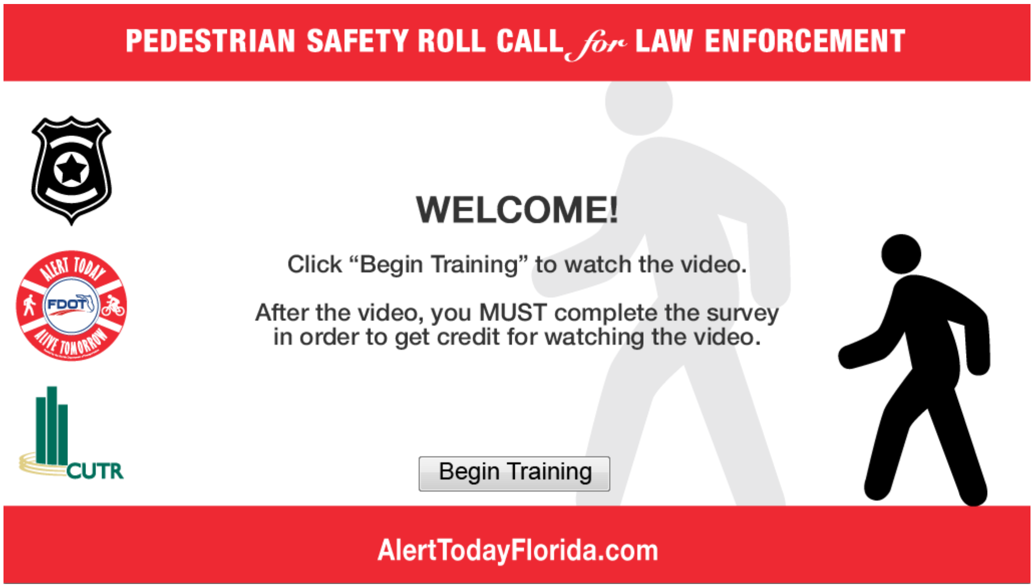


Figure 38. Locations of WalkWise business sweeps along high crash corridors

Law Enforcement Role Call Training

Two 11-minute videos were created by FDOT for law enforcement education, one pedestrian-specific and the other bike-specific. These videos can be viewed on DVD in group settings or streamed individually to an officer’s in-car computer or PC. The videos help officers to familiarize themselves with common pedestrian and bicycle crash types, identify dangerous pedestrian, bicyclist, and motorist behaviors, learn the various Florida statues that pertain to pedestrian and bicycle safety, observe effective education and enforcement techniques, become aware of resources available to them, and help them understand their role in making Florida’s roadways safer for pedestrians and bicyclists.



PEDESTRIAN SAFETY ROLL CALL *for* LAW ENFORCEMENT

WELCOME!

Click “Begin Training” to watch the video.

After the video, you MUST complete the survey in order to get credit for watching the video.

AlertTodayFlorida.com

Figure 39. Pedestrian safety roll call for law enforcement

Public-Private Partnerships

Public-private partnerships are based on a shared commitment to strengthen pedestrian safety at the community level through positive promotion of education and enforcement initiatives. During a 2015–2016 HVE project, FDOT partnered with the Hillsborough County Sheriff’s Office and Chick-fil-A restaurants to pilot a positive reinforcement program (FDOT, 2015). Officers were provided with Chick-fil-A promotional cards that were given to pedestrians, bicyclists, and motorists who were observed obeying pedestrian and bicycle safety laws. This creative partnership received local media coverage and brought attention to the program. Similar partnerships with specific stores such as Walmart are recommended in the low-income areas of Broward and Palm Beach counties to improve pedestrian safety.

6. CONCLUSIONS AND RECOMMENDATIONS

The objectives of this research project were to (1) develop a demographics-based methodology that identifies low-income areas that possess a combination of pre-conditions for greater pedestrian hazard, (2) identify major factors associated with pedestrian crash frequency and injury severity and quantify their relationships, and (3) develop recommendations for both engineering countermeasures and pedestrian safety education/outreach plans that will resonate with a given area's demographics. Through this research project, the CUTR team successfully identified the related databases, proposed and tested the methodological flowchart, and obtained major findings to recommend implementation strategies for pedestrian safety, as summarized in the following sub-sections.

6.1 Summary of Databases

The databases used for demographic analysis to pedestrian safety include the following:

- FDOT Crash Analysis Reporting (CAR) System – on-system and off-system crashes
  - www.dot.state.fl.us/safety/11A-SafetyEngineering/SafetyEngineering1.shtm
- US Census Databases – demographic data
  - factfinder.census.gov/
  - TIGER/Line® with Selected Demographic and Economic Data: https://www.census.gov/geo/maps-data/data/tiger-data.html
- FDOT TranStat GIS Data – RIC and traffic counts
  - www.dot.state.fl.us/planning/statistics/gis/
- Land use data
  - Property Appraiser data from the Florida Geographic Data Library: http://www.fgdl.org/metadataexplorer/explorer.jsp
  - HERE Navigation data from FDOT Unified database: https://www3.dot.state.fl.us/unifiedbasemaprepository/
  - Licensee Files of Public Records from the Florida Department of Business & Professional Regulations:
  - http://www.myfloridalicense.com/dbpr/sto/file_download/index.html
- General Transit Feed Specification (GTFS) and Transit Agencies- transit data
  - www.gtfs-data-exchange.com/agency/

6.2 Summary of Methodology

To achieve the research objectives, the CUTR team proposed a technical approach (flowchart) including identified inputs, outputs, and outcomes for pedestrian safety analysis, as illustrated in the flowchart shown in Figure 5 in Section 3. The technical approach flowchart consists of three key components: inputs, outputs, and outcomes. Specifically, the research team determined the variables (inputs) that should be used in the geographic analysis and statistical modeling to generate outputs and used those outputs to produce recommendations (outcomes) for engineering and education countermeasures.

The methodological flowchart consists of six steps:

Step 1. Data Collection and Compilation
Step 2. Data Preparation by Analysis Unit
Step 3. GIS Visualization and Spatial Analysis
Step 4. Statistical Tests and Modeling
Step 5. Discussion of Results of Data Analysis
Step 6. Education and Engineering Countermeasures

First, pedestrian crash, census, roadway inventory, land use, and other related data are collected from different sources. The ArcGIS platform is used to visualize different data by different layers. Then, low-income areas are identified and determined based on the poverty-related data. Given the low-income areas, the associated variables are identified and analyzed through geographic analysis and statistical modeling. Through statistical tests and modeling, the demographic and other variables correlating to the pedestrian crash rates are identified. Outputs are the result of the analysis of these variables, such as percentage of older population, level of car ownership, and geographic trends in low-income areas. Informed by the outputs, outcomes for both engineering and education countermeasures are recommended for implementation.

6.3 Summary of Findings

- **Pedestrian crashes are more frequent in low-income BGs that have more population, a smaller proportion of older adults, are minority-dominated, have zero-car ownership neighborhoods, and are among populations with a low education level.**
    - Average marginal effects on pedestrian crash frequency indicate that the top four influential variables related to demographic characteristics are the proportion of older adults (negative effect), the proportion of commuters using public transit or biking, the proportion of people with a low education level (less than high school), and the proportion of zero-car ownership.
- **Pedestrian crashes are more frequent in low-income BGs with more intersections, traffic signals, and bus stops and a larger proportion of roads with higher speed limits.**
    - Average marginal effects on pedestrian crash frequency indicate that the most influential variable related to roadway factors is the number of traffic signals per BG, followed by the number of bus stop per mile. The third most influential variable is the proportion of lower-speed road (negative effect). The increase on the proportion of lower-speed roads in a low-income BG can help decrease pedestrian crashes.
- **Pedestrian crashes occurred more frequently in low-income BGs with the presence of a Walmart store and with greater densities of discount department stores, fast-food restaurants, convenience stores, grocery stores, and barber shops.**

  - Average marginal effects on pedestrian crash frequency indicate that the most influential variable related to land use types is density of discount stores, followed by density of convenience stores and density of fast-food restaurants.
- **Individual characteristics including the involvement of older pedestrians, non-crosswalk locations of pedestrians, improper pedestrian action (dart/dash), impaired pedestrians, and aggressive drivers have positive effects on the severe injury of a pedestrian crash.**
  - Average marginal effects on pedestrian crash injury severity indicate that alcohol or drug involvement of a pedestrian is the most influential variable for severe injury of a pedestrian crash, followed by the involvement of aggressive driver and older pedestrians in a pedestrian crash.
- **Environmental factors including lighting conditions, roadway speed limits, and the presence of traffic control devices have significant effects on the injury severity of a pedestrian crash.**
  - Average marginal effects on pedestrian crash injury severity indicate that the dark–not lighted condition is the most influential variable for severe injury pedestrian crash, followed closely by the dark-lighted condition. The third most influential variable is higher speed limit. A dark–lighted condition seems indicate that various lighting level could have different impacts on the injury severity of a pedestrian crash.
- **Pedestrian crashes are more frequent in segments in which the average number of fast-food restaurants, department stores, and banks is higher than average for the corridor.**
- **Pedestrian crashes are more frequent in segments in which the average number of bus stops and intersections is higher than average for the corridor.**
- **Proximity analysis illustrated that impaired pedestrian crashes tend to be more frequent in alcohol availability buffer (near location of bars and alcohol retail) in low-income areas.**

6.4 Summary of Implementation Strategies

Engineering countermeasures are safety treatments and programs from an engineering perspective that have demonstrated success in preventing or reducing pedestrian crash frequency or injury severities. The recommended engineering countermeasures include the following:

- **Roadway lighting and lighting levels**
  - Presence of lighting
  - Adequate lighting level and uniformity
  - Proper pedestrian lighting placement

- **Treatments at non-intersection locations**
  - Midblock pedestrian crossing signals (HAWKs, RRFBs)
  - High-visibility crosswalk
  - Medians and crossing islands
  - Appropriate LANDSCAPING
- **Bus stop improvements**
  - Bus stop reallocation
  - Transit stop request lights
- **Speed reduction treatments**
  - Slow speed zones
  - Road diets
  - Roundabouts
  - Traffic calming on residential streets
- **Road Safety Audits (RSA)**

An education and outreach plan aims to teach drivers, walkers, and bicyclists to improve their safety knowledge and awareness and encourages gradual cultural change towards improved pedestrian safety. The desired outcome of the educational outreach effort is to decrease pedestrian crashes and fatalities in coordination with local law enforcement and engineering efforts and to document an increase in knowledge. The recommended education and outreach plan includes the following:

- **WalkWise safety education**
- **Distribution of education tip cards**
- **Social media outreach**
- **Community networking**
- **Business sweeps**
- **Law enforcement role call training**
- **Public-private partnerships**

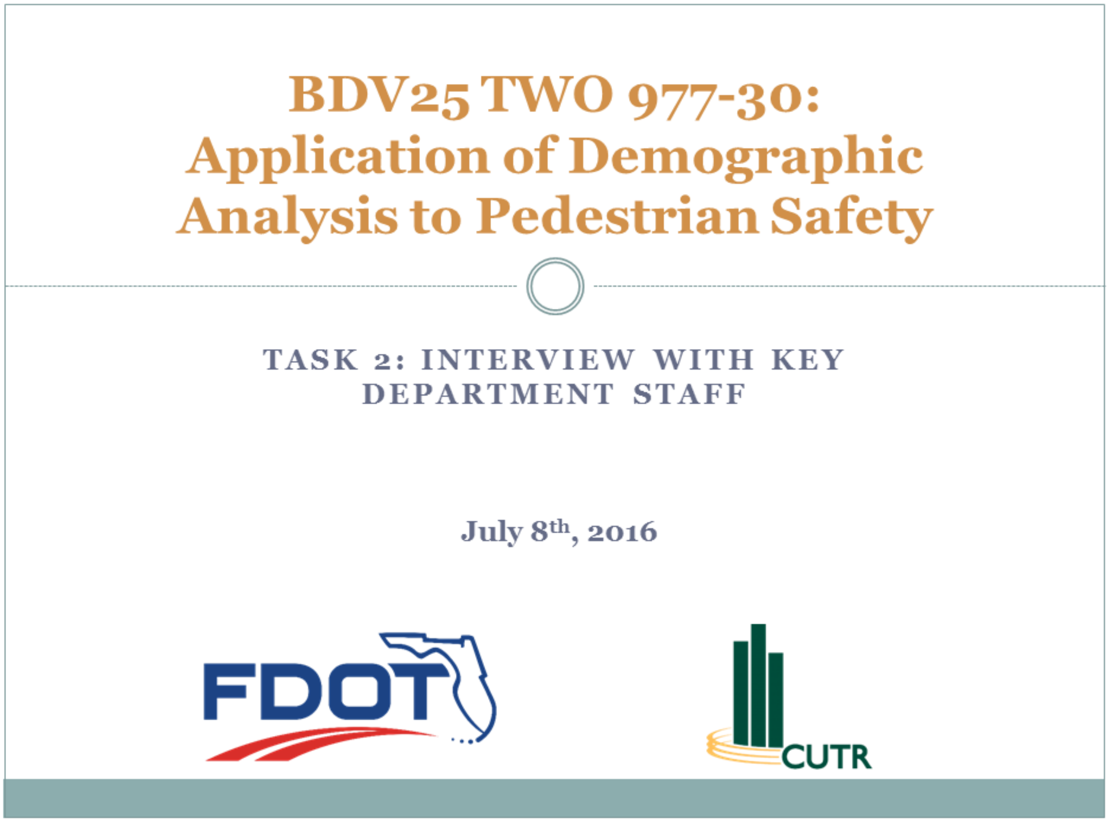
Table 23 in Section 5 lists an education and outreach plan that can be implemented according to locations, approaches, contents, and audiences. The implementation of an education and outreach plan along with targeted HVE has great potential in reducing both crash and injury frequency and severity. The combined engineering, education, and enforcement approach could produce the most benefits in reducing pedestrian fatalities, injuries, and crashes with a given area’s demographics.

APPENDIX A – PRESENTATION OF FINDINGS FROM LITERATURE REVIEW

A short informative and interactive PowerPoint presentation was developed by the CUTR team for use in the interviews. The presentation included a brief introduction, major findings and common variables identified from the literature review, and guidelines for discussion:

- Introduction
- Major Findings from Literature Review
  - Identified Common Variables
  - Identified Tools and Methods
  - Identified Data Sources
- Discussions

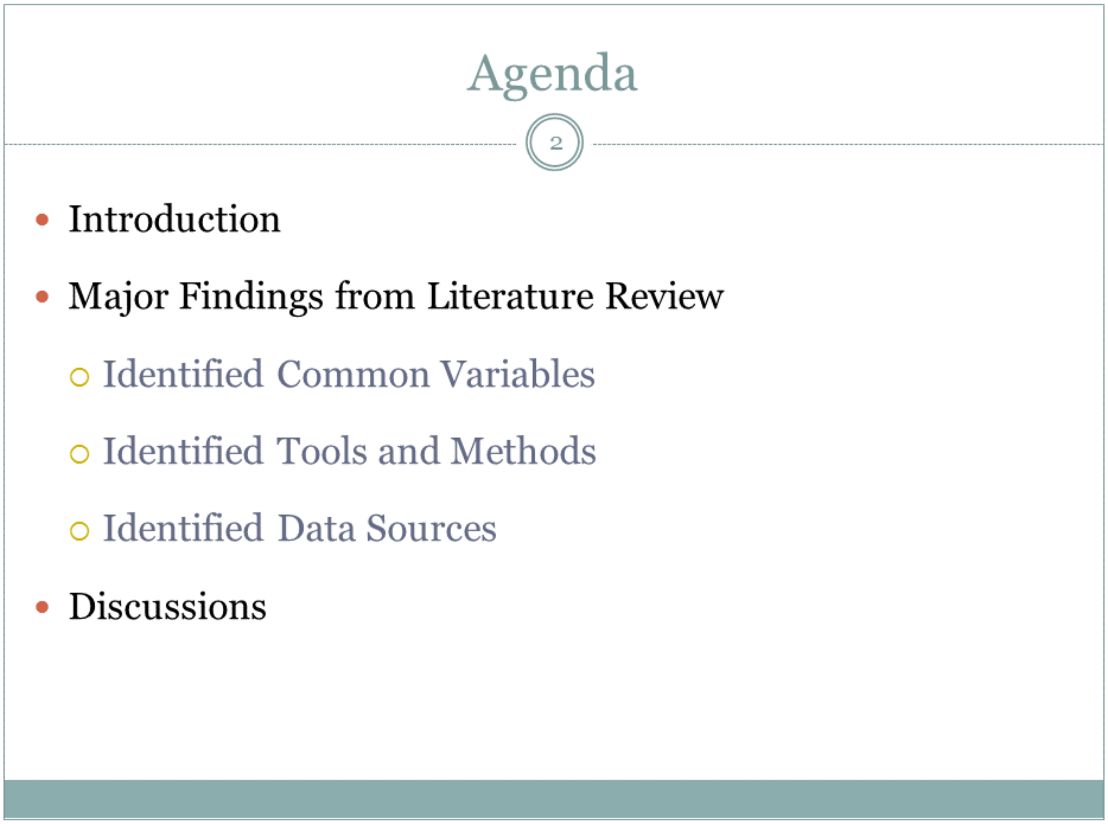
Details can be found in the following presentation slides.



BDV25 TWO 977-30: Application of Demographic Analysis to Pedestrian Safety

TASK 2: INTERVIEW WITH KEY DEPARTMENT STAFF

July 8th, 2016



Agenda

- Introduction
- Major Findings from Literature Review
  - Identified Common Variables
  - Identified Tools and Methods
  - Identified Data Sources
- Discussions

Introduction

Objective of the Interview

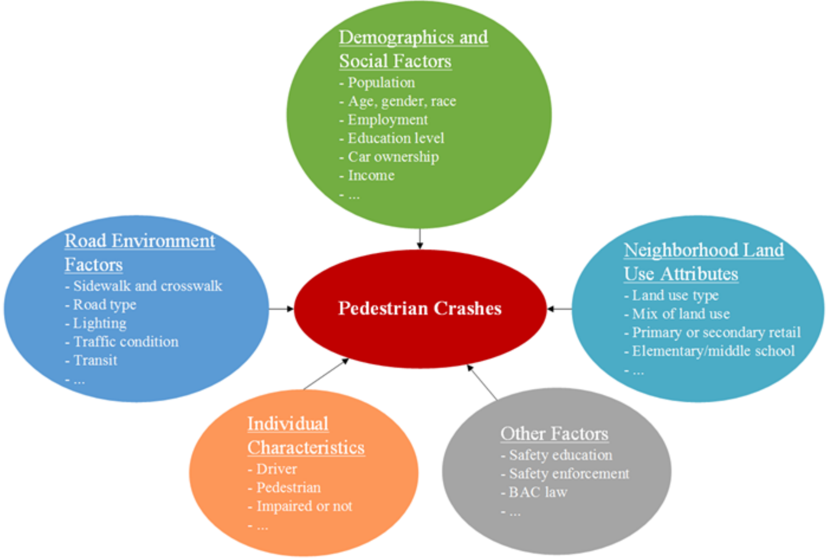
- To present the major findings and common variables from literature review to key Department staff
- To obtain input from key Department staff to identify:
  - **Inputs** (variables)
  - **Outputs** (results of analysis and modeling)
  - **Outcomes** (engineering and education countermeasures)

Introduction

Major Findings from Literature Review

- Examined Variables Associated with Pedestrian Crashes
  - Demographic and Social Factors
  - Road Environment Factors
  - Neighborhood Land Use Attributes
  - Individual Characteristics
- Reviewed Methodologies for Pedestrian Crashes Analysis
  - GIS Visualization and Analysis
  - Statistical Modeling
- Identified Existing GIS Databases and Tools
  - Crash, census, roadway, traffic condition, transit, land use etc.

Identified Common Variables



Demographics and Social Factors
- Population
- Age, gender, race
- Employment
- Education level
- Car ownership
- Income
- …

Road Environment Factors
- Sidewalk and crosswalk
- Road type
- Lighting
- Traffic condition
- Transit
- …

Pedestrian Crashes

Neighborhood Land Use Attributes
- Land use type
- Mix of land use
- Primary or secondary retail
- Elementary/middle school
- …

Individual Characteristics
- Driver
- Pedestrian
- Impaired or not
- …

Other Factors
- Safety education
- Safety enforcement
- BAC law
- …

Identified variables associated with pedestrian crashes

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1) Demographic and Social Factors

Inputs

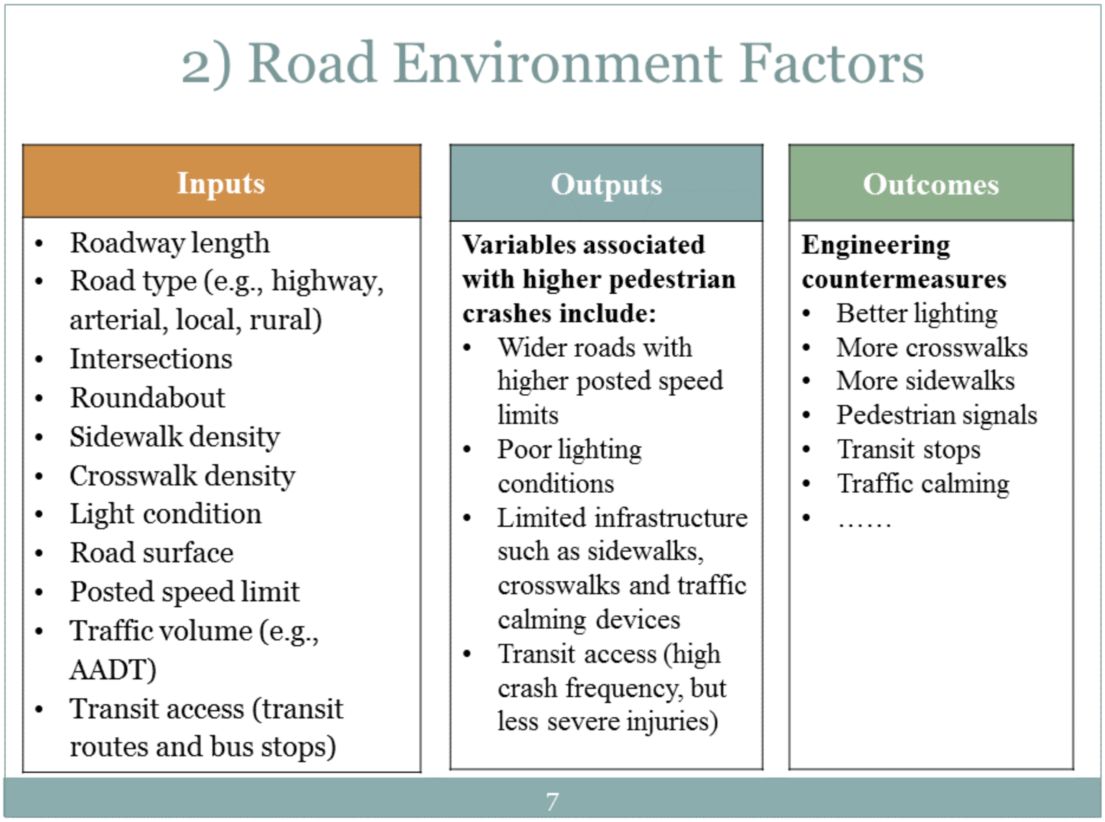
- Population Density
- Age groups
- Gender
- Race/minority groups
- Poverty by household
- Income
- Work status
- Education level
- Car ownership
- Marital status
- English language fluency
- Commute mode
- Travel time to work

Outputs

Variables associated with higher pedestrian crashes include:
- Poorer, densely populated, minority-dominated neighborhoods
- High unemployment rates
- Low education level
- Little or no English-speaking ability
- High number of households without vehicles

Outcomes

Educational outreach according to:
- Socioeconomic status
- Employment status
- Residential status (e.g., homeless)
- Age (e.g., older adult populations)
- Gender (e.g., male)
- ……



2) Road Environment Factors

Inputs

- Roadway length
- Road type (e.g., highway, arterial, local, rural)
- Intersections
- Roundabout
- Sidewalk density
- Crosswalk density
- Light condition
- Road surface
- Posted speed limit
- Traffic volume (e.g., AADT)
- Transit access (transit routes and bus stops)

Outputs

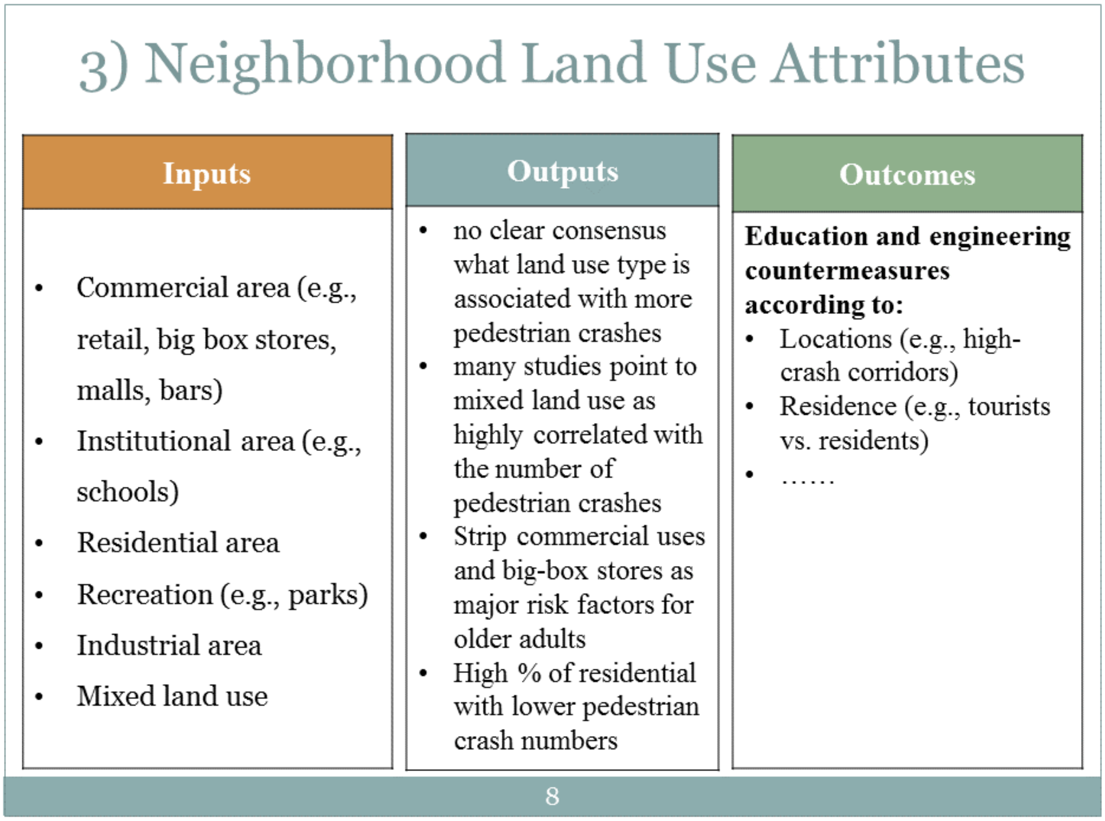
Variables associated with higher pedestrian crashes include:

- Wider roads with higher posted speed limits
- Poor lighting conditions
- Limited infrastructure such as sidewalks, crosswalks and traffic calming devices
- Transit access (high crash frequency, but less severe injuries)

Outcomes

Engineering countermeasures

- Better lighting
- More crosswalks
- More sidewalks
- Pedestrian signals
- Transit stops
- Traffic calming
- ……



3) Neighborhood Land Use Attributes

Inputs

- Commercial area (e.g., retail, big box stores, malls, bars)
- Institutional area (e.g., schools)
- Residential area
- Recreation (e.g., parks)
- Industrial area
- Mixed land use

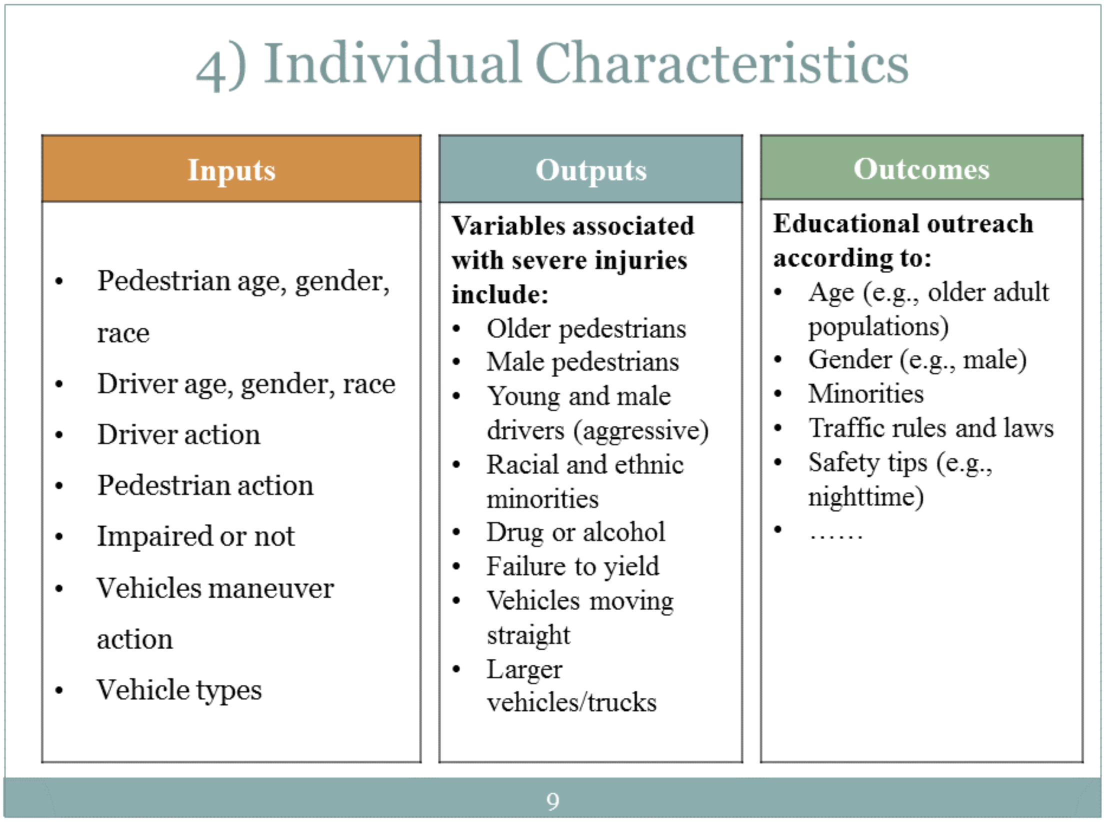
Outputs

- no clear consensus what land use type is associated with more pedestrian crashes
- many studies point to mixed land use as highly correlated with the number of pedestrian crashes
- Strip commercial uses and big-box stores as major risk factors for older adults
- High % of residential with lower pedestrian crash numbers

Outcomes

Education and engineering countermeasures according to:

- Locations (e.g., high-crash corridors)
- Residence (e.g., tourists vs. residents)
- ……



4) Individual Characteristics

Inputs

- Pedestrian age, gender, race
- Driver age, gender, race
- Driver action
- Pedestrian action
- Impaired or not
- Vehicles maneuver action
- Vehicle types

Outputs

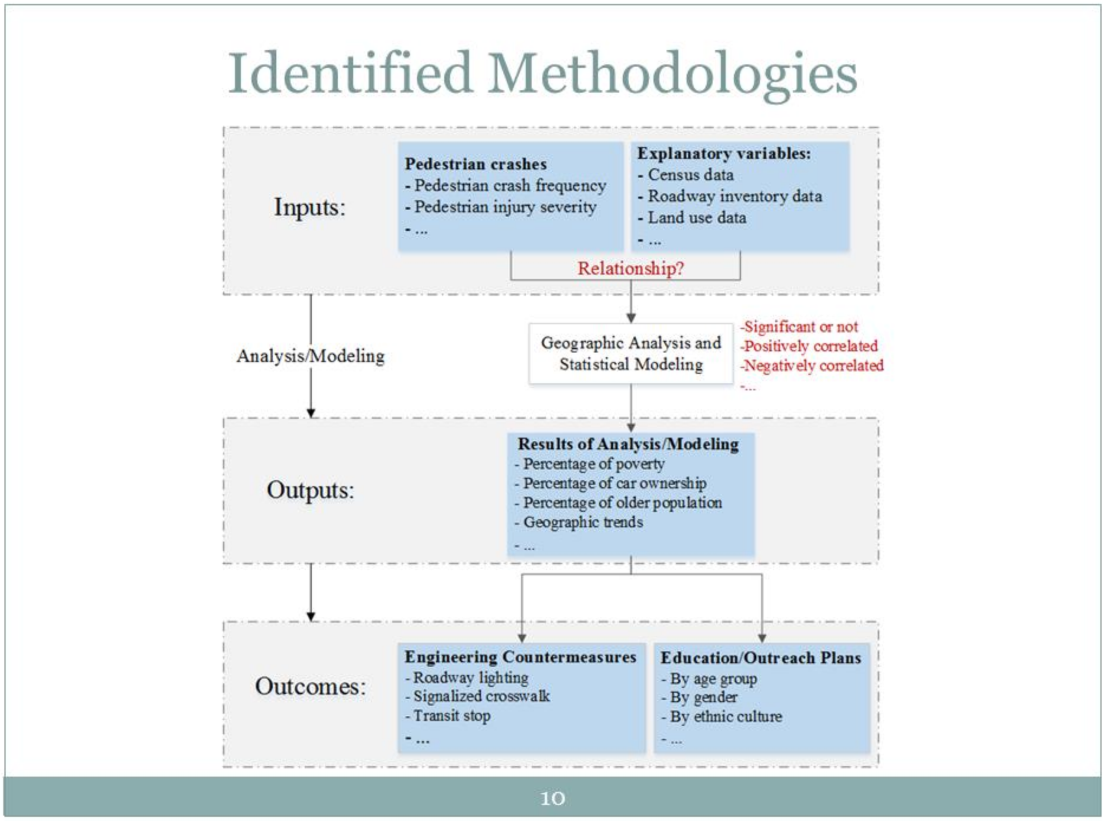
Variables associated with severe injuries include:

- Older pedestrians
- Male pedestrians
- Young and male drivers (aggressive)
- Racial and ethnic minorities
- Drug or alcohol
- Failure to yield
- Vehicles moving straight
- Larger vehicles/trucks

Outcomes

Educational outreach according to:

- Age (e.g., older adult populations)
- Gender (e.g., male)
- Minorities
- Traffic rules and laws
- Safety tips (e.g., nighttime)
- ……



Identified Methodologies

Inputs:

Pedestrian crashes
- Pedestrian crash frequency
- Pedestrian injury severity
- ...

Explanatory variables:
- Census data
- Roadway inventory data
- Land use data
- ...

Relationship?

Analysis/Modeling

Geographic Analysis and Statistical Modeling

-Significant or not
-Positively correlated
-Negatively correlated
-...

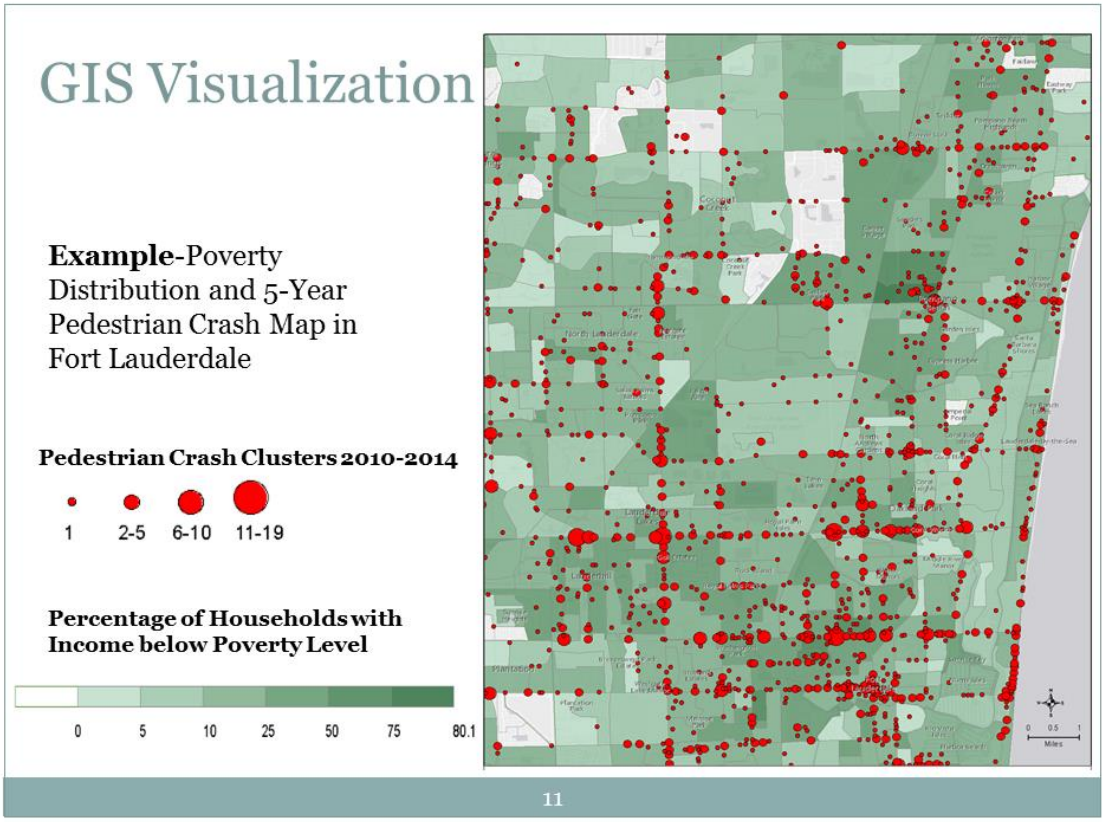
Outputs:

Results of Analysis/Modeling
- Percentage of poverty
- Percentage of car ownership
- Percentage of older population
- Geographic trends
- ...

Outcomes:

Engineering Countermeasures
- Roadway lighting
- Signalized crosswalk
- Transit stop
- ...

Education/Outreach Plans
- By age group
- By gender
- By ethnic culture
- ...



GIS Visualization

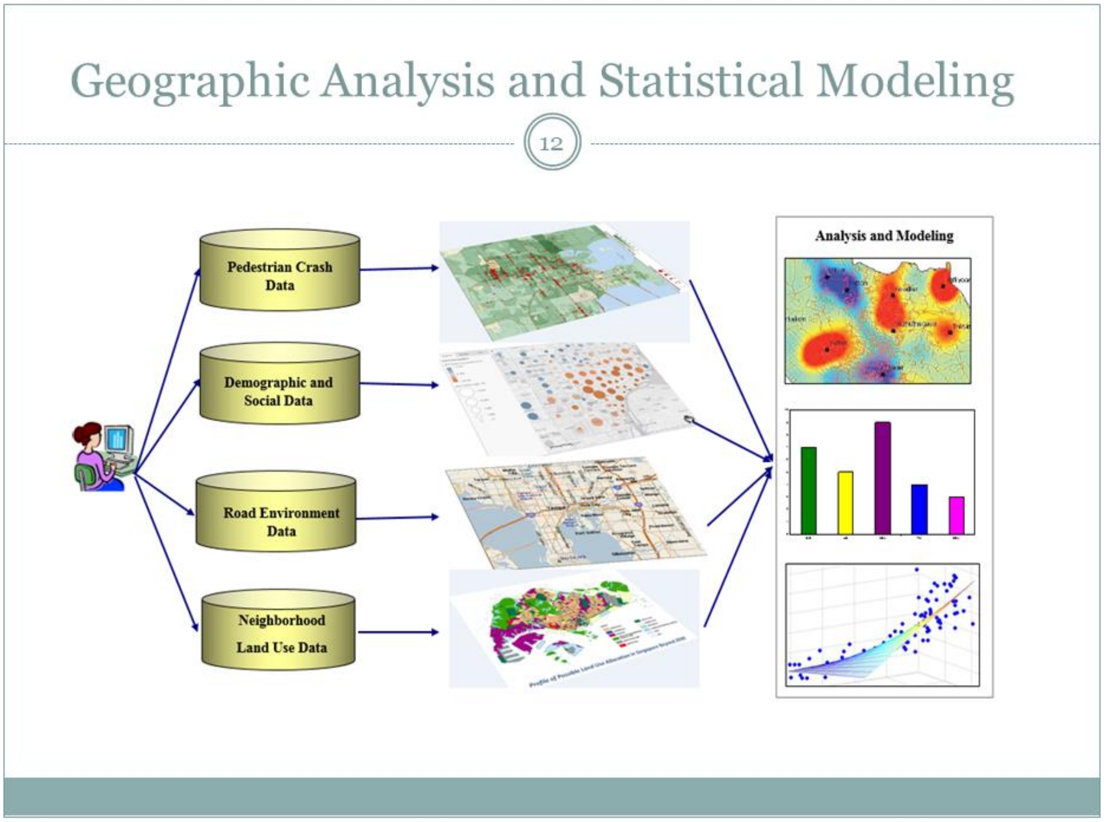
Example-Poverty Distribution and 5-Year Pedestrian Crash Map in Fort Lauderdale

Pedestrian Crash Clusters 2010-2014

● 1 ● 2-5 ● 6-10 ● 11-19

Percentage of Households with Income below Poverty Level

0 5 10 25 50 75 80.1



Geographic Analysis and Statistical Modeling

Identified Data Sources

- FDOT Crash Analysis Reporting (CAR) System
- U.S. Census Databases
- FDOT Road and Traffic Information Databases
- Land Use, Transit and Other Databases

GTFS Data Exchange

Search - Use the options on the left (topics, geographies, ...) to

Your Selections

'Your Selections' is empty

load search | save search

earch using the options below:

Topics (age, income, year, dataset, ...)

Geographies (states, counties, places, ...)

Race and Ethnic Groups (race, ancestry, tribe)

To search for tables and other files

1 Enter search terms and an optior

topic or table name

● topics ○ race/ancest

– or –

Select from Topics, Race and E

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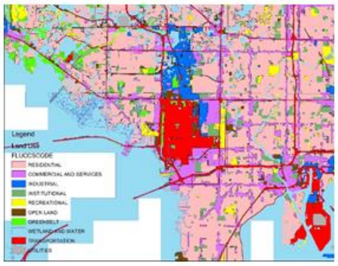


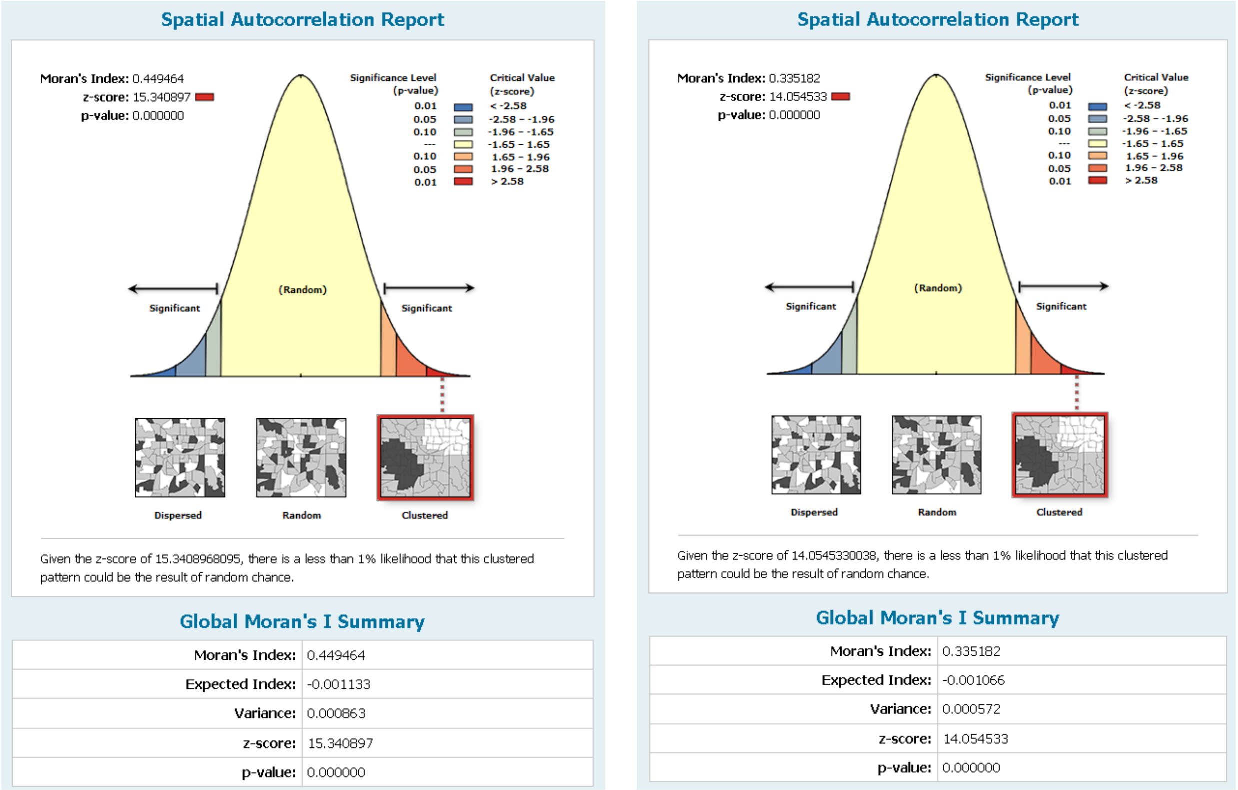
Thank you!

Comments and Discussions

APPENDIX B – GIS ANALYSIS

Using the compiled data, spatial statistics tools were applied to analyze patterns, clusters, and spatial relationships between pedestrian crashes and other collected variables (demographic, road inventory, land use types).

Global Moran’s I (Spatial Autocorrelation) was employed to analyze if there was any spatial correlation between the number of pedestrian crashes within BGs in Palm Beach and Broward counties. The positive values of Moran’s I (0.45 and 0.35 for Palm Beach and Broward, respectively) indicate the positive spatial autocorrelation and clustering of BGs where high number of pedestrian crashes occur. The results are presented in Figure 40.



Given the z-score of 15.3408968095, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.

Global Moran's I Summary

Moran's Index:	0.449464
Expected Index:	-0.001133
Variance:	0.000863
z-score:	15.340897
p-value:	0.000000

Given the z-score of 14.0545330038, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.

Global Moran's I Summary

Moran's Index:	0.335182
Expected Index:	-0.001066
Variance:	0.000572
z-score:	14.054533
p-value:	0.000000

a) Palm Beach County b) Broward County

Figure 40. Global Moran’s I spatial autocorrelation results

A Hot Spot analysis was used to identify the locations of clusters of pedestrian crashes. Based on this method, a BG was categorized as a hot spot when many pedestrian crashes occurred within its boundary and all its neighboring BGs also had a high number of pedestrian crashes. The outputs of hot spot analyses for Palm Beach and Broward counties are presented in Figure 41and Figure 42, respectively. The dark red color represents statistically-significant clusters of BGs with a high number of pedestrians. The analyses showed no cold spots in either county, meaning that there is no clustering of BGs that have a low number of pedestrian crashes.

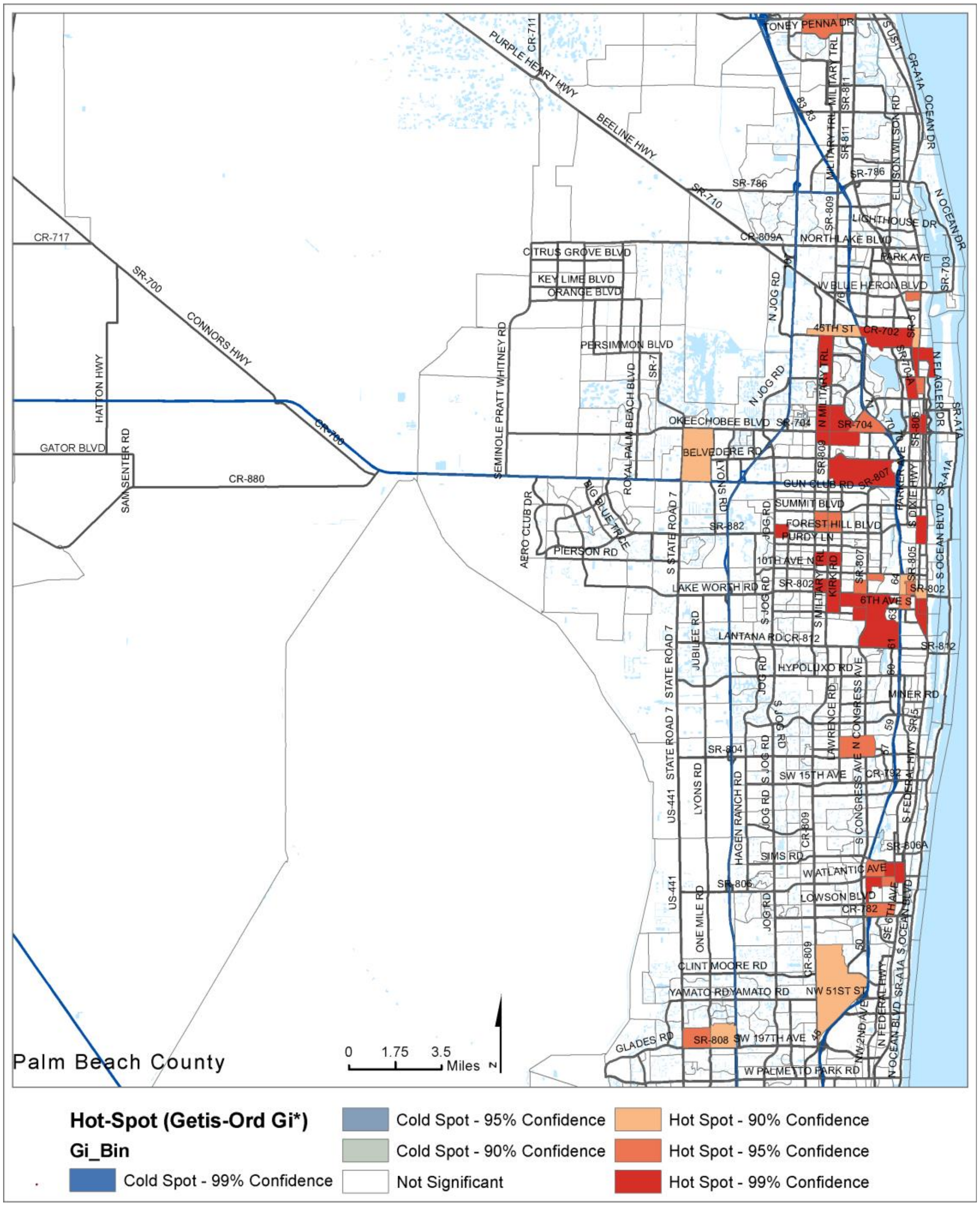


Figure 41. Locations of hot spots in Palm Beach County

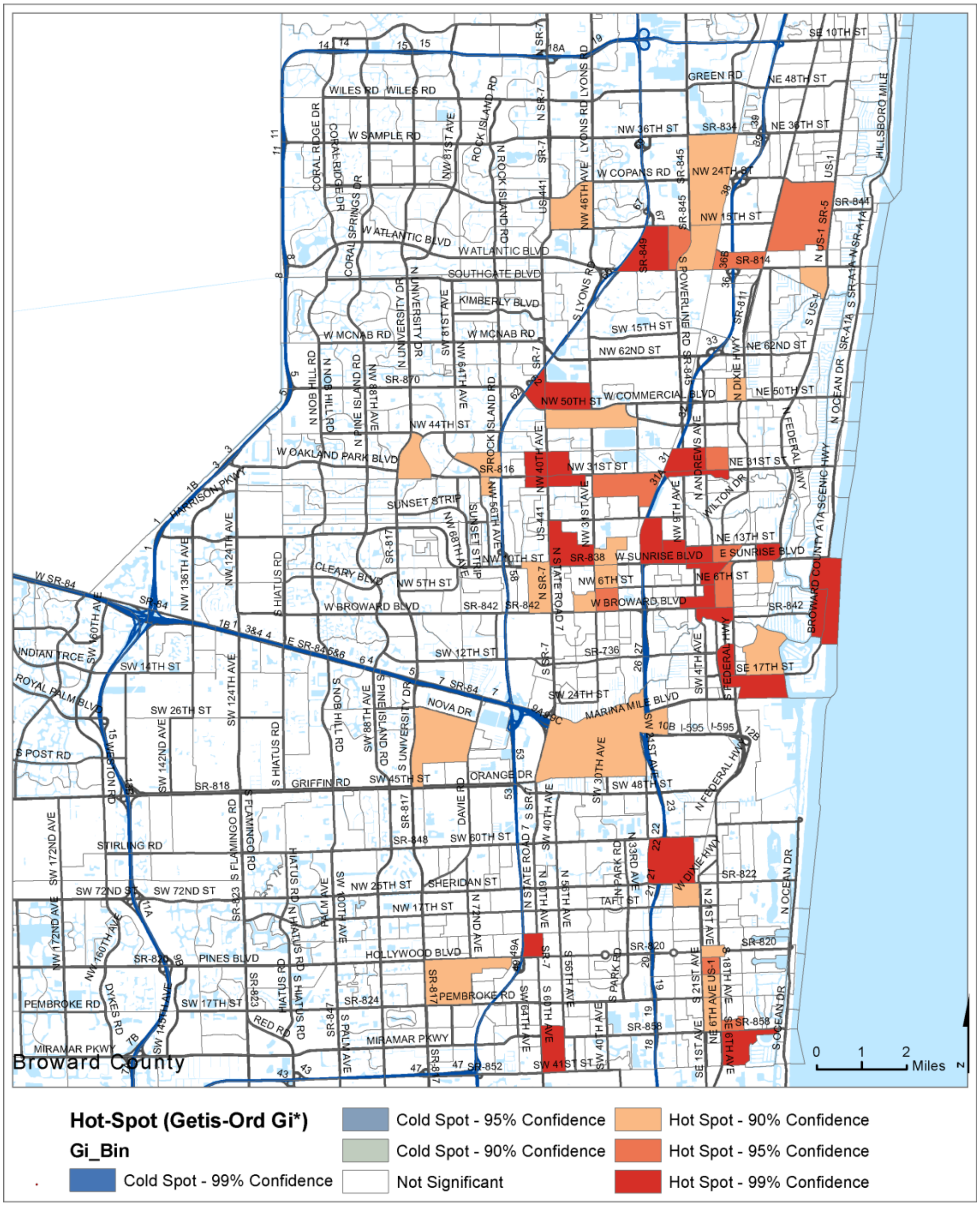


Figure 42. Locations of hot spots in Broward County

Figure 43 shows the poverty distribution and locations of hot spots for severe and non-severe injury in pedestrian crashes. In the selected areas, both severe and non-severe hot spots correspond with the BGs with impoverished communities.

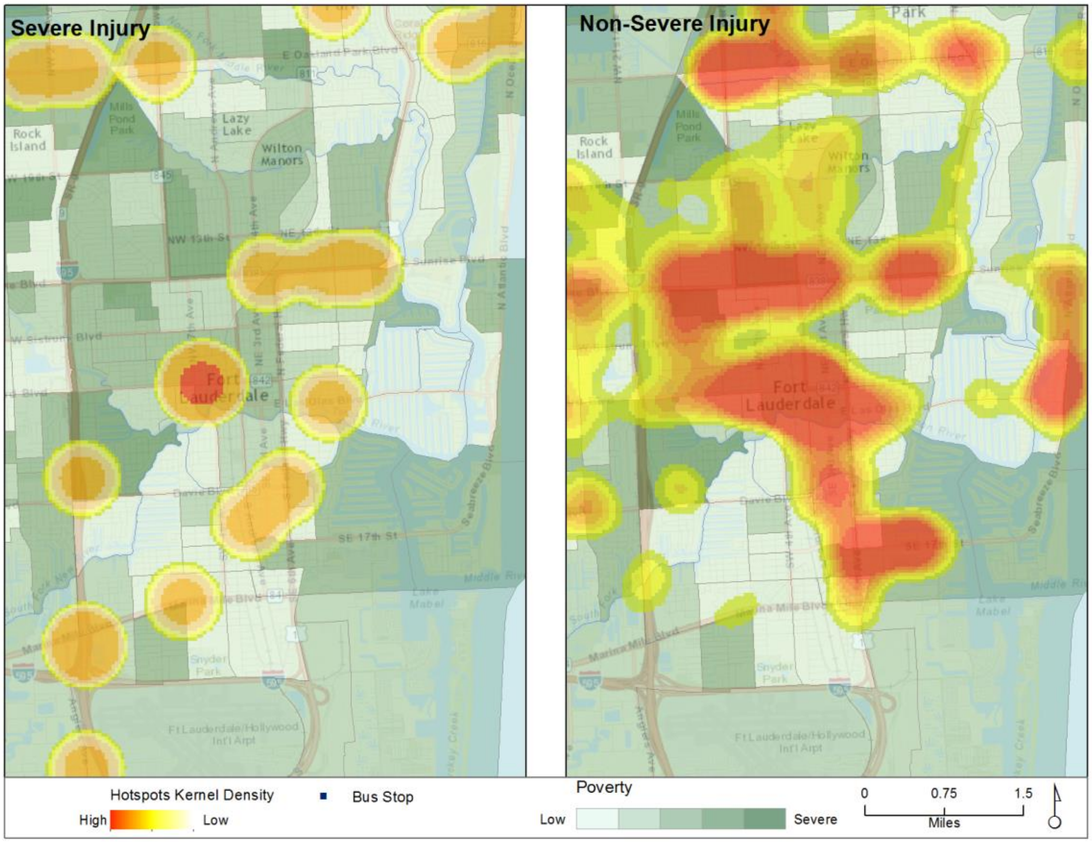


Figure 43. Hot spots of pedestrian crashes with severe and non-severe injuries and poverty distribution

APPENDIX C – STATISTICAL TESTS

Quantitative data analysis was conducted to provide quantifiable and easy-to-understand results. A statistical hypothesis test was used to assess the likelihood that a specific statement or hypothesis is true. For example, a *t*-test assesses whether the means of two groups are statistically different from each other, and a chi-square goodness-of-fit test allows testing of whether the observed proportions for a categorical variable differ from hypothesized proportions.

For statistical tests, the observed variables were categorized into two groups: feature group (low-income area) and control group (higher-income area), and their proportions (*P*) were calculated respectively, as shown in Table 24.

Table 24. Statistical Hypothesis Test between Two Groups

Group	With Feature (e.g., lighting, signal)	Without Feature (e.g., lighting, signal)
Low-income area	P_{FE}	$P_{FU} = 1 - P_{FE}$
Higher-income area	P_{CE}	$P_{CU} = 1 - P_{CE}$

- P_{FE} (proportion of observations with feature in low-income area) = N_{FE} (number of observations with feature in low-income area) / N (total observations in low-income area)
- P_{CE} (proportion of observations with feature in higher-income area) = N_{FE} (number of observations with feature in higher-income area) / N (total observations in higher-income area).

Comparisons of the features were conducted between low- and higher-income areas. Chi-square tests were used to determine whether the proportion of observations with feature in low-income area *(P_{FE})* was significantly different from that in higher-income area *(P_{CE})*.

H_0: $P_{FE} = P_{CE}$ (proportion of observations with feature in low-income area is same as that in higher-income area)

H_a: $P_{FE} \neq P_{CE}$ (proportion of observations with feature in low-income area is different from that in higher-income area)

Proportion comparisons also were conducted between different demographics (e.g., age group, gender, race, education, etc.), roadway characteristics (e.g., intersection, signal, crosswalk, lighting, etc.), and pedestrian and driver characteristics (e.g., improper actions and risk groups) between low- and higher-income areas. All hypothesis tests were conducted at a minimum confidence level of 95% ($p<0.05$).

APPENDIX D – MODELING METHODS

Extensive research has been conducted analyzing roadway and pedestrian crashes. Two methods are studying the counts of crashes (or crash frequency) in a geographic region (e.g., 200 ft from intersection) or studying crash severities.

Traditionally, Poisson distribution is used to model crash frequency. However, crash frequency, as the dependent variable, usually has the characteristics of over-dispersion or under-dispersion, which violates the assumption of Poisson distribution, where the mean and variance should equal each other. Variants of Poisson distribution, such as Negative Binomial (or called Poisson-gamma), Poisson-lognomal, zero-inflated Poisson, and Conway-Maxwell-Poisson were developed to manage the over- or/and under-dispersion issues. Other modeling challenges also exist for analyzing crash frequency. Both dependent and explanatory variables may have temporal and spatial correlations; ignoring the correlations will lead to inaccurate regression results. Furthermore, less severe crashes usually are under-reported, which leads to biased estimates if the under-reporting is not taking into consideration. Other challenges include endogeneity, non-linear functional form of the relationship between crash frequencies and explanatory variables, and considerable complex of regression if random parameters are applied. Lord and Mannering (2010) provided an overview of the models used for crash frequency analysis and summarized the pros and cons of each model for managing the different challenges (see Table 25 and Table 26).

Table 25. Data and Methodological Issues Associated with Crash-Frequency Data

Data/Methodological Issue	Associated Problems
Over-dispersion	Can violate some basic count-data modeling assumptions of some modeling approaches
Under-dispersion	As with over-dispersion, can violate basic count-data modeling assumptions of some modeling approaches
Time-varying explanatory variables	Averaging of variables over studied time intervals ignores potentially important variations within time intervals, which can result in erroneous parameter estimates
Temporal and spatial correlation	Correlation over time and space causes losses in estimation efficiency
Low sample-mean and small sample size	Causes an excess number of observations where zero crashes are observed, which can cause errors in parameter estimates
Injury severity and crash-type correlation	Correlation between severities and crash types causes losses in estimation efficiency when separate severity-count
Under-reporting	Under-reporting can distort model predictions and lead to erroneous inferences with regard to influence of explanatory variables
Omitted-variables bias	If significant variables omitted from model, parameter estimates will be biased, and possibly erroneous inferences with regard to influence of explanatory variables will result
Endogenous variables	If endogenous variables included without appropriate statistical corrections, parameter estimates will be biased, and erroneous inferences with regard to influence of explanatory variables may be drawn
Functional form	If incorrect functional used, result will be biased parameter estimates and possibly erroneous inferences with regard to influence of explanatory variables
Fixed parameters	If parameters are estimated as fixed when they actually vary across observations, result will be biased parameter estimates and possibly erroneous inferences with regard to influence of explanatory variables

Source: Lord and Mannering, 2010

Table 26. Summary of Existing Models for Analyzing Crash-Frequency Data

Model Type	Advantages	Disadvantages
Poisson	Most basic model; easy to estimate	Cannot handle over- and under dispersion; negatively influenced by low sample-mean and small sample size bias
Negative binomial/ Poisson-gamma	Easy to estimate; can account for over-dispersion	Cannot handle under-dispersion; can be adversely influenced by low sample-mean and small sample size bias
Poisson-lognormal	More flexible than Poisson- gamma to handle over-dispersion	Cannot handle under- dispersion; can be adversely influenced by low sample-mean and small sample size bias (less than Poisson-gamma)l cannot estimate a varying dispersion parameter
Zero-inflated Poisson and negative binomial	Handles datasets that have large number of zero-crash observations	Can create theoretical inconsistencies; zero-inflated negative binomial can be adversely influenced by low sample-mean and small sample size bias
Conway–Maxwell–Poisson	Can handle under- and over- dispersion or combination of both using a variable dispersion (scaling) parameter	Could be negatively influenced by low sample-mean and small sample size bias; no multivariate extensions available to date
Gamma	Can handle under-dispersed data	Dual-state model with one state having long-term mean equal to zero
Generalized estimating equation	Can handle temporal correlation	May need to determine or evaluate type of temporal correlation a priori; results sensitive to missing values
Generalized additive	More flexible than traditional generalized estimating equation models; allows non-linear variable interactions	Relatively complex to implement; may not be easily transferable to other datasets
Random-effects	Handles temporal and spatial correlation	May not be easily transferable to other datasets
Negative multinomial	Can account for over-dispersion and serial correlation; panel count data	Cannot handle under-dispersion; can be adversely influenced by low sample-mean and small sample size bias
Random-parameters	More flexible than traditional fixed parameter models in accounting for unobserved heterogeneity	Complex estimation process; may not be easily transferable to other datasets
Bivariate/ multivariate	Can model different crash types simultaneously; more flexible functional form than generalized estimating equation models (can use non- linear functions)	Complex estimation process; requires formulation of correlation matrix
Finite mixture/Markov	Can be used for analyzing sources; switching of dispersion in data	Complex estimation process; may not be easily transferable to other data
Duration	By considering time between crashes (as opposed to crash frequency directly), allows for very in-depth analysis of data and duration effects	Requires more detailed data than traditional crash frequency models; time-varying explanatory variables difficult to handle

Hierarchical/ multilevel	Can handle temporal, spatial, and other correlations among groups of observations	May not be easily transferable to other datasets; correlation results can be difficult to interpret
Neural network, Bayesian neural network, and support vector machine	Non-parametric approach does not require assumption about distribution of data; flexible functional form; usually provides better statistical fit than traditional parametric models	Complex estimation process; may not be transferable to other datasets; work as black-boxes; may not have interpretable parameters

Source: Lord and Mannering, 2010

For crash-injury severity, traditional discrete data forms (e.g., police-reported data) are represented by KABCO scale—i.e., fatal injury or killed (K), incapacitating injury (A), non-incapacitating (B), possible injury (C), and property damage only (O). Such multiple response outcomes have been treated as both ordinal (accounting for the ordinal nature of injury data) and nominal (i.e., unordered). One direction is to combine the multiple response outcomes into binary categories, e.g. injury vs. non-injury crashes or fatal vs. non-fatal crashes, then use either Bayesian hierarchical binary logit/simultaneous binary logit or Bivariate/multivariate binary probit to model the binary dependent variable. The second direction is to account for the ordinal nature of injury data. The methods for analyzing the multiple response outcomes include 1) a copula-based multivariate approach simultaneously estimating models of injury severities and the number of crash- involved individuals, 2) bivariate ordered probit, 3) heterogeneous choice model managing the possible heteroskedastic of the error terms, 4) generalized ordered logit, and 5) Bayesian ordered probit/mixed generalized ordered logit (see Table 27).

Another direction is to take the multiple response outcomes as unordered multinomial discrete outcome. The methods to model such unordered data include 1) multinomial logit models, 2) sequential logit and probit models, 3) Markov switching multinomial logit assuming that there exist two unobserved states of roadway safety, 4) nest logit model if the independence of irrelevant alternative (IIA) assumption is violated, and 5) mixed logit models (random parameters logit models) allowing for heterogeneous effects and correlation in unobserved factors. In addition to these methods, researchers also tried to apply artificial neural networks and data mining techniques such as classification and regression tree approach; however, an artificial neural network is more suitable for prediction purposes, and a data mining technique does not provide for the interpretive capabilities of discrete outcomes models.

Recently, understanding the limitations of both ordered and non-ordered models, researchers have begun to use another approach, the partial proportional odds (PPO) model, to bridge the gap between ordered and non-ordered severity modeling frameworks. PPO models allow certain individual independent variables to affect each level of the response variable differently, whereas other independent predictors adhere to the proportional odds assumption (refer to Sasidharan and Menendez [2014] for empirical comparison of PPO with ordered logit modal and multinomial logit models.) Evidence demonstrates that PPO model outperformed logit and MNL models.

Table 27. Summary of Previous Research Analyzing Crash-Injury Severities

Model Type	Suitable Circumstances
1. Binary Outcomes Models	
Bayesian hierarchical binary logit/ simultaneous binary logit	Considering injury-severity level of more than one crash-involved individual in same crash (i.e., within-crash correlation)
Bivariate/multivariate binary probit	Account for endogeneity of explanatory variables with respect to dependent variables
2. Ordered Discrete Outcome Models	
Copula-based multivariate approach	Considering injury-severity level of more than one crash-involved individual in same crash, simultaneously estimate models of injury severities and number of crash- involved individuals
Bivariate ordered probit	Hierarchical system of two equations used to model simultaneous relationship, addressing possible issues of endogeneity
Heterogeneous choice model	Account for heteroskedastic of error variances
Generalized ordered logit	Consider situation in which parameter estimates not constant across severity levels
Bayesian ordered probit/mixed generalized ordered logit	Allow for random coefficients capable of capturing observation-specific differences in effects of covariates on injury severity; allow for injury severity data to be supplemented by prior knowledge regarding model parameters
3. Unordered Multinomial Discrete Outcome Models	
Multinomial logit models	Do not explicitly consider ordering present in outcomes
Sequential logit and probit models	Allow treatment of severity thresholds across ordered response levels by separate parameter coefficients for explanatory variables and heterogeneity in effects of injury severity determinants
Markov switching multinomial logit	Assume two unobserved states of roadway safety
Nested logit model	When independence of irrelevant alternatives (IIA) assumption violated
Mixed logit models	Address limitations of multinomial logit by allowing for heterogeneous effects and correlation in unobserved factors
4. Other Models	
Artificial neural networks	Search for data patterns and allow for potentially non-linear relationships between injury severity levels and covariates

Source: Savolainen et al. 2011

In summary, with a thorough literature review and understanding of the pros and cons of many different methodologies, it was proposed to study both crash frequency and crash-injury severities. For crash frequency, it was proposed to apply map-based spatial analysis together with negative binomial model. For crash-injury severities, it was proposed to apply logistic regression model.

APPENDIX E – RESULTS OF STATISTICAL MODELING

Pedestrian Crash Frequency: Negative Binomial Regression Model

The software package Stata 13 was used to estimate the negative binomial model for pedestrian crash frequency and severe injury pedestrian crash frequency in low-income areas. The estimated parameters, *t*-statistics, and average marginal effects are presented in Table 28.

Table 28. Modeling Results for Pedestrian Crash Frequency in Low-income Areas

Variables	**Pedestrian Crash Frequency in Low-income Area**			**Severe Injury Pedestrian Crash Frequency in Low-income Area**		
	Estimated Parameter	***t-statistic***	***Marginal Effect***	***Estimated Parameter***	***t-statistic***	***Marginal Effect***
_Constant	0.290	2.70***		-0.799	-4.86***	
Demographic Characteristics						
Population (in 000)	0.142	4.67***	0.910	0.183	4.01***	0.307
Older population (%)	-0.009	-4.46***	-0.055	-0.013	-4.28***	-0.022
African American (%)	0.003	3.60***	0.019	/	/	/
Public transit or bike (%)	0.008	2.10**	0.052	/	/	/
Zero car ownership (%)	0.007	2.41**	0.043	0.010	2.50**	0.016
Low education level (%)	0.007	3.47***	0.047	0.012	2.50***	0.020
Road Environment Characteristics						
Intersections (#)	0.013	7.01***	0.082	0.011	4.23***	0.019
Traffic signals (#)	0.102	9.00***	0.655	0.101	5.99***	0.170
Bus stops per mi (#)	0.027	4.36***	0.170	0.027	3.02***	0.046
Lower-speed roads (%)	-0.002	-2.02**	-0.012	-0.005	-3.24***	-0.008
Land Use Characteristics						
Walmart (presence or not)	0.309	1.90*	1.803	/	/	/
Discount stores ($\#/\text{mi}^2$)	0.035	2.96***	0.226	0.050	2.98***	0.085
Convenience stores ($\#/\text{mi}^2$)	0.011	2.92***	0.071	/	/	/
Fast-food restaurants ($\#/\text{mi}^2$)	0.011	3.81***	0.069	0.017	4.60***	0.029
Grocery stores ($\#/\text{mi}^2$)	0.009	2.47**	0.057	/	/	/
Barber shops ($\#/\text{mi}^2$)	0.008	1.97**	0.049	/	/	/
Number of observations	812			812		
Log-likelihood	-2048.37			-1268.56		
[1]Prob.>=chibar2	0.000***			0.000***		
Pseudo R-squared ($\rho 2$)	0.13			0.11		

***, **, * ==> Significance at 1%, 5%, 10% levels.

[1] *The likelihood ratio tests comparing the negative binomial model to a Poisson model strongly suggest the negative binomial model is more appropriate than the Poisson model for both models in this study.*

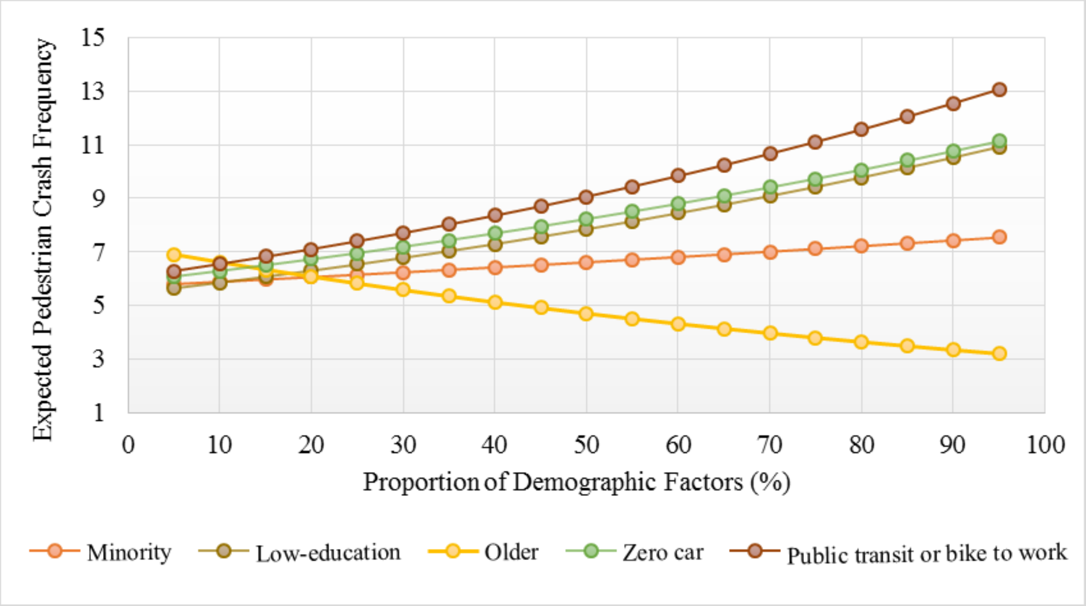


Figure 44. Expected pedestrian crash frequency by demographics in low-income BGs

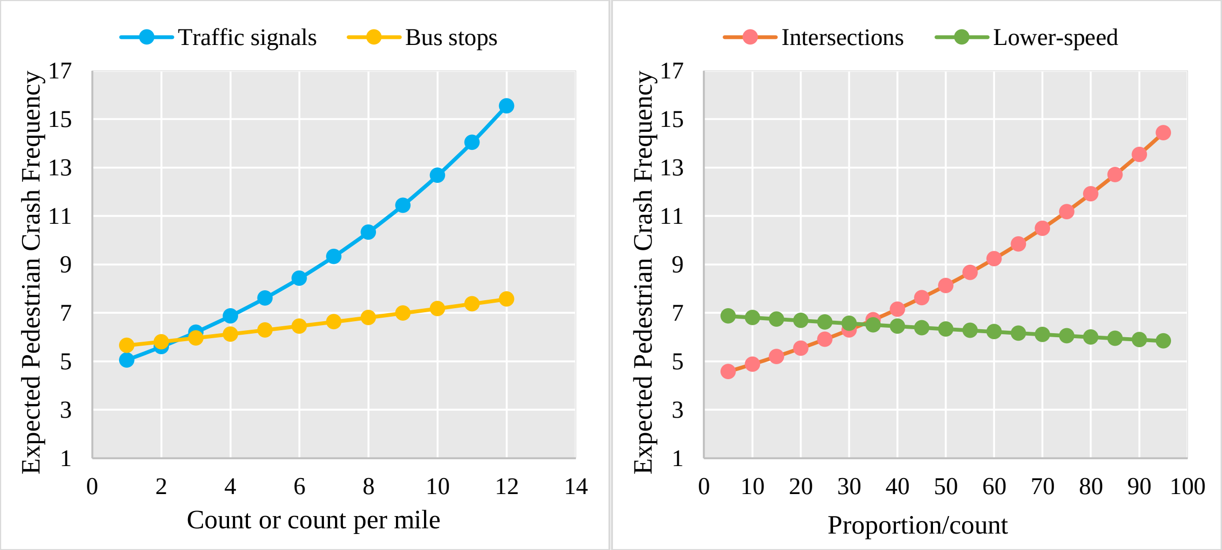


Figure 45. Expected pedestrian crash frequency by road factors

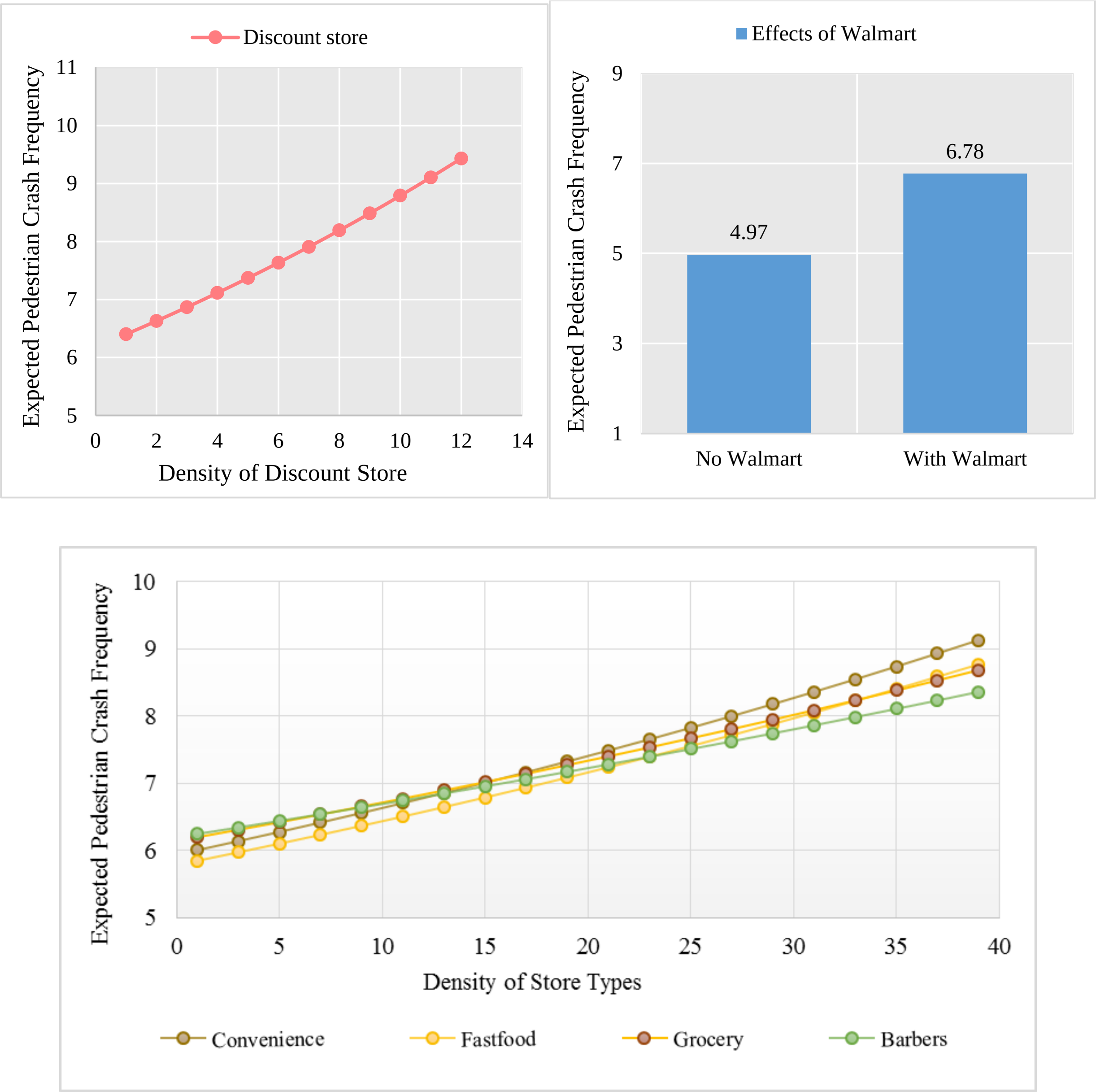


Figure 46. Expected pedestrian crash frequency by land use types

Pedestrian Crash Injury Severity: Logistic Regression Model

Table 29 shows the candidate variables and descriptive statistics for injury severity model in low-income area.

Table 29. Candidate Variables and Descriptive Statistics for Injury Severity Model

Variable Description *(number of observations in low-income area: 2,501)*	**Mean**
Dependent Variable	
Severe injury indicator (1=if highest crash severity is fatality or incapacitating injury, 0=otherwise)	0.273
Individual Characteristics	
Youth pedestrian (1=if pedestrian age under age 18, 0=otherwise)	0.165
Teen driver (1=if driver age 15–19, 0=otherwise)	0.043
Older pedestrian (1=if pedestrian age 65 or more, 0=otherwise)	0.065
Aging driver (1=if driver age 65 or more, 0=otherwise)	0.106
Pedestrian in travel lane other than crosswalk (1=if pedestrian location in travel lane other than crosswalk, 0=otherwise)	0.269
Pedestrian darting/dashing (1=if pedestrian action is dart/dash, 0=otherwise)	0.182
In roadway improperly (1=if pedestrian action is in roadway improperly, e.g., standing, lying, working, playing, 0=otherwise)	0.120
Pedestrian crossing (1=if pedestrian crossing roadway, 0=otherwise)	0.609
Impaired pedestrian (1=if pedestrian under influence of alcohol or drugs, 0=otherwise)	0.016
Impaired driver (1=if driver under influence of alcohol or drugs, 0=otherwise)	0.009
Distracted driver (1=if distracted drivers involved, 0=otherwise)	0.045
Aggressive driver (1=if aggressive drivers involved, 0=otherwise)	0.013
Road Environment Factors	
Dark–not lighted (1=if crash occurred at dark without light, 0=otherwise)	0.079
Dark–lighted (1=if crash occurred at dark with light, 0=otherwise)	0.331
Peak traffic (1=if crash occurred at peak time [6–9 AM, 4–7 PM], 0=otherwise)	0.332
Inclement weather condition (1=inclement weather (rain, fog, cloudy), 0=clear	0.213
Dry surface condition (1=dry, 0=otherwise)	0.891
Low speed limit (1=if posted speed limit less than 40 mph, 0=otherwise)	0.611
Traffic control (1=if with traffic control, 0=otherwise)	0.431
Intersection-related (1=if crash related to intersection, 0=otherwise)	0.433

The software package Stata 13 was used to estimate the logistic regression model for pedestrian crash injury severity in low-income area. The estimated parameters, *t*-statistics, and average marginal effects are presented in Table 30.

Table 30. Modeling Results for Pedestrian Crash Injury Severity in Low-income Area

Variables *(Insignificant variables removed from modeling)*	**Pedestrian Crash Severity in Low-income Area**		
	Estimated Parameter	***t- statistic***	***Marginal Effect (%)***
_Constant	-1.318	-11.07***	
Individual Characteristics			
Older pedestrian (≥65)	0.550	3.05***	11.61
Pedestrian in travel lane other than crosswalk	0.556	5.21***	11.20
Pedestrian darting/dashing	0.249	2.02**	4.91
Impaired pedestrian	4.019	3.95***	70.32
Aggressive driver	0.879	2.30**	19.64
Road Environment Factors			
Dark–not lighted condition	0.972	5.69***	21.56
Dark–lighted condition	0.928	9.02***	18.82
Inclement weather condition	0.318	2.78***	6.33
Low speed limit	-0.572	-5.79***	-11.19
Traffic control	-0.363	-3.55***	-6.84
Model Statistics			
Number of observations	2501		
Log-likelihood	-1308.80		
McFadden pseudo R-squared (ρ^2)	0.11		

****, **, * ==> Significance at 1%, 5%, 10% levels.*

APPENDIX F – OTHER LAND USE TYPES

Social Security Offices

Since there are only four Social Security Administration (SSA) offices in Broward County, only simple counts of pedestrian crashes were shown:

- Two SSA offices in low-income area – 10 (4+6) pedestrian crashes in 500m buffer from 2011–2014
- One SSA office in area mixed with low-income and higher-income BGs – 4 pedestrian crashes in 500m buffer from 2011–2014
- One SSA office in higher-income area – 3 pedestrian crashes in 500m buffer from 2011–2014

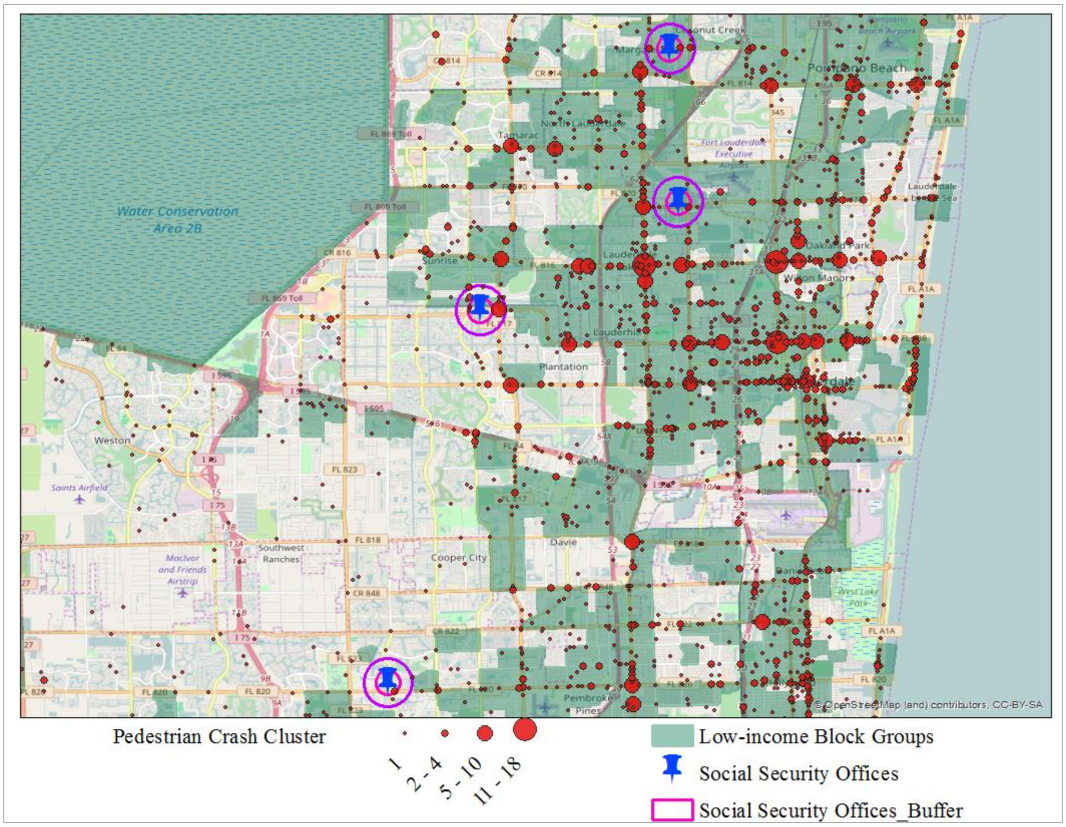
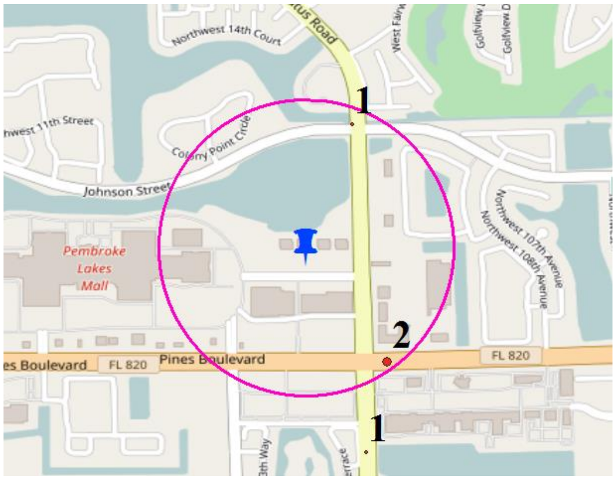
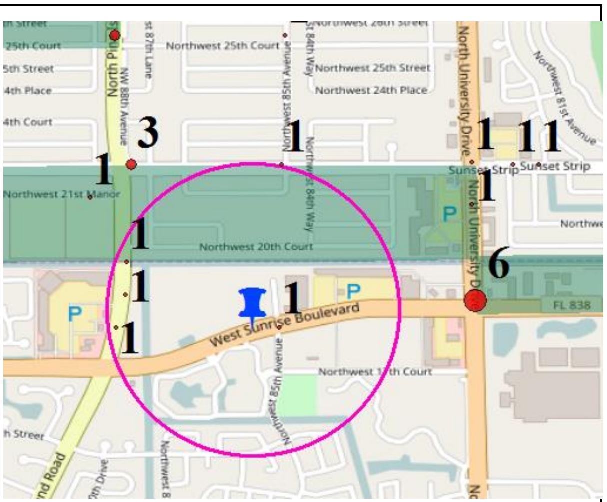


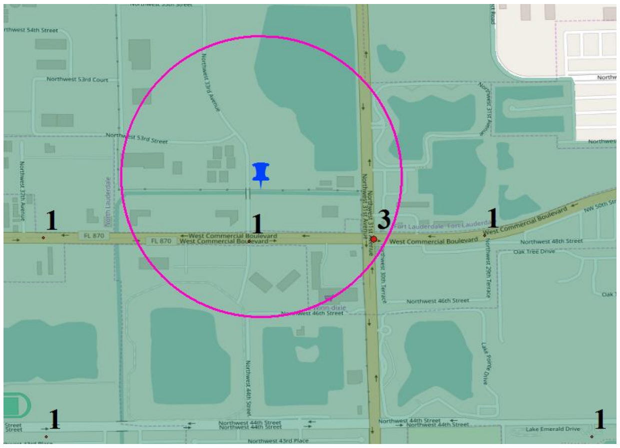
Figure 47. Pedestrian crash clusters and locations of Social Security Administration offices



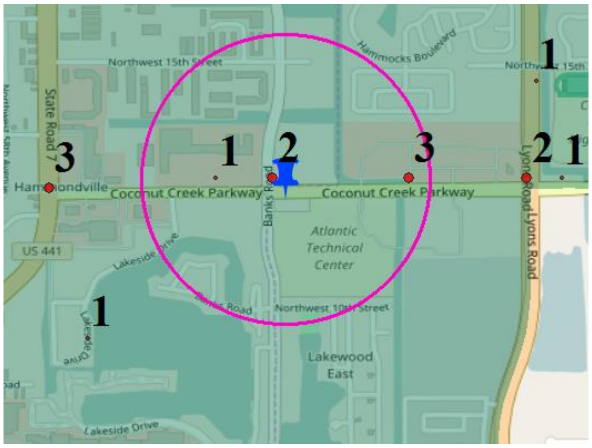
Higher-income area



Mixed with low-income and higher-income BGs



Low-income area



Low-income area

Figure 48. Pedestrian crashes in 500m buffer of Social Security Administration offices

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