Original research paper

Development of countermeasures to effectively improve pedestrian safety in low-income areas

Pei-Sung Lin[1*], Rui Guo[2], Elzbieta Bialkowska-Jelinska[1], Achilleas Kourtellis[1], and Yu Zhang[3]

[1]Center for Urban Transportation Research, University of South Florida, 4202 E. Fowler Ave., CUT100, Tampa, FL 33620;

[2]Civil, Environmental, and Construction Engineering, Texas Tech University, 2500 Broadway, Lubbock, TX 79409

[3]Department of Civil and Environmental Engineering, University of South Florida, 4202 E. Fowler Ave., ENB118, Tampa, FL 33620

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. 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 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 paper 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.

Keywords:

Pedestrian safety; low-income area; countermeasures; land use types

*Corresponding author. Tel.: (813) 974-4910,
E-mail: lin@cutr.usf.edu (Pei-Sung Lin, PhD, Program Director).
rui.guo@ttu.edu (Rui Guo, PhD, Lecturer)
elzbieta@cutr.usf.edu (Elzbieta Bialkowska-Jelinska, GIS analyst)
kourtellis@cutr.usf.edu (Achilleas Kourtellis, PhD, Research Associate)
yuzhang@usf.edu (Yu Zhang, PhD, Associate Professor)

1 Introduction

In recent years, state departments of transportation (DOTs) have been investing 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 occurring in 2008–2012 found that pedestrians were fatally injured at disproportionately higher rates in US poorer neighborhoods, as presented in Table 1 (*Governing*, 2014).

Table 1 Pedestrian Fatality Rates for All Census Tracts in 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 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 year; however, its statewide PDI has declined by 5.8 points since 2011 due to statewide safety efforts. The Florida Department of Transportation (FDOT) has set the improvement of pedestrian safety as a priority and has established strategic plans, identified resources, and built alliances with local partners and safety advocates to improve pedestrian safety at every level to create a safer, friendlier, and better-connected walking and bicycling environment.

Florida traditionally has 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. As a result, Florida’s roadways tend to be more dangerous for people walking and bicycling. Florida is also a state with an aging population, high tourism, low-density neighborhoods, and diverse cultures, factors that contribute to pedestrian crashes, injuries, and fatalities in low-income areas in Florida, making it an ideal state for researching these contributing factors and developing associated countermeasures.

This study investigated selected low-income areas in Florida, developed a demographics-based methodology to identify low-income areas that possess a combination of "pre-conditions" for greater pedestrian hazard, analyzed critical factors associated with pedestrian crashes and their injury severities, and developed recommendations for both engineering countermeasures and pedestrian safety education/outreach plans that resonate with a given area's demographics.

2 Literature review

To develop a demographic-based approach to pedestrian safety, a comprehensive literature review was conducted to identify the variables or "pre-conditions" associated with high pedestrian crash rates. Accumulating evidence from previous studies revealed five categories of major factors related to pedestrian crashes, as shown in Fig. 1.

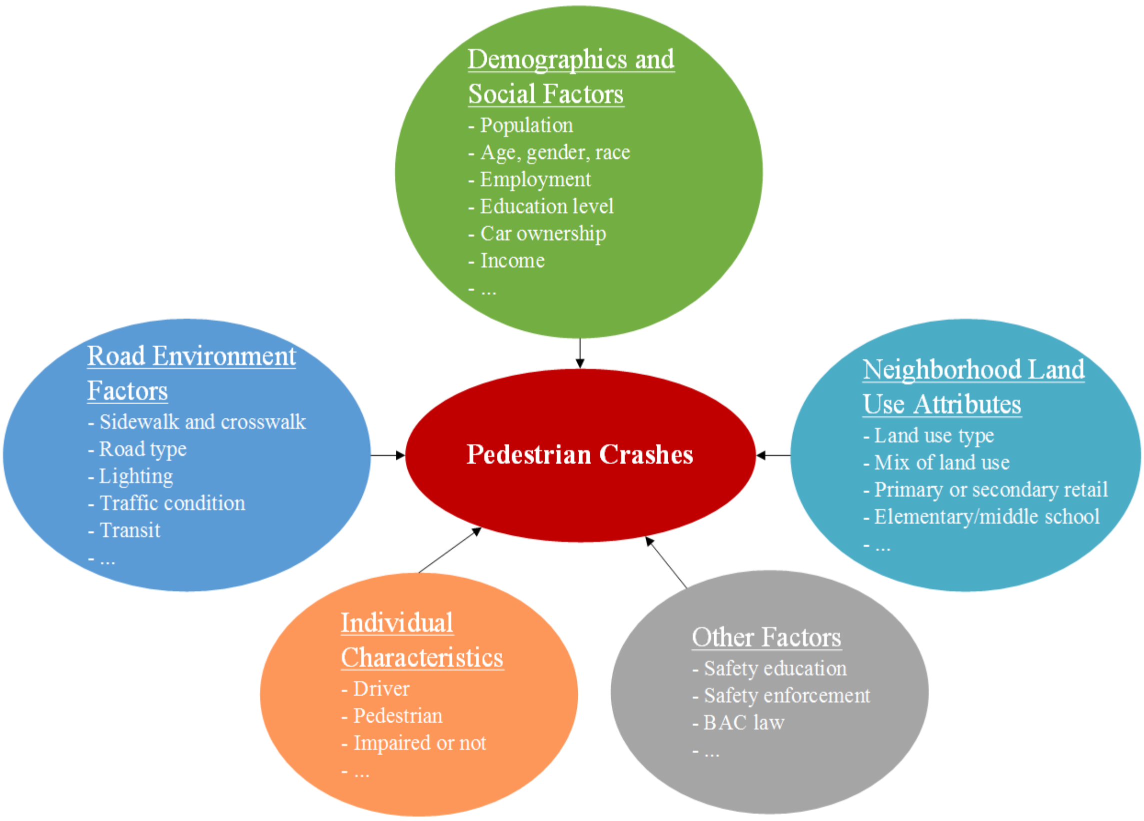

Fig. 1 Potential factors associated with pedestrian crashes.

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 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).

Road environment factors also play important roles in pedestrian crashes, mainly because individual behaviors, perceptions, and attentiveness are affected by the environments through which people travel (Moudon et al., 2011). Road environment factors include road inventory characteristics (e.g., 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 also are 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 that such infrastructure was more common in high-income communities (RWJF, 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). Although pedestrians are more likely to be in greater numbers in locations with more pedestrian activities, 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.

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, 2012; Amoh-Gyimah et al. 2016). There is no clear consensus on 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 numbers of pedestrian crashes; 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). Dumbaugh (2012) suggests that strip commercial uses and big-box stores are major risk factors for older adults. Conversely, neighborhoods with a high proportion of residential land use have a lower likelihood of pedestrian crashes (Ukkusuri et al., 2012).

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, typically being 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 have 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 by drivers or pedestrians. This may indicate that crash frequency could be reduced by following 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 addition, from the methodology perspective, the identified methodologies for pedestrian crash analysis include geographic analysis and statistical modeling for pedestrian crashes, crash frequency modeling, and crash severity modeling. The ArcGIS platform typically is used to visualize data by different layers. In previous studies, spatiotemporal techniques were used to identify low-income areas or hotspot crash locations (Prasannakumar et al., 2011). To analyze associated variables (e.g., demographics), different statistical models (e.g., generalized logic, spatial autoregressive, multilevel, random parameter, Bayesian, etc.) were investigated to identify how explanatory variables correlate with pedestrian crashes.

In summary, significant research efforts in pedestrian crash characteristics have been undertaken in previous studies. However, there still remain some challenges in pedestrian crash modeling and analysis. First, the impacts of an area's characteristics on pedestrian crash frequency and injury severity of pedestrian crashes still need more investigation. Second, the specifications adopted in many existing studies for pedestrian injury severity tends to be limited by the variables available in the established crash databases. Thus, it is interesting to compile the contextual factors from census and parcel land use databases by Geographic Information Systems (GIS) and test to determine if additional variables can better serve the objectives of pedestrian crash modeling.

3 Data and methodology

Based on the literature review and input from an FDOT project panel, demographic-based approaches to research pedestrian safety problems and associated countermeasures in low-income areas were developed. The three major components of this demographic-based methodology include input, output, and outcome. Inputs are relevant demographic variables pertinent to pedestrian crash frequency and injury severity for analysis. Outputs are the result of the analysis of input variables and include results and findings of statistical analysis of the data and analysis of geographic trends in the data. Outcomes are the recommendations of engineering countermeasures and pedestrian safety education/outreach plans that resonate with a given area's demographics and are informed and produced based on the outputs. A methodological flowchart developed for the demographic analysis of pedestrian safety is presented in Fig. 2 and consists of six steps.

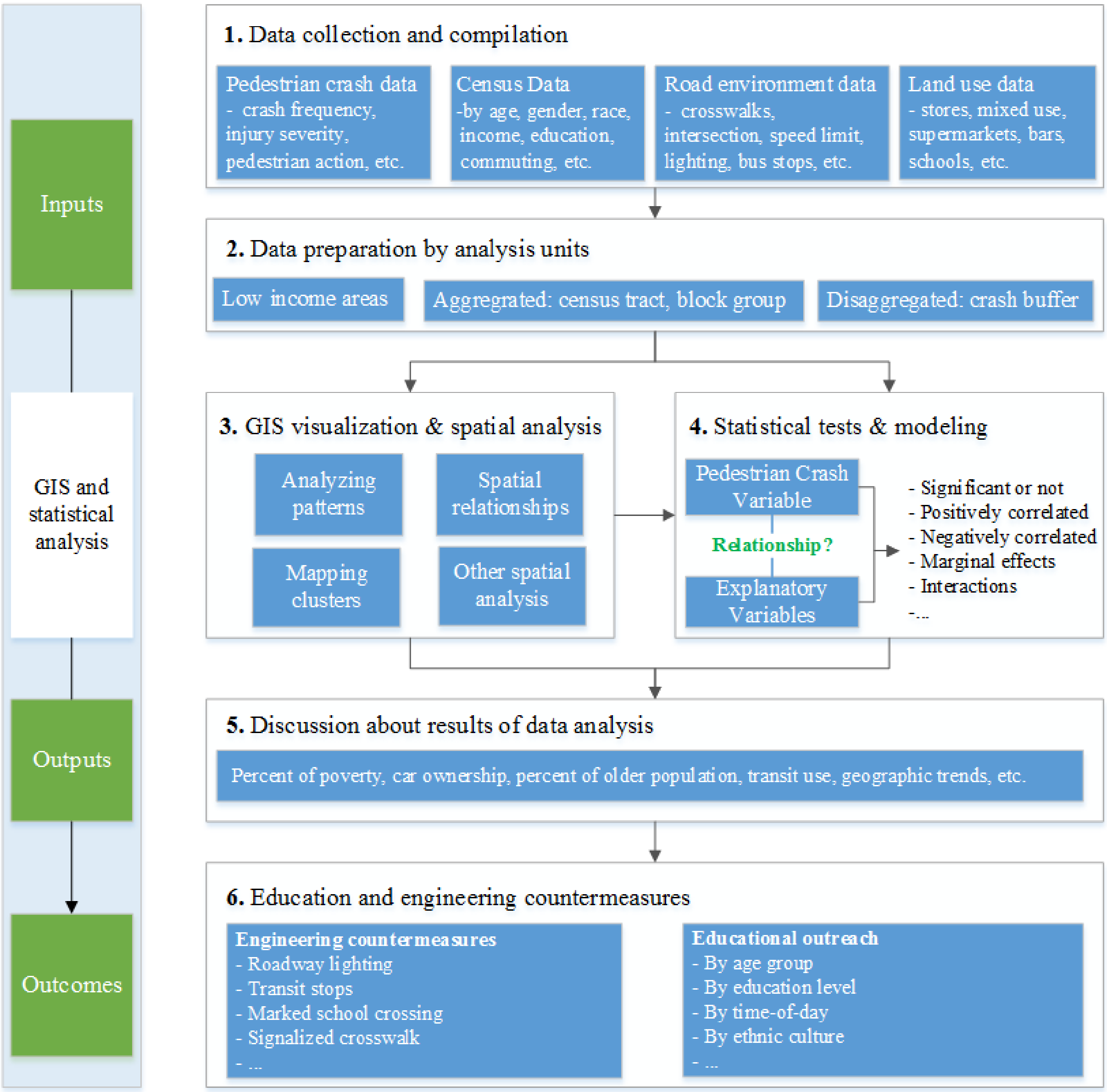

Fig. 2 Methodological flowchart

Step 1. Data collection and compilation

Geo-located pedestrian crashes occurring between 2011 and 2014 in two counties of FDOT District 4 (Broward and Palm Beach) were used for this study. The data set developed for this study was compiled from five major sources. Crash data were derived from information on the Florida Long Form provided by the Department of Highway Safety and Motor Vehicles (DHSMV) and maintained by the FDOT Crash Analysis Reporting (CAR) System. The road environment data were acquired from FDOT TranStat GIS Shapefiles and Geodatabases, and the transit data (e.g., bus stop locations) were collected from General Transit Feed Specification (GTFS) or obtained directly from transit agencies. Demographic social data for the studied years were obtained from the US Census Bureau, and parcel-level land use data were downloaded from the Florida Geographic Data Library (FGDL) with the Metadata Explorer.

Step 2. Data preparation by analysis unit

Based on the compiled data, the ArcGIS platform was used to visualize different data by different layers. All candidate variables were prepared by analysis unit, which include data (a) aggregated at census block group level and (b) disaggregated at crash level (with crash buffer).

For the analysis of pedestrian crash frequency, pedestrian crashes, demographic factors, road environment, and land use attributes were aggregated as geographical/spatial units to test and model their spatial correlations. The commonly-used spatial units for crash frequency analysis are census block groups (BGs) and census 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.

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.

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 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. Hot Spot analysis was used to detect clusters among pedestrian crashes, and Kernel Density function aided data visualization. The data generated in the GIS environment served as an input to the statistical testing and modeling.

Low-income areas were identified through mapping cluster analysis based on poverty-related data. Based on “America’s Poor Neighborhoods Plagued by Pedestrian Deaths” (*Governing*, 2014), low-income areas and poor neighborhoods were defined based on per-capita income and poverty rates in a census area. Accordingly, in this study, 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 are those with poverty rates >15% or per-capita income < $21,559, and higher-income BGs are those with poverty rates $\leq$ 15% or per-capita income $\geq$ $21,559.

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. In this study, the negative binomial (Poisson-Gamma) regression model was used to quantify the factors that affect the occurrence of pedestrian crashes, and logistic regression, or logit regression or logit model, was used to quantify the factors that affect the severity of a pedestrian injury. Injury severity was described as a binary variable (1=severe injury, including fatality or incapacitating injury; 0=others).

(a) Pedestrian crash frequency: Negative binomial (Poisson-Gamma) model

The negative binomial (NB) model is an extension of the Poisson model to address over-dispersion in crash data. The Poisson regression model can be written as:

$$P(y_i) = \frac{EXP(-\lambda_i)\lambda_i^{y_i}}{y_i!} \tag{1}$$

where P (y_i) is the probability of curve segment *i* having y_i crashes per a given period and λ_i is the Poisson parameter for curve segment *i,* which is equal to curve segment *i*th expected number of crashes per a given period, E[y_i]. The Possion regression model can be estimated by specifying the Possion parameter λ_i as a function of explanatory variables by typically using a log-linear function:

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

where X_i is a vector of explanatory variables and β is the vector of regression coefficients. To address this over-dispersion issue, the NB model can be derived as

$$\lambda_i = EXP(\beta X_i + \varepsilon_i) \tag{3}$$

where EXP(ε_i) is a gamma-distributed error term with mean 1 and variance α. The addition of this term allows the variance to differ from the mean as VAR[y_i] = E[y_i][1 + αE[y_i]]= E[y_i] + αE[y_i]^2. The negative binomial probability density function can be described as

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

where Γ(·) is a gamma function.

(b) Pedestrian crash injury severity: Logistic model (binary logit model)

The logistic model, also named the binary logit model, is expressed as:

$$P(y_i = 1 | X_i) = \Phi(X_i\beta) = \frac{\exp(X_i\beta)}{1+\exp(X_i\beta)} \tag{5}$$

where P denotes the probability of the injury severity (y_i) of crash observation i; β is the vector of regression coefficients; X_i is the vector of explanatory variables for crash observation i; and Φ is the cumulative distribution function of the logistic distribution. The maximum likelihood estimation (MLE) technique was used to estimate the coefficients of the logistic model.

Step 5. Discussion of results of data analysis

The geographic analysis and statistical modeling of the identified variables (inputs) produce results (outputs) such as significance of percentage or level of car ownership, significance of percentage of older population, marginal effects of demographic factors, marginal effects of roadway characteristics, geographic trends, and so on. Detailed discussion of results of data analysis can be found in Section 4.

Step 6. Education and engineering countermeasures

Informed by the outputs, outcomes for engineering countermeasures (roadway lighting, signalized crosswalks, etc.), and education/outreach plans (by age group or ethnic culture, etc.) were recommended for implementation (Section 5).

4 Results and discussion

In this study, two counties in FDOT District 4, Broward and Palm Beach, were used as testbeds to test the methodology and show the analysis results. After removing BGs with no population, 812 were identified as valid low-income BGs based on the definition of low-income area. Two analysis units were used to address pedestrian safety issues in low-income area from two aspects: how demographic factors, road environment, and land use types influence pedestrian crash occurrence (based on frequency data), and how demographic and other factors influence the severity in a pedestrian crash (based on severity data). 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 findings from both analyses are important for prioritizing neighborhoods for the development of effective pedestrian safety countermeasures.

4.1 Pedestrian crash frequency: Negative binomial regression model

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. 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. To capture the information occurring within the boundaries of the spatial units, the approach in the previous literature was followed, and a 100-ft buffer was developed around each BG. Crash information can be assigned within the BG itself as well as within the buffer area along its edges. The candidate variables and descriptive statistics for total pedestrian crash frequency model are shown in Table 2. For the highly-correlated variables indicated in the correlation test (proportion of children and proportion of older adults), only one was used in the model.

Table 2. Candidate Variables and Descriptive Statistics for Total Crash Frequency Model

(Number of low-income BGs: 812)

Factors	**Variable Description**	**Low-income BGs**
		Mean
Demographic Characteristics		
Population	Population in thousands	1.70
Age & gender	Proportion of children (ages 5–14) (%)	11.60
	Proportion of older people ($\geq$ age 65) (%)	16.71
Minority groups	Proportion of African American population (%)	34.14
	Proportion of Hispanic population (%)	25.80

Factors	Variable Description	Low-income BGs
		Mean
Demographic Characteristics		
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
Road Environment Characteristics		
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
Land Use Characteristics		
Walmart stores	Presence of Walmart stores in low-income BG	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 BG	0.17

The estimated parameters, *t*-statistics, and average marginal effects for pedestrian crash frequency are presented in Table 3. Results showed 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 3. 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 (#/mi^2)	0.035	2.96***	0.226	0.050	2.98***	0.085
Convenience stores (#/mi^2)	0.011	2.92***	0.071	/	/	/
Fast food restaurants (#/mi^2)	0.011	3.81***	0.069	0.017	4.60***	0.029
Grocery stores (#/mi^2)	0.009	2.47**	0.057	/	/	/
Barber shops (#/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 (ρ2)	0.13			0.11		

***, **, * ==> Significance at 1%, 5%, 10% levels.
Likelihood ratio tests comparing negative binomial model to Poisson model strongly suggest negative binomial model is more appropriate than Poisson model for both models in this study.

Based on the *t*-statistics and marginal effects, the following summarizes the major findings from both analyses for total and severe pedestrian crash frequency:

- For pedestrian crash frequency, the top four influential variables related to demographic characteristics are 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.
- For pedestrian crash frequency, the most influential variables related to roadway factors are number of traffic signals per BG, followed by number of bus stops per mile, followed by proportion of lower-speed roads (negative effect); an increase in proportion of lower-speed roads in a low-income BG can help decrease pedestrian crashes. Note that the information related to sidewalks and bike lanes may be incomplete, especially for off-state-system roads. Thus, the test of roadway factors is inconclusive at best.
- 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. For pedestrian crash frequency, the most influential variable related to land use types is density of discount stores, followed by density of convenience stores and fast-food restaurants.

4.2 Pedestrian crash injury severity: Logistic regression model

Based on the findings from the 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. The candidate variables and descriptive statistics for injury severity model are shown in Table 4. The estimated parameters, *t*-statistics, and average marginal effects for pedestrian crash injury severity are presented in Table 5.

Table 4. Candidate Variables and Descriptive Statistics for Injury Severity Model

Variable Description *(number of observations in low-income area:2501)*	**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 is age under 18, 0=otherwise)	0.165
Teen driver (1=if driver is age 15–19, 0=otherwise)	0.043
Older pedestrian (1=if pedestrian is age 65 or more, 0=otherwise)	0.065
Aging driver (1=if driver is age 65 or more, 0=otherwise)	0.106
Pedestrian in travel lane other than crosswalk (1=if pedestrian location is 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 is crossing roadway, 0=otherwise)	0.609
Impaired pedestrian (1=if pedestrian under the influence of alcohol or drugs, 0=otherwise)	0.016
Impaired driver (1=if driver under the 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, 4-7pm], 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 is less than 40 mph, 0=otherwise)	0.611
Traffic control (1=if with traffic control, 0=otherwise)	0.431
Intersection related (1=if crash is related to intersection, 0=otherwise)	0.433

Table 5. Modeling Results for Pedestrian Crash Injury Severity in Low-income Area

Variables *(insignificant variables removed from modelling)*	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

As shown in Table 5, individual characteristics such as the involvement of older pedestrians, impaired pedestrians, and aggressive drivers have a significant effect on the injury severity of a pedestrian crash. Environmental factors such as lighting conditions and roadway speed limits have a significant effect on the injury severity of a pedestrian crash.

Based on the *t*-statistics and marginal effects, the following summarizes the major findings from the analysis for pedestrian crash injury severity:

- For injury severity, the most influential variable related to individual characteristics is alcohol or drug involvement of the pedestrian, followed by involvement of aggressive drivers and older pedestrians in a pedestrian crash.
- For injury severity, the most influential variable related to environmental factors is dark–not lighted condition, followed closely by dark–lighted condition and higher speed limit. The dark-lighted condition seems indicate that various lighting levels could have different impacts on the injury severity of a pedestrian crash.
- A lower speed limit is likely to decrease the probability of severe injuries in pedestrian crashes. Older pedestrians (> age 65) involved in a pedestrian crash are more likely to experience severe injuries.
- The presence of a traffic control device (signal, STOP sign, YIELD sign, school zone device, flashing signal, etc.) is likely to decrease the probability of higher injury severity in pedestrian

crashes.

5 Recommended countermeasures to improve pedestrian safety

Based on the findings and analysis of pedestrian crash frequency and injury severity, safety-oriented engineering countermeasures and education/outreach plans were developed. The engineering countermeasures, shown in Table 6, serve two functions: (1) prevent pedestrian crash occurrence (reduce crash frequency) and (2) reduce severity when a pedestrian crash does occur.

Table 6. Recommended Engineering Countermeasures for Low-income Areas

Roadway lighting and lighting levels	a. Presence of lighting to increase nighttime visibility
	b. Adequate lighting level and uniformity
	c. Proper pedestrian lighting placement to increase visibility
Treatments at non-intersection locations	a. Rectangular rapid flashing beacon (RRFB), high-intensity activated crosswalk (HAWK) beacon, or pedestrian signal
	b. High-visibility crosswalk to improve visibility of pedestrians
	c. Medians and crossing islands (refuge or center islands)
	d. Appropriate landscaping to prevent pedestrians from crossing
Bus stop improvement	a. Bus stop reallocation to improve sight distance problems and reduce conflicts
	b. Transit stop request lights to increase visibility of riders
Speed reduction treatments	a. Slow speed zones to improve pedestrian and bicycle safety
	b. Road diets to calm traffic and provide space for bicycle lanes, turn lanes, wider sidewalks, and other purposes
	c. Roundabouts to control traffic flow at intersections
	d. Traffic calming on residential streets
Road Safety Audit (RSA) – Identify and resolve pedestrian safety-related issues	

The goals of education/outreach plans, shown in Table 7, are to (1) increase the knowledge level of safety actions for pedestrians and drivers in selected high-crash emphasis areas, (2) increase compliance with existing laws, and (3) coordinate with local law enforcement and engineering efforts in pedestrian safety.

Table 7. Recommended Education/Outreach Plan for Low-income Areas

Locations (*where*)	• High-crash corridors or intersections • Stores: discount stores, fast-food restaurants, convenience stores
Approaches (*how*)	• Grassroots safety education and business sweeps • Public-private partnerships • High-visibility law enforcement
Contents (*what*)	• Safety education for pedestrians and drivers at nighttime • Education on pedestrian laws and traffic control devices • Making safer choices and avoiding improper pedestrian actions • Avoiding distractions and impairment while driving or walking • Avoiding aggressive driving and speeding; yield to pedestrians
Audiences (*who*)	• Residents in low-income communities

	• Commuters using public transit or bike • Adults with low-education level (less than high school) • Minority groups (e.g., African and Hispanic Americans) • Older adult populations
Time (*when*)	• Sooner the better • Depending on each agency (needs, resources, efforts, etc.)

The recommended education and outreach plan includes (a) WalkWise safety education, (b) distribution of education tip cards, (c) social media outreach, (d) community networking, (e) business sweeps, (f) law enforcement role call training, and (g) public-private partnerships. The implementation of an education and outreach plan along with targeted high-visibility enforcement has great potential for 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.

6 Conclusions

This study developed a demographics-based methodology to analyze critical factors associated with pedestrian crash frequency and injury severity in low-income areas, presented the analysis results and major findings, and developed recommendations that resonate with a given area’s demographics. 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 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 paper 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.

Acknowledgments

The authors express their gratitude to FDOT project manager Mark Plass and his colleagues for their assistance and support in this research. The authors also thank Natalia Barbour, Zhao Zhang, and Adam Wu of the University of South Florida for their valuable help and input. The opinions, findings, and conclusions expressed in this paper are those of the author(s) and not necessarily those of the Florida Department of Transportation or the US Department of Transportation.

References

Amoh-Gyimah, R., Saberi, M., Sarvi, M., 2016. Macroscopic modeling of pedestrian and bicycle crashes: a cross-comparison of estimation methods. Accident Analysis & Prevention, 93, 147-159.

Braseth, M., 2012. The effects of land use patterns and street network connectivity on the frequency of child pedestrian-vehicle collisions: an aggregate analysis in Portland, Oregon. Master's thesis, University of Oregon.

Centers for Disease Control and Prevention (CDC), 2013. Motor vehicle traffic-related pedestrian deaths—United States, 2001–2010. http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6215a1.htm.

Chakravarthy, B., Anderson, C. L., Ludlow, J., Lotfipour, S., Vaca, F. E., 2010. The relationship of pedestrian injuries to socioeconomic characteristics in a large Southern California County. Traffic Injury Prevention, 11(5), 508-513.

Chakravarthy, B., Anderson, C. L., Ludlow, J., Lotfipour, S., Vaca, F. E., 2012. A geographic analysis of collisions involving child pedestrians in a large Southern California county. Traffic Injury Prevention, 13(2), 193-198.

Chimba, D., Emaasit, D., Cherry, C. R., Pannell, Z., 2014. Patterning demographic and socioeconomic characteristics affecting pedestrian and bicycle crash frequency. In the 93rd Transportation Research Board Annual Meeting, Washington D.C. No. 14-0600.

Cottrill, C. D., Thakuriah, P. V., 2010. Evaluating pedestrian crashes in areas with high low-income or minority populations. Accident Analysis & Prevention, 42(6), 1718-1728.

Chimba, D., Emaasit, D., Cherry, C. R., Pannell, Z., 2014. Patterning demographic and socioeconomic characteristics affecting pedestrian and bicycle crash frequency. In the 93rd Transportation

Research Board Annual Meeting, Washington D.C. No. 14-0600.

Clifton, K. J., Burnier, C. V., Akar, G., 2009. Severity of injury resulting from pedestrian–vehicle crashes: What can we learn from examining the built environment? Transportation Research Part D: Transport and Environment, 14(6), 425-436.

Dissanayake, D., Aryaija, J., Wedagama, D. P., 2009. Modelling the effects of land use and temporal factors on child pedestrian casualties. Accident Analysis & Prevention, 41(5), 1016-1024. doi:10.1016/j.aap.2009.06.015.

Dumbaugh, E., Zhang, Y., Li, W., 2012. Community design and the incidence of crashes involving pedestrians and motorists aged 75 and older. Final Report. University Transportation Center for Mobility.

Governing, 2014. America's poor neighborhoods plagued by pedestrian deaths. A Governing Research Report.

Ha, H., Thill, J., 2011. Analysis of traffic hazard intensity: A spatial epidemiology case study of urban pedestrians. Computers, Environment and Urban Systems, 35(3), 230-240. doi:10.1016/j.compenvurbsys.2010.12.004.

Hess, P. M., Moudon, A. V., Matlick, J. M., 2004. Pedestrian safety and transit corridors. Journal of Public Transportation, 7(2), 5.

Lascala, E. A., Gerber, D., Gruenewald, P. J., 2000. Demographic and environmental correlates of pedestrian injury collisions: A spatial analysis. Accident Analysis & Prevention, 32(5), 651-658. doi:10.1016/s0001-4575(99)00100-1.

LaScala, E. A., Gruenewald, P. J., Johnson, F. W., 2004. An ecological study of the locations of schools and child pedestrian injury collisions. Accident Analysis & Prevention, 36(4), 569-576.

Lee, C., Abdel-Aty, M., 2005. Comprehensive analysis of vehicle–pedestrian crashes at intersections in Florida. Accident Analysis & Prevention, 37(4), 775-786.

Miranda-Moreno, L. F., Morency, P., El-Geneidy, A. M., 2011. The link between built environment, pedestrian activity and pedestrian–vehicle collision occurrence at signalized intersections. Accident Analysis & Prevention, 43(5), 1624-1634.

Moudon, A. V., Lin, L., Jiao, J., Hurvitz, P., Reeves, P., 2011. The risk of pedestrian injury and fatality in collisions with motor vehicles, a social ecological study of state routes and city streets in King County, Washington. Accident Analysis & Prevention, 43(1), 11-24.

Musinguzi, A., Chimba, D., 2015. Spatial variation in local road pedestrian and bicycle crashes. 2015 Annual ESRI International User Conference, San Diego, California.

Noland, R. B., Quddus, M. A., 2004. A spatially disaggregate analysis of road casualties in England. Accident Analysis & Prevention, 36(6), 973-984. doi:10.1016/j.aap.2003.11.001.

Prasannakumar, V., Vijith, H., Charutha, R., Geetha, N., 2011. Spatio-temporal clustering of road accidents: GIS-based analysis and assessment. Procedia— Social and Behavioral Sciences, 21, 317-325. doi:10.1016/j.sbspro.2011.07.020.

Rivara F.P., Barber M., 1985. Demographic analysis of childhood pedestrian injuries. Pediatrics, 76(3): 375-81.

Robert Wood Johnson Foundation, 2012. Income disparities in street features that encourage walking. http://www.bridgingthegapresearch.org/_asset/02fpi3 /btg_street_walkability_FINAL_03-09-12.pdf.

Smart Growth America, 2016. Dangerous by Design 2016. Smart Growth America and National Complete Streets Coalition.

Siddiqui, N., Chu, X., Guttenplan, M., 2006. Crossing locations, light conditions, and pedestrian injury severity. Transportation Research Record, 1982, 141-149.

Sullivan, J. M., Flannagan, M. J., 2002. The role of ambient light level in fatal crashes: inferences from daylight saving time transitions. Accident Analysis & Prevention, 34(4), 487-498.

Ukkusuri, S., Miranda-Moreno, L. F., Ramadurai, G., Isa-Tavarez, J., 2012. The role of built environment on pedestrian crash frequency. Safety Science, 50(4), 1141-1151.

Wier, M., Weintraub, J., Humphreys, E. H., Seto, E., Bhatia, R., 2009. An area-level model of vehicle-pedestrian injury collisions with implications for land use and transportation planning. Accident Analysis & Prevention, 41(1), 137-145. doi:10.1016/j.aap.2008.10.001.

Yu, C. Y., 2015. Built environmental designs in promoting pedestrian safety. Sustainability, 7(7), 9444-9460.