**Final Report**

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# Comprehensive Study to Reduce Pedestrian Crashes in Florida

Prepared for:

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# METRIC CONVERSION CHART

| 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 |
| **mm** | millimeters | 0.039 | inches | in |
| **m** | meters | 3.28 | feet | ft |
| **m** | meters | 1.09 | yards | yd |
| **km** | kilometers | 0.621 | miles | mi |
| **SYMBOL** | **WHEN YOU KNOW** | **MULTIPLY BY** | **TO FIND** | **SYMBOL** |
| **AREA** | | | | |
| **$in^2$** | square inches | 645.2 | square millimeters | $mm^2$ |
| **$ft^2$** | square feet | 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 | $km^2$ |
| **$mm^2$** | square millimeters | 0.0016 | square inches | $in^2$ |
| **$m^2$** | square meters | 10.764 | square feet | $ft^2$ |
| **$m^2$** | square meters | 1.195 | square yards | $yd^2$ |
| **ha** | hectares | 2.47 | acres | ac |
| **$km^2$** | square kilometers | 0.386 | square miles | $mi^2$ |
| **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 | $m^3$ |
| **mL** | milliliters | 0.034 | fluid ounces | fl oz |
| **L** | liters | 0.264 | gallons | gal |
| **$m^3$** | cubic meters | 35.314 | cubic feet | $ft^3$ |
| **$m^3$** | cubic meters | 1.307 | cubic yards | $yd^3$ |
| NOTE: volumes greater than 1,000 L shall be shown in $m^3$ | | | | |

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16. Abstract

Pedestrian crashes are a major traffic safety concern in Florida. This project aims to improve pedestrian safety on Florida's state roads by identifying crash patterns and contributing factors at both the statewide and site-specific level and proposing potential countermeasures to reduce pedestrian crashes. The specific project objectives include: (1) perform a comprehensive review of existing pedestrian safety studies; (2) identify statewide pedestrian crash patterns and causes; (3) identify factors contributing to pedestrian injury severity; and (4) identify and analyze pedestrian high crash locations at both signalized and non-signalized locations for crash causes and propose the potential countermeasures for these crash causes.

A total of 6,434 pedestrian crashes that occurred on state roads during 2008-2010 were identified and analyzed. Police reports for these crashes were carefully reviewed to obtain additional crash details, including those from police descriptions and illustrative sketches. In addition, additional roadway information not available from the state roadway inventory such as types of crosswalks were visually identified. Both of these efforts were performed using two in-house web-based systems developed to facilitate police report review and data collection.

At the statewide level, crash patterns as they relate to pedestrian, vehicle, traffic control, roadway, and environmental characteristics were analyzed. As pedestrian crashes are typically severe, a mixed logit model was developed to identify factors contributing to pedestrian injury severity at signalized and non-signalized locations. At the site-specific level, pedestrian high crash locations were identified by identifying clusters of pedestrian crashes at both signalized and non-signalized locations. Both district-wide and statewide pedestrian high crash locations were identified. The statewide locations were further analyzed to identify location-specific crash causes and countermeasures.

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# EXECUTIVE SUMMARY

Pedestrian crashes are a major safety concern in Florida. About one in every five traffic-related fatalities in the state is a pedestrian. The goal of this project is to conduct a comprehensive study to improve pedestrian safety on state roads in Florida. The specific project objectives include:

1. Reviewing and summarizing existing pedestrian safety studies, including methods of analysis, and findings on pedestrian crash causes, crash contributing factors, and potential countermeasures.
2. Identifying statewide pedestrian crash patterns and causes.
3. Identifying factors contributing to pedestrian injury severity.
4. Identifying and analyzing pedestrian high crash locations at both signalized and non-signalized locations for crash causes and potential countermeasures.

For this study, a total of 6,434 pedestrian crashes that occurred on state roads during 2008-2010 were identified. A major effort of this project involved detailed review of police reports for these crashes to obtain additional crash details, including those from police descriptions and illustrative sketches, which are not available from crash summary records. In addition, additional roadway information not available from the state roadway inventory such as types of crosswalks were visually identified. Both of these efforts were performed using two in-house web-based systems developed to facilitate police report review and data collection.

## Literature Review

There has been significant effort in analyzing pedestrian crashes and identifying pedestrian risk factors. Existing methods for identifying pedestrian hot spots are broadly classified into three categories: density, clustering, and exposure estimation. In the density method, simple and Kernel methods are the two commonly used crash density calculation methods. Among these two methods, the Kernel method is regarded as a better approach since it generates a well fitted smooth curve. The second method relies on the clustering technique and has been successfully applied in safety analysis to identify groups of crashes. The third method of hot spot identification is exposure estimation. This includes statistical regression models, sketch plan and network models, micro-simulation models, and computer vision techniques.

Several pedestrian countermeasures have been proposed in the literature to improve pedestrian safety. These include but are not limited to, converting intersections to roundabouts, installing raised medians and refuge islands, adding on-street parking, installing pedestrian signals, modifying signal phasing, installing pedestrian countdown signals, improving lighting at intersections, and illuminating crosswalks. The majority of these countermeasures were found to have been effective in reducing pedestrian crashes and fatalities.

## Statewide Crash Patterns and Causes

Statewide crash patterns and causes were identified based on the 6,434 pedestrian crashes in the three-year analysis period. The crashes resulted in a total of 663 pedestrian fatalities (i.e., 10.3%). Overall, there were 124.7 total crashes and 13 fatal crashes per million population annually. Of the different age groups, the young pedestrian group (16-25 years) experienced the highest number of pedestrian crashes per million population and also the highest pedestrian crash rate per million walk trips per year. Older people were found to experience a slightly higher number of fatal crashes per million walk trips per year. Although a majority of crashes occurred during daytime, they resulted in a lower proportion of fatalities. At 5% significance level, the proportion of fatal crashes that occurred during nighttime were significantly greater compared to the proportion of fatal crashes in the daytime.

Overall, pedestrians were found to be at fault in over 53.0% of the crashes and drivers were at fault in 28.2% of the crashes. Irrespective of who was at fault, failing to yield right-of-way and disregarding traffic control devices were the two major contributing causes for pedestrian crashes. Moreover, crashes where pedestrian was at fault were found to be more severe compared to the crashes where the driver was at fault, and this difference was found to be statistically significant.

A majority of the crashes occurred primarily on urban principal arterials. Although the majority of pedestrian crashes occurred in urban areas and especially in metropolitan areas, fatal crashes were disproportionately high in rural areas. Moreover, the proportion of fatal crashes decreased with urbanization. Crashes along the locations with higher speed limits resulted in a greater proportion of fatal crashes. At a 5% significance level, there was no significant difference in the proportion of fatal crashes at signalized intersections across the following crosswalk types: standard, continental, ladder, and solid with special surface. Furthermore, crash data did not indicate that continental and ladder types had a better safety performance than standard crosswalks at signalized intersections during nighttime.

### Statewide Crash Severity Contributing Causes

Mixed logit models were developed to identify significant geometric, traffic, road user, environmental, and vehicle factors contributing to pedestrian injury severity at signalized and non-signalized locations. At both signalized and non-signalized locations, the following ten variables were chosen to be included in the model: percentage of trucks, natural logarithm of average annual daily traffic (AADT), crosswalk type, lighting condition, pedestrian age, speed limit, hour of crash, at-fault road user, vehicle type, and weather condition.

The results from the mixed logit models showed that:

- Crashes where pedestrians were at fault were more likely to result in severe injuries compared to the crashes where drivers were at fault or both pedestrians and drivers were at fault at both signalized and non-signalized locations.
- Crashes involving at-fault pedestrians resulted in a greater probability of severe injuries at non-signalized locations compared to signalized locations.
- Very young pedestrians were associated with lower probability of severe injuries at both signalized and non-signalized locations.
- Very old pedestrians were associated with higher probability of severe injuries at both signalized and non-signalized locations.

- Very old pedestrians have a greater severity risk at signalized locations compared to non-signalized locations.
- At signalized locations, rainy weather was associated with a slight increase in the probability of severe injuries compared to other weather conditions.
- Dark conditions, with and without street light, were associated with an increase in the probability of severe injuries at both signalized and non-signalized locations.
- At non-signalized locations, vans were found to be associated with an increase in the probability of severe injuries compared to other vehicle types.
- Increasing the speed limit at signalized and non-signalized locations was associated with higher severe injury probability.
- The increase in speed limit at non-signalized locations posed greater pedestrian severity risk compared to signalized locations.
- At non-signalized locations, pedestrians crossing the roadway were associated with higher probability of severe injuries compared to pedestrians walking along the roadway.
- At signalized locations, increasing the AADT and the percentage of trucks significantly increased the probability of severe pedestrian injuries.
- At signalized locations, the probability of severe pedestrian injuries was higher during the night and dawn off-peak periods.

### Pedestrian Crash Causes and Countermeasures at Signalized Locations

Urban signalized intersections with observed pedestrian crash frequency greater than three standard deviations from the average crash frequency were identified and analyzed. A total of 21 signalized intersections with ≥ 6 pedestrian crashes during 2008-2010 were included in the analysis. Police reports of all the crashes that occurred at these high crash intersections were reviewed and the crash contributing factors related to each of the following six types of crashes were analyzed:

1. Crashes that involved right-turning vehicles.
2. Crashes that involved left-turning vehicles.
3. Crashes that occurred in the vicinity of bus stops.
4. Crashes that involved pedestrians who were not crossing at designated crossing locations.
5. Crashes that occurred in left-turning lanes and right-most lanes.
6. Crashes that involved pedestrians in a crosswalk and through traffic.

Pedestrian crashes involving turning traffic at signalized intersections could be prevented by eliminating the potential vehicle-pedestrian conflicts. At locations with high pedestrian volumes, prohibiting right turns on red could be an easy strategy to minimize pedestrian conflicts involving right-turning vehicles. Additionally, providing a leading pedestrian interval (LPI) that gives pedestrians a head start while crossing the intersection could improve pedestrian safety. Pedestrian crashes involving left-turning vehicles could be reduced by providing either a protected left-turn phase or an exclusive protected pedestrian signal.

Several pedestrian crashes occurred when the pedestrian walked in front of the bus onto the approaching traffic. These types of pedestrian crashes could be prevented by improving roadway lighting and providing curb extensions in the vicinity of bus stops. Furthermore, relocating near-side bus stops to the far-side of the intersection could eliminate sight-distance restrictions, improving pedestrian safety.

At locations where pedestrians are expected to cross multi-lane roads with high travel speeds and heavy traffic, the following countermeasures could be effective in reducing pedestrian crash frequency and severity:

- ensure curb ramps are provided to make crossing easier for all pedestrians,
- install lighting along the corridor,
- require pedestrians to cross the roadway at designated crossing locations such as crosswalks, and
- install traffic calming measures, such as providing speed bumps, lane narrowing, etc.

Agency-wide education campaigns on the laws pertaining to pedestrians and the safety benefits of using pedestrian facilities such as crosswalks, sidewalks, and pedestrian refuge islands could improve pedestrian safety. Furthermore, extensive driver education campaigns that focus on driver compliance with pedestrian right-of-way laws and stricter enforcement could prevent the crashes that were due to driver error.

### Pedestrian Crash Causes and Countermeasures at Non-signalized Locations

ArcGIS 10.0 was used to identify the non-signalized locations with more than one pedestrian crash. The top high crash non-signalized locations were identified based on critical pedestrian crash frequency (i.e., greater than three standard deviations from the average crash frequency). A total of 14 non-signalized locations with $\geq$ 5 crashes during 2008-2010 were included in the analysis. Police reports of the 115 crashes that occurred at these 14 locations were reviewed in detail to identify pedestrian crash causes and potential countermeasures. Several of the pedestrian crash types identified at signalized intersections were also found at non-signalized locations. Particularly, the following types of crashes were observed at both signalized and non-signalized locations:

1. Crashes that occurred in the vicinity of bus stops.
2. Crashes that involved pedestrians who were not crossing at designated crossing locations.
3. Crashes that occurred in left-turning lanes and right-most lanes.
4. Crashes that involved pedestrians in a crosswalk and through traffic.

In addition to the above identified crash types, the following two types of crashes were identified at non-signalized locations: crashes that occurred at undivided roadways, and crashes that involved pedestrians walking along a roadway. Crash contributing factors related to these two types of crashes were analyzed.

Undivided roadway segments were found to experience a greater number of pedestrian crashes compared to the locations with raised medians. Raised medians act as pedestrian refuge areas, providing an opportunity for pedestrians to pause while crossing multiple lanes of traffic. Therefore, constructing raised medians is recommended on multi-lane corridors with high traffic. In addition to the construction of raised medians, agency-wide pedestrian education campaigns focusing on the safety benefits of raised medians is recommended to discourage pedestrians from crossing multiple travel lanes without stopping and waiting for sufficient gaps to cross.

Sidewalks not only encourage walking but also significantly improve pedestrian safety. At locations with no sidewalks, pedestrians are forced to walk along the edge of the roadway, increasing the potential for pedestrian crashes. If feasible, it is recommended to provide sidewalks, or at a minimum paved shoulder, on both sides of the road.

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## LIST OF ACRONYMS/ABBREVIATIONS

| | |
|---|---|
| AADT | Average Annual Daily Traffic |
| ADA | Americans with Disabilities Act |
| AIC | Akaike Information Criterion |
| B/C | Benefit-to-Cost Ratio |
| BIC | Bayesian Information Criterion |
| CAR | Crash Analysis Reporting |
| CMF | Crash Modification Factor |
| CRF | Crash Reduction Factor |
| DUI | Driving Under Influence |
| EPDO | Equivalent Property Damage Only |
| FDOT | Florida Department of Transportation |
| FHWA | Federal Highway Administration |
| GEE | Generalized Estimating Equation |
| GIS | Geographic Information System |
| HAWK | High Intensity Activated Crosswalk |
| HSIP | Highway Safety Improvement Program |
| IID | Independently and Identically Distributed |
| ITS | Intelligent Transportation Systems |
| KDE | Kernel Density Estimation |
| LC | Latent Class |
| LED | Light Emitting Diode |
| LPI | Leading Pedestrian Interval |
| MUTCD | Manual on Uniform Traffic Control Devices |
| NB | Negative Binomial |
| NCHRP | National Cooperative Highway Research Program |
| NHTS | National Household Travel Survey |
| NHTSA | National Highway Traffic Safety Administration |
| NLMIXED | Nonlinear Mixed |
| NPV | Net Present Value |
| OOB | Out-of-Bag |
| PA | Pedestrian Actuated |
| PDI | Pedestrian Danger Index |
| PELICAN | Pedestrian Light Controlled |
| PRI | Pedestrian Risk Index |
| PUFFIN | Pedestrian User-Friendly Intelligent |
| RCI | Roadway Characteristic Inventory |
| ROW | Right-of-way |
| RTM | Regression-To-the-Mean |
| RTOR | Right-Turn on Red |
| RV | Recreational Vehicle |
| SafeTrec | Safe Transportation Education and Research Center |
| SSAM | Surrogate Safety Assessment Model |
| T4A | Transportation for America |
| TDTC | Time Difference to Collision |

| | |
|---|---|
| TTC | Time-to-Collision |
| TWLTL | Two-Way Left-Turn Lanes |
| U.S. | United States |
| UZA | Urbanized Areas |
| VRICS | Visual Roadway Inventory Collection System |
| VISSIM | Verkehr In Städten - SIMulationsmodell |

# CHAPTER 1
# INTRODUCTION

## 1.1 Background

Pedestrian safety is of particular concern to Florida as one in every five traffic-related fatalities in the state is a pedestrian. A recent study by Transportation for America (T4A) (2011) has ranked Florida as the most dangerous state in the country for pedestrians. The same study also ranked 52 large metropolitan areas with over 1 million population. In this ranking, the top four unfortunate spots went to Orlando/Kissimmee, Tampa/St. Petersburg/Clearwater, Jacksonville, and Miami/Fort Lauderdale/Pompano. These rankings were given based on the Pedestrian Danger Index (PDI), which computes the rate of pedestrian deaths relative to the amount of walk-to-work trips in an area. Although the index favors metro areas that tend to have a higher percentage of walk-to-work trips, the simple fact remains that Florida has the highest pedestrian fatalities per capita based on the 2009 statistics of 2.51 pedestrian fatalities per 100,000 population.

Analyzing pedestrian crashes is a different challenge compared to analyzing vehicle crashes because of the following reasons: pedestrian crashes are relatively rare and often very severe; pedestrian exposure is a function of both pedestrian and vehicle volumes and their combined effect is difficult to quantify; and pedestrian volumes are usually unavailable and are too costly to collect especially for area-wide studies and on a regular basis. Unlike counting vehicles, which can be automatically recorded when vehicles run over pneumatic road tubes, counting pedestrians in the field remains largely the task of human observers.

For area-wide studies, some surrogate measures have been used to estimate the level of pedestrian activities. A good example is the amount of walk-to-work trips used in the above T4A study. However, such data are usually collected with very low sample sizes, and thus the data could only be reported for very large areas such as United States Census urbanized areas (UZAs), as is the case with the walk-to-work trips used in the T4A study. In general, surrogate data for estimating pedestrian activities are typically unavailable at the local level for site-specific studies, such as at an intersection or along a corridor.

Like any other site-specific safety studies, a pedestrian safety study starts with identifying pedestrian high crash locations. As signalized intersections involve many features uniquely affecting pedestrian safety, including design of signal timing, presence and type of crosswalks, a concentration of bus stops with passenger transfer activities, etc., they are typically analyzed separately from non-signalized locations. However, in both cases the locations are usually identified based on pedestrian crash frequencies rather than crash rates for three reasons. First, as pointed out above, pedestrian exposure depends on both pedestrian and vehicle volumes, and pedestrian volumes are very difficult and expensive to collect especially continuously or regularly. Second, surrogate data for estimating pedestrian volumes are not available or are not sufficiently accurate at the local level. Third, pedestrian crashes are relatively rare, thus subject to fluctuations from the random nature of crash occurrences. In other words, similar to using crash rates on low-volume roads, the random occurrence of a single crash could raise the crash rate at a location high enough to place it on the high crash list.

## 1.2 Project Goal and Objectives

The goal of this project is to conduct a comprehensive study to improve pedestrian safety on state roads in Florida. The specific project objectives include:

1. Reviewing and summarizing existing pedestrian safety studies, including methods of analysis, and findings on pedestrian crash causes, crash contributing factors, and potential countermeasures.
2. Identifying statewide pedestrian crash patterns and causes.
3. Identifying factors contributing to pedestrian injury severity.
4. Identifying and analyzing pedestrian high crash locations at both signalized and non-signalized locations for crash causes and potential countermeasures.

The scope of this project is comprehensive as it involves multiple years of pedestrian crashes statewide and with detailed review of all police reports to obtain additional details, including those from police descriptions and illustrative sketches, which are not available from crash summary records.

## 1.3 Report Organization

The rest of the report is organized as follows. Chapter 2 provides an extensive review of existing literature on pedestrian safety, including risk factors affecting frequency and severity of pedestrian crashes, pedestrian exposure measures, pedestrian-vehicle conflict analysis techniques, pedestrian hot spot identification methods, pedestrian crash countermeasures and their evaluation, and pedestrian safety programs.

Chapter 3 summarizes the effort undertaken to review police reports and collect data on existing pedestrian facilities at signalized intersections. Chapter 4 focuses on identifying the overall statewide pedestrian crash patterns and causes. Particularly, general trends by crash and roadway characteristics are discussed. The Chapter also includes a discussion on the statewide pedestrian high crash concentrations.

As pedestrian crashes typically result in injuries, Chapter 5 aims to identify significant factors contributing to pedestrian crash injury severity. Chapters 6 and 7 focus on the identification and analysis of pedestrian high crash signalized and non-signalized locations, respectively. Finally, Chapter 8 provides a summary of this project effort and the relevant findings and conclusions.

# CHAPTER 2
# LITERATURE REVIEW

This chapter provides a comprehensive review of literature on pedestrian safety. The specific areas covered include risk factors affecting frequency and severity of pedestrian crashes, pedestrian exposure measures, use of surrogate crash measures and conflict analysis to evaluate pedestrian safety and crossing behaviors, methods to identify pedestrian high crash locations, evaluation of pedestrian crash countermeasures, and pedestrian safety programs.

## 2.1 Risk Factors Affecting Pedestrian Crashes

### *2.1.1 Pedestrian Crash Frequency Risk Factors*

There have been numerous studies that aimed to identify significant factors affecting frequency and severity of pedestrian crashes. This section highlights studies that investigated pedestrian crash frequency risk factors. Noland and Quddus (2004) used cross-sectional time series data for 11 regions in Great Britain over a period of 20 years. Using the negative binomial (NB) model, the authors found that alcohol involvement was positively associated with increased pedestrian crashes. Ukkusuri et al. (2011) identified the significant socio-demographic and environmental characteristics affecting pedestrian crash frequency at different census tracts or geographic regions in New York City. They found a significant positive correlation between pedestrian crash frequency in the vicinity of African-American or Hispanic neighborhoods, and across areas with a greater proportion of median-age and uneducated populations. They also found that areas with a greater number of schools and commercial land uses were more prone to pedestrian crashes. These findings were consistent to those from Kim and Ortega (1999), LaScala et al. (2000), and Azam et al. (2012). For example, Azam et al. (2012) observed that increased pedestrian activities in dense road networks increased pedestrian exposure and resulted in more pedestrian crashes.

Findings similar to those of Ukkusuri et al. (2011) were also observed by Kravetz and Noland (2012) who examined the relationship between pedestrian crashes and low-income communities in three counties in northern New Jersey (in the New York metropolitan area). The authors used the NB regression model and found that low median income and high Black and Latino populations were associated with high pedestrian crashes. Another study on the New York metropolitan area was conducted by Ukkusuri et al. (2012) who used five-year crash data and identified contributing factors of pedestrian crashes. They found that regions with a greater fraction of residential land had significantly lower likelihood of pedestrian crashes, which concurs with the study by Kim and Yamashita (2002). The authors also showed that the likelihood of pedestrian crashes increased with the increase in road width. Similarly, Garder (2004) also concluded that wider roads could increase pedestrian crash frequency.

Prato et al. (2012) identified pedestrian crash patterns to design preventive measures. The authors employed neural networks approach to analyze pedestrian fatal crashes during the four-year period between 2003 and 2006 in Israel. They observed five notable pedestrian crash patterns: (a) elderly pedestrians crossing on crosswalks mostly far from intersections in metropolitan areas; (b) pedestrians crossing from hidden places and colliding with two-wheel vehicles in urban areas; (c) male pedestrians crossing at night and hit by four-wheel vehicles in rural areas; (d) young male pedestrians crossing at night in both urban and rural areas; and (e) children and teenagers crossing in small rural communities. The observed crash patterns pointed to the importance of designing education and information campaigns for road users, and allocating resources for infrastructural interventions.

Fernandes et al. (2012) analyzed pedestrian crashes at 1,875 signalized intersections in Canada to identify potential geometric and environmental factors affecting pedestrian safety. Various NB models were fitted to the data with and it was found that vehicular traffic was the main contributing factor affecting pedestrian crash frequency. They also found that through vehicular movements at intersections had a greater effect on crash rates than left- and right-turn movements. In addition, geometric variables that were found significant included number of exclusive left-turn lanes, number of commercial entrances and exits, and total crossing distance. Higher number of exclusive left-turn lanes was found to decrease pedestrian crashes, whereas longer crossing distances and more commercial entrances and exits were found to increase pedestrian crashes. Another study by Qi and Li (2012) found that right-turn-on-red (RTOR) maneuvers did not lead to increased pedestrian crash frequency.

While comparing the analysis of pedestrian crashes in China and the U.S., Zhou et al. (2013) found that the crash data statistics in both countries followed the same declining trends, and the total number of traffic fatalities in the U.S. was about one half of that in China. A consistent finding was that drivers accounted for the largest fatality proportion in both countries. Furthermore, males were involved in more pedestrian fatalities than females in both countries. On the other hand, some discrepancies existed. For example, the second largest death group in traffic crashes was vehicle passengers in the U.S.; however, in China, pedestrians rank the second. In addition, in China, middle-aged individuals between 36-45 years were the most risky group in pedestrian crashes, while in the U.S., young people aging 16-24 were the most vulnerable. The authors proposed some countermeasures and strategies to improve pedestrian safety in both countries, e.g., installing pedestrian overpasses/underpasses and refuge islands, and promoting educational and enforcement campaigns.

While analyzing pedestrian traffic fatalities in Seattle, Washington, between 1990 and 1995, Harruff et al. (1998) found that that the average age of pedestrians involved in traffic fatalities was 49 years. This finding was also observed by Al-Shammari et al. (2009). Furthermore, Campbell et al. (2004) concluded that male pedestrian fatalities outnumbered female fatalities in every age group, which was consistent with other studies, including Lee and Abdel-Aty (2005), Al-Shammari et al. (2009), and Zhou et al. (2013).

The studies conducted by Lee and Abdel-Aty (2005) and Jang et al. (2013) are two examples of research that analyzed both frequency and severity of pedestrian crashes. Lee and Abdel-Aty (2005) analyzed the frequency and injury severity of vehicle-pedestrian crashes at intersections in Florida using four years of data from 1999 to 2002. They found that middle-age male drivers and pedestrians were more involved in pedestrian crashes than the other age and gender groups; and passenger cars were more likely to be involved in pedestrian crashes than trucks, vans, and buses. In addition, more crashes occurred on undivided roads with a greater number of lanes than divided roads with fewer lanes. Some of the significant factors affecting crash injury severity have included pedestrian age, weather and lighting conditions, and vehicle size. For example, pedestrian injury involving a large vehicle was more severe than those involving a passenger car.

Jang et al. (2013) used six years of pedestrian crashes from 2002 to 2007 in the City of San Francisco to identify risk factors on the frequency and injury severity of pedestrian-involved crashes. They used an ordered probit model and found that pedestrian characteristics that increased pedestrian injury severity were alcohol involvement, cell phone use, and age – either below 15 years of age or above 65 years. Environmental characteristics that were associated with high pedestrian severity included nighttime, weekends, and rainy weather. The influence of alcohol was found to be the primary crash factor associated with the most severe injuries. They also found that larger vehicles such as pickups, trucks, and buses were associated with more pedestrian severe injury compared to passenger cars.

Several studies had investigated pedestrian crashes along rarely studied locations, e.g., campus areas (Schneider et al., 2013), parking lots (Charness et al., 2012), and highway-rail crossings (Khattak and Luo, 2011). Schneider et al. (2013) analyzed pedestrian crashes at 22 intersections on the boundary of the University of California, Berkeley campus during typical spring and fall semester weekdays. The authors measured pedestrian exposure by extrapolating pedestrian counts using data from three automated counter locations. They found that pedestrian crash risk was highest at intersections with the lowest pedestrian volumes. In addition, pedestrian crash risk in the evening (6 p.m. to midnight) was found to be three times higher than that in the daytime (10 a.m. to 4 p.m.).

Charness et al. (2012) investigated pedestrian safety at parking lots based on pedestrian age. The authors concluded that pedestrians in all age groups (i.e., young, middle, and old) used crosswalks more frequently in parking lots. However, no significant variation was detected in using crosswalks across age groups. More walk distractions were observed among younger pedestrians than the elder pedestrians. Additionally, no significant differences were observed in the attention patterns such as head turns and eye fixation while walking in crosswalks across pedestrians in different age groups.

Khattak and Luo (2011) investigated pedestrian violations at dual-quadrant gated highway-rail grade crossings in Fremont, Nebraska using video surveillance equipment. Examples of the violations studied included: passing under descending gates, passing around fully lowered gates, passing under ascending gates, and passing around fully lowered gates between successive trains. They found that children of around eight years of age or younger were involved in 25% more gate-related violations than older crossing individuals. Additionally, violations were shown to increase with the presence of more individuals at the crossing during train crossing events.

Luoma and Peltola (2013) examined the safety impact of walking direction on pedestrian crash frequencies along rural two-lane roads with no pavement or pedestrian lanes in Finland. Reported crashes between 2006 and 2010 were included in the analysis. They observed that when pedestrians were facing traffic, there was a 77% reduction in fatal and injury pedestrian crashes as compared to pedestrians walking in the direction of traffic.

Another study by Abdel-Aty et al. (2007) focused on the safety of school-aged pedestrians in Orange County, Florida. They used five years of crash data and found that middle and high school children were more involved in pedestrian crashes, especially on high-speed multi-lane roadways. Significant predictors of pedestrian crashes included driver's age and gender, alcohol use, pedestrian's age, number of lanes, median type, and speed limit.

### *2.1.2 Pedestrian Crash Severity Risk Factors*

Studies that focused on investigating risk factors affecting pedestrian crash severity have included Oh et al. (2005), Tarko and Azam (2011), Sarkar et al. (2011), Mohamed et al. (2013), Nasar and Troyer (2013), and Khattak (2013). Oh et al. (2005) identified the significant factors affecting the probability of pedestrian fatalities in Korea using a logistic regression model. They found that the collision speed was the most significant contributing factor. The increase in collision speed was associated with an increase in the pedestrian fatality likelihood. Furthermore, they found that children had a higher probability of fatality in a pedestrian crash.

Tarko and Azam (2011) linked both police and hospital crash injury data to identify significant injury risk predictors by applying the bi-variate probit model. The authors found that male and older pedestrians were more exposed to severe injuries compared to other groups. Rural and high-speed urban roadways were found to be more dangerous for pedestrians, especially while crossing these roads. The most dangerous identified pedestrian behavior was crossing a road between intersections (i.e., at midblock locations). In addition, the size and weight of the vehicle involved in a pedestrian crash were significant predictors of pedestrian injury level.

Sarkar et al. (2011) developed binary logistic regression models to identify pedestrian fatality risk factors along Bangladesh’s roadways using crash data from 1998 to 2006. The authors found an increased likelihood of a fatality risk among elderly pedestrians (individuals older than 55 years of age) and young pedestrians (individuals younger than 15 years of age). A higher risk of fatality was observed for pedestrians who crossed the road compared to those who walked along the road. Pedestrian crashes with trucks, buses, and tractors had a higher fatality risk compared to cars. Furthermore, pedestrian crashes occurring during the rainy season had a higher probability of fatality compared to other seasons, and pedestrian crashes occurring at locations with no traffic control or stop control had a higher fatality risk than those occurring at locations with traffic signals.

Mohamed et al. (2013) used two pedestrian injury severity datasets from New York City (2002-2006) and Montreal, Canada (2003-2006), and applied the ordered probit and multinomial logit models for analyzing severity of pedestrian crashes. Both models are common approaches for severity investigation and the main difference is that the ordered probit model accounts for the ordered nature of injury levels, while the multinomial logit model ignores this ordinal nature. Several common variables, such as presence of heavy vehicles, absence of lighting, and prevalence of mixed land use, were found to increase the probability of fatal pedestrian crashes in both cities.

Nasar and Troyer (2013) hypothesized that pedestrians could experience reduced awareness, distraction, and unsafe behavior when talking or texting on their mobile phones. Using data from the U.S. Consumer Product Safety Commission on injuries in hospital emergency rooms from 2004 through 2010, they found that mobile-phone related injuries among pedestrians increased relative to total pedestrian injuries. Moreover, pedestrian injuries related to mobile phone use were higher for males and for people under 31 years of age. Similarly, Byington and Schwebel (2013) concluded that pedestrian behavior was considered riskier while simultaneously using mobile internet and crossing the street than when crossing the street with no distraction.

Using crashes from 2007 to 2010, Khattak (2013) employed an ordered probit modeling scheme to identify significant factors affecting pedestrian injury severity along national highway-rail grade crossings. The model showed that more severe injuries were associated with higher train speeds and the injury severity was higher for female pedestrians compared to male pedestrians. Pedestrian severities were found to be higher on commercial land use areas compared to residential areas. Pedestrian severities were also found to be higher in clear weather. In addition, lower pedestrian severities were found at highway-rail crossings with greater number of crossing highway lanes and standard flashing light signals.

### 2.2 Pedestrian Exposure

Because pedestrian exposure data (e.g., pedestrian volumes) are not readily available and is expensive to collect, researchers often rely on surrogate measures to estimate pedestrian exposure (Kennedy, 2008), such as population or population density (Chu, 2003), number of lanes crossed (Keall, 1995), time spent walking (Chu, 2003), number of pedestrian trips (SafeTrec, 2010), and aggregate distance traveled by all pedestrians in a specific area of interest (SafeTrec, 2010).

Since different measures of exposure have to be used depending on the purpose of the study, the Safe Transportation Education and Research Center (SafeTrec, 2010) summarized the issues related to the most common exposure measures. Tables 2-1 through 2-5 discuss exposure measures based on number of pedestrians, number of trips, distance traveled, population, and time spent walking, respectively.

Although there are different types of exposure measures, they have been criticized since they do not account for the actual amount of walking people do (Qin and Ivan, 2001). To address this concern, researchers have developed statistical regression models; implemented sketch plan, network, and micro-simulation models; or applied computer vision techniques to estimate pedestrian exposure or pedestrian volumes.

### Table 2-1: Exposure Based on Number of Pedestrians (SafeTrec, 2010)

| | |
|---|---|
| **Appropriate Uses** | • Estimating pedestrian volume and risk in a specific location<br>• Assessing changes in pedestrian volume or characteristics due to countermeasure implementation at that site |
| **How Data Is Gathered** | • Manual or automated counts of pedestrians |
| **Pros** | • Counts are simpler to collect than other measures such as time or distance walked<br>• Automated methods for counting number of pedestrians are improving |
| **Cons** | • Does not differentiate pedestrians by walking speed, age, or other factors that may influence individual risk<br>• Does not account for the amount of time spent walking or the distance walked<br>• Not easily adapted to assess exposure over wide areas (for example, a city) |
| **Common Measures** | • Average number of pedestrians per day, sometimes called average annual number of pedestrians<br>• Number of pedestrians per time period, e.g., hour |

### Table 2-2: Exposure Based on Number of Trips (SafeTrec, 2010)

| | |
|---|---|
| **Appropriate Uses** | • Assessing pedestrian behavior in large areas, such as cities, states, or countries<br>• Examining changes in pedestrian behavior over time<br>• Making comparisons between jurisdictions<br>• Assessing common characteristics of walking trips, such as purpose, route, etc. |
| **How Data Is Gathered** | • Data is gathered through use of surveys, such as the National Household Travel Survey |
| **Pros** | • Appropriate for use in large areas<br>• Best metric to assess relationship of walking with trip purpose<br>• Trips can be assessed as a function of person, household and location attributes |
| **Cons** | • As with most surveys, a large number of respondents are needed to adequately represent the underlying population<br>• Unlikely to provide information at the level of detail needed to assess risk at specific locations<br>• Pedestrian trips are often underreported in surveys |
| **Common Measures** | • Average number of walking trips made by members of a population per day, week or year<br>• Proportion of walking trips taken for particular purposes, such as commuting or shopping |

### Table 2-3: Exposure Based on Distance Traveled (SafeTrec, 2010)

| | |
|---|---|
| **Appropriate Uses** | • Estimating exposure at the micro or macro level<br>• Estimating whether risk increases in a linear manner with distance traveled<br>• Assessing how crossing distance affects risk |
| **How Data Is Gathered** | • For individual level exposure, through surveys such as the National Household Travel Survey<br>• For aggregate level exposure, measurement of the length of the area of interest, combined with a manual or automatic count of the number of pedestrians |
| **Pros** | • Can be used to measure exposure at the micro and macro levels<br>• More detailed than pedestrian volumes or population data<br>• Can be used to compare risk between different travel modes<br>• Common measure of vehicle exposure |
| **Cons** | • Does not take into account the speed of travel and thus cannot be reliably used to compare risk between different modes (e.g. walking and driving)<br>• Assumes risk is equal over the distance walked<br>• Must typically assume that each pedestrian walks the same distance in a crossing or along a sidewalk |
| **Common Measures** | • Average miles walked, per person, per day<br>• Total aggregate distance of pedestrian travel across an intersection |

**Table 2-4: Exposure Based on Population (SafeTrec, 2010)**

| | |
|---|---|
| **Appropriate Uses** | • Used as an alternative to exposure data when cost constraints make collecting exposure data impractical<br>• Used to compare jurisdictions over time because population data is available for many geographies and time periods |
| **How Data Is Gathered** | • Population data for most cities is available on an annual basis through the American Community Survey |
| **Pros** | • Easy and low-cost to obtain; available for most geographies and time periods<br>• Adjusts for differences in the underlying resident population of an area – for example, sparsely populated suburbs versus densely populated inner-city areas<br>• Provides a crude adjustment for amount of vehicle traffic on the streets, since areas where more people live also tend to be areas where more people drive<br>• May be the only way to represent exposure if direct measurements cannot be taken |
| **Cons** | • Does not accurately represent pedestrian exposure<br>• Does not account for the number of people who walk in the area<br>• Does not provide information about amount of time or distance that members of the population were exposed to traffic |
| **Common Measures** | • Number of people in a given area: neighborhood, city, county, state, or country<br>• Number of people in a particular demographic group: by age, sex, race, immigrant status or socioeconomic status |

**Table 2-5: Exposure Based on Time Spent Walking (SafeTrec, 2010)**

| | |
|---|---|
| **Appropriate Uses** | • Estimating total pedestrian time exposure for specific locations<br>• Comparing risks between different modes of travel (e.g. walking vs. riding in a car)<br>• Estimating whether risk increases in a linear manner with walking time<br>• Comparing risk between intersections with different crossing distances and between individuals with different walking speeds |
| **How Data Is Gathered** | • The number of persons passing through an area multiplied by the time traveled<br>• Time spent on walking activities reported on surveys |
| **Pros** | • Accounts for different walking speeds<br>• Allows for accurate comparison between different modes of travel<br>• Can be used to measure exposure at the micro and macro levels<br>• More detailed than pedestrian volumes or population data |
| **Cons** | • Time based measures assume risk is equal over the entire distance of a crossing. Only a small portion of time spent walking on roadways represents real exposure to vehicle traffic. This portion would include time spent crossing roads, walking on the road surface, or possibly walking along the roadside where there are no curved sidewalks<br>• Time spent on walking can be overestimated in surveys, because people perceive that they spend more time walking than they actually do<br>• Walking may also be under-reported in surveys, because people may forget walk trips or may purposely choosing not to report. Both of these reasons are related to the fact that walking trips are relatively short. These very short trips may not register in the memory of respondents or the respondents may think that these short trips are unimportant |
| **Common Measures** | • Average time walked, per person, per day or year<br>• Total aggregate travel time of pedestrian travel across an intersection |

### *2.2.1 Statistical Regression Models*

A number of studies have applied statistical regression models to model and predict pedestrian exposure, such as pedestrian volumes. Hess et al. (1999), Qin and Ivan (2001), and McMahon et al. (2002) agreed that the presence of sidewalks is the most significant factor affecting pedestrian activities. Apart from statistical models, some studies have made use of probability distribution functions, e.g., Espino et al. (2003). The authors used a Poisson probability distribution function to determine pedestrian hot spots in Florida. The authors provided a framework for identifying pedestrian hot spots on the state highway system as part of the Highway Safety Improvement Program (HSIP). The authors defined the Poisson probability function of a pedestrian crash frequency for every 1-mile segment as follows:

$$P(y)=\frac{\lambda^{y}}{y!}e^{-\lambda} \tag{2-1}$$

where $\lambda$ is the average number of pedestrian crashes per mile and $y$ is the number of pedestrian crashes.

Hess et al. (1999) estimated the relation between pedestrian volumes and site design elements such as block size, block length, and presence of sidewalks while controlling for population density, income, and land use. The study found that pedestrian volumes at urban sites with smaller blocks and extensive sidewalks were significantly different from the volumes at suburban sites with larger blocks and limited sidewalk facilities. Furthermore, on average, urban sites experienced approximately three times more pedestrian volumes compared to suburban sites. In addition, it was found that block size, length of sidewalk, and routes traveled largely impacted pedestrians' willingness to walk. The authors found that population density, income levels, and land use were not significantly correlated with the observed pedestrian volumes, which is similar to the findings of Qin and Ivan (2001).

Qin and Ivan (2001) developed linear regression models to predict weekly pedestrian volumes in rural areas in Connecticut. The authors investigated factors such as population density, presence of sidewalks, number of pedestrian crossing lanes, area type, traffic control type, and household income. The linear model took the following functional form:

$$V = P^{\alpha} \times e^{(\beta_0+\beta_S X_S+\beta_D X_D+\beta_A X_A+\beta_R X_R+\epsilon)}$$

where,

| | | |
|---|---|---|
| $V$ | = | dependent variable or weekly pedestrian volumes, |
| $P$ | = | population density in the sidewalk area, |
| $X_S$ | = | site characteristics (e.g., presence of sidewalk or crosswalk, traffic control type), |
| $X_D$ | = | demographic characteristics (e.g., median household income), |
| $X_A$ | = | area type characteristics (e.g., downtown area, residential area), |
| $X_R$ | = | roadway characteristics (e.g., number of lanes), |
| $\alpha$ | = | regression coefficient of population density, |
| $\beta_0$ | = | intercept coefficient, |
| $\beta_{S,D,A,R}$ | = | regression coefficients to be estimated, and |
| $\varepsilon$ | = | error term. |

The authors found that area type, presence of sidewalks, and number of lanes were the only significant variables in predicting pedestrian exposure. Moreover, McMahon et al. (2002) investigated the relationship between pedestrian exposure (in terms of crashes involving pedestrians walking along the roadway) and several demographic and roadway factors. Presence of sidewalk was among the most significant predictors of crashes involving pedestrians walking along the roadway. Furthermore, the study identified different levels of exposure for pedestrians walking along the road and pedestrians crossing the road.

A study by Raford and Ragland (2006) developed a space regression model using the Geographic Information Systems (GIS) tool to estimate pedestrian volumes in urban areas in Boston, Massachusetts. The explored variables included land use type, walking distance from each study area to the closest transit station, walking distance from each study area to the closest rail station, and walking distance from each study area to tourist attractions. It was found that the model was accurate enough to predict pedestrian volumes after including walking distances to transit stops and major tourist attractions. The model provided guidance for planners to predict future pedestrian volumes in the study areas.

### *2.2.2 Sketch Plan Models*

Sketch plan models are often used at a regional level to estimate pedestrian volume. Zupan and Pushkarev (1971) developed sketch models based on observed counts and commercial land use space to estimate the sidewalk levels. Schwartz et al. (1999) developed planning guidelines to estimate pedestrian volume based on key indicators such as square footage of office space, parking capacity, vehicular traffic movements, and movement levels in similar environments. Similarly, Raford and Ragland (2006) estimated pedestrian volume by applying the sketch plan model to large regional urban environments. However, the accuracy of this model is questionable because of the little data collection needed. Also, the developed sketch model is unable to assign pedestrian volumes to specific streets or intersections since those types of analyses rely on detailed data collection that these sketch models lack (Raford and Ragland, 2006).

### *2.2.3 Network Models*

Network-type models have the capability to estimate pedestrian volumes for street segments and intersections on larger areas such as an entire city or neighborhood. These models work by assuming the amount of walking trips in a study area and various route choice algorithms to generate and distribute trips (Senevarante and Morall, 1986). In the City of Toronto, Canada, Ness et al. (1969) created an origin-destination matrix of traffic zones, and then assigned trip distributions using a gravity based model. Other approaches such as space syntax to measure route directness based on a graph "nearness" algorithm was used in combination with pedestrian counts to obtain calibration factors to convert the relative values into actual hourly pedestrian volume estimates (Teklenburg et al., 1993; Raford and Ragland, 2006). Using the same approach, Hillier et al. (1993) and Penn et al. (1998) estimated an $R^2$ value of 0.77 in central London. According to Raford and Ragland (2006), Europe and the United Kingdom have been using this approach in large-scale projects and suggest that it offers relatively accurate numbers and a more economical way of network calibration.

### *2.2.4 Micro-simulation and Computer Vision Techniques*

Another approach for estimating pedestrian exposure is to use micro-simulation tools and computer vision techniques. However, compared to statistical models, this approach is not extensively used by researchers. This is mainly due to the micro-simulation approach's complexity, significant data requirements, and relatively limited geographic coverage area (Raford and Ragland, 2006). A relevant study that applied micro-simulation to estimate pedestrian volumes is Helbing et al. (2001). The authors microscopically simulated pedestrian streams and interpreted pedestrians' patterns of motion as a self-organizing phenomenon that arose from nonlinear interactions among pedestrians. The authors further found that pedestrians' self-organization flow pattern could significantly change the capacity of pedestrian facilities.

Li et al. (2012) investigated the use of computer vision techniques for automated collection of pedestrian exposure data, e.g., measurement of pedestrian counts, tracking, and walking speeds. The authors applied an efficient pedestrian tracking algorithm which combined different sources of information effectively. The applications were demonstrated with a real-world data set from Vancouver, Canada that included 1,135 pedestrian tracks. Manual counts were performed to validate the results of the automated data collection. It was found that a 5% average error in counting was gained, which was acceptable for the scope of the study. Pedestrian gender and age were found to significantly influence the pedestrian mean walking speed. In addition, there was a strong agreement between the manual and automated walking speed values.

There have been studies that investigated pedestrian crossing behavior to detect abnormal behavior, such as the studies by Hu et al. (2012) and Kourtellis et al. (2013). For example, Hu et al. (2012) used a video tracking method to automatically detect abnormal pedestrian crossing behavior. Based on object trajectories data extracted by video tracking, pedestrian motion patterns were observed. The proposed approach was implemented and tested at real-world crosswalks. The authors deduced two main causes for abnormal pedestrian crossing behavior. The first cause was that pedestrians mostly ignored regular crossing behavior and wanted to reach the destination using the shortest way. The second cause was that pedestrians had to cross the street using an abnormal path to avoid potential crash risks with motor-vehicles. Some countermeasures were proposed as a result of the investigation, e.g., installing pedestrian crossing signals.

In another pedestrian behavior study, Kourtellis et al. (2013) developed a risk score to assess pedestrian crossing behavior at select sites in Hillsborough and Miami-Dade Counties in Florida. They surveyed pedestrians and bicyclists about their interactions with motorists. The locations where the surveys were conducted were selected based on site characteristics including pedestrian features, crash history, and land use. They observed that 12% of sites in Miami-Dade County and 15% of sites in Hillsborough County exhibited marginally safer behavior. For both counties, the driver risk score was lower than the pedestrian risk score, which implied that drivers riskier and more dangerous towards pedestrians. Other results were that 44% of drivers did not yield to a crossing pedestrian while on a crosswalk. In addition, 58% of bicyclists knew that they had to ride with traffic; however, 52% were observed riding against traffic.

### 2.3 Pedestrian Conflict and Behavior Analyses

There have been studies that applied the pedestrian-vehicular conflict analysis as an alternative to historical crash data analysis. Examples of such studies include Qi and Yuan (2012), Zhang et al. (2012), Pratt et al. (2013), and Zaki et al. (2013). Qi and Yuan (2012) investigated the impacts of intersections with permissive left-turn signal control on pedestrian safety using traffic engineers' survey, field traffic-conflict analysis, and historical crash data analysis. Using eight study intersections in Texas, it was found that pedestrian volume, opposing through-vehicle volume, left-turn vehicle volume, and intersection width in the opposing direction were significant risk factors affecting the safety of pedestrians. In addition, three-legged intersections were found more dangerous than four-legged intersections under the operation of a permissive left-turn signal. The authors found high correlation between the data on collected historical crashes and observed traffic conflicts, which showed that conducting traffic conflict studies could be an effective approach for safety analysis.

A recent study similar to Qi and Yuan (2012) was conducted by Pratt et al. (2013). The authors studied conflicts between pedestrians and left-turning vehicles at 20 signalized intersections in Texas. Conflict frequency models were developed using the nonlinear mixed (NLMIXED) regression procedure. The models showed that conflict frequency increased with increasing pedestrian volume and left-turning vehicle volume. On the contrary, conflict frequency decreased with the provision of a protected left-turn phase. Furthermore, the models showed that conflict rates were higher for illegal pedestrians than for legal pedestrians.

The use of image processing technique in analyzing pedestrian-vehicular conflicts can be found in Zhang et al. (2012) and Zaki et al. (2013). For example, using video data, Zhang et al. (2012) applied the time difference to collision (TDTC) measure to identify and classify pedestrian behavior. According to the authors, the pedestrian-vehicular TDTC was defined as the time difference for a pedestrian and a vehicle to travel to the potential conflict point given their speeds were kept constant. The potential conflict point was defined as the intersection of the predicted trajectories of pedestrian and vehicle. The results showed that the closer a TDTC was to zero, the more dangerous a pedestrian-vehicular conflict could be. Moreover, negative TDTC values were considered more dangerous than positive TDTC values. The authors concluded that the TDTC parameter was useful in indicating pedestrian-vehicle conflicts, where in approximately 80% of the cases, pedestrian-vehicular conflicts could be correctly specified.

Similarly, Zaki et al. (2013) investigated pedestrian-vehicular conflicts at a major signalized intersection in Downtown Vancouver, Canada, using computer vision. The authors extracted conflict and violation indicators from video sequences in a fully automated way. They applied the time-to-collision (TTC) conflict indicator as a measure of the severity of the detected conflicts. They defined TTC as the extrapolated time for the collision to occur. TTC was continually calculated between conflicting road-users until a final set of values was estimated for each conflict. The minimum TTC was used to indicate the maximum severity of the conflict. The authors observed that the majority of conflicts occurred between right-turning or left-turning vehicles and crossing pedestrians.

### 2.4 Pedestrian Hot Spot Identification Methods

Identification of pedestrian hot spots is a different challenge compared to identifying vehicle hot spots. This is mainly because, unlike vehicular volume, pedestrian counts are usually not available for the calculation of pedestrian exposure. Therefore, the methods used to identify hot spots for vehicle crashes cannot be directly applied to identify pedestrian hot spots. The existing methods for identifying pedestrian hot spots can be divided into the following three general categories:

1. density methods,
2. clustering methods, and
3. exposure estimation methods (as discussed in Section 2.2).

### *2.4.1 Density Methods*

The density methods attempt to identify high concentrations of pedestrian crashes. The degree of concentration is measured based on density, calculated as pedestrian crash frequency per unit area (e.g., square miles) or unit length (e.g., mile). Two common density methods are the simple density method and the Kernel Density Estimation (KDE) method.

#### *Simple Density Method*

As documented in Pulugurtha et al. (2007), in the simple density method, the entire study region is first divided into a predetermined number of cells. As shown in Figure 2-1, a circular search area is drawn around each cell. The individual cell density values are then calculated as the ratio of total number of crashes that fall within the search area to the extent of the search area. In this approach, the extent of the search area (i.e., its radius) affects the resulting density map, where larger radius results in a smoother density surface.

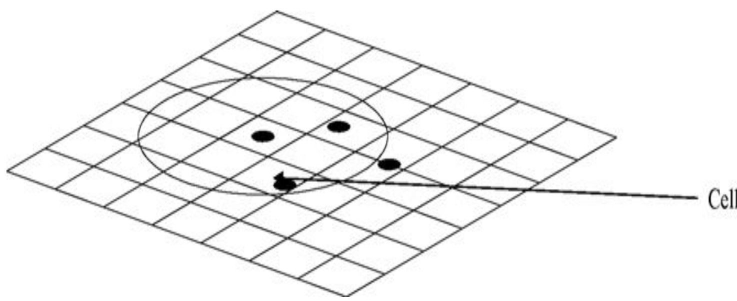



**Figure 2-1: Simple Density Method (Pulugurtha et al., 2007)**

#### *Kernel Density Estimation Method*

The Kernel Density Estimation (KDE) method uses a statistically sophisticated procedure to estimate crash density (Pulugurtha et al., 2007). Similar to the simple method, the entire study region is also divided into a predetermined number of cells. However, contrary to the simple method, a circular search area is drawn around each crash rather than each cell, as shown in Figure 2-2. A Kernel density function is then applied to each crash to calculate the Kernel values. Kernel density function is a non-parametric weighting function to estimate random variables' density function. It is a non-negative real value that satisfies the following two conditions:

- $\int_{-\infty}^{\infty} K(u)du=1$, where u is a random variable.
- $K(-u)=K(u)$ for all u values.

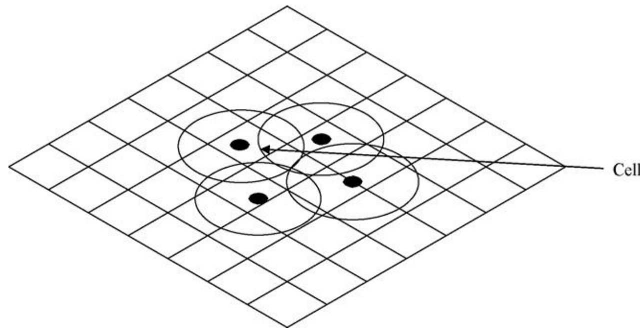



**Figure 2-2: Kernel Density Estimation Method (Pulugurtha et al., 2007)**

There are many types of Kernel functions and they include uniform, triangular, bi-weight, tri-weight, tri-cube, Gaussian, and cosine functions. For example, the functional form of a Gaussian Kernel function is:

$$K(u)=\frac{1}{\sqrt{2\pi}}e^{\frac{-u^2}{2}}$$

To calculate the Kernel density estimator $f_h(X)$, let ($X_1$, $X_2$, …, $X_N$) be an *iid* (*independent and identically distributed*) sample drawn from an unknown density function or distribution, f. The Kernel density estimator is defined as follows:

$$f_h(X)=\frac{1}{Nh}\sum_{i=1}^{N}K\left(\frac{X-X_i}{h}\right)$$

where K(•) is the Kernel function and h > 0 is the smoothing parameter also known as the bandwidth or Kernel size.

The most significant parameter in Equation (4) is the bandwidth parameter (h) and several values of bandwidths have to be tested to reach the best value that leads to a smooth curve. In the KDE method, the density value is highest at the crash location and diminishes with increasing distance from the crash, reaching zero at the radial distance from the crash (i.e., at the boundaries of the circle around each crash). The individual cell densities are then calculated as the sum of the overlapping Kernel values over the cell. The larger the radius, the flatter the Kernel density surface. The concentration areas in the crash concentration or crash cluster maps are categorized into very low, low, medium, high, and very high pedestrian crash risk locations, representing the five quantiles. The very low risk category represents density values in the first $20^{th}$ percentile. Likewise, the very high risk category represents density values in the $80^{th}$ percentile.

Compared to the simple density method, a smoother density surface (i.e., a well fitted smooth curve, as shown by the red curve in Figure 2-3) is generally produced by the Kernel density calculations (Pulugurtha et al., 2007). Therefore, the Kernel method is more appropriate since a smoother surface can better identify hot spots.

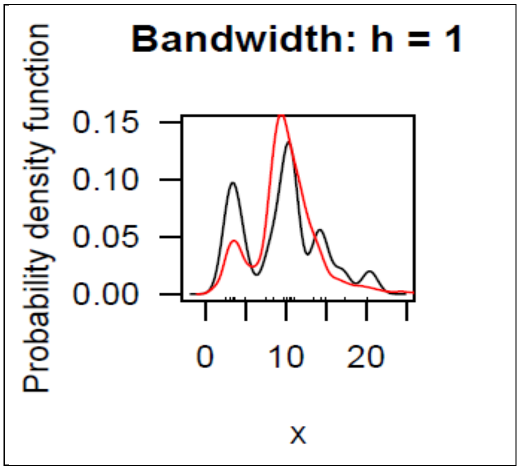



**Figure 2-3: Kernel Probability Density Curve Smoothing (Zucchini, 2003)**

As documented in Truong and Somenahalli (2011), while the KDE method has been successfully applied to identify pedestrian and vehicle hot spots (e.g., Pulugurtha et al., 2007; Anderson, 2009), it has two main issues. First, concentration or clustering maps could have different search bandwidths and neighborhood sizes which might lead to inconsistent comparisons of clusters. This issue could be addressed using a network-type KDE method. Several studies have extended the KDE method to network spaces that estimate the density over a unit distance instead of a unit area (e.g., Xie and Yan 2008). However, according to Xie and Yan (2008) and Anderson (2009), one main limitation of both traditional and network KDE methods is that neither of them can be tested for statistical significance. The second main issue with the KDE method is that the exposure measures (e.g., pedestrian volumes) are neglected in the analysis since clusters are defined using absolute crash counts. This issue could be addressed by using crash frequencies per unit exposure or crash rates stratified by different injury severity levels, e.g., serious injury, fatal injury, etc.

*Relevant Studies*

Two studies that successfully applied the crash density analysis are Pulugurtha et al. (2007) and Jang et al. (2013). Pulugurtha et al. (2007) used the crash density method using the GIS tool to study the spatial patterns of pedestrian crashes to identify pedestrian hot spots. The authors created crash density maps using the simple and KDE methods and prioritized hot spots using ranking methods, such as crash frequency, crash density, crash rate, as well as a combination of methods such as the sum-of-the-ranks and the crash score methods. The authors used five years (1998-2002) of crash data from the Las Vegas metropolitan area. They concluded that the KDE method is better than the simple method since it results in a smoother density surface. The results obtained from ranking pedestrian hot spots showed a significant variation in ranking when individual methods were applied. However, rankings of high pedestrian crash zones were relatively consistent with little variation when the sum-of-the-ranks method and the crash score method were used. The authors further recommended a combination of methods while ranking pedestrian hot spots instead of using individual methods.

Jang et al. (2013) identified pedestrian hot spots and the risk factors affecting pedestrian crash injury severity using six-year crash data (2002-2007) from San Francisco. The authors used the KDE method in GIS to generate pedestrian crash density maps. It was found that the pedestrian crash frequency was higher in the vicinity of the central business district, while the pedestrian crash rate (crash frequency normalized by pedestrian exposure) was higher in the periphery of the city. It could, therefore, be concluded that disregarding pedestrian exposure could significantly affect the results.

### *2.4.2 Clustering Methods*

Clustering is classification of data into homogeneous groups or clusters that share similar characteristics. It has been successfully applied in fields such as data mining, pattern recognition, image processing, and safety analysis. K-means and latent class (LC) are the two examples of clustering methods that have been used in safety analysis.

#### *K-Means Clustering Method*

K-means clustering is one of the simplest clustering methods and it works in an iterative process. K-means clusters rely on the distance between the dataset attributes and attempt to maximize the similarity within each cluster and the dissimilarity between clusters (Mohamed et al., 2013). The procedure can be explained in the following four main steps:

1. The dataset is partitioned into K clusters and the data points are randomly assigned to the clusters, so that clusters have roughly the same sample size.
2. The mean or centroid of each cluster is then estimated.
3. For each data point in a cluster, the distance from the data point to the mean point of each cluster is then calculated. If the data point is closest to its own cluster, leave it where it is, and if not, move it into the closest cluster.
4. Repeat the previous step until no data point can be moved from one cluster to another. At this stage, the clusters are said to be stable.

There are four main properties of the K-means clustering method:

1. There are always K clusters.
2. At least one item is assigned to each cluster.
3. The clusters do not overlap.
4. Every member of a cluster is closer to its cluster than to any other cluster.

Note that the K-means algorithm aims at minimizing an objective function or a squared error function. The objective function f(J) is defined as follows (Likas et al., 2003):

$$f(J)=\sum_{j=1}^{K}\sum_{i=1}^{n}\left\|x_i-c_j\right\|^2$$

where,

$x_i$ = attribute value of data point i,
$n$ = total number of data points,
$c_j$ = centroid or mean value of cluster j, and
$K$ = total number of clusters.

### *Latent Class Clustering Method*

Latent class (LC) clusters are probabilistic and consider that the data come from a mixed model of several probability distributions. This cluster is similar to fuzzy clustering as it considers uncertainty in the analysis (Mohamed et al., 2013). According to Vermunt and Magison (2002), the basic LC cluster functional form is as follows:

$$f(z_i|\theta) = \sum_{k=1}^{K} \pi_k f_k(z_i|\theta_k)$$

where,

$z_i$ = vector of observed variables of the ith crash,
$K$ = total number of clusters,
$\pi_k$ = prior probability of being assigned to cluster k,
$\theta_k$ = vector of parameters of the kth latent class cluster model, and
$f_k(z_i|\theta)$ = probability density function.

The parameter estimation of the LC model is based on maximum likelihood estimation. The best LC model (or optimum number of clusters) is obtained by trying multiple models and computing various information criteria such as Bayesian Information Criterion (BIC) and Akaike Information Criterion (AIC). The optimum number of clusters is the one that minimizes the scores of these criteria. As indicated in Mohamed et al. (2013), LC is advantageous over the K-means method since it does not depend on the distance between the elements and there is no need to normalize the data before processing. Furthermore, according to Depaire et al. (2008) and Mohamed et al. (2013), variables of different types (e.g., ordinal, nominal, continuous) can be included in the analysis without special consideration.

### *Relevant Studies*

Several studies have successfully applied clustering analysis, such as Truong and Somenahalli (2011), Mohamed et al. (2013), and the method adopted by Florida Department of Transportation (FDOT) District 6. Truong and Somenahalli (2011) proposed severity indices instead of traditional crash counts in analyzing and ranking pedestrian hot spots and unsafe bus transit stops. The authors used the ArcGIS software for the spatial and cluster analyses. The authors used 13 years (1996-2008) of pedestrian crash data from the Adelaide metropolitan area in Australia and concluded that the approach was reliable in identifying pedestrian hot spots and in ranking unsafe bus stops. Mohamed et al. (2013) used cluster analysis by applying K-means clusters and LC clusters. The authors generated cluster maps based on crash characteristics such as traffic control, lighting conditions, vehicle type, and land use.

In the recent study for FDOT District 6 (AECOM, 2013), a combination of clustering and density methods was applied in a GIS environment to identify pedestrian and bicyclist hot spots. The procedure consists of the following steps:

1. *Aggregate crash data and identify groupings of crashes:* Apply an ArcGIS application to identify groups of crashes based on a predetermined 250-ft search radius. Next, exclude groups containing fewer than five pedestrian crashes from further investigation.

2. *Identify pedestrian crash clusters:* Rerun the ArcGIS application using a larger search radius of 600 feet to identify larger pedestrian crash clusters.

3. *Normalize crash frequency for each cluster:* Normalize crash counts by segment length along each roadway segment within a cluster to yield pedestrian crash frequency per mile.

4. *Rank locations:* Rank roadway segments based on pedestrian crash frequency normalized per unit length.

As part of the study, pedestrian crash data for the latest available five-year period for all state roads within FDOT District 6's jurisdiction were used. It was observed that for small clusters (i.e., roadway segments less than 0.2 miles), normalized crash frequencies were inflated, and these segments were ranked among the highest. Clusters were then categorized into intersections and corridors using a 500-ft threshold. Segments shorter than the threshold were identified as intersections, while those longer than the threshold were identified as corridors. Pedestrian crash frequency was used to rank intersections, and pedestrian crash rate (crashes per mile) was used to rank corridors. A total of 116 pedestrian crash clusters were first identified, where a majority of these clusters were at intersections. A list of top 15 intersections and corridors was then prepared.

## 2.5 Evaluation of Pedestrian Countermeasures

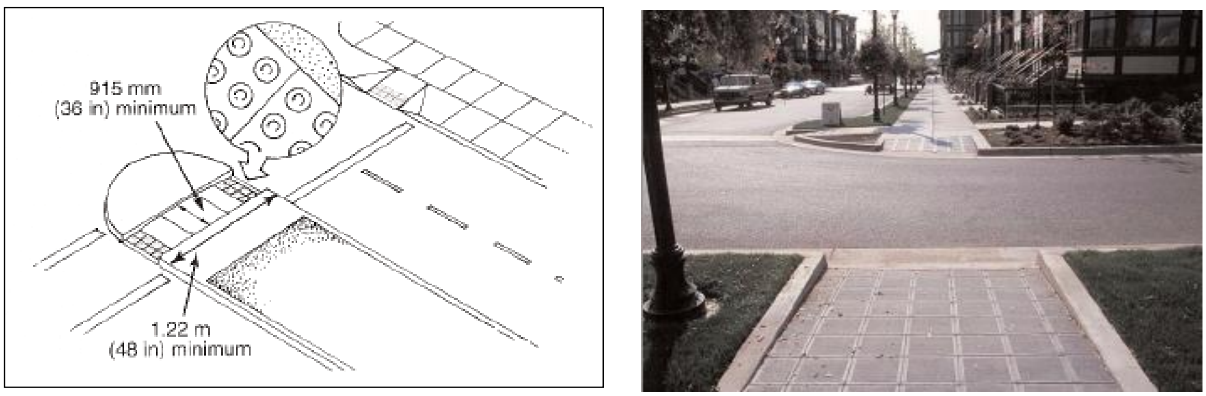
### *2.5.1 Examples of Pedestrian Countermeasures*

An essential step in the pedestrian safety investigation is to evaluate countermeasures to alleviate pedestrian crashes and injuries. Two major publications that detail pedestrian countermeasures are Volume 10 of the National Cooperative Research Program (NCHRP) Report 500 (Zegeer et al., 2004) and the PEDSAFE Handbook (Harkey and Zegeer, 2004). For example, the PEDSAFE Handbook discussed several pedestrian countermeasures that should be used in specific locations to be successfully implemented. It includes the following seven categories of countermeasures:

1. Pedestrian facility design
2. Roadway design
3. Intersection design
4. Traffic calming
5. Traffic management
6. Signals and signs
7. Other measures

*Pedestrian Facility Design*

Pedestrian facilities consist of sidewalks, curb ramps, marked crosswalks, transit stop treatments, roadway lighting improvements, and street furniture. According to Harkey and Zegeer (2004), appropriate walking areas “improve pedestrian safety dramatically”. The Florida Department of Transportation (FDOT, 2000) determined that the crash reduction factor (CRF) for an installation of a sidewalk or walk way is 75%. Designing “pedestrian lanes” that separate pedestrians from vehicles provides a safe and efficient way for pedestrians to travel (Zegeer and Seiderman, 2001). Adding buffers to sidewalks give pedestrians a safer and more comfortable space separating them from vehicles on the road. Curb ramps, as shown in Figure 2-4, give disabled patrons an easy access to the sidewalk and are mandatory by federal legislation (Americans with Disabilities Act “ADA”, 1990).




(a) Curb Ramp Design (b) Example of Curb Ramp

**Figure 2-4: Curb Ramps (Harkey and Zegeer, 2004)**

Marked crosswalks warn drivers that pedestrians might cross the street. These markings help vehicles yield to pedestrians and provide a safe and designated area for pedestrians to cross. Studies have shown that a crash modification factor (CMF) of 0.35 can be used for crash predictions at unsignalized intersection (Haleem and Abdel-Aty, 2012). The Manual on Uniform Traffic Control Devices (MUTCD) includes a variety of patterns for crosswalk markings. Figure 2-5 shows examples of the different types of crosswalk marking patterns.

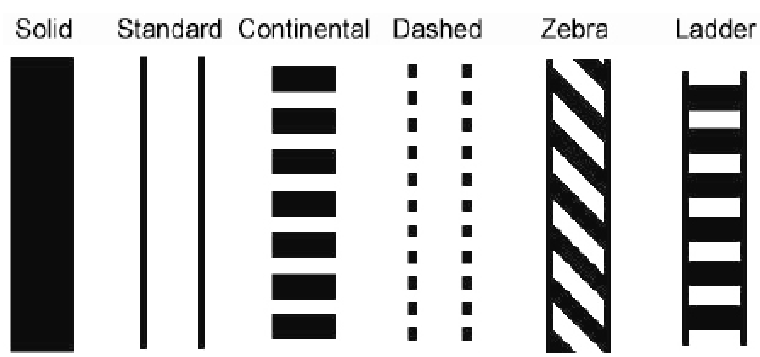



**Figure 2-5: Crosswalk Marking Types (Harkey and Zegeer, 2004)**

The study by Richards (1999) found that crosswalk markings at unsignalized intersections were associated with high pedestrian crash rates. Harkey and Zegeer (2004) stated that motorists could see the ladder pattern more than the conventional standard type, and should generally be installed with additional enhancements such as pedestrian signs for better safety performance. Figure 2-6 shows an example of a ladder crosswalk.


**Figure 2-6: Crosswalk with Ladder Pattern (Harkey and Zegeer, 2004)**

Bus stops, street furniture, and pedestrian walking environment have to be inviting to the pedestrians. The walking facility has to be safe and provide adequate lighting and amenities so that pedestrians feel comfortable. Roadway lighting makes the pedestrian path safer by increasing pedestrian visibility. Illumination of intersections is an important countermeasure when designing a good pedestrian facility. A CMF of 0.62 can be used for serious and minor injuries at night (Elvik and Vaa, 2004) when predicting pedestrian crashes. Bahar et al. (2007a) developed CMFs for lighting improvements for fatal (0.22) and injury (0.58) pedestrian crash severities.

### *Roadway Design*

Roadway design affects pedestrian safety in multiple ways, e.g., the impact of lane width and direction of traffic. For example, the time it takes for pedestrians to cross the street depends on the lane width and number of lanes, and the direction of traffic directly impacts the number of conflicts between vehicles and pedestrians. Some of the countermeasures related to roadway design include bicycle lane installation, lane narrowing, reduction in number of lanes, installation of pedestrian refuge areas such as raised medians, conversion of two-way streets to one-way streets, and reduction in curb radius.

Bicycle lanes are exclusive lanes for bicyclists that provide separation between vulnerable road users and motorists and shorten the crossing distance for pedestrians. Using a before-and-after study, Jensen (2008) found that the installation of bicycle lanes resulted in a CMF of 0.9 for pedestrian crashes involving right-turning vehicles.

Narrowing a roadway can be done by removing travel lanes, narrowing lane widths, adding on-street parking, or by curb relocation. Narrowing a roadway will provide safer pedestrian movements by reducing vehicle speeds (VN Engineers, 2012). Distributing the available space to other components of the roadway such as bicycle lanes, sidewalks, etc., will likely enhance the safety of all road users. The other countermeasure, lane reduction, should only be used if there is excess road capacity. Reducing the number of lanes can provide pedestrians a shorter crossing distance and might help optimize signal timing (ITE, 2010).

Constructing raised medians is another countermeasure that can be implemented to improve pedestrian safety. Raised medians provide a place of refuge for pedestrians crossing a wide intersection or a midblock section (ITE, 2010). High speed and high volume roads can benefit from raised medians with respect to pedestrian safety. Gan et al. (2005) stated that a CMF of 0.31 can be used for raised medians on a major approach for pedestrian crashes.

Although conversions of two-way streets to one-way streets reduce conflicts between the motorists and pedestrians, this countermeasure is generally expensive and requires large-scale implementation. It generally reduces speed, but can also increase travel distances for drivers. Another roadway design countermeasure is reducing the turning radius of the curb, which will lower the turning speed of the vehicles, reducing pedestrian crashes that involve right-turning vehicles. A larger curb radius encourages vehicles to turn at a higher speed and also increases the crossing distance for pedestrians (Harkey and Zegeer, 2004). Figure 2-7 shows an example of a location with tighter corner radius.

(a) Example of Tight Turning Radii (b) Comparison of Different Radius Curbs

**Figure 2-7: Intersection with Tight Turning Radii (Harkey and Zegeer, 2004)**

Curb extensions extend the sidewalk out to the parking lane, and help reduce the crossing distance, improve visibility between motorists and pedestrians, and reduce crossing time. Curb extensions also reduce vehicle turning speeds (ITE, 2010). Figure 2-8 shows an example of a curb extension.

Adding on-street parking on urban corridors could improve pedestrian safety since it creates a buffer between vehicles and pedestrians and narrows the crossing distance (VN Engineers, 2012). This countermeasure decreases the pedestrian exposure time and encourages slower speeds. However, restricting on-street parking near intersections improves intersection sight distance and could improve overall safety (ITE, 2010). For example, Gan et al. (2005) found a 30% reduction in pedestrian crashes when parking is restricted near intersections.

**Figure 2-8: Curb Extension (Harkey and Zegeer, 2004)**

Crossing islands are used as pedestrian refuge areas at intersections and at midblock locations. These give the pedestrians the advantage of crossing only one direction of traffic at a time. According to the National Highway Traffic Safety Administration (NHTSA, 2012), a crossing island and a curb extension, if used together, could improve pedestrian safety. Furthermore, crossing island facilities have proven to show substantial reduction in the percentage of pedestrian crashes. For example, Zegeer et al. (2005) found that raised medians resulted in significantly lower pedestrian crash rates on multi-lane roads, compared to other roads with no raised medians. Figure 2-9 gives an example of a refuge center island.

**Figure 2-9: Pedestrian Refuge Island (FHWA, 2013)**

### *Intersection Design*

Roundabouts often improve both the safety and mobility of pedestrians (Shen et al., 2000). Roundabouts reduce speed and number of conflict points, eliminate left turns, and improve traffic flow effectiveness. However, roundabouts have to be carefully designed. Accommodations for pedestrians using splitter islands for crossing can make a roundabout safer and more efficient for drivers, pedestrians, and bicyclists. Constructing a roundabout resulted in a CMF of 0.73 compared to an unsignalized intersection (De Brabander and Vereeck, 2007). In order to observe a positive pedestrian safety impact, roundabouts should have a low design speed. Figure 2-10 shows a roundabout constructed as a traffic calming measure and to improve safety.

**Figure 2-10: Roundabout (Harkey and Zegeer, 2004)**

Right-turn slip lane design is mostly used on large arterial streets with large volume of right-turn traffic. This design gives pedestrians an advantage to only have to worry about the right-turning vehicles first. It reduces conflicts when trying to cross a multi-lane arterial street and shorten the crossing distance. The right-turn slip also slows down motorists and allows drivers to see pedestrians clearly (Harkey and Zegeer, 2004). Figure 2-11 shows an example of a right-turn slip lane.

**Figure 2-11: Right-turn Slip Lane (Harkey and Zegeer, 2004)**

*Traffic Calming*

Speed humps have been known to have a speed reduction impact and make it safer for pedestrians to cross the street. The speed humps not only slow down vehicles but they also increase motorists’ awareness of a pedestrian crossing. A CMF of 0.95 was used for urban and suburban areas (Elvik and Vaa, 2004). Speed humps have to be designed correctly not to increase noise due to truck traffic and not to cause drainage problems. Additionally, special attention must be placed in constructing the speed hump to minimize potential discomfort to motorists. Figure 2-12 shows an example of a speed hump in a residential street.

**Figure 2-12: Speed Hump (Harkey and Zegeer, 2004)**

Another countermeasure that can be adopted is a raised pedestrian sidewalk. This not only reduces speeds of motorists, but also enhances the pedestrian crossing. A CMF of 0.55 can be used in urban areas (Elvik and Vaa, 2004); however, it should not be used in areas with bus routes. Figure 2-13 shows an example of a raised pedestrian crossing.

**Figure 2-13: Raised Pedestrian Crossing (Harkey and Zegeer, 2004)**

### *Traffic Management*

The PEDSAFE Handbook (Harkey and Zegeer, 2004) states that traffic management should be assessed from an area-wide perspective. For traffic management to be successful it should be complemented with traffic calming devices. Figure 2-14 shows an example of a traffic diverter from the PEDSAFE Handbook.

**Figure 2-14: Traffic Diverter (Harkey and Zegeer, 2004)**

### *Signals and Signs*

Traffic control devices such as traffic signals and pedestrian signals can be used to improve pedestrian safety. For example, crosswalk marking and a pedestrian signal together would substantially enhance pedestrian safety. Using traffic signals to create gaps for pedestrians to cross at midblock locations on high-speed multi-lane arterials will also increase pedestrian safety. MUTCD states that pedestrian signals should be installed wherever warranted. Pedestrian signals are important to provide pedestrians with the necessary clearance time to cross the street and to provide an indication of when it is safe to cross.

Pedestrian signals eliminate the conflict between vehicles and pedestrians. Although fixed time signals increase safety, they can decrease the efficiency of the intersection. Traffic signal enhancements such as automatic pedestrian detectors, large signals, and countdown signals are being used in some cities in the U.S. to reduce vehicle-pedestrian conflicts. High intensity Activated crossWalKs (HAWKs) are traffic signals that are used to allow pedestrians to cross safely (Fitzpatrick and Park, 2010). Fitzpatrick and Park (2010) developed a CMF of 0.31 for vehicle-pedestrian crashes in urban areas with HAWK signals. Figures 2-15, 2-16, and 2-17 show an example of HAWK, enhanced signal diagram, and countdown signal, respectively. Reddy et al. (2008) conducted a before-and-after analysis to evaluate the effectiveness of countdown pedestrian signals by comparing pedestrian behavior before and after the installation of countdown signals. The pedestrian behavior measures included the percentage of pedestrians initiating crossing during flashing “Don’t Walk” and steady “Don’t Walk” modes, as well as the percentage of successful crossings. It was found that the pedestrian countdown signals were effective in increasing the percentage of successful crossings and decreasing the percentage of pedestrians who initiated crossing during the flashing “Don’t Walk” mode.


**Figure 2-15: High Intensity Activated Crosswalk (HAWK) (Harkey and Zegeer, 2004)**

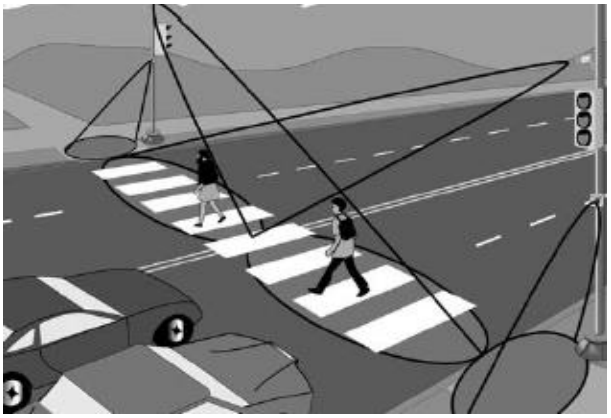


**Figure 2-16: Enhanced Signal Diagram (Harkey and Zegeer, 2004)**


**Figure 2-17: Countdown Signal (Harkey and Zegeer, 2004)**

Charness et al. (2011) conducted a study that evaluated pedestrian signals using human factors approach. They found that pedestrian signals at intersections did not assist drivers in deciding whether or not to yield/stop to pedestrians. Additionally, middle-aged pedestrians were more likely to comply with pedestrian signals compared to younger pedestrians. In another study, Charness et al. (2009) investigated different materials for pedestrian warning signs at intersections. They concluded that there was negligible advantage in using the more expensive micro-prismatic fluorescent sheeting compared to the diamond grade sheeting.

Crashes involving vehicles turning right on red are very common at intersections. Right-turning vehicles often do not yield to pedestrians crossing the intersection. Many drivers do not make a complete stop or simply block the crosswalk path for pedestrians waiting for a gap in the traffic. The placement of a standard NO TURN ON RED sign or an electronic blank out sign could be effective in preventing this behavior (Harkey and Zegeer, 2004). Figure 2-18 shows an example of standard NO TURN ON RED and blank out signs.

(a) Standard NO TURN ON RED Sign


(b) Blank out Sign

**Figure 2-18: Standard and Blank out Signs (Harkey and Zegeer, 2004)**

Red light cameras are an Intelligent Transportation System (ITS) based countermeasure that can be implemented at intersections. Bechtel et al. (2003) conducted a study which showed that although installing cameras has reduced the number of violations for running a red light, it did not reduce the number of crashes. This could be because violations often occurred in a short duration immediately after the signal turned to red.

Illuminated push buttons can also be implemented in areas where pedestrian crossings are frequent. The Light Emitting Diode (LED) light that turns on when the push button is pushed lets the pedestrian know that the device is working. Huang and Zegeer (2001) showed that this measure was ineffective in almost all the areas where it was implemented.

Flashing crossing lights have had a positive impact on pedestrian crashes, with an 80% reduction in pedestrian crash frequencies (Katz, Okitsu & Associates, 2001). These illuminated crosswalks were found to increase the driver braking distance by 17% during daytime and 53% during nighttime (Weinberger, 1997). Findings suggest that installing flashing crossing lights increases the compliance of pedestrian right-of-way and decreases the vehicle-pedestrian conflicts (Huang and Zegeer, 2001). Figure 2-19 gives an example of a flashing pedestrian crossing lights.

**Figure 2-19: Flashing Pedestrian Crossing Lights (McNally, 2012)**

The most recent countermeasure using ITS technology is the animated eye. The animated eye is a pedestrian signal that displays an eye which is supposed to make pedestrians more aware of potential conflicts surrounding them. The "eye" is programmed to look from side to side to prompt pedestrians to look both ways. FDOT (2000) found that the implementation of the animated eye changed the pedestrian's behavior and resulted in a reduction in pedestrian crashes. Similarly, Van Houten and Malenfant (2001) observed changes in motorists' behavior when the animated eye was implemented. Figure 2-20 shows an example of a pedestrian signal with an animated eye.

**Figure 2-20: Pedestrian Signal with Animated Eye (Rodegerdts et al., 2004)**

### *Other Measures*

Adding advanced stop lines, as shown in Figure 2-21, help improve pedestrian safety. Pedestrian visibility will be improved and vehicles will have to stop behind the crosswalk line which will give pedestrians more room to cross (Harkey and Zegeer, 2004). In summary, Table 2-6 gives the most common pedestrian countermeasure and their corresponding CMFs.

**Figure 2-21: Signalized Intersection with Advanced Stop Lines (Harkey and Zegeer, 2004)**

### *2.5.2 Relevant Studies*

Studies that have evaluated pedestrian countermeasures include Cafiso et al. (2011), Vasudevan et al. (2011), Pulugurtha et al. (2012), Chen et al. (2012), Pratt et al. (2012), and Deng et al. (2013). Cafiso et al. (2011) evaluated the safety performance of traffic calming devices such as speed humps that were installed instead of zebra crosswalks in Valencia, Spain. They used the traffic conflict technique as a surrogate safety measure and proposed a pedestrian risk index (PRI), which linked the probabilities of pedestrian crash and pedestrian severity in a single measure. The PRI could reveal a significant improvement in pedestrian safety and was effective in highlighting enhancements in drivers' behavior due to installation of speed humps as an alternative to zebra crosswalks.

Vasudevan et al. (2011) conducted a pilot study to evaluate the effectiveness of pedestrian call buttons, pedestrian countdown signals with animated eyes, and pedestrian activated flashing yellow signals. The treatments were deployed in the Las Vegas metropolitan area in Nevada and were installed at three sites, two intersections and one midblock location. The evaluations were based on field observations of pedestrian and driver behavior before and after the installation of these countermeasures. Several measures of countermeasure effectiveness were used, such as number of pedestrians trapped in the roadway, number of cycles in which call button was pushed, frequency of signal violation, number of pedestrians who looked for vehicles before crossing, number of pedestrians who began to crossing during the WALK phase, number of drivers yielding to pedestrians, and number of drivers making RTOR who came to complete stop. In general, the authors observed that the pedestrian crash countermeasures were successful in enhancing safety and there were safety enhancements in pedestrians' behavior. However, the three countermeasures did not affect drivers' yielding behavior.

### Table 2-6: Common Pedestrian Countermeasures and Corresponding CMFs

| Category | Countermeasure | Crash Type | Crash Severity | CMF | Source |
|---|---|---|---|---|---|
| **Intersection Design** | Convert unsignalized intersection to roundabout | Ped | Fatal/Injury | 0.73 | De Brabander and Vereeck (2009) |
| | Convert intersection to roundabout | Ped | All | 0.11 | Schoon and Van Minnen (1994) |
| **Roadway Design** | Install pedestrian overpass | Ped | Fatal/Injury | 0.10 | Gan et al. (2005) |
| | Install raised median | Ped | All | 0.75 | Gan et al. (2005) |
| | Install raised median (marked crosswalk) | Ped | All | 0.54 | Zegeer and Seiderman (2001) |
| | Install raised median (unmarked crosswalk) | Ped | All | 0.61 | Elvik and Vaa (2004) |
| | Install refuge island | Ped | All | 0.44 | ITE (2004) |
| | Bicycle lanes (veh w/ped from right) | Ped | All | 0.90 | Jensen (2008) |
| | Bicycle lanes (veh w/ped from left) | Ped | All | 1.05 | Jensen (2008) |
| **Signs and Signals** | Permit right-turn on red (New York) | Ped | All | 1.43 | Bahar et al. (2007b) |
| | Permit right-turn on red (New Orleans) | Ped | All | 1.81 | Bahar et al. (2007b) |
| | Permit right-turn on red (Ohio) | Ped | All | 1.57 | Bahar et al. (2007b) |
| | Permit right-turn on red (Wisconsin) | Ped | All | 2.08 | Bahar et al. (2007b) |
| | Prohibit left turn | Ped | All | 0.90 | Gan et al. (2005) |
| | Install pedestrian signals | Ped | All | 0.47 | Gan et al. (2005) |
| | Modify signal phasing | Ped | All | 0.95 | ITE (2004) |
| | Install pedestrian countdown signal heads | Ped | Fatal/Injury | 0.75 | Markowitz et al. (2006) |
| | Add exclusive pedestrian phasing | Ped | All | 0.66 | ITE (2004) |
| | Install HAWK | Ped | All | 0.31 | Fitzpatrick and Park (2010) |
| | Restrict parking near intersection | Ped | All | 0.70 | Gan et al. (2005) |
| **Traffic Calming** | Install speed humps | Ped | All | 0.95 | Elvik and Vaa (2004) |
| | Install raised pedestrian crossing | Ped | All | 0.92 | Elvik and Vaa (2004) |
| | Install raised intersection | Ped | All | 1.05 | Elvik and Vaa (2004) |
| **Pedestrian Facility Design** | Install sidewalks and walkways | Ped | All | 0.25 | Gan et al. (2005) |
| | Install marked crosswalks (minor intersection) | Ped | All | 0.35 | Haleem and Abdel-Aty (2012) |
| | Improve lighting at intersection | Ped | Fatal | 0.22 | Elvik and Vaa (2004) |
| | Improve lighting at intersection | Ped | Injury | 0.58 | Elvik and Vaa (2004) |

On the same metropolitan area in Las Vegas, Nevada, Pulugurtha et al. (2012) evaluated the safety effectiveness of pedestrian infrastructure countermeasures, such as high-visibility crosswalks and pedestrian refuge areas. The authors used field observations of pedestrian and driver behavior before and after the installation of the countermeasures to evaluate the countermeasures. A total of eight sites were evaluated and measures of effectiveness similar to Vasudevan et al. (2011) were used. High-visibility crosswalk was found to improve behavior of both pedestrians and motorists, and was considered one of the most economical treatments. In addition, pedestrian refuge islands showed significant safety improvements in the yielding behavior of both pedestrians and drivers.

Similar to Pulugurtha et al. (2012), Chen et al. (2012) evaluated the safety effectiveness of high-visibility crosswalks in New York City. They further evaluated other pedestrian countermeasures, such as the change in split phase timing and total cycle length increase. They adopted a two-stage design that first identified a comparison group corresponding to each treatment group, then estimated an NB model with the generalized estimating equation (GEE) method to control for confounding factors and within-subject correlation. They found that the change in split phase timing was more effective in reducing pedestrian crashes than the high visibility crosswalks. Furthermore, increasing total cycle length was considered effective near senior centers, where there was a higher percentage of elderly pedestrians.

Pratt et al. (2012) evaluated the safety effectiveness of four pedestrian treatments at six signalized intersection approaches in Texas. These treatments were adding a leading protected left-turn phase, implementing split phasing, implementing pedestrian recalls, and increasing the WALK interval duration. They collected video recordings of about 4,300 pedestrians crossing the path of a left-turning vehicle, of which 100 conflicts between pedestrians and left-turning vehicles were observed during the 24 hours of recording. A before-and-after comparison of observed conflict revealed that there was an overall reduction in conflicts; however, the safety benefit of increasing the WALK interval duration was questionable. Therefore, the authors recommended this treatment to be installed at sites with high pedestrian volumes.

Using traffic microscopic simulation, Deng et al. (2013) evaluated the safety and mobility of four pedestrian treatments at midblock crossings, pedestrian actuated (PA), pedestrian light controlled (PELICAN), HAWK, and pedestrian user-friendly intelligent (PUFFIN). The authors used the VISSIM (Verkehr In Städten - SIMulationsmodell) and SSAM (Surrogate Safety Assessment Model) simulation packages and found that pedestrian signal violations during the clearance interval reduced pedestrian delay, but on the other hand resulted in a rapid increase in pedestrian-vehicle conflicts, especially for the HAWK-type crosswalk. In addition, they found that PA led to high delay of both pedestrians and vehicles, but less conflicts. PELICAN was found beneficial for vehicular traffic by reducing vehicle delay; however, unbeneficial for pedestrian traffic since pedestrian delay was always high. HAWK and PUFFIN were found better than PA and PELICAN for balancing both safety and mobility for all road users. HAWK had an acceptable safety performance at “low” pedestrian volumes, but more conflicts were observed when pedestrian volumes turned to “middle” and “high”. Furthermore, PUFFIN had a better safety performance than HAWK when pedestrian volumes were classified as “middle” and “high”.

FDOT has been involved in multiple research projects sponsored by the Federal Highway Administration (FHWA) that investigated the safety of pedestrian countermeasures. Examples are the studies by FHWA (2002 and 2008). The FHWA (2002) study recommended conducting surveys of pedestrians before introducing pedestrian countermeasures. As part of the study, many ITS countermeasures were proposed, such as pedestrian signals, no right-turn on red signs, and LED transponders for blind pedestrians. The FHWA (2008) study evaluated several countermeasures, e.g., pedestrian push buttons, midblock traffic signals, elimination of permissive left turns at signalized intersections, and reduction of minimum green time at midblock crosswalks controlled by traffic signals. It was found that inexpensive pedestrian safety engineering measures could produce a significant reduction in crashes if accompanied by public education and enforcement programs that focus on pedestrian safety.

Hagen (2005) conducted a study to identify pertinent information on ITS applications related to pedestrian safety. It was found that the use of countdown displays and in-pavement lighting were very well received by the public. Compared to the flashing hands, the countdown displays were found to be easier for pedestrians to understand. In-pavement lighting was found to reduce vehicular speeds in the crossing area, making it much safer for the pedestrian crossing the roadway.

### 2.6 Pedestrian Safety Programs

An important approach to improve pedestrian safety is involving citizens themselves in the safety management process. As such, many communities have sponsored programs to enhance pedestrian safety. For example, FHWA sponsored two programs: "How to Develop a Pedestrian Safety Action Plan" (Zegeer et al., 2009) and "Pedestrian Safety Strategic Plan: Recommendations for Research and Product Development" (Zegeer et al., 2010). Zegeer et al. (2010) set a 15-year strategic pedestrian plan by developing dissemination activities and innovation strategies. Examples of the dissemination activities were event marketing, in-person and web-based training, and software development, whereas some of the recommended innovative strategies included convening interactive webinars and developing a video-share website. Other programs include the Community Pedestrian Safety Engagement Workshops in California (Babka et al., 2011), the evaluation of a comprehensive pedestrian safety program in the City of Detroit (Savolainen et al., 2011), and the identified barriers in pedestrian safety programs in large central cities (Shin et al., 2011). Turner (2000) evaluated the yielding behavior of motorists to pedestrians in crosswalks in Tampa, Florida. It was concluded that 60% of motorists at signalized intersections have successfully yielded to pedestrians in crosswalks. On the other hand, only 3% of motorists at unsignalized intersections yielded to pedestrians.

Zegeer et al. (2009) outlined a roadmap for developing a pedestrian safety action plan. The following seven steps were identified for a successful safety action plan:

1. Define objectives: A clear objective should be identified at the beginning of the plan, such as specific types of pedestrian crashes to be reduced (e.g., walk-to-school) and the target percent of reduction (e.g., 20% severe injury reduction).

2. Identify high crash locations: A list of areas with high concentrations of pedestrian crashes has to be identified, e.g., at signalized intersections, unsignalized intersections, and midblocks.

3. Select countermeasures: After identifying the list of high-crash locations in the second step, more investigation of these locations is required to identify high frequencies of pedestrian crashes. This would help devise the appropriate countermeasures. Examples are designing refuge islands for high pedestrian midblock crashes and adding "NO TURN ON RED" sign at signalized intersections with high pedestrian crashes involving right-turning vehicles.

| | | |
|---|---|---|
| 4. | Prioritize countermeasures: | After selecting a list of countermeasures, the list has to be prioritized based on a pre-specified benefit-to-cost (B/C) ratio or a net present value (NPV). For example, if a B/C ratio of 2 is desired, then only the countermeasures with an estimated B/C ratio $\geq 2$ will be included. |
| 5. | Implement strategy: | This is a crucial step of the safety action plan involving all the stakeholders. Stakeholders could include citizens, public agencies, law enforcement agencies, and the private sector. In this step, stakeholders will be informed about the intended countermeasures to be implemented and will be educated on how to improve pedestrian safety. The education could be via focus groups or workshops. |
| 6. | Reinforce commitment: | In this step, awards for innovative ideas or projects that provide safer pedestrian conditions could be provided. Furthermore, the Department of Transportation could collaborate with the Department of Health on conducting education programs such as focus group studies. |
| 7. | Evaluate results: | The final step is to evaluate the plan through before-and-after safety studies or public surveys. A final conclusion on whether or not the anticipated safety benefit was achieved should be determined. |

Babka et al. (2011) discussed the strategies used to engage residents and local professionals in the Community Pedestrian Safety Engagement Workshops in California. These workshops were designed to engage and educate residents to ensure they have the knowledge they needed to improve pedestrian safety in their neighborhood. Several case studies were highlighted that focused on a variety of engagement techniques, such as outreach and working with groups, working with youth volunteers, Video Voice, and peer learning and sharing. The workshops resulted in enhancing the residents' understanding about potential directions to improve pedestrian safety in communities in California.

Savolainen et al. (2011) documented a series of activities performed in the City of Detroit, Michigan, that aimed at improving pedestrian safety following Detroit's designation as a Pedestrian Safety Focus City by FHWA in 2004. The activities included creation of a Pedestrian Safety Action Team, development of a Pedestrian Safety Action Plan, and implementation of a series of education, enforcement, and engineering countermeasures. The interventions included development of new pavement marking guidelines for pedestrian crosswalks, phased installation of countdown pedestrian signals, implementation of a pedestrian training curriculum for children in grades K-8, and implementation of enforcement programs. The interventions resulted in reducing pedestrian crashes and injuries in Detroit. In addition, the target crashes specific to each countermeasure were reduced.

Shin et al. (2011) highlighted institutional settings, interagency collaboration, high risk population groups, and institutional barriers in 13 large central cities in the U.S. (Chicago, Illinois; Columbus, Ohio; Denver, Colorado; Indianapolis, Indiana; Los Angeles, California; Milwaukee, Wisconsin; New York City, New York; Philadelphia, Pennsylvania; Phoenix, Arizona; San Francisco, California; San Jose, California; Seattle, Washington; and Washington, District of Columbia). Large cities were defined as cities with over a population of 500,000. To achieve the study objectives, planning officials from the 13 cities were interviewed. The authors found several barriers that needed to be addressed to improve pedestrian safety. These barriers included competing priorities among agencies, lack of resources, and data gaps. The study concluded that pedestrian countermeasures alone might not be sufficient for enhancing pedestrian safety. The authors also found that participation and formalized policy integration among multiple parties were required to create an effective pedestrian safety strategy.

## 2.7 Summary

This chapter reviewed studies on pedestrian safety, including risk factors affecting frequency and severity of pedestrian crashes, pedestrian exposure measures, pedestrian-vehicle conflict analysis techniques, pedestrian hot spot identification methods, pedestrian crash countermeasures and their evaluation, and pedestrian safety programs. The review of literature has shown that there has been abundant effort in analyzing pedestrian crashes and identifying pedestrian risk factors. Several studies have concluded that higher pedestrian crashes were observed in commercial areas, in dense road networks, and among uneducated populations. On the other hand, residential areas were associated with relatively fewer pedestrian crashes.

The majority of studies that identified significant predictors of pedestrian injury severity have observed an increased likelihood of a fatality risk among elderly pedestrians (individuals older than 55 years of age) and young pedestrians (individuals younger than 15 years of age). A higher risk of fatality was also observed for pedestrians who crossed the road compared to those who walked along the road. Furthermore, pedestrian crashes involving trucks, buses, and tractor trailers had a higher fatality risk compared to cars.

Existing methods for identifying pedestrian hot spots are broadly classified into three categories: density, clustering, and exposure estimation. In the density method, simple and Kernel methods are the two commonly used crash density calculation methods. A circular search area is used to calculate density in each of the two methods and the variation in the search radius could lead to inconsistent pedestrian high crash clusters. However, among these two methods, the Kernel method is regarded as a better approach since it generates a well fitted smooth curve. The second method relies on the clustering technique and it has been successfully applied in safety analysis to identify groups of crashes. Clusters are defined using a predetermined search radius, e.g., 250 ft or 500 ft, and crashes are excluded if they are fewer than the minimum threshold. The most common types of clustering techniques are the K-means and latent class methods.

The third method of hot spot identification is exposure estimation. This includes statistical regression models, sketch plan and network models, micro-simulation models, and computer vision techniques. These models have been used by researchers to estimate pedestrian exposure, e.g., pedestrian volumes, due to the difficulty and high cost associated with collecting pedestrian volumes, especially in urban areas. Common measures of pedestrian exposure are population density, number of pedestrians, number of lanes crossed, time spent walking, number and frequency of walk trips, etc. Several regression models have used population density and time spent walking as surrogate measures to estimate pedestrian exposure. However, these measures are flawed because they ignore the amount of walking people do. The other models to estimate pedestrian volumes, such as micro-simulation and computer vision techniques, are not extensively used as regression models. Specifically, the micro-simulation approach is relatively complex and requires extensive data; thus, not preferred.

There have been studies that applied the pedestrian-vehicular conflict analysis as an alternative to historical crash data analysis due to the rarity of observed crashes. These studies were found to be successful in observing pedestrian-vehicle conflicts, e.g., conflicts that occurred between right-turning or left-turning vehicles and crossing pedestrians. These studies could also successfully identify the safety performance of the locations of interest.

Several pedestrian countermeasures have been proposed in the literature to improve pedestrian safety. These include but are not limited to, converting intersections to roundabouts, installing raised medians and refuge islands, adding on-street parking, installing pedestrian signals, modifying signal phasing, installing pedestrian countdown signals, improving lighting at intersections, and illuminating crosswalks. The majority of these countermeasures were found to have been effective in reducing pedestrian crashes and fatalities.

In addition to pedestrian crash investigations, some studies and communities have proposed pedestrian safety action plans that involved citizens and stakeholders in the safety management process to enhance pedestrian safety through education and enforcement programs. The two programs sponsored by FHWA, “How to Develop a Pedestrian Safety Action Plan” and “Pedestrian Safety Strategic Plan: Recommendations for Research and Product Development” are two good examples of these programs. During the evaluation phase of these programs, a reduction in pedestrian crashes and injuries were observed as a result of the proposed safety plan.

# CHAPTER 3
# DATA PREPARATION

This chapter describes the data collection and preparation efforts undertaken to analyze pedestrian crashes that occurred on state roads in Florida. It discusses the police reports' review process used to identify underlying pedestrian crash patterns and crash causes. It also describes an effort undertaken to collect data on the presence and type of pedestrian facilities, including crosswalks and pedestrian signals, at signalized intersections.

## 3.1 Pedestrian Crash Data

Three years of crash data from 2008-2010 was used to identify pedestrian crashes on state roads. In total, 7,630 crashes were identified from the Crash Analysis Reporting (CAR) system as vehicle-pedestrian crashes. Police reports of these 7,630 crashes were downloaded from the FDOT Hummingbird System and were reviewed in detail to collect information that is not typically available in the crash summary records. As such, for each vehicle-pedestrian crash, the following information was collected:

- Birth year of the pedestrian.

- Injury severity of the pedestrian.
  - Fatal injury
  - Incapacitating injury
  - Non-incapacitating injury
  - Possible injury
  - None

- Who was at fault?
  - Pedestrian
  - Driver
  - Both
  - Not sure

- Where did the crash happen?
  - Signalized location
  - Non-signalized location
  - Not sure

- Are there any types of pedestrian signals in the vicinity?
  - Yes, which type? ___________________________
  - No
  - Not sure

- Is there a raised median/a pedestrian refuge area in the vicinity?
  - Yes
  - No

        - Not sure

- Is there a crosswalk in the vicinity?
    - Yes
      If yes, what type of crosswalk?
        - Solid
        - Standard
        - Continental
        - Dashed
        - Zebra
        - Ladder
        - Other
    - No
    - Not sure

- If a crosswalk is present, is the pedestrian walking in the designated area?
    - Yes
    - No
    - Not sure

- Is the pedestrian crossing the street or walking along the roadway when hit?
    - Crossing the street
    - Walking along the roadway
    - Not sure

All the above information was collected by reviewing descriptions and illustrative sketches in the police reports and the aerial images of crash location. Particularly, the at-fault road user was identified from the descriptions. For example, Figure 3-1 gives the description of a pedestrian crash (crash ID: 105745350) where the driver was cited for careless driving, and therefore, was considered to be at fault.

> On 10/06/2010, I, Ofc Cooper was dispatched to the intersection of 17th Street and Orange Avenue in reference to a vehicle vs pedestrian car crash. Upon arrival I made contact both the driver, Elease Siplin, and the pedestrian, Mariann Goggin.
>
> Mrs. Goggin had sustained a bump on her head from the crash and was transported to Lawnwood Emergency Room by St. Lucie County Fire Rescue. Mrs. Siplin stated that she was at the traffic light at N. 17th Street and Orange Avenue facing Southbound when she turned left to head Eastbound on Orange Avenue. Mrs. Siplin stated that she did not see Mrs. Goggin, who was crossing Orange Avenue at the crosswalk, and that Mrs. Goggin had fell into her car.
>
> I made contact with Mrs. Goggin at the emergency room and asked what had happened. Mrs. Goggin stated she was headed to S. 17th Street and Delaware Avenue. Mrs. Goggin stated that as she was crossing Orange Avenue Mrs. Siplin had sideswiped her with the vehicle causing her to fall to the ground.
>
> Mrs. Siplin was issued a UTC (2852-WAV) for careless driving due to the fact she struck a pedestrian while driving.

**Figure 3-1: Description in Police Report (Crash ID: 105745350)**

As another example, in Crash ID: 90438654, the pedestrian was found to be at fault as the pedestrian stepped into the middle of the road in front of traffic. Figure 3-2 gives the description of this crash.

On 09/08/09 at 1600 hours I reported to the 1300 block of Orange Avenue for a traffic crash with a pedestrian.

The vehicle was traveling east on Orange Avenue when the pedestrian just walked out into the middle of the street. The driver then crashed with the pedestrian. The pedestrian was then taken to Lawnwood ER. I was informed from a nurse at the ER that the pedestrian had been involved in a similar accident where he had walked out into traffic a few years back. Nothing further to add at this time.

**Figure 3-2: Description in Police Report (Crash ID: 90438654)**

An existing in-house web-based tool was adapted for this study to facilitate the process of reviewing the police reports. The tool has the capability to display the police report of each crash and the aerial photo of the crash location, as shown in Figure 3-3. The tool helps to quickly navigate from one police report to the next by either clicking the “Next” and “Previous” buttons, or by typing the crash number in the Search box. The tool also has the capability to query crashes based on roadway ID and mileposts.

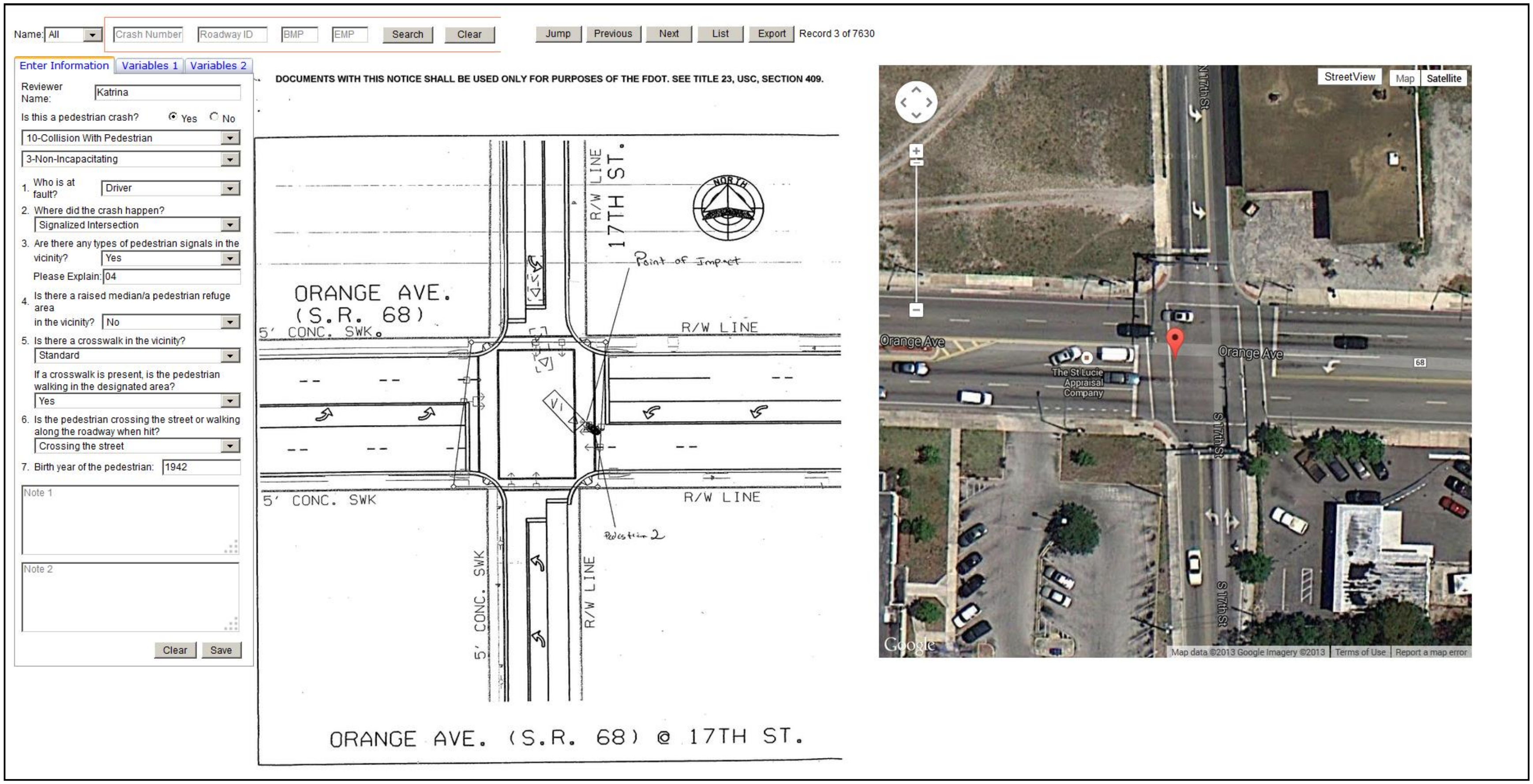



**Figure 3-3: A Web-based Tool Customized to Review Police Reports**

## 3.2 Intersection Data

Information on the presence and type of crosswalks at signalized intersections is currently unavailable. Therefore, a major effort of this study was to manually collect this information. First, Signalized Intersections GIS layer was used to identify all signalized intersections in the state of Florida. Since crash data are available only for crashes that occurred on state roads, only the locations where two or more state roads intersect were included in the analysis. The Signalized Intersections layer and the State Roads layer were overlaid in ArcGIS 10.0 to identify locations where state roads intersecting state roads. A total of 8,374 signalized intersections were identified using this approach. An in-house web-based data collection tool, Visual Roadway Inventory Collection System (VRICS), was customized to collect data at these 8,374 signalized intersections. The VRICS application is a web-based system developed to facilitate the process of collecting roadway data using Google Street View. Figure 3-4 shows a screen capture of the main interface of the system. The system reads a linear-referenced roadway segment/intersection, converts its coordinates to the Google Maps projection, and then displays the location using Google Street View.

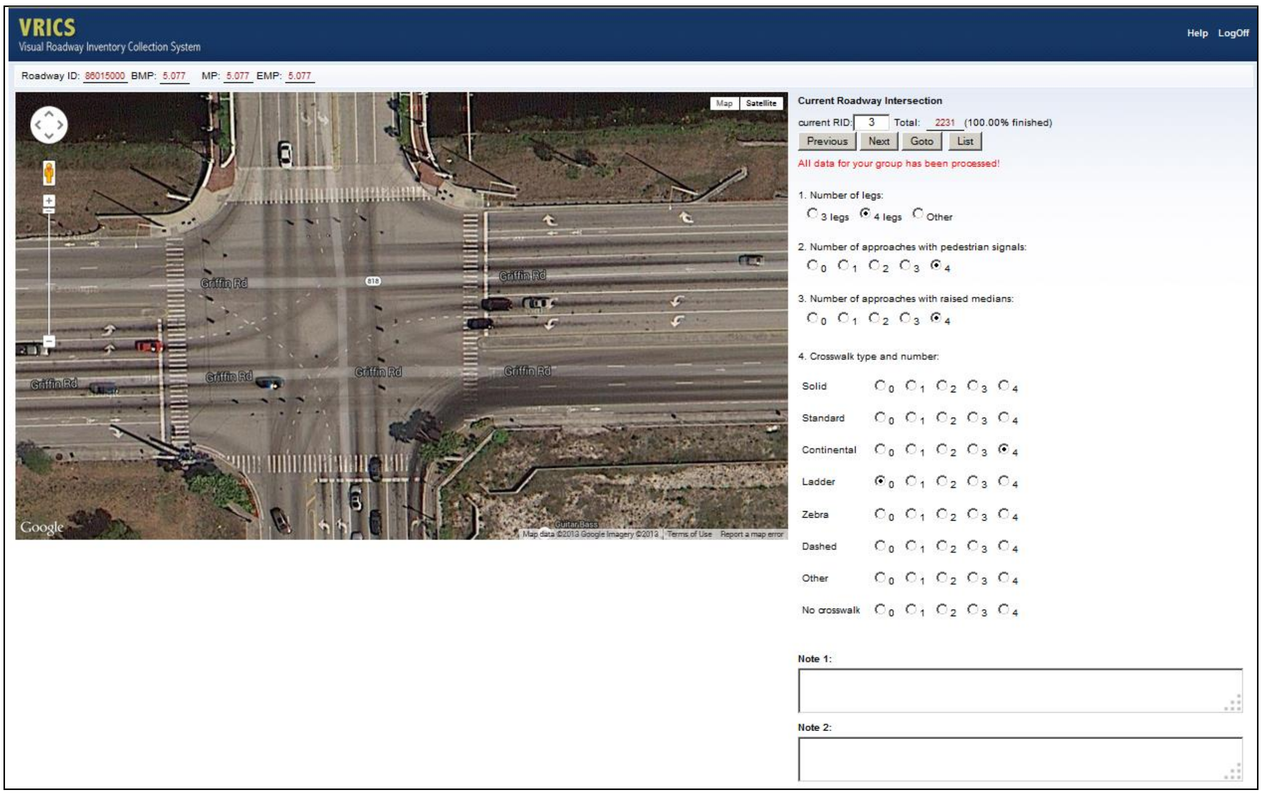



**Figure 3-4: A Web-based VRICS Tool Customized to Collect Intersection Data**

For each signalized intersection, the following data were collected:

- total number of legs,
- number of legs with pedestrian signals,
- number of legs with pedestrian refuge areas (i.e., raised medians),

- number of legs with each of the following types of crosswalks:
  - Solid
  - Standard
  - Continental
  - Ladder
  - Zebra
  - Dashed
  - Other
  - None

### 3.3 Summary

This chapter described the data collection and preparation efforts undertaken to analyze pedestrian crashes that occurred on state roads in Florida. Police reports of a total of 7,630 pedestrian crashes that occurred during 2008-2010 were reviewed to identify pedestrian crash patterns and contributing causes. Information on the presence and type of pedestrian facilities, including crosswalks and pedestrian signals, at 8,374 signalized intersections on state roads was collected.

# CHAPTER 4
# STATEWIDE CRASH PATTERNS AND CAUSES

This chapter focuses on identifying the overall statewide pedestrian crash patterns. In this chapter, general trends in crash data and roadway characteristics data based on 6,434 pedestrian crashes that occurred on state roads are identified. It also discusses the pedestrian high crash corridors identified using Kernel Density function in ArcGIS 10.0. General trends by crash characteristics are identified based on:

- crash severity,
- population,
- number of walk trips,
- lighting condition, and
- at-fault road user.

Likewise, general trends by roadway characteristics are identified based on:

- functional classification,
- area type,
- speed limit,
- crash location, and
- crosswalk type.

## 4.1 Crash Characteristics

### *4.1.1 Crash Severity*

Table 4-1 gives annual pedestrian crash frequency by crash severity for years 2008-2010. Overall, 10.3% of all pedestrian crashes resulted in fatalities and 81.5% of total pedestrian crashes resulted in an injury to the pedestrians. As expected, only a very small percentage of crashes (4.3%) resulted in no injury to the pedestrians. The crash severity of 248 pedestrian crashes (3.9%) was unknown as a discrepancy exists between the coded crash severity in the CAR system and that in the actual police report, or when the code is missing. There was 5.6% reduction in total crashes from 2008 to 2009, but the total crashes between 2009 and 2010 were essentially the same.

**Table 4-1: Annual Pedestrian Crash Statistics by Severity**

| Crash Severity | 2008 | 2009 | 2010 | Total |
|---|---|---|---|---|
| Fatal | 231 (10.4%) | 236 (11.2%) | 196 (9.3%) | **663** (10.3%) |
| Injury | 1822 (81.7%) | 1699 (80.8%) | 1723 (82.0%) | **5244** (81.5%) |
| No Injury | 91 (4.1%) | 85 (4.0%) | 103 (4.9%) | **279** (4.3%) |
| Unknown Severity | 85 (3.8%) | 83 (3.9%) | 80 (3.8%) | **248** (3.9%) |
| **Total** | **2,229** (100.0%) | **2,103** (100.0%) | **2,102** (100.0%) | **6,434** (100.0%) |

### *4.1.2 Population and Number of Walk Trips*

Since pedestrian exposure data (e.g., pedestrian volumes) are not readily available and is expensive to collect, researchers often rely on surrogate measures to estimate pedestrian exposure, such as population or population density (Chu, 2003), number of lanes crossed (Keall, 1995), time spent walking (Chu, 2003), number of pedestrian trips (SafeTrec, 2010), and aggregate distance traveled by all pedestrians in a specific area of interest (SafeTrec, 2010).

In this study, pedestrian crashes in each age group were normalized by population (i.e., crashes per million) and number of walk trips (i.e., crashes per million walk trips). The 2009 travel survey data extracted from the National Household Travel Survey (NHTS) database were used to estimate population and number of walk trips by age group (FHWA, 2009).

Table 4-2 gives the summary statistics of pedestrian crashes by age group, population, and crash severity. Among the different age groups, young people between 16 and 25 years of age experienced 183 crashes per year per million. Pedestrians in the age group 46-55 years experienced the highest fatal crash rate of 22 fatal crashes per year per million. The results from this table have to be interpreted with caution because the statistics are based on the population and it might not reflect the actual pedestrian exposure. For example, older population (i.e., over 65 years of age) experienced fewer crashes per million than the total pedestrian crash frequency per million for all the age groups combined.

**Table 4-2: Statistics by Age, Population, and Crash Severity**

| Age Group (years) | Fatal Crashes (2008-2010) | Injury Crashes (2008-2010) | Total Crashes (2008-2010)[1] | Population (in Millions) | Crashes per Year per Million Population | Fatal Crashes per Year per Million Population |
|---|---|---|---|---|---|---|
| 0-5 | 4 | 32 | 42 | 0.22 | 63.7 | 6.0 |
| 6-15 | 10 | 356 | 397 | 2.26 | 58.7 | 1.3 |
| 16-25 | 62 | 1,045 | 1,195 | 2.18 | 183.0 | 9.7 |
| 26-35 | 88 | 688 | 848 | 1.89 | 149.7 | 15.7 |
| 36-45 | 103 | 775 | 957 | 2.94 | 108.3 | 11.7 |
| 46-55 | 167 | 1,013 | 1,256 | 2.53 | 165.7 | 22.0 |
| 56-65 | 97 | 646 | 804 | 2.22 | 120.7 | 14.7 |
| 66-75 | 60 | 316 | 403 | 1.60 | 83.7 | 12.3 |
| >75 | 42 | 237 | 303 | 1.35 | 74.7 | 10.3 |
| Unknown | 30 | 136 | 229 | -- | -- | -- |
| **Total** | **663** | **5,244** | **6,434** | **17.19** | **124.7** | **13.0** |

[1] Total crashes include crashes with no injury and unknown injury.

Table 4-3 gives the summary statistics of pedestrian crashes by age group, number of walk trips, and crash severity. Again, among the different age groups, young people between 16 and 25 years of age experienced 0.79 crashes per year per million walk trips. In terms of fatal crashes, pedestrians in the age group 46-55 years experienced the highest fatal crash rate of 0.082 fatal crashes per year per million walk trips.

**Table 4-3: Statistics by Age, Number of Walk Trips, and Crash Severity**

| Age Group (years) | Fatal Crashes (2008-2010) | Injury Crashes (2008-2010) | Total Crashes (2008-2010)[1] | Total Walk Trips in a Year (in Millions) | Crashes per year per Million Walk Trips | Fatal Crashes per year per Million Walk Trips |
|---|---|---|---|---|---|---|
| 0-5 | 4 | 32 | 42 | 48 | 0.29 | 0.028 |
| 6-15 | 10 | 356 | 397 | 574 | 0.23 | 0.006 |
| 16-25 | 62 | 1,045 | 1,195 | 505 | 0.79 | 0.041 |
| 26-35 | 88 | 688 | 848 | 448 | 0.63 | 0.065 |
| 36-45 | 103 | 775 | 957 | 710 | 0.45 | 0.048 |
| 46-55 | 167 | 1,013 | 1,256 | 676 | 0.62 | 0.082 |
| 56-65 | 97 | 646 | 804 | 513 | 0.52 | 0.063 |
| 66-75 | 60 | 316 | 403 | 345 | 0.39 | 0.058 |
| >75 | 42 | 237 | 303 | 225 | 0.45 | 0.062 |
| Unknown | 30 | 136 | 229 | -- | -- | -- |
| **Total** | **663** | **5,244** | **6,434** | **4,043** | **0.53** | **0.055** |

[1] Total crashes include crashes with no injury and unknown injury.

### *4.1.3 Lighting*

Lighting condition can affect pedestrian safety obviously because pedestrians are less visible to drivers at night. Table 4-4 gives the pedestrian crash statistics by lighting condition. Although a majority of crashes (49.0%) occurred during daylight, they resulted in a lower percentage of fatal crashes. Crashes that occurred at night at locations with no additional lighting resulted in a disproportionately high percentage of fatal crashes. The *Z*-test was used to compare the proportion of fatal crashes that occurred during daytime and nighttime. The following equations were used to calculate the Z-test statistic:

$$\text{Z test statistic}= \frac{(\hat{P}_1-\hat{P}_2)}{\sqrt{(\hat{P}\left(1-\hat{P}\right) \times (\frac{1}{N_1}+\frac{1}{N_2})}}; \hat{P}= \frac{x_1+x_2}{N_1+N_2} \tag{4-1}$$

where,

$\hat{P}_1$ and $\hat{P}_2$ = proportion of fatal crashes that occurred during daytime and nighttime, respectively;

$N_1$ and $N_2$ = total number of crashes that occurred during daytime and nighttime, respectively; and

$x_1$ and $x_2$ = number of fatal crashes that occurred during daytime and nighttime, respectively.

At a 5% significance level, there was sufficient evidence to suggest that there was a significant difference in the proportion of fatal crashes that occurred during daytime and nighttime.

**Table 4-4: Statistics by Lighting Condition**

| Lighting Condition | Fatal Crashes | Injury Crashes | Total Crashes[1] |
|---|---|---|---|
| Daylight | 100 (3.2%) | 2,755 (87.4%) | 3,152 (100.0%) |
| Dusk | 10 (6.5%) | 127 (82.5%) | 154 (100.0%) |
| Dawn | 7 (8.4%) | 73 (88.0%) | 83 (100.0%) |
| Dark with Street Light | 333 (14.8%) | 1,757 (78.2%) | 2,247 (100.0%) |
| Dark with No Street Light | 213 (27.9%) | 501 (65.7%) | 763 (100.0%) |
| Unknown | 0 (0.0%) | 31 (88.6%) | 35 (100.0%) |
| **Total** | **663** (10.3%) | **5,244** (81.5%) | **6,434** (100.0%) |

[1] Total crashes include crashes with no injury and unknown injury.

### *4.1.4 At-fault Road User*

For each pedestrian crash, the at-fault road user (i.e., driver, or pedestrian, or both) was identified based on the descriptions in the police reports. Table 4-5 provides these statistics. The at-fault road user cannot be determined for about 20% of the crashes. Drivers were found to be at fault in 28.2% of the crashes while pedestrians were at fault in over fifty percent (i.e., 53.0%) of the crashes. From Table 4-5, it can be inferred that crashes where pedestrian was found to be at fault were more severe compared to the crashes where the driver was at fault. At a 5% significance level, there was sufficient evidence to suggest that the proportion of fatal crashes was significantly greater when pedestrian was at fault compared to the proportion when the driver was at fault.

**Table 4-5: Statistics by At-fault Road User**

| At-fault Road User | Fatal Crashes | Injury Crashes | Total Crashes[1] |
|---|---|---|---|
| Both Driver and Pedestrian | 9 (13.6%) | 53 (80.3%) | 66 (100.0%) |
| Driver | 56 (3.1%) | 1,572 (86.7%) | 1,814 (100.0%) |
| Pedestrian | 431 (12.6%) | 2,739 (80.3%) | 3,411 (100.0%) |
| Not Sure | 167 (14.6%) | 880 (77.0%) | 1,143 (100.0%) |
| **Total** | **663** (10.3%) | **5,244** (81.5%) | **6,434** (100.0%) |

[1] Total crashes include crashes with no injury and unknown injury.

When the driver was found to be at fault, the following were the most frequent contributing causes:

- careless driving,
- failed to yield right-of-way, and
- disregarded traffic signal or other traffic control.

When the pedestrian was found to be at fault, the most frequent contributing causes were:

- failed to yield right-of-way,
- alcohol and/or drugs – under influence, and
- disregarded traffic signal or other traffic control.

Irrespective of who was at fault, failing to yield right-of-way and disregarding traffic control devices were the two major contributing causes for pedestrian crashes. Further, a high percentage of pedestrians were found to be under the influence of alcohol and/or drugs. Similar observations were indicated in Table 4-6, which provides the summary of crash statistics by contributing cause as recorded in the police reports. As shown in the table, failure to yield right-of-way, careless driving, disregarding traffic control, driving under influence, were the most frequent contributing causes.

**Table 4-6: Statistics by Contributing Cause**

| Contributing Cause | Fatal Crashes | Injury Crashes | Total Crashes[1] |
|---|---|---|---|
| No Improper Driving | 107 (9.6%) | 893 (80.2%) | 1,114 (100.0%) |
| Failure to Yield Right-of-way | 185 (11.1%) | 1,390 (83.1%) | 1,673 (100.0%) |
| Careless Driving | 20 (3.1%) | 561 (86.4%) | 649 (100.0%) |
| Disregarded Traffic Control | 18 (7.3%) | 210 (85.4%) | 246 (100.0%) |
| Driving Under Influence | 115 (50.9%) | 101 (44.7%) | 226 (100.0%) |
| Improper Driving | 2 (1.9%) | 93 (86.1%) | 108 (100.0%) |
| All Other Contributing Causes[2] | 15 (13.6%) | 89 (80.9%) | 110 (100.0%) |
| Coded as "Others"[3] | 201 (8.7%) | 1,907 (82.6%) | 2,308 (100.0%) |
| **Total** | **663 (10.3%)** | **5,244 (81.5%)** | **6,434 (100.0%)** |

1 Total crashes include crashes with no injury and unknown injury.
2 All other contributing causes include: followed too closely, exceeded safe speed limit, exceeded stated speed limit, failed to maintain vehicle/equipment, drove left of center, obstructed traffic, improper load, drove wrong-side, fled police, vehicle modified, and distracted driving.
3 Coded as "Others" in the police report.

## 4.2 Roadway Characteristics

### *4.2.1 Functional Classification*

Table 4-7 provides pedestrian crash statistics by functional classification of the road network and crash severity. A total of 65 crashes occurred on limited access facilities, and were considered to be rare and random events. As expected, a majority of the crashes occurred in urban areas, and primarily on urban principal arterials. Table 4-8 gives the crash statistics by speed limit and crash severity. A majority of the crashes (91.5%) occurred at locations with speed limits lower than 55 mph. Crashes along the locations with higher speed limits resulted in a greater proportion of fatal crashes. This is expected as higher vehicular speeds result in severe crashes.

### *4.2.2 Area Type*

Table 4-9 gives the statistics by area type and crash severity. The table also provides the percentage of fatal crashes that occurred within each area type. Although the majority of pedestrian crashes occurred in urban areas and especially in metropolitan areas, fatal crashes were disproportionately high in rural areas. Moreover, the proportion of fatal crashes decreased with urbanization. For example, metropolitan areas, although experienced 70.9% of total pedestrian crashes (4,565 crashes out of 6,434 crashes), only 8.6% of them were fatal. On the other hand, rural areas experienced 3.4% of total pedestrian crashes (222 crashes out of 6,434 crashes); however, 22.5% of these crashes resulted in fatalities.

**Table 4-7: Statistics by Functional Class**

| Functional Classification | Fatal Crashes | Injury Crashes | Total Crashes[1] | Total Miles | Crashes per year per 100 miles |
|---|---|---|---|---|---|
| Rural Interstate | 2 | 2 | 6 | 748 | 0.27 |
| Rural Principal Arterial | 32 | 110 | 157 | 2,865 | 1.83 |
| Rural Minor Arterial | 13 | 32 | 47 | 2,458 | 0.64 |
| Rural Major Collector | 3 | 4 | 8 | 4,286 | 0.06 |
| Urban Interstate | 5 | 12 | 18 | 756 | 0.79 |
| Urban Principal Arterial- Other Freeways | 6 | 27 | 41 | 572 | 2.39 |
| Urban Principal Arterial | 483 | 3426 | 4,236 | 3,680 | 38.37 |
| Urban Minor Arterial | 112 | 1539 | 1,810 | 4,214 | 14.32 |
| Urban Collector | 6 | 61 | 73 | 7,222 | 0.34 |
| Urban Local | 0 | 3 | 4 | 1,488 | 0.09 |
| Unknown | 1 | 28 | 34 | -- | -- |
| **Total** | **663** | **5244** | **6,434** | **28,289** | **7.58** |

[1] Total crashes include crashes with no injury and unknown injury.

**Table 4-8: Statistics by Speed Limit**

| Speed Limit (mph) | Total Miles | Crashes /100 miles | Fatal Crashes | Injury Crashes | Total Crashes[1] |
|---|---|---|---|---|---|
| <40 | 3,968 | 49.02 | 102 (5.2%) | 1658 (85.2%) | 1,945 (100.0%) |
| 40-50 | 6,937 | 56.84 | 441 (11.2%) | 3206 (81.3%) | 3,943 (100.0%) |
| ≥ 55 | 9,407 | 5.00 | 116 (24.7%) | 318 (67.7%) | 470 (100.0%) |
| Unknown | 31,193 | 0.24 | 4 (5.3%) | 62 (81.6%) | 76 (100.0%) |
| **Total** | 51,505 | 12.49 | **663** (10.3%) | 5244 (81.5%) | **6,434** (100.0%) |

[1] Total crashes include crashes with no injury and unknown injury.

**Table 4-9: Statistics by Area Type**

| Area Type | Fatal Crashes | Injury Crashes | Total Crashes[1] | Total Miles | Crashes per Year per 100 Miles | Fatal Crashes per Year per 100 Miles |
|---|---|---|---|---|---|---|
| Rural | 50 (22.5%) | 152 (68.5%) | 222 (100.0%) | 18,556 | 0.40 | 0.09 |
| Small Urban | 35 (14.8%) | 182 (76.8%) | 237 (100.0%) | 1,665 | 4.74 | 0.70 |
| Small Urbanized | 103 (14.9%) | 554 (80.2%) | 691 (100.0%) | 3,764 | 6.12 | 0.91 |
| Large Urbanized | 81 (11.3%) | 583 (81.2%) | 718 (100.0%) | 3,457 | 6.92 | 0.78 |
| Metropolitan | 394 (8.6%) | 3,772 (82.6%) | 4,565 (100.0%) | 9,804 | 15.52 | 1.34 |
| Unknown | 0 (0.0%) | 1 (100.0%) | 1 (100.0%) | -- | -- | -- |
| **Total** | **663** (10.3%) | **5,244** (81.5%) | **6,434** (100.0%) | **51,505** | **4.16** | **0.43** |

[1] Total crashes include crashes with no injury and unknown injury.

Figure 4-1 gives the pedestrian crash statistics by area type and population. The 2009 travel survey data extracted from the NHTS database was used to estimate population in urban and rural areas (FHWA, 2009). A majority of the population lives in urban areas, and these areas experienced a significantly high number of pedestrian crashes.

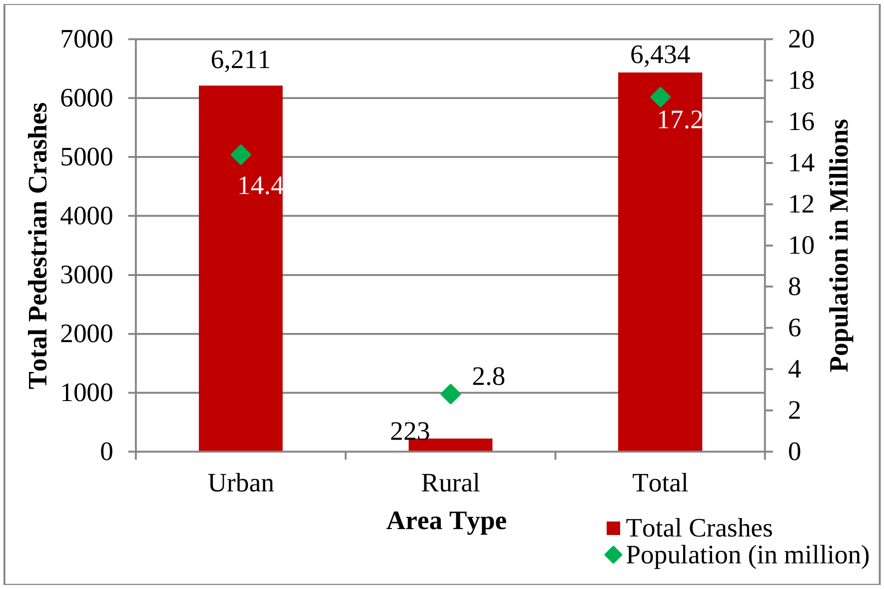



**Figure 4-1: Pedestrian Crash Statistics by Area Type and Population**

### *4.2.3 Crash Location*

Table 4-10 gives pedestrian crash statistics by crash location and crash severity. Crash locations were broadly divided into two categories: signalized intersections and all other locations. Locations outside the vicinity of signalized intersections experienced a greater number of pedestrian crashes. These locations also experienced high pedestrian fatalities compared to signalized intersections. From Table 4-10, it can be inferred that 13.9% of total crashes that occurred at locations with no signals (i.e., unsignalized intersections and midblocks) resulted in fatalities, while 6.8% of total crashes that occurred at signalized intersections were fatal crashes. This is expected as vehicles travel at higher speeds at locations with no signalized intersections compared to the vehicles at signalized intersections. Also, drivers are more likely to expect pedestrians at signalized intersections.

**Table 4-10: Statistics by Crash Location**

| Crash Location | Fatal Crashes | Injury Crashes | Total Crashes[1] |
|---|---|---|---|
| Signalized intersection | 205 (6.8%) | 2,569 (84.7%) | 3,034 (100.0%) |
| At all other locations | 408 (13.9%) | 2,313 (78.5%) | 2,945 (100.0%) |
| Not sure | 50 (11.0%) | 362 (79.6%) | 455 (100.0%) |
| **Total** | **663** (10.3%) | **5,244** (81.5%) | **6,434** (100.0%) |

[1] Total crashes include crashes with no injury and unknown injury.

### *4.2.4 Crosswalk Type*

Crosswalks are often installed to improve accessibility, mobility, and safety of pedestrians crossing the street. Figure 2-5 in Chapter 2 shows the most frequently used types of crosswalks. This section focuses on the safety performance of crosswalks at 7,054 three- and four-legged signalized intersections. These 7,054 intersections, constituting 27,082 legs, were found to experience a total of 2,591 pedestrian crashes during 2008-2010. Of these, 20,789 (76.8%) legs have some type of crosswalk, and the remaining 6,293 legs have no crosswalk.

Table 4-11 gives the pedestrian crash statistics at signalized intersections by crosswalk type and crash severity. Of all the types of crosswalks, standard type was the most frequent, followed by continental, solid with special surface such as brick, and ladder. In terms of total pedestrian crashes per year per 1,000 legs, solid crosswalk with special surface experienced the highest number of crashes, followed by ladder, continental, and standard. On the other hand, solid crosswalk with special surface experienced a relatively low 1.46 fatal crashes per year per 1,000 legs.

**Table 4-11: Statistics by Crosswalk Type**

| Crosswalk Type | Fatal Crashes | Injury Crashes | Total Crashes[1] | Total Number of Legs | Crashes per Year per 1,000 Legs | Fatal Crashes per Year per 1,000 Legs |
|---|---|---|---|---|---|---|
| Standard | 75 | 1,004 | 1,185 | 11,270 | 35.05 | 2.22 |
| Continental | 60 | 616 | 728 | 6,211 | 39.07 | 3.22 |
| Ladder | 7 | 173 | 195 | 1,474 | 44.10 | 1.58 |
| Solid with Special Surface (e.g., brick) | 7 | 239 | 270 | 1,679 | 51.63 | 1.46 |
| Solid with White Paint | 1 | 10 | 13 | 148 | -- | -- |
| Dashed | 0 | 5 | 5 | 5 | -- | -- |
| Zebra | 0 | 2 | 2 | 2 | -- | -- |
| Unknown | 2 | 19 | 23 | -- | -- | -- |
| None | 16 | 140 | 170 | 6,293 | 9.00 | 0.85 |
| **Total** | **168** | **2,208** | **2,591** | **27,082** | **31.89** | **2.07** |

[1] Total crashes include crashes with no injury and unknown injury.

The 6,293 legs with no crosswalk experienced 170 pedestrian crashes (i.e., 9 crashes per year per 1,000 legs), and this statistic was lower than the performance of any type of crosswalk. This could be because major signalized intersections with even a small level of pedestrian activity have crosswalks. In other words, major signalized intersections with no crosswalks might only cater to a minimum level of pedestrian activity.

The *Z*-test was used to compare the proportion of fatal crashes that occurred at different crosswalk types at signalized intersections. Table 4-12 summarizes these results. At a 5% significance level, there was sufficient evidence to suggest that there was no significant difference in the proportion of fatal crashes that occurred at standard vs. continental, standard vs. ladder, and standard vs. solid crosswalk types, respectively.

**Table 4-12: Significance Tests for Pedestrian Crashes that Occurred at Different Crosswalks**

| Comparison Between Crosswalk Types | | Percent of Fatal Crashes That Occurred at Crosswalk Type A | Percent of Fatal Crashes That Occurred at Crosswalk Type B | *Z*-Test Statistic | Is Proportion of Fatal Crashes at Crosswalk Type A Significantly Different from those that Occurred at Crosswalk Type B? |
|---|---|---|---|---|---|
| Type A | Type B | | | | |
| Standard | Continental | 6.33% | 8.24% | 1.59 | No |
| Standard | Ladder | 6.33% | 3.59% | 1.50 | No |
| Standard | Solid with Special Surface | 6.33% | 2.83% | 2.40 | No |

Note: Statistics are based on pedestrian crashes at signalized intersections only.

Unlike the standard crosswalk which has two parallel lines, continental and ladder types, also known as special emphasis crosswalks, provide increased crosswalk visibility, especially at nighttime when visibility is generally low. Table 4-13 provides the pedestrian crash statistics at signalized intersections by crosswalk type and lighting condition to determine whether or not continental and ladder types have increased safety benefit at nighttime as a result of potentially increased visibility. Overall, 41.4% of pedestrian crashes occurred during nighttime. The proportions of nighttime crashes were similar at standard, continental, and ladder types. Additionally, Z-test statistic was used to compare the performance of standard type with continental and ladder types of crosswalks at signalized intersections during nighttime. At a 5% significance level, there was no evidence to suggest that there was a significant difference in the performance of special emphasis crosswalks (i.e., continental and ladder types) and standard type in terms of nighttime pedestrian crashes. In other words, crash data did not suggest that continental and ladder types had a better safety performance than standard type during nighttime.

**Table 4-13: Statistics by Crosswalk Type and Lighting Condition**

| Crosswalk Type | Lighting Condition | | | | | | % of Nighttime Crashes |
|---|---|---|---|---|---|---|---|
| | Day | Dusk | Dawn | Night | Unknown | Total | |
| Standard | 657 | 30 | 17 | 474 | 7 | 1,185 | 40.0% |
| Continental | 391 | 15 | 9 | 307 | 6 | 728 | 42.2% |
| Ladder | 112 | 5 | 2 | 75 | 1 | 195 | 38.5% |
| Solid with Special Surface | 158 | 10 | 7 | 93 | 2 | 270 | 34.4% |
| Solid with White Paint | 4 | 0 | 0 | 9 | 0 | 13 | -- |
| Dashed | 3 | 0 | 0 | 2 | 0 | 5 | -- |
| Zebra | 1 | 0 | 0 | 1 | 0 | 2 | -- |
| Unknown | 7 | 1 | 0 | 15 | 0 | 23 | -- |
| No Crosswalk | 69 | 4 | 0 | 97 | 0 | 170 | 57.1% |
| **Total** | **1,402** | **65** | **35** | **1,073** | **16** | **2,591** | **41.4%** |

Note: Statistics are based on pedestrian crashes at signalized intersections only.

### 4.3 Statewide Pedestrian Crash Concentrations

As discussed in Section 2.4.1, the density methods attempt to identify high concentrations of pedestrian crashes. The degree of concentration was measured based on density, calculated as pedestrian crash frequency per unit area (e.g., square miles) or unit length (e.g., mile). In this section, statewide pedestrian crash concentrations were identified using pedestrian crash density maps generated in ArcGIS 10.0. Figures 4-2 and 4-3 provide the density maps for the entire state of Florida using three-year pedestrian crash data. From Figure 4-2, it can be inferred that a majority of pedestrian crashes occurred along the coastline and in major urban areas including Jacksonville, Miami, Orlando, Tallahassee, and Tampa. Figure 4-3 gives the pedestrian crash density calculated using Kernel Density Function. Again, from the figure, it is clear that Miami and Broward counties had the highest pedestrian crash density, followed by Pinellas and Hillsborough, and Orange and Seminole counties, respectively.

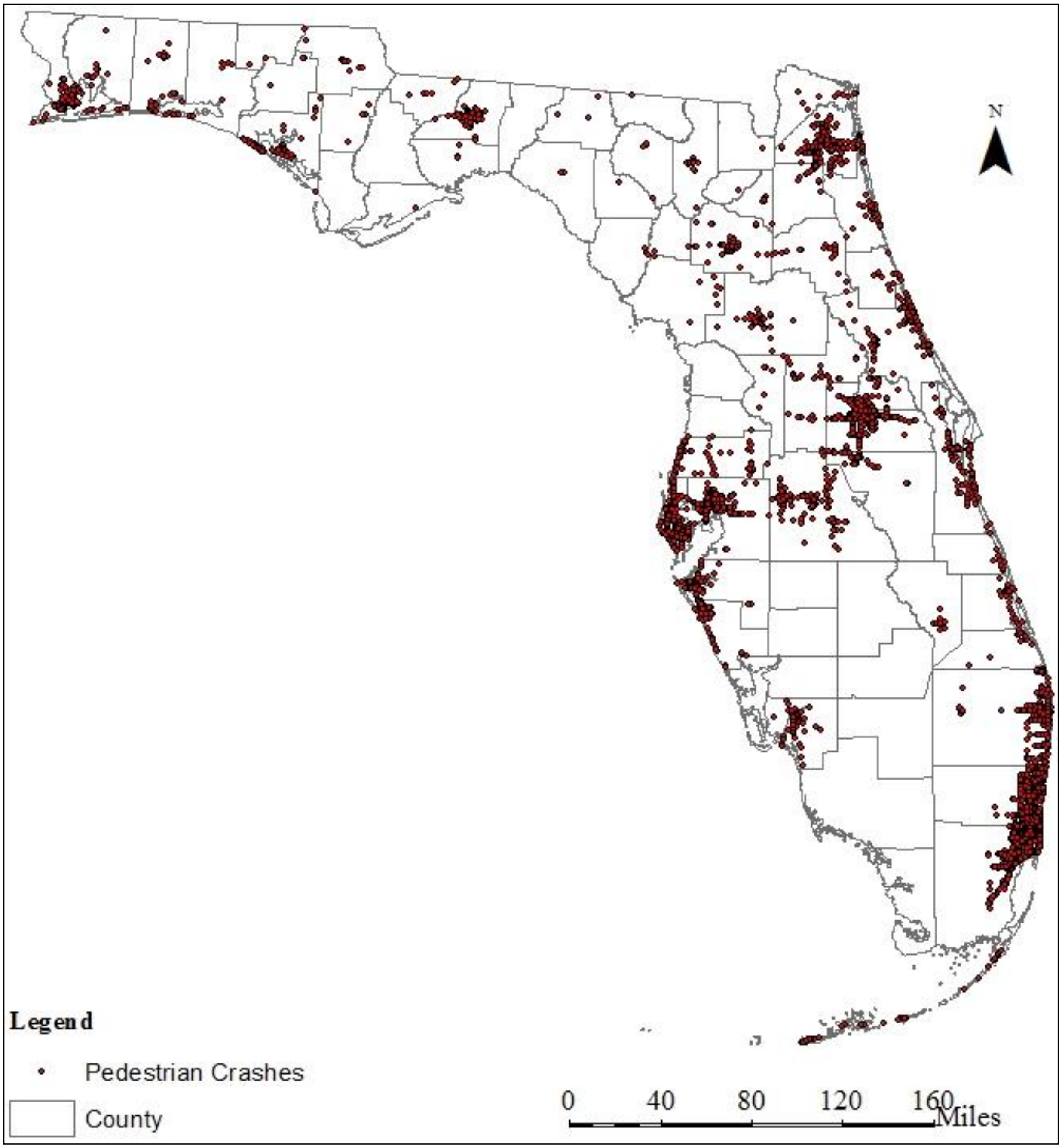



**Figure 4-2: Spatial Distribution of Pedestrian Crashes**

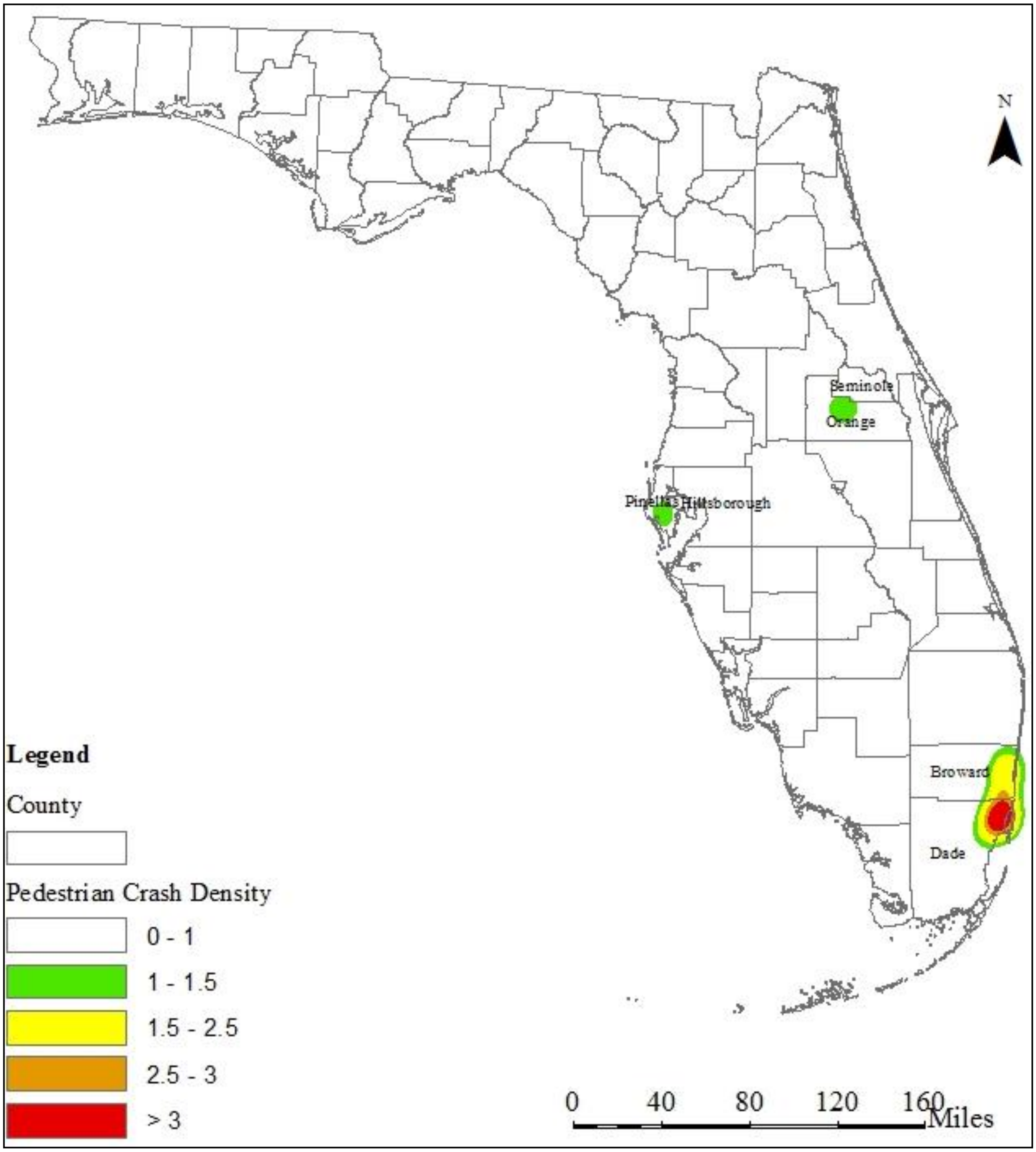



**Figure 4-3: Pedestrian Crash Density**

### 4.4 Summary

This chapter focused on the statewide pedestrian crash causes and patterns. The analysis was based on 6,434 pedestrian crashes that occurred on state roads during 2008-2010. In the three-year analysis period, a total of 663 pedestrians (i.e., 10.3%) were killed on state roads. The statistics show that there were 124.7 total crashes and 13 fatal crashes per million population annually. Of the different age groups, the young pedestrian group (16-25 years) experienced highest number of pedestrian crashes per million population. Pedestrians in the same age group (16-25 years) experienced the highest pedestrian crash rate of 0.79 crashes per million walk trips per year. The annual fatal crash rate (fatal crashes per million walk trips) was found to be slightly higher for the older age groups.

Although a majority of crashes occurred during daytime, they resulted in a lower proportion of fatalities. At 5% significance level, the proportion of fatal crashes that occurred during nighttime were significantly greater compared to the proportion of fatal crashes in the daytime.

Of the 6,434 total pedestrian crashes, pedestrian was found to be at fault in 53.0% of the crashes and the driver was at fault in 28.2% of the crashes. Irrespective of who was at fault, failing to yield right-of-way and disregarding traffic control devices were the two major contributing causes for pedestrian crashes. Moreover, crashes where pedestrian was at fault were found to be more severe compared to the crashes where the driver was at fault, and this difference was found to be statistically significant.

A majority of the crashes occurred primarily on urban principal arterials. Although the majority of pedestrian crashes occurred in urban areas and especially in metropolitan areas, fatal crashes were disproportionately high in rural areas. Moreover, the proportion of fatal crashes decreased with urbanization. Crashes along the locations with higher speed limits resulted in a greater proportion of fatal crashes.

A majority of signalized intersections on state roads were found to have crosswalks on at least one of its legs. Of all the types of crosswalks, standard type was the most frequent, followed by continental, solid with special surface such as brick, and ladder. Although the solid crosswalk with brick fill experienced the highest number of pedestrian crashes per 1,000 legs, it experienced a relatively low 1.46 fatal crashes per year per 1,000 legs. However, at 5% significance level, there was no significant difference in the proportion of fatal crashes at signalized intersections across the following crosswalk types: standard, continental, ladder, and solid with special surface. Furthermore, crash data did not indicate that continental and ladder types had a better safety performance than standard crosswalks at signalized intersections during nighttime.

# CHAPTER 5
# STATEWIDE CRASH SEVERITY CONTRIBUTING FACTORS

This chapter identifies the significant factors that affect pedestrian crash injury severity at signalized and non-signalized locations using the mixed logit model. It first provides an overview of the data preparation and the exploratory variables used in developing the models. The random forest technique (used to rank the importance of independent variables) and the mixed logit model (used to determine the significant factors affecting injury severity) are discussed. The analysis results along with detailed discussion are then provided.

## 5.1 Data Preparation

As mentioned in Section 3.1, a total of 7,630 pedestrian crashes occurred on state roads in Florida during 2008-2010. About 35% of these crashes had to be excluded from this analysis due to insufficient information in the police reports. Finally, a total of 4,923 pedestrian crashes were included in the analysis. Of these crashes, 2,360 occurred at signalized locations, 2,282 occurred at non-signalized locations, and the locations of the remaining 281 pedestrian crashes were unknown. In addition to the data available in the crash summary records and the data collected from reviewing the police reports (as discussed in Section 3.1), additional information on roadway characteristics (e.g., road surface condition and land use type) and traffic (e.g., average annual daily traffic (AADT), speed limit, and percentage of trucks) at the crash location was retrieved from 2011 FDOT's Roadway Characteristics Inventory (RCI) database.

The analysis in this chapter focuses on analyzing pedestrian injury severity at each of signalized and non-signalized locations separately to identify the significant factors affecting injury severity at each location to help in the appropriate selection of countermeasures. Note that the non-signalized locations include unsignalized intersections and midblocks. For modeling pedestrian injury severity, two types of severity were considered: non-severe injury (i.e., no injury, possible injury, and non-incapacitating injury) and severe injury (i.e., incapacitating and fatal injuries).

Tables 5-1 and 5-2 provide a description of the dependent and independent variables and their summary statistics at signalized and non-signalized locations, respectively. Two new variables, at-fault road user and pedestrian maneuver type, were identified by reviewing the police reports and were included in the analysis. Additional geometric and traffic variables such as presence of pedestrian refuge areas, presence and type of crosswalk, presence of pedestrian signals, and type of vehicle involved in the crash were also explored in this chapter. The analysis also included environmental and temporal variables such as lighting condition, weather, and crash time (i.e., on- and off-peak crash hours).

The correlations among the explored independent variables at both signalized and non-signalized locations were examined. Tables 5-3 and 5-4 show the correlation matrices of the 15 explored independent variables at signalized and non-signalized locations, respectively. From both tables, it can be seen that all correlation coefficients were close to zero. Hence, all the variables were considered independent from each other and no meaningful correlations were found to exist.

**Table 5-1: Summary Statistics of Explored Variables at Signalized Locations**

| Category | Variable Name | Summary Statistics[1] |
|---|---|---|
| | | *Dependent Variable* |
| Response | Pedestrian Injury Severity | *F* (Non-Severe Injury) = 1,555 (*65.89%*);<br>*F* (Severe Injury) = 805 (*34.11%*) |
| | | *Continuous Independent Variables* |
| Traffic | Ln (AADT) | *M* = 10.42, *SD* = 0.49 |
| | Speed Limit | *M* = 40.35, *SD* = 6.07 |
| | Percentage of Trucks | *M* = 4.56, *SD* = 2.58 |
| | | *Categorical Independent Variables* |
| Environmental | Lighting Condition | *F* (Daylight) = 1,289 (*54.62%*); *F* (Dusk) = 56 (*2.37%*);<br>*F* (Dawn) = 29 (*1.22%*);<br>*F* (Dark Street Light) = 839 (*35.55%*);<br>*F* (Dark No Street Light) = 134 (*5.67%*);<br>*F* (Unknown) = 13 (*0.55%*) |
| | Weather Condition | *F* (Clear) = 1,821 (*77.16%*); *F* (Cloudy) = 373 (*15.81%*);<br>*F* (Rainy) = 152 (*6.44%*); *F* (Foggy) = 2 (*0.08%*);<br>*F* (Other) = 12 (*0.51%*) |
| Traffic | Presence of Pedestrian Signals? | *F* (Yes) = 2,166 (*91.78%*); *F* (No) = 160 (*6.78%*);<br>*F* (Not Sure) = 34 (*1.44%*) |
| | Hour of Crash | *F* (Morning Peak) = 384 (*16.27%*);<br>*F* (Morning Off-Peak) = 558 (*23.64%*);<br>*F* (Afternoon Peak) = 609 (*25.81%*);<br>*F* (Night/Dawn Off-Peak) = 809 (*34.28%*) |
| Geometric | Road Surface Condition | *F* (Dry) = 2,102 (*89.07%*);<br>*F* (Wet/Slippery) = 243 (*10.29%*); *F* (Other) = 15 (*0.64%*) |
| | Land Use Type | *F* (Urban/Suburban) = 2,345 (*99.36%*);<br>*F* (Rural) = 15 (*0.64%*) |
| | Presence of Ped. Refuge Area? | *F* (Yes) = 1,420 (*60.17%*); *F* (No) = 914 (*38.73%*);<br>*F* (Not Sure) = 26 (*1.10%*) |
| | Crosswalk Type | *F* (No Crosswalk) = 166 (*7.03%*); *F* (Solid) = 7 (*0.29%*);<br>*F* (Standard) = 1,042 (*44.15%*); *F* (Ladder) = 215 (*9.11%*);<br>*F* (Continental) = 641 (*27.16%*); *F* (Zebra) = 8 (*0.34%*);<br>*F* (Dashed) = 4 (*0.17%*); *F* (Other) = 277 (*11.74%*) |
| Pedestrian/Driver -Related | Pedestrian Age | *F* (Very Young, Age ≤ 19 years) = 303 (*12.84%*);<br>*F* (Young, 20 years ≤ Age ≤ 24 years) = 225 (*9.53%*);<br>*F* (Middle, 25 years ≤ Age ≤ 64 years) = 1,491 (*63.18%*);<br>*F* (Old, 65 years ≤ Age ≤ 79 years) = 266 (*11.27%*);<br>*F* (Very Old, Age ≥ 80 years) = 75 (*3.18%*) |
| | Who is At-fault? | *F* (Ped.) = 1,372 (*58.14%*); *F* (Driver) = 605 (*25.64%*);<br>*F* (Both) = 29 (*1.23%*); *F* (Not Sure) = 354 (*15%*) |
| | Pedestrian Maneuver Before Crash | *F* (Crossing Street) = 2,175 (*92.16%*);<br>*F* (Walking along Roadway) = 48 (*2.03%*);<br>*F* (Not Sure) = 137 (*5.81%*) |
| Vehicle-Related | Driver's Vehicle Type | *F* (Passenger Cars) = 802 (*33.98%*);<br>*F* (Vans) = 89 (*3.77%*);<br>*F* (SUVs and Pick-ups) = 194 (*8.22%*);<br>*F* (Medium Trucks) = 7 (*0.29%*);<br>*F* (Heavy Trucks) = 6 (*0.25%*);<br>*F* (Buses) = 12 (*0.51%*); *F* (Bicycles) = 1 (*0.04%*);<br>*F* (Motorcycles) = 6 (*0.25%*); *F* (Other) = 1,243 (*52.67%*) |

[1] *F* = Crash frequency (*italicized %* in parentheses), *M* = Mean, and *SD* = Standard deviation.

## Table 5-2: Summary Statistics of Explored Variables at Non-Signalized Locations

| Category | Variable Name | Summary Statistics[1] |
|---|---|---|
| | | *Dependent Variable* |
| Response | Pedestrian Injury Severity | *F* (Non-Severe Injury) = 1,241 (*54.38%*);<br>*F* (Severe Injury) = 1,041 (*45.62%*) |
| | | *Continuous Independent Variables* |
| Traffic | Ln (AADT) on Major Road | *M* = 10.24, *SD* = 0.62 |
| | Speed Limit on Major Road | *M* = 42.31, *SD* = 7.54 |
| | % of Trucks on Major Road | *M* = 5.21, *SD* = 3.48 |
| | | *Categorical Independent Variables* |
| Environmental | Lighting Condition | *F* (Daylight) = 1,013 (*44.39%*); *F* (Dusk) = 57 (*2.49%*);<br>*F* (Dawn) = 29 (*1.27%*);<br>*F* (Dark Street Light) = 767 (*33.61%*);<br>*F* (Dark No Street Light) = 404 (*17.70%*);<br>*F* (Unknown) = 12 (*0.52%*) |
| | Weather Condition | *F* (Clear) = 1,779 (*77.96%*); *F* (Cloudy) = 360 (*15.77%*);<br>*F* (Rainy) = 121 (*5.30%*); *F* (Foggy) = 5 (*0.22%*);<br>*F* (Other) = 17 (*0.74%*) |
| Traffic | Presence of Pedestrian Signals? | *F* (Yes) = 128 (*5.61%*); *F* (No) = 2,079 (*91.10%*);<br>*F* (Not Sure) = 75 (*3.29%*) |
| | Hour of Crash | *F* (Morning Peak) = 262 (*11.48%*);<br>*F* (Morning Off-Peak) = 494 (*21.65%*);<br>*F* (Afternoon Peak) = 572 (*25.07%*);<br>*F* (Night/Dawn Off-Peak) = 953 (*41.76%*);<br>*F* (Unknown) = 1 (*0.04%*) |
| Geometric | Road Surface Condition | *F* (Dry) = 2,035 (*89.17%*);<br>*F* (Wet/Slippery) = 233 (*10.21%*); *F* (Other) = 14 (*0.61%*) |
| | Land Use Type | *F* (Urban/Suburban) = 2,162 (*94.74%*);<br>*F* (Rural) = 120 (*5.25%*) |
| | Presence of Ped. Refuge Area? | *F* (Yes) = 1,098 (*48.11%*); *F* (No) = 1,120 (*49.08%*);<br>*F* (Not Sure) = 64 (*2.80%*) |
| | Crosswalk Type | *F* (No Crosswalk) = 1,902 (*83.35%*); *F* (Solid) = 2 (*0.08%*);<br>*F* (Standard) = 146 (*6.40%*); *F* (Ladder) = 22 (*0.96%*);<br>*F* (Continental) = 64 (*2.80%*); *F* (Zebra) = 1 (*0.04%*);<br>*F* (Other) = 145 (*6.35%*) |
| Pedestrian/Driver -Related | Pedestrian Age | *F* (Very Young, Age ≤ 19 years) = 234 (*10.25%*);<br>*F* (Young, 20 years ≤ Age ≤ 24 years) = 228 (*9.99%*);<br>*F* (Middle, 25 years ≤ Age ≤ 64 years) = 1,517 (*66.48%*);<br>*F* (Old, 65 years ≤ Age ≤ 79 years) = 212 (*9.29%*);<br>*F* (Very Old, Age ≥ 80 years) = 91 (*3.98%*) |
| | Who is At-fault? | *F* (Ped.) = 1,323 (*57.98%*); *F* (Driver) = 573 (*25.11%*);<br>*F* (Both) = 30 (*1.31%*); *F* (Not Sure) = 356 (*15.60%*) |
| | Pedestrian Maneuver Before Crash | *F* (Crossing Street) = 1,821 (*79.79%*);<br>*F* (Walking along Roadway) = 206 (*9.03%*);<br>*F* (Not Sure) = 255 (*11.17%*) |
| Vehicle-Related | Driver's Vehicle Type | *F* (Passenger Cars) = 662 (*29%*);<br>*F* (Vans) = 78 (*3.42%*);<br>*F* (SUVs and Pick-Ups) = 234 (*10.25%*);<br>*F* (Medium Trucks) = 13 (*0.57%*);<br>*F* (Heavy Trucks) = 7 (*0.31%*); *F* (RVs) = 1 (*0.04%*);<br>*F* (Buses) = 7 (*0.31%*); *F* (Motorcycles) = 16 (*0.70%*);<br>*F* (Other) = 1,264 (*55.39%*) |

[1] *F* = Crash frequency (*italicized %* in parentheses), *M* = Mean, and *SD* = Standard deviation.

### Table 5-3: Correlation Matrix of Explored Variables at Signalized Locations

| | Var. 1* | Var. 2 | Var. 3 | Var. 4 | Var. 5 | Var. 6 | Var. 7 | Var. 8 | Var. 9 | Var. 10 | Var. 11 | Var. 12 | Var. 13 | Var. 14 | Var. 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Var. 1** | 1 | -0.15 | 0.45 | -0.09 | -0.04 | -0.42 | -0.08 | -0.04 | 0.01 | -0.02 | 0.00 | 0.00 | 0.07 | 0.15 | -0.01 |
| **Var. 2** | | 1 | -0.03 | 0.08 | 0.02 | 0.04 | 0.09 | 0.06 | 0.04 | 0.02 | 0.03 | 0.02 | 0.03 | -0.07 | -0.03 |
| **Var. 3** | | | 1 | -0.12 | 0.11 | -0.43 | -0.06 | 0.00 | -0.01 | -0.02 | 0.02 | 0.01 | 0.14 | -0.03 | 0.02 |
| **Var. 4** | | | | 1 | -0.05 | 0.11 | -0.04 | 0.13 | 0.04 | 0.01 | -0.03 | -0.04 | -0.25 | -0.02 | -0.02 |
| **Var. 5** | | | | | 1 | 0.08 | 0.30 | 0.04 | 0.00 | 0.00 | -0.02 | -0.01 | 0.07 | -0.07 | -0.03 |
| **Var. 6** | | | | | | 1 | 0.05 | 0.03 | 0.00 | 0.04 | 0.00 | 0.00 | -0.12 | -0.06 | 0.00 |
| **Var. 7** | | | | | | | 1 | 0.04 | -0.03 | 0.02 | 0.00 | -0.01 | 0.02 | -0.02 | -0.01 |
| **Var. 8** | | | | | | | | 1 | 0.02 | 0.00 | 0.00 | -0.01 | -0.08 | -0.02 | -0.03 |
| **Var. 9** | | | | | | | | | 1 | -0.01 | -0.01 | -0.04 | -0.04 | 0.04 | -0.03 |
| **Var. 10** | | | | | | | | | | 1 | 0.39 | 0.19 | 0.06 | -0.01 | 0.00 |
| **Var. 11** | | | | | | | | | | | 1 | 0.43 | -0.04 | 0.01 | -0.02 |
| **Var. 12** | | | | | | | | | | | | 1 | 0.02 | 0.01 | 0.00 |
| **Var. 13** | | | | | | | | | | | | | 1 | -0.01 | -0.01 |
| **Var. 14** | | | | | | | | | | | | | | 1 | -0.01 |
| **Var. 15** | | | | | | | | | | | | | | | 1 |

*Var. 1 = Ln (AADT); Var. 2 = Percent of Trucks; Var. 3 = Speed Limit;
Var. 4 = Who is At-fault?; Var. 5 = Presence of Ped. Signals; Var. 6 = Presence of Pedestrian Refuge;
Var. 7 = Crosswalk Type; Var. 8 = Pedestrian Maneuver; Var. 9 = Hour of Crash;
Var. 10 = Lighting Condition; Var. 11= Weather Condition; Var. 12 = Road Surface Condition;
Var. 13 = Vehicle Type; Var. 14 = Land Use Type; Var. 15 = Pedestrian Age.

### Table 5-4: Correlation Matrix of Explored Variables at Non-Signalized Locations

| | Var. 1* | Var. 2 | Var. 3 | Var. 4 | Var. 5 | Var. 6 | Var. 7 | Var. 8 | Var. 9 | Var. 10 | Var. 11 | Var. 12 | Var. 13 | Var. 14 | Var. 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Var. 1** | 1 | -0.32 | 0.06 | -0.06 | 0.07 | -0.26 | -0.02 | -0.15 | -0.02 | -0.02 | -0.01 | -0.01 | 0.00 | 0.45 | -0.09 |
| **Var. 2** | | 1 | 0.23 | 0.02 | 0.05 | 0.03 | 0.01 | 0.12 | 0.03 | 0.05 | 0.04 | 0.05 | 0.06 | -0.40 | 0.02 |
| **Var. 3** | | | 1 | -0.06 | 0.12 | -0.32 | 0.14 | 0.08 | 0.01 | 0.05 | -0.03 | -0.01 | 0.18 | -0.34 | -0.03 |
| **Var. 4** | | | | 1 | 0.04 | 0.11 | -0.11 | 0.19 | 0.00 | -0.01 | 0.01 | 0.02 | -0.20 | -0.02 | -0.03 |
| **Var. 5** | | | | | 1 | 0.10 | 0.29 | 0.02 | 0.02 | -0.02 | 0.01 | 0.02 | 0.00 | -0.02 | -0.03 |
| **Var. 6** | | | | | | 1 | -0.08 | 0.08 | -0.01 | -0.05 | 0.00 | -0.02 | -0.20 | -0.04 | 0.05 |
| **Var. 7** | | | | | | | 1 | 0.06 | -0.01 | -0.02 | 0.00 | 0.01 | 0.13 | -0.04 | -0.02 |
| **Var. 8** | | | | | | | | 1 | -0.04 | 0.02 | 0.05 | 0.04 | -0.05 | -0.12 | 0.00 |
| **Var. 9** | | | | | | | | | 1 | -0.01 | 0.02 | -0.04 | -0.02 | 0.00 | 0.00 |
| **Var. 10** | | | | | | | | | | 1 | 0.27 | 0.15 | 0.08 | -0.02 | -0.04 |
| **Var. 11** | | | | | | | | | | | 1 | 0.34 | 0.02 | 0.02 | -0.03 |
| **Var. 12** | | | | | | | | | | | | 1 | 0.02 | -0.01 | -0.02 |
| **Var. 13** | | | | | | | | | | | | | 1 | -0.04 | -0.08 |
| **Var. 14** | | | | | | | | | | | | | | 1 | -0.04 |
| **Var. 15** | | | | | | | | | | | | | | | 1 |

*Var. 1 = Ln (AADT); Var. 2 = Percent of Trucks; Var. 3 = Speed Limit;
Var. 4 = Who is At-fault?; Var. 5 = Presence of Ped. Signals; Var. 6 = Presence of Pedestrian Refuge;
Var. 7 = Crosswalk Type; Var. 8 = Pedestrian Maneuver; Var. 9 = Hour of Crash;
Var. 10 = Lighting Condition; Var. 11= Weather Condition; Var. 12 = Road Surface Condition;
Var. 13 = Vehicle Type; Var. 14 = Land Use Type; Var. 15 = Pedestrian Age.

## 5.2 Methodology

### *5.2.1 Random Forest Technique*

As documented in previous research (e.g., Moore et al., 2011; Haleem and Gan, 2013), a major issue while fitting the mixed logit model is to determine random parameters. The random forest technique is adopted in the analysis for screening the severity predictors before fitting the mixed logit model. In this technique, a number of trees are grown by randomly selecting some observations from the original dataset with replacement, then searching over a randomly selected subset of variables at each split till the variable importance is ranked (Haleem et al., 2010).

### *5.2.2 Mixed Logit Model*

As documented in Kim et al. (2010), the traditional approaches of modeling injury severity such as the multinomial logit and nested logit models assume that the effect of each variable is constant across the observations. While these approaches have been applied in many severity studies, they cannot model the influence of unobserved predictors, such as pedestrian's physical health and driver behavior. To account for unobserved predictors, the mixed logit model, also referred to as the random parameters logit model, is applied. It allows the parameter estimates to randomly vary across the observations. The mixed logit model is a good modeling alternative when the data for unobserved predictors are not present.

The methodological approach adopted in the analysis follows Milton et al. (2008), Pai et al. (2009), and Train (2009). As documented in Haleem and Gan (2013), the function ($U_{jn}$) that defines the crash injury severity category *j* probability (severe injury or non-severe injury) on segment *n* is:

$$U_{jn} = \beta_j^{'} X_{jn} + \varepsilon_{jn} \tag{5-1}$$

where,

| | | |
|---|---|---|
| $\beta_j^{'}$ | = | vector of parameters to be estimated; |
| $X_{jn}$ | = | vector of explored variables (geometric, traffic, environmental, pedestrian/driver-related, and vehicle-related); and |
| $\varepsilon_{jn}$ | = | random error term that is iid (independently- and identically-distributed) extreme value. |

As pointed out in Train (2009), $\beta_j$ or $\varepsilon_{jn}$ cannot be observed. Thus, the probability $P_n(j)$ of injury severity *j* from all injury severity categories *J* (representing non-severe and severe injuries) on segment *n* is the following:

$$P_n(j) = \frac{\exp(\beta_j^{'} X_{jn})}{\sum_J \exp(\beta_j^{'} X_{jn})} \tag{5-2}$$

Equation (5-2) describes the probability conditioned on $\beta_j$, which is unknown; thus, the unconditioned choice probability, also known as the mixed logit probability, is the integral of $P_n(j)$ over all possible values of $\beta_j$, as follows:

$$P_{jn} = \int \frac{\exp(\beta_j^{'} X_{jn})}{\sum_J \exp(\beta_j^{'} X_{jn})} f(\beta / \theta)\, d\beta \tag{5-3}$$

where $f(\beta / \theta)$ is the density function of $\beta$, and $\theta$ is the vector of parameters for the assumed distribution (e.g., mean and variance for the normal distribution). For example, if $f(\beta/\theta)$ has a normal distribution, then $\beta$ ~ N ($b$, $W$), with $b$ and $W$ denote the components of the $\theta$ vector.

From Equation (5-3), $\beta$ can now account for segment-specific variations of the effect of $X$ on injury probabilities. The mixed logit probabilities are a weighted average for different values of $\beta$ across segments, where some components are held fixed and some are randomly-distributed. For the random parameters, the mixed logit weights are determined by the density function $f(\beta/\theta)$.

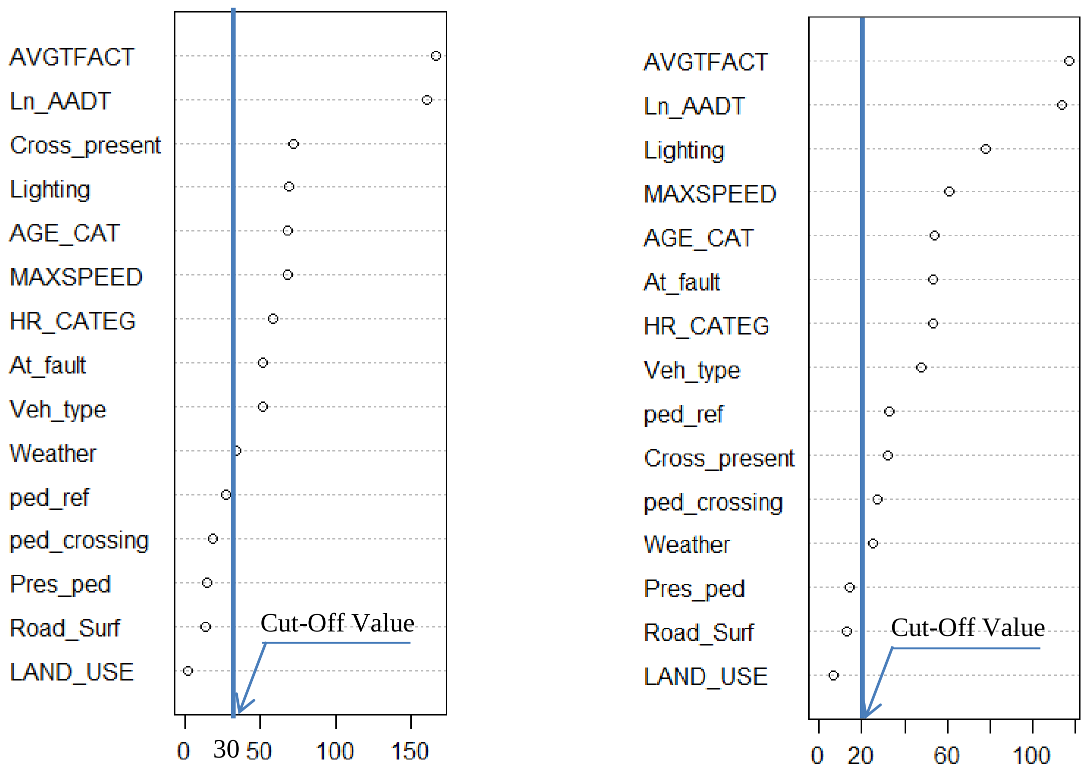
The mixed logit model in this study is fitted while considering the normal distribution of the parameters as random parameters. The parameter estimates of a mixed logit model are computed via the simulated maximum likelihood simulation which is performed using 200 Halton draws. The mixed logit model is fitted using the LIMDEP software package (Econometric Software, Inc.). Further, a 10% significance level is used to test the statistical significance of explored variables.

### 5.3 Random Forest Technique Results

The random forest technique was used to rank the importance of the 15 independent variables at both signalized and non-signalized locations before fitting the mixed logit models. Figures 5-1(a) and 5-1(b) provide the results from the random forest technique at signalized and non-signalized locations, respectively. At both locations, a total of 500 trees were used to grow the forest using the “randomForest” library in the R package (R Software). Using the Gini index measure to indicate the variable purity, the variables were ranked in descending order from the most to the least important. As shown in Figure 5-1(a), in the case of signalized locations, a cut-off value of 30 was used and the following ten variables were chosen to be included in the model: percentage of trucks, natural logarithm of AADT, crosswalk type, lighting condition, pedestrian age, speed limit, hour of crash, at-fault road user, vehicle type, and weather condition.

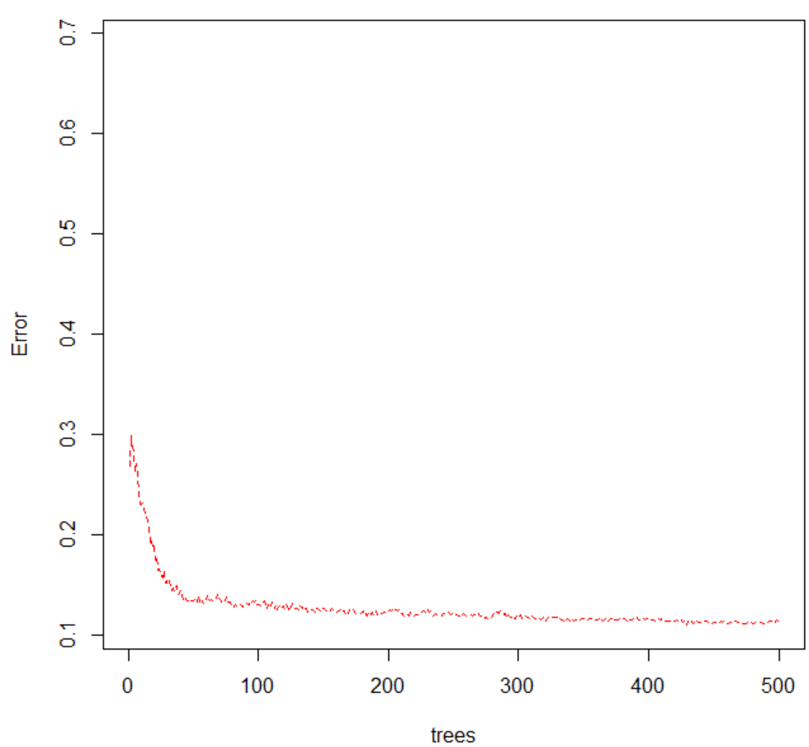
As shown in Figure 5-1(b), for non-signalized locations, a cut-off value of 20 was used and the following twelve variables were chosen to be included in the mixed logit model: percentage of trucks, natural logarithm of AADT, lighting condition, speed limit, pedestrian age, at-fault road user, hour of crash, vehicle type, presence of pedestrian refuge, crosswalk type, pedestrian maneuver, and weather condition. Note that all the above variables except for two (presence of pedestrian refuge and pedestrian maneuver) were included in the signalized locations model. It can be also inferred from Figure 5-1 that the land use type was the least important variable. This could be because the majority of pedestrian crashes occurred in urban and suburban areas, as shown in Tables 5-1 and 5-2.

To confirm that the pruned 500 trees at both signalized and non-signalized locations would lead to consistent and unbiased results, the plot of the out-of-bag (OOB) error against the number of trees is shown in Figure 5-2. In Figures 5-2(a) and 5-2(b), the minimum OOB error rates were achieved using 500 trees. Furthermore, the OOB error began to stabilize from 300 and 450 trees at signalized and non-signalized locations, respectively. This shows that using 500 trees was sufficient to yield reliable variable ranking using the random forest technique.

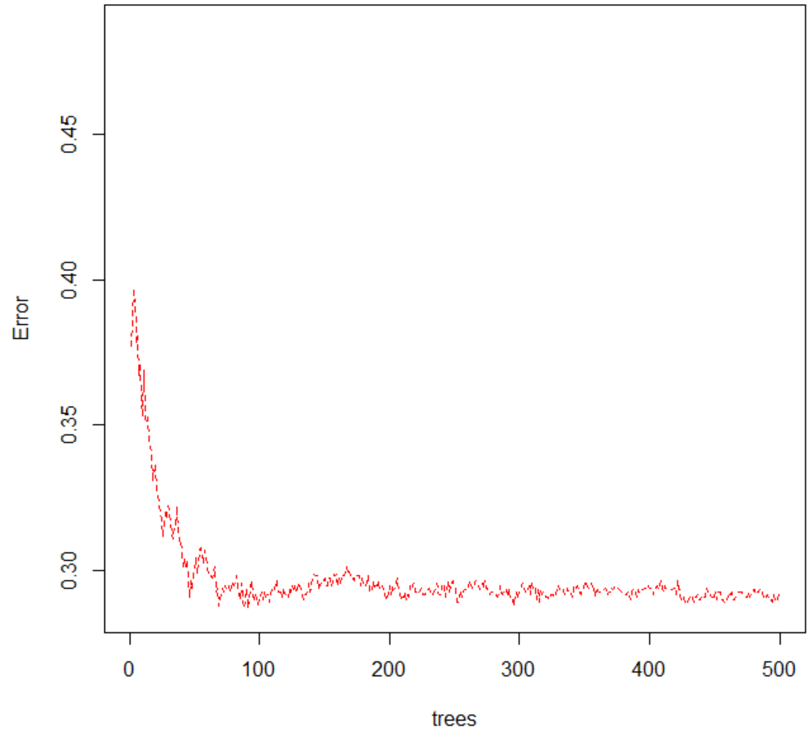



(a) Signalized Locations (b) Non-signalized Locations

**Figure 5-1: Variable Importance Ranking Using Random Forest**




(a) Signalized Locations




**(b) Non-signalized Locations**

**Figure 5-2: Plot of Out-of-Bag Error Against Number of Trees**

## 5.4 Mixed Logit Model Results

### *5.4.1 Signalized Locations Model*

Table 5-5 shows the fitted mixed logit model for pedestrian injury severity at signalized locations using 200 simulated Halton draws. It also provides the goodness-of-fit statistics for the model including log-likelihood at convergence, log-likelihood at zero, McFadden Pseudo $R^2$, and Akaike information criterion (AIC). The fitted mixed logit model is considered to have a good fit as the McFadden's Pseudo $R^2$ of the model is greater than 0.1 (Ulfarsson et al., 2010).

The parameters were considered to be random if they yielded statistically significant standard deviations for the normal distribution. On the other hand, if the parameters' estimated standard deviations were not statistically different from zero, the parameters were held fixed across the observations. As shown in Table 5-5, the percentage of trucks, speed limit, and very young pedestrians were found to be statistically significant random parameters. On the other hand, the natural logarithm of AADT, very old pedestrians, at-fault pedestrians, weather condition, lighting condition, and night/dawn off-peak hours were found to be the fixed parameters in the model.

The last column in Table 5-5 shows the elasticities or marginal effects of the severe injury probabilities. The marginal effects are the partial derivatives of the probability of crash injury severity with respect to the vector of independent variables (Zhang, 2010). The marginal effects depict the effect of change in a certain independent variable on the probability of a specific injury severity level (Haleem and Gan, 2013). For continuous variables, the marginal effect measures the influence of a unit change in an independent variable on the probability of injury occurrence. For categorical variables, the marginal effect represents the percentage the variable is associated with injury occurrence.

**Table 5-5: Mixed Logit Model Estimates at Signalized Locations**

| Variable Description | Simulated Maximum Likelihood Estimate | Standard Error | P-Value | Severe Injury Elasticity (%) |
|---|---|---|---|---|
| ***Random Parameters*** | | | | |
| Percentage of Trucks | 0.381 (1.490)[a] | 0.183 (0.463)[a] | 0.037 (0.001)[a] | 1.370 |
| Speed Limit | 0.671 (1.115)[a] | 0.177 (0.591)[a] | 0.000 (0.059)[a] | 1.221 |
| Very Young Pedestrians[b] | -0.308 (1.966)[a] | 0.186 (0.533)[a] | 0.097 (0.000)[a] | -0.029 |
| ***Fixed Parameters*** | | | | |
| Intercept for Severe Injury | -0.797 | 0.063 | 0.000 | --- |
| Ln(AADT) | 0.023 | 0.004 | 0.000 | 15.680 |
| Very Old Pedestrians[b] | 0.049 | 0.007 | 0.000 | 30.858 |
| Pedestrian At-fault[b] | 0.367 | 0.089 | 0.000 | 3.445 |
| *Weather Condition*: Clear[b] | -0.263 | 0.112 | 0.019 | -3.056 |
| Rainy[b] | 0.353 | 0.184 | 0.055 | 0.385 |
| *Lighting Condition*: Dark with Street Light[b] | 0.733 | 0.118 | 0.000 | 4.666 |
| Dark with No Street Light[b] | 1.637 | 0.215 | 0.000 | 1.523 |
| Night/Dawn Off-Peak Hour (8:00 pm-6:59 am)[b] | 0.441 | 0.118 | 0.000 | 2.654 |
| ***Number of Observations*** | | 2,360 | | |
| ***Log-Likelihood at Convergence*** | | -1,287.33 | | |
| ***Log-Likelihood at Fitting the Intercept*** | | -1,635.83 | | |
| ***McFadden's Pseudo $R^2$*** | | 0.21 | | |
| ***AIC*** | | 2,604.66 | | |

[a] Standard deviation.

[b] Binary categorical variables inserted as "1" if true; "0" otherwise.

### *Random Parameters*

The percentage of trucks is normally distributed with a mean of 0.381 and a standard deviation of 1.49. The probability that the distribution is less than zero can be calculated using the following equation:

$$Z = \frac{0 - \text{Mean Parameter Estimate}}{\text{St. Deviation of Estimate}} \tag{5-4}$$

The Z-value calculated from the above equation is - 0.25. This value corresponds to 40.13%. In other words, 40.13% of the distribution is less than 0 and the remaining 59.87% is greater than 0.

This indicates that the percentage of trucks is associated with higher probability of severe injuries at signalized locations. The severe injury elasticity is 1.37%, which means that a one-percent increase in the percentage of trucks increases the probability of severe injuries by about 1.4%.

Speed limit is also normally distributed with a mean of 0.671 and a standard deviation of 1.115, which corresponds to a Z-value of -0.6. From the Z-tables, 27.43% of the distribution is less than 0 and the remaining 72.57% is greater than 0. Based on this, in 72.57% of the pedestrian crash observations, higher speed limits are associated with greater severe injury probability. Furthermore, a one mile per hour increase in the speed limit increases the probability of severe injuries by 1.2%. This result is similar to several other studies, e.g., Milton et al. (2008), Kim et al. (2010), Haleem and Abdel-Aty (2010), Haleem and Gan (2013), and Obeng and Rokonuzzaman (2013).

The last random parameter, very young pedestrians, has a mean of -0.308 and a standard deviation of 1.966. This corresponds to a Z-value of 0.16. From the Z-tables, approximately 56% of the distribution is less than 0 and the remaining 44% is greater than 0. Thus, in 56% of the pedestrian crash observations, very young pedestrians are associated with lesser probability of severe injuries compared to other age groups.

*Fixed Parameters - Environmental Factors*

Two significant environmental predictors are weather and lighting conditions. Clear weather is associated with 3% reduction in the severe injury probability compared to other weather conditions. On the other hand, rainy weather is associated with 0.4% increase in the severe injury probability compared to other weather conditions. This shows the adverse impact of rainy weather on pedestrian injuries, which could mainly be due to visibility constraints.

The two lighting condition variables, dark with street light and dark with no street light, are also significant variables. Both conditions are associated with an increase in the probability of severe injuries compared to other lighting conditions. This shows that dark lighting conditions increase severe injuries to pedestrians.

*Fixed Parameters - Traffic Factors*

Increasing the AADT at signalized locations significantly increases the probability of severe injuries by around 16%, mainly due to the increase in vehicle-pedestrian conflicts. This result is consistent with previous studies, e.g., Obeng and Rokonuzzaman (2013). The probability of severe injury is increased by 2.7% during the night and dawn off-peak periods.

*Fixed Parameters – Pedestrian/Driver-Related Factors*

Very old pedestrians (80 years and older) are associated with 30.8% higher probability of severe injuries compared to other age groups. This is mainly due to their weak physical conditions, resulting in an increased probability of severe injuries. This result is consistent with the findings of Kim et al. (2010).

Crashes involving at-fault pedestrians are associated with around 3.4% higher severe injury probability compared to the crashes where drivers are at fault or both pedestrians and drivers are at fault. This concurs with the studies by Kim et al. (2010) and Ulfarsson et al. (2010).

### *5.4.2 Non-signalized Locations Model*

Table 5-6 gives the fitted mixed logit model for pedestrian injury severity at non-signalized locations using 200 simulated Halton draws. The table also provides the goodness-of-fit statistics. Similar to the signalized locations models, the fitted mixed logit model for non-signalized locations is also considered to have a good fit as the McFadden's Pseudo $R^2$ of the model is greater than 0.1.

#### *Random Parameters*

As shown in Table 5-6, the old pedestrian age and pedestrian crossing maneuver were the two random parameters included in the model. The random parameter old pedestrian age has a mean of 0.373 and a standard deviation of 0.995. This corresponds to a Z-value of - 0.37. From the Z-tables, approximately 36% of the distribution is less than 0 and the remaining 64% is greater than 0. Thus, in approximately 64% of the pedestrian crash observations, older pedestrians are associated with higher probability of severe injuries compared to other age groups. This result is comparable to the signalized locations and is consistent with the study by Lee and Abdel-Aty (2005).

Crashes involving pedestrians crossing the roadway are associated with higher severe injury probabilities compared to the crashes involving pedestrians walking along the roadway. This parameter has a mean of 0.187 and a standard deviation of 1.579, which corresponds to a Z-value of - 0.12. From the Z-tables, approximately 45% of the distribution is less than 0 and the remaining 55% is greater than 0.Thus, crossing the intersection maneuver is associated with higher probability of severe injuries in 55% of the observations. This is anticipated and is mainly due to the increased odds of pedestrian-vehicle conflicts at both unsignalized intersections and midblocks. This result is also consistent with the finding of Sarkar et al. (2011). As it can be inferred from Table 5-6, the crossing maneuver is associated with 1.8% higher probability of severe injuries compared to walking along the roadway.

#### *Fixed Parameters - Environmental and Vehicle Factors*

The three lighting condition variables, daylight, dark with street light, and dark with no street light, are significant environmental predictors. The daylight condition is associated with 2.4% reduction in the probability of severe injuries, whereas both dark with and without street lights are associated with an increase in the probability of severe injuries by 4.9% and 3.3%, respectively. This result is consistent with the results at signalized locations.

Vans are associated with around 0.2% increase in the probability of severe injuries compared to other vehicle types. A possible explanation could be that vans are relatively large vehicles and when involved in a crash with pedestrians, regardless of who is at fault, is expected to result in severe injuries to pedestrians. Chu (2006) also reached the same conclusion and indicated that large vehicles are relatively difficult to stop and could collide at greater speeds compared to small vehicles such as passenger cars.

### Table 5-6: Mixed Logit Model Estimates at Non-signalized Locations

| Variable Description | | Simulated Maximum Likelihood Estimate | Standard Error | P-Value | Severe Injury Elasticity (%) |
|---|---|---|---|---|---|
| ***Random Parameters*** | | | | | |
| Pedestrians Crossing Street[b] | | 0.187 (1.579)[a] | 0.124 (0.349)[a] | 0.131 (0.000)[a] | 1.822 |
| Old Pedestrians[b] | | 0.373 (0.995)[a] | 0.193 (0.491)[a] | 0.053 (0.042)[a] | 0.393 |
| ***Fixed Parameters*** | | | | | |
| Speed Limit on Major Road | | 0.039 | 0.006 | 0.000 | 27.725 |
| *Pedestrian Age:* | Very Young[b] | -0.475 | 0.177 | 0.007 | -0.584 |
| | Middle[b] | 0.318 | 0.133 | 0.016 | 3.717 |
| | Very Old[b] | 0.970 | 0.227 | 0.000 | 0.720 |
| Pedestrian At-fault[b] | | 0.838 | 0.092 | 0.000 | 9.297 |
| Van Vehicle Type[b] | | 0.354 | 0.206 | 0.085 | 0.178 |
| *Lighting Condition*: | Day[b] | -0.440 | 0.185 | 0.017 | -2.363 |
| | Dark with Street Light[b] | 0.715 | 0.185 | 0.000 | 4.917 |
| | Dark with No Street Light[b] | 0.925 | 0.202 | 0.000 | 3.320 |
| ***Number of Observations*** | | | 2,282 | | |
| ***Log-Likelihood at Convergence*** | | | -1,274.00 | | |
| ***Log-Likelihood at Fitting the Intercept*** | | | -1,581.76 | | |
| ***McFadden's Pseudo $R^2$*** | | | 0.19 | | |
| ***AIC*** | | | 2,574.00 | | |

[a] Standard deviation.

[b] Binary categorical variables inserted as "1" if true; "0" otherwise.

#### *Fixed Parameters - Traffic Factors*

Increasing the speed limit on major roads at non-signalized locations by one mile per hour is associated with 27.7% higher severe injury probability. This is anticipated and was previously concluded from the injury severity analysis at signalized locations. However, the increase in speed limits nearby non-signalized locations poses higher pedestrian severity risk compared to the signalized locations. This could be due to the lack of pedestrian signals and push buttons at non-signalized locations.

#### *Fixed Parameters – Pedestrian/Driver-Related Factors*

The three age groups, very young, middle, and very old, were found to be significant predictors in the model. As previously concluded from the model at signalized locations, very young pedestrians are associated with lesser probability of severe injuries compared to other age groups. On the other hand, very old pedestrians are associated with higher probability of severe injuries, mainly due to their weak physical conditions. It is also noticed that very old pedestrians experience a greater severity risk at signalized locations compared to non-signalized locations. Additionally, similar to very old pedestrians, middle-aged pedestrians are associated with increased severity likelihood at non-signalized locations.

When pedestrians are at fault, these crashes are associated with 9.3% higher severe injury probability compared to where drivers are at fault or both pedestrians and drivers are at fault. This concurs with the result from the analysis at signalized locations. However, when pedestrians are at-fault, they are more vulnerable of severe injuries at non-signalized locations compared to signalized locations.

### 5.5 Summary

This chapter identified the geometric, traffic, road user, environmental, and vehicle predictors of pedestrian injury severity at both signalized and non-signalized locations in Florida using the mixed logit model. The analysis was based on 4,923 pedestrian crashes that occurred on state roads during 2008-2010. The following relatively new injury severity predictors were identified from the detailed review of police reports and were considered in the analysis: at-fault road user, pedestrian maneuver before crash, presence of pedestrian refuge area, type of crosswalk, and presence of pedestrian signals. The random forest technique was first used to rank the importance of independent variables at each location, and ten variables were common important severity predictors at both locations. These variables were: percentage of trucks, natural logarithm of AADT, crosswalk type, lighting condition, pedestrian age, speed limit, hour of crash, at-fault road user, vehicle type, and weather condition.

The results from the mixed logit models showed that:

- Crashes where pedestrians were at fault were more likely to result in severe injuries compared to the crashes where drivers were at fault or both pedestrians and drivers were at fault at both signalized and non-signalized locations.
- Crashes involving at-fault pedestrians resulted in a greater probability of severe injuries at non-signalized locations compared to signalized locations.
- Very young pedestrians were associated with lower probability of severe injuries at both signalized and non-signalized locations.
- Very old pedestrians were associated with higher probability of severe injuries at both signalized and non-signalized locations.
- Very old pedestrians have a greater severity risk at signalized locations compared to non-signalized locations.
- At signalized locations, rainy weather was associated with a slight increase in the probability of severe injuries compared to other weather conditions.
- Dark conditions, with and without street light, were associated with an increase in the probability of severe injuries at both signalized and non-signalized locations.
- At non-signalized locations, vans were found to be associated with an increase in the probability of severe injuries compared to other vehicle types.
- Increasing the speed limit at signalized and non-signalized locations was associated with higher severe injury probability.

- The increase in speed limit at non-signalized locations posed greater pedestrian severity risk compared to signalized locations.
- At non-signalized locations, pedestrians crossing the roadway were associated with higher probability of severe injuries compared to pedestrians walking along the roadway.
- At signalized locations, increasing the AADT and the percentage of trucks significantly increased the probability of severe pedestrian injuries.
- At signalized locations, the probability of severe pedestrian injuries was higher during the night and dawn off-peak periods.

The analysis results could help recommend appropriate countermeasures to reduce the severity of pedestrian crashes. For example, since crashes where pedestrians were at fault were found to result in an increased probability of severe pedestrian injuries, it is recommended to conduct safety awareness and education campaigns targeting pedestrians on the laws and pedestrian rights-of-way at both signalized and non-signalized locations. Since very old pedestrians were associated with a greater probability of severe injuries at both signalized and non-signalized locations, older population could be one of the main target age groups in the education programs. Stricter enforcement of speeding and driver compliance with pedestrian right-of-way laws could also improve pedestrian safety. These campaigns should be organized through the coordination of law enforcement officers, safety engineers, and the public to integrate the components of the four E’s: engineering, education, enforcement, and emergency response. It is also recommended to improve lighting in the vicinity of signalized and non-signalized locations to reduce severe pedestrian injuries at night and early morning.

# CHAPTER 6
# SIGNALIZED LOCATIONS

As discussed in Section 4.2.3, about 50% of pedestrian crashes occurred at signalized intersections. This chapter focuses on identifying and analyzing signalized intersections with high pedestrian crash frequencies. It includes district-wide list of signalized intersections with high pedestrian crashes. It also includes the analysis of high crash urban signalized intersections in the entire state. The statewide analysis focused on urban signalized intersections with crash frequency greater than the critical crash frequency. Police reports of all the crashes that occurred at these high crash intersections are reviewed in detail to identify specific pedestrian crash types. Crash contributing factors related to each crash type along with specific countermeasures are then discussed.

## 6.1 District-wide Pedestrian High Crash Signalized Intersections

Tables 6-1 through 6-7 provide the list of top pedestrian crash signalized intersections by district ranked based on total pedestrian crash frequency during 2008-2010. In these tables, intersection location identifiers including street names, roadway ID and milepost of each location are provided. In addition, a clickable Google Maps hyperlink to the map location is embedded under the intersection street names. As pedestrian crash frequencies differ among the districts, different cut-off points are used. For example, none of the signalized intersections in District 1 experienced more than three crashes whereas a total of 16 signalized intersections in District 6 experienced five or more crashes.

**Table 6-1: Pedestrian High Crash Signalized Intersections in District 1**

| No. | Intersection | Roadway ID | Milepost | Fatal Crashes | Injury Crashes | Total Crashes |
|---|---|---|---|---|---|---|
| 1 | W Daughtery Rd & US 98 | 16210000 | 5.623 | 2 | 1 | 3 |
| 2 | US 98 & Pyramid Pkwy | 16210000 | 2.889 | 1 | 2 | 3 |
| 3 | Cortez Rd W & 14th St W | 13010000 | 5.284 | 0 | 3 | 3 |
| 4 | Martin Luther King Way & N Washington Blvd | 17120000 | 2.155 | 0 | 2 | 3 |
| 5 | Stickney Point Rd & Gateway Ave | 17070000 | 0.461 | 0 | 2 | 3 |
| 6 | Cortez Rd W & 20th St W | 13040000 | 7.349 | 0 | 2 | 3 |

*Notes: There are 27 locations with 2 crashes. Total crashes include no injury and unknown injury crashes.*

**Table 6-2: Pedestrian High Crash Signalized Intersections in District 2**

| No. | Intersection | Roadway ID | Milepost | Fatal Crashes | Injury Crashes | Total Crashes |
|---|---|---|---|---|---|---|
| 1 | Timuquana Rd & Seaboard Ave | 72220000 | 9.661 | 1 | 3 | 4 |
| 2 | 103rd St & Harlow Blvd | 72220000 | 8.040 | 1 | 3 | 4 |
| 3 | University Blvd W & Barnes Rd S | 72014000 | 2.502 | 0 | 4 | 4 |
| 4 | NW 16th Ave & NW 13th St | 26010000 | 15.212 | 0 | 4 | 4 |
| 5 | W University Ave & Buckman Dr | 26070000 | 19.179 | 0 | 3 | 4 |

*Notes: There are 12 locations with 3 crashes. Total crashes include no injury and unknown injury crashes.*

### Table 6-3: Pedestrian High Crash Signalized Intersections in District 3

| No. | Intersection | Roadway ID | Milepost | Fatal Crashes | Injury Crashes | Total Crashes |
|---|---|---|---|---|---|---|
| 1 | W Tennessee St & Basin St | 55060000 | 6.832 | 0 | 5 | 5 |
| 2 | W Tennessee St & N Ocala Rd | 55060000 | 6.202 | 0 | 5 | 5 |
| 3 | Mobile Hwy & Massachusetts Ave | 48020000 | 9.974 | 0 | 3 | 4 |
| 4 | N Fairfield Dr & N Pace Blvd | 48050000 | 22.722 | 1 | 2 | 3 |
| 5 | Mobile Hwy & N Fairfield Dr | 48020000 | 11.095 | 0 | 4 | 4 |
| 6 | W Tennessee St & N Copeland St | 55060000 | 7.848 | 0 | 3 | 3 |
| 7 | W Tennessee St & Dewey St | 55060000 | 7.661 | 0 | 3 | 3 |
| 8 | W Tennessee St & N Woodward Ave | 55060000 | 7.391 | 0 | 3 | 3 |
| 9 | Front Beach Rd & Hills Rd | 46010000 | 9.117 | 0 | 3 | 3 |

*Notes: There are 23 locations with 2 crashes. Total crashes include no injury and unknown injury crashes.*

### Table 6-4: Pedestrian High Crash Signalized Intersections in District 4

| No. | Intersection | Roadway ID | Milepost | Fatal Crashes | Injury Crashes | Total Crashes |
|---|---|---|---|---|---|---|
| 1 | E Oakland Park Blvd & N Andrews Ave | 86090000 | 6.858 | 0 | 11 | 11 |
| 2 | NW 50th St & SR 7 | 86014000 | 3.220 | 1 | 6 | 8 |
| 3 | W Oakland Park Blvd & SR 7 | 86090000 | 3.323 | 0 | 7 | 7 |
| 4 | W Sunrise Blvd & NW 7th Ave | 86110000 | 7.247 | 0 | 7 | 7 |
| 5 | W Broward Blvd & NW 31st Ave | 86006000 | 4.120 | 1 | 5 | 6 |
| 6 | 10th  Ave N & S Congress Ave | 93006000 | 2.847 | 1 | 5 | 6 |
| 7 | E Oakland Park Blvd & NE 6th  Ave | 86090000 | 7.356 | 1 | 5 | 6 |
| 8 | Sheridan St & SR 7 | 86100000 | 4.091 | 1 | 4 | 5 |
| 9 | NW 41st St & SR 7 | 86100000 | 14.079 | 1 | 4 | 5 |
| 10 | W Atlantic Blvd & SR 845 | 86130000 | 3.788 | 1 | 4 | 5 |
| 11 | Griffin Rd & SR 7 | 86100000 | 6.226 | 1 | 3 | 5 |
| 12 | W Oakland Park Blvd & N University Dr | 86220000 | 13.640 | 0 | 5 | 5 |
| 13 | W Broward Blvd & NW 1st Ave | 86006000 | 6.706 | 0 | 4 | 5 |
| 14 | W Broward Ave & N Andrews Ave | 86006000 | 6.773 | 0 | 4 | 5 |

*Notes: There are 12 locations with 4 crashes. Total crashes include no injury and unknown injury crashes.*

### Table 6-5: Pedestrian High Crash Signalized Intersections in District 5

| No. | Intersection | Roadway ID | Milepost | Fatal Crashes | Injury Crashes | Total Crashes |
|---|---|---|---|---|---|---|
| 1 | Silver Star Rd & N Pine Hills Rd | 75250000 | 6.304 | 0 | 7 | 8 |
| 2 | Silver Star Rd & N Hiawassee Rd | 75250000 | 4.812 | 2 | 4 | 7 |
| 3 | Old Cheney Hwy & N Semoran Blvd | 75003000 | 7.611 | 2 | 3 | 6 |
| 4 | US 192 & N John Young Pkwy | 92090000 | 14.635 | 0 | 6 | 6 |
| 5 | Mason Ave & N Ridgewood Ave | 79030000 | 1.192 | 0 | 5 | 5 |
| 6 | Lokanotosa Trail & N Alafaya Trail | 75037000 | 1.128 | 1 | 3 | 4 |
| 7 | N Atlantic Ave & St Lucie Ln | 70060000 | 35.837 | 0 | 4 | 4 |
| 8 | SR 436 & Oxford Rd | 77080000 | 7.718 | 0 | 4 | 4 |
| 9 | E Colonial Dr & N Bumby Ave | 75060000 | 2.653 | 0 | 3 | 4 |

*Notes: There are 16 locations with 3 crashes. Total crashes include no injury and unknown injury crashes.*

**Table 6-6: Pedestrian High Crash Signalized Intersections in District 6**

| No. | Intersection | Roadway ID | Milepost | Fatal Crashes | Injury Crashes | Total Crashes |
|---|---|---|---|---|---|---|
| 1 | NE 167th St & NE 6th Ave | 87170000 | 1.477 | 0 | 7 | 7 |
| 2 | Miami Gardens Dr & NW 27th Ave | 87019000 | 2.740 | 0 | 6 | 7 |
| 3 | NW 95th St & NW 7th Ave | 87140000 | 6.666 | 0 | 6 | 7 |
| 4 | S Dixie Highway & Caribbean Blvd | 87020000 | 12.383 | 0 | 6 | 7 |
| 5 | NW 54th St & NW 7th Ave | 87140000 | 4.126 | 1 | 4 | 6 |
| 6 | 174th St & Collins Ave | 87060000 | 15.142 | 0 | 6 | 6 |
| 7 | NW 79th St & NW 7th Ave | 87080900 | 38.493 | 0 | 5 | 6 |
| 8 | NE 35th Terrace & Biscayne Blvd | 87030000 | 13.480 | 0 | 3 | 6 |
| 9 | NW 27th Ave & NW 54th St | 87240000 | 5.787 | 0 | 4 | 5 |
| 10 | NE 79th St & N Miami Ave | 87080900 | 39.257 | 1 | 3 | 5 |
| 11 | NE 163rd St & NE 12th Ave | 87170000 | 2.306 | 0 | 5 | 5 |
| 12 | S Dixie Hwy & SW 27th Ave | 87030000 | 6.518 | 0 | 5 | 5 |
| 13 | NW 14th St & NW 12th Ave | 87085000 | 2.504 | 0 | 5 | 5 |
| 14 | NW 79th St & NW 27th Ave | 87240000 | 7.310 | 0 | 4 | 5 |
| 15 | NE 125th St & NE 6th Ave | 87066000 | 1.520 | 0 | 4 | 5 |
| 16 | NE 135th St & NE 6th Ave | 87008000 | 8.648 | 0 | 3 | 5 |

*Notes: There are 19 locations with 4 crashes. Total crashes include no injury and unknown injury crashes.*

**Table 6-7: Pedestrian High Crash Signalized Intersections in District 7**

| No. | Intersection | Roadway ID | Milepost | Fatal Crashes | Injury Crashes | Total Crashes |
|---|---|---|---|---|---|---|
| 1 | W Waters Ave & N Florida Ave | 10020000 | 5.362 | 0 | 8 | 8 |
| 2 | E Fowler Ave & N 15th St | 10290000 | 1.013 | 0 | 7 | 7 |
| 3 | Ulmerton Ave & 66th St N | 15061000 | 6.447 | 0 | 2 | 5 |
| 4 | 38th Ave N & 4th St N | 15090000 | 2.903 | 0 | 5 | 5 |
| 5 | Gulf to Bay Blvd & Belcher Rd S | 15040000 | 3.441 | 0 | 5 | 5 |
| 6 | SR 600 & N 40th St | 10005000 | 2.845 | 0 | 5 | 5 |
| 7 | W Hillsborough Ave & Hanley Rd | 10150000 | 6.049 | 0 | 2 | 5 |
| 8 | Trouble Creek Rd & US 19 | 14030000 | 3.593 | 0 | 5 | 5 |
| 9 | E Fletcher Ave & N Florida Ave | 10020000 | 8.388 | 1 | 3 | 4 |
| 10 | SR 54 and & Rowan Rd | 14570000 | 2.720 | 0 | 4 | 4 |
| 11 | E Hillsborough Ave & N 22nd St | 10030000 | 0.999 | 0 | 3 | 4 |
| 12 | Sunset Dr S & Pasadena Ave S | 15110000 | 1.536 | 0 | 4 | 4 |
| 13 | 5th Ave N & 34th St N | 15010000 | 2.502 | 0 | 4 | 4 |
| 14 | 62nd Ave N & 34th St N | 15150000 | 8.398 | 0 | 3 | 4 |

*Notes: There are 26 locations with 3 crashes. Total crashes include no injury and unknown injury crashes.*

## 6.2 Statewide Pedestrian High Crash Signalized Intersections

In this section, the overall top high crash intersections statewide were further identified based on critical pedestrian crash frequency for detailed analysis.

### *6.2.1 Location Identification*

Urban signalized intersections with observed pedestrian crash frequency greater than three standard deviations from the average crash frequency were identified and analyzed. Overall, 1,962 urban signalized intersections experienced at least one pedestrian crash from 2008-2010. Over two-thirds of these intersections (i.e., 1,340) experienced one pedestrian crash during the analysis period. These 1,340 signalized intersections were excluded from the analysis as one crash is considered to be a random occurrence. A total of 622 urban signalized intersections that experienced two or more pedestrian crashes during the three-year analysis period were analyzed. During 2008-2010, these intersections experienced an average of 2.66 pedestrian crashes, with a standard deviation (σ) of 1.16 pedestrian crashes. Note that the standard deviation (σ) is calculated using the following equations:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2}\,;\ \mu = \frac{1}{N}\sum_{i=1}^{N} x_i \tag{6-1}$$

where,

| | | |
|---|---|---|
| $\sigma$ | = | standard deviation, |
| N | = | total number of urban signalized intersections that experienced more than one pedestrian crash during the analysis period, |
| $x_i$ | = | crash frequency at intersection i, and |
| $\mu$ | = | average crash frequency at the urban signalized intersections. |

A total of 21 signalized intersections experienced ≥ 6 crashes (i.e., crash frequency > $\mu+3\sigma$) during 2008-2010. Table 6-8 lists these 21 urban signalized intersections.

**Table 6-8: Statewide Pedestrian High Crash Urban Signalized Intersections**

| No. | Intersection | District | Roadway ID | Milepost | Fatal Crashes | Injury Crashes | Total Crashes |
|---|---|---|---|---|---|---|---|
| 1 | E Oakland Park Blvd & N Andrews Ave | 4 | 86090000 | 6.858 | 0 | 11 | 11 |
| 2 | Silver Star Rd & N Pine Hills Rd | 5 | 75250000 | 6.304 | 0 | 7 | 8 |
| 3 | NW 50th St & SR 7 | 4 | 86014000 | 3.220 | 1 | 6 | 8 |
| 4 | W Waters Ave & N Florida Ave | 7 | 10020000 | 5.362 | 0 | 8 | 8 |
| 5 | Silver Star Rd & N Hiawassee Rd | 5 | 75250000 | 4.812 | 2 | 4 | 7 |
| 6 | E Fowler Ave & N 15th St | 7 | 10290000 | 1.013 | 0 | 7 | 7 |
| 7 | NW 95th St & NW 7th Ave | 6 | 87140000 | 6.666 | 0 | 6 | 7 |
| 8 | S Dixie Highway & Caribbean Blvd | 6 | 87020000 | 12.383 | 0 | 6 | 7 |
| 9 | Miami Gardens Dr & NW 27th Ave | 6 | 87019000 | 2.740 | 0 | 6 | 7 |
| 10 | W Sunrise Blvd & NW 7th Ave | 4 | 86110000 | 7.247 | 0 | 7 | 7 |
| 11 | W Oakland Park Blvd & SR 7 | 4 | 86090000 | 3.323 | 0 | 7 | 7 |
| 12 | NE 167th St & NE 6th Ave | 6 | 87170000 | 1.477 | 0 | 7 | 7 |
| 13 | NE 35th Terrace & Biscayne Blvd | 6 | 87030000 | 13.480 | 0 | 3 | 6 |
| 14 | NW 54th St & NW 7th Ave | 6 | 87140000 | 4.126 | 1 | 4 | 6 |
| 15 | NW 79th St & NW 7th Ave | 6 | 87080900 | 38.493 | 0 | 5 | 6 |
| 16 | Old Cheney Hwy & N Semoran Blvd | 5 | 75003000 | 7.611 | 2 | 3 | 6 |
| 17 | E Oakland Park Blvd & NE 6th Ave | 4 | 86090000 | 7.356 | 1 | 5 | 6 |
| 18 | 10th Ave N & S Congress Ave | 4 | 93006000 | 2.847 | 1 | 5 | 6 |
| 19 | 174th St & Collins Ave | 6 | 87060000 | 15.142 | 0 | 6 | 6 |
| 20 | W Broward Blvd & NW 31st Ave | 4 | 86006000 | 4.120 | 1 | 5 | 6 |
| 21 | US 192 & N John Young Pkwy | 5 | 92090000 | 14.635 | 0 | 6 | 6 |

*Note: Total crashes include crashes with no injury and unknown injury.*

### *6.2.2 Condition-collision Diagrams*

Figures 6-1 through 6-21 plot the "condition-collision" diagrams of the 21 high crash urban signalized intersections. In these diagrams, the locations of all pedestrian crashes were plotted on the satellite images. The figures also provide additional information on the injury severity of the pedestrian using the following codes:

- red – fatal
- yellow – injury
- green – no injury to pedestrian
- blue – unknown injury to pedestrian

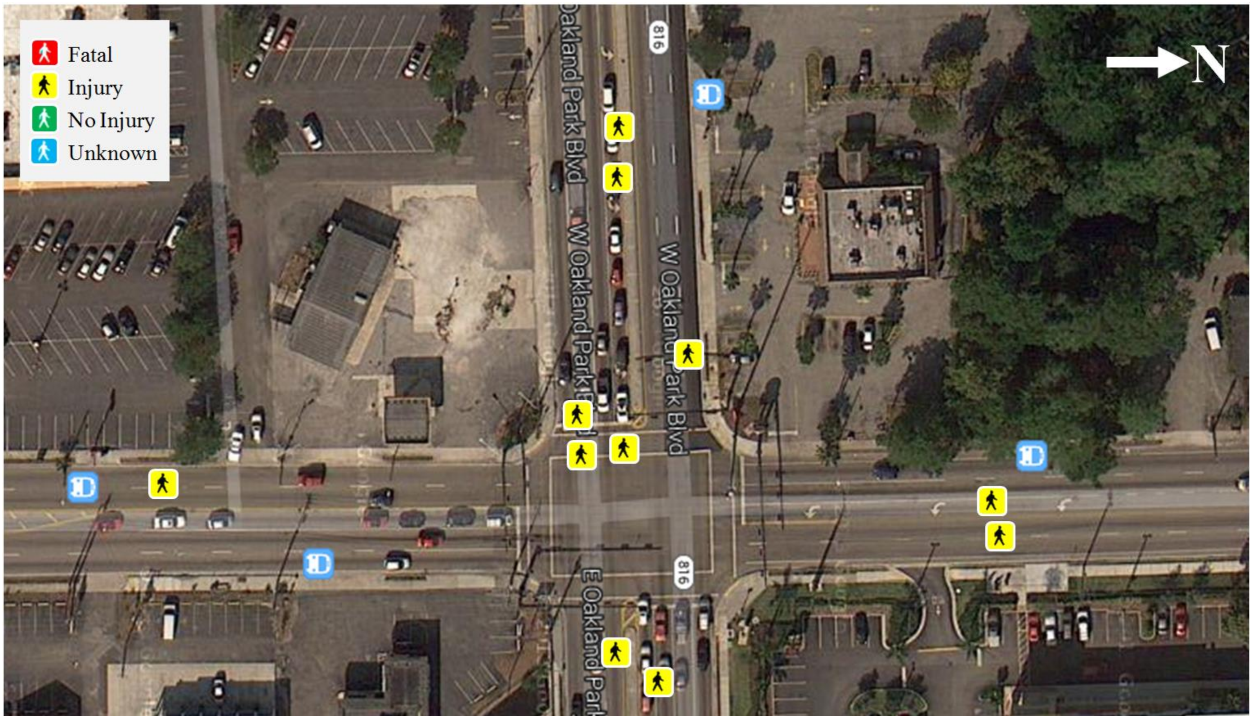



**Figure 6-1: E Oakland Park Blvd and N Andrews Ave (Roadway ID 86090000; MP 6.858) ([Map](#))**

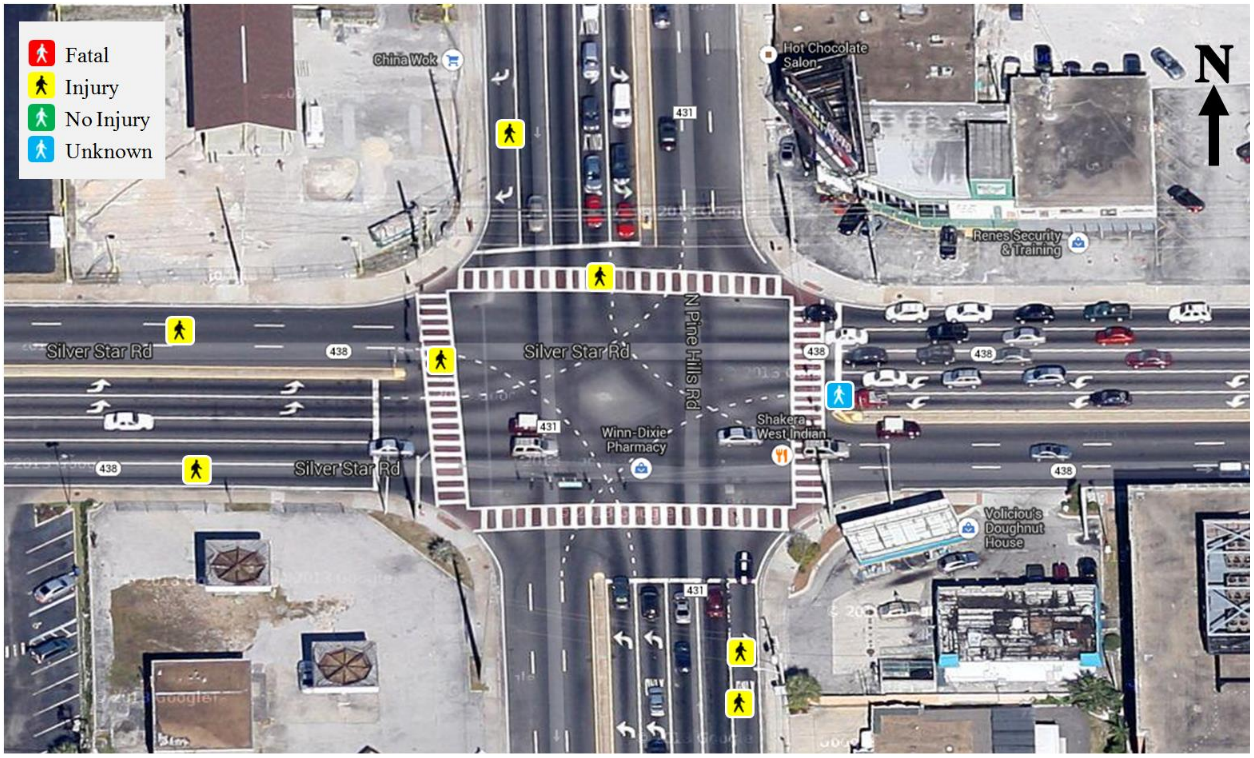



**Figure 6-2: Silver Star Rd and N Pine Hills Rd (Roadway ID 75250000; MP 6.304) ([Map](#))**

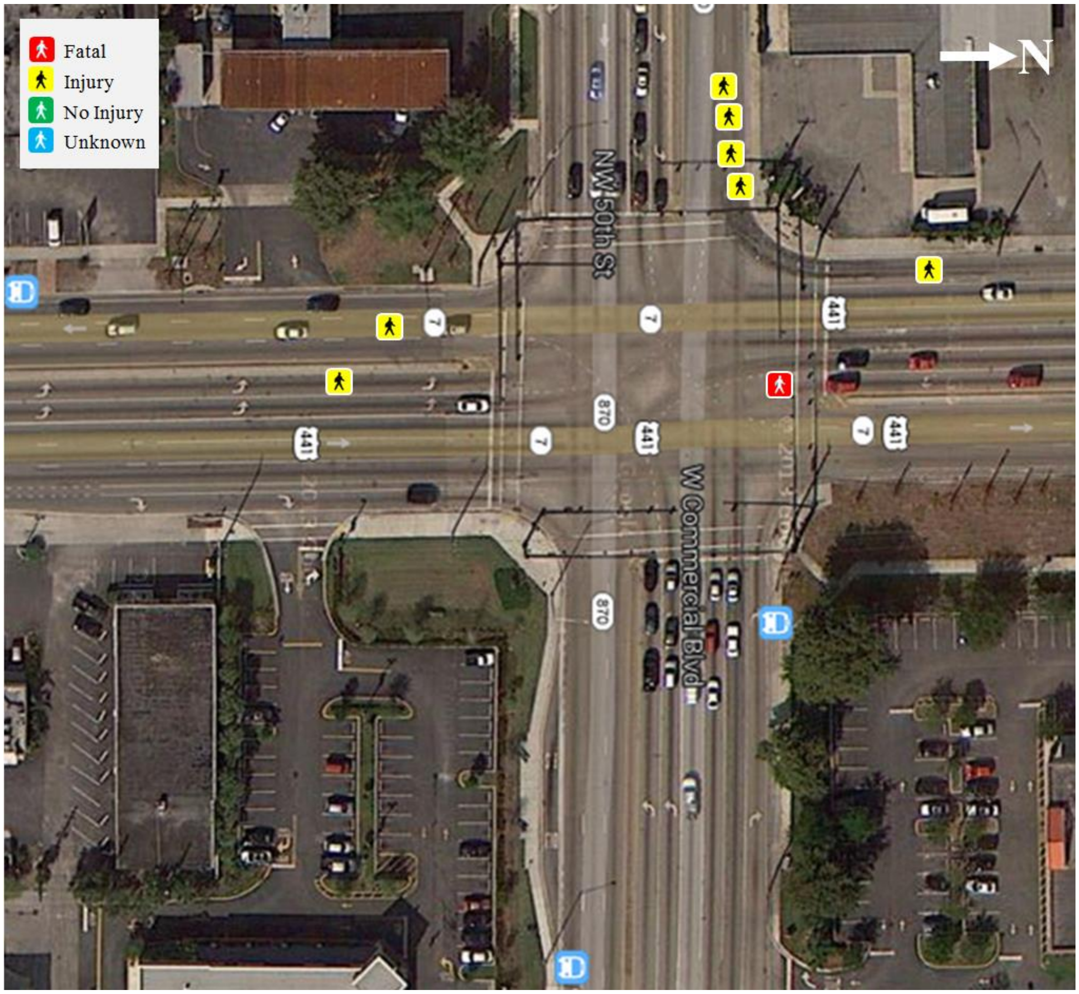


Figure 6-3: SR 7 and NW 50th St (Roadway ID 86014000; MP 3.220) (Map)

Figure 6-4: W Waters Ave and N Florida Ave (Roadway ID 10020000; MP 5.362) (Map)

Figure 6-5: Silver Star Rd and N Hiawassee Rd (Roadway ID 75250000; MP 4.812) (Map)

Figure 6-6: E Fowler Ave and N 15th St (Roadway ID 10290000; MP 1.013) (Map)

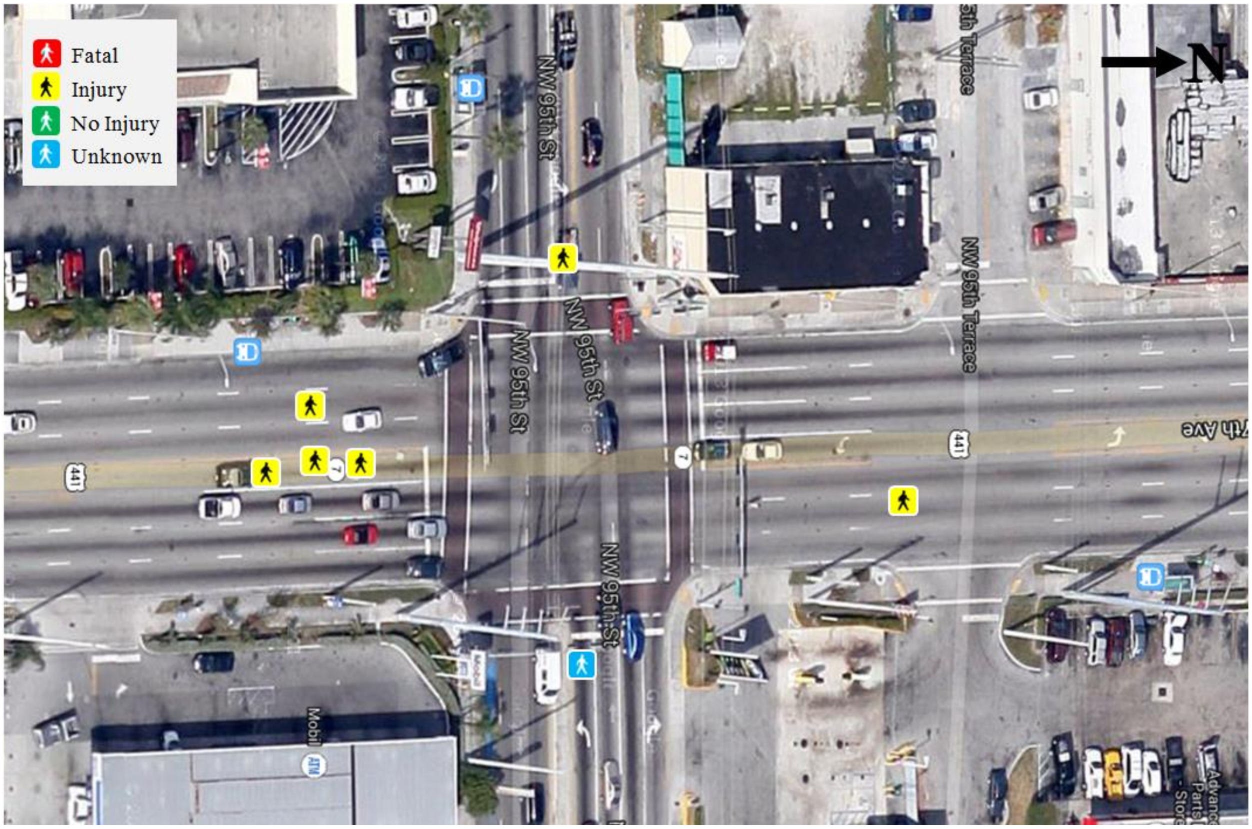


Figure 6-7: NW 95th St and NW 7th Ave (Roadway ID 87140000; MP 6.666) ([Map](Map))

Figure 6-8: S Dixie Hwy and Caribbean Blvd (Roadway ID 87020000; MP 12.383) ([Map](Map))

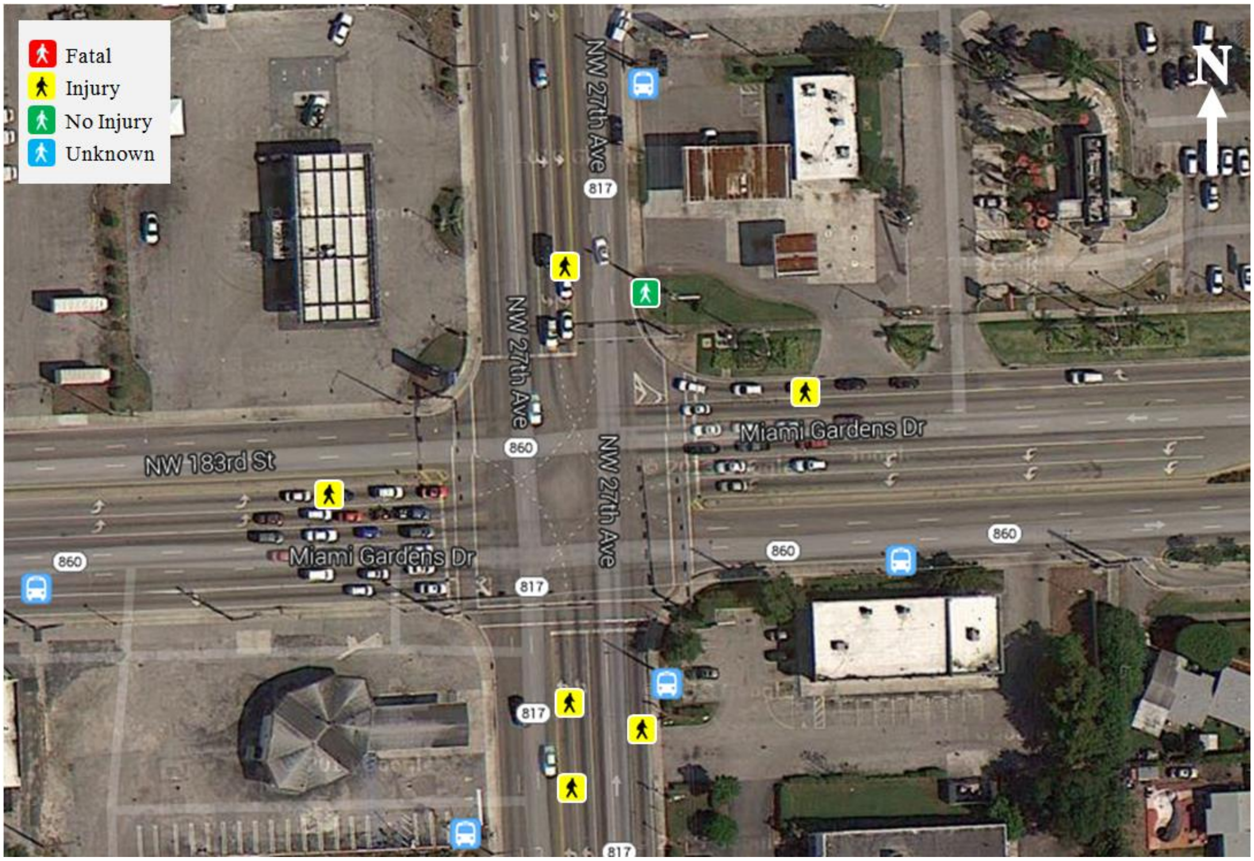


Figure 6-9: NW 27th St and NW 183rd St (Roadway ID 87019000; MP 2.74) (Map)

Figure 6-10: W Sunrise Blvd and NW 7th Ave (Roadway ID 86110000; MP 7.247) (Map)

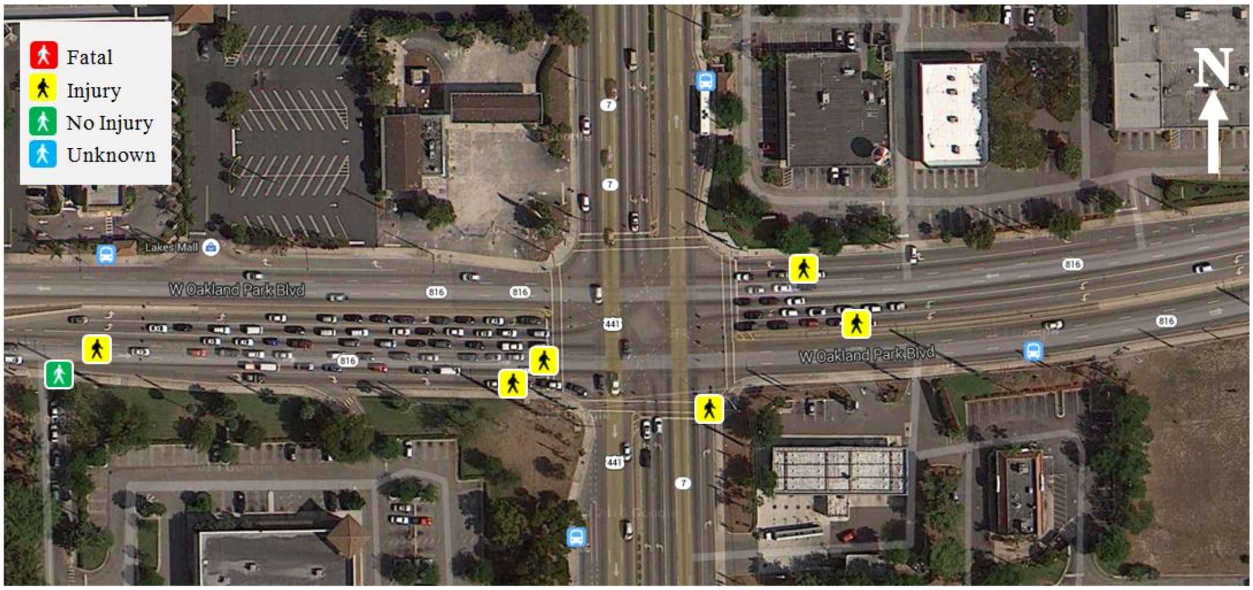



**Figure 6-11: W Oakland Park Blvd and SR 7 (Roadway ID 86090000; MP 3.323) ([Map](#))**

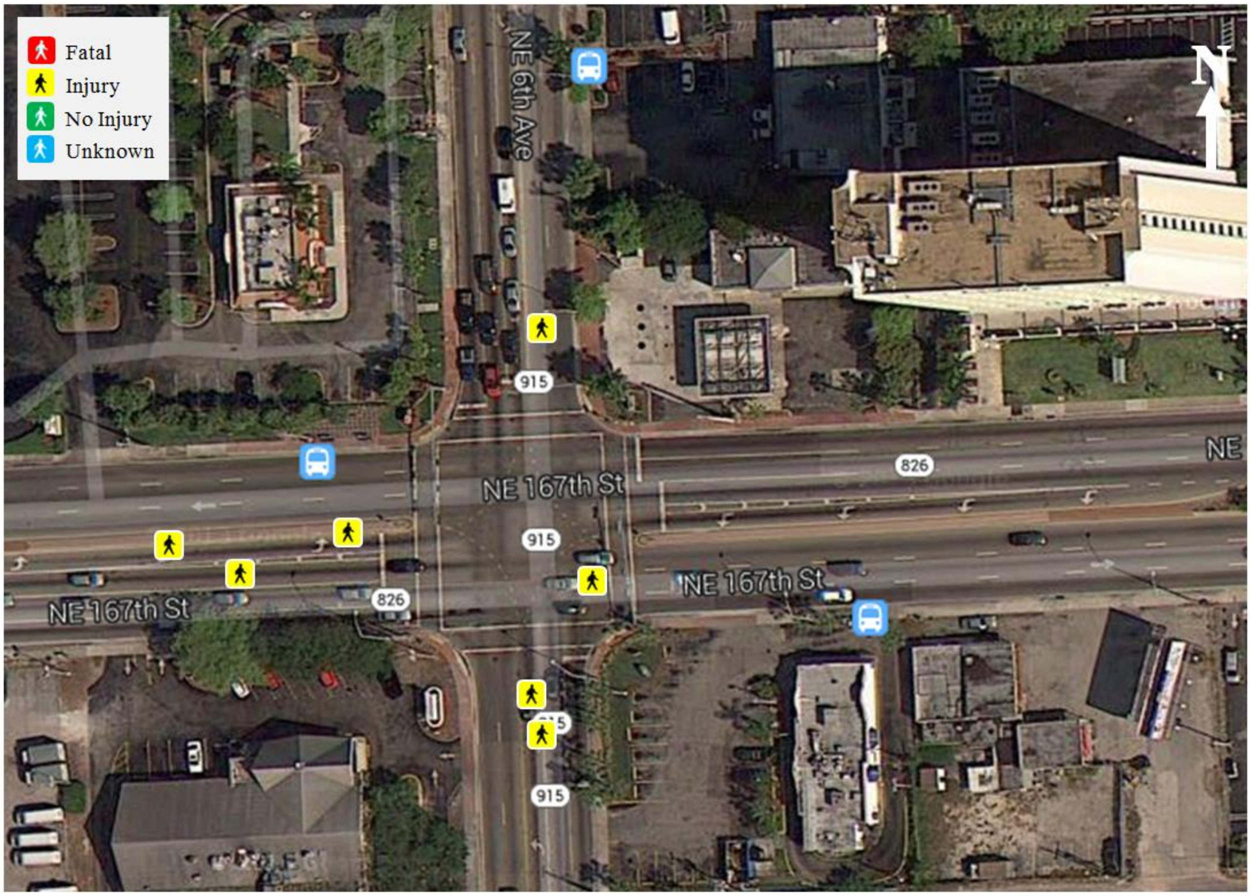



**Figure 6-12: NE 167th St and NE 6th Ave (Roadway ID 87170000; MP 1.477) ([Map](#))**

Figure 6-13: NE 36th St and Biscayne Blvd (Roadway ID 87030000; MP 13.48) ([Map])

Figure 6-14: NW 7th Ave and NW 54th St (Roadway ID 87140000; MP 4.126) ([Map])

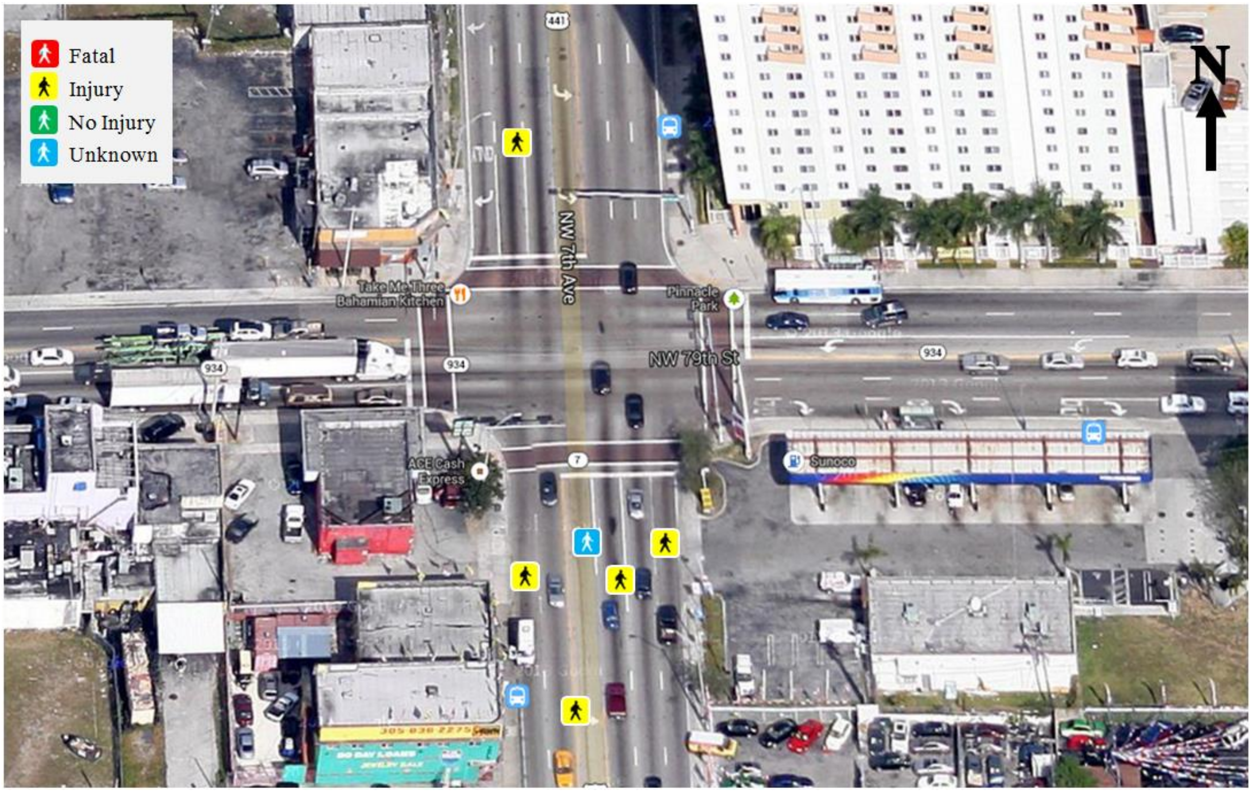


Figure 6-15: NW 79th St and NW 7th Ave (Roadway ID 87080900; MP 38.493) (Map)

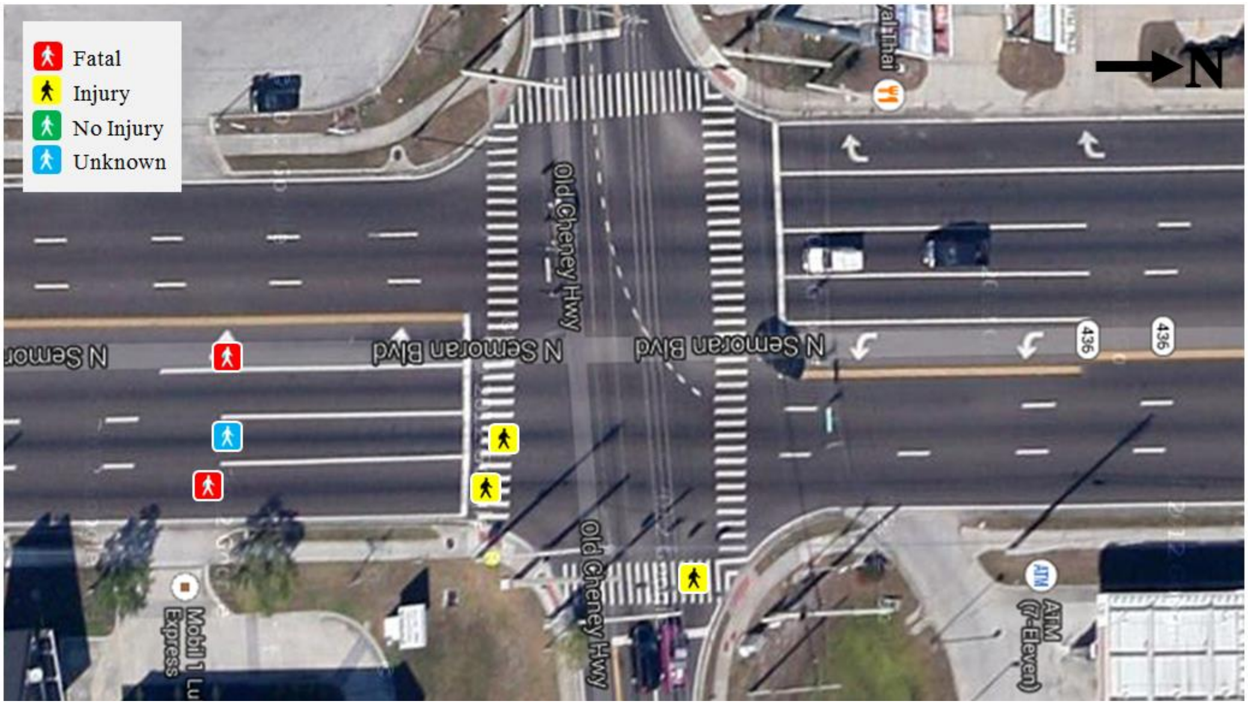


Figure 6-16: N Semoral Blvd and Old Cheney Hwy (Roadway ID 75003000; MP 7.611) (Map)

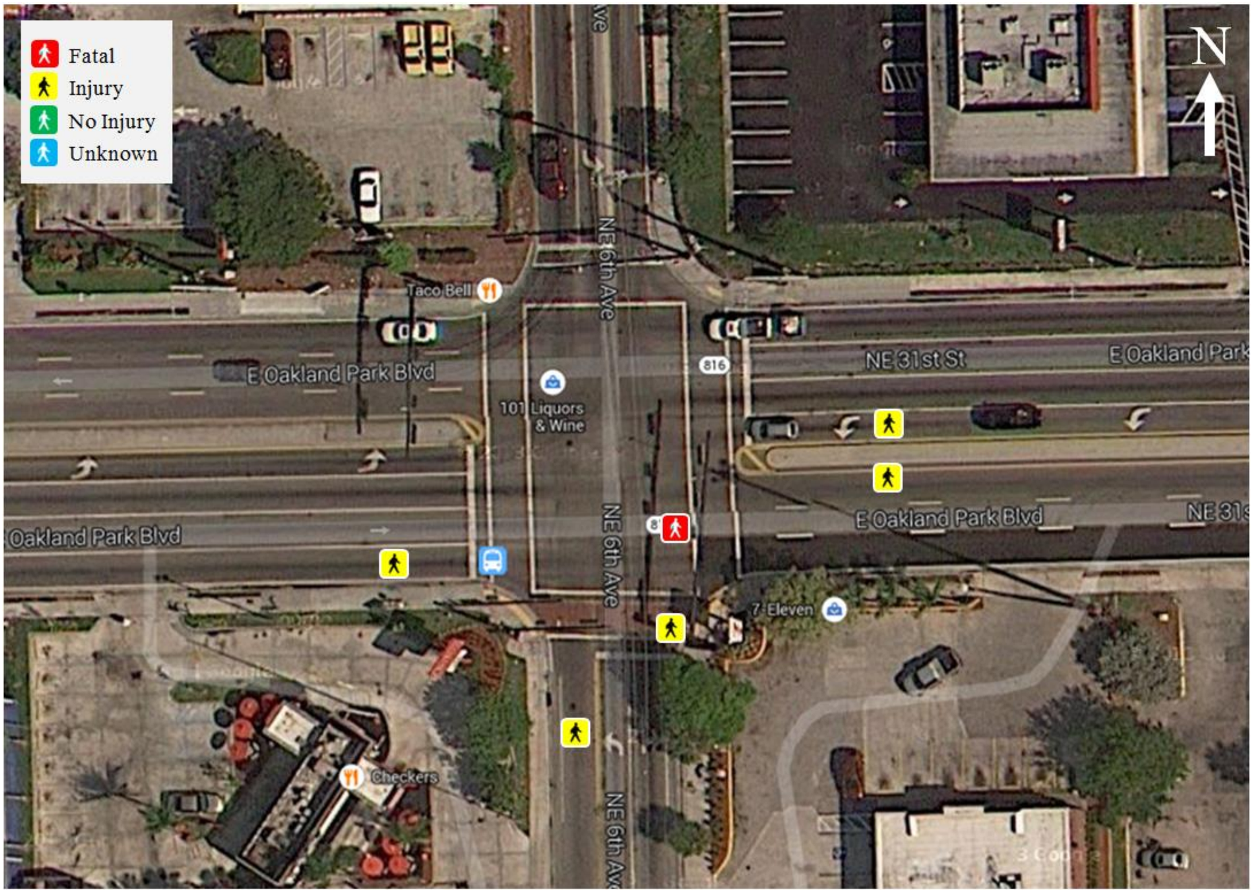



Figure 6-17: E Oakland Park Blvd and NE 6th Ave(Roadway ID 86090000; MP 7.356) (Map)

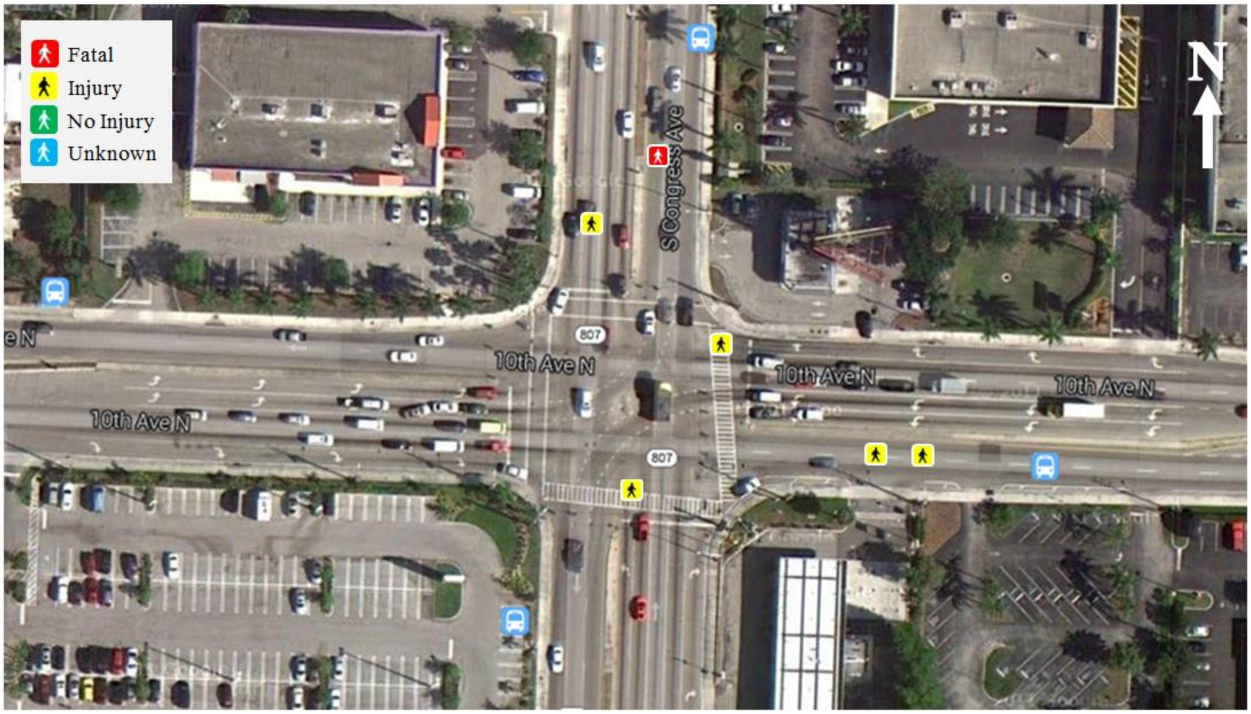



Figure 6-18: 10th Ave N and S Congress Ave (Roadway ID 93006000; MP 2.847) (Map)

Figure 6-19: Collins Ave and 174th St (Roadway ID 87060000; MP 15.142) (Map)

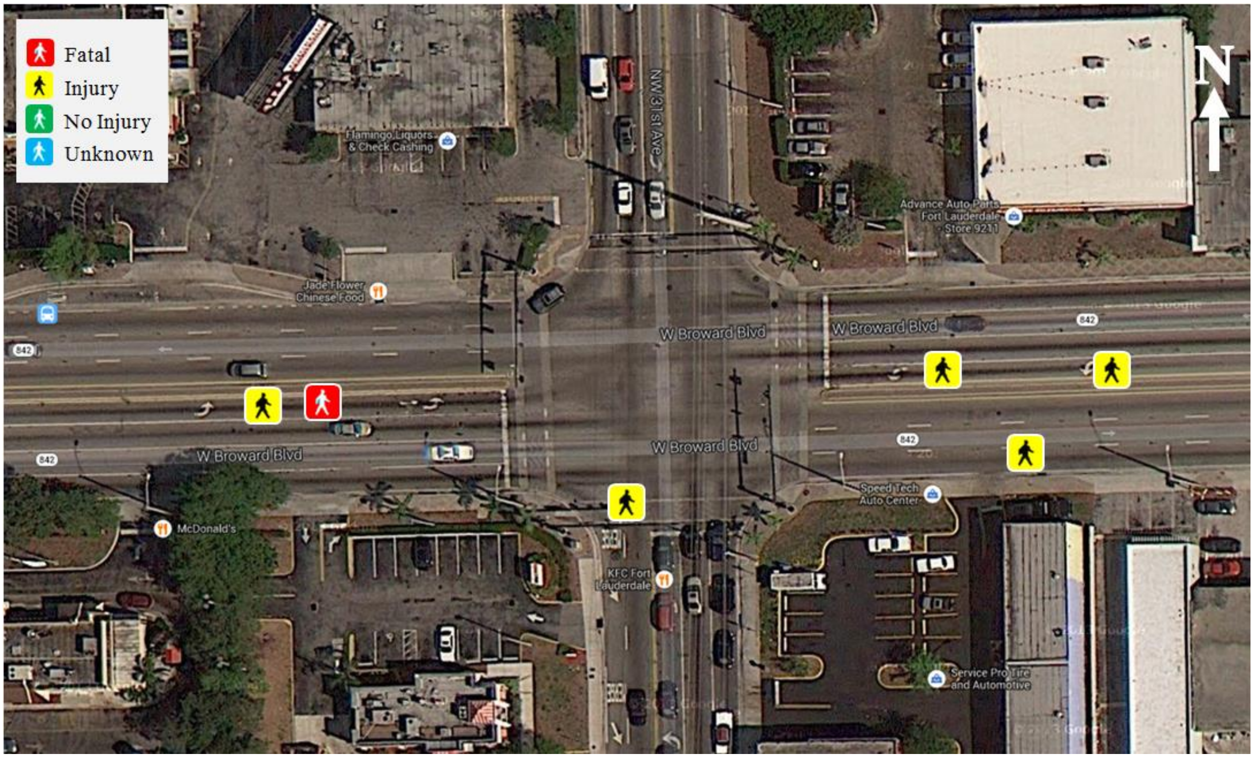


Figure 6-20: W Broward Blvd and NW 31st Ave (Roadway ID 86006000; MP 4.12) (Map)


**Figure 6-21: US 192 and N John Young Pkwy (Roadway ID 92090000; MP 14.635) (Map)**

### *6.2.3 Crash Contributing Factors and Potential Countermeasures*

This section focuses on reviewing the police reports of pedestrian crashes to identify factors that adversely affect the safety of pedestrians at signalized intersections. The 21 high crash urban signalized intersections experienced a total of 153 pedestrian crashes during 2008-2010. The illustrative sketches and descriptions in the police reports of these 153 crashes were reviewed and the crash contributing factors related to each of the following six types of crashes were analyzed:

1. Crashes that involved right-turning vehicles.
2. Crashes that involved left-turning vehicles.
3. Crashes that occurred in the vicinity of bus stops.
4. Crashes that involved pedestrians who were not crossing at designated crossing locations.
5. Crashes that occurred in left-turning lanes and right-most lanes.
6. Crashes that involved pedestrians in a crosswalk and through traffic.

#### *Crashes That Involved Right-turning Vehicles*

Although the law requires right-turning traffic to come to a full stop and yield to side-street traffic and pedestrians prior to turning right on red, motorists do not comply with these regulations. For example, two pedestrian crashes involving right-turning vehicles occurred on the south leg of the intersection shown in Figure 6-10. Figure 6-22 gives an example of a pedestrian crash involving a right-turning vehicle. In such scenarios, prohibiting right turns on red could be an easy strategy to minimize pedestrian conflicts involving right-turning vehicles.

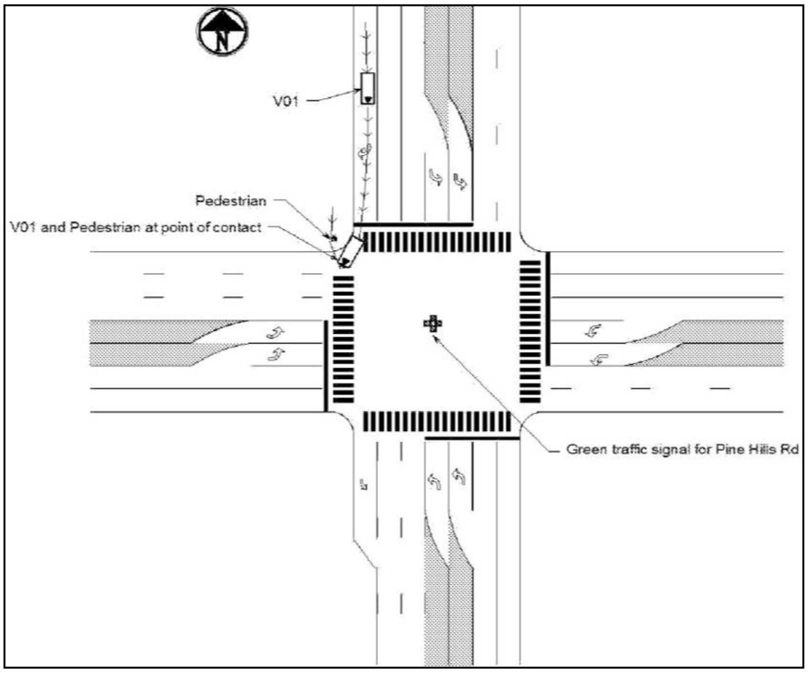



**Figure 6-22: Pedestrian Crash Involving Right-turning Vehicle (Crash ID: 819722650)**

At intersections with high right-turning traffic and pedestrian volumes, a leading pedestrian interval (LPI) could improve pedestrian safety. The LPI, also known as "Pedestrian Head Start" or "Delayed Vehicle Green" provides the "Walk" signal for additional 3-5 seconds before the adjacent through movement phase. This strategy gives pedestrians a head start while crossing the intersection, reducing conflicts between pedestrians in the crosswalk and the right-turning vehicles. It also makes the pedestrians more visible (Cheng, 2012). Figure 6-23 gives the ring-barrier diagram with LPI signal phase. Figure 6-24 illustrates the LPI signal.

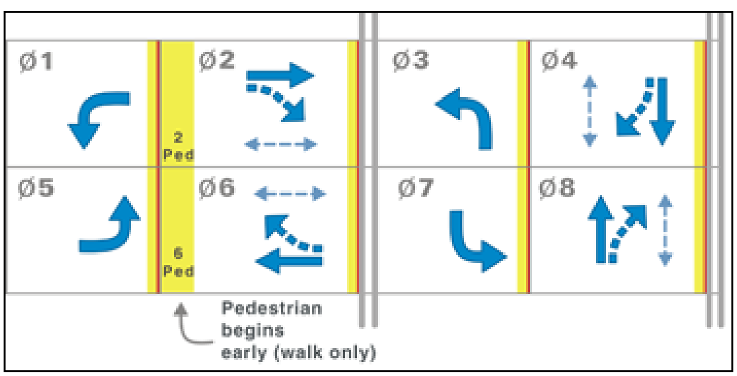
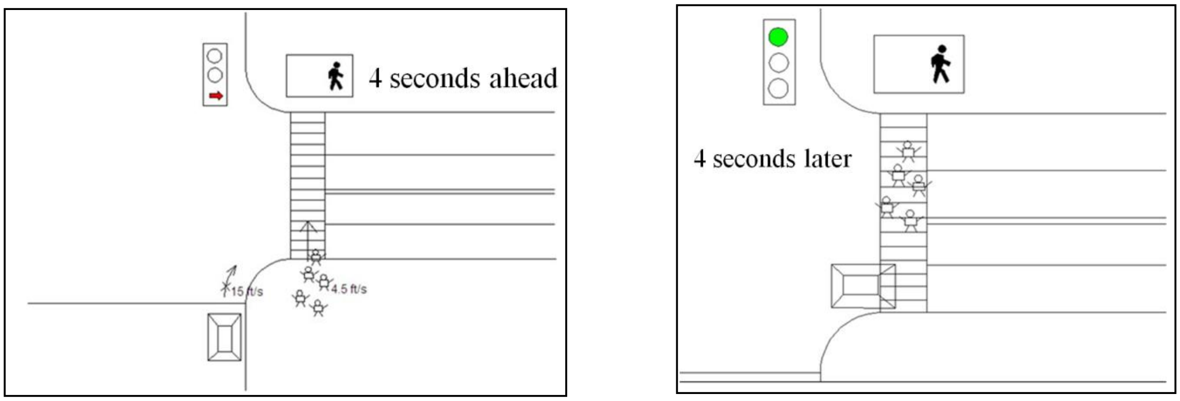



**Figure 6-23: Ring-Barrier Diagram with a Leading Pedestrian Interval (Koonce et al., 2008)**




(a) Start of the LPI (b) Four seconds later of the LPI

**Figure 6-24: An Illustrative Example of Leading Pedestrian Interval (Cheng, 2012)**

### *Crashes That Involved Left-turning Vehicles*

At signalized intersections with permissive or protected-permissive left-turn phase, the left-turning traffic has to yield to pedestrians and opposing through traffic prior to accepting the gap and completing the turn. In such scenarios, the left-turning vehicles sometimes fail to yield to pedestrians crossing the street. Figure 6-25 shows the vehicle-vehicle and vehicle-pedestrian conflict areas involving left-turning vehicles at signalized intersections. Figure 6-26 gives an example of a crash where a pedestrian in a crosswalk was hit by a left-turning vehicle.

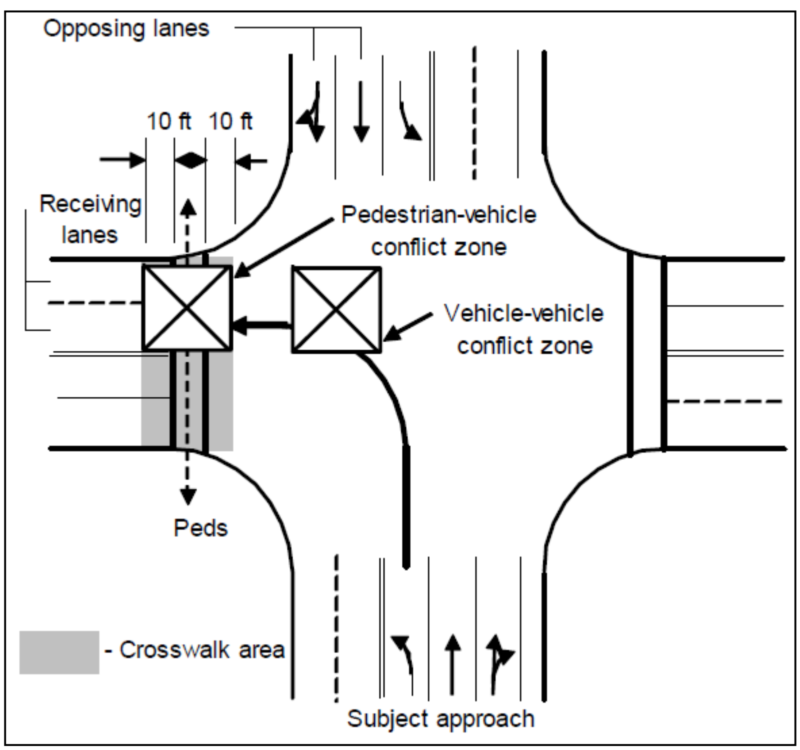



**Figure 6-25: Intersection Conflict Areas of Left-turning Traffic (Bonneson et al., 2011)**

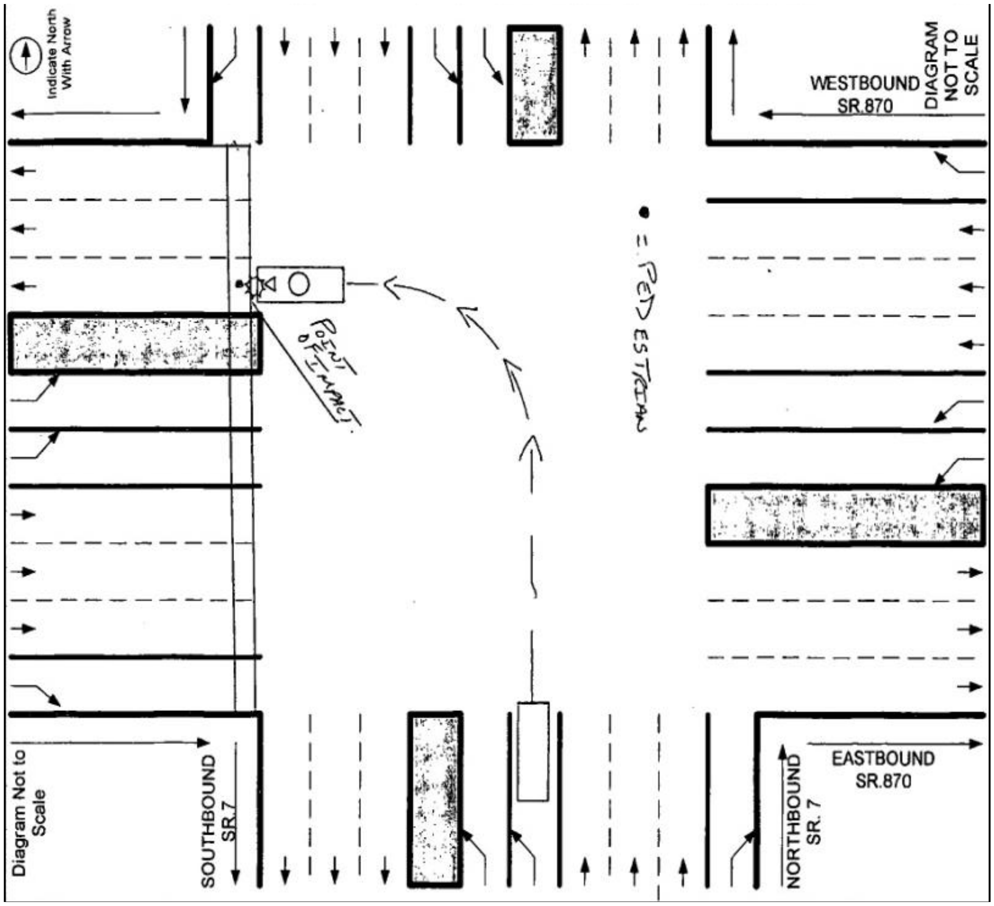



**Figure 6-26: Pedestrian Crash Involving Left-turning Vehicle (Crash ID: 909009530)**

Intersections with permissive or protected-permissive left-turn phasing could potentially have a high number of conflicts involving pedestrians and left-turning vehicles. These could be eliminated with a protected left-turn phase. Hence, at intersections with a high frequency of pedestrian crashes involving left-turning vehicles, the feasibility of providing protected left-turn signal phasing has to be considered. Although the locations do not warrant installation of protected left-turn signal phasing, it is recommended at locations with high pedestrian activity such as in school zones and near special-event facilities. Further, adding special pedestrian signal phasing, such as exclusive protected pedestrian signal could improve pedestrian safety.

### *Crashes That Occurred in the Vicinity of Bus Stops*

Proper placement of bus stops (i.e., at near-side or far-side of signalized intersections) is crucial to pedestrian safety. Near-side bus stops often block the pedestrian's view of oncoming traffic and the driver's view of pedestrians (PEDSAFE, 2013). Review of police reports at the 21 intersections found that several crashes occurred when pedestrian walked in front of the bus onto the approaching traffic. Figure 6-27 gives an example of a pedestrian crash where the pedestrian walked in front of the bus. Several crashes were also found to occur in the vicinity of bus stops. For example, at the intersection shown in Figure 6-7, four pedestrian crashes occurred on the south leg in the vicinity of the bus stop. Likewise, at the intersection shown in Figure 6-9, three pedestrian crashes occurred on the south leg in the vicinity of the bus stop.

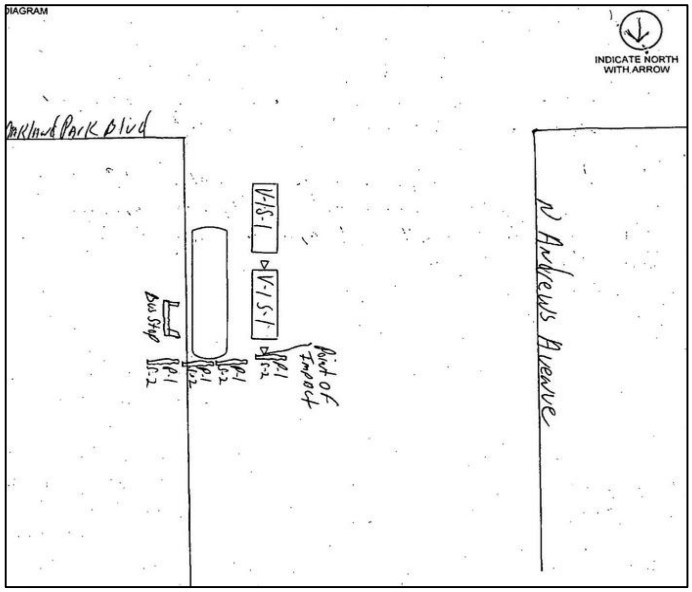



**Figure 6-27: Crash That Involved Pedestrian Walking In front of a Bus (Crash ID: 761813570)**

These types of pedestrian crashes could be prevented by improving roadway lighting and providing curb extensions in the vicinity of bus stops. Furthermore, since far-side bus stops generally encourage pedestrians to cross behind the bus, restrictions on sight-distance are eliminated, improving pedestrian safety. Therefore, the feasibility of relocating near-side bus stops to the far-side of the intersection has to be studied. Furthermore, signs to warn drivers of increased pedestrian activity near bus stops could make the drivers more attentive, and improve pedestrian safety.

*Crashes That Involved Pedestrians Who Were Not Crossing at Designated Crossing Locations*

Although 20 of the 21 intersections have crosswalks on their approaches, it was found that 80% of the 145 pedestrian crashes occurred while the pedestrian was not in the crosswalk. For example, the two signalized intersections shown in Figures 6-14 and 6-15 have a solid crosswalk with special surface on all of their approaches. These two intersections experienced a total of twelve pedestrian crashes, none of which occurred while pedestrians were walking in the crosswalk. Figure 6-28 gives a specific example of a pedestrian crash when the pedestrian was not using the crosswalk when hit by the vehicle. From the figure, it is clear that a standard crosswalk is present within a few feet from the pedestrian crossing location. Such crashes could have been prevented if the pedestrians were using the designated crossing locations, i.e., crosswalks. This behavior could be due to the lack of pedestrian education and enforcement. Pedestrians are often ignorant of the rules and right-of-way at pedestrian-vehicle conflict points. Further, stricter and consistent enforcement could change the pedestrian behavior.

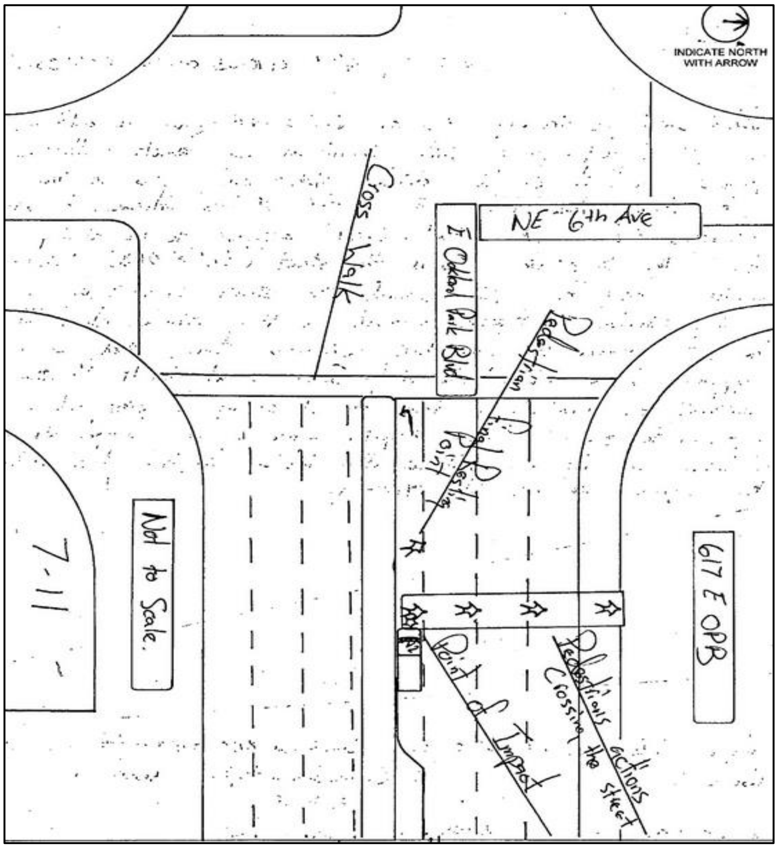



**Figure 6-28: Crash Where Pedestrian Was Not Using a Crosswalk Although a Crosswalk Is in the Vicinity (Crash ID: 906723850)**

*Crashes That Occurred in Left-turning Lanes and Right-most Lanes*

From reviewing the police reports, it was observed that several crashes occurred when pedestrians were crossing multiple lanes. For example, the intersection shown in Figure 6-16 experienced two fatal pedestrian crashes that occurred on the right-most and left-turning lanes on the south leg with no raised median. Figures 6-29 and 6-30 give examples of pedestrian crashes that occurred on the right-most and left-turning lanes, respectively. In these two crashes pedestrians were struck while crossing the fifth lane. At locations where pedestrians are expected to cross multi-lane roads with high travel speeds and heavy traffic, the following countermeasures could be effective in reducing pedestrian crash frequency and severity (PEDSAFE, 2013):

- ensure curb ramps are provided to make crossing easier for all pedestrians,
- install lighting along the corridor,
- require pedestrians to cross the roadway at designated crossing locations such as crosswalks,
- install traffic calming measures, such as providing speed bumps, lane narrowing, etc., and
- install raised medians.

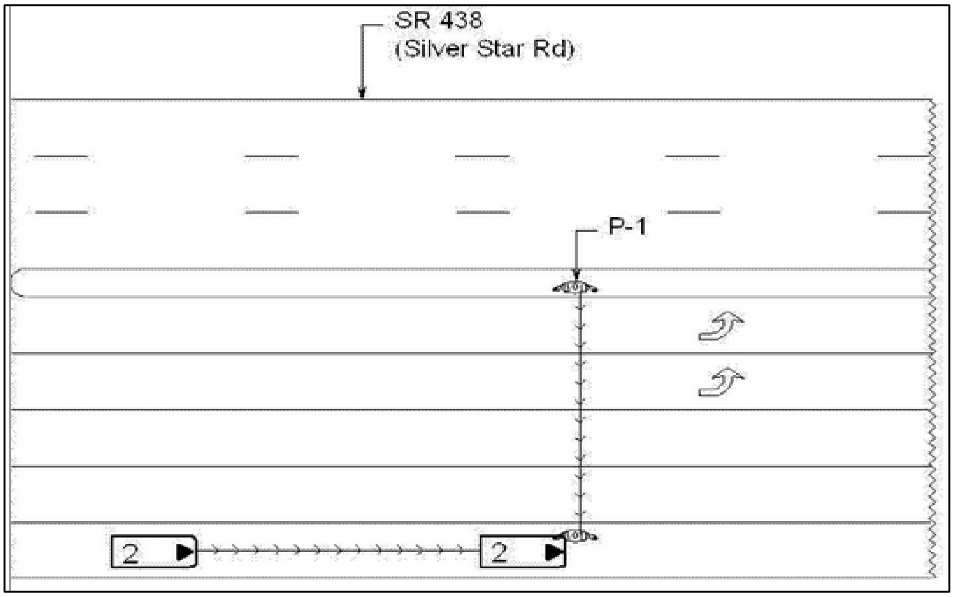



**Figure 6-29: Pedestrian Crash That Occurred in the Right-most Lane (Crash ID: 774261190)**

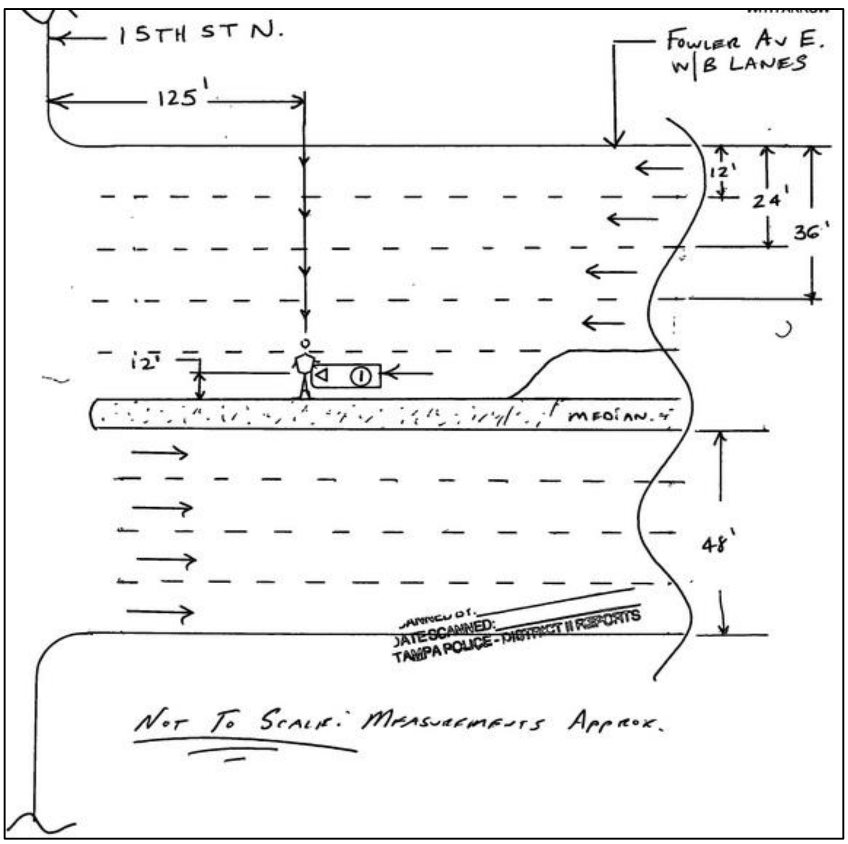
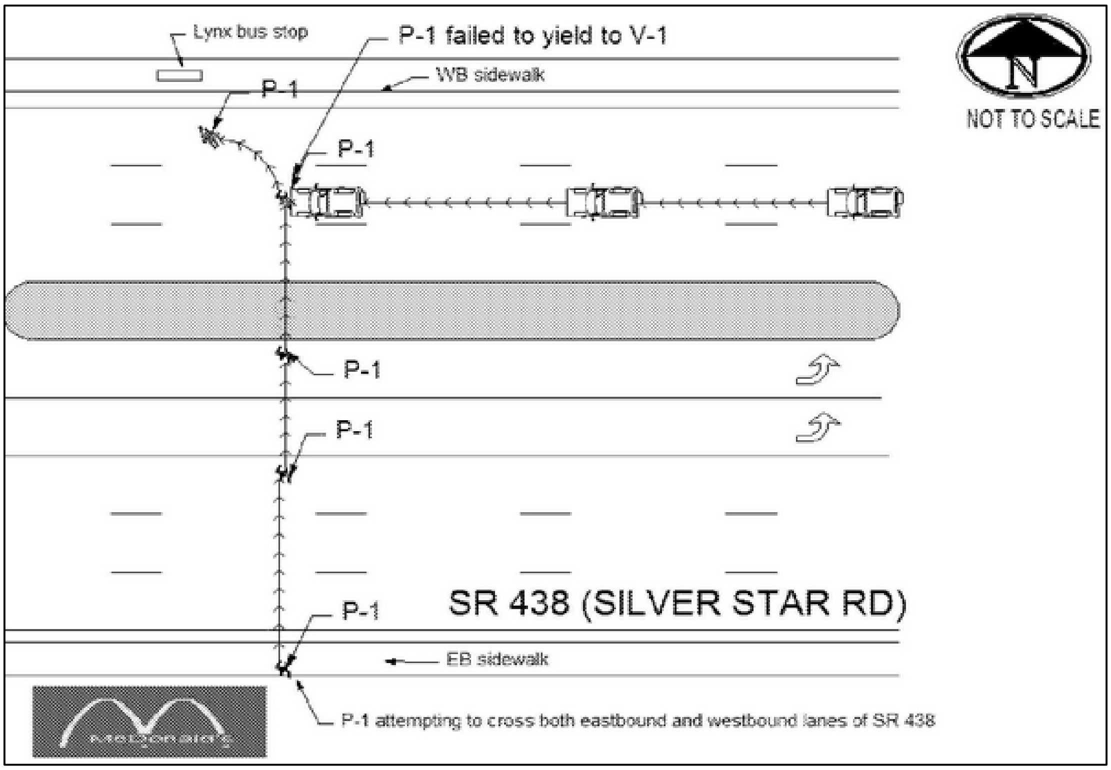



**Figure 6-30: Pedestrian Crash That Occurred in the Left-most Lane (Crash ID: 902134760)**

Although providing pedestrian refuge areas is often considered an effective countermeasure to improve the safety of pedestrians while crossing busy streets, police reports of some of the pedestrian crashes found that pedestrians sometimes do not stop at the median and continue to cross multiple lanes. For example, Figure 6-31 gives the description and illustrative sketch of a crash when a pedestrian was struck in the left-most lane. From the description in Figure 6-31(b), it is clear that the pedestrian did not use the median to stop and wait prior to crossing the west bound lanes. Therefore, agency-wide pedestrian education focusing on pedestrian right-of-way, the safety benefits of using crosswalks and pedestrian refuge areas, etc. could be beneficial.




(a) Illustrative Sketch from the Police report

Pedestrian 1 (P-1) was attempting to travel north across all eastbound and westbound lanes of SR 438 (Silver Star Rd) from the eastbound sidewalk while failing to yield to approaching traffic. Vehicle 1 (V-1) was traveling westbound on SR 438 (Silver Star Rd) in the center lane. P-1 while continuing to travel north on the westbound portion of SR 438 (Silver Star Rd) failed to yield to V-1, resulting in the front of V-1 colliding with the lower portion of P-1. P-1 as a result of the initial collision was thrown onto the right westbound lane of SR 438 (Silver Star Rd). Prior to my arrival P-1 had been moved from his final rest and was transported to Florida Hospital South. V-1 also had been moved from its final rest into a parking space at the China Wok restaurant parking lot (2702 Silver Star Rd, Orlando FL 32808). First Harmful Event 1 Unit 1 (77): V-1's front collided with the lower portion of P-1.Note: P-1 stated he failed to yield to approahing traffic because he was attempting to get to the Lynx bus stop on the westbound sidewalk on SR 438 (Silver Star Rd).
Latitude: 28.578325 Longitude: -81.4528233333333

(a) Crash Description from the Police report

**Figure 6-31: Pedestrian Crash Where Median Was Not Used as a Refuge Area (Crash ID: 776997890)**

*Crashes That Involved Pedestrians in a Crosswalk and Through Traffic*

Through traffic is required to stop for pedestrians in crosswalks. Although vehicles in one lane often stop for pedestrians, the drivers in the other lanes sometimes do not see the pedestrians in crosswalks and do not stop, resulting in potential vehicle-pedestrian conflicts. Figure 6-32 illustrates this scenario. Figure 6-33 gives an example of a pedestrian crash where traffic in two lanes stopped for the pedestrian and the vehicle in the right-most lane hit the pedestrian who was crossing the street in the crosswalk. These crashes are often severe since the through traffic travels at high speeds. These crashes could be eliminated through extensive driver education campaigns that focus on driver compliance with pedestrian right-of-way laws. Furthermore, stricter enforcement could prevent these types of crashes.

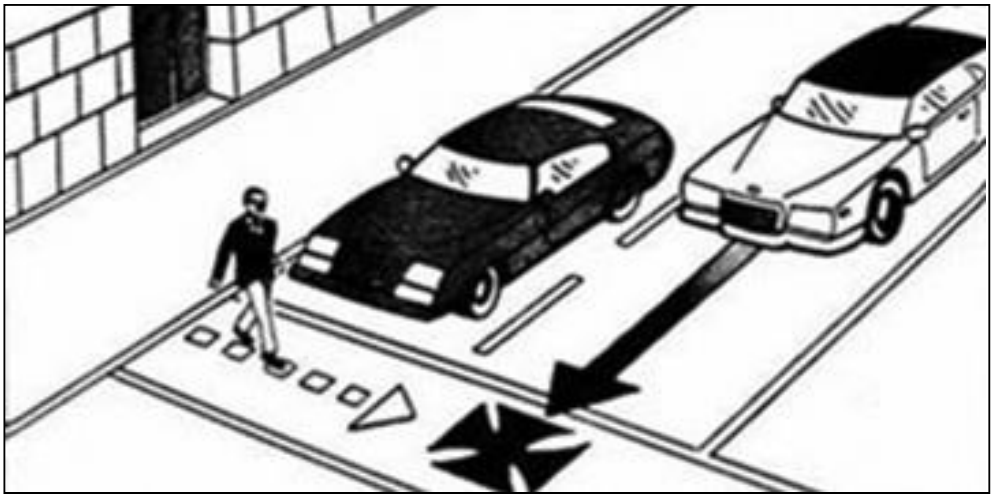


**Figure 6-32: Potential Conflict between Pedestrian in a Crosswalk and Through Traffic (University of Georgia, 2013)**

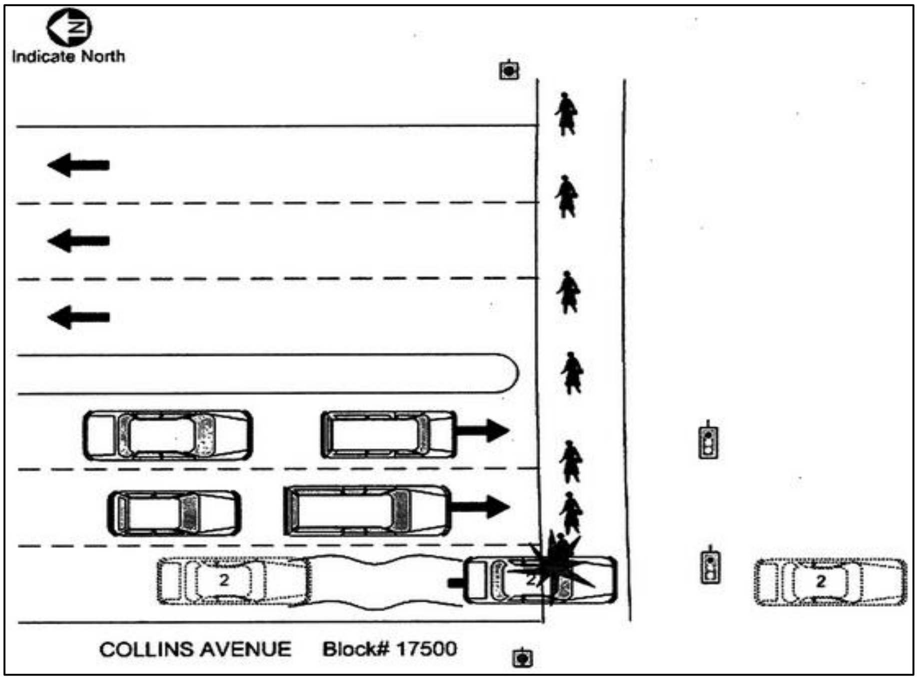



**Figure 6-33: Pedestrian Hit by Oncoming Traffic in Adjacent Lane (Crash ID: 801572120)**

### 6.3 Summary

This chapter focused on identifying and analyzing urban signalized intersections with high pedestrian crash frequencies. Urban signalized intersections with observed pedestrian crash frequency greater than three standard deviations from the average crash frequency were identified and analyzed. A total of 21 signalized intersections with $\geq$ 6 pedestrian crashes during 2008-2010 were included in the analysis. Police reports of all the crashes that occurred at these high crash intersections were reviewed and the crash contributing factors related to each of the following six types of crashes were analyzed:

1. Crashes that involved right-turning vehicles.
2. Crashes that involved left-turning vehicles.
3. Crashes that occurred in the vicinity of bus stops.
4. Crashes that involved pedestrians who were not crossing at designated crossing locations.
5. Crashes that occurred in left-turning lanes and right-most lanes.
6. Crashes that involved pedestrians in a crosswalk and through traffic.

At locations where pedestrians are expected to cross multi-lane roads with high travel speeds and heavy traffic, the following countermeasures could be effective in reducing pedestrian crash frequency and severity (PEDSAFE, 2013):

- ensure curb ramps are provided to make crossing easier for all pedestrians,
- install lighting along the corridor,
- require pedestrians to cross the roadway at designated crossing locations such as crosswalks,
- install traffic calming measures, such as providing speed bumps, lane narrowing, etc., and
- install raised medians.

Several pedestrian crashes at signalized intersections involved left-turning and right-turning vehicles. Turning vehicles often hit pedestrians in crosswalk and when pedestrians have the right-of-way. These types of crashes could be prevented by eliminating the potential vehicle-pedestrian conflicts. At locations with high pedestrian volumes, prohibiting right turns on red could be an easy strategy to minimize pedestrian conflicts involving right-turning vehicles. Additionally, providing a leading pedestrian interval (LPI) that gives pedestrians a head start while crossing the intersection could improve pedestrian safety. Pedestrian crashes involving left-turning vehicles could be reduced by providing either a protected left-turn phase or an exclusive protected pedestrian signal.

Several pedestrian crashes occurred when the pedestrians walked in front of the bus onto the approaching traffic. These types of pedestrian crashes could be prevented by improving roadway lighting and providing curb extensions in the vicinity of bus stops. Furthermore, relocating near-side bus stops to the far-side of the intersection could eliminate sight-distance restrictions, improving pedestrian safety.

About 80% of the 145 pedestrian crashes that occurred at the 21 signalized intersections occurred while the pedestrian was not in the crosswalk. However, it is to be noted that 20 of these 21 intersections have crosswalks on their approaches. Several of these crashes could have been prevented if the pedestrians were walking in the crosswalks. This behavior could be due to the lack of pedestrian education and enforcement. Agency-wide education campaigns on the laws pertaining to pedestrians and the safety benefits of using pedestrian facilities such as crosswalks, sidewalks, and pedestrian refuge islands could improve pedestrian safety. Furthermore, extensive driver education campaigns that focus on driver compliance with pedestrian right-of-way laws and stricter enforcement could prevent the crashes that were due to driver error.

# CHAPTER 7
# NON-SIGNALIZED LOCATIONS

This chapter focuses on identifying and analyzing non-signalized locations with high pedestrian crash frequencies. It provides the district-wide list of pedestrian high crash non-signalized locations. It includes the analysis of high crash non-signalized locations in the entire state. The statewide analysis focused on locations with pedestrian crash frequency greater than the critical crash frequency. Police reports of all the crashes that occurred at these high crash non-signalized locations are reviewed in detail to identify specific pedestrian crash types. Crash contributing factors related to each crash type along with specific countermeasures are then discussed.

## 7.1 District-wide Pedestrian High Crash Non-signalized Locations

As identified in Section 4.2.3, a total of 2,945 pedestrian crashes were found to occur at non-signalized locations, which include both non-signalized intersections and midblock sections. ArcGIS 10.0 was used to identify the high crash non-signalized locations. The 2,945 pedestrian crashes that occurred at non-signalized locations during 2008-2010 were first imported into ArcGIS 10.0 and were spatially located along the State Roads Layer using Linear Referencing Tool. A 150-ft buffer was then generated around each crash. Locations with higher concentrations of pedestrian crashes were identified by dissolving the overlapping buffers. For example, if two crashes were within 150 ft of each other, their buffers (which overlap) were dissolved to create a larger buffer. Information on the roadway ID and begin and end milepost of each of the dissolved buffer was then retrieved. Also, the total number of crashes in each dissolved buffer was retrieved. These dissolved buffers are considered as non-signalized locations with at least one pedestrian crash, and are used in the analysis. Table 7-1 provides the list of pedestrian high crash non-signalized locations by district ranked based on total pedestrian crash frequency during 2008-2010.

**Table 7-1: Pedestrian High Crash Non-signalized Locations in Each District**

| No. | Roadway Name | Roadway ID | Milepost | Fatal Crashes | Injury Crashes | Total Crashes |
|---|---|---|---|---|---|---|
| **District 1** | | | | | | |
| 1 | 14th St W near 27th Ave W, Bradenton | 13010000 | 6.233 | 2 | 2 | 4 |
| 2 | 14th St W near 66th Ave, Bradenton | 13010000 | 2.688 | 1 | 2 | 3 |
| 3 | N Tamiami Trail near Crescent Lake Dr, North Fort Myres | 12001000 | 2.237 | 1 | 2 | 3 |
| 4 | N Washington Blvd near 5th St, Sarasota | 17120000 | 0.852 | 1 | 1 | 3 |
| 5 | N Combee Rd near Tanglewood St, Lakeland | 16006000 | 3.586 | 0 | 3 | 3 |
| 6 | 14th St W near 56th Ave, Bradenton | 13010000 | 3.876 | 0 | 3 | 3 |
| **District 2** | | | | | | |
| 1 | 3rd St N near 2nd Ave N, Jacksonville Beach | 72100000 | 17.909 | 0 | 4 | 4 |
| **District 3** | | | | | | |
| 1 | Gulf Bch Hwy near Colbert Ave, Pensacola | 48050000 | 15.737 | 0 | 4 | 5 |
| 2 | Front Brach Rd near 16th St, Panama City Beach | 46010000 | 4.335 | 1 | 2 | 3 |

| No. | Roadway Name | Roadway ID | Milepost | Fatal Crashes | Injury Crashes | Total Crashes |
|---|---|---|---|---|---|---|
| 3 | Front Beach Rd near Cobb Rd, Panama City Beach | 46010000 | 6.597 | 0 | 3 | 3 |
| 4 | W Cervantes St near North N St, Pensacola | 48020000 | 13.559 | 0 | 2 | 3 |
| | **District 4** | | | | | |
| 1 | Griffin Rd near SW 33rd Ave, Ft Lauderdale | 86015000 | 7.957 | 4 | 2 | 6 |
| 2 | S Federal Hwy near SE 19th St, Ft Lauderdale | 86010000 | 8.644 | 1 | 3 | 4 |
| 3 | S Military Trail near Sunset Ranch Rd, West Palm Beach | 93070000 | 22.864 | 0 | 4 | 4 |
| 4 | N Ocean Dr near Buchanan St, Hollywood | 86030000 | 2.966 | 0 | 4 | 4 |
| 5 | Commercial Blvd near Poincian St, Lauderdale-by-the-Sea | 86014000 | 9.833 | 0 | 4 | 4 |
| | **District 5** | | | | | |
| 1 | US 441 and 41st St, Orlando | 75010000 | 10.646 | 1 | 5 | 6 |
| 2 | US 441 near 45th St, Orlando | 75010000 | 10.357 | 1 | 2 | 4 |
| 3 | SR 530 near Seralago Blvd, Kissimmee | 92090000 | 7.454 | 1 | 2 | 3 |
| 4 | Edgewater Dr near Satel Dr, Orlando | 75260000 | 4.486 | 1 | 2 | 3 |
| 5 | US 92 near Principal Row, Orlando | 75010000 | 5.345 | 1 | 2 | 3 |
| 6 | SR 436 (S Semoran Blvd) near Danube Way, Orlando | 75003000 | 5.831 | 1 | 2 | 3 |
| 7 | US 1 near Cottrell Ave, Cocoa | 70020000 | 29.052 | 1 | 1 | 3 |
| 8 | US 441 near Washington Ave, Kissimmee | 92010000 | 12.424 | 0 | 3 | 3 |
| 9 | US 441 near Doss Ave, Orlando | 75010000 | 8.355 | 0 | 3 | 3 |
| 10 | Hoffner Ave near Kempston Dr, Orlando | 75080000 | 11.921 | 0 | 3 | 3 |
| 11 | E Colonial Dr near Sherman St, Orlando | 75060000 | 14.757 | 0 | 2 | 3 |
| | **District 6** | | | | | |
| 1 | SW 12th Ave near SW 3rd St, Miami | 87085000 | 1.303 | 1 | 6 | 9 |
| 2 | NE 6th Ave near NE 149th St, Miami | 87034000 | 3.899 | 0 | 9 | 9 |
| 3 | SW 8th St near SW 36th Ct, Miami | 87120000 | 14.179 | 1 | 7 | 8 |
| 4 | SW 107th Ave South of SW 88th St, Miami | 87072000 | 0.960 | 0 | 7 | 7 |
| 5 | Collins Ave near 15th St, Miami Beach | 87060000 | 4.661 | 0 | 6 | 6 |
| 6 | NW 79th St near NW 9th Ave, Miami | 87080900 | 38.273 | 0 | 4 | 5 |
| 7 | SR 989 near SW 211th St, Miami | 87015000 | 2.747 | 0 | 4 | 4 |
| 8 | NE 6th Ave/SR 915 near NE 154th St, Miami | 87034000 | 4.137 | 0 | 4 | 4 |
| 9 | NW 47th Ave near NW 183rd St, Miami Gardens | 87012000 | 0.038 | 0 | 4 | 4 |
| 10 | NW 183rd St near Red Rd/NW 57th Ave in Hialeah | 87026000 | 0.038 | 0 | 4 | 4 |
| 11 | NW 183rd St/Miami Gardens Dr near NW 47th Ave, Miami Gardens | 87026000 | 1.041 | 0 | 4 | 4 |
| 12 | NW 79th St near NW 4th Ave, Miami | 87080900 | 38.850 | 0 | 3 | 4 |

| No. | Roadway Name | Roadway ID | Milepost | Fatal Crashes | Injury Crashes | Total Crashes |
|---|---|---|---|---|---|---|
| 13 | NW 7th Ave North of NW 121st St, North Miami | 87140000 | 8.378 | 0 | 2 | 4 |
| **District 7** | | | | | | |
| 1 | Gulf Blvd near 106th Ave, Treasure Island | 15100000 | 4.833 | 1 | 6 | 8 |
| 2 | 4th St N North of 6th Ave N, St Petersburg | 15090000 | 1.021 | 0 | 5 | 7 |
| 3 | Seminole Blvd near 98th Ave, Seminole | 15010000 | 13.274 | 2 | 1 | 5 |
| 4 | Blind Pass Rd near 77th Ave, St Petersburg | 15100000 | 2.727 | 1 | 4 | 5 |
| 5 | 4th St N near 74th Ave N, St Petersburg | 15090000 | 5.204 | 0 | 4 | 5 |
| 6 | US 19 South of SR 52, Bayonet Point | 14030000 | 11.375 | 2 | 2 | 4 |
| 7 | Seminole Blvd near 14th Ave SW, Largo | 15010000 | 16.195 | 1 | 3 | 4 |
| 8 | US 19 near Panorama Ave, Holiday | 14030000 | 0.476 | 1 | 3 | 4 |
| 9 | US 19 near Bartelt Rd, Holiday | 14030000 | 0.786 | 1 | 3 | 4 |
| 10 | Gulf to Bay Blvd near Elizabeth Ave, Clearwater | 15040000 | 5.103 | 2 | 1 | 3 |
| 11 | US 19 near Green Key Rd, New Port Richey | 14030000 | 5.647 | 1 | 2 | 3 |
| 12 | SR 52 East of US 19, Bayonet Point | 14120000 | 0.106 | 0 | 3 | 3 |
| 13 | US 19 near Florestate Dr, Hudson | 14030000 | 12.782 | 0 | 3 | 3 |
| 14 | 5th Ave N near 15th St N, St Petersburg | 15010000 | 0.932 | 0 | 3 | 3 |

*Notes: This table includes locations with at least 3 crashes, with the exceptions (i.e., not listed) of 15 locations with 3 crashes in District 4, and 24 locations with 3 crashes in District 6. Total crashes include no injury and unknown injury crashes. The mileposts in this table represent the approximate center position of each non-signalized location.*

## 7.2 Statewide Pedestrian High Crash Non-signalized Locations

In this section, the overall top high crash non-signalized locations statewide were further identified based on critical pedestrian crash frequency for detailed analysis.

### *7.2.1 Location Identification*

Similar to the analysis of signalized intersections in Chapter 6, non-signalized locations with observed pedestrian crash frequency greater than three standard deviations from the average crash frequency were identified and analyzed. Non-signalized locations that experienced one pedestrian crash during the three-year analysis period were excluded from the analysis as one crash is considered to be a random occurrence. A total of 351 non-signalized locations were found to experience more than one pedestrian crash during the three-year analysis period. During 2008-2010, these locations experienced an average of 2.50 pedestrian crashes, with a standard deviation ($\sigma$) of 1.06 pedestrian crashes. A total of 14 non-signalized locations experienced $\geq 5$ crashes (i.e., crash frequency > avg. freq. + $3\sigma$) during 2008-2010. Table 7-2 lists these 14 non-signalized locations.

**Table 7-2: Statewide Pedestrian High Crash Non-signalized Locations**

| No. | Roadway Name | District | Roadway ID | Milepost | Fatal Crashes | Injury Crashes | Total Crashes |
|---|---|---|---|---|---|---|---|
| 1 | NE 6th Ave near NE 149th St, Miami | 6 | 87034000 | 3.899 | 0 | 9 | 9 |
| 2 | SW 12th Ave near SW 3rd St, Miami | 6 | 87085000 | 1.303 | 1 | 6 | 9 |
| 3 | SW 8th St near SW 36th Ct, Miami | 6 | 87120000 | 14.179 | 1 | 7 | 8 |
| 4 | Gulf Blvd near 106th Ave, Treasure Island | 7 | 15100000 | 4.883 | 1 | 6 | 8 |
| 5 | SW 107th Ave South of SW 88th St, Miami | 6 | 87072000 | 0.960 | 0 | 7 | 7 |
| 6 | 4th St N North of 6th Ave N, St Petersburg | 7 | 15090000 | 1.021 | 0 | 5 | 7 |
| 7 | Collins Ave near 15th St, Miami Beach | 6 | 87060000 | 4.661 | 0 | 6 | 6 |
| 8 | US 441 and 41st St, Orlando | 5 | 75010000 | 10.646 | 1 | 5 | 6 |
| 9 | Griffin Rd near SW 33rd Ave, Ft Lauderdale | 4 | 86015000 | 7.957 | 4 | 2 | 6 |
| 10 | Seminole Blvd near 98th Ave, Seminole | 7 | 15010000 | 13.274 | 2 | 1 | 5 |
| 11 | NW 79th St near NW 9th Ave, Miami | 6 | 87080900 | 38.273 | 0 | 4 | 5 |
| 12 | 4th St N near 74th Ave N, St Petersburg | 7 | 15090000 | 5.204 | 0 | 4 | 5 |
| 13 | Blind Pass Rd near 77th Ave, St Petersburg | 7 | 15100000 | 2.727 | 1 | 4 | 5 |
| 14 | Gulf Bch Hwy near Colbert Ave, Pensacola | 3 | 48050000 | 15.737 | 0 | 4 | 5 |

*Note: Total crashes include no injury and unknown injury crashes. The mileposts in this table represent the approximate center position of each non-signalized location.*

### *7.2.2 Condition-collision Diagrams*

Figures 7-1 through 7-14 plot the "condition-collision" diagrams of the 14 high crash non-signalized locations. In these diagrams, the locations of all pedestrian crashes were plotted on the satellite images. The figures also provide additional information on the injury severity of the pedestrian using the following codes:

- red – fatal
- yellow – injury
- green – no injury to pedestrian
- blue – unknown injury to pedestrian

Figure 7-1: NE 6th Ave near NE 149th St in Miami (Roadway ID 87034000; MP 3.899) ([Map](#))

Figure 7-2: SW 12th Ave near SW 3rd St in Miami (Roadway ID 87085000; MP 1.303) ([Map](#))

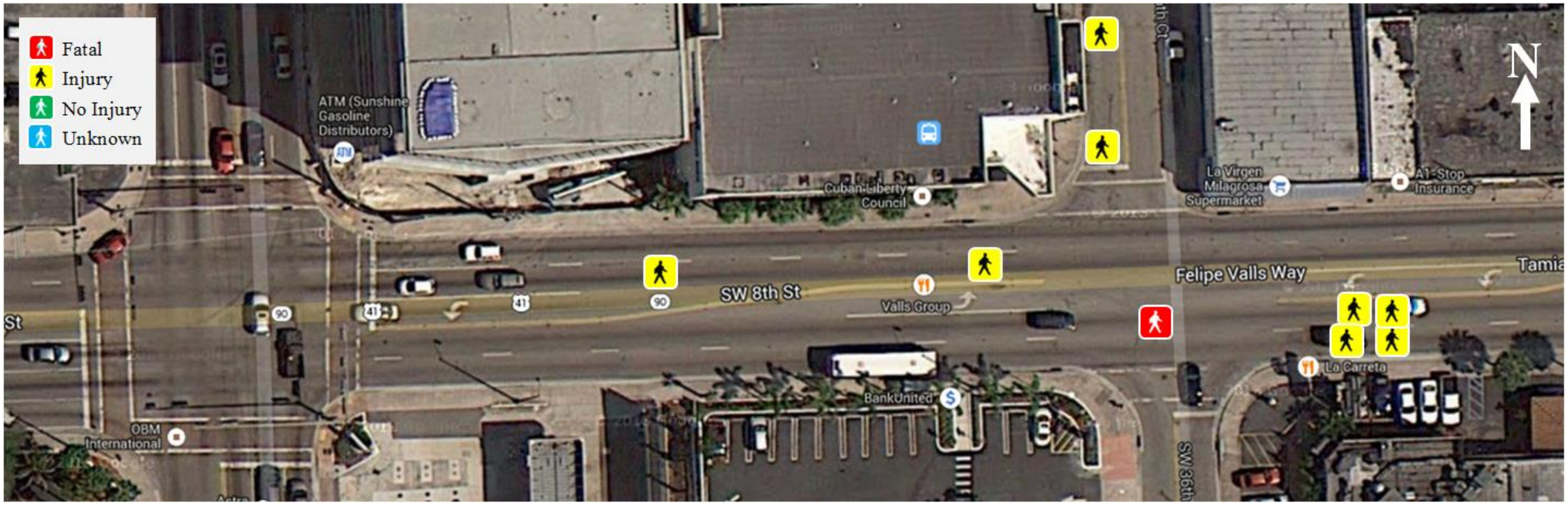



Figure 7-3: SW 8th St near SW 36th Ct in Miami (Roadway ID 87120000; MP 14.179) (Map)

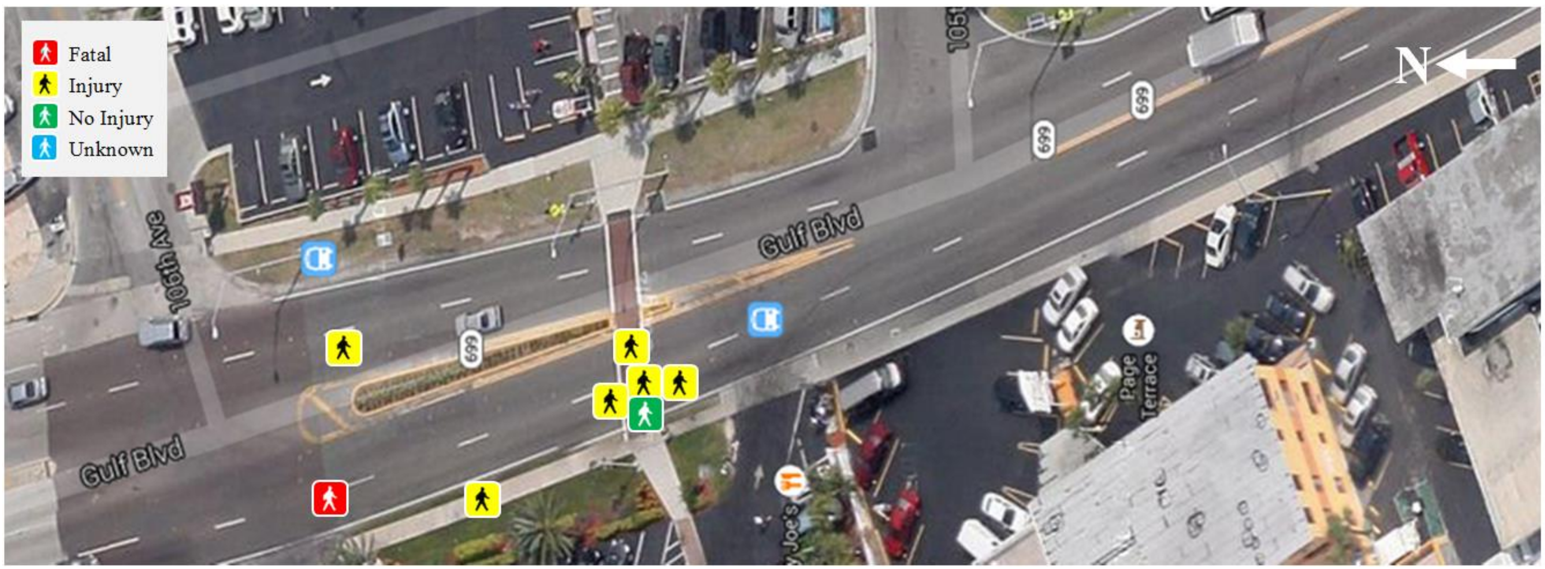



Figure 7-4: Gulf Blvd near 106th Ave in Treasure Island (Roadway ID 15100000; MP 4.883) (Map)

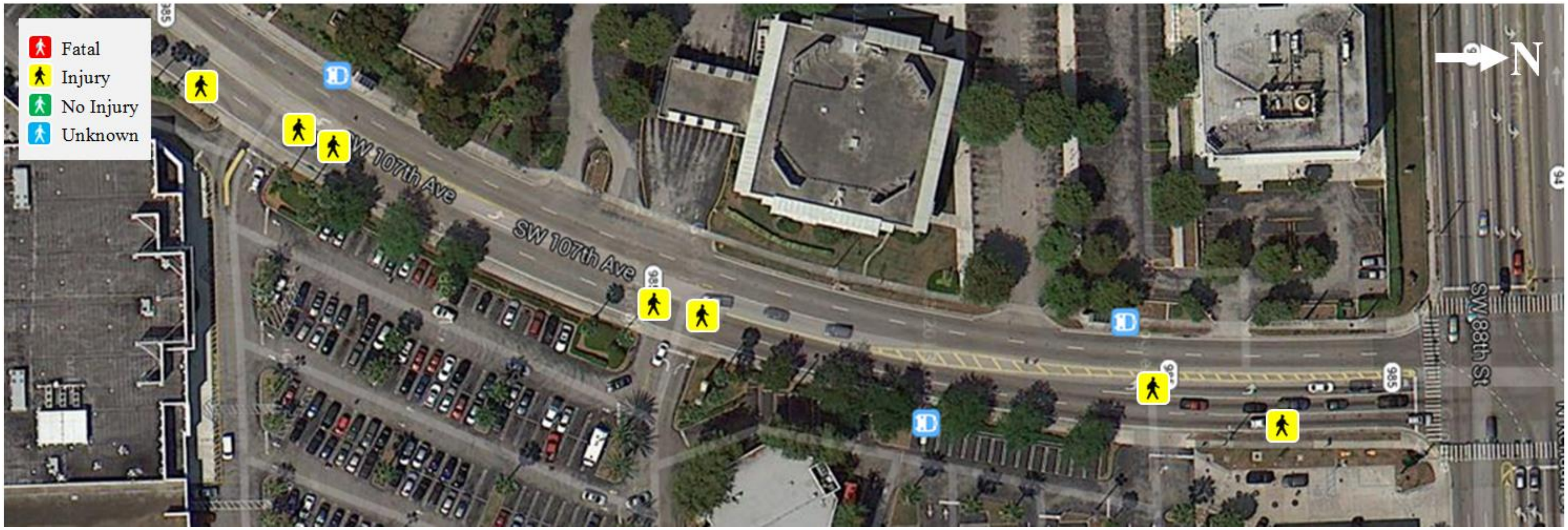


Figure 7-5: SW 107th Ave South of SW 88th St in Miami (Roadway ID 87072000; MP 0.960) ([Map](#))

Figure 7-6: 4th St N near 6th Ave N in St Petersburg (Roadway ID 15090000; MP 1.021) ([Map](#))

Figure 7-7: Collins Ave near 15th St in Miami Beach (Roadway ID 87060000; MP 4.661) ([Map](Map))

Figure 7-8: US 441 and 41st Street in Orlando (Roadway ID 75010000; MP 10.646) ([Map](Map))


**Figure 7-9: Griffin Rd near SW 33rd Ave in Ft Lauderdale (Roadway ID 86015000; MP 7.957) ([Map](#))**


**Figure 7-10: Seminole Blvd near 98th Ave in Seminole (Roadway ID 15010000; MP 13.274) ([Map](#))**

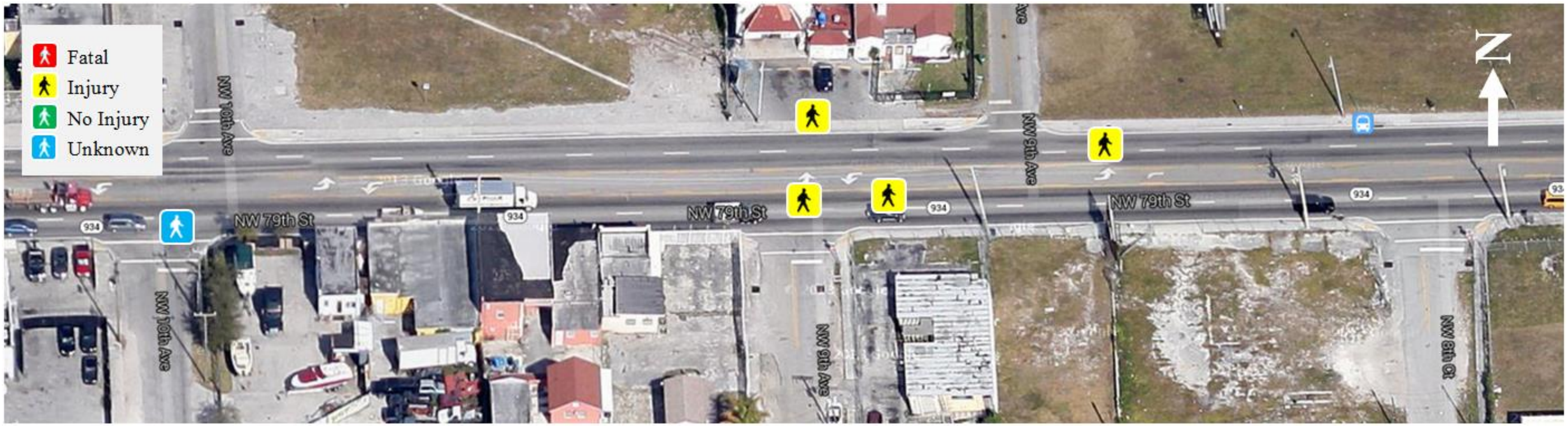


Figure 7-11: NW 79th St near NW 9th Ave in Miami (Roadway ID 87080900; MP 38.273) (Map)

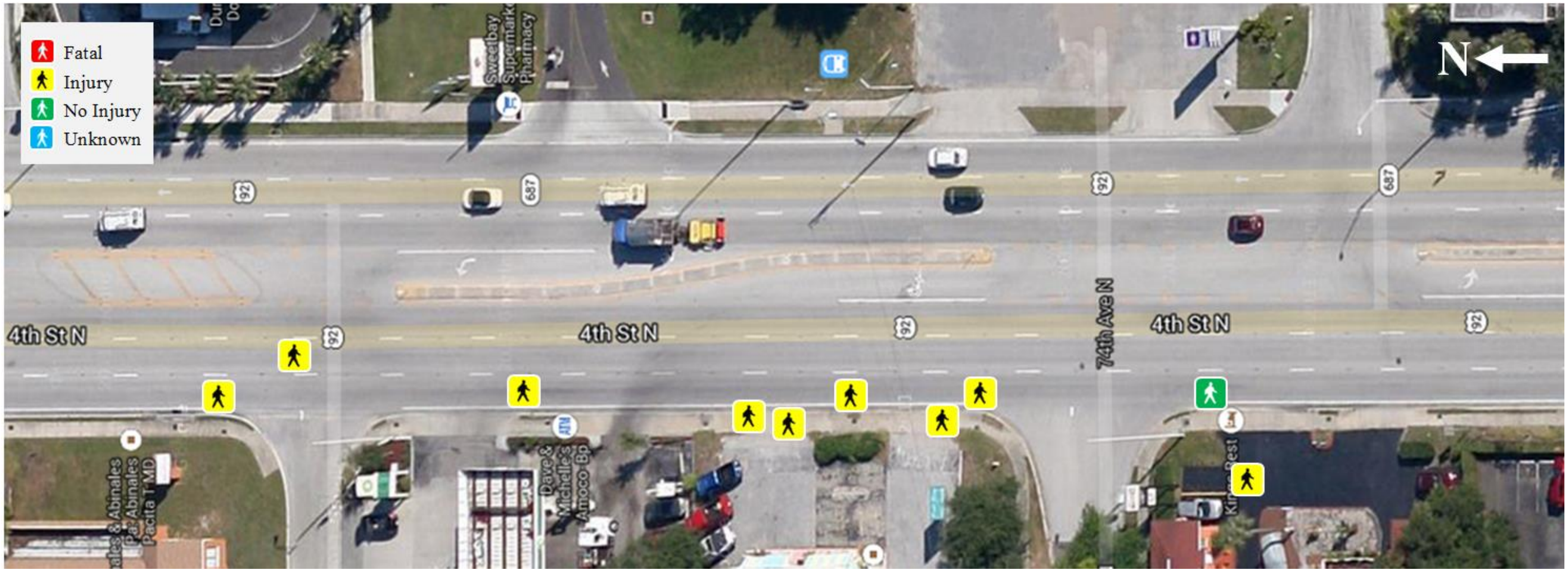


Figure 7-12: 4th St N near 74th Ave N  in St Petersburg (Roadway ID 15090000; MP 5.204) (Map)

Figure 7-13: Blind Pass Rd near 77th Ave in St Pete Beach (Roadway ID 15100000; MP 2.727) (Map)

Figure 7-14: Gulf Bch Hwy near Colbert Ave in Pensacola (Roadway ID 48050000; MP 15.737) (Map)

### *7.2.3 Crash Contributing Factors and Potential Countermeasures*

This section focuses on reviewing the police reports of pedestrian crashes to identify factors that adversely affect the safety of pedestrians at non-signalized locations. The 14 high crash non-signalized locations experienced a total of 115 pedestrian crashes during 2008-2010. The illustrative sketches and descriptions in the police reports of these 115 crashes were reviewed. Both signalized and non-signalized locations were found to experience similar types of pedestrian crashes. Particularly, the following four crash types were observed at both signalized and non-signalized locations:

1. Crashes that occurred in the vicinity of bus stops.
2. Crashes that involved pedestrians who were not crossing at designated crossing locations.
3. Crashes that occurred in left-turning lanes and right-most lanes.
4. Crashes that involved pedestrians in a crosswalk and through traffic.

In addition to the above identified crash types, the following two types of crashes were observed at non-signalized locations: crashes that occurred at undivided roadways, and crashes that involved pedestrians walking along a roadway. Crash contributing factors related to these two types of crashes were analyzed.

#### *Crashes That Occurred at Undivided Roadways*

Of the 14 high crash non-signalized locations, only four locations had raised medians while the remaining 10 locations were undivided. During 2008-2010, the four locations with medians experienced a total of 24 pedestrian crashes (i.e., 6.0 crashes per location) while the remaining 10 locations experienced a total of 91 pedestrian crashes (i.e., 9.1 crashes per location). Figure 7-15 gives an example of a pedestrian crash where a pedestrian was struck while crossing a multi-lane arterial with no raised medians. Figure 7-16 gives another example of a pedestrian crash where the pedestrian was struck while crossing the street in a crosswalk at a location with two-way left-turn lane (TWLTL). It is evident from the illustrative sketches in the police reports that pedestrians are at a higher risk of getting involved in a crash while crossing multi-lane arterials with no raised medians.

Raised medians act as pedestrian refuge areas and "allow pedestrians to cross one direction of traffic at a time, significantly reducing the complexity of the crossing" (FHWA, 2013). However, raised medians often encourage high speeds and might result in an increase in pedestrian crash severity. It was also observed from the police reports that pedestrians sometimes do not stop at the raised medians, diminishing their actual safety benefits. In summary, locations with raised medians increase pedestrian safety compared to undivided sections and corridors with TWLTLs. In addition to the construction of raised medians, agency-wide pedestrian education campaigns focusing on the safety benefits of using pedestrian refuge areas is recommended. Also, at locations with high pedestrian activity, deployment of speed monitoring trailers and increased enforcement of speed limit discourages drivers from speeding, providing a safer environment for pedestrians to cross.

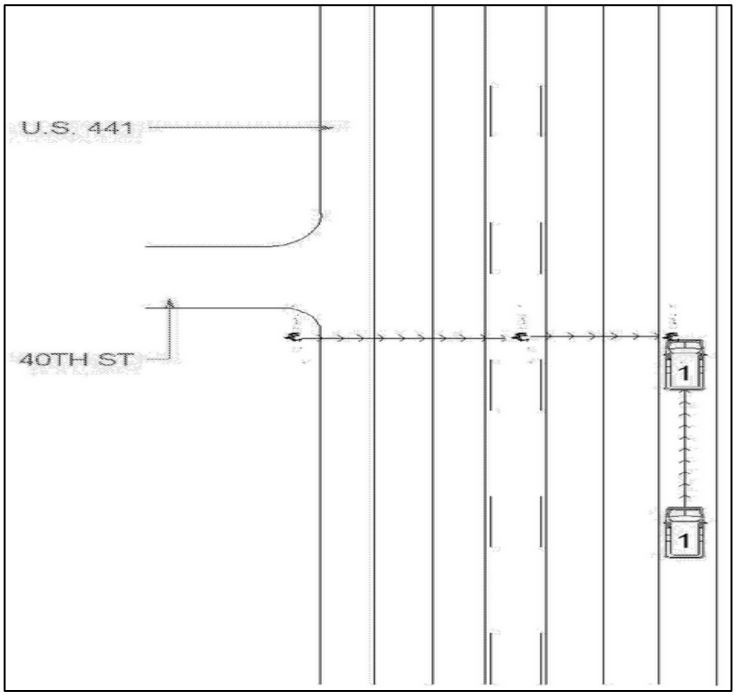



**Figure 7-15: Pedestrian Crash at a TWLTL (Crash ID: 774292040)**

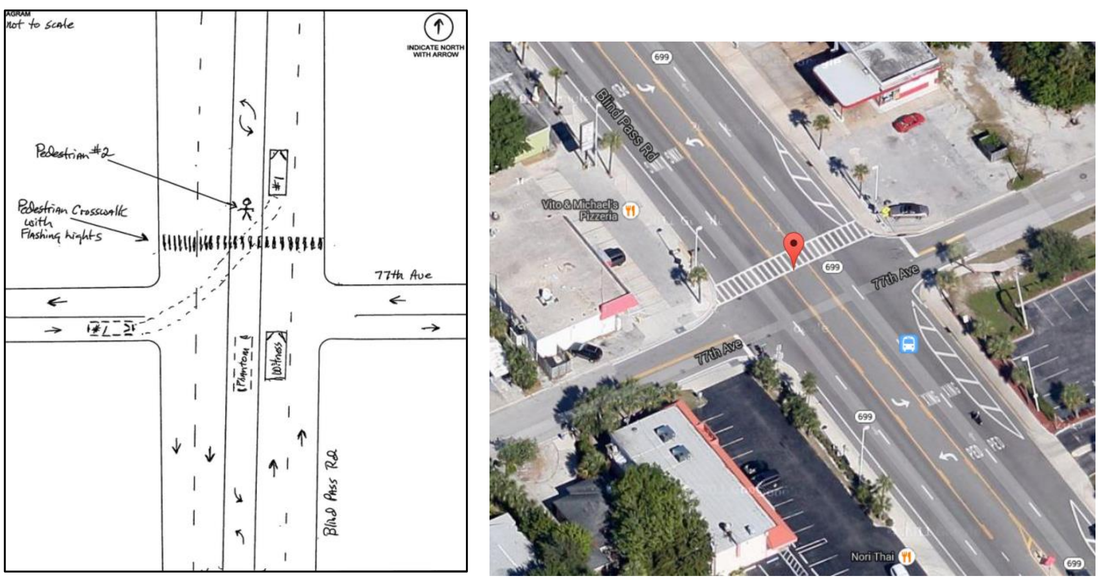



**Figure 7-16: An Example of a Crash Where a Pedestrian was Struck While in Crosswalk at a Location with TWLTL (Crash ID: 730487530)**

*Crashes That Involved Pedestrians Walking Along a Roadway*

A majority of pedestrian crashes occur while the pedestrian was crossing the street. Nonetheless, pedestrians being hit by through traffic while walking along the roadway are also quite common. Figure 7-17 shows a crash involving a pedestrian when struck while walking along a roadway.

These types of crashes are more frequent at locations with no sidewalks. In such locations, pedestrians sometimes walk along the edge of the roadway, and often in the direction of traffic, increasing the crash risk.

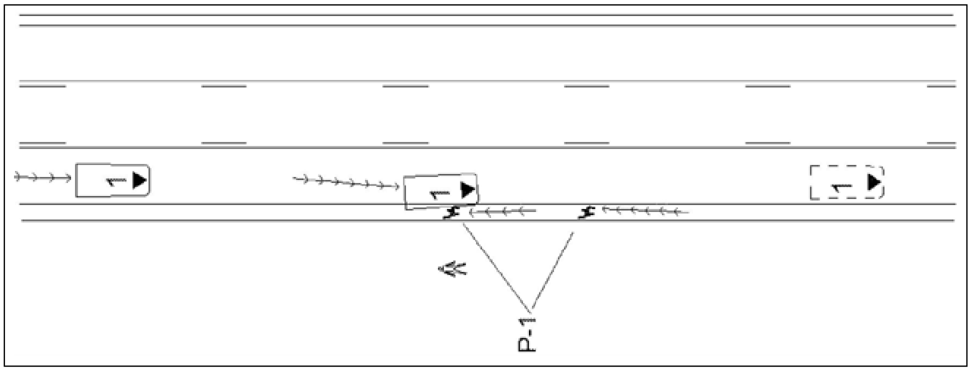



**Figure 7-17: Pedestrian Crash That Occurred While Pedestrian was Walking Along the Roadway (Crash ID: 770947240)**

One of the most effective countermeasures to improve the safety of pedestrians while walking along the roadway is to provide sidewalks on both sides of the road. At locations where providing sidewalks is not feasible, paved shoulders could also help improve pedestrian safety (PEDSAFE, 2013). Encouraging pedestrians to walk against the direction of traffic could potentially make the pedestrians more visible. Also, encouraging pedestrians to wear reflective accessories such as florescent shoes, clothing, or carrying a flashlight improves pedestrian safety by making them visible and more conspicuous to motorists.

### 7.3 Summary

This chapter focused on identifying and analyzing non-signalized locations with high pedestrian crash frequencies. ArcGIS 10.0 was used to identify the non-signalized locations with more than one pedestrian crash. The top high crash non-signalized locations were identified based on critical pedestrian crash frequency (i.e., greater than three standard deviations from the average crash frequency). A total of 14 non-signalized locations with ≥ 5 crashes during 2008-2010 were included in the analysis. Police reports of the 115 crashes that occurred at these 14 locations were reviewed in detail to identify specific factors that adversely affected pedestrian safety. Several of the pedestrian crash types identified at signalized intersections were also found at non-signalized locations. Particularly, the following types of crashes were observed at both signalized and non-signalized locations:

1. Crashes that occurred in the vicinity of bus stops.
2. Crashes that involved pedestrians who were not crossing at designated crossing locations.
3. Crashes that occurred in left-turning lanes and right-most lanes.
4. Crashes that involved pedestrians in a crosswalk and through traffic.

In addition to the above identified crash types, the following two types of crashes were identified at non-signalized locations: crashes that occurred at undivided roadways, and crashes that involved pedestrians walking along a roadway.

Undivided roadway segments were found to experience a greater number of pedestrian crashes compared to the locations with raised medians. Raised medians act as pedestrian refuge areas, providing an opportunity for pedestrians to pause while crossing multiple lanes of traffic. Therefore, constructing raised medians is recommended on multi-lane corridors with high traffic. In addition to the construction of raised medians, agency-wide pedestrian education campaigns focusing on the safety benefits of raised medians is recommended to discourage pedestrians from crossing multiple travel lanes without stopping and waiting for sufficient gaps to cross.

Sidewalks not only encourage walking but also significantly improve pedestrian safety. At locations with no sidewalks, pedestrians are forced to walk along the edge of the roadway, increasing the potential for pedestrian crashes. If feasible, it is recommended to provide sidewalks, or at a minimum paved shoulder, on both sides of the road. Encouraging pedestrians to walk against the direction of traffic could potentially make the pedestrians more visible.

# CHAPTER 8
# SUMMARY AND CONCLUSIONS

Pedestrian crashes are a major safety concern in Florida. About one in every five traffic-related fatalities in the state is a pedestrian. The goal of this project was to conduct a comprehensive study to improve pedestrian safety on state roads in Florida. The specific project objectives included:

1. Reviewing and summarizing existing pedestrian safety studies, including methods of analysis, and findings on pedestrian crash causes, crash contributing factors, and potential countermeasures.
2. Identifying statewide pedestrian crash patterns and causes.
3. Identifying factors contributing to pedestrian injury severity.
4. Identifying and analyzing pedestrian high crash locations at both signalized and non-signalized locations for crash causes and potential countermeasures.

For this study, a total of 6,434 pedestrian crashes that occurred on state roads during 2008-2010 were identified. A major effort of this project involved detailed review of police reports for these crashes to obtain additional crash details, including those from police descriptions and illustrative sketches, which are not available from crash summary records. In addition, additional roadway information not available from the state roadway inventory such as types of crosswalks were visually identified. Both of these efforts were performed using two in-house web-based systems developed to facilitate police report review and data collection.

## 8.1 Literature Review

There has been significant effort in analyzing pedestrian crashes and identifying pedestrian risk factors. Existing methods for identifying pedestrian hot spots are broadly classified into three categories: density, clustering, and exposure estimation. In the density method, simple and Kernel methods are the two commonly used crash density calculation methods. Among these two methods, the Kernel method is regarded as a better approach since it generates a well fitted smooth curve. The second method relies on the clustering technique and it has been successfully applied in safety analysis to identify groups of crashes. The third method of hot spot identification is exposure estimation. This includes statistical regression models, sketch plan and network models, micro-simulation models, and computer vision techniques.

Several pedestrian countermeasures have been proposed in the literature to improve pedestrian safety. These include but are not limited to, converting intersections to roundabouts, installing raised medians and refuge islands, adding on-street parking, installing pedestrian signals, modifying signal phasing, installing pedestrian countdown signals, improving lighting at intersections, and illuminating crosswalks. The majority of these countermeasures were found to have been effective in reducing pedestrian crashes and fatalities.

## 8.2 Statewide Crash Patterns and Causes

Statewide crash patterns and causes were identified based on the 6,434 pedestrian crashes in the three-year analysis period. The crashes resulted in a total of 663 pedestrian fatalities (i.e., 10.3%). Overall, there were 124.7 total crashes and 13 fatal crashes per million population annually. Of the different age groups, the young pedestrian group (16-25 years) experienced the highest number of pedestrian crashes per million population and also the highest pedestrian crash rate per million walk trips per year. Older people were found to experience a slightly higher number of fatal crashes per million walk trips per year. Although a majority of crashes occurred during daytime, they resulted in a lower proportion of fatalities. At 5% significance level, the proportion of fatal crashes that occurred during nighttime were significantly greater compared to the proportion of fatal crashes in the daytime.

Overall, pedestrians were found to be at fault in over 53.0% of the crashes and drivers were at fault in 28.2% of the crashes. Irrespective of who was at fault, failing to yield right-of-way and disregarding traffic control devices were the two major contributing causes for pedestrian crashes. Moreover, crashes where pedestrian was at fault were found to be more severe compared to the crashes where the driver was at fault, and this difference was found to be statistically significant.

A majority of the crashes occurred primarily on urban principal arterials. Although the majority of pedestrian crashes occurred in urban areas and especially in metropolitan areas, fatal crashes were disproportionately high in rural areas. Moreover, the proportion of fatal crashes decreased with urbanization. Crashes along the locations with higher speed limits resulted in a greater proportion of fatal crashes. At a 5% significance level, there was no significant difference in the proportion of fatal crashes at signalized intersections across the following crosswalk types: standard, continental, ladder, and solid with special surface. Furthermore, crash data did not indicate that continental and ladder types had a better safety performance than standard crosswalks at signalized intersections during nighttime.

### 8.3 Statewide Crash Severity Contributing Causes

Mixed logit models were developed to identify significant geometric, traffic, road user, environmental, and vehicle factors contributing to pedestrian injury severity at signalized and non-signalized locations. At both signalized and non-signalized locations, the following ten variables were selected to be included in the model: percentage of trucks, natural logarithm of AADT, crosswalk type, lighting condition, pedestrian age, speed limit, hour of crash, at-fault road user, vehicle type, and weather condition.

The results from the mixed logit models showed that:

- Crashes where pedestrians were at fault were more likely to result in severe injuries compared to the crashes where drivers were at fault or both pedestrians and drivers were at fault at both signalized and non-signalized locations.
- Crashes involving at-fault pedestrians resulted in a greater probability of severe injuries at non-signalized locations compared to signalized locations.
- Very young pedestrians were associated with lower probability of severe injuries at both signalized and non-signalized locations.
- Very old pedestrians were associated with higher probability of severe injuries at both signalized and non-signalized locations.

- Very old pedestrians have a greater severity risk at signalized locations compared to non-signalized locations.
- At signalized locations, rainy weather was associated with a slight increase in the probability of severe injuries compared to other weather conditions.
- Dark conditions, with and without street light, were associated with an increase in the probability of severe injuries at both signalized and non-signalized locations.
- At non-signalized locations, vans were found to be associated with an increase in the probability of severe injuries compared to other vehicle types.
- Increasing the speed limit at signalized and non-signalized locations was associated with higher severe injury probability.
- The increase in speed limit at non-signalized locations posed greater pedestrian severity risk compared to signalized locations.
- At non-signalized locations, pedestrians crossing the roadway were associated with higher probability of severe injuries compared to pedestrians walking along the roadway.
- At signalized locations, increasing the AADT and the percentage of trucks significantly increased the probability of severe pedestrian injuries.
- At signalized locations, the probability of severe pedestrian injuries was higher during the night and dawn off-peak periods.

### 8.4 Pedestrian Crash Causes and Countermeasures at Signalized Locations

Urban signalized intersections with observed pedestrian crash frequency greater than three standard deviations from the average crash frequency were identified and analyzed. A total of 21 signalized intersections with $\geq 6$ pedestrian crashes during 2008-2010 were included in the analysis. Police reports of all the crashes that occurred at these high crash intersections were reviewed and the crash contributing factors related to each of the following six types of crashes were analyzed:

1. Crashes that involved right-turning vehicles.
2. Crashes that involved left-turning vehicles.
3. Crashes that occurred in the vicinity of bus stops.
4. Crashes that involved pedestrians who were not crossing at designated crossing locations.
5. Crashes that occurred in left-turning lanes and right-most lanes.
6. Crashes that involved pedestrians in a crosswalk and through traffic.

Pedestrian crashes involving turning traffic at signalized intersections could be prevented by eliminating the potential vehicle-pedestrian conflicts. At locations with high pedestrian volumes, prohibiting right turns on red could be an easy strategy to minimize pedestrian conflicts involving right-turning vehicles. Additionally, providing a leading pedestrian interval (LPI) that gives pedestrians a head start while crossing the intersection could improve pedestrian safety. Pedestrian crashes involving left-turning vehicles could be reduced by providing either a protected left-turn phase or an exclusive protected pedestrian signal.

Several pedestrian crashes occurred when the pedestrian walked in front of the bus onto the approaching traffic. These types of pedestrian crashes could be prevented by improving roadway lighting and providing curb extensions in the vicinity of bus stops. Furthermore, relocating near-side bus stops to the far-side of the intersection could eliminate sight-distance restrictions, improving pedestrian safety.

At locations where pedestrians are expected to cross multi-lane roads with high travel speeds and heavy traffic, the following countermeasures could be effective in reducing pedestrian crash frequency and severity:

- ensure curb ramps are provided to make crossing easier for all pedestrians,
- install lighting along the corridor,
- require pedestrians to cross the roadway at designated crossing locations such as crosswalks, and
- install traffic calming measures, such as providing speed bumps, lane narrowing, etc.

Agency-wide education campaigns on the laws pertaining to pedestrians and the safety benefits of using pedestrian facilities such as crosswalks, sidewalks, and pedestrian refuge islands could improve pedestrian safety. Furthermore, extensive driver education campaigns that focus on driver compliance with pedestrian right-of-way laws and stricter enforcement could prevent the crashes that were due to driver error.

### 8.5 Pedestrian Crash Causes and Countermeasures at Non-signalized Locations

ArcGIS 10.0 was used to identify the non-signalized locations with more than one pedestrian crash. The top high crash non-signalized locations were identified based on critical pedestrian crash frequency (i.e., greater than three standard deviations from the average crash frequency). A total of 14 non-signalized locations with ≥ 5 crashes during 2008-2010 were included in the analysis. Police reports of the 115 crashes that occurred at these 14 locations were reviewed in detail to identify pedestrian crash causes and potential countermeasures. Several of the pedestrian crash types identified at signalized intersections were also found at non-signalized locations. Particularly, the following types of crashes were observed at both signalized and non-signalized locations:

1. Crashes that occurred in the vicinity of bus stops.
2. Crashes that involved pedestrians who were not crossing at designated crossing locations.
3. Crashes that occurred in left-turning lanes and right-most lanes.
4. Crashes that involved pedestrians in a crosswalk and through traffic.

In addition to the above identified crash types, the following two types of crashes were identified at non-signalized locations: crashes that occurred at undivided roadways, and crashes that involved pedestrians walking along a roadway. Crash contributing factors related to these two types of crashes were analyzed.

Undivided roadway segments were found to experience a greater number of pedestrian crashes compared to the locations with raised medians. Raised medians act as pedestrian refuge areas, providing an opportunity for pedestrians to pause while crossing multiple lanes of traffic. Therefore, constructing raised medians is recommended on multi-lane corridors with high traffic. In addition to the construction of raised medians, agency-wide pedestrian education campaigns focusing on the safety benefits of raised medians is recommended to discourage pedestrians from crossing multiple travel lanes without stopping and waiting for sufficient gaps to cross.

Sidewalks not only encourage walking but also significantly improve pedestrian safety. At locations with no sidewalks, pedestrians are forced to walk along the edge of the roadway, increasing the potential for pedestrian crashes. If feasible, it is recommended to provide sidewalks, or at a minimum paved shoulder, on both sides of the road.

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