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Evaluating Pedestrian Crossings on High-Speed Urban Arterials

by

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13. Abstract

The aim of this study is to provide a preliminary assessment of Louisiana's high-speed urban arterials in terms of existing pedestrian crossing facilities and identify any associations of pedestrian crashes with the presence or lack of such pedestrian crossing facilities. In achieving this aim, several tasks were undertaken including: documenting pedestrian crossing facilities and which is appropriate for a roadway type; documenting how other states have defined high-speed roadways and recommending a definition for Louisiana; documenting policies governing provision of pedestrian crossing facilities on high-speed arterials; documenting legislation prohibiting pedestrians on roadways other than interstates; documenting classification of an area into urban, suburban, or rural categories and recommending a roadway categorization of Louisiana's high-speed urban arterials for the purpose of this study; documenting data types and studies required for the provision of several pedestrian crossing facilities, and identifying pedestrian crash locations and how they correlate to certain roadway features. To achieve this objective, this study looked at nine study areas that make up Louisiana's urban and urbanized areas: New Orleans, Baton Rouge, Lafayette, Shreveport, Houma, Monroe, Alexandria, Hammond, and Lake Charles. The research team compiled and analyzed data from a database of crash data between 2013 and 2017, GIS data from DOTD that provided roadway information, and aerial view roadway features extracted from Google Earth. The analyses undertaken include data-driven safety analysis to identify any correlation between pedestrian crash frequencies and roadway characteristics, and also with intersection/non-intersection features; spatial hotspot or heat map analysis to visually identify hotspots of high pedestrian crash locations and whether they correlate with bus stop locations; decision tree analysis to identify significant influencing variables that impact pedestrian crash frequency; and location movement classification method analysis to understand how different pedestrian and motorist movements correlate with pedestrian crash frequencies. The outcome of this study is a preliminary assessment upon which a follow-up study can be undertaken that will evaluate the impact of providing appropriate countermeasures, install and evaluate before and after studies analysis, and develop a statewide guideline for the provision of pedestrian facilities on Louisiana's high-speed arterials.

Project Review Committee

Each research project will have an advisory committee appointed by the LTRC Director. The Project Review Committee is responsible for assisting the LTRC Administrator or Manager in the development of acceptable research problem statements, requests for proposals, review of research proposals, oversight of approved research projects, and implementation of findings.

LTRC appreciates the dedication of the following Project Review Committee members in guiding this research study to fruition.

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Abstract

The aim of this study was to provide a preliminary assessment of Louisiana's high-speed urban arterials in terms of existing pedestrian crossing facilities and identify any associations of pedestrian crashes with the presence or lack of such pedestrian crossing facilities. In achieving this aim, several tasks were undertaken including: documenting pedestrian crossing facilities and which is appropriate for a roadway type; documenting how other states have defined high-speed roadways and recommending a definition for Louisiana; documenting policies governing provision of pedestrian crossing facilities on high-speed arterials; documenting legislation prohibiting pedestrians on roadways other than interstates; documenting classification of an area into urban, suburban, or rural categories and recommending a roadway categorization of Louisiana's high-speed urban arterials for the purpose of this study; documenting data types and studies required for provision of several pedestrian crossing facilities; and identifying pedestrian crash locations and how they correlate to certain roadway features. To achieve these objectives, this study looked at nine study areas that make up Louisiana's urban and urbanized areas: New Orleans, Baton Rouge, Lafayette, Shreveport, Houma, Monroe, Alexandria, Hammond, and Lake Charles. The research team compiled and analyzed data from a database of crash data between 2013 and 2017, GIS data from DOTD that provided roadway information, and aerial view roadway features extracted from Google Earth. The analyses undertaken include: data-driven safety analysis to identify any correlation between pedestrian crash frequencies and roadway characteristics as well as with intersection/non-intersection features; spatial hotspot or heat map analysis to visually identify hotspots of high pedestrian crash locations and whether they correlate with bus stop locations; decision tree analysis to identify significant influencing variables that impact pedestrian crash frequency; and location movement classification method analysis to understand how different pedestrian and motorist movements correlate with pedestrian crash frequencies. The outcome of this study was a preliminary assessment upon which a follow-up study can be undertaken that will evaluate the impact of providing appropriate countermeasures, install and evaluate before-and-after-studies analysis, and develop a statewide guideline for the provision of pedestrian facilities on Louisiana's high-speed arterials.

Acknowledgments

This project was completed with the support of the Louisiana Department of Transportation and Development (DOTD) and the Louisiana Transportation Research Center (LTRC). The research team also gratefully acknowledges the support from the many student workers who laboriously read every crash narrative to extract the information necessary for the project to be a success. Lastly, the research team acknowledges the Project Review Committee (PRC) members for their valuable feedback and all other DOTD personnel involved during the course of this project.

Implementation Statement

The achievement of this research has been to undertake a comprehensive study for each pedestrian crash for the period 2013-2017 for Louisiana's high-speed urban arterials, read the crash narratives to establish probable cause of the crash, collect pertinent roadway information on features and characteristics, and establish any correlations between pedestrian crash frequencies and facility type. An understanding of where (facility type) most pedestrian crashes occurred and the presence or lack thereof of pedestrian crossing facilities may provide further insights into whether Louisiana has a pedestrian crash problem on its high-speed arterials.

The purpose of this study was to provide a preliminary assessment of the situation. To this end, the implementation phase of this project will focus on a recommendation for a follow-up study that will use this study's findings as a basis to achieve the following:

- Evaluate the need for the provision of pedestrian crossing facilities on Louisiana's high-speed arterials.
- Recommend which pedestrian facilities or countermeasures will be appropriate for Louisiana's high-speed arterials.
- Install countermeasures at select locations and undertake before-and-after analysis.
- Develop a statewide guideline on the provision of pedestrian facilities or countermeasures on Louisiana's high-speed arterials.

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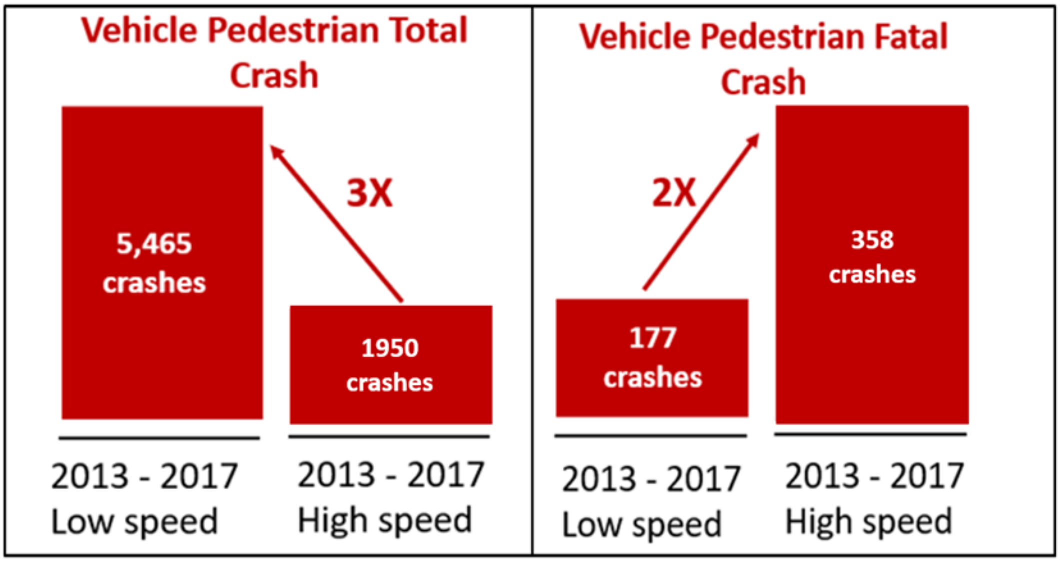
Introduction

Louisiana's Strategic Highway Safety Plan (SHSP) has a goal to halve fatalities on Louisiana's roadways by 2030 [1]. From 1981 to 2015, the traffic fatality rate per 100 million vehicle miles traveled (VMT) has been on a steady decline from 3.35 to 1.16. Although this shows an improvement in traffic safety, the trend for 2013 to 2017 has generally been on the rise [1], [2], [3]. For instance, the National Highway Traffic Safety Administration (NHTSA) reports an increase in the proportion of pedestrian and bicycle fatalities to total traffic fatalities accounting for 14.5% (up from 10.9%) and 2.3% (up from 1.7%), respectively [2], [3]. Between 2013 and 2017, pedestrian fatalities increased from 4,735 to 5,977, with the highest recorded in 2016, where 6,080 pedestrians were killed. Within the same period, bicycle fatalities followed a similar upward trend from 743 to 783, with the highest record also being 2016, where 852 bicyclists were killed. Although yearly comparison shows both an increase and decreases in fatalities for different years, the overall trend points to higher fatalities of vulnerable road users for the period of 2013 to 2017 [4]–[7]. The 2016 NHTSA report shows that, on average, 16 pedestrians are killed daily in the United States [8].

In 2016, the state of Louisiana ranked the seventh-worst state in pedestrian fatalities, behind New Mexico, Florida, South Carolina, Arizona, Delaware, and Nevada [9]. Initial analysis of pedestrian crashes in the state of Louisiana from 2013 to 2017 paints a clearer picture of the lingering problem. Out of the 7,415 pedestrian crashes, 74% occurred on low-speed roadways, while 26% occurred on high-speed roadways, yet fatal pedestrian crashes on high-speed roadways account for two-thirds of the total pedestrian fatalities in the state [2]. Figure 1 shows the trend in crash frequency and fatal crash frequency on low-speed and high-speed roadways in the state of Louisiana. The figure shows the high level of fatalities on high-speed roadways, considering that only 26% of the total pedestrian crashes occur on this roadway [2]. NHTSA included fatalities by land-use as part of its 2017 traffic safety facts, and part of its findings reveal that "although pedestrian fatalities decreased by 1.7% in 2017, pedestrian fatalities in urban areas have increased by 46% since 2008 while rural areas decreased by 6%" [7]. Over the past 10 years, from 2007 to 2016, FARS reported a 12% decrease in total highway fatalities, yet pedestrian fatalities within the same period increased by 27% [10]. National Transportation Safety Board's (NTSB) assessment of crash data from various Departments of Transportation (DOTs) reveals pedestrian crashes in metropolitan areas account for more than half of highway fatalities [11].

Figure 1. Pedestrian total and fatal crashes on low and high-speed roadways



The concept of roadway safety, viewed from substantive safety analysis, can be estimated using crash rate, crash frequency, crash type, and crash severity [12]. Although the frequency of crashes on high-speed roadways is lower compared to low-speed roadways, the high numbers of higher serious injury crashes make them less safe and dangerous for pedestrians.

Land-use analysis of pedestrian crashes on Louisiana high-speed roadways reveals a similar trend. As seen in Table 1, between 2013 and 2017, metropolitan areas account for 80% of total pedestrian crashes, 71% of fatal pedestrian crashes, 81% of serious injury crashes, and 82% of other injuries [2]. This further reveal that the problem is more pronounced on high-speed roadways in metropolitan areas than in rural areas.

Table 1. Land-Use distribution of pedestrian high-speed roadway crashes

Land Use Type	**Pedestrian High-Speed Roadway Crashes**			
	Fatal Crashes	Serious Injury Crashes	Other Injury Crashes	Total Crash
Metropolitan	254 (71%)	169 (81%)	1137 (82%)	1560 (80%)
Rural	104 (29%)	38 (19%)	248 (18%)	390 (20%)
Total	358 (100%)	207 (100%)	1385 (100%)	1950 (100%)

Even though previous studies on pedestrian safety have focused on frequency, severity, and contributing factors, little work has been done specifically on high-speed urban roadways. While some findings and recommendations from these previous research works apply to high-speed roadways, others do not. For instance, the implementation of pedestrian safety facilities like in-street crossing sign, raised crosswalks, and curb extensions are not feasible with high-speed roadways, partly because of the configuration and operational characteristics of high-speed roadways. These factors necessitate the need to perform specific research on understanding the problems on high-speed urban roadways and finding ways to mitigate the current vulnerability of pedestrians on these roadways.

The purpose of this project is to provide an assessment of the current situation in Louisiana. It does this by first determining pedestrian crash locations, determining whether the crash narratives lead to a trend or pattern, and lastly, assessing how such a possible pattern correlates to roadway characteristics. It is anticipated that the findings will provide the basis for the development of state guidelines in determining appropriate countermeasures to combat pedestrian crashes on Louisiana's high-speed urban arterials.

Literature Review

High-Speed Urban Arterials and Recommended Definition for Louisiana

Arterial roads are roadway facilities which connect freeways and major business districts of an area. As part of the project of evaluating and improving pedestrian crossing facilities in the state of Louisiana, the Louisiana Department of Transportation and Development (DOTD) seeks to develop a comprehensive definition of high-speed urban arterials. Several definitions have been formulated about high-speed urban arterials, which have led to the varying interpretation of the scope and limit of what a high-speed urban arterial is. This section of the literature presents an extensive literature on the definition of a high-speed and arterial roadway by researchers, state, federal, and other agencies. The goal of this section is to justify a definition of high-speed arterials roadway for the state of Louisiana. Later sections of this literature will address the definition of urban roads.

High Speed

Speed is one of the primary factors drivers and commuters take into consideration in deciding whether to use a transportation facility. The performance of transportation facilities to transport goods and people from one place to another is assessed by using convenience, time, safety, and economy, which has a direct relationship with speed. Speed is a general term in transportation, and it has varying meanings under different contexts, which include design speed, operating speed, posted speed, advisory speed, and statutory speed, among others. A brief exposition of the three forms of speed often considered by transportation professionals, namely design speed, operating speed, and posted speed will be considered in this section. It is important to note that the definition of these terms evolved with time, and these definitions are based on the latest information gathered by the research team.

Design speed is the selected speed used to determine the various geometric design features of the roadway [13]-[15]. The selection of a design speed should be based on the topography, expected land use, anticipated operating speed, and the functional classification of the road. The attainment of the desired level of safety, mobility, and efficiency in the transportation of goods and people within the limits of an environment affects the selection of the design speed [14]. Based on a selected value, a facility may be considered as a low-speed facility or high-speed facility, which will impact the nature and type of geometric features of the roadway, such as curvature, super-elevation, lane width, and sight distance.

Operating speed is a general term that describes the actual speed of a group of vehicles over a free-flow section of the roadway [15]. It can be defined as the speed at which drivers of free-flowing vehicles choose to drive on a section of roadway [16]. The measure of the operating speed of a roadway is determined using the 85th percentile of the distribution of observed speeds while taking into account the roadway features and land-use [14]. The Manual on Uniform Traffic Control Devices (MUTCD) defines operating speed as the speed at which a typical vehicle or the overall traffic operates. Operating speed may be referred to by terms such as average speed, pace, or 85th percentile speed [13].

Lastly, posted speed is the maximum speed limit that vehicles are supposed to travel under ideal conditions. The selection of the posted speed of a roadway is based on factors such as the operating speed of the roadway and roadway environment. Statistical analysis shows that a strong relationship exists between posted speed and operating speed [15]. The 85th percentile speed (operating speed) is a key factor used in the determination of the maximum speed limit of the roadway under ideal conditions [17].

Different literature materials were reviewed to establish the definition of high-speed roadway limits. A detailed review of materials from researchers, states, federal, and other agencies are included in Appendix A.

Table 2 summarizes reviewed materials on the definition of high-speed roadways based on roadway posted speed limit. Where two speed values are shown for an agency, it means both values have been used to define lower limits across different segments of roadways. Altogether, 25 lower limits were documented in Table 2.

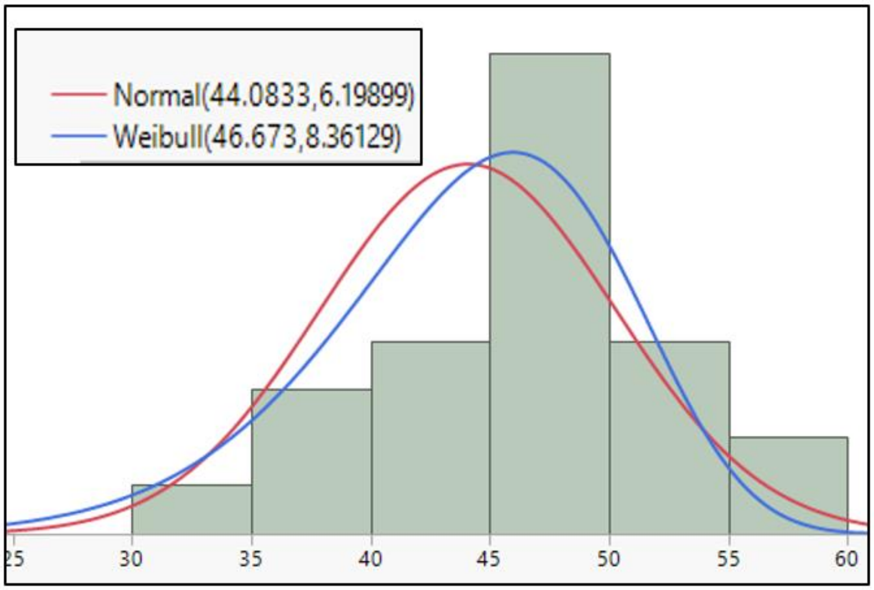
Table 2. Summary of high-speed roadway definition

High-Speed Definition by Researchers		High-Speed Definition by State Agency	
Source	**Lower limit**	**State DOT**	**Lower limit**
Naik et al. [18]	45 mph	Alaska Department of Transportation [19]	55 mph 45 mph
Kockelman et al. [20]	50 mph	Connecticut Department of Transportation [21]	>45 mph
Stapleton et al. [22]	45 mph	Illinois Department of Transportation [23]	>45 mph
Richie and Lenters [24]	40 mph	Michigan Department of Transportation [25]	>35 mph
Isebrand and Hallmark [26]	40 mph	Virginia Department of Transportation [27]	>35 mph
Gates et al. [28]	55 mph	Minnesota Department of Transportation [29]	>35 mph 45 mph
Naess et al. [30]	70 km/h (43.5 mph)	Oregon Department of Transportation [31]	45 mph
Taylor et al. [32]	50 mph	Kentucky Transportation Cabinet [33]	40 mph
Zhou et al. [34]	45 mph		
Fortuijn et al. [35]	50 mph		
High-Speed Definition by Federal and Other Agencies			
ASSHTO [14]	50 mph		
MUTCD [13]	>35 mph 45 mph		
NHTSA [36]	30 mph		
NCHRP [37]	45 mph		

Statistical Summary of High-Speed Roadway Definition

Statistical assessment of the 25 lower limit speed values documented in Table 2 was used in determining a lower speed limit definition of high-speed roadways for Louisiana. The median, mode, and mean parameters were used in estimating the lower limit of high-speed definition. The estimation of the mean is the calculation of the average based on the speed values. Since the mean is less robust and susceptible to outliers, the median estimate, which is more robust, can give a more accurate estimation of the lower speed limit definition, in this case. The data points were plotted in Figure 2 to determine the mean, mode, and median of the distribution. The goodness-of-fit test using the Shapiro Wilk test was 0.927. This value provides a good indication that the 25-speed values are normally distributed and evidenced by the bell-shaped distribution shown in Figure 2.

Figure 2. Distribution of lower limit definition of high-speed roadways



The normal distribution fit for the data has a mean estimate of 44.083 mph and a standard deviation of 6.199 mph. Posted speed values are given in incremental limits of 5 mph, and fitting this data to a normal distribution will generate a minimum deviation of 5 mph. The average of the upper 95% portion of the data was 46.7 mph, while the average of the lower 95% portion of the data was 41.46 mph. The standard error of the mean was 1.27 mph, and the median was 45 mph. Judging from the mean and median values of 44.08 mph and 45 mph, respectively, the data set is almost normally distributed, although slightly skewed to the left. The modal value observed was 45 mph, which is consistent with the mean and median estimates from the normal distribution analysis of the data.

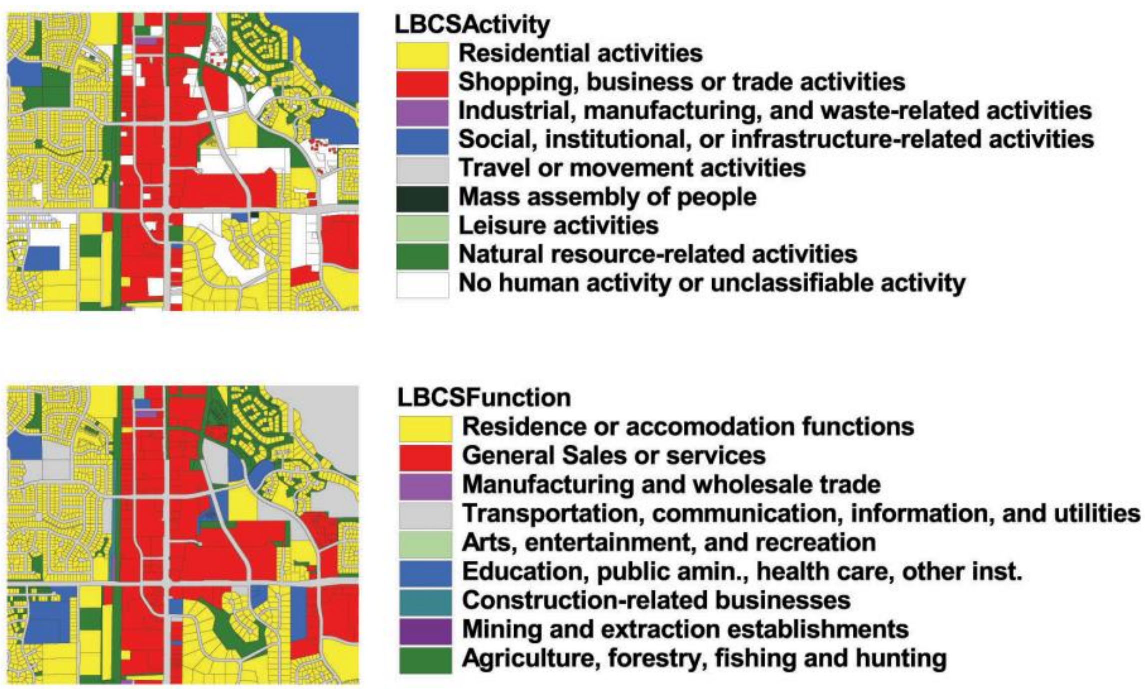
Recommended Definition of High-Speed Roadway

Based on the literature and the statistical analysis conducted by the research team, the recommended definition of high-speed roadways is “roadways with posted speeds of 45 mph or greater." This definition guides the selection of roads analyzed in subsequent stages of the project.

Land-Use Based Classification Roadways

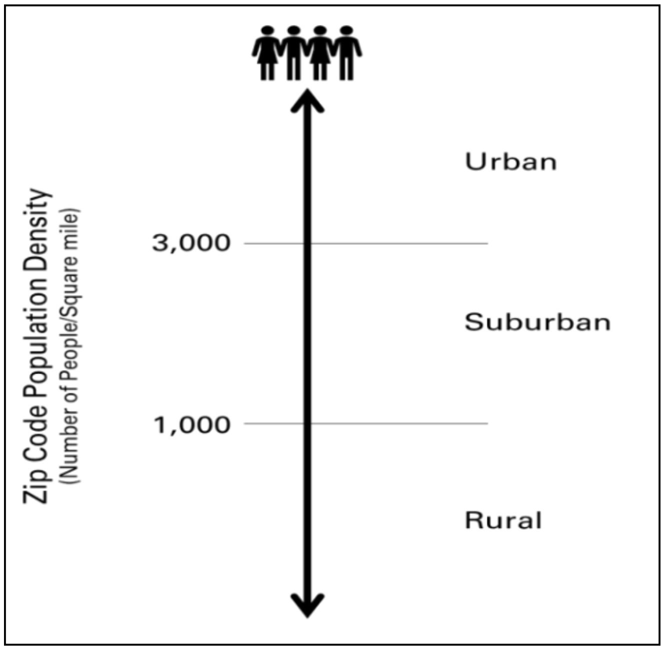
Land-use based classification provides information on land cover and the types of human activity involved in land use. For land-use considerations, various bodies determine the most suitable basis for their classification, to suit the purpose of such definitions. For instance, the American Planning Association (APA) maintains a Land-Based Classification System (LBCS) designed for local planning purposes [38]. This system classifies areas according to activity, function, (dominant) structure type, ownership, and site development. These classes are termed as APA LBCS dimensions. An LBCS activity map contains nine colors describing the observed land-use activity of an area such as residential, farming, business, shopping, and manufacturing. Figure 3 shows the color codes for activity and function and their corresponding descriptions.

Figure 3. LBCS color codes for function and activity [38]



Most area classification systems based on population only consider an area as either urban or rural. The US Department of Defense (DoD), however, created definitions of urban, suburban, and rural-based on zip area populations for the Medicare Modernization Act 2003. This criterion considers a zip code's population density to determine its urban status. Figure 4 shows zip codes reaching a thousand people per square mile are considered rural, three thousand, suburban, and those exceeding three thousand, noted as urban [39].

Figure 4. Classification based on zip code population density [39]

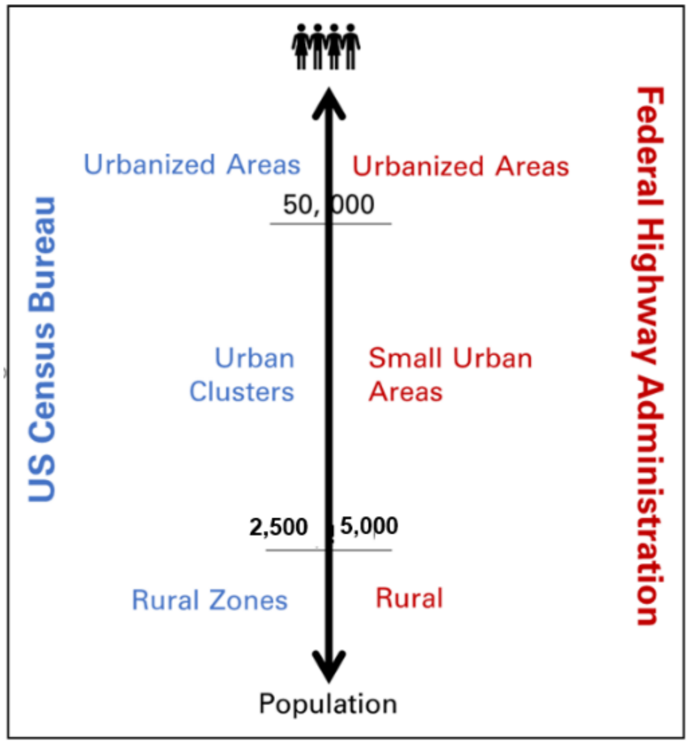


Unlike the DoD, the US Census Bureau's (USCB) classification system is based solely on the population of a specific geographical location and groups areas into Urbanized Areas (UAs), Urban Clusters (UC), and Rural Zones. The population ranges are 50,000 and above, 2,500 to 49,999, and below 2,500, respectively [40].

On the other hand, FHWA classifies urbanized areas as locations with population ranges of 50,000 and more (similar to USCB), small urban areas as having a population between 5,000 and 49, 999 (lower limit differing from USCB), and rural areas as having populations less than 5,000 (different from USCB). Figure 5 shows how USCB and FHWA compare.

Most transportation agencies across the US rely on the FHWA's adjusted boundaries to do their urban/rural classification, whilst only introducing a slight change where necessary. For instance, the Florida DOT uses the same upper limits for its classification but terms the intermediate class urban, instead of the FHWA's "small urban."

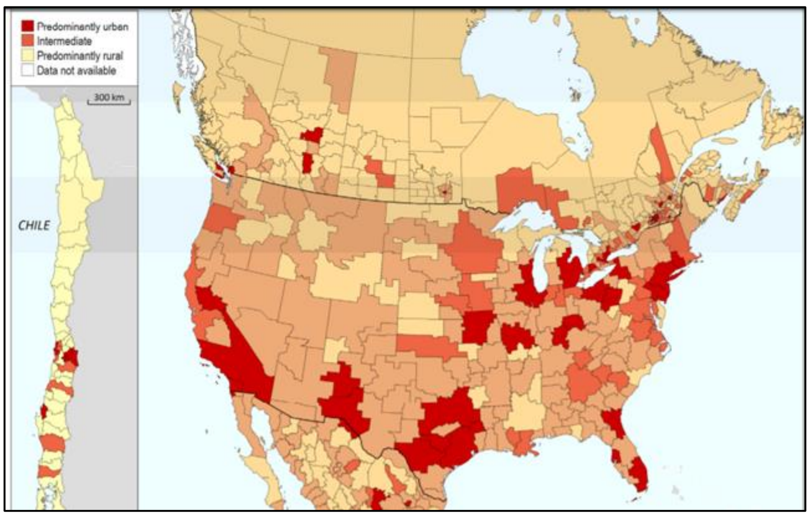
Figure 5. Comparing US Census Bureau and FHWA population classification



Outside the US, some notable agencies simply classify locations as urban or rural. What may be classified as suburban in the US often fits into a rural or urban definition. For instance, the Road Safety Observatory of the UK defines urban roads as all major and minor roads found in an urban enclave with populations exceeding 10,000. Anything below this cap is considered rural per this classification system [41]. Statistics Canada – the Canadian Government's agency commissioned with producing statistics to help better understand Canada, its population, and resources – considers both population size and density in its urban/rural classification. An urban area is defined as having a population of 1,000 and a density of 400 or more people per square kilometer. All territories not meeting both requirements are considered rural [42].

In the Organization for Economic Cooperation and Development (OECD) regional typology, regions are grouped into Predominantly Urban, Intermediate, and Predominantly Rural. Brezzi et al. [43] provide an extension to the OECD typology, by describing a classification system based on Gross Domestic Product (GDP) per capita of a specific region: it portrays this metric as an accurate representation of the economic status of an area and does not rely solely on population statistics. OECD is mostly not applied in the United States as no local units, counties nor parishes, have sufficient records of GDPs [43]. In a quest to find other reliable variables of classification, outside the OECD's prescribed metrics, the Food and Agriculture Organization of the United Nations (FAO) applied an econometric logistic regression model to two datasets for Italy, an OECD country, and China, a non-OECD country. They successfully proved that population density, human resources, and skills, level of agricultural engagement, services available, are all statistically significant, and present a stronger method of measuring urbanity of an area [44]. OECD classification map for the US is shown in Figure 6.

Figure 6. OECD classification results of the US

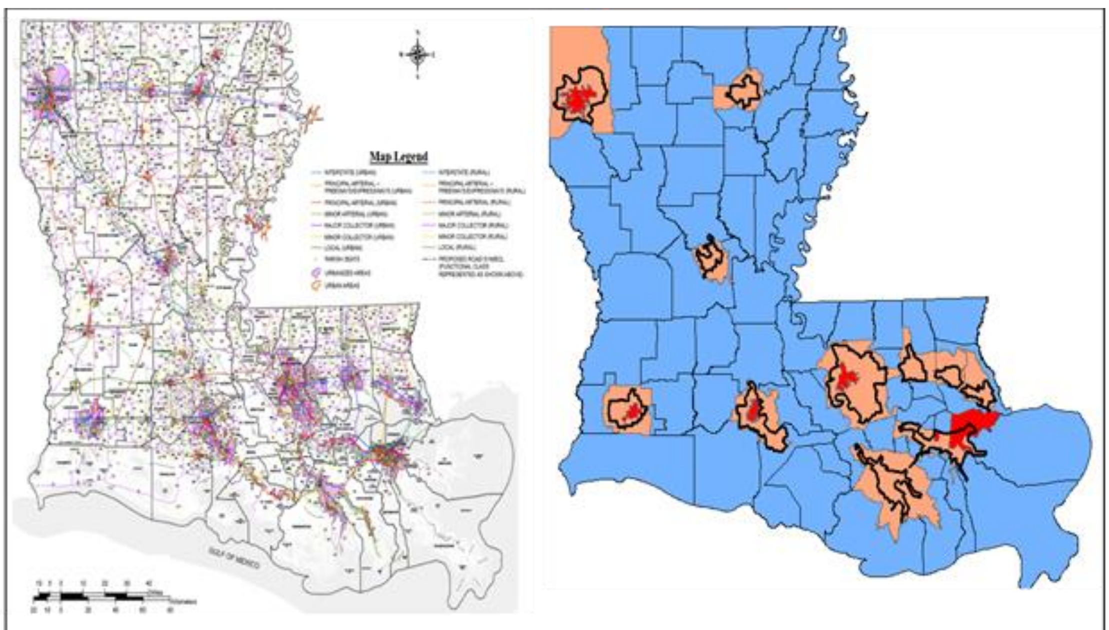


Current Louisiana Roadway Classification

The current roadway classification for the state of Louisiana is based on the Functional Classification System (FCS). Cities are classified as either urbanized, urban, or rural areas using population values of 50,000 people and above, between 2,500 and 49,999 people and less than 2,500 people, respectively, similar to the limits used by USCB. The central zone of cities such as Shreveport, Baton Rouge, and New Orleans are classified as urbanized areas while the surrounding areas are classified as urban areas.

Based on the function (vehicular mobility) of a section of the roadway network in urban and urbanized areas, the road is either classified as urban interstate, urban arterial (major/minor), urban collector, or urban local road. It is important to note that portions of a large rural area may be classified as an urban area, in which case, the roadway network within this urban portion will be classified as either urban arterial, urban collector, or urban local roads. Roadways in rural areas follow the same protocol in name classification. Figure 7 (a) gives a detailed breakdown of the current roadway network classification for the state of Louisiana. While generally illegible, it shows the Urbanized Areas and a mesh of roadway networks going across the entire state. These urbanized areas are further highlighted by the black boundaries within the urban highlighted areas in Figure 7(b). The urbanized areas used in the research study are Shreveport, Alexandria, Monroe, Lake Charles, Lafayette, Baton Rouge, and New Orleans.

Figure 7. Louisiana urban areas and roadway network

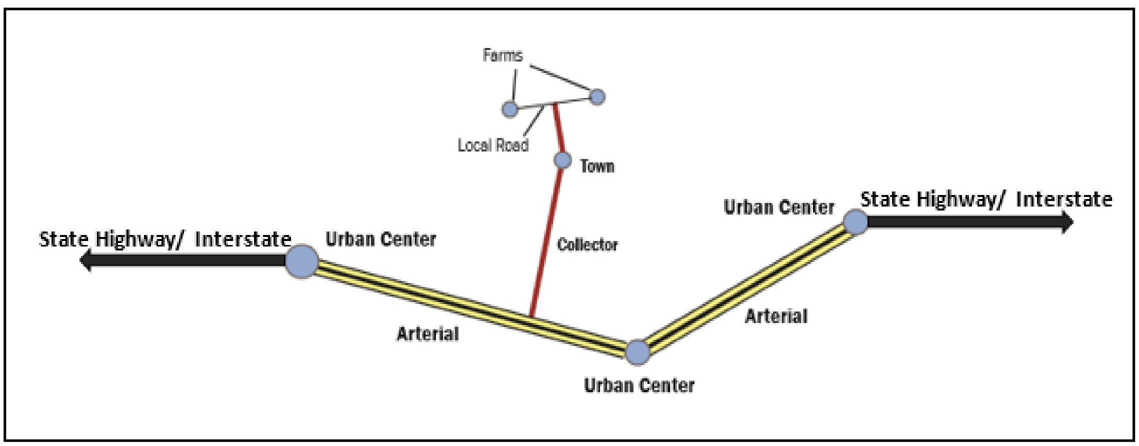


(a) Louisiana Roadway Network (b) Urban areas considered for research

Classification of Roads

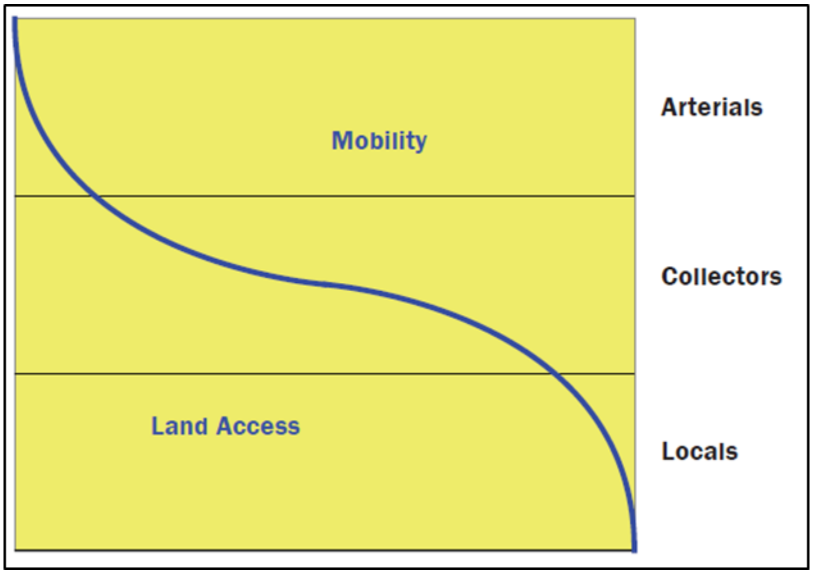
Arterial roads are part of a classification system of roadway based on their primary function in a complete road network of an area. This section presents the definition of arterial roads as provided by federal and state agencies. The basic functional classification categories of roadways are local roads, collectors, and arterials. These three classifications do not function in isolation but work as a collective network of links. Arterial roads connect towns to state highways or interstates. They carry a large amount of traffic and are mostly straight with smooth curves. Arterial roads should not pass through the heart of a city and should have fewer obstructions such as buildings, parking places, and pedestrians on the carriageway [14]. The key purpose of all roadways is to provide access and mobility. Local roads chiefly provide access, while arterials primarily provide mobility. The relationship between the different road classes and relative purpose is illustrated in Figure 8. It shows that the interstates provide the greatest mobility but the least access to facilities, while local roads provide the least mobility but the greatest access. Arterials and collectors are wedged in the middle with arterials providing greater mobility but lesser accessibility.

Figure 8. Hierarchy of highway systems



Mobility is measured with respect to the ability of traffic to pass through a defined area in a reasonable amount of time. Common elements of mobility include: operating speed, level of service, and riding comfort. Accessibility is measured in terms of the road system's capability to provide access to and between land-use activities within a defined area. The relationship between mobility, accessibility, and the different types of roadway classes is illustrated in Figure 9.

Figure 9. Hierarchical classification of roadways



As seen in Figure 9, the conventional purposes elaborated above designate roads as arterials, collectors or local depending on their proportion of mobility or land accessibility. Based on conventional functional class, arterials are designed mainly for high mobility; however, a recent critique of road classification points to the fact that mobility should reflect a multimodal approach and not building roads only for private motor vehicles and freight, especially in urban areas. The shift can be seen in changes being made in the development of new guides such as AASHTO Policy on Geometric Design of Highways and Streets, Designing Walkable Urban Thoroughfares: A context-sensitive Approach by Institute of Transportation Engineers [45] in conjunction with the Congress for New Urbanism and FHWA [46], NACTO Urban Bikeway Design Guide in 2011, and Urban Street Design Guide in 2012 [47].

Urban Principal and Minor Arterials

Urban principal arterial roads are roadways that serve major activity centers in urban areas. These roads constitute a relatively small percentage of the total roadway but carry a high proportion of the total traffic as they provide the highest traffic volume corridor and the longest trip desires. Most of the trips on urban arterials, between major activity centers, are through movements that pass the central city. Principal arterials serve major activity centers of a metropolitan area and provide continuity for major rural corridors. A significant amount of internal travel between the business district and outer residential areas are carried by principal arterials. Due to the nature of the services provided by urban principal arterials, they have fully or partially controlled access facilities [14].

Urban minor arterials include all arterials not classified as urban principal arterials and contain facilities that place more emphasis on land access. There is a balance of mobility against accessibility, which includes the need to accommodate pedestrians, bicyclists, and transit users. Unlike urban principal arterials, urban minor arterials include facilities such as bus routes and provide intra-community continuity [48]. They, however, limit penetration into neighborhoods; thus, they do not enter the heart of the community. They augment the principal arterial system and provide service to moderate trip lengths with lower mobility. Victoria Transport Policy Institute, Canada, described its minor arterials as having relatively low speed, good sidewalk, shop oriented to pedestrians, and relatively good public transit [49].

State and City Agency Definitions of Urban Arterials

The New York State Department of Transportation (NYSDOT) classifies urban arterials as principal and minor urban arterials. Characteristics of principal urban arterial include [50]:

- Serve major centers of activity of a metropolitan area.
- Have highest traffic volume corridors, i.e., carry high proportion of the total urban area travel.
- Carry the majority of through movement desiring to bypass the central city.
- Mostly have fully or partially controlled accessed facilities.

The city of Lenexa, Kansas, in their road classification system [51], subdivides arterials into major arterials and minor arterials. Major arterials are characterized with high speeds and high volumes (above ADT 20,000 vpd) with limited access. Their major function is to move traffic and provide secondary functions such as access to abutting properties. Minor arterials connect activity centers but for less intense development areas such as small retail centers. Average trip length is one or two miles long with moderate speeds and having ADT ranging from 10,000 to 25,000 vpd.

The city of Shoreline in Washington describes the difference between its principal and minor arterials using road characteristics such as function, speed limit, daily volume, number of lanes, lane stripping, transit, bicycle facilities, and pedestrian facilities. Table 3 provides the geometric and road facility difference between principal and minor arterials for Shoreline, WA.

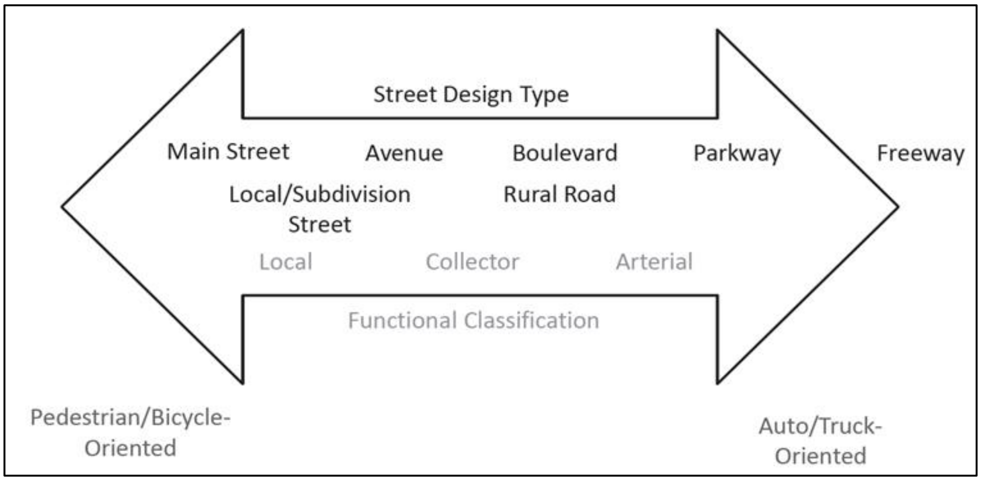
Table 3. Typical street characteristics for Shoreline, WA

Characteristics of road	Principal Arterials	Minor Arterials
Function	Connect cities and urban centers with minimum delay, Connect traffic to the interstate system, Accommodate long and through trips	Connect activity centers within the city, Connect traffic to principal arterials and interstate, Accommodate some long trips.
Speed limit	30 – 40 mph	30 – 35 mph
Daily volume	More than 15,000	7,000 to 20,000
Number of Lanes	Three or more lanes	Two or more lanes
Lane stripping	Pavement markings used to delineate travel lanes	Pavement markings used to delineate travel lanes
Transit	Buses/transit stops allowed	Buses/ transit stops allowed
Bicycle facilities	May contain bicycle lanes, shared lanes or signage	May contain bicycle lanes, shared lanes or signage
Pedestrian facilities	Sidewalks on both sides Amenity zones	Sidewalks on both sides Amenity zones

In addition to this, Washington state, in its 2016 “Urban and Suburban Arterial Safety Performance Function” final report [52], computed the upper limits AADT of the different geographic road types. The analysis suggests the upper limit of large urbanized arterial roadway as 56,440 and that for minor arterial roadway as 22,400.

The state of North Carolina used a different approach. Their definition of the street type is based on the mix of road users, which is impacted by the land-use characteristics of the roadway. From a Complete Street perspective, North Carolina Complete Streets report categorizes streets by function, and street name suffixes range from a predominant pedestrian-oriented to auto-oriented system [53]. Based on this, streets are classified as either Main Street, Avenue, Boulevard, Parkway, Rural Road, or Local/Subdivision Street. Figure 10 illustrates the level of predominance by pedestrian or vehicle. Although the design of all roadways should accommodate all road users from a complete street concept, compromise is made based on the mix of users, as shown in Figure 10. The characteristics of the different street types are discussed at a later part of this report.

Figure 10. Street type and road users mix level



Justification of Urban Arterial definition

Currently, Louisiana uses AASHTO Classification to classify roadways as interstate, principal arterials, other principal arterials, minor arterials, major collectors, minor collectors, and locals. However, arterials in Louisiana do not generally fit the AASHTO definition of arterials as having fully controlled access facilities.

Major intercity communities are connected by principal arterials, which also serve as connectors to major suburban centers. Urban minor arterials are arterials in urban and urbanized areas outside principal arterials that provide services at a relatively lower speed to smaller geographic areas. Urban minor arterials should contain facilities for land access and lower levels of traffic mobility.

Legislation that Disallows Pedestrian on Roadways Other than Interstate

Most research consider pedestrian crossing behavior at unapproved locations as illegal crossing, and in state laws, it is termed as jaywalking. Illegal pedestrian crossing may include crossing at an unmarked mid-block section [54], [55]. Also, pedestrian crossing at grade, at locations with grade-separated crossings like a footbridge or overhead, may be considered as illegal [56]. Legal crossing locations may include crossing at an unsignalized marked crosswalk [57], signalized marked crosswalks, and an unmarked intersection crosswalk [58].

From a state or city legislation point of view, jaywalking is the violation of pedestrian laws, which could comprise a myriad of laws concerning pedestrian crossing roadways, pedestrians at transit stops, pedestrians at a railroad crossing, pedestrians soliciting for rides or business and many others. However, this study limits its focus on pedestrian roadway crossing actions. Jaywalking laws vary from state to state based on how strict a state's pedestrian laws are. Some pedestrian actions that are considered as jaywalking in some states but not in other states like Louisiana, Arizona, Colorado, Pennsylvania, Maine, Montana, and Nebraska include the following:

- Pedestrians are allowed to cross roadways outside a crosswalk, at an intersection or mid-block, but must yield the right-of-way to the vehicle.
- Pedestrians are allowed to cross roadways at-grade, even where a pedestrian tunnel or overhead crossing exists, but must yield the right-of-way to all vehicles.

Pedestrian Prohibition Laws on Louisiana High-Speed Roadways

The following pedestrian prohibition laws apply on Louisiana high-speed roadways according to Louisiana Laws Revised Statutes "Title RS 32:212 – Pedestrians right-of-way in crosswalks," "Title RS 32:213 – Crossing at other than cross walks" and "Title 32 RS 32:216 – Pedestrians on highways or interstate highways" [58]:

- R.S. 32:212: When traffic control devices are not in place or are not in operation, vehicle must yield to pedestrian. Pedestrians must not leave curb or other place of safety and walk or run into the path of a vehicle which is so close that it is impossible for the driver to yield.
- R.S. 32:213: Pedestrians outside crosswalk must yield right of way to all vehicles. If there are traffic signals, pedestrians may not cross outside crosswalk.
- RS 32:216: It shall be unlawful for any pedestrian to cross an interstate highway, except in the case of an emergency.
- RS 32:216: Where sidewalks are provided, it shall be unlawful for any pedestrian to walk along and upon an adjacent highway.
- RS 32:216: Where sidewalks are not provided, any pedestrian walking along and upon a highway shall when practicable, walk only on the left side of the highway or its shoulder, facing traffic which may approach from the opposite direction.

Other Pedestrian Crossing Prohibition Laws

One general crossing prohibition law is “Pedestrians are prohibited from crossing roadways separated by two adjacent signalized intersections.” Twenty-three states, including Louisiana, were identified to have this policy in their pedestrian laws. Pedestrian laws [59] identified in other states include the following:

1. Denver pedestrian crossing guidelines states that “it shall be unlawful for any pedestrian to cross a roadway that is a through street or a through highway at any place other than a crosswalk.”
2. Another prohibition law states that except on a local street, it is unlawful for any pedestrian to cross a roadway directly to a vehicle stopped, parked, or standing on the opposite side of the roadway.
3. Where sidewalks are provided, it is unlawful for pedestrians to walk or move along or upon an adjacent roadway.
4. Pedestrians are prohibited from crossing roadways in a business district except at crosswalks, which may be established by ordinance.

A business district is defined as the territory contiguous to and including a highway, as herein defined; when within any six hundred feet along such highway, there are buildings in use for business or industrial purposes, including but not limited to hotels, banks or office buildings, railroad stations and public buildings which occupy at least three hundred feet of frontage on one side or three hundred feet collectively on both sides of the highways [52]. Three states were identified to have this policy, namely Nebraska, North Dakota, and Indiana.

Pedestrian Crossing Facilities

Roadways are mainly made for motorists, cyclists, and pedestrians. Of these three groups of road users, pedestrians are arguably the most vulnerable as they have the least protection and hence, highest risk. They are, therefore, to be significantly considered when planning and designing roadways to ensure their safety always. The concept of pedestrian crossing facilities primarily serves pedestrians by allowing a safe and convenient interface between vehicular traffic and pedestrians, especially in urban areas where both vehicular and pedestrian traffic are of a high magnitude.

Types of Pedestrian Crossing Facilities

There are different kinds of pedestrian crossing facilities, and each is most suitable for specific conditions. A broad classification of pedestrian crossing facilities reveals they may either be at-grade crossing facilities or grade separated crossing facilities.

At-Grade Crossing Facilities

These are pedestrian crossing facilities that share a path of travel with vehicular traffic at the same elevation. These facilities, often termed as crosswalks, do not allow for simultaneous use of the roadway by motorists and pedestrians: one party stops for the other to cross. The 2000 Uniform Vehicle Code Section 1-118 defines a crosswalk as any portion of a roadway, at an intersection or elsewhere, distinctly indicated for pedestrian crossing, by lines or other surface markings [60].

Crossing facilities can be located at a controlled or uncontrolled portion of the roadway. The former describes situations where a traffic signal device apportions definite time periods for motorists and pedestrians in a cyclic manner. At uncontrolled crosswalks, pedestrians can determine gaps in vehicular traffic that provide a safe and convenient time to cross the road. The risk of vehicle-pedestrian collision is significantly increased at uncontrolled intersections. At-grade crossing facilities are broadly classified as marked crosswalks or unmarked crosswalks. Legally, the two are no different, but markings may be used to designate a wider crosswalk and must be provided at mid-block crossings to legally establish it as a crosswalk [61].

Marked Crosswalks

Marked crosswalks physically indicate preferred zones for pedestrian crossing and help to designate right of way for motorists to either stop for or yield to pedestrians. The physical indicator is painted line marks on the surface of the road. The markings conventionally consist of two parallel white lines, with perpendicular or diagonal lines added for improved visibility [61]. The Manual on Uniform Traffic Control Devices (MUTCD) specifies various marking patterns. Marked crosswalks are common in midblock crosswalks because motorists expect pedestrian crossing at intersections, but not mid-block locations. The presence of markings at mid-blocks also establishes it as a legal crosswalk.

Crosswalks are the most low-cost option for pedestrian crossing facilities. Complex crosswalk patterns result in a slight increase in cost. Crosswalks alone are often considered insufficient and should be installed together with other road features like curb extensions and ramps for wheelchair access, to fortify the safety function they serve [61].

Different jurisdictions, cities, and states have their own adopted warrants for the installation of crosswalks. These are often based on pedestrian volumes, vehicular approach speeds, nearness to other crosswalks, visibility conditions, illumination, and accessibility. The following are examples of specific warrants for crosswalk installation:

1. Locations close to schools and within a one-block radius along routes leading to the school [62].
2. Locations adjacent to public parks, community centers, libraries, and high use public facilities [62].
3. Areas within the city center core blocks [62].
4. Locations where accident records, pedestrian volume, sight obstructions, or demographic analysis warrant the installation [62] – such as adjacent to bus stops.
5. Locations where there are more than 300 vehicles per hour and at least 75 pedestrians per hour in any 8-hour period of a day [63].
6. The location must have relatively low traffic speeds, sufficient sight distance, and good illumination [63].

Midblock Crossings

In modern times, blocks have become longer, intersections are often far apart, and vehicle speeds much higher. This evolution has rendered crossing only at intersections impractical. Human beings are naturally drawn to paths of least resistance and, therefore, will not walk long distances away to cross a road safely. In response to this situation, traffic engineers are burdened with the task of finding safe points of crossing roads between intersections that are relatively far apart. Designers tend to prefer locations with frequent gaps, improved lighting, and where motorists have a good chance to safely detect and respond to pedestrians crossing the road [63]. Midblock crossings require careful evaluation as vehicles will not necessarily stop for a pedestrian.

Geometric treatments such as medians and refuge islands complement the function of midblock crossings by providing “refuge” mid-way through the road section, especially for wider roadways. These are raised longitudinal spaces separating the two main directions of traffic. They are further discussed in later sections of this report.

Louisiana Policy on Crosswalk Installation

Louisiana State Law RS 32:1(13) [64] defines a crosswalk as:

a) *That part of a roadway at an intersection included within the connections of the lateral lines of the sidewalks, shoulders, or a combination thereof on opposite sides of the highway measured from the curbs or, in absence of curbs, from the edges of the traversable roadway or if there is neither a sidewalk nor shoulder, a crosswalk is the portion of the roadway at an intersection that would be included within the prolongation of the lateral lines of the sidewalk, shoulder, or both on the opposite side of the street if there were a sidewalk or shoulder.*
b) *Any portion of a roadway at an intersection or elsewhere distinctly indicated for pedestrian crossing by lines or other markings on the surface.*

Louisiana policy discourages the indiscriminate placement of striped crosswalk, but where necessary, the 2016 memorandum [65] signed by the DOTD Chief Engineer provides guidance on the installation of crosswalk. The document states that:

On a local route:

1. The placement of striped intersection crosswalk should be in accordance with MUTCD.
2. For a mid-block crosswalk, an engineering study, as defined by DOTD Traffic Engineering Manual and stamped by a licensed engineer in the state of Louisiana, must be undertaken before a marked crosswalk shall be installed.

On a state route:

The installation of crosswalks must first go through an engineering study and approved by the District Traffic Operations Engineer (DTOE) to justify the provision of the facility. Sections 3B.2.4 to 3B.2.8 of the DOTD Traffic Engineering Manual [66] provides guidance on the placement of crosswalks at uncontrolled approaches, midblock locations, and controlled approaches for state routes.

Section 3B.2.6 Uncontrolled approach at an intersection

A crosswalk may be installed if:

1. *There are a minimum of 20 pedestrians crossing in a 2-hour period during any 24-hour period and the pedestrians have fewer than 5 gaps in traffic per 5-minute period; or*
2. *Engineering judgment indicated a need.*

A crosswalk must not be installed if:

1. *Posted speeds exceed 40 mph;*
2. *On a roadway with 4 or more lanes:*
    a. *without a raised median or crossing island that has (or will soon have) an ADT of 12,000 or more;*
    b. *with an ADA compliant raised median or crossing island that has (or will soon have) an ADT of 15,000 or more;*
3. *If engineering judgment indicates.*

Section 3B.2.7 Mid-block crosswalks

A crosswalk may be installed if:

1. *There are 40 or more pedestrians that cross during a one-hour period or 25 or more cross per hour for 4 consecutive hours and fewer than 5 gaps in traffic during the peak 5-minute period; and*
2. *The Average Daily 2-way traffic is above 3500 vehicles per day; or*
3. *Engineering judgment indicated a need.*

A crosswalk must not be installed if:

1. *Another crosswalk exists within 600 ft.; or*
2. *Posted speeds exceed 40 mph; or*
3. *If engineering judgment indicates.*

Section 3B.2.8 Controlled approach at an intersection

A crosswalk may be installed if:

1. *There are a minimum of 20 pedestrians crossing in a 2-hour period during any 8-hour period; or*
2. *If engineering judgment indicates a need.*

Unmarked Crosswalks

Unmarked crosswalks are simply areas across the roadway where pedestrians can safely cross, despite the absence of a clear paint mark or demarcations on the road surface. Most intersections are considered safe zones for pedestrian crossings, even with the absence of paint marks on the pavement. At unmarked crosswalk locations, delay times for pedestrians are significantly increased as motorists often refuse to yield [67]. Unmarked crosswalks are only located at intersections and never at mid-block locations. At midblock locations, the only indication of legally crossing is the presence of markings on the road surface. Intersections without crosswalk markings or strips or intersections with only colored pavement are still unmarked crossings.

Grade Separated Crossing Facilities

Grade separated crossing refers to facilities that allow for pedestrians and vehicles to cross a roadway at different elevations [61]. They allow complete segregation of pedestrians from automobiles and enhance accessibility and connectivity for pedestrians to nearby local activity centers. These also allow for simultaneous action where neither party needs to stop making way for the others to use the roadway. It, therefore, reduces delays for both motorists and pedestrians. Additionally, this type of facility significantly reduces pedestrian vulnerability as well as pedestrian-vehicle conflicts. Grade separated crossing facilities are either overpasses or underpasses. Both are nearly equally suitable for urban conditions.

The primary selling point of grade separated crossing facilities is ultimate safety; no other pedestrian crossing facility provides the level of safety offered by these. These facilities completely remove all vehicle-pedestrian interference and so completely prevents a possible collision between the two. However, grade separated crossing facilities are most disliked amongst pedestrians, due to the time and effort required to use them. Studies suggest women and older pedestrians tend to avoid underpasses, especially for their personal security [68]. For this reason, fencing and other strict measures must be employed to force pedestrians to use the facility. Additionally, grade separated crossing facilities are highly expensive to construct and difficult to implement. Due to the high cost associated with these compared to at-grade crossings, compelling purpose and need are often primary requisites to obtain approval for the construction of these.

The following conditions often justify the selection of a grade-separated pedestrian crossing when pedestrian safety is an issue:

1. Moderate to high pedestrian demand to cross freeway or expressway.
2. Many young people often crossing the road, e.g., locations near schools.
3. High vehicular traffic within urban enclave with high foot traffic.
4. No other convenient crossing facility nearby.
5. Extreme hazard for pedestrians.

Overpasses. Overpasses allow for uninterrupted traffic flow by providing safe passage of pedestrians above the road. As required by the Americans with Disabilities Act (ADA), both stairs and ramps must be installed to assist pedestrians to reach the overpass. Occasionally, the road may be depressed, and the pedestrian passageway maintained at ground level. Overpasses are commonly referred to as footbridges. Footbridges are generally more effective when the roadway lies below the naturally occurring ground line/surface [69]. Railings and screening are sometimes provided, to prevent pedestrians from falling or from throwing objects down into the vehicular path.

Underpasses. Underpasses also provide an interference-free travel path for pedestrians. It does so by providing a passageway beneath the road surface. Commonly termed pedestrian tunnels, these structures must also comply with ADA requirements to accommodate disabled persons.

Pedestrian Crossing Features and Enhancements

The mere presence of a crosswalk does not guarantee pedestrian safety. Traffic engineers often employ the use of some features to increase the effectiveness of installed crosswalks. These ancillary measures to improve safety are called crossing treatments. Factors impacting the decision to select a specific treatment method include the type of pedestrian crossing facility, foot, and vehicular traffic volumes, number of lanes, crossing length, the location of an intersection, cost, etc. Some of the crossing treatments identified include:

- Staggered crosswalks.

- Curb Ramps.
- Median refuges.
- Pedestrian Hybrid Beacons (PHBs).
- Illumination.
- Raised Crosswalks.
- Advanced Stop/Yield Lines.
- Rectangular Rapid Flashing Beacons (RRFB).

A detailed discussion of these crossing figures is included in Appendix B.

Engineering Data Studies for a Marked Crosswalk

Louisiana Traffic Engineering Manual [66] proposes studies needed for the justification of a marked crosswalk. Studies may vary from site to site, and the listed studies are by no means exhaustive as other studies may be considered. They are:

1. Speed and traffic volume data on streets being crossed.
2. Pedestrian volume (note the approximate number of young children and seniors and level of mobility).
3. Location of pedestrian origin and destination points and crossing pattern.
4. Existing sidewalk network and sidewalk ramps.
5. Sight distances and sight obstructions.
6. Street characteristics including grades, curvature, pavement widths, and number of vehicle and bicycle lanes.
7. Location of adjacent driveways.
8. On-street parking.
9. Street lighting.
10. Location of drainage structures.
11. Distance to nearest protected or marked crossing.
12. Traffic signal progression.

13. Potential for rear-end accidents.
14. ADA compliance.

The state traffic engineering manual provides in-depth discussion on some of the studies listed above. The discussion of the engineering studies can be found in Appendix C.

Policies Adopted by the United States Regarding Pedestrian Crossing Facilities on High-Speed Arterials

Pedestrian crossing facilities are access points on roadways used by a pedestrian to cross or walk along the roadway. Roadways with high speeds like arterials pose a higher risk to pedestrians than collectors or local roads do. To improve pedestrian safety and mobility in the United States, federal, state, local agencies and jurisdictions apply policies and treatments. Different states and local agencies embrace different goals, resulting in varying pedestrian safety policies and treatment practices among cities, and state agencies [70]. Historically, the conventional goal of moving more vehicles rapidly through the network led to the implementation of policies and practices to deal with the increasing dominance of automobiles on the roadway. The current concept of design and planning seeks to address the challenges of pedestrians and encourages pedestrian mobility (walking and cycling) to improve safety and public health [71]. This section documents the policies and treatment practices adopted by states and cities on pedestrian crossing facilities on high-speed arterials. This includes treatments and policies for pedestrian safety at both signalized and unsignalized crossings.

Treatment is defined as measures or traffic devices installed at crossing points to improve the safety of pedestrians and meet pedestrians' or would-be pedestrians' expectation of a safe crossing as well as eliminating potential barriers to walking. Policies are conceptual ideologies that guide the priorities and decision processes of national, state, and local agencies.

The research relied on current comprehensive pedestrian research synthesis which includes;

- NCHRP Synthesis 498: Application of Pedestrian Crossing Treatments for Streets and Highways [70].

- NCHRP Synthesis 436: Local Policies and Practices That Support Safe Pedestrian Environments [71].
- Delivering Safe, Comfortable, and Connected Pedestrian and Bicycle Networks: A Review of International Practices [72].
- TCRP report 112/NCHRP report 562: Improving Pedestrian Safety at Unsignalized Crossings [73].
- Federal, State, and City Pedestrian Crosswalk Guidelines.

A selection is summarized as below.

Federal Policies

The FHWA 2000 publication, "Accommodating Bicycle and Pedestrian Travel: A Recommended Approach (FHWA HEP 2012a) [74]" is anchored on four major statements, and apart from statement 2, the rest relates to high-speed arterials. The detailed policy is included in Appendix D.

The supplementary design guideline for Bicycle and Pedestrian Project Policy [75] provides further clarification on the original document as follows:

a. *The supplementary design guideline seeks to explain what is meant by "excessively disproportionate." It also adds "probable use" to that statement. The full statement now reads, "The cost of establishing bikeways or walkways would be excessively disproportionate to the need or probable use. Excessively disproportionate is defined as exceeding 20 percent of the cost of the larger transportation project." This twenty percent (20%) figure should be used in an advisory rather than an absolute sense.*
b. *The supplementary design guideline also provides clarity to the "1,000 vehicles per day requirement" for the provision of paved shoulders. It states that 'the particular vehicle volume used to justify the provision of paved shoulders may vary from state to state. Nevertheless, paved shoulders provide clear safety and operational benefits for both motorized and nonmotorized users."*

The US Code Policy

The US code policy, which applies to all states, requires them to develop a Statewide Transportation Plan and programs to improve the safety of pedestrians. The policy states that: *The Statewide Transportation Plan and the Transportation Improvement Program developed for each State shall provide for the development and integrated management and operation of transportation systems and facilities (including accessible pedestrian walkways, bicycle transportation facilities, and intermodal facilities that support intercity transportation, including intercity buses and intercity bus facilities and commuter van pool providers) that will function as an intermodal transportation system for the State and an integral part of an intermodal transportation system for the United States* [76].

Complete Streets Policies and Guidance

Complete Streets are streets designed to provide safe access for all users, including pedestrians, bicyclists, transit users, and motorists, regardless of age, race, ethnicity, income, or physical ability [77]. Since 2016, over 1,400 Complete Streets policies have been passed in the United States, including those adopted by 33 state governments, the Commonwealth of Puerto Rico, and the District of Columbia. Currently, 1,200 Complete Streets policies have been passed at the city level, 91 at the regional level, and 90 at the county level, and 51 at the state level. The ten ideal elements of a comprehensive Complete Streets Policy are:

- Vision
- All users and modes
- All projects and phases
- Clear, accountable exceptions
- Network
- Jurisdiction
- Design
- Context sensitivity
- Performance measures
- Implementation steps

Based on the summary analysis of the response by states and local agencies, the NCHRP 498 report concludes that nearly one third of state agencies have Complete Streets policies while others also work with local jurisdictions that have Complete Streets policies [70].

The state of Louisiana has a Complete Streets policy mainly to accomplish the following goals [66]:

- To safely and efficiently accommodate all road users.
- To create a network that balances integration of context sensitivity, access, and mobility for all users.
- To provide leadership and establish partnerships with local public agencies on implementing the policy.

National Association of City Transportation Officials (NACTO)

NACTO's mission is to build cities as places for people, with safe, sustainable, accessible, and equitable transportation choices that support a strong economy and vibrant quality of life. NACTO provides guidelines for the regulation and management of Shared Active Transportation (SAT). Two of the design guides provided by the organization are the Urban Street Design Guide and the Urban Bikeway Design Guide. According to NCHRP Report 498, 42% of local jurisdictions consult these two guidelines for treatments to pedestrian crossing facilities, higher than the 35% that reported using the AASHTO Pedestrian Design Guide. States such as Colorado, Connecticut, Massachusetts, Washington, and Wisconsin rely on the NACTO Design Guide [70]. Some NACTO recommendations [78] for the improvement of pedestrian safety at mid-blocks include:

- Installing vertical elements such as trees, landscaping, and overhead signage helps to identify crosswalk and refuge island.
- Day-lighting (removing parking spaces adjacent to curbs) in advance of a crosswalk improves pedestrian visibility.
- Stop lines at midblock should be between 20 and 50ft. before the crosswalk.
- Stripe the crosswalk regardless of the paving pattern or materials.
- Refuge island creates a safe two-stage crossing for pedestrians.
- At transit stops, pedestrians should preferably cross behind the transit vehicle.

Additional NACTO recommendations [73], [79] for the improvement of pedestrian safety at mid-block include:

- A median refuge island to make the street crossing easier and more convenient.
- Advanced yield lines to improve the visibility of crossing pedestrians.
- Removal of parking and installation of curb extensions to improve visibility.
- Pedestrian-activated flashing beacons to warn motorists of crossing pedestrians.
- Motorist signs to indicate that pedestrians have the legal right-of-way.
- Pedestrian signs to encourage looking behavior, crosswalk compliance, and pushbutton activation.
- In-pavement warning lights with advance signing to inform drivers of the crossing.
- Countdown signals with a pedestrian (Walk/Don't Walk) signal if appropriate for the treatment (e.g., high-intensity activated crosswalk [HAWK] signal or other pedestrian traffic control signals).

State and Local Agencies' Policies for Pedestrian Crossings

This section of the research relied extensively on the NCHRP 498 report on "Application of Pedestrian Crossing Treatment for Streets and Highways" to determine the various treatment practices being used by states and local agencies. The concept of safety for all road users has been embraced widely by state and city jurisdictions. While many agree on the need for improved pedestrian safety, the approach being used differs from one jurisdiction to another. This section provides examples of practices adopted by various cities to improve pedestrian safety at crosswalks.

Boston Massachusetts – Boston Complete Streets Guidelines

Boston, also referred to as the walking city, has many close-in cities and towns such as Cambridge, Somerville, and Quincy, which are densely packed neighborhoods. The city of Boston's transportation department has adopted Complete Streets approach guidelines in its street design. The goal of the department is to ensure a multimodal approach in the reconstruction of streets. This is aimed at improving the quality of life in Boston by creating streets that have both great public spaces and sustainable transportation networks. Some of the recommended practices in the design guideline [80] to improve pedestrian safety include the following:

1. Refuge islands can be combined with mid-block pedestrian crossings to reduce crossing distances.
2. Additional treatments should be added to crosswalks on major street crossings. Such treatments may include signage, median refuge islands, curb extensions, rapid flash beacons, bicycle-sensitive loop detectors, and/or bicycle signal heads.

Amarillo, Texas – Downtown Amarillo Urban Design Standards

The guideline includes measures to improve pedestrian safety and walkability, promoting pedestrian-oriented urban forms, maximization of connectivity of road users, and accessibility. The standards [81] enforces walkability and safety of pedestrians at crosswalks by recommending some of the following design practices:

1. Providing wider sidewalks, pedestrian lighting, and street trees in the furnishing zone.
2. Having lighting on roadways with pedestrian activities such as downtown areas improve the safety of pedestrians, especially at crosswalks.
3. Features such as bulb-outs can be used to improve pedestrian crosswalks, but this must have the approval of city staff.

DeKalb County, Georgia – Clifton Corridor Urban Design Guidelines

Clifton City in Georgia has seen much growth and development due to its location. The DeKalb County was noted as the county with the highest pedestrian fatality in Georgia. The guideline defines a good crosswalk as having convenient signaling, high visibility to drivers, accessible connections to sidewalks, and median refuges where necessary. The design standard [82] addresses pedestrian safety at crosswalks by suggesting the following mitigation measures:

1. Providing wider sidewalks.
2. Using raised and colored crosswalks.
3. Installing bulb-outs and other pedestrian infrastructure elements.
4. Provision of pedestrian signals that display a numeric countdown of remaining crossing time and have an audible indication of phase.

5. For locations where pedestrian volumes are prominent, crosswalks may be colored, preferably striped parallel or at an angle painted markings to clearly distinguish crosswalk from adjacent traffic paving.
6. Provide curb cuts linking crosswalks to sidewalks.
7. For crosswalks at intersections spanning more than four traffic lanes provide, if possible, a median refuge preferably 6 feet wide.

Los Angeles, California – Downtown Design Guide

Los Angeles is the second-most populous city in the United States, with 3.8 million residents. One of the major goals of the city is to reinforce walkability, bikeability, and well-being of its citizens. Thus, the creation of more opportunities for pedestrians and bicyclists to effortlessly connect public open space reinforces the need for workability and wellbeing. Some recommendations for pedestrian crosswalks for large-scale developments in its residential city-wide design guidelines [83] include:

1. Incorporate features such as white markings, signage, and lighting so that pedestrian crossings are visible to moving vehicles during day and night.
2. Improve visibility for pedestrians in crosswalks by installing curb extensions outs and advance stop bars and eliminating on-street parking spaces adjacent to the crossing.
3. Use devices such as crossing signals, visible and accessible pushbuttons for pedestrian-activated signals, and dual sidewalk ramps directed to each crosswalk.
4. Create the shortest possible crossing distance at pedestrian crossings on wide streets or shorten crossing distances by using mid-block crossing islands, or a minimal curb radius.

Treatments Implemented by Agencies on High-Speed Roadways

Countermeasures implemented to improve pedestrian safety on high-speed roadways vary among agencies. Although the suggested definition of high-speed roadways is roads with speeds at and above 45 mph, other agencies define their high-speed roadways as roads with speeds at 40 mph and above. Based on this, some agencies caption crosswalk treatments for roads with speeds 40 mph as treatments for their high-speed roads.

San Diego Pedestrian Crosswalk Guidelines (2015)

San Diego County in California pedestrian crosswalk guidelines [84] suggests certain treatments for specific roadway conditions. Table 4 shows different roadway conditions (Category A, B, C, D) and corresponding treatments are provided in Table 5. The description for high-speed arterial roads can be captured by superscript number 1 as defined in the footnote.

Table 4. Threshold for uncontrolled marked crosswalks

Crossing Distance[2]	Roadway ADT (vehicles per day)								
	<1,500	1,501-5,000		5,001 – 12,000		12,001 – 15,000		>15,000	
< 40 ft.	A	B		B		C		C	D
40 ft.-52 ft.	A	B		C		C	D[1]	D	
>52 ft.	A	B	C[1]	C[1]	D[1]	D		D	

1. For streets with more than one lane at an approach or posted speed limit 30 mph or greater
2. Crossing distance can be measured to a pedestrian refuge island if one is present

Source: San Diego pedestrian crosswalk guideline 2015

Table 5. Treatment for uncontrolled marked crosswalk

Category	Crossing Treatments
A	**The following is required** • (W11-2) Pedestrian Warning Signage with the corresponding (W16-7P) arrow plaque
B	**At least one of the following is required** • (R1-6) State Law – Yield to Pedestrian sign if median is present • Rectangular Rapid flashing Beacons (RRFBs) • Raised crosswalk or other calming treatments if the city of San Diego's Traffic Calming Guidelines are met
C	**At least two of the following are required:** • Radar speed feedback signs • Striping changes such as narrower lanes, painted medians, road diets, or other speed-reducing treatments • RRFBs • Staggered crosswalks and pedestrian refuge island • Horizontal deflection traffic calming treatments[1] if the city of San Diego's Traffic Calming Guidelines are met

Category	Crossing Treatments
D	A Traffic Signal is required if the CA MUTCD warrants are met, and it is recommended by a traffic engineering study. Otherwise, at least one of the following is required: • Pedestrian Hybrid Beacon if the CA MUTCD warrants are met • Horizontal deflection traffic calming treatment[1] with RRFBs if the City of San Diego Traffic Calming Guidelines are met
1. Horizontal deflection treatment includes, but are not limited to: roundabouts, pedestrian refuge islands, and pedestrian bulb-out	

Washington Pedestrian Crossing Prototype

Implementation of countermeasures and pedestrian facilities for the state of Washington are documented in planning and designing for pedestrian guidelines [85] developed for the San Diego Regional Planning Agency. The prototype of different high-speed arterial conditions and installed pedestrian facilities in cities in Washington are shown in Table 6.

Table 6. Pedestrian crossing prototypes [85]

Location	Setting	Features
Kirkland, Washington 	• On Major Arterial between Freeway and Downtown • Unsignalized Intersection • Higher Speed (40+ mph) • Near Park and Transit Stop • Moderate to High Traffic Volumes • Moderate Pedestrian Activity	• Overhead Illuminated Sign • Refuge Island • Pedestrian Crossing Signs on Curbs, Medians, and Overheads
Bellevue, Washington 	• Adjacent to Major Transit Stop • High-Speed Corridor (45 mph) • Four-lane Arterial • Traffic Volume Greater than 25,000 Vehicles per Day	• Staggered Crosswalk • Median with Pedestrian Corral • Overhead Signs and Flashing Beacons • Advance Stop Bars • Ladder Crosswalk Stripping

Las Vegas Lake Mead Boulevard Midblock Countermeasure

Pedestrian countermeasures were implemented on a high-speed arterial midblock location in Las Vegas arterial roadway [86]. Table 7 shows the site description and proposed countermeasures. The findings of the test showed that:

- Pedestrian delay was significantly reduced.
- No impact on vehicle delay.
- 40% of drivers yielded after installation.

Table 7. Danish offset on Las Vegas high-speed midblock

<table>
<tr><th>Location</th><th>Description</th><th>Countermeasure</th></tr>
<tr><td>Lake Mead Boulevard (Belmont St. to McCarran St.)
</td><td>• A midblock location
• Major arterial in a primarily residential area
• Speed limit of 45 mph
• AADT 44,000</td><td>• Danish offset
• High-visibility crosswalk
• Advance yield markings
• Yield here to pedestrian signs</td></tr>
</table>

City of Boulder Pedestrian Crossing Guidelines

The guidelines provided a decision tree flowchart to determine if a location meets the requirement for a pedestrian crosswalk. Table 8 recommends six different treatment levels for different roadway characteristics. Arterial roadway treatments meet the characteristics of roadways with speeds ≥45 mph. Level D, E, and F treatments [87] are suggested for crosswalks provided on such roadway.

Table 8. Treatment levels for different roadway characteristics

Roadway Configuration	# of lanes crossed to reach a refuge[1]	# of multiple threat lanes[2] per crossing	Roadway ADT and Posted Speed															
			1,500-9,000 vpd				9,000-12,000 vpd				12,000-15,000 vpd				> 15,000 vpd			
			≤ 30 mph	35 mph	40 mph	≥ 45 mph	≤ 30 mph	35 mph	40 mph	≥ 45 mph	≤ 30 mph	35 mph	40 mph	≥ 45 mph	≤ 30 mph	35 mph	40 mph	≥ 45 mph
2 Lanes (one way street)	2	1	A	B	C	E	A	B	C	E	B	B	C	E	B	C	C	E
2 Lanes (two way street with no median)	2	0	A	B	C	E	A	B	C	E	B	B	C	E	B	C	C	E
3 Lanes w/Raised Median	1 or 2	0 or 1	A	B	D	E	A	C	D	E	B	D	D	E	C	D	D	E
3 Lanes w//Striped Median	3	0 or 1	C	C	D	E	C	C	D	E	C	C	D	E	C	D	D	E
4 Lanes (two way street with no median)	4	2	A	D	D	E	B	D	D	E	B	D	D	E	D	D	D	E
5 Lanes w/Raised Median	2 or 3	2	A	B	D	E	B	C	D	E	B	C	D	E	C	C	D	E
5 Lanes w/Striped Median	5	2	D	D	D	E	D	D	D	E	D	D	D	E	D	D	D	E
6 Lanes (two way street with or without median)	3 to 6	4	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F

Notes:

1. Painted medians can never be considered a refuge for a crossing pedestrian. Similarly, a 4 foot wide raised median next to a left turn lane can only be considered a refuge for pedestrians if the left turning volume is less than 20 vehicles per hour (meaning that in most cases the left turn lane is not occupied while the pedestrian is crossing).
2. A multiple threat lane is defined as a through lane where it is possible for a pedestrian to step out from in front of a stopped vehicle in the adjacent travel lane (either through or turn lane).

Source: City of Boulder Pedestrian Treatment Installation Guidelines (September 2011)

Level D Treatment

- Median refuge island.
- "Yield to Pedestrian" sign can be mounted on the roadway.
- Advance pedestrian warning signs (W11-2).
- Pedestrian actuated Rectangular Rapid Flash Beacons (RRFBs).
- Add curb extension.

Level E Treatment

- If initial speed is equal or greater than 45 mph, determine if speed limit can be effectively reduced to 40 mph.
- If not, consider treatment F.

Treatment F

- If there are three or more lanes in one direction, the site is not suitable for uncontrolled marked crosswalk.
- Consider HAWK beacon, pedestrian traffic signal, or grade-separated pedestrian crossing.

Summary of Recommended Crosswalk Treatments at Mid-blocks

Engineering studies should be carried out on a site by site basis to determine whether providing a marked crosswalk is appropriate or not. Providing marked crosswalks and appropriate treatments is one way of creating safe gaps for pedestrians to cross the road. More importantly, having a well-planned and organized street environment will enhance the safety of pedestrians. For instance, Boston is the safest largest city to walk and has the highest rate of walking to work of any major city. Other large cities, like Jacksonville, have a very low rate of walking to work. A pedestrian in Jacksonville is forty-six times more likely to be struck by a car compared to a pedestrian in Boston [88].

Objective

The purpose of this study was to provide a preliminary assessment of Louisiana's roadways in terms of existing pedestrian crossing facilities, identify any associations of pedestrian crashes with the presence or lack of such pedestrian crossing facilities, and provide information on studies needed to be undertaken to provide DOTD with a system-wide solution for pedestrian crossing facilities on its high-speed arterials.

Specifically, the main objectives were to:

1. Conduct a literature review of state legislation on the provision of pedestrian crossing facilities on arterials.
2. Undertake a study of pedestrian crashes to identify any associations with the lack or presence of pedestrian crossing facilities.
3. Determine and review the types of traffic studies that need to be conducted in order to provide appropriate pedestrian crossing facilities on urban arterials.

The first phase of the research, which was in the preceding sections, provided comprehensive literature that provides an explanation to key terms in the project and provides perspective into strategies and policies adopted by other state agencies to improve pedestrian safety. The literature, presented thus far, addressed the following topics:

- How other state agencies and publications have defined "high-speed roadways" and further recommend a definition for Louisiana based on its findings.
- Definition of rural, urban, and suburban, based on land-use characteristics of an area mainly to help classify high-speed arterials into urban, suburban, and rural.
- Possible legislation prohibiting pedestrians on certain roadway types other than the interstate.
- The available types of pedestrian crossing facilities.
- Legislations (policies) adopted by US state agencies on the provision of pedestrian crossing facilities on both urban and high-speed arterials.

- Policies and guidelines being enforced by other states on the provision of pedestrian crossing facilities (e.g., median refuges, marked crosswalks, mid-block crossings, grade separation, barriers between intersections to guide or channel pedestrians to authorized crossings, tunnels, bridges, etc.).

The second part of the analysis, which follows this section, focuses on identifying factors contributing to pedestrian crashes on Louisiana high-speed urban arterial roadways, specifically in New Orleans, Baton Rouge, Lafayette, Shreveport, Houma, Monroe, Alexandria, and Hammond. The research investigates how different movement types, by pedestrians and motorists, influence pedestrian crashes on high-speed urban roadways while probing the influence other traffic and roadway characteristics of high-speed roadways have on the occurrence of pedestrian crashes. To achieve these aims, the following specific research objectives were pursued:

1. Propose a breakdown classification of high-speed arterial roadways.
2. Identify factors contributing to pedestrian crash severity on Louisiana high-speed urban roadways.
3. Identify and examine the main predictors of pedestrian crash severity.
4. Identify geometric and traffic control characteristics that influence the frequency of pedestrian crashes.
5. Identify pedestrian motorist movements that result in pedestrian crashes.
6. For intersection crashes, identify locations with frequent pedestrian crashes and type of control at these intersections.

The research team first identified all pedestrian crash locations between 2013 and 2017, read the crash narratives to confirm the details have been correctly coded, checked for existing pedestrian facilities at the crash locations, documented roadway features/characteristics at the locations, and determined whether crash patterns correlated with certain roadway features. Several analysis tools were utilized and can be summarized as follows: data-driven safety analysis (DDSA), spatial hotspot or heat map analysis, decision tree analysis, and location movement classification method (LMCM) analysis.

Being able to determine whether a pedestrian crash problem exists, and which roadway features contribute to this, is a desirable outcome of the study. It is anticipated that such findings will provide supporting documentation to enable further studies to be undertaken that will focus on developing a state guideline to tackle such a pedestrian crash problem in the state of Louisiana.

Scope

Nine major metropolitan areas in the state of Louisiana that capture major urbanized areas were used for this study. These sites were selected based on their size and geographical location. The central portions of most metropolitan areas in Louisiana are urbanized, with surrounding areas being urban areas. Table 9 shows a comparison of commonly used land-use terms with corresponding terms used in the state of Louisiana. The study areas used in the research are New Orleans, Baton Rouge, Lafayette, Shreveport, Houma, Monroe, Alexandria, Hammond, and Lake Charles.

Table 9. Land-use name comparison

(Common) Land-use Classification	Louisiana Classification
Urban	Urbanized
Suburban	Urban
Rural	Rural

Only high-speed roadways were included in this research. High-speed roadways were defined after reviewing different literature from federal, state, and local agencies. Generally, high-speed roadways were defined based on posted speed. The lower limit of high-speed roadways varied from study to study. Based on the literature and the analysis conducted, the recommended definition of high-speed roadways is “roadways with posted speeds of 45 mph or greater.” Pedestrian crashes on high-speed arterial roadways from 2013 to 2017 were extracted from the Louisiana crash database for all study sites.

Methodology

DDSA crash tree analysis, spatial hotspot analysis, decision tree analysis, and LMCM analysis were undertaken separately to investigate the pedestrian crashes on high-speed urban arterials. The data collected for this analysis were combined to form a mass database. Each is described below.

Data-Driven Safety Analysis (DDSA) using Crash Tree

Crash tree analysis is part of a systemic safety project selection tool used to identify focus crash types, risk factors, and select facility types where the focus crash types most frequently occur. The crash tree allows for different formats and manipulations to sort the data availability. This tool is part of a US DOT Federal Highway Administration (FHWA) office of safety apparatus which works from a macro-enabled workbook. The DDSA tool was used in a reverse analysis to determine specific high-speed arterials which had frequent pedestrian crashes. Pedestrian crash focus types relate to the categorization of crash severity levels (e.g., fatal, serious injury crashes, and minor) and their rate of occurrence. Facility type in this research relates to characteristics such as the number of lanes and traffic control type. Risk factors imply finding the characteristics of the roadway and its environment that correlate to the occurrence of crashes. This may include roadway alignment, median type, traffic control type, and road surface condition.

Spatial Hotspot/Heat Map Analysis

Hotspot analysis using spatial autocorrelation involves using the Getis-Ord GI* functions, and Kernel density estimations for crash distribution. The term “hotspot” has been used generically to describe an area that exhibits statistically significant clustering in the spatial pattern of crash events. The focal point of this analysis was to use the weighted point feature called ICount to estimate whether clusters exist. Hot spots of cluster zones are generated over arterial roadway network to identify specific high-speed arterials with frequent crashes. Getis-Ord GI* function works by looking at the neighborhood features of each point or event. The estimate is calculated as the ratio of the local sum of a feature and its neighboring features to the sum of all features. For cases where the local sum is very large, there is a significantly large difference between the actual and the expected result if the event was to be a random chance. This statistic has previously been shown to identify the areas where crash risk is of concern [25], [89]–[91]. Equation 1 provides the mathematical expression for estimating GI*.

$$Gi^{*}(\mathrm{d}) = \frac{\sum j\, W_{ij}(d)x_j - W_i^{*}\bar{x}^{*}}{s^{*}\left\{\frac{\left[(nS^{*}1i) - W_i^{*2}\right]}{(n-1)}\right\}1/2} \quad \text{where,} \qquad [1]$$

(d)	=	spatial weight vector with values for all cells “j”
W*I	=	sum of weights, S*1i is the sum of squared weighs
s*	=	standard deviation of the data in the cells
n	=	total number of features
s and x	=	standard deviation and median

Decision Tree Analysis

This is a data-driven base analysis that revolves around the machine learning or regression modeling of crash patterns. The analysis compares the output of the classification, and regression tree (CART) model, the random forest (RF) model, and the extreme gradient boosted model. The analysis feeds the model with about thirty different characteristics of each pedestrian crash for 75% of the crash data for the data training process. The trained model is then tested using the remaining 25% of the crash data.

The metrics used to compare the performance of the different model types are Accuracy (ACC), Sensitivity (Sens), Specificity (Spec), and Kappa. ACC gives the percentage of the test data the model can predict correctly as expressed in Equation 2. This is expressed as the proportion of correct predictions to the total possible predictions. Equation 3 is an expression for Sensitivity, which is the percentage of true positive predictions (fatal crash), while Specificity is the percentage of true negative predictions (serious injury), as seen in Equation 4. Cohen's Kappa value is another measure of accuracy in the machining learning model. This is expressed in Equation 5.

$$ACC = \frac{P_{cor}}{P} \quad \text{where,} \qquad [2]$$

P_{cor}	=	the number of correct possible predictions
P	=	the number of all possible prediction for the given model

$$Sens = \frac{TP}{TP+FN} = \frac{TP}{POS} \quad \text{where,} \qquad [3]$$

TP	=	the number of true positives
FN	=	the number of false-negatives
POS	=	the number of positives

$$Spec = \frac{TN}{TN+FP} = \frac{TN}{NEG} \quad \text{where,} \qquad [4]$$

TN	=	the number of true negatives
FP	=	the number of false-positives
NEG	=	the number of negative

$$Kappa = \frac{P_0 - P_c}{1 - P_c} \quad \text{where,} \qquad [5]$$

P_0	=	the total agreement of probability, or the accuracy
P_c	=	the agreement probability which is due to randomness

Location Movement Classification Method Analysis (LMCM)

LMCM is a type of crash typing method suggested by Schneider et al. [92] as a supplementary data to complement the pedestrian and bicycle crash analysis tool (PBCAT). Some classification characteristics of the LMCM exist in the NHTSA classification. Yet, the principal focus of the NHTSA classification is behavioral characteristics like "failure to yield" and situational characteristics such as "drug-impaired" [92]. Summary of crashes in the PBCAT was based on NHTSA and Schneider et al. work [92] that argued that implementing the LMCM crash type as part of the PBCAT output will help propose appropriate countermeasures.

Data Input and Pre-Processing

Crash data on urban arterials for the selected study zones were obtained from the DOTD Crash database. The crash data for the most recent five-years from 2013 to 2017 were used in the analysis. Roadway geometric data such as median width, presence of bus stop, and pavement width were collected using Google Earth for each crash location. Louisiana Highway Safety Research Department Traffic GIS database was also used to obtain traffic characteristics such as AADT, intersection control type, and signal control. A database of all the collected characteristics of crash events was created using all the information gathered. The data collected were verified with the state database, where available, to remove all inaccurate information. These variables were fed into different machine learning predictive models to identify influential variables in pedestrian motorist crashes on high-speed urban arterials. The summary of the data processing steps used in all analysis is shown in Figure 11.

Figure 11. Data processing and analysis workflow chart

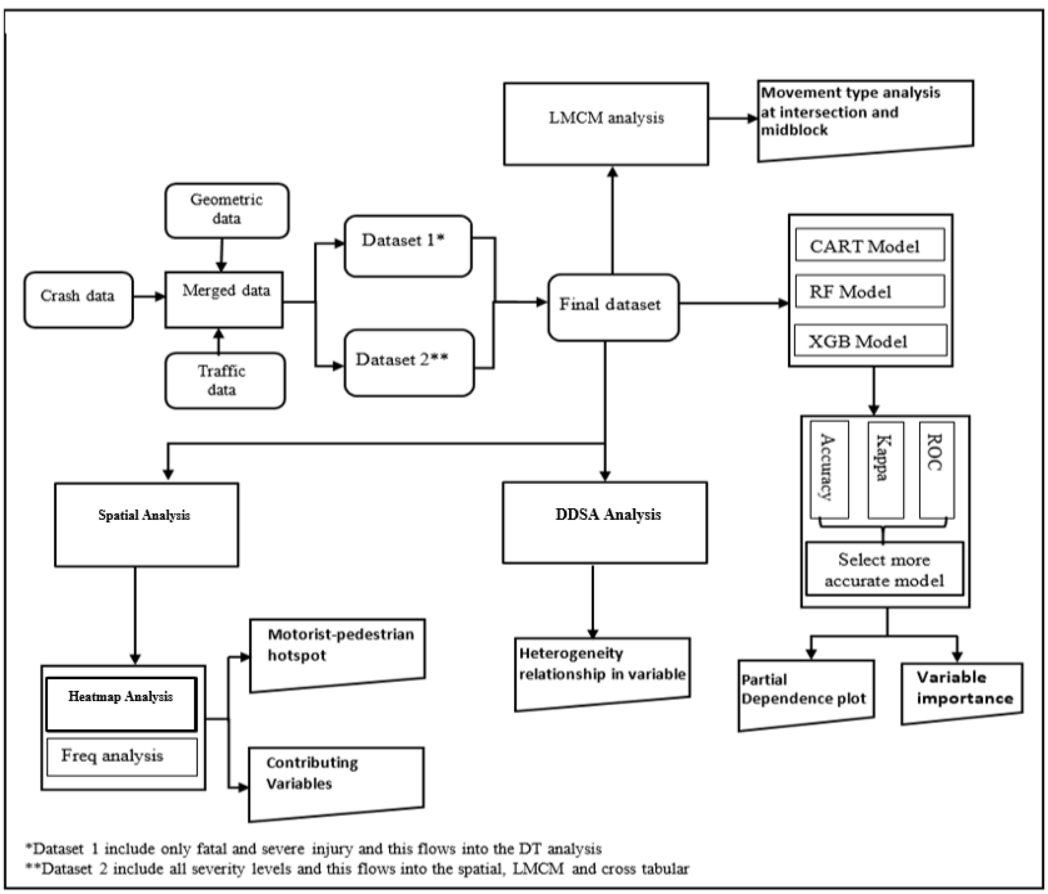
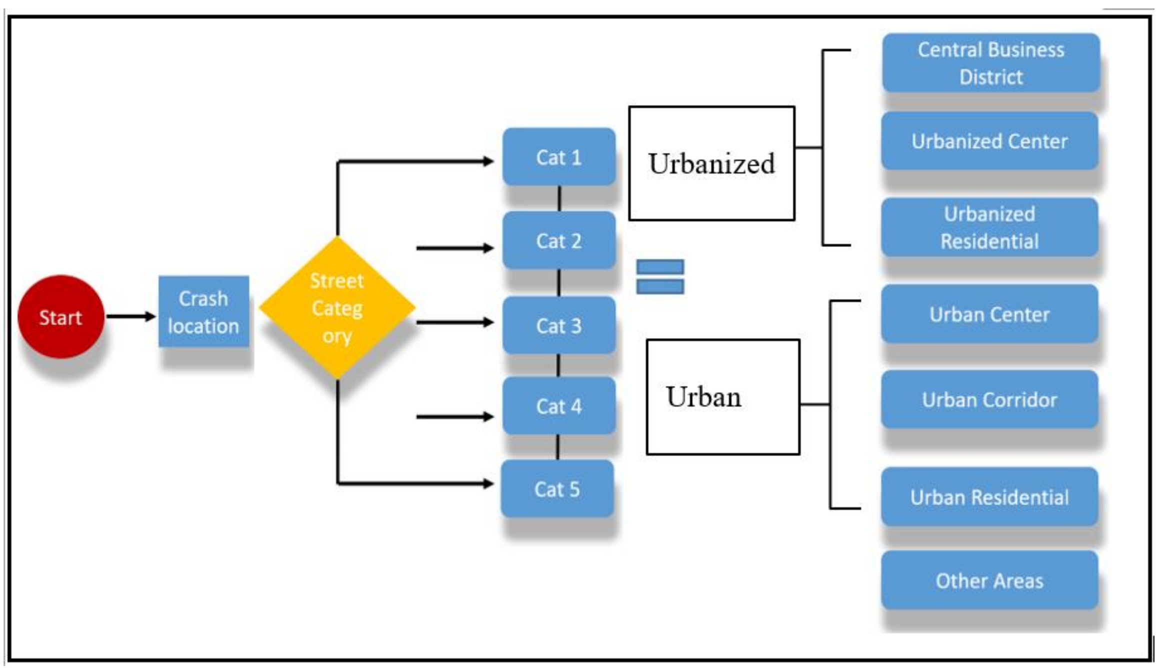


Figure 11 shows that the crash data (including the crash narratives) was combined with the geometric data and traffic data to form a merged data. The following two data sets were created: (i) data to include only fatal and severe injury, and (ii) data to include all severity levels. Both data combined constitute the final data set in the crash base. However, the first data set was used for the decision tree analysis, while the second data set was used for all remaining analysis.

Proposed Urban Street Classification

Part of the objectives of this project was to develop a detailed classification of high-speed arterial roadways. Figure 12 shows the flowchart for street classification. This is a combination of street type and area type classification. The proposed urban street classification, first, separates streets into five categories (CAT 1-CAT 5) with CAT 1 being highly tailored toward pedestrians and CAT 5 being highly tailored towards vehicles, like the North Carolina Street Design Guide. Table 10 shows the street name categorization. Although there are more street names in Louisiana, the streets listed in the table accounted for roads where at least one crash event was identified.

Figure 12. Proposed street classification for urban and urbanized area



The classification is partly associated with the function of the roadway but not directly linked to its design. For instance, *CAT 1* can be associated with local roadways which show more pedestrian activities and exposure. Moving to higher ranks shows a shift to roadways which are more auto-oriented. Most high-speed arterials, from the initial analysis, fell between *CAT 3-CAT 5* which shows roads with arterial functionality. Interstate roadway was not included in this table mainly because most states' pedestrian policy, including Louisiana, prohibit pedestrian movement on the interstate. Pedestrian crashes on interstate roadways were investigated separately in this project, and not included in the overall analysis. The basis of doing this additional analysis was to provide context on why there were pedestrian crashes observed on the interstates. The findings have been included as Appendix E.

Table 10. Street name classification

	CAT 1	**CAT 2**	**CAT 3**	**CAT 4**	**CAT 5**
Street Generic Name	Place	Main Street	Avenue	Boulevard	Parkway
	Terrace/Trail	Ramp and Point	Road	Frontage	Highway
	Court	Plaza	Drive	Causeway	Throughway
	Crescent	Alley	Lane	Service Roads	Turnpike
	Cove	Park	Street		Freeway
	Loop	Squares			Beltway
	Pass and path				Expressway
	Bypass and bus				

In accordance with Figure 12, the second step in the proposed classification was to break down land-use into different subclasses. The current urbanized and urban area classification of roads in Louisiana is subdivided into 3 subcategories. Urbanized areas are divided into a central business district (CBD), urbanized centers, and urbanized residential, while urban areas are subdivided into urban centers, urban corridors, and urban residential. All other areas were referred to as “Other Areas” and will not be included in the analysis.

Discussion of Results

This section presents the results of the four main analyses undertaken, namely: data-driven safety analysis, spatial hotspot or heat map analysis, decision tree analysis, and location movement classification method analysis. Several analyses were performed under each main analysis, and each is described below.

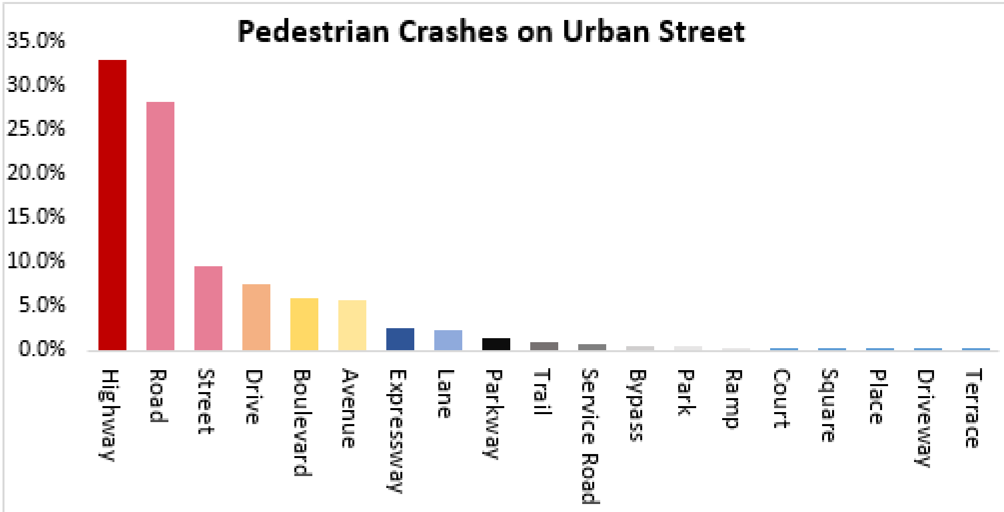
Results of Data-Driven Safety Analysis (DDSA)

This consisted of several sub-analyses to mainly understand how pedestrian crash patterns correlated with roadway characteristics or features. It begins by identifying trends in individual street types and then aggregating to the five (5) roadway categories level. Crash trees were then developed separately for urban and urbanized roadway types with the view to determine which roadway features had the most number of crashes. Furthermore, the crash data was analyzed to identify trends associated with intersection or non-intersection locations. The data used for this analysis comprised crash data, data from Google Earth, and GIS data. Pedestrian crash data was grouped on the KABCO scale: K-killed, A-Incapacitated, B-Non-incapacitated, C-Possible Injury, and O-No injury. The purpose of this analysis was to explore the possibility of identifying a crash trend in any of the analysis levels.

Street Level Analysis

The street level analysis examines crash frequencies based on generic street names like highway, drive, boulevard, road, among others. The frequency of crashes on each street type within the period of 2013 to 2017 was analyzed for urban and urbanized areas. Urban areas recorded 910 pedestrian crashes, which occurred on 19 different street types. Six out of the 19 accounted for 90.0% (819) of the crashes. These include highway, road, street, drive, boulevard, and avenue, accounting for 33.0%, 28.2%, 9.6%, 7.6%, 5.9%, and 5.7%, respectively. Figure 13 shows the crash distribution along different urban street types.

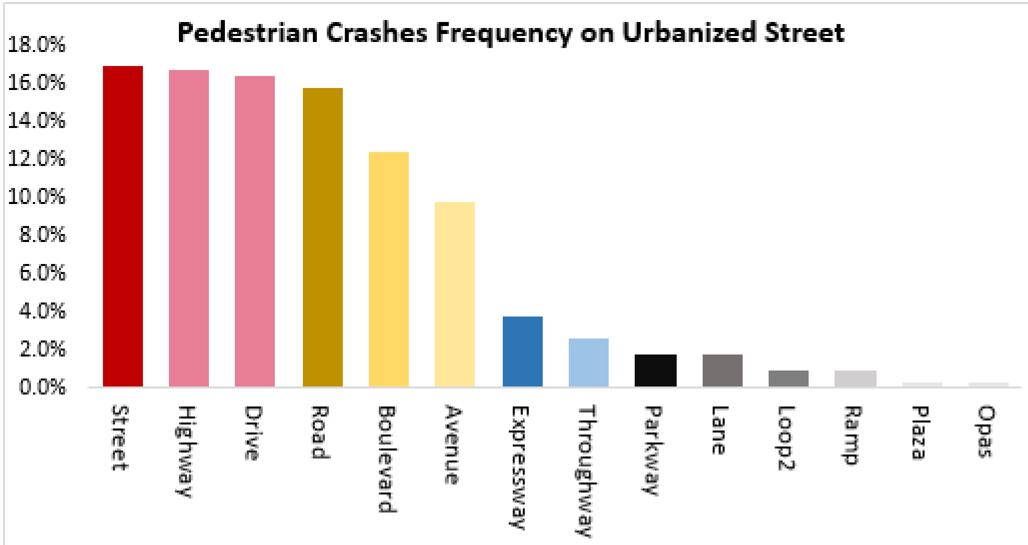
Figure 13. Crash distribution on urban street



Street Name	Proportion of Crashes	Street Name	Proportion of Crashes
Highway	33.0%	Trail	1.0%
Road	28.2%	Service Road	0.7%
Street	9.6%	Bypass	0.6%
Drive	7.6%	Park	0.4%
Boulevard	5.9%	Ramp	0.3%
Avenue	5.7%	Court	0.2%
Expressway	2.5%	Square	0.1%
Lane	2.4%	Place	0.1%
Parkway	1.5%	Driveway	0.1%
		Terrace	0.1%

For urbanized areas, there were a total of 348 crashes that were identified on 14 different street types. Six out of the 14 accounted for 87.9% (306) of the crashes. These include street, highway, drive, road, boulevard, and avenue accounting for 17.0%, 16.7%, 16.4%, 15.8%, 12.3% and 9.7%, respectively. Figure 14 shows the crash distribution, along with different urbanized street types.

Figure 14. Crash distribution on urbanized street



Street Name	Proportion of Crashes	Street Name	Proportion of Crashes
Street	17.0%	Throughway	2.6%
Highway	16.7%	Parkway	1.7%
Drive	16.4%	Lane	1.7%
Road	15.8%	Loop 2	0.9%
Boulevard	12.3%	Ramp	0.9%
Avenue	9.7%	Plaza	0.3%
Expressway	3.7%	Overpass (Opas)	0.1%

While it may not be glaringly obvious to identify any trends with the street level analysis, six street types accounted for approximately 90% of the pedestrian crashes observed for either urban or urbanized areas, namely: avenue, boulevard, drive, street, road, and highway. It could well be that these listed street types make up the majority of street types in the state. For this reason, the crash data was normalized based on the length of the roadway type within the nine study areas. Table 11 shows the crash densities for each street name type for both urban and urbanized areas. It shows that for urban areas, street names with "plaza" showed the highest crash densities while "expressway" showed the highest densities for urbanized areas. Areas with yellow shade show fair crash densities, red shows very high crash densities, and green shows the least crash densities.

Table 11. Normalized total crashes for street names

Street Name	Roadway Length (Miles)		Crash Count		Crash Density (per 1000 miles)	
	Urbanized	Urban	Urbanized	Urban	Urbanized	Urban
Street	2171.0	3739.5	59	87	27.18	23.27
Highway	245.4	1259.7	58	300	236.37	238.16
Drive & Driveway	1338.9	4060.7	57	70	42.57	17.24
Road	723.3	8059.8	55	257	76.04	31.89
Boulevard	471.5	885.7	43	54	91.20	60.97
Avenue	921.8	1368.6	34	52	36.88	37.99
Expressway	15.7	102.8	13	23	827.84	223.63
Throughway	44.5	13.0	9	0	202.22	0.00
Parkway	95.6	125.0	6	13	62.73	104.02
Lane	186.7	1437.3	6	22	32.14	15.31
Loop	33.6	88.1	3	0	89.38	0.00
Ramp	118.2	232.5	3	3	25.38	12.90
Plaza	2.5	1.1	1	1	398.80	909.90
Overpass	5.0	0.0	1	0	200.00	0.00
Trail	30.0	121.3	0	9	0.00	74.20
Service Road	4.4	22.7	0	6	0.00	264.51
Bypass	0.3	32.2	0	5	0.00	155.32
Park	0.3	25.2	0	4	0.00	158.52
Court	82.0	352.8	0	2	0.00	5.67
Square	3.0	6.6	0	1	0.00	150.78
Terrace	0.0	8.0	0	1	0.00	125.00
Total	6493.6	21942.8	348	910	-	-

Roadway Category Analysis

As in Table 10, street types were further aggregated to five roadway categories. Following the street level analysis performed in the previous section, a roadway category analysis was undertaken to explore whether any pedestrian crash trends will be identified at the roadway category level. This was undertaken separately for urban and urbanized areas.

Table 12 shows a summary of the total crashes by severity level on the five roadway categories in urban areas. A total of 910 pedestrian crashes were recorded on urban roadway classes. CAT 3 and CAT 5 had the highest record of crashes with 53.5% (487)

and 36.9% (336), respectively. As seen in Table 12, the number of fatal and injury-related crashes (severe and moderate) remain relatively higher than non-injury crashes. Out of the total 910 crashes, 62.4% (568) were fatal and injury crashes, 30.4% (277) were non-injury (compliant) and 7.1% (65) were no injury crashes.

Table 12. Urban crashes severity by roadway category

Roadway Category	Fatal	Severe	Moderate	Complaint	No injury	Total	Percentage
CAT 1	2	3	6	7	0	18	2.0%
CAT 2	1	0	3	5	0	9	1.0%
CAT 3	68	43	189	147	40	487	53.5%
CAT 4	11	6	20	17	6	60	6.6%
CAT 5	71	35	110	101	19	336	36.9%
Total	153	87	328	277	65	910	100.0%

As with Table 12, Table 13 shows the results of the same analysis for urbanized areas. A total of 348 pedestrian crashes were recorded on urbanized roadway classes. Again, CAT 3 and CAT 5 had the highest record of crashes with 60.6% (211) and 24.7% (86), respectively. As seen in Table 13, the number of fatal and injury-related crashes (severe and moderate) remain relatively higher than non-injury crashes. Out of the total 348 crashes, 66.4% (231) were fatal and injury crashes, 25.8% (90) were non-injury (compliant), and 7.8% (27) were no injury crashes.

Table 13. Urbanized crashes severity by roadway category

Roadway Category	Fatal	Severe	Moderate	Complaint	No injury	Total	Percentage
CAT 1	1	0	2	1	0	4	1.1%
CAT 2	1	2	1	0	0	4	1.1%
CAT 3	23	34	87	51	16	211	60.6%
CAT 4	2	3	20	13	5	43	12.4%
CAT 5	11	14	30	25	6	86	24.7%
Total	**38**	**53**	**140**	**90**	**27**	**348**	**100.0%**

While Tables 12 and 13 give a perspective into trends in the occurrence of pedestrian crashes on the roadway categories, they do not consider the variation in total roadway mileage and its impact on the number of crashes. There is the need to normalize the number of crashes across the roadway mileage. Further analysis of roadway category type was done by summing up the total road length of all streets in each roadway category. GIS data of all street types in the nine study areas (New Orleans, Baton Rouge, Lafayette, Shreveport, Houma, Monroe, Alexandria, Hammond, and Lake Charles) were queried to find the total mileage in urban and urbanized areas. Crash density was calculated as a standardized measure using total road mileage for each roadway category as a divider of the total crashes.

Table 14 shows the crash density for both urbanized and urban roadway categories. The color-coded numbers show the number of crashes per 1000 mile for each roadway class. The green shade shows the least crash density while red shade shows the highest crash density, calculated by normalizing the total number of pedestrian crashes over the roadway mileage in each category. The results show that for both urbanized and urban areas, CAT 5 roadway class recorded the highest crash density with more than 200 pedestrian crashes per 1000 miles within the study period. CAT 4 and CAT 3 followed consecutively, recording the second and third highest crash density respectively. From Table 10, CAT 5 roadway type comprises Parkway, Highway, Throughway, Turnpike, Freeway, Beltway, and Expressway. It can be seen that this roadway category type is not the dominant type in terms of roadway mileage, but surpasses its proportionate number of pedestrian crashes.

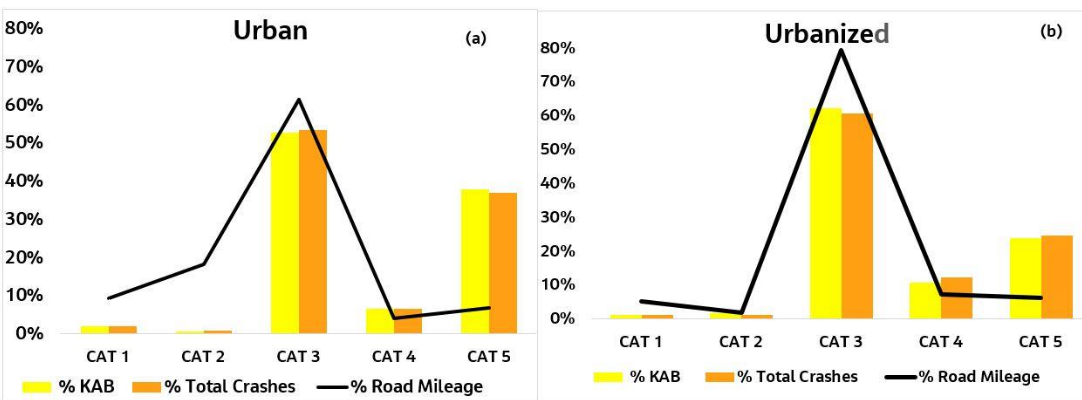
Table 14. Normalized total crashes for roadway categories

Roadway Category	Total Length (Mile)		Crash Count		Crash Density (per 1000 miles)	
	Urbanized	**Urban**	**Urbanized**	**Urban**	**Urbanized**	**Urban**
CAT 1	339	2035	4	18	11.8	8.8
CAT 2	124	265	4	9	32.3	34.0
CAT 3	5155	17225	211	487	40.9	28.3
CAT 4	476	908	43	60	90.3	66.1
CAT 5	401	1501	86	336	214.5	223.9

An alternative analysis approach is to compare the proportion of road mileage to the proportion of crashes on each roadway category, as demonstrated in Figure 15. For any roadway category, the bar chart is supposed to be at the same level as the trend line, which represents the road mileage proportion of the respective category. Where the bar chart exceeds the trend line, it means there exists an over-proportionate number of crashes. Likewise, where the trend line is above the bar chart represents a case of an under-proportionate number of crashes. One major observation from the figure is the consistency in killed, incapacitated, and non-incapacitated (KAB) and total crash proportion across the different roadway classes in both urbanized and urban areas.

Figure 15(a) shows a breakpoint at CAT 4 and over-proportionate representation of KAB and total crashes for CAT 5 roadway types. Similarly, Figure 15(b) shows a breakpoint at CAT 4 (but for only KAB and not total crashes) and over-proportionate representation of KAB and total crashes for CAT 5 roadway types.

Figure 15. (a) Urban crashes (b) urbanized crashes per proportion of road mileage



The findings show that although there are more crashes on CAT 3 roadway type when normalized by roadway mileage, CAT 4 and CAT 5 roadway types have the most crashes per mile for both urban and urbanized areas. Also, CAT 1 and CAT 2 roadway types account for less than 5% of total high-speed crashes.

Crash Tree Analysis

To identify roadway characteristics that observed the most number of total pedestrian crashes, crash tree analysis was undertaken separately for urban and urbanized areas. Three main roadway characteristics used in this analysis were median, annual daily traffic (ADT), and sidewalks. The objective of the crash tree analysis is to identify the facility type (based on median, ADT and sidewalks) on which the identified pedestrian crashes most frequently occurred. Each roadway characteristic is analyzed below for both urban and urbanized areas.

Median: This analysis looks at whether all the pedestrian crashes (KABCO) occurred most frequently at locations with medians present or not. Since the presence of medians tends to correlate with roadway width, it first looks at roadway widths, before partitioning into median presence or not. Figure 16 shows the results for urban areas, while Figure 17 shows the result for urbanized areas.

Figure 16. Crash tree based on median presence for urban areas

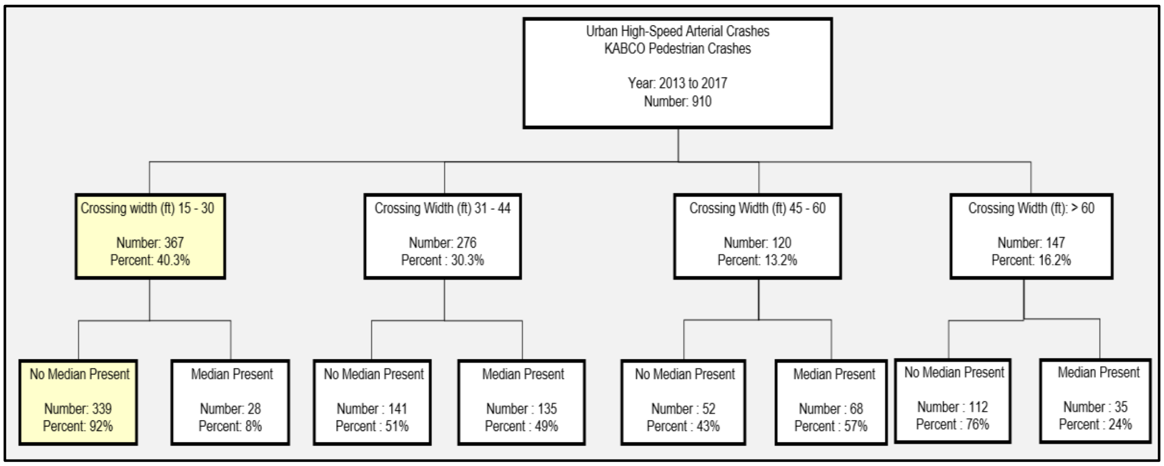
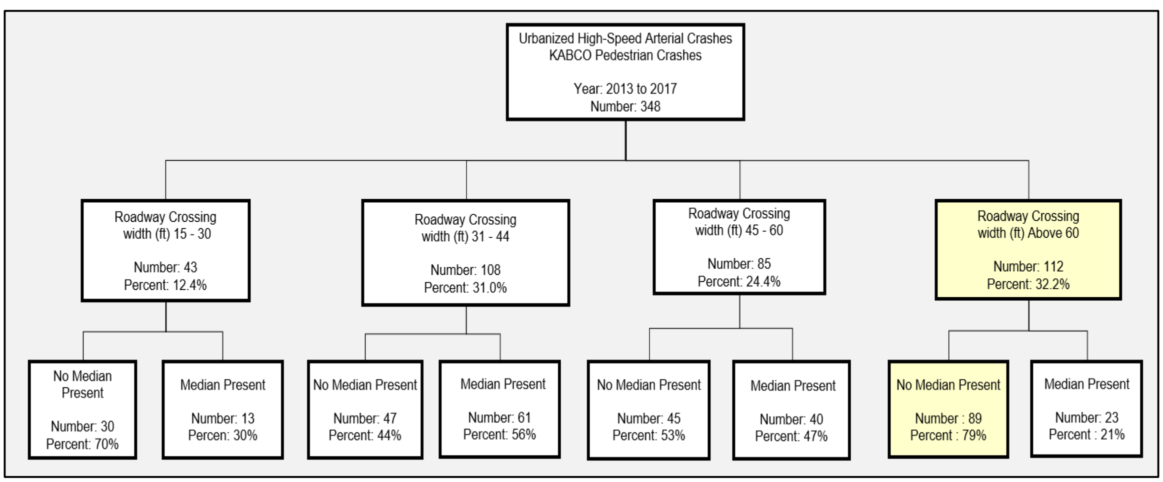


Figure 17. Crash tree based on median presence for urbanized areas



For undivided roadways, the roadway crossing width is the total width of the road, while for a divided roadway, it is the distance to the median. Figure 16 shows that for urban areas, most pedestrian crashes were observed on roadways with crossing widths of 15 ft.-30 ft. with no medians. On the contrary, Figure 17 shows that for urbanized areas, roadways with crossing widths above 60 ft. with no medians observed the most number of pedestrian crashes. Due to a lack of an inventory database, it was not possible to determine the make-up of all roadway crossing widths and median presence within the study area to normalize the findings. Nevertheless, the findings reveal that most pedestrian crashes for the study period occurred at locations with no medians.

ADT: The purpose of this analysis was to delve deeper into the roadway facility identified in the previous analysis with the view to obtain more insights into the facility type that observed the most number of pedestrian crashes. For both urban and urbanized areas, the two roadway crossing widths with the most number of pedestrian crashes were further split by ADT thresholds and then by whether the roadway was divided or undivided. Figures 18 and 19 show the crash tree analysis results for urban and urbanized areas, respectively.

For urban areas, Figure 18 shows different results for the two roadway crossing widths considered. Roadways with crossing widths of 15 ft.-30 ft. observed most pedestrian crashes on undivided sections with ADT less than 9,000 vpd, while roadways with crossing widths of 31 ft.-44 ft. observed most pedestrian crashes on divided sections with ADT above 15,000 vpd.

For urbanized areas, Figure 19 showed some consistency in that roadways with ADT above 15,000 vpd had the most frequent pedestrian crashes for the two top roadway crossing widths with the most crashes, i.e., 31 ft.-44 ft. and above 60 ft. However, the former recorded more observations on its divided sections while the latter saw more observations on its undivided sections.

Once again, it was not possible to normalize the data according to how much of each facility type was available in the study area because of the lack of an inventory database. While the mixed results offer no visible trend, it clearly identifies the facility types with the most number of pedestrian crashes for urban and urbanized areas.

Figure 18. Crash tree based on ADT for urban areas

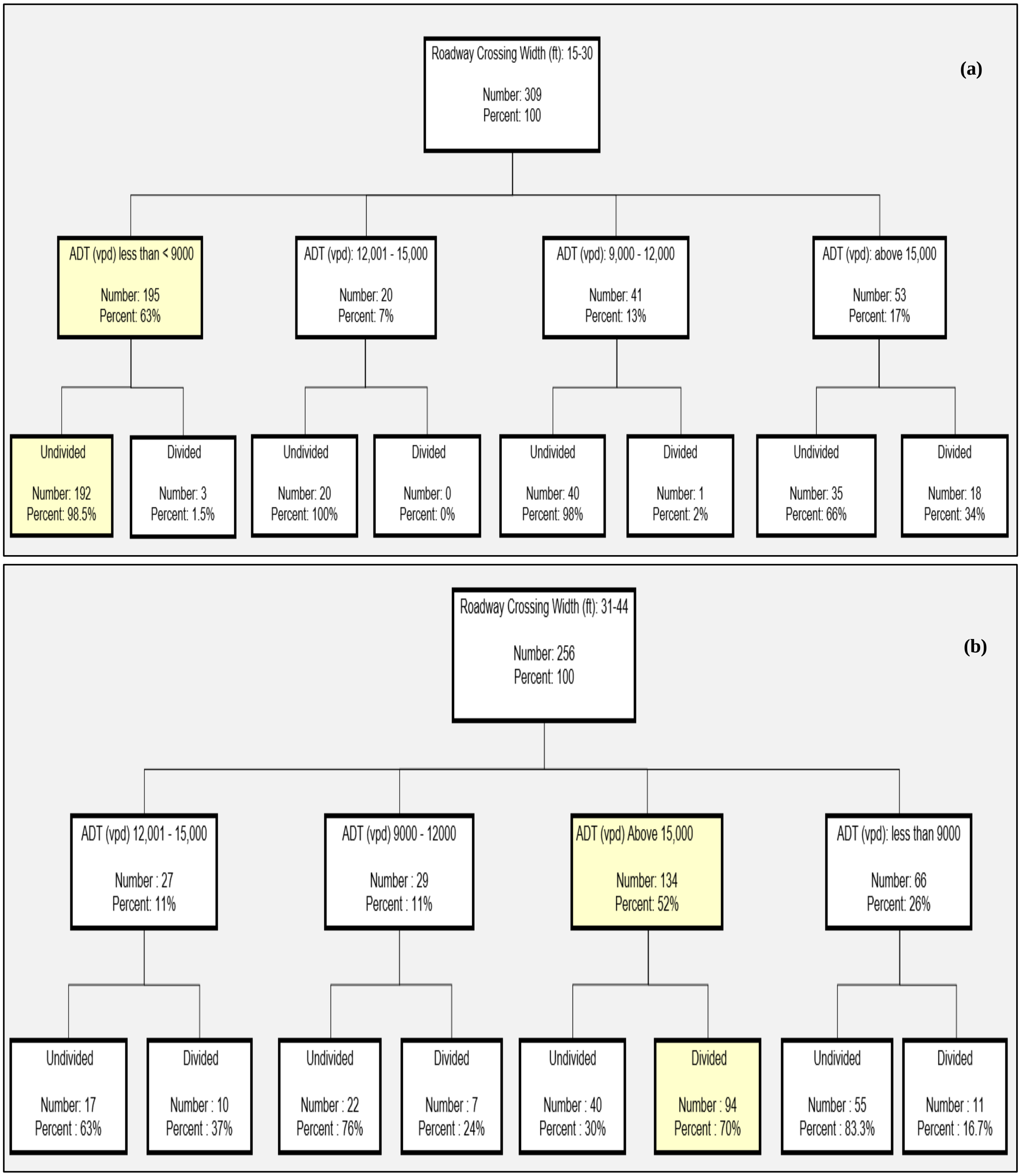
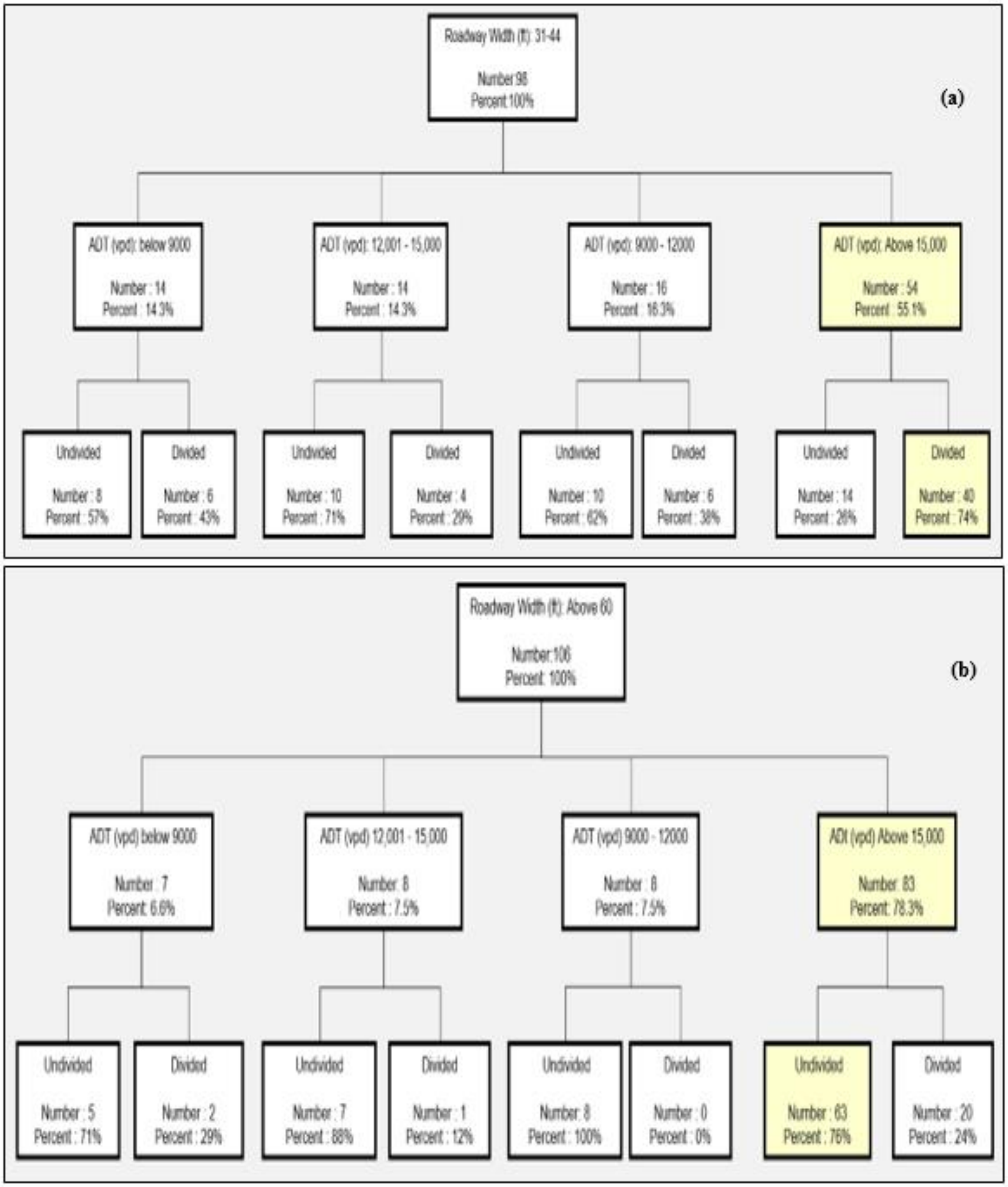


Figure 19. Crash tree based on ADT for urbanized areas



Sidewalks: Sidewalks are the primary facilities to provide pedestrian movement along roadways. In some situations, such as space constrained or sparsely populated areas, shoulders can also be designed to accommodate pedestrian movement.

From the ADT analysis from the previous section, for urban areas, locations with ADT less than 9,000 vpd and also above 15,000 vpd saw the most number of pedestrian crashes. Tables 15 and 16 further shows the breakdown of sections within the respective roadway types in terms of presence or not of shoulders and sidewalks. For roadways with ADT less than 9,000 vpd, segments with no shoulder and no sidewalks observed the most amounts of pedestrian crashes at 69.3%. For roadways with ADT above 15,000 vpd, segments with shoulders but no sidewalks saw the greatest proportion of pedestrian crashes at 53.7%.

Table 15. Crash distribution by pedestrian facility on urban area roadways with ADT less than 9000 (vpd)

Facilities Present on Roadways with ADT less than 9000 vpd	Proportion of Pedestrian Crashes
No shoulder and No Sidewalk	69.3% (203)
Shoulder and No Sidewalk	25.6% (75)
No Shoulder and Sidewalk Present	4.4% (13)
Shoulder Present and Sidewalk Present	0.7% (2)

Table 16. Crash distribution by pedestrian facility on urban area roadways with ADT above 15000 (vpd)

Facilities Present on Roadway with ADT above 15000 (vpd)	Proportion of Pedestrian Crashes
Shoulder and No Sidewalk	53.7% (196)
No Shoulder and No Sidewalk	28.2% (103)
No Shoulder and Sidewalk Present	15.1% (55)
Shoulder Present and Sidewalk Present	3.0% (11)

A similar analysis was undertaken for urbanized roadways, but for locations with ADT greater than 15,000 vpd. Table 17 shows the results of the analysis and reports that for urbanized areas, segments with shoulders but no sidewalks accounted for the locations with the most amount of pedestrian crashes at 39%, closely followed by segments with no shoulders but with sidewalk present, at 35.5%.

Table 17. Crash distribution by pedestrian facility on urbanized area roadways with ADT above 15000 (vpd)

Facilities Present on Roadway with ADT above 15000 (vpd)	Proportion of Pedestrian Crashes
Shoulder and No Sidewalk Present	39.0% (136)
No Shoulder and Sidewalk	35.5% (124)
No Shoulder and No Sidewalk	22.1% (77)
Shoulder Present and Sidewalk Present	3.4% (12)

Once again, it was not possible to normalize these findings since it was not possible to determine the facilities (shoulders and sidewalk) make up of all the roadways within the study area. Nevertheless, this analysis identifies the facility types on which pedestrian crashes most frequently occur within the state of Louisiana.

Intersection and Non-Intersection Categorization

This analysis focuses on identifying trends with intersection or non-intersection related pedestrian crashes. Intersection crashes comprise crashes within the intersection and crashes within 50 ft. of the nearest intersection stop line. Using the crash coordinates, the distances from the crash location to the near-side stop line of the intersections were measured on Google Earth for all the crash data points. The crash data for both urban and urbanized areas were combined to result in a total pedestrian crash of 1,258 for all severity levels. Each crash location was then analyzed to verify whether it occurred at an intersection or non-intersection. Furthermore, each crash location was identified as within a marked crosswalk, unmarked crosswalk, or no crosswalk markings. Table 18 shows the result of this exercise.

Table 18. Pedestrian crashes by crash type

Crash Type	Marked Crosswalk	Unmarked Crosswalk	No Crosswalk Markings	Grand Total	Percentage
Intersection Related	44	376	0	420	33.4%
Non-Intersection Related	0	0	838	838	66.6%
Grand Total	**44**	**376**	**838**	**1258**	**100.0%**

Out of the total 1,258 crashes over the five years, 420 crashes (33.4%) were intersection related, and 838 crashes (66.6%) were non-intersection related. The majority of intersection related crashes occurring at unmarked crosswalk location, with 89.5% (376) of intersection related crashes occurred at unmarked crosswalk location while 10.5% (44) occurred at marked crosswalk location. On the other hand, all 838 non-intersection related crashes occurred at locations without a crosswalk. Intersection and non-intersection analysis are further discussed below.

Intersection Analysis: Traffic control at intersections influence the yielding behavior of drivers and pedestrians, and hence, has an influence on the frequency of pedestrian crashes at intersections. Table 19 shows the distribution of pedestrian crashes at different traffic control facilities at intersections within the study area. The highest frequency of crashes was recorded at "Stop/Yield Sign" control accounting for 63.81% (268) crashes, followed by "Signal control" location, with 35.00% (147) pedestrian crashes. Uncontrolled and roundabout locations recorded the least number of crashes with 0.95% (4) and 0.24% (1) crashes respectively. Once again, it was not possible to normalize these findings because of lack of a database of all traffic control facilities at intersections.

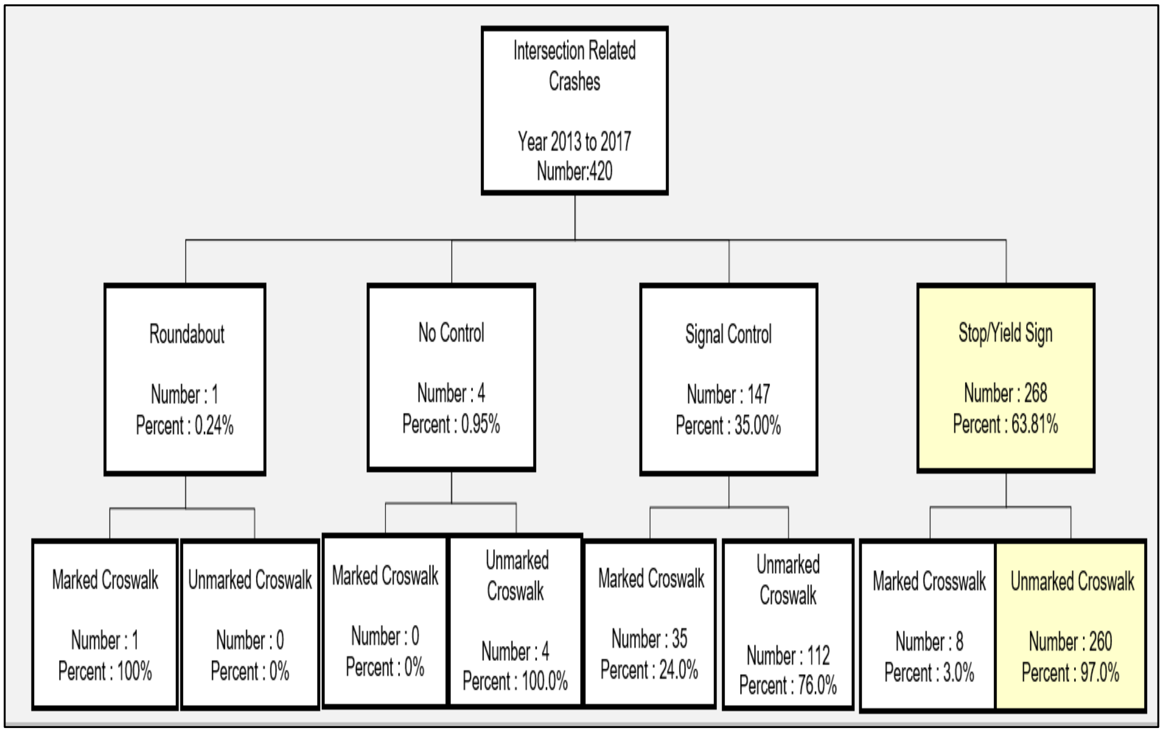
Table 19. Intersection related pedestrian crashes by traffic control facility

Traffic Control Facility	Count of Crashes at Location	Percentage
Stop/Yield Sign	268	63.81%
Signal Control	147	35.00%
No Control	4	0.95%
Roundabout	1	0.24%
Grand Total	**420**	**100.0%**

From reading the crash narratives, some of the factors accounting for higher crashes at stop/yield and signalized control include motorists failing to yield to pedestrians crossing the roadway, and pedestrian failure to obey right of way rules at signalized controls.

Figure 20 shows the frequency of pedestrian crashes at the different traffic control types. At stop/yield locations, 97% (260) of pedestrian crashes occurred at locations with unmarked crosswalks. Also, at signal controls, 76% (112) of pedestrian crashes occurred at unmarked crosswalks.

Figure 20. Intersection related pedestrian crashes by traffic control type

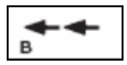
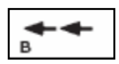
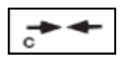
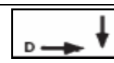
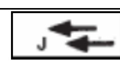
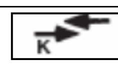


Another analysis performed for intersection related crashes is the manner of collisions at intersections, further divided into marked and unmarked crosswalks at intersections. Manner of collision describes the way the vehicles initially came into contact with a pedestrian, each other, or another obstacle. All collisions are coded with variables “A” to “K” and “Y” based on *Louisiana Uniform Crash Report – Form DPSSP 3105.*

Table 20 shows the manner of the collision of intersection crashes categorized by marked and unmarked crosswalk locations. A “Non-Collision with Motor Vehicle” implies only one vehicle was involved in the crash with one or more pedestrians, and no other vehicles were involved. The remaining manner of collision types (such as rear-end, right angle, head-on, left turn, etc.) all involved multiple vehicles and one or more pedestrians.

At both marked and unmarked crosswalk locations, the manner of collision with the most frequent observations was the “Non-Collision with Motor Vehicle” event, involving a single vehicle and one or more pedestrians.

Table 20. Intersection crashes by manner of collision

Marked Crosswalk			
Manner of Collision	**Symbol**	**Number of Crashes**	**Percentage**
Non-Collision with Motor Vehicle	A	39	88.63%
Rear-End		1	2.27%
Right Angle		2	4.55%
Other		2	4.55%
Location Total		**44**	**100.00%**
Unmarked Crosswalk			
Non-Collision with Motor Vehicle	A	274	72.87%
Rear-End		24	6.38%
Head-On		5	1.33%
Right Angle		24	6.38%
Left Turn		6	1.60%
Left Turn		1	0.27%
Right Turn		1	0.27%
Sideswipe Same Direction		5	1.33%
Sideswipe Opposite Direction		4	1.06%
Other		32	8.51%
Location Total		**376**	**100.00%**
Grand Total		**420**	

Non-Intersection Analysis: The distance between the locations of a pedestrian crash to the stop line at an intersection is referred to as "Proximity to Intersection" for the purpose of this study. This analysis indicates the relative distance between pedestrian crash locations to the nearest intersection. It can be seen from Table 21 that 54.6% of non-intersection crashes occurred within 300 ft. of the nearest intersection stop line. The Table shows the number of crashes observed at other ranges of distances from the intersection stop line. Above 600 ft. describe locations outside the reach of an intersection, mostly observed on highways or expressway.

Table 21. Non-intersection related pedestrian crashes

Proximity to Intersection (ft.)	Count of Crashes at Location	Percentages
50 - 150	254	30.3%
150 - 300	204	24.3%
300 - 450	78	9.3%
450 - 600	53	6.3%
Above 600	175	20.9%
Unknown	74	8.9%
Grand Total	**838**	100.0%

With non-intersection locations, the presence of medians and median types was investigated because it is known that different types of median along a segment of a roadway (non-intersection) impact pedestrian safety differently. A median is the portion of a divided highway separating the travel way for traffic in opposite directions. A median can be physical, such as grass or a raised surface like concrete, or simply painted. Table 22 shows the distribution of pedestrian crashes along non-intersections with the corresponding median type. Locations without a median accounted for 69.5% (582) of crashes, while grass/vegetation median accounted for 20.6% (173) of crashes. Traversable median and median barriers recorded a very low number of crashes, 5.6% (47) and 4.3% (36), respectively.

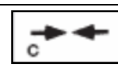
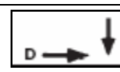
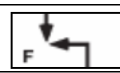
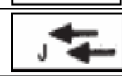
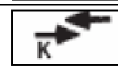
Table 22. Non-intersection related pedestrian crashes at median type location

Median Type	Number of Crashes	Percentage
No Median	582	69.5%
Grass/Vegetation	173	20.6%
Traversable Median	47	5.6%
Median Barrier	36	4.3%
Grand Total	**838**	**100.0%**

As in previous statements, it was not possible to normalize the crashes by the median type because no database existed that provided an inventory of median type for all roadways within the study area. However, the analysis reports on which medium type has observed the most frequent occurrence of pedestrian crashes in the state.

Table 23 shows the manner of collision of non-intersection crashes. All non-intersection crashes occurred outside a crosswalk location, so had no crosswalk markings. Collisions involving a vehicle and one or more pedestrians were the most predominant manner of collision accounting for 71.83% (602) of all total crashes. All the remaining crash types involved multiple vehicles and one or more pedestrians. Other types of crashes that saw an appreciable number of crashes include "B-Rear-end collision," and "J-Sideswipe same direction" collision accounting for 10.38% (87) and 5.73% (48), respectively. Rear-end collision and sideswipe same direction crashes involving pedestrians are mostly due to pedestrian crossing movements. This usually involves a vehicle slowing down to allow the pedestrian to cross while the pedestrian may be in the blind spot of a second vehicle, mostly speeding through the intersection.

Table 23. Non-intersection crashes by manner of collision

Manner of Collision	Symbol	Number of Crashes	Percentage
Non-Collision with Motor Vehicle	A	602	71.83%
Rear-End		87	10.38%
Head-On		4	0.48%
Right Angle		22	2.63%
Left Turn		3	0.36%
Left Turn		1	0.12%
Right Turn		1	0.12%
Right Turn		2	0.24%
Sideswipe Same direction		48	5.73%
Sideswipe Opposite direction		12	1.43%
Other		56	6.68%
Grand Total		**838**	100.0%

Spatial Hotspot/Heat Map Analysis of Crashes

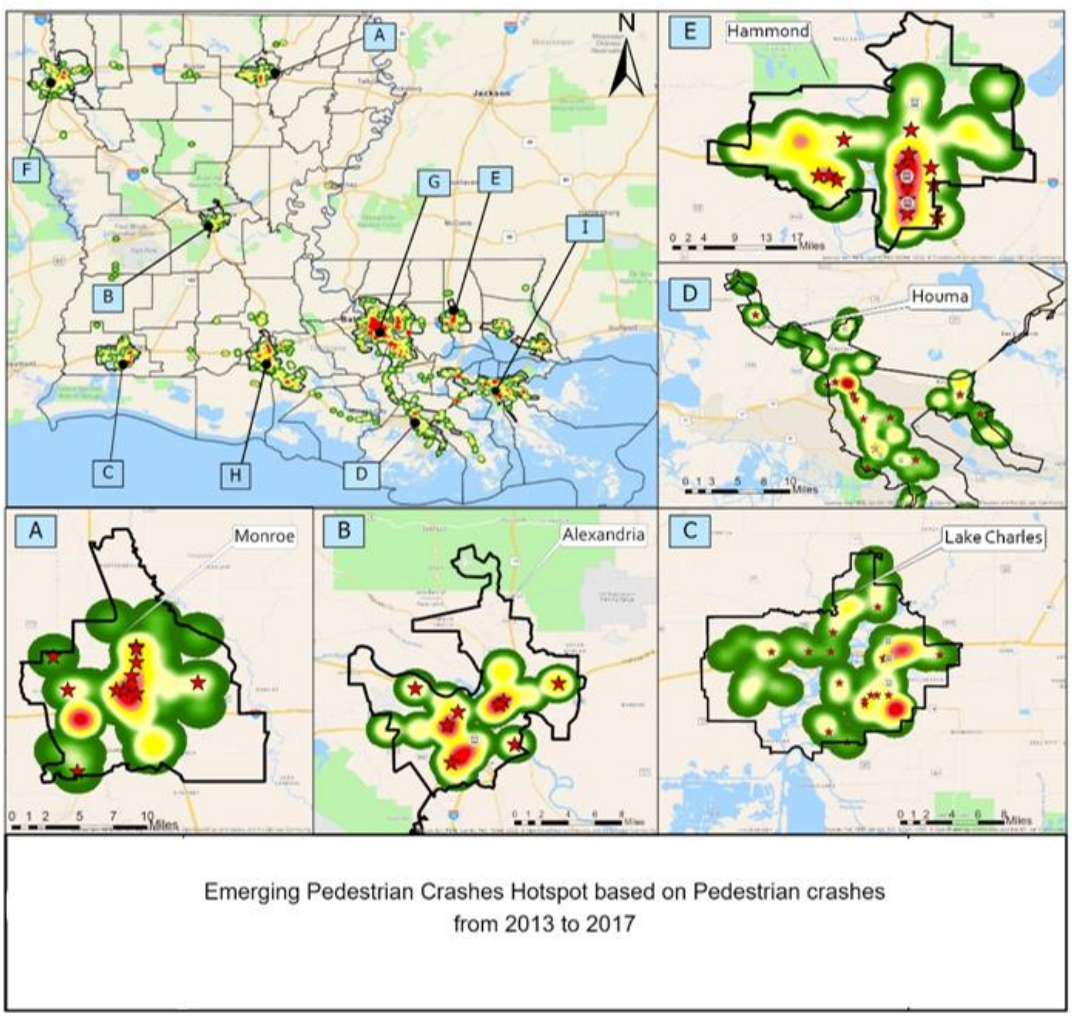
This analysis was undertaken to spatially identify locations of high crash clusters (hotspots) and to determine whether they correlate with bus stop locations. Each pedestrian crash location over the five year study duration was spatially mapped for all nine (9) study areas. Furthermore, where present, bus stop locations in the vicinity of each crash location were mapped. The data sources used were the crash database and Google Earth to identify the bus stop locations.

Figure 21 shows the results of the heat map analysis for five of the nine study areas, namely Monroe, Alexandria, Lake Charles, Houma, and Hammond; while Figure 22 shows the results for the remaining four study areas, namely Shreveport, Lafayette, Baton Rouge, and New Orleans.

For both figures, green shaded areas show less cluster of crashes, yellow shaded areas show a fair amount of cluster, and a red shaded area shows a dense cluster of crashes or hot spots. Locations marked with a red star represent approximate locations for fatal crashes or incapacitated injuries, and bus stop locations are shown with bus symbols.

In Figure 21, it can be seen that these locations had fewer bus stop locations in the vicinity of the crashes. In Monroe, hotspot zones coincided with the clustering of fatal and incapacitated injuries along portions of Highway 165 bypass. Small pockets of hotspots were also identified around Siegle and Bronsville road. In Alexandria, hotspots were identified along sections of Coliseum Boulevard, a portion of US-165 and it is surrounding corridors. In Lake Charles, some surrounding arterials around I-210 and I-10 interchange and some portion of Chalkley arterials.

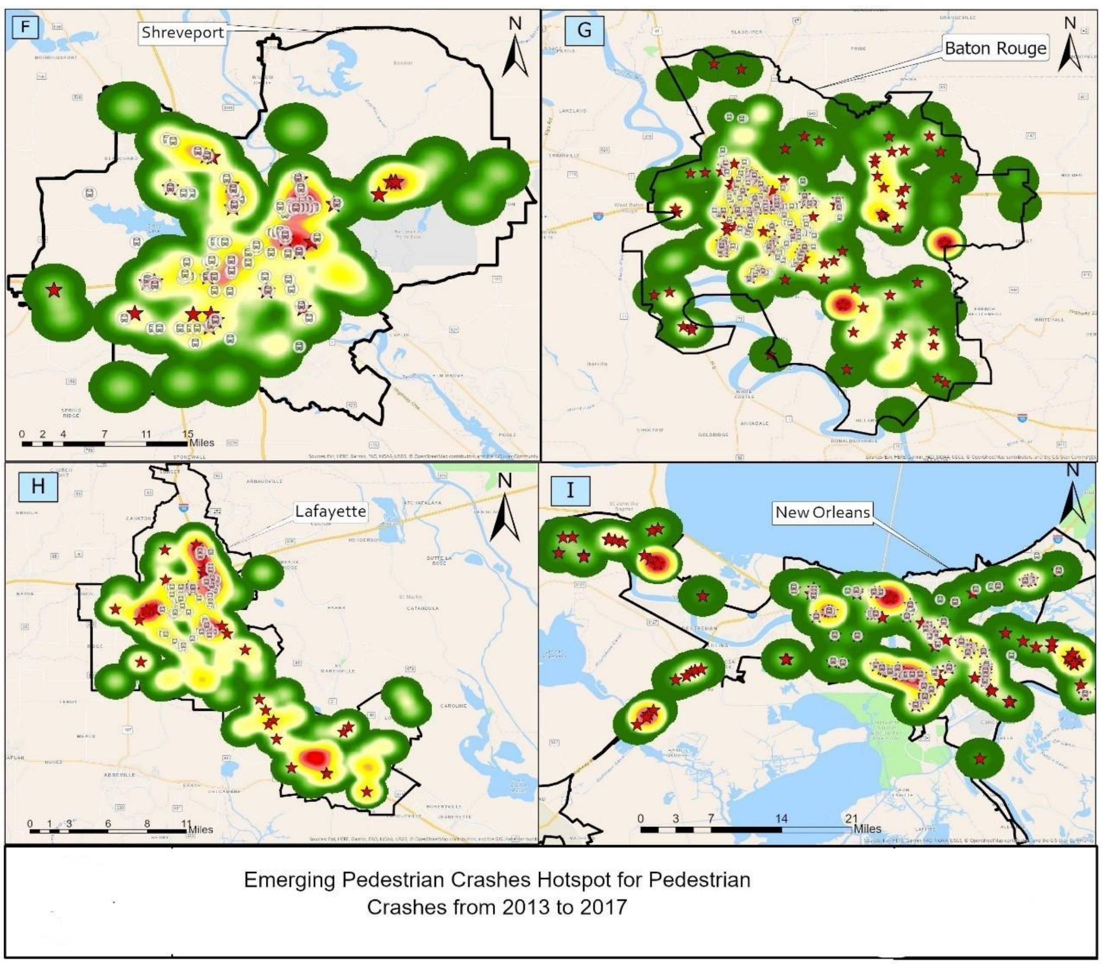
Figure 21. Pedestrian crash heat map in select cities



Houma generally had fewer crashes along its corridors. The only hotspot location in Houma was along portions of LA 659 in Schriever and its surrounding arterials. Lastly, Morrison Boulevard and its surrounding arterials in Hammond were identified as hotspot locations. Few fatal and incapacitated injuries were identified in most urban areas compared to less severe injuries. Most of these fatal and incapacitated injuries were along hotspot locations.

Figure 22 shows more clusters of bus stop locations, and it could be because Shreveport, Baton Rouge, Lafayette, and New Orleans are more urbanized than the other cities shown in Figure 21.

Figure 22. Pedestrian crash heat map in densely populated cities



In Shreveport, hotspot zones were identified along Plantation Dr. and its surrounding roadways. Generally, the central part of Shreveport experienced higher levels of crashes, mainly around arterials connecting the loop of I-20, I-49, and I-220. Fewer hotspot zones were identified in the Lafayette area with the main hotspot zone identified on arterials around I-10/I-49 interchange. Duller Dr. and neighboring arterials also account for high pedestrian crash frequency. The highest number of fatal and incapacitating injury crashes were recorded in Baton Rouge. Hotspot zones in Baton Rouge were more centralized around the loop formed between I-10, I-110, and US-90 near the Mississippi river. New Orleans, on the other hand, had a lot of hotspot pockets at different locations. Arterials around Causeway Boulevard, Westbank Expressway, Evangeline Road, and Highway 90, including its surrounding roadway, were identified hotspot zones.

Within the state of Louisiana, bus stop locations were more clustered in the more urbanized locations, and there was a high correlation between bus stop location and pedestrian hotspot zones.

Decision Tree Analysis

Decision tree (DT) analysis was additionally undertaken to develop predictive models to identify significant influencing variables that impact the severity of pedestrian crashes. For this analysis, the crash database, along with data from Google Earth and GIS data from DOTD, were utilized.

Three DT models were developed, namely CART, Random Forest (RF), and XGBoost. These were developed using 27 input variables, including temporal characteristics (e.g., weekday), environmental characteristics (e.g., lighting condition), vehicle characteristics (e.g., driver age), and crash variables (e.g., collision type). Each model utilized these variables to predict the response variable (severity level): fatal or serious injury as a positive response and moderate to no “injury” crashes as a negative response. This analysis used 75% of the data as training data and 25% as testing data. The output of the CART, RF, and XGBoost models were compared by model performance. Relative importance features helped to identify the ranking of explanatory variables to predict the pedestrian crash severity. The ranking of variables was based on the Gini splitting criterion.

Model Performance

Table 24 shows the predictive performance of the three models (CART, RF, and XGBoost). Using the CART model as the benchmark, the RF model’s accuracy was 6.2%

higher, while the XGBoost model’s accuracy was 6.6%. The Kappa metric shows the ensemble tree models performed better than the CART model. RF model showed a 28% improvement in Kappa, while the XGBoost showed a 26.4% improvement. The RF model improved the sensitivity by 2.2%, while XGBoost model's sensitivity decreased by 7.6%.

Conversely, the XGBoost model’s specificity improved by 40.3%, while the RF model showed an improvement of 15.8%. Model accuracy is the general performance of the models in predicting both fatal and severe injury crashes. Using this parameter, the models improved from CART to RF and finally to the XGBoost model. Overall, XGBoost model was recommended over the CART model and the RF model.

Table 24. Performance of decision tree models

Model type	Accuracy (%)	Kappa (%)	AUC (%)	Sensitivity (%)	Specificity (%)
CART	69.57	34.47	72.82	80.36	52.78
Random Forest	73.91	44.13	74.4	82.14	61.11
XGBoost Model	74.19	43.55	70.78	74.24	74.07

Model Significant Factors

The three models ranked “Condition of Pedestrian” as the most important predictor, and this describes if the pedestrian was normal, inattentive, distracted, alcohol-impaired, or drug-impaired. Although the three models had variations in their ranking of the first 10 predictors, “condition of pedestrian,” “distance to control,” “ADT,” and “day of the week” ranked highly in all three models. The two highest-performing models, RF and XGBoost, also had the “roadway width,” “median width,” and the type of “land use” highly ranked.

Partial dependency plots (PDP) focus on exploring the variation in each contributing factor on fatal or serious injury crashes. All PDP plots have been included in Appendix F. PDP of “Condition of Pedestrian” shows pedestrian conditions like “distracted,” “alcohol-impaired,” and “inattentive” highly influence the occurrence of serious injury crashes. This observation agrees with previous research in this area. For instance, Dultz et al. suggested that pedestrian use of alcohol has a significant relationship with fatal pedestrian crashes [93]. Also, cell phone usage is a factor associated with pedestrian crashes [94].

The PDP of “Roadway Width” variable shows that the wider the crossing distance, the higher the probability of a fatal or serious injury crash occurring. A significant increase in fatal or serious injury crash probability is seen when the crossing width increases from 27 ft.-32 ft. for the XGBoost model and 17 ft.-35 ft. for the RF model. This finding suggests that pedestrians are at more risk of fatal or serious injury crashes when crossing a distance greater than 30 ft.

PDP of “Traffic Volume” variable shows fatal or serious injury crashes are highly influenced by traffic volumes above 40,000 vpd. The RF and XGBoost model show a plateauing of the influence of ADT on fatal crash occurring when ADT is above 90,000 vpd and 50,000 vpd, respectively.

“Distance to Control” estimates the proximity of the crash location to the nearest intersection. From the PDP plots, the two models indicate a strong positive influence of "Distance to Control" to serious crash occurrence from 50 ft. to 200 ft. This suggests that pedestrians are more at risk of fatal or serious injury when they attempt to cross roadways outside the vicinity of an intersection. Pedestrian action describes the action of the pedestrian before a crash. The RF model suggests pedestrian actions like "Crossing Not at an Intersection," "Walking with Traffic," and "Standing by Roadway" had strong influences on serious crash occurrence.

The PDP of “Driver Age” showed up as a significant predictor of a pedestrian fatal or serious injury crash. The RF model suggests a positive influence of drivers in the age range 17-25 on fatal or serious injury crash occurrence. The model continues to predict a U-shape behavior which implies that the influence of driver age on the probability of such a crash drops and later picks up at the age of 32 years. Likewise, the XGBoost model shows that drivers in the age range of 17-25 have a positive correlation to fatal or serious injury crash occurrence. The influence on fatal or serious injury crash drops as driver age increases, as implied from the U-shape portion of the graph. Both models suggest drivers above the age of 50 years have the highest influence on fatal or serious injury crash occurrence. In the XGBoost model, the driver age above 50 years has no additional influence on fatal or serious injury crashes, as shown by the horizontal section of the graph.

Contrary to this, the random forest model shows a negative influence of 49-75 years age range on fatal or serious injury crashes. This implies that the effect of this age range on fatal crashes drops. Generally, this shows that younger drivers positively impact the occurrence of fatal or serious injury pedestrian crashes.

The PDP of "Land Use" indicates that industrial areas, and commercial had the strongest influence on a serious crash occurrence based on the RF model. This may be partly due to the unique settlement plan of urban areas in Louisiana. In most of the urban areas, there are more mixed land-use settlements, and most are not distinct. The models' variable ranking of significant contributing factors and PDP images are included in Appendix F.

Location Movement Classification Method (LMCM) Analysis

LMCM analysis provides perspective into the type of movements made by motorists or pedestrians before the occurrence of the crash. This was performed to understand how different pedestrian and motorist movements relate to the frequency of pedestrian crashes observed during the study period at the nine study locations. Data were sourced from the crash narratives accompanying each crash record.

Pedestrian movements are described relative to the driver's position. Based on this, pedestrian movements are classified as:

- Motorist's left approach.
- Motorist's right approach.
- Opposite direction as motorist.
- Same direction as motorist.

These four movements can further be classified into parallel movement (opposite or same direction as motorist) and crossing movement (motorist's right or left approach). Altogether, 12 motorist movements are considered in LMCM analysis. For each crash, the crash narrative report was read to identify the series of events that led to the crash. A total of 1,099 pedestrian crash narratives were obtained from the state crash database from 2013 to 2017. Out of this, pedestrian and motorist movement information were identified for 1,015 crash events, 805 for urban areas and 210 for urbanized areas. All of the 805 urban crash narrative reports were centered between CAT 3-CAT5 roadway categories while 204 out of the 210 urbanized crash narrative reports were for CAT 3-

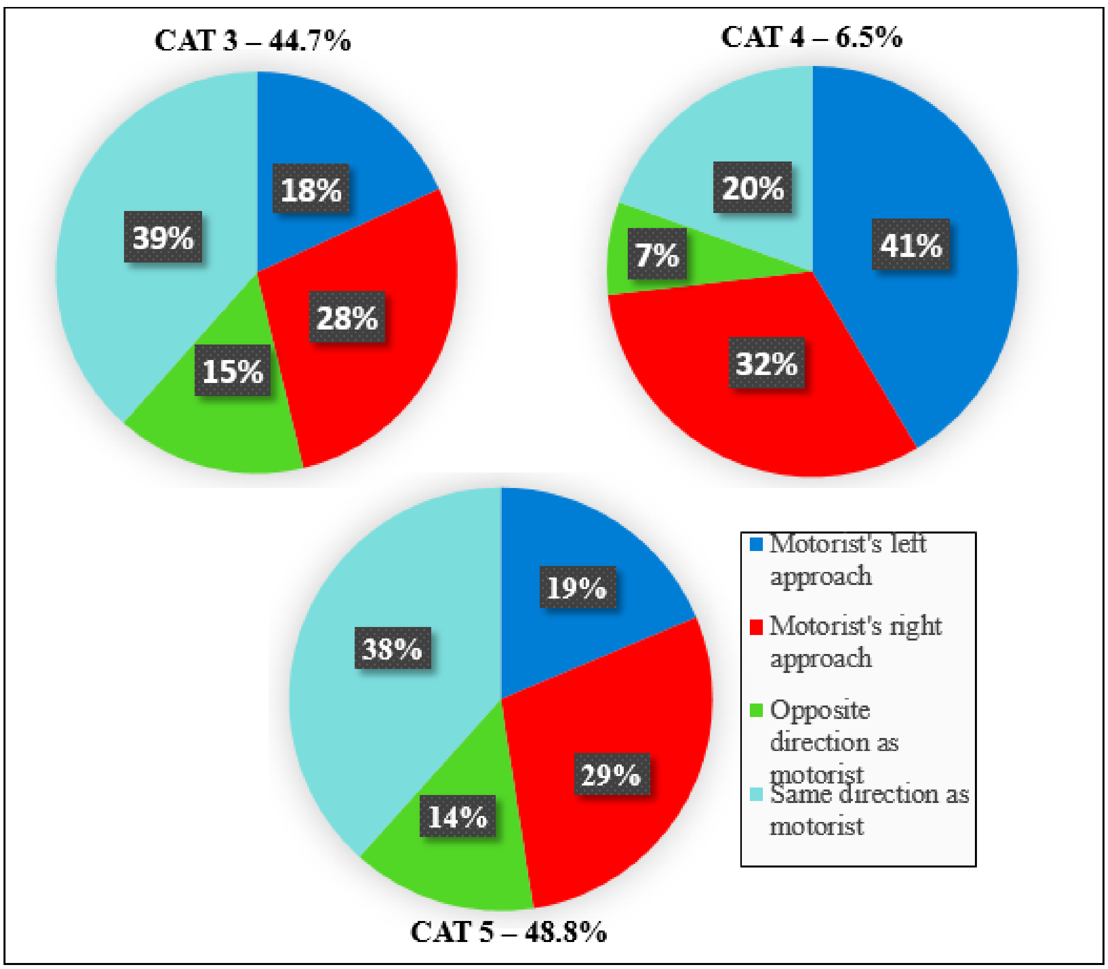
CAT5 roadway categories. Since this analysis focuses on CAT 3-CAT 5, the total data used for this analysis was 1,009. The manual for the LMCM coding describing all pedestrian-motorist movements can be found in Appendix G.

Pedestrian Movements Analysis

The four pedestrian movements prior to the occurrence of a pedestrian crash, identified in the previous section, were mapped separately for urban and urbanized areas.

For urban areas, 805 crash narrative reports were retrieved, centered between CAT 3-CAT 5 roadway categories. Figure 23 shows the pie chart distribution of the pedestrian movements prior to a pedestrian crash for each roadway category.

Figure 23. Pedestrian movements for urban areas



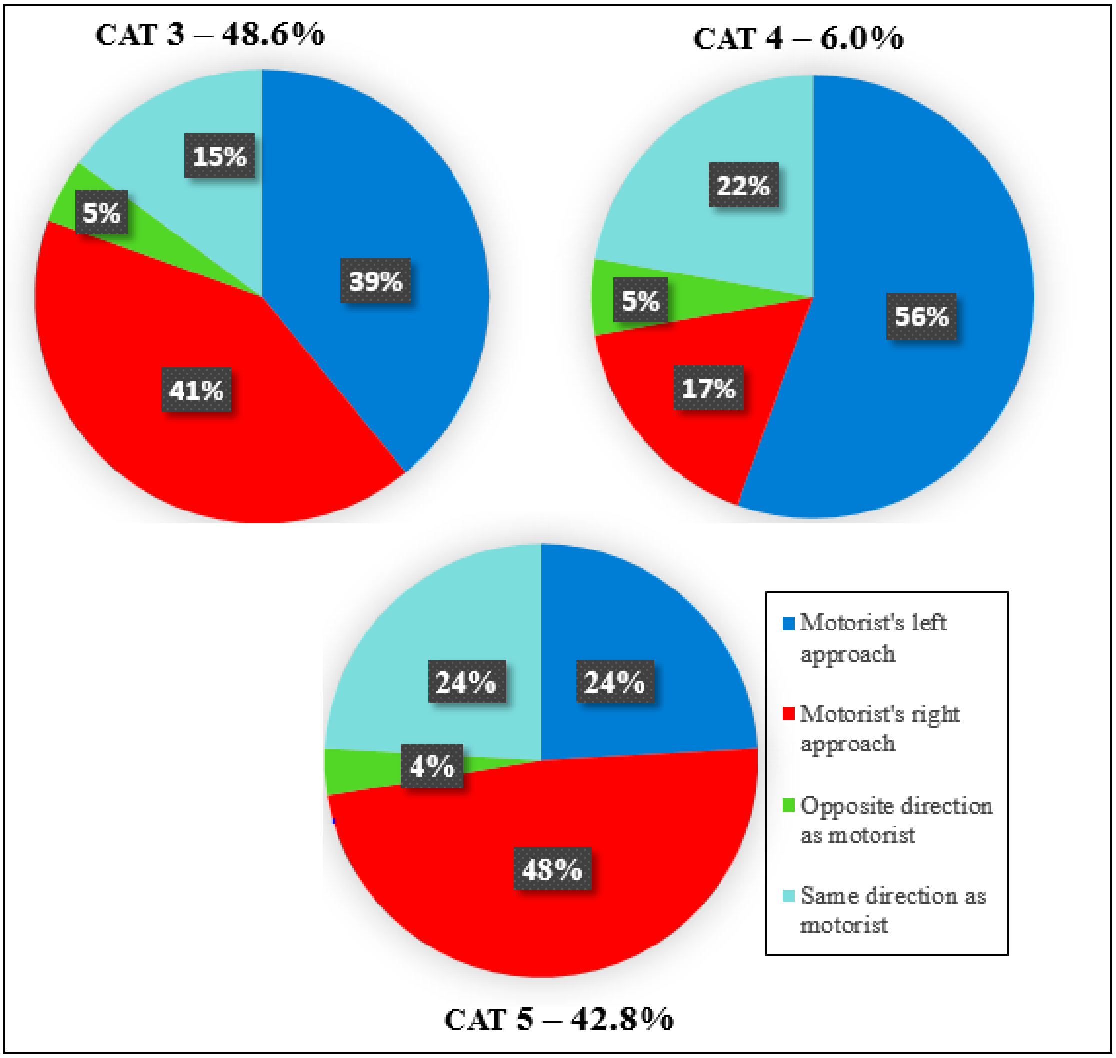
Out of the total 805 crashes, 44.7% (360) occurred on urban CAT 3 roadways crashes, 6.5% (52) were on urban CAT 4 roadway crashes, and 48.8% (393) were on urban CAT 5 roadway crashes. Pedestrian “same direction as motorist” movement resulted in the highest number of crashes, 39%, and 38%, on urban CAT 3 and CAT 5 roadway, respectively. The second pedestrian movement type resulting in more crashes was pedestrians crossing from “motorist’s right approach” on CAT 3 and Cat 5 roadway categories, accounting for 28% and 29% of crashes, respectively. Urban CAT 4 roadway category crashes were mostly as a result of pedestrian crossing from “motorist’s left approach” and “motorist’s right approach,” resulting in 41% and 32% of the crashes, respectively.

Overall, as a proportion of the total 805 crashes, 35% (280) were due to pedestrians walking in “same direction as motorist” movement, 10.2% (82) were due to pedestrians walking from “opposite direction as motorist” movement, 33% (272) were due to pedestrians crossing from “motorist’s right approach” movement, and 21.8% (171) were due to pedestrians crossing from “motorist’s left approach” movement. Pedestrian moving in the same direction as traffic resulted in the highest number of crashes while pedestrian moving in the opposite direction of traffic resulted in the least number of crashes for urban areas.

Similarly, Figure 24 shows the pie chart distribution of the pedestrian movements, prior to a pedestrian crash, for each roadway category for urbanized areas. A total of 210 crash narratives reports were obtained for urbanized roadways. The majority of crashes were centered between CAT 3–CAT 5, accounting for 97.4% (205) crashes, 48.6% (102) of the total crashes occurred on urbanized CAT 3 roadways categories, 6.0% (13) were on urbanized CAT 4 roadway categories and 42.8% (90) were on urbanized CAT 5 roadway categories. Pedestrians crossing from “motorist’s right approach” resulted in the highest number of crashes, at 41%, and 48%, on urbanized CAT 3 and CAT 5 roadway categories, respectively. The second pedestrian movement type resulting in more crashes on urbanized CAT 3 and Cat 5 roadways was pedestrians crossing from “motorist’s left approach,” accounting for 39% and 24% of crashes, respectively. Urbanized CAT 4 roadway crashes were mostly a result of pedestrians crossing from “motorist’s left approach,” resulting in 56% of the crashes.

As a proportion of the total 205 crashes for CAT 3–CAT 5, 44.1% (90) were due to pedestrians crossing from “motorist’s right approach” movement, 35.6% (73) were due to pedestrians crossing from “motorist’s left approach” movement, 16.4% (34) were due to pedestrians walking in “same direction as motorist” movement, and 3.9% (8) were due to pedestrians walking from "opposite direction as motorist" movement. Pedestrian crossing movements were the common movement types that resulted in pedestrian crashes on urbanized roadways.

Figure 24. Pedestrian movements for urbanized areas



Motorist Movement Analysis

In addition to analyzing the pedestrian movements, the movements of motorists were also analyzed. Twelve types of motorist movements were identified based on the LMCM coding. Four out of the twelve movement types accounted for 94% (957) of pedestrian crashes. These were "straight," "depart road," "changing lanes," and "left turn" motorist movements. Out of the 179 fatal crashes, straight traveling motorists accounted for 82.0% of all pedestrian fatal crashes while departing roadway, changing lanes, and left-turning motorists accounted for 7.3%, 6.8%, and 0.5%, respectively. Table 25 shows how different motorist movements affected pedestrian crash severity. Motorist turning movement accounted for less severe crashes (moderate to no injury) than incapacitated injury.

Table 25. Distribution of motorist movement in pedestrian crash occurrence

Motorist Movement	Fatal Crash	Severe Injury Crash	Moderate Injury Crash	Compliant Injury Crash	No injury	Grand Total
Straight	146	91	256	179	46	718
Depart Road	13	7	37	37	14	108
Changing Lanes	12	10	21	24	9	76
Left-turn	2	3	20	26	4	55
Right-turn	1	1	6	7	1	16
Other	5	2	12	14	3	36
Grand Total	**179**	**114**	**352**	**287**	**77**	**1009**

Conclusions

The purpose of this study was to provide a preliminary assessment of Louisiana's high-speed arterials in terms of existing pedestrian crossing facilities and identify any associations of pedestrian crashes with the presence or lack of such pedestrian crossing facilities and roadway characteristics. It is anticipated that the outcome of this study will be a preliminary report upon which a follow up study will be undertaken that will evaluate the impact of providing appropriate pedestrian facilities and include before and after studies analysis. The ultimate goal of such a follow up study will be to develop a statewide guideline for the provision of pedestrian facilities on Louisiana's high-speed arterials.

To achieve this objective, this study looked at nine study areas that make up Louisiana's urban and urbanized areas: New Orleans, Baton Rouge, Lafayette, Shreveport, Houma, Monroe, Alexandria, Hammond, and Lake Charles. The research team compiled and analyzed data from a database of crash data between 2013 and 2017, GIS data from DOTD that provided roadway information, and aerial view roadway features extracted from Google Earth. Several analyses were performed to meet the research goals, and each is summarized below.

Data-Driven Safety Analysis (DDSA) was undertaken to (i) identify any correlation between roadway characteristics (such as pavement widths, AADT, sidewalk presence, etc.) and crash frequencies; and (ii) identify any correlations between intersection/non-intersection features (such as the presence of marked crosswalks, control type, etc.), and crash frequencies. It provided many assessments and trends for future studies to analyze to provide further insights. For instance, crash densities were highest on roadways with generic names "Plaza" and "Expressway," and also tend to increase from roadway categories CAT 1 to CAT 5. Pedestrian crashes in urban areas were most frequent on roadways without shoulders and sidewalks, while for urbanized areas, it was roadways with high ADT and no sidewalks. Furthermore, pedestrian crashes were more frequent at non-intersections than at intersections. Most pedestrian crashes involved a single motorist, but there were several cases where multiple vehicles were involved with one or more pedestrians.

Spatial hotspot or heat map analysis was undertaken to visually identify areas of high pedestrian crash densities (hotspot) and whether they correlated with bus stop locations. The findings showed that most fatal and serious injury crashes were at hotspot locations.

For both urban and urbanized areas, hotspots were identified mostly along roadway networks surrounding interstate corridors. For the very large and densely populated study areas, such as Shreveport, Lafayette, Baton Rouge, and New Orleans, most of the hotspot locations had a high concentration of bus stop locations.

Decision tree analysis was undertaken to develop three predictive models and evaluate their performance in identifying significant influencing variables that impact pedestrian crash frequency. The following variables ranked highly in all models: condition of pedestrians (such as alcohol impaired, inattentive, etc.), distance to control, ADT, and day of week.

Location Movement Classification Method (LMCM) Analysis was undertaken to understand how different pedestrian and motorist movements correlate with pedestrian crash frequencies. The findings reveal that most pedestrian crashes involved pedestrians trying to cross the first half of a roadway, while the movement with the least amount of crashes was pedestrians moving opposite to the direction of traffic flow. For motorists, straight movements, rather than turning movements, correlated most with high pedestrian crash frequencies.

Findings from these four broad analyses offer plenty preliminary assessments that can be used as the basis for additional studies. The study has been able to map out pedestrian crashes, from 2013 to 2017, on high-speed arterials in urban and urbanized areas of Louisiana. It has also developed an inventory of roadway features, including existing pedestrian facilities, at the sites of all identified crashes. Furthermore, some of the analysis has revealed interesting patterns and trends that can be further explored.

A major limitation of the study was the inability to normalize the crash frequencies for the majority of the assessments. A lack of database, providing a statewide inventory of certain facility types (such as mileage of divided or undivided roadways, number of all intersection traffic control types, number of marked or unmarked crosswalks, etc.) made it impossible for crash frequencies to be normalized. Nevertheless, the study has been able to identify the facility types or roadway characteristics for which the identified pedestrian crashes most frequently occurred.

Recommendations

Based on the research experience, challenges faced, and measures adopted in the duration of this research, the following recommendations have been reached:

- A thorough literature review was undertaken to understand how other states have defined roadways as high speeds. This study undertook a statistical evaluation of the lower limits used by other states and compared to the speed limits of Louisiana's roadways and arrived on a recommendation that the definition of high speed for Louisiana is roadways with posted speeds of 45 mph or greater.
- The current Louisiana roadway classification is based on the functional classification system such that roadways can be classified as one of the following: urban/rural interstate, urban/rural major arterial, urban/rural minor arterial, urban/rural collector, or urban/rural local road. Urban refers to areas within urban and urbanized locations. For the purpose of the analysis undertaken, the study proposed five roadway categories, similar to what is used in the North Carolina's Street Design Guide. Category CAT 1 is highly tailored to pedestrian movements while CAT 5 is high speed and tailored towards vehicles on high-speed routes. CAT 2, CAT 3, and CAT 4 fall linearly between the two extremes.
- In analyzing the crash narratives, the research team found a number of inconsistencies in the actual narrative and what has been coded in the database. A quality assurance check is recommended for random crash reports at regular intervals to ensure officers' narratives are being properly coded.
- No recommendations for pedestrian crossing facilities on high-speed arterials are being made in this study. Instead, this study has provided findings that are to be used as a foundation for future studies that will help DOTD develop a system-wide solution to address pedestrian safety on its high-speed arterials. The study has been able to identify meaningful correlations between certain roadway features and pedestrian crash frequencies. Such associations can be further explored or investigated for how the implementation of certain pedestrian facilities, or lack thereof, may reduce pedestrian fatalities and injuries on all of Louisiana's high-speed arterials. Future research could include actual implementations and before/after studies to evaluate any potential countermeasures.

Acronyms, Abbreviations, and Symbols

Terms	Description
AADT	Annual Average Daily Traffic
AASHTO	American Association of State and Highway Official
ACC	Accuracy
ADA	Americans with Disabilities Act
ADT	Average Daily Traffic
APA	American Planning Association
BAC	blood alcohol content
BPLSESEM	Bayesian Poisson lognormal simultaneous equation spatial error model
CART	Classification and regression tree
CAT	Category
CBD	Central Business District
DDSA	Data-Driven Safety Analysis
DOT	Departments of Transportation
DOTD	Department of Transportation and Development
DT	Decision tree
DTOE	District Traffic Operations Engineer
FAO	Food and Agriculture Organization
FARS	Fatality Analysis Reporting System
FCS	Functional Classification System
FHWA	Federal Highway Administration
GBM	gradient boosting machine
GDP	Gross Domestic Product

GIS	Geographic information system
HAWK	High-Intensity Activated Crosswalks
KDE	Kernel density estimation
LBCS	Land-Based Classification System
LMCM	Location-movement classification method
LTRC	Louisiana Transportation Research Center
MUTCD	Manual on Uniform Traffic Control Devices
NACTO	National Association of City Transportation Officials
NHTSA	National Transportation Safety Board
NTSB	National Transportation Safety Board
NYSDOT	New York State Department of Transportation
OECD	Organization for Economic Cooperation and Development
PBCAT	Pedestrian and Bicyclist Crash Analysis Tools
PDP	Partial dependency plot
PHBs	pedestrian hybrid beacons
PRC	Project Review Committee
RF	Random Forest
RRFB	Rectangular Rapid Flashing Beacons
SAT	Shared Active Transportation
SHSP	Strategic Highway Safety Plan
STEP	Safe Transportation for Every Pedestrian
USCB	US Census Bureau
VMT	vehicle mile traveled
VPD	Vehicle Per Day
XGBoost	Extreme Gradient Boosting

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Appendices

Appendix A: Definition of High-Speed Roadway Based on Publications, State and Federal Agency Material

Researchers Definition

Naik et al., in their research work on "Are Dilemma Zone Protection System Useful on high-speed arterials with signal coordination?" considered Nebraska Hwy/Highway 2 Lincoln, NE, as a case study. The characteristics of this roadway which was considered a high-speed urban arterial included having a posted speed limit of 45 mph, a relatively high traffic volume (ADT>30,000) and six signalized intersections on a 3.5-mile road. This study, based its definition of high-speed as roadways with posted speeds of 45 mph or greater [18] .

On the other hand, Kockelman et al., project "Safety impacts and other implications of raised speed limits on high-speed roads" defined high-speed as a roadway with speed limit above 55 mph. In this study, Kockelman et al. developed a model to predict crash rate using the speed limit. Three segments of non-interstate roadway were categorized as low, medium, and high-speed. These tangent sections were used to investigate the model's predictions regarding the speed limit and crash rate. The respective speed limit corresponding to low, medium, and high-speed used in this study was 45, 50, and 55 mph [20].

Stapleton et al., focused on high-speed roads while addressing the issue of "Treatments for speed reduction on high-speed approaches to roundabouts" in urban areas. Roundabouts require low speed on entry and circulation, but the presence of roundabout on high-speed roads result in drivers maneuvering it at high-speed. The authors focused on reviewing the state-of-the-art practices using geometric design principles and traffic control devices to help engineers make appropriate decisions in selecting good speed reduction treatments for high-speed approaches to roundabouts. In the context of this topic, vehicles approaching a roundabout with speeds of 45 mph and above were considered high-speed [22]. A series of countermeasures were summarized as implementation consideration for the treatment of roadways with high-speed approaches which ranged from 45 mph approach to 75 mph approach speed.

Richie et al., in a related research work answered the question of whether modern roundabouts were appropriate at intersections with high-speed approaches based on safety research. The roadway links considered for this research were high-speed roadways connecting to a roundabout in suburban and rural areas. Richie et al. consideration of high-speed corridors were roadways with speeds 45 mph or greater [24] .

In 2012, Isebrand and Hallmark [26], conducted negative binomial regression analysis and model prediction for roundabouts on high-speed rural roadways using 19 different intersections in the United States. Data from these high-speed roadway approaches to the roundabout were used for a before and after analysis and the finding was consistent with the hypothesis that roundabouts are effective in reducing crashes at intersections. High-speed roadway, as used in this research, was defined as roadways having speeds of 40 mph and above [26]. Consistent with their definition, all the 19 roadways used for the analysis had speeds between 40 mph to 65 mph.

Michigan Department of Transportation (MDOT), in an effort to reduce its fatalities on high-speed non-freeways, carried out a 3-year state initiative of installing rumble strips on centerline and shoulders of its high-speed roadways. Gates et al., in 2012, evaluated the impact of centerline and shoulder rumble strips on high-speed roadways. Using data collected by video cameras installed at 18 passing zones and 12 curves two-lane roadway, the research concluded that lateral drifting of vehicles from roadway events was significantly reduced. Based on Gates' works, roadways considered to be high-speeds were roads with posted speeds of 55 mph and above [28].

An observational study of child restraining practice on Norwegian high-speed roads was conducted by Naess et al. in 2013. This research was to provide an estimate of the restraining practices among children younger than 16 years. A total of 1,260 child occupants of vehicles on roads with speed 70 km/h was assessed in the study. Roads in Norway considered high-speed for this research were roads with posted speeds greater than or equal to 70 km/h (≥ 43.5 mph) [30].

Taylor et al., worked on an Artificial Neural Network Speed Profile Model for work zone construction on high-speed highways. The model developed used horizontal and vertical alignment variables along with speed and vehicle distribution to model speed profile for construction work zone on high-speed roadways. Ten high-speed roadways in Pennsylvania and seven sites from Texas were used for the data collection. The study defined high-speed highways as roads and highways with free flow operating speed of 80 km/h (≥ 50 mph) and higher [32].

Zhou et al., studied pedestrian safety on multi-lane high-speed arterials to reveal the relationship between pedestrian crashes and other elements of the high-speed arterial like access density, lighting and transit stop density. The site considered for this study was US 19 (SR) located in Pinellas County, Florida. This 32-mile corridor has a posted speed ranging from 35 mph to 55 mph. The study considered the corridor as high-speed because most parts of the corridor had posted a speed of 45 mph and higher. High-speed was defined in the study as roads with posted speed 45 mph or over [34].

Fortuijn et al., conducted a study on 38 intersections in the province of Zuid-Holland, Netherlands, on sustainably safe signalized intersections on high-speed roads using speed plateaus with camera enforcement. The paper investigated crashes on high-speed signalized intersection approaches and the application of measures like speed plateau will drop the high-speed of the vehicle. The finding suggests that speed plateau reduces the high-speed of vehicles from 80 km/h (50 mph) to a speed of nearly 50 km/h (30 mph). High-speed in this research was considered as speeds of 50 mph or greater [35].

State Agencies Definition

Alaska traffic manual defined high-speed while providing criteria for the installation of Active Advance Warning Flashers (AAWFs). The AAWF's highway signals are installed in advance of the conventional traffic signal to provide advance awareness of the onset of the yellow indication. One of the conditions to warrant the installation of AAWF on a roadway is for it to be a high-speed approach. High-speed was further explained to be approaching with a speed of 55 mph and above [19]. In a later section, while addressing the road type and the distance from the traffic signal for the installation of the AAWF, the manual provided requirements for urban low-speed and urban high-speed roadways. Urban low-speed was defined as roadways with posted speeds of 40 mph or less and high-speed was defined as roadways with posted speeds of 45 mph or greater.

Connecticut Department of Transportation (ConnDOT), in their highway design manual 2003 edition provided criteria for high-speed urban highway and low-speed urban street in addressing "Horizontal Alignment." In presenting criteria for horizontal alignment of the type of horizontal curve, the minimum radii, super-elevation, and sight distance around horizontal curves, ConnDOT explained that these criteria differ for high-speed and low-speed urban streets. High-speed are defined as roadways with speeds greater than 45 mph and low-speed urban streets to be roadways with speeds less than or equal to 45 mph [21].

Illinois Department of Transportation (IDOT), in their book "Bureau of Local Roads and Streets Manual," defined high-speed from a geometric design perspective as roadways with speeds greater than 45 mph and low-speed roadways as those with speeds 45 mph or less. On the issue of curbs and gutters for roadway, IDOT generally suggests that barrier curbs or continuous countable curbs should be used on high-speed facilities. Consistent with its earlier definition, IDOT defined high-speed facilities as roadways with posted speed limits greater than 45 mph [23].

Michigan Department of Transportation (MDOT), in their book "Guidance for the installation of pedestrian crosswalks on Michigan State Trunk line Highways," also provided a definition for high-speed. Regarding the installation of pedestrian hybrid beacon (HAWK) or rectangular rapid flashing beacon (RRFB) on different road types, MDOT defined low-speed roads as roads with speeds less than or equal to 35 mph and high-speed roads as roads with speeds greater than 35 mph [25].

Virginia Department of Transportation (VDOT) addressed the definition of high-speed while stating warrants for the installation of a pedestrian crosswalk. VDOT suggested that where the installation of a pedestrian crosswalk facility will be necessary on a high-speed roadway, consideration should be given to installing RRFBs. High-speed in this context is defined as roadways with speeds greater than 35 mph [27].

Minnesota Department of Transportation (MnDOT) provided guidelines for the installation of the Pedestrian Hybrid Beacons in their traffic manual. After an engineering study warrants the installation of the beacon, the manual in chapter four provides specifications for its installation on high-speed roadways and low-speed roadways. Under this subject matter, low-speed roadways are defined as roadways with posted speeds of 35 mph or less. High-speed roadways are defined as roadways with posted speeds of more than 35 mph [29]. On the other hand, while providing guidelines for left turn protected phase selection, the manual suggested that drivers have difficulty judging gaps accurately in traffic approaching at high-speed. As a result, engineers are advised to exercise high discretion when deciding a protected or permissive left-turn phase on a high-speed roadway. High-speed roadways were defined as roadways with speeds of 45 mph or above.

Oregon Department of Transportation (ODOT) in chapter six (6) of the 2016 edition of their traffic manual, discussed the condition that may warrant or disqualify the addition of a right turn lane at an intersection. Some roadways are designed to have right turn lanes at intersections and this is mainly to allow through traffic to keep moving and avoid potential rear-end collisions. The manual discourages the use of a right turn lane on roadways classified as a high-speed approach to an uncontrolled intersection. Adding such a feature on a high-speed uncontrolled intersection approach is unsafe for accurate judgment of gaps and endangers pedestrians and cyclists. High-speed highways are defined by ODOT as roads with posted speeds of 45 mph or greater [31].

In a presentation on clear zones by Bill Gulick, the Director of Highway Design of Kentucky Department of Transportation, roadway speed was considered for determining the minimum distance for a clear zone. High-speed roadways and low-speed roadways had different clear zone requirements. Low-speed roadways have speed limits ranging from 35 mph and below with their corresponding minimum clear zone ranges. High-speed, on the other hand, had speed limit 40 mph or greater with its corresponding clear zone distance stated in a table [33]. The inferred definition of high-speed roadway considered by the state are roadways with a posted speed limit of 40 mph or greater.

Federal and other Agencies' Definition

In chapter 2 of AASHTO's book "A Policy on Geometric Design of Highway and Streets 2011 6th Edition," talks about the difference in design criteria applicable for low and high-speed designs. The upper limit for low-speed design is 45 mph and the lower limit for high-speed design is 50 mph. AASHTO, therefore, considers high-speed roadways in geometric design as roadways with speeds of 50 mph or greater [14].

The Manual for Uniform Traffic Control Device (MUTCD) 2009 Edition has varying definitions for low and high-speeds. High-speed roadways are mentioned many times in the manual but are defined under three subject areas. Firstly, while addressing guidelines for the installation of pedestrian hybrid in section 4F.02, it described speeds of 35 mph or less as low-speed and speed of more than 35 mph as high-speed [13]. On the other hand, while addressing the issue of the channelizing device for high-speed and low-speed roadways in section 6, MUTCD described high-speed roadways as having speed greater than or equal to 45 mph while low-speed roadways were defined as having speeds of 40 mph and less. Lastly, the manual provides a formula for calculating shoulder taper for high-speed roadways and low-speed roadways. Similar to high-speed and low-speed roadways definition given for channelizing device section, high-speed roadways are defined as roadways with a posted speed of 45 mph or greater.

The consideration of high-speed from the National Highway and Transportation Safety Administration (NHTSA) perspective was based on their "High-speed Unbelted Test Requirement of Fmvss No. 208 Analysis of Issues Raised by Public Comments" report. In this report, NHTSA performed 14 unbelted male rigid barrier crash tests on a range of 1998/1999 vehicle moving at a speed of 30 mph. In a similar test using females for rigid test on production vehicles, the high-speed test was performed at 30 mph. This research work was to determine if these vehicles' airbags meet the injury criteria for both the driver and passenger side at high-speed (30 mph). High-speed being used in this report is defined as speed of 30 mph or greater [36].

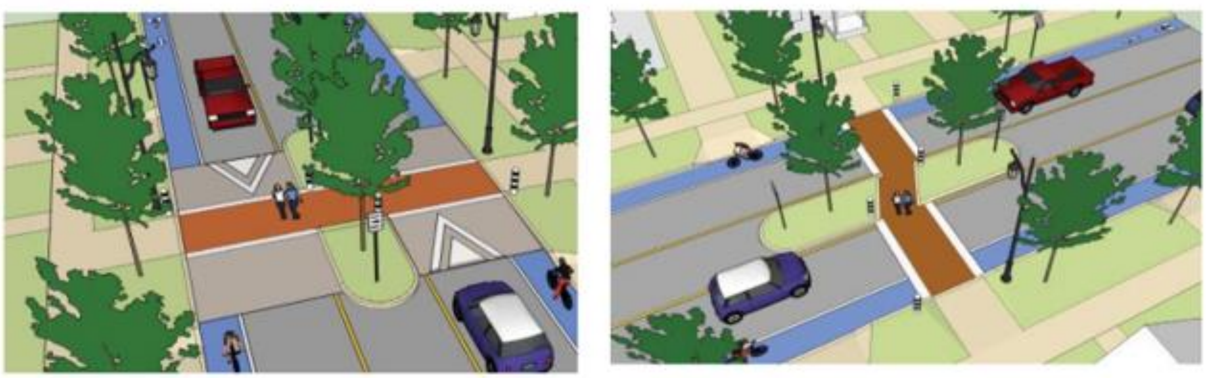
Another report from the National Cooperative Highway Report Program (NCHRP) on "Design Speed, Operating Speed, and Posted Speed Practices" discussed the characteristics of different functional classes of roads. Characteristics of rural minor arterials described by NCHRP included anticipated speeds of 45 to 70 mph and this was described by the report as relatively high-speed with minimal interference to through movement. Although this description is for rural minor arterials, the lower limit of the speed range was 45 mph. With the classification of the minor arterial as a relative high-speed roadway, it is safe to suggest that NCHRP considers speeds of 45 mph as high-speed [37].

Appendix B: Pedestrian Crossing Enhancement Facilities

Staggered Crosswalks

Staggered crosswalks differ from regular crosswalks by their layout; they are split by a median and offset on either side of the median. They are reserved for midblock installation and thus considered a non-intersection pedestrian crossing facility. The offset configuration is an improved safety feature that compels pedestrians to turn within the median and face oncoming traffic before crossing the road. However, for pedestrians with even mild forms of visual impairments, they may be thrown off course by the forced inclined path within the median, prior to crossing the opposite lane [95]. Figure B1 displays the difference between a regular crosswalk and a staggered crosswalk.

Figure B1. Difference between a regular crosswalk and staggered crosswalk



Curb Ramps

The surface of sidewalks is by nature a few inches above the road surface, creating a sharp depression at the edge of sidewalks onto the roadway. Pedestrians crossing the road first get off the sidewalks before stepping on the road. This process is challenging for cyclists, persons using crutches, walkers' handcarts, and wheelchairs. Curb ramps, as shown in Figure B2, are a solution to this challenge as they provide access between the sidewalk and the roadway to favor people who struggle to step up and down high curbs [61]. Federal Legislation (1973 Rehabilitation Act) requires that curb ramps be installed at all intersections and midblock locations. To further favor visually impaired individuals, ADA requires that ramps have detectable warnings in the form of a series of small domes that contrast in color and texture with surrounding sidewalks and streets. These patterns in texture are intended to be felt by the pedestrians' feet.

Figure B2. Pedestrian curb ramps

Medians and Refuge Islands

A median or refuge island refers to the central longitudinal portion of the road separating opposing traffic. The two features serve the same purpose but differ in length; medians run one or many blocks, but refuge islands typically run about a 100 to 250 ft. [95]. Medians simplify the task of crossing by assisting pedestrians to cross one direction of traffic at a time. It allows room to reassess gaps in traffic and estimate vehicle speeds in the other direction of travel, after safely crossing the first half of the roadway. The FHWA reveals there is at least a 46% reduction in pedestrian crashes where raised medians and crossing islands are installed [96]. Figure B3 shows a refuge island.

High-Intensity Activated Crosswalk (HAWK)

The HAWK is a pedestrian crossing beacon developed in the late 1990s by the city of Tucson, Arizona, to assist pedestrians to cross at intersections where major arterials intersect minor streets [97]. They are also known as Pedestrian Hybrid Beacon. These are designed for midblock installation or at least a 100ft. away from intersections. Pedestrian Hybrid Beacons are pedestrian activated, they are inactive until a pedestrian arrives and pushes a button, noting his intent to cross the road. The signal alerts the pedestrian when it is safe to do so, by showing a stop sign to oncoming vehicles, until such time allotted for crossing has elapsed. Figure B4 shows a HAWK control for pedestrians. This system reduces travel delays as motorists are not required to stop unless a pedestrian is present and has pushed the button on the device. However, the complex nature or technology required to build and install the system makes it costly. They may be used at intersections or midblock locations.

Figure B3. Median within crosswalk

Figure B4. HAWK activation for pedestrians

Illumination

Illumination involves increasing brightness and therefore visibility at a specific crosswalk location. This can be achieved by installing street lamps or removing trees and objects that cast shadows on the roadway during the daytime. Lighting improves both safety and road user comfort. The *FHWA Information Report on Lighting Design for Mid-block Crosswalks* suggests illumination of 20 lux before a crosswalk, and 5 ft. above the road surface is often enough in most circumstances. Crosswalk lighting must be of a different color to provide contrast from standard roadway lighting. It is known that up to 50% of pedestrian crashes occur at night when there is poor visibility. Illumination potentially reduces the chances of pedestrian fatalities.

In recent times, In-Pavement Warning Lights, otherwise called In-Roadway Warning Lights have supplanted the use of traditional street lamps, especially in the states of California and Washington, where they burgeoned. These are small sized warning lamps installed in the roadway pavement, surrounding the crosswalk markings. The protrusion out of the pavement is often about half an inch. As most illumination methods are cost-effective and require little maintenance, they are warranted at crosswalk locations with increased foot traffic at night. A typical school crosswalk for instance, may not require lighting as schools operate only during the daytime when there is often sufficient lighting. Figure B5 shows a pedestrian crossing a crosswalk illuminated by an in-roadway warning light.

Figure B5. Crosswalk with in-road warning lights

Raised Crosswalks

Crosswalks may be elevated a few inches above the road surface. When speed tables are merged with crosswalks, they are called raised crosswalks. These enhance pedestrian safety by reducing vehicle speeds and placing pedestrians in a more visible position. Raised crosswalks are best suited on local and collector roads with relatively high operating speeds. They are highly preferred near elementary schools where they elevate kids by a few inches and make them conspicuous. However, these are inappropriate for crossings on curves and steep roadway grades, and roads known to be part of emergency routes. Figure B6 shows a raised pedestrian crosswalk.

Figure B6. Raised pedestrian crosswalk

Advanced Stop/Yield Lines

Advanced yield/stop lines as shown in Figure B7 are thick white line-markings placed ahead of crosswalks on multi-lane approaches. This makes drivers stop far away enough to prevent obstruction of a pedestrian's view of a second approaching vehicle often on the left side of the first vehicle. Section 3B.16 of the MUTCD manual specifies placing these yield/stop lines between 20 and 50 ft. before the crosswalk. Location conditions like traffic control, vehicle speeds, street width, and number of lanes are considered in deciding an appropriate distance within the suggested range of the MUTCD. Standard practice in Louisiana requires the installation of this feature at all crosswalks.

Figure B7. Advanced stop line

Rectangular Rapid Flashing Beacon (RRFB)

These are user-actuated amber LED arrays used to supplement warning signs at uncontrolled crosswalks, as shown in Figure B8. RRFBs increase driver awareness of potential pedestrian crossings. The LEDs in RRFBs have an irregular flash pattern like those used by emergency services: they are highly conspicuous even in daylight. Pedestrians activate these systems either manually by pushing a button, or automatically (passively) by walking through an infrared field installed within the curb ramp where pedestrians first stop before stepping on the roadway. These are known to achieve very high compliance rates by motorists, especially when installed on both sides of the approach lane. RRFBs must be limited to areas of most critical safety concerns. Their effectiveness is significantly reduced when they are too many within a specific area.

Figure B8. Rectangular rapid flashing beacon

Appendix C: Discussion of Engineering Studies for the Installation of Marked Crosswalk

The following engineering study discussions were identified from the study of Louisiana traffic engineering manual and other states' traffic engineering manuals.

- **Pedestrian volume per hour:** The total number of pedestrians using the crossing during the highest pedestrian volume hour. Some pedestrian guidelines suggest that children under 13 years, elderly over 64 years and/or disabled persons should be counted as 1.33 pedestrians [59] while others count them as 1.5 pedestrians. More safety conservative pedestrian crossing guidelines criteria count them as 2 pedestrians [27], [70]. Most of the criteria suggest a minimum of 20 pedestrians per hour. In addition to this, others suggest 18 pedestrians per hour in any two hours or 15 pedestrians per hour per any three hours [27]. San Diego pedestrian guidelines propose a lower minimum value of 10 pedestrians per hour during the peak pedestrian hour [84] . Virginia pedestrian crosswalk guidelines state that where a school crossing exists, there is no minimum pedestrian volume requirement. A school crossing is defined as a crossing location where at least 10 student-pedestrians are crossing per hour. Louisiana crosswalk guideline proposes a minimum of 20 pedestrians per a 2-hour period during any 8 hours for a controlled intersection or a minimum of 20 pedestrians per a 2-hour period during any 24 hours for an uncontrolled intersection or a minimum of 40 pedestrians per 1-hour period [66].

- **Crossing distance/number of lanes:** This represents the distance the pedestrian needs to cross before reaching the far end of the curb or a median refuge island. Fitzpatrick et al. NCHRP 562 report prefers the use of crossing distance rather than the number of lanes to account for the extra time needed by pedestrians to cross bike lanes, two-way left-turn lanes, and wide lanes [73]. The number of lanes is the count of the individual lanes on both approaches. For a roadway with an adequate median or refuge island, the number of lanes will be the count of lanes on each approach. A proposed location with more than two lanes would require additional treatment consideration.

- **Distance from adjacent controlled location:** Adjacent distance of the proposed crosswalk to a controlled crossing location or adjacent crosswalk should be estimated. The San Diego pedestrian crosswalk guidelines propose a minimum acceptable distance of 250 ft. to the closest edge of the controlled crossing. Virginia pedestrian crossing treatment guidelines suggest a minimum distance of 200 ft. City and county of Denver uncontrolled pedestrian crossing guidelines also propose a minimum distance of 300 ft. [59]. NCHRP 562 report by Fitzpatrick et al. also suggests the minimum distance from adjacent controlled locations should be 300 ft. On the other hand, DOTD traffic manual suggests that a crosswalk should not be installed at a midblock if an adjacent crosswalk is within 600 ft. [66].

- **Critical gap:** This is the minimum time in seconds that a pedestrian will use to cross the roadway at an average speed without the need for a driver to yield. Highway Capacity Manual provides an equation to calculate the critical gap (tc) using pedestrian walking speed (Sp), crossing distance (L), and start-up and end clearance time (ts). The equation is given by tc = (L/Sp) + ts. The estimation of the critical gap is further used to determine average pedestrian delay. In other guidelines, the number of acceptable gap time is counted during the peak vehicular hour and averaged per five-minute period. For guidelines like San Diego pedestrian guidelines which include a point base score, gap time warrant score is used to allocate points based on the number of gap time within a five-minute time period.

- **Pedestrian delay:** Pedestrian delay is the total time pedestrians wait at the location to cross. This is dependent on the critical time gap time. The average pedestrian delay equation is provided by HCM which is based on vehicular flow, critical gap, and the mean vehicular headway. High pedestrian delay will result in an elevated likelihood of noncompliance [59]. A higher level of noncompliance implies the need for a marked crosswalk and possibly other treatments to improve motorist yield compliance. Louisiana traffic manual suggests a minimum of 5 gaps per 5 minutes [66].

- **Pedestrian sidewalk wide:** Adequate sidewalk width is dependent on other roadway factors such as traffic volume and land-use patterns. The potential conflict between pedestrian and motorist parking activities will be reduced by having an adequate sidewalk width. The minimum adequate sidewalk width is 3 ft., and the maximum is 6 ft. [27]. Although Louisiana does not specify a specific sidewalk width, the traffic manual requires the width is ADA compliant [66]. ADA propose a minimum sidewalk width of 3 ft.

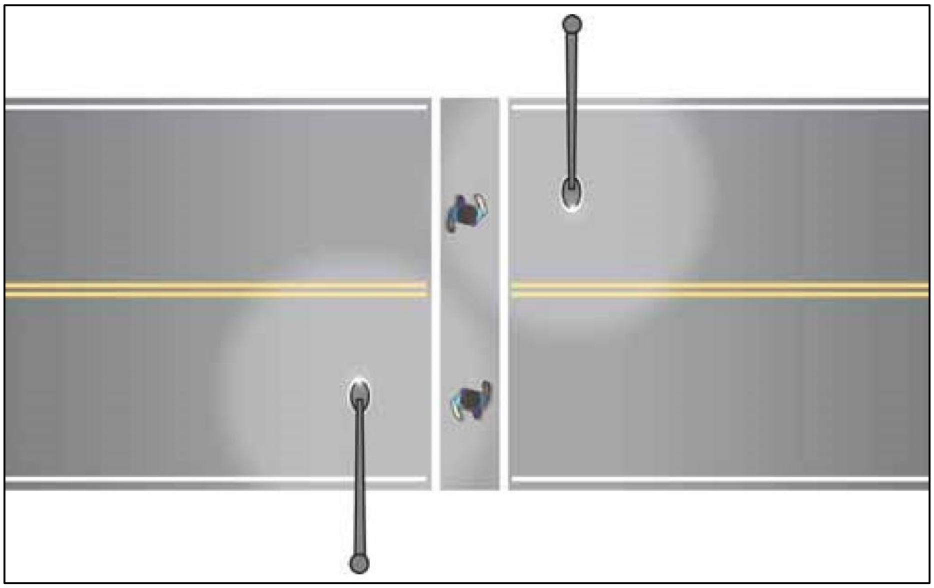
- **Average daily traffic (ADT):** The total vehicular volume of both approaches of the roadway during 24 hours of the day. For a roadway with a median of sufficient size, thus a minimum of 6 ft., the estimation of the traffic volume should be carried out for each approach. The higher traffic volume during 24 hours should be used in the assessment. For locations where the ADT is higher or equal to 1,500 veh/day, additional treatment may be considered for the location. Virginia pedestrian crosswalk guideline proposes that average daily traffic (ADT) for both approaches of the roadway should exceed 3,000 veh/day for the consideration of a marked crosswalk. DOTD propose for a location with ADT above 3,500 vehicle per day, for a two-way traffic crosswalk installation to be considered at midblock. On the other hand, DOTD prohibits the installation of a crosswalk at an uncontrolled intersection with ADT above 12,000 [66].

- **The posted or statutory speed limit:** The 85^{th} speed of the roadway or the posted speed of the location should be determined. For high-speed roadway, most treatment measures are meant to improve drivers' yieldedness, reduce pedestrian delay time, and give pedestrians the right-of-way. As stated in an earlier chapter, some states including Louisiana currently prohibit the installation of pedestrian crosswalks on roads with posted speed of 45 mph and above (high-speed roadway). While some guidelines suggest installing traffic calming measures to reduce the speed of the section [87] others recommend geometric improvement of the roadway [59], or treatments to improve pedestrian safety.

- **Stopping sight distance**: This is also referred to as visibility warrant in other pedestrian guidelines. This represents the minimum unrestricted view of the motorist of all pedestrians at the proposed location. The minimum acceptable stopping sight distance criteria is dependent on the 85^{th} percentile speed of the roadway. The higher the speed the wider the required minimum distance. Many guidelines provide a table of speed and its corresponding minimum stopping sight distance value. These values are mostly at an incremental of 5 mph, and interpolation can be used to calculate the stopping sight distance of speed values within the provided limits. The sight distance should be measured from the driver's perspective to the outer edges of the traveled lanes.

- **Availability of street lighting:** The proposed location should be assessed for good illumination. Factors affecting illumination relates to conflicts between vehicles and pedestrians. Recommended illuminance levels for urban streets based on pedestrian area classification at midblock crosswalk should be based on the appropriate luminaire and luminaire height. Since the position of the pedestrian is vertical, if all light from the luminaire is directed downwards, the vertical profile of the pedestrian will not be adequately illuminated. The light intensity distribution must meet the geometric requirement. The desired vertical illuminance for a crosswalk is 20 vertical lux and the position of the luminaire (250-W HPS) flat lens cobra-head) should be at least 10 ft. from the crosswalk [98]. Gibbon et al [98], suggest that for a roadway with traffic in both directions especially those without a median, luminaires should be placed on both sides of the roadways. Figure C1 shows the luminaires should be placed prior to the crosswalk from the drivers' perspective.

Figure C1. Design for midblock crosswalk lighting layout



- **Land-use characteristics:** Adjacent land-use characteristics of a location can be a pedestrian attractor or generator. Such land-use features include transit stop, elementary/middle/high school, park & recreation, and neighborhood civic facilities like hospitals, libraries, post offices and religious facilities. San Diego pedestrian guidelines suggest that the crosswalk must be located within ¼-mile of the pedestrian attractor or generator. If the pedestrian volume per hour at a location does not meet the minimum requirement, but the location directly serves similar land-use characteristics stated above, it qualifies to meet the pedestrian volume requirement [59].

- **Presence of bus stop**: Pedestrian risk model analysis conducted using isolated environmental variables such as sidewalk width, parking lane width, ADT, and vehicle gap shows that the presence of a bus stop is associated with an increase in pedestrian risk [84] The presence of a bus stop within 100 ft. of the proposed location of the crosswalk warrants the consideration of a crosswalk.

Appendix D: The 2000 Policy Accommodating Bicycle and Pedestrian Travel: A Recommended Approach (FHWA HEP 2012a)

The four policy statements are:

1. *Bicycle and pedestrian ways shall be established in new construction and reconstruction projects in all urbanized areas unless one or more of the three conditions are met:*
    - *Bicycles and pedestrians are prohibited by law from using the roadway.*
    - *The cost of establishing bikeways would be excessively disproportionate to the need.*
    - *Where sparsity of population indicates an absence of need.*
2. *In rural areas, paved shoulders should be included in all new construction and reconstruction projects on roadways used by more than 1,000 vehicles per day, as in states such as Wisconsin. Paved shoulders have safety and operational advantages for all road users in addition to providing a place for bicyclists and pedestrians to operate.*
3. *Sidewalks, shared-use paths, street crossings (including over-and undercrossings), pedestrian signal, signs, street furniture, transit stops and facilities, and all connecting pathways shall be designed, constructed, operated and maintained so that all pedestrians, including people with disabilities, can travel safely and independently.*
4. *The design and development of the transportation infrastructure shall improve conditions for bicycling and walking through the following additional steps:*
    - *planning projects for the long-term. Transportation facilities are long-term investments that remain in place for many years. The design and construction of new facilities that meet the criteria in item 1) above should anticipate likely future demand for bicycling and walking facilities and not preclude the provision of future improvements. For example, a bridge that is likely to remain in place for 50 years, might be built with sufficient width for safe bicycle and pedestrian use in anticipation that facilities will be available at either end of the bridge even if that is not currently the case.*
    - *addressing the need for bicyclists and pedestrians to cross corridors as well as travel along them. Even where bicyclists and pedestrians may not commonly use a particular travel corridor that is being improved or constructed, they will likely need to be able to cross that corridor safely and conveniently. Therefore, the design of intersections and interchanges shall accommodate bicyclists and pedestrians in a manner that is safe, accessible, and convenient.*
    - *getting exceptions approved at a senior level. Exceptions for the non-inclusion of bikeways and walkways shall be approved by a senior manager and be documented with supporting data that indicates the basis for the decision.*
    - *designing facilities to the best currently available standards and guidelines. The design of facilities for bicyclists and pedestrians should follow design guidelines and standards that are commonly used, such as the AASHTO Guide for the Development of Bicycle*

Facilities, AASHTO's A Policy on Geometric Design of Highways and Streets, and the ITE Recommended Practice "Design and Safety of Pedestrian Facilities."

Appendix E: Interstate Crash Analysis

Although specific laws prohibit pedestrian activities on the interstate, as highlighted in the literature review section of this document, and pedestrian crashes on interstates were not included in the analysis thus far, it was necessary to undertake this analysis to explain the rather high number of pedestrian crashes reported for Louisiana interstates. A review of the crash database showed 226 pedestrian crashes on interstates for the study period of 2013 to 2017. From this total, only 149 pedestrian crash narratives were retrieved, and were further used for the analysis presented below.

Table E1 breaks down the total number of interstate crashes (149) by the severity type. It can be seen that generally, there has been an increase in pedestrian crashes on interstate corridors over the last five years. The number of crashes increased from a total of 15 in 2013 to 36 in 2017, thus more than a 100% increase in pedestrian crashes on interstate corridors. The total number of fatal and serious injury (fatal and incapacitating) crashes remained relatively high compared to the lower severity crashes. 33.6% (50) of all interstate crashes were fatal while 12.8% (19) were serious injury crashes. Out of the total 149 crashes, 93.29% (139) were injury crashes, 6.04% (9) were non-injury, and 0.67% (1) were of unknown severity.

Table E1. Pedestrian interstate crash by severity types

Year	Fatal Crash	Serious Injury Crash	Moderate Injury Crash	Compliant Injury Crash	No injury	Unknown	Grand Total
2013	5	2	5	2	0	1	15
2014	9	2	8	7	0	0	26
2015	11	9	5	8	4	0	37
2016	12	3	8	8	4	0	35
2017	13	3	12	7	1	0	36
Total	**50**	**19**	**38**	**32**	**9**	**1**	**149**

Table E2 shows the roadway section type analysis summary which describes the part of the interstate corridor the crashes occurred. Out of the total 149 crashes, 87.25% (130) occurred on the interstate mainline corridor, and 12.75% (19) occurred on interstate ramps. This shows that the majority of crashes on interstates are mainly due to pedestrian movements on mainlines.

Table E2. Pedestrian interstate crash by roadway section type

Roadway Section Type	2013	2014	2015	2016	2017	Total Crashes	Percentage
Interstate Mainline	14	25	30	30	31	130	87.25%
Interstate Ramp	1	1	7	5	5	19	12.75%
Total	15	26	37	35	36	149	100%

Figure E1 shows the distribution of different pedestrian movement types that resulted in interstate crashes. Pedestrians of a stopped vehicle, which describes either a driver or passenger out of the vehicle, accounted for 31% of interstate crashes. Pedestrian crossing movement, which implies a pedestrian attempting to cross the interstate corridor, accounted for 29% of crashes. Pedestrians of stalled vehicles accounted for 16% of crashes. Pedestrian parallel movement on the interstate also accounted for 11%. Standing or laying in roadway and unknown movement were the lowest movement types occurring at 6% and 7%, respectively.

Figure E1. Distribution of pedestrian movements on interstate crashes

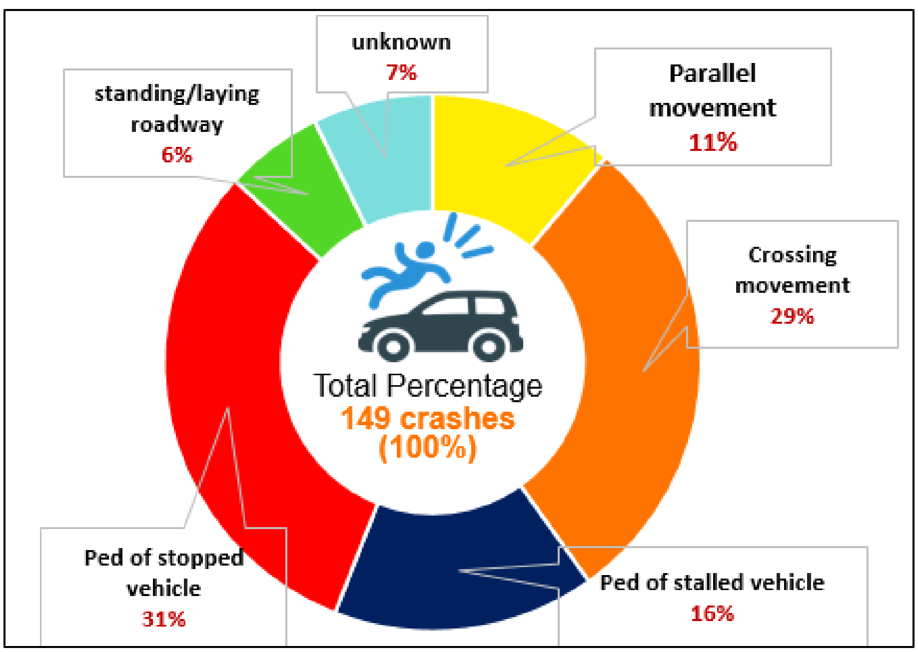
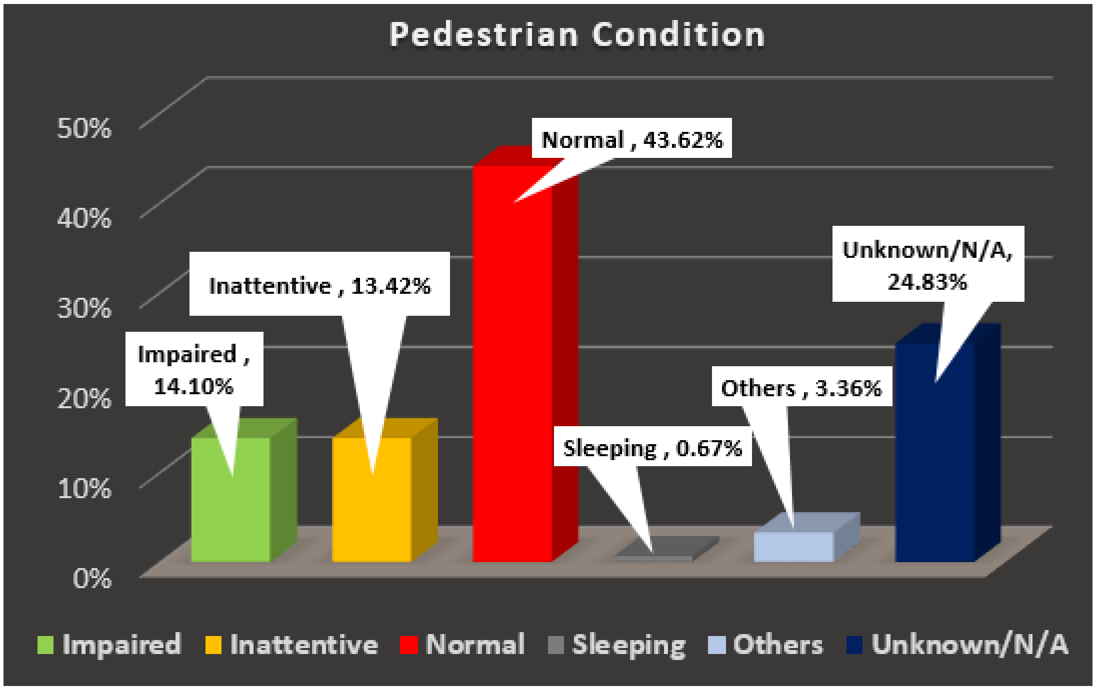


Figure E2 shows the distribution of pedestrian actions when they were involved in crashes with motorists on the interstate. It shows that about 43.62% of pedestrians were in normal condition, 14.10% were impaired, 13.42% were inattentive, and 24.83% were of unknown conditions. From the crash narratives, pedestrians involved in interstate crashes include tow truck drivers, roadside workers, emergency workers, drivers getting out of their stalled vehicles and walking on a shoulder, pedestrians of drivers of stalled vehicles wanting to cross the roadway to safety, and pedestrians being chased by police.

Figure E2. Distribution of pedestrian action on interstate crashes



Pedestrian Action	Number of Crashes	Proportions of Crashes
Impaired	21	14.10%
Inattentive	20	13.42%
Normal	65	43.62%
Sleeping	1	0.67%
Others	5	3.36%
Unknown N/A	37	24.83%

Appendix F: Ranking of Significant Contributing factors for CART, RF and XGBoost Model

Figure F1. Ranking of importance of predictors for CART model

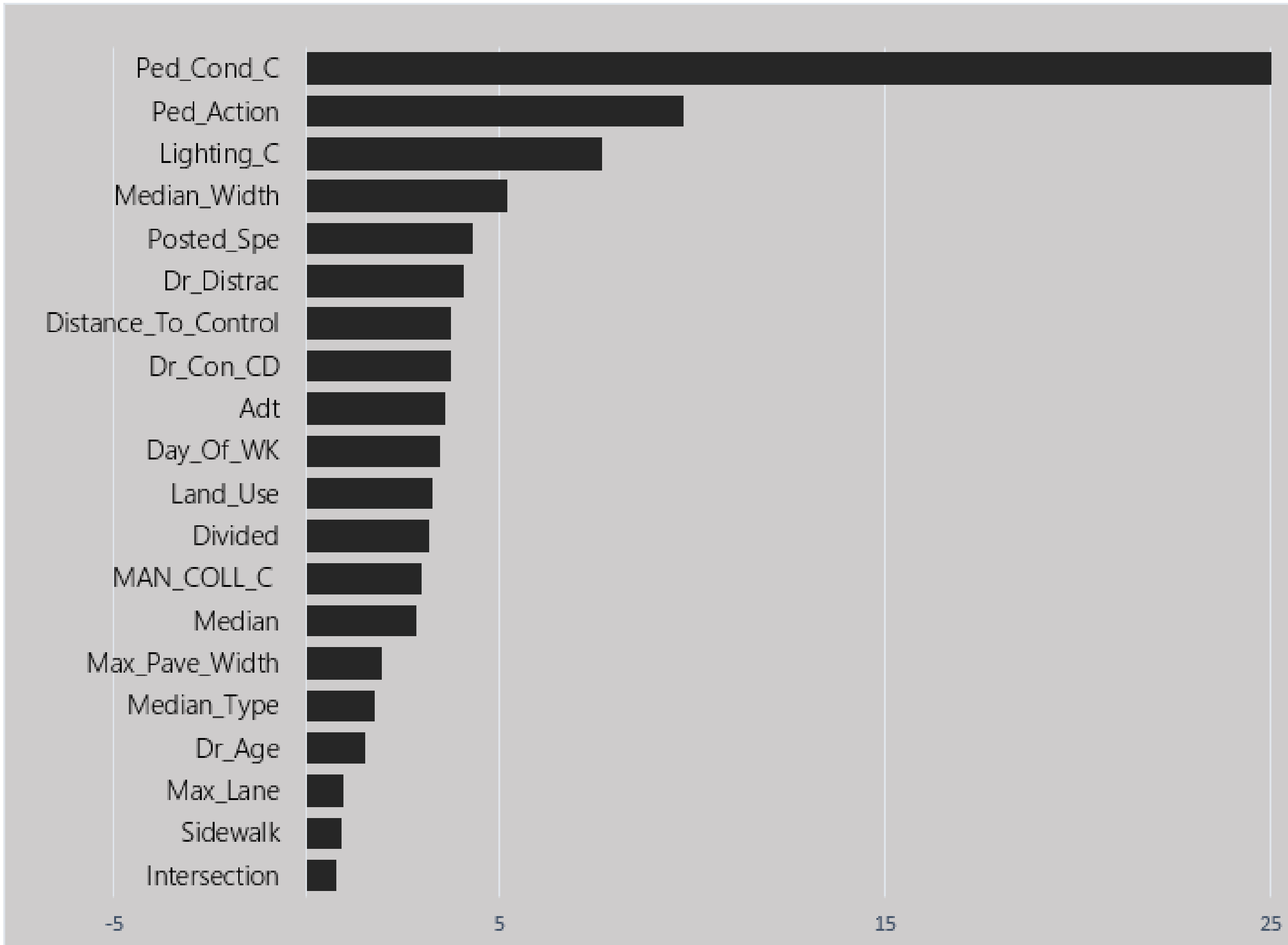


Figure F2. Ranking of importance of predictors for random forest (RF) model

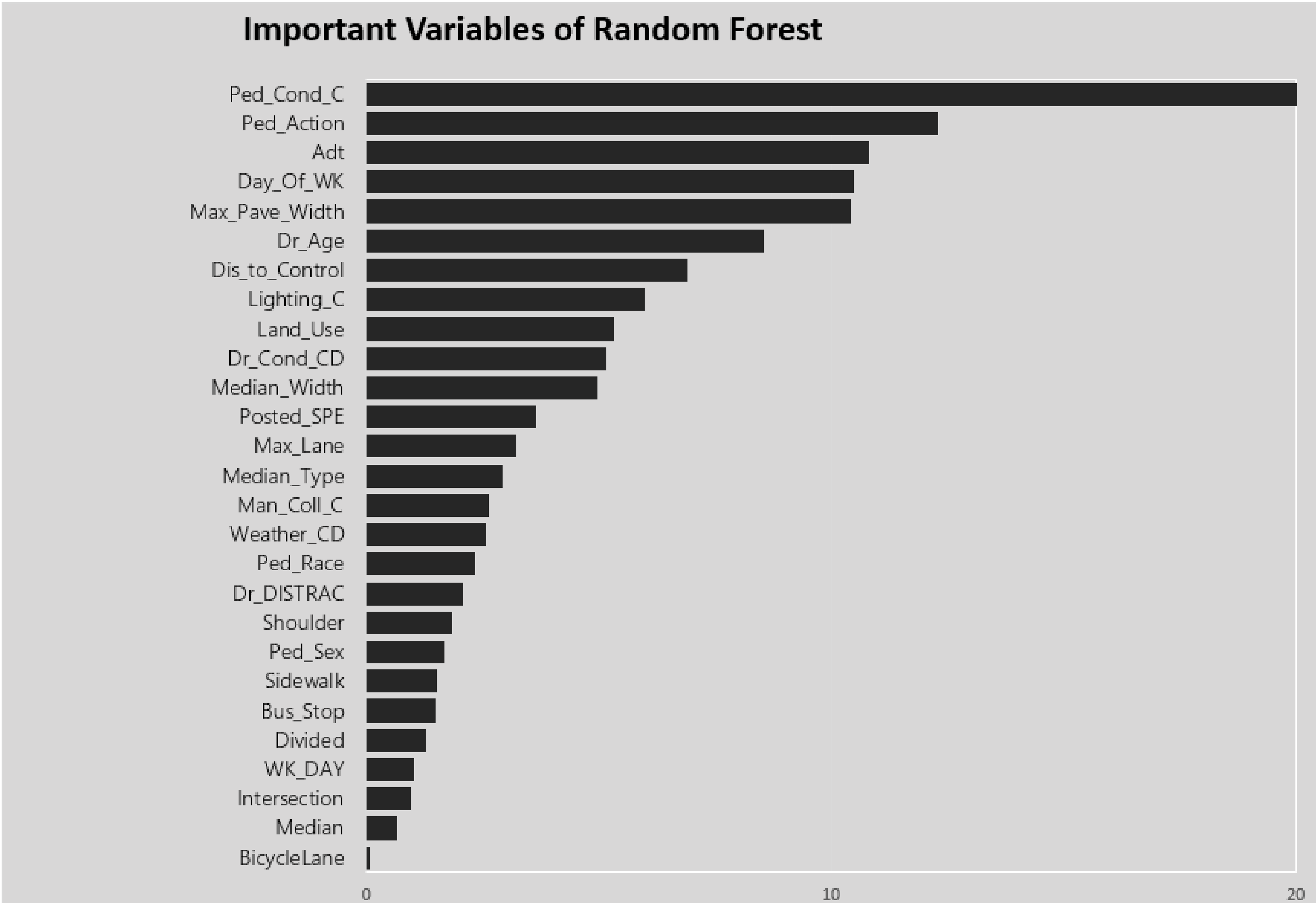


Figure F3. Ranking of importance of predictors for XGBoost model

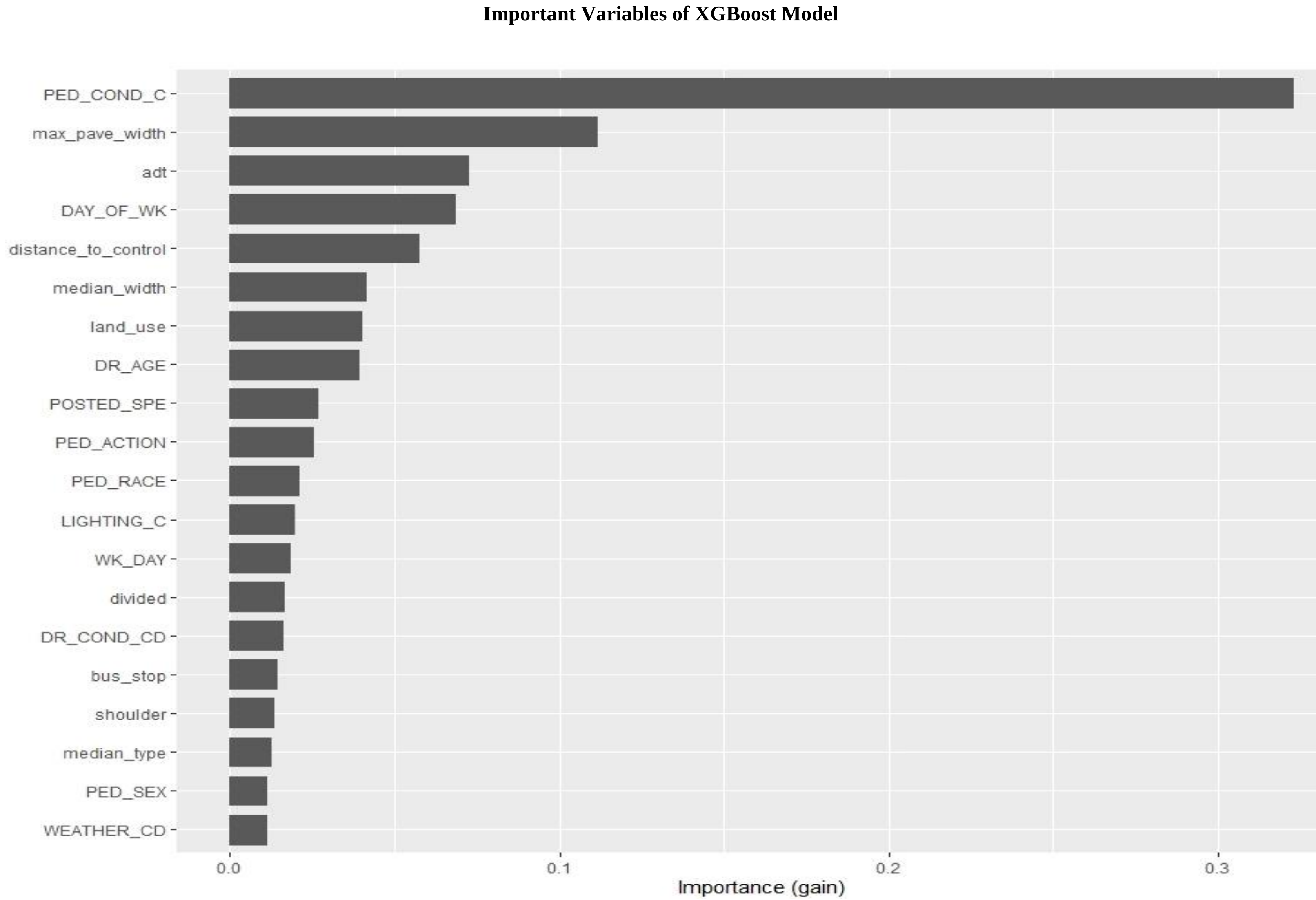


Figure F4. Dependency plots of important predictor variables from RF and XGBoost

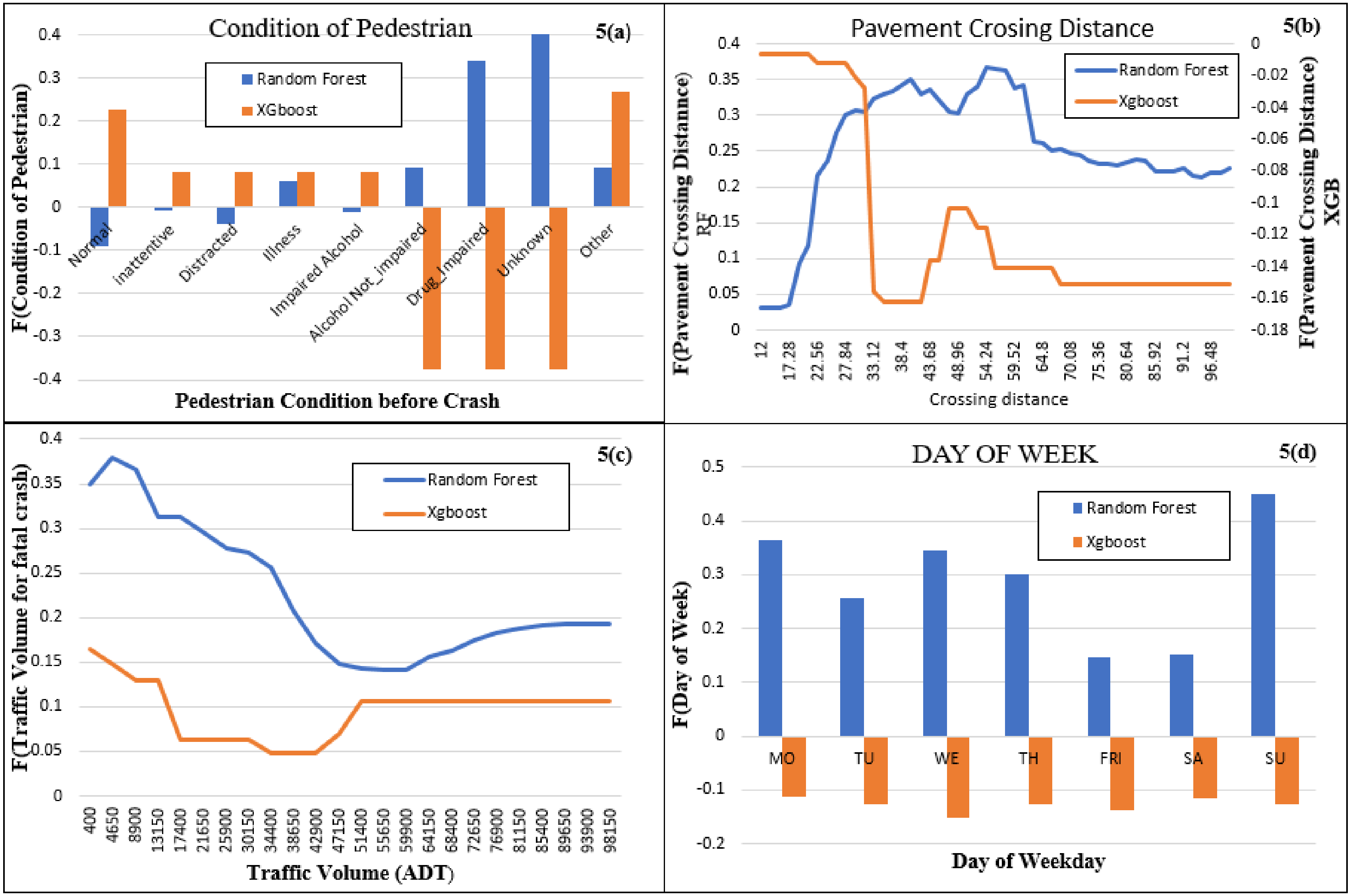
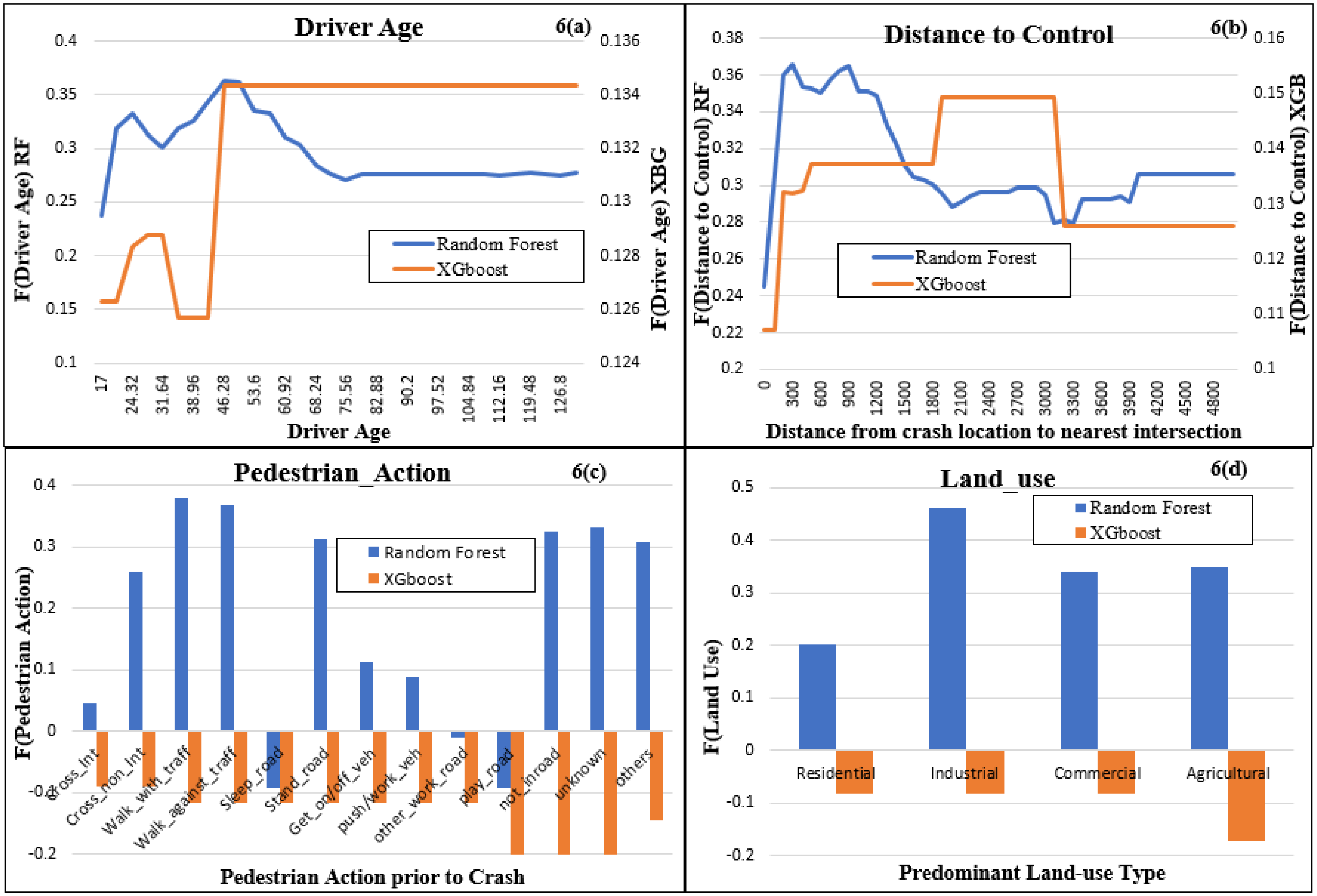


Figure F5. Dependency plots of important predictor variables from RF and XGBoost



Appendix G: LMCM Training Manual

TRAINING MANUAL FOR VERIFICATION OF PEDESTRIAN CRASH ELEMENTS FOR NON-MOTORIZED CRASH

ASSESSMENT

Select crash report number from dropdown box or provided by supervisor. Locate copy of crash report and read narrative found on the last page of the report. Use the narrative as your first source of information to verify any data elements. If checking data elements not included in the narrative, use the additional officer coded elements. When circumstances are not clear, defer first to narrative then to crash report elements. Do not override officer elements with "unknown" Note any assumptions or discrepancies in the Column AA "Notes".

A. Mgmt.- crash report status in spreadsheet, automatically populates based on columns filled.

Done	= information completes for selected row
Finish	= information incomplete for selected row

B. Crash Number- enter crash number as it appears on tracking sheet, verify on crash report. Copy the crash number into Column B for each line needed per report.

C. Prefix- one for each CRASH, one for each DRIVER and one for each PEDESTRIAN involved in the crash; determines elements to code for each level.

CRASH = CRASH level elements

DR = DRIVER level elements

PED = PEDESTRIAN level elements

D. Vehicle or Pedestrian Number (Unit Serial) – sequential by person type, code one line for each DRIVER/PEDESTRIAN involved in the crash. Enter the drivers/pedestrians in the order listed on the crash report, found in the upper left-hand corner of the first driver/pedestrian page.

For example, if there are 2 cars and 3 pedestrians involved in the crash, Columns B:D will contain the following:

CRASH NUMBER	PREFIX	Unit Serial
12345678915	CRASH	
12345678915	DR	1
12345678915	DR	2
12345678915	PED	1
12345678915	PED	2
12345678915	PED	3

E. Crash Date – Enter date of crash MM/DD/YYYY, CRASH-level only.

F. Crash Time – Enter time of crash as reported by officer, CRASH-level only. If officer indicates crash time is unknown, leave Column F blank.

G. Lighting Code – CRASH-level element only

A = daylight	E = dusk
B = dark– no streetlights	F = dawn
C = dark–continuous street light	Y = unknown
D = dark–street light at intersection only	Z = other

H. Hit and Run – true or false value for DRIVER-level only, must fill out for each driver.

I. Vehicle Configuration – Code the letter corresponding to the vehicle type below for each DRIVER.

VEHICLE CONFIGURATION						
A PASSENGER CAR	D A, B, C, OR S WITH TRAILER	G OFF-ROAD VEHICLE	J BUS W/SEATS FOR 9 -15 OCCUPANTS	M SINGLE UNIT TRUCK W/ 3 AXLES OR MORE	Q TRACTOR SEMI-TRAILER	T FARM EQUIPMENT
B LT. TRUCK (P.U., ETC.)	E MOTORCYCLE	H EMERGENCY VEHICLE IN USE	K BUS W/SEATS FOR 16 OR MORE OCC.	N TRUCK/ TRAILER	R TRUCK DOUBLE	V MOTOR HOME
C VAN	F PEDALCYCLE	I SCHOOL BUS	L SINGLE UNIT TRUCK W/ 2 AXLES	P TRUCK/ TRACTOR	S SUV	Z OTHER

J. Driver Distraction – DRIVER-level only, one for each DRIVER based on narrative.

A= cell phone

B= other electronic device (GPS, etc.)

C= other inside the vehicle (food, passenger, etc.)

D = other outside the vehicle (animal, sign, etc.)

E = not distracted

Y = unknown

K. Movement Prior to Crash (vehicle) – code for each DRIVER, if multiple, apply code in prioritized order below. If movement prior is "R=properly parked" and vehicle is otherwise unoccupied, no additional DRIVER level elements (Column N through Column V) do not need to be coded.

C = traveling wrong way

G = ran off road (not while making turn at intersection

F = crossed center line into opposing lane

H = changing lanes on multi-lane road

D = backing

E = crossed median into opposing lane

S = parking maneuver

K = stopped, preparing to, or making U-turn

I = making left turn

J = making right turn

L = making turn, direction unknown

W = entering traffic from private lane or driveway

T = entering traffic from shoulder

U = entering traffic from median

V = entering traffic from parking lane

M = stopped, preparing to turn left

N = stopped, preparing to turn right

O = slowing to make left turn

P = slowing to make right turn

Q = slowing to stop

R = properly parked

A = stopped

B = proceeding straight ahead

X = entering freeway from on ramp

Y = leaving freeway via off ramp
Z = other or unknown

L. Driver Vision Obscurement – code one element per DRIVER

A= rain, snow, etc. on windshield
B= windshield otherwise obscured
C= vision obscured by load
D= trees, bushes, etc.
E= building
F = embankment
G= sign boards
H= hillcrest
I = parked vehicles
J = moving vehicles
K = blinded by headlights
L = blinded by sunglare
M = distracted by neon lights in field of view
N = no obscurement
Y = unknown
Z = other

M. Posted Speed (vehicle) – DRIVER level only, coded for each driver, must be multiple of 5. Code posted speed as listed or stated according to officer. If not listed as a multiple of 5, or indicated unknown or blank, leave Column O blank.

N. Pedestrian or Driver Age – code age of each individual involved if unknown code 200. If birthday is included in the narrative, use date to verify age listed.

O. Pedestrian or Driver Sex – code female (F) or male (M) for each individual involved, if unknown or non-binary – leave blank

P. Condition of Pedestrian or Driver – code for each individual involved in crash.

A= normal
B= inattentive
C= distracted
D= illness
E = fatigued
F = apparently asleep/blackout
G = drinking alcohol – impaired
H = drinking alcohol – not impaired
I = drug use – impaired
J = drug use – not impaired
K = physical impairment (eyes, ears, limbs)
Y = unknown
Z = other

Q. Person Substance Suspected – code for each individual involved in crash based on police officer coding and on-scene assessment. Use narrative description to code when available.

A= neither alcohol nor drugs present
B= yes (alcohol present)
C = yes (drugs present)
D = yes (alcohol & drugs present)
Y = unknown

R. Person Alcohol Test Status

A= test refused	C = test given, results pending
B = no test given	D = test given, BAC

S. Person BAC Result- as number from 0.01 to 0.75, if available. Note if results are pending and not included in report in column AC.

T. Injury – person level injury code for each DRIVER or PEDESTRIAN involved in crash.

A = fatal	D = possible injury
B = suspected serious injury	E = no apparent injury
C = suspected minor injury	

U. Pedestrian Action – code for each PEDESTRIAN, based on narrative/officer coding.

A = crossing, entering road at intersection	H = pushing, working on vehicle in road
B = crossing, entering road not at intersection	I = other working in roadway
C = walking in road – with traffic	J = playing in roadway
D = walking in road – against traffic	K = not in roadway
E = sleeping in roadway	Y = unknown
F = standing in roadway	Z = other
G = getting on or off other vehicle	

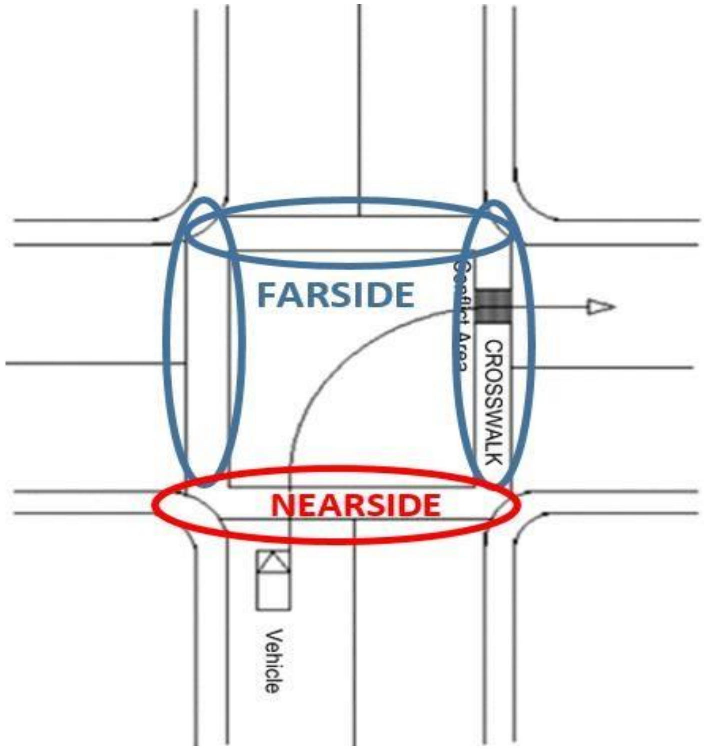
V. Person Type – code for each PEDESTRIAN, based on narrative.

04 = Occupant of non-motorized	08 = personal conveyance (scooter, wheelchair, etc.)
05 = pedestrian	10 = in or on building
06 = bicyclist	19 = unknown
07 = other cyclist	

W. – **Z.** Location-Movement Classification Method – code for each PEDESTRIAN, based on narrative

Main Crash Category	(W) First Part of Code	(X) Second Part of Code	(Y)Third Part of Code	(Z) Fourth Part of Code
Roadway intersection	General location I = roadway intersection	Side of intersection N = nearside, or where motorist enters intersection F = farside, or where motorist exits intersection	Motorist movement S = straight L = left-turn R = right-turn D = depart road	Pedestrian movement L = motorist's left approach O = opposite direction as motorist R= motorist's right approach S= same direction as motorist X = unknown direction Z = other
Roadway non-intersection	General location N = roadway intersection	Location on the roadway A = left-side sidewalk C = left-side shoulder or bike lane E = left-side roadway lane G = middle roadway J = right-side roadway lane L = right-side shoulder or bike lane N = right-side sidewalk	Motorist movement B = backing C = changing lanes D = depart road L = turn left P = parking maneuver R = turn right S = straight U = making U-turn W = wrong way travel Z = other	Pedestrian movement L = motorist's left approach O = opposite direction as motorist R = motorist's right approach S = same direction as motorist X = unknown direction Z = other
Driveway	General location D = driveway	Motorist movement F = forward B = backward	None	None
Other	General location O = other	Crash circumstance C = prior crash L = parking lot W = working on vehicle Z = other	None	None

Nearside/Farside Determination – Marked or unmarked crosswalk area closest to approaching vehicle is considered nearside. Beyond that marked or unmarked crosswalk space is considered farside. If position of pedestrian is unclear NOTE in Column AA description of situation.



Supporting evidence for LMCM coding may be found under DAMAGE TO VEHICLE on the second vehicle page, the distance from intersection listed on the first page of each report.

AA. Notes – please include unusual circumstances, missing data elements or information, incomplete reports, and/or any assumptions made for each crash. This information can be used to later improve data quality and identify potential coding errors.

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