TECHNICAL REPORT STANDARD PAGE

1. Title and Subtitle
Reduce Pedestrian Fatal Crashes in Louisiana by Improving Lighting Conditions

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5. Report No.
FHWA/LA.17/674

6. Report Date
September 2022

7. Performing Organization Code
LTRC Project Number: 19-2SA
SIO Number: DOTLT1000291

8. Type of Report and Period Covered
Final Report
September 2020 – May 2022

9. No. of Pages
102

10. Supplementary Notes
Conducted in Cooperation with the U.S. Department of Transportation, Federal Highway Administration

11. Distribution Statement
Unrestricted. This document is available through the National Technical Information Service, Springfield, VA 21161.

12. Key Words
Lighting; Night; Dark clothing; High-speed; Fatal

13. Abstract
Due to the stochastic nature of pedestrian crash occurrence, it is a challenge to investigate and pinpoint the exact common crash attributes. However, due to limited visibility at night, it is well accepted that pedestrians are vulnerable during that time. Thus, the nature of crashes and the effect of lighting at night should be clearly understood. The primary objective of this study is three fold – to review lighting policies/guidelines/practices in Louisiana and other states, investigate the impact of lighting conditions on pedestrian crashes, and estimate the benefit of lighting over the cost of crashes. The collected lighting policies and guidelines show that the majority of the states and cities within the United States have similar pedestrian lighting or overall streetlight policies. A total of 8,149 pedestrian crash data from 2014 to 2018 was explored. The data showed a higher fatality rate between 6 p.m. and 6 a.m. The majority of crashes occurred in urban areas; however, the fatality rate was higher in rural areas. Even in rural areas, most pedestrian fatalities occurred in dark areas without light. The statistical model at intersections and segments found that areas with low pedestrian visibility are more likely to have illumination. In addition, the data-mining model suggests that driver impairment and their physical condition (inattentive, distracted, illness, fatigued, asleep), specific pedestrian and driver age group (>64 years), and crashes occurred in locations such as interstate and open country that were associated with the daylight condition. At dark with or without lights, pedestrian alcohol/drug involvement, pedestrian walking with/against the traffic, and pedestrian dark clothing were detected as key factors leading to crashes. Additionally, pedestrians on high-speed roadways were found to be vulnerable to fatal crashes in dark lighting conditions. A Crash Modification Factor (CMF) from the clearinghouse website was used to conduct the cost-benefit analysis. It revealed a significant effect of lighting, especially in reducing fatal and severe pedestrian crashes. Overall, the result indicates the positive impact of lighting on pedestrian crashes at both intersections and segments.

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Reduce Pedestrian Fatal Crashes in Louisiana by Improving Lighting Conditions

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SIO No. DOTLT1000291

conducted for
Louisiana Department of Transportation and Development
Louisiana Transportation Research Center

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The collected lighting policies and guidelines show that the majority of the states and cities within the United States have similar pedestrian lighting or overall streetlight policies. A total of 8,149 pedestrian crash data from 2014 to 2018 was explored. The data showed a higher fatality rate between 6 p.m. and 6 a.m. The majority of crashes occurred in urban areas; however, the fatality rate was higher in rural areas. Even in rural areas, most pedestrian fatalities occurred in dark areas without light. The statistical model at intersections and segments found that areas with low pedestrian visibility are more likely to have illumination. In addition, the data mining model suggests that driver impairment and their physical condition (inattentive, distracted, illness, fatigued, asleep), specific pedestrian and driver age group (>64 years), and crashes occurred in locations such as interstate and open country that were associated with the daylight condition. At dark with or without lights, pedestrian alcohol/drug involvement, pedestrian walking with/against the traffic, and dark pedestrian clothing were detected as key factors leading to crashes. Additionally, pedestrians on high-speed roadways were found to be vulnerable to fatal crashes in dark lighting conditions. A Crash Modification Factor (CMF) from the clearinghouse website was used to conduct the cost-benefit analysis. It revealed a significant effect of lighting, especially in reducing fatal and severe pedestrian crashes. Overall, the result indicates the positive impact of lighting on pedestrian crashes at both intersections and segments.

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 acknowledges the assistance from Lafayette Utility System for providing the cost estimates on streetlight, Project Review Committee (PRC) members for their valuable feedback, and all other personnel involved during the course of this project, including all students involved in the project.

Implementation Statement

By reviewing the lighting policies and guidelines within and outside the state, the majority of the states and cities within the United States have similar pedestrian lighting or overall streetlight policies. The data exploration revealed key information on the effect of lighting on pedestrian crashes. The pedestrian fatality rate was significantly higher during the night, and most of them were in rural areas in the dark with no light. The findings from the data mining model can be used to prioritize the locations for providing pedestrian lighting. Overall, the study provides a deeper and more comprehensive understanding of several pedestrian crash contributing factors at night and the effect of lighting on it. The findings from this study can be used by stakeholders, especially during roadway safety assessments. The findings also provide some key information to support Louisiana's vision of Destination Zero Deaths.

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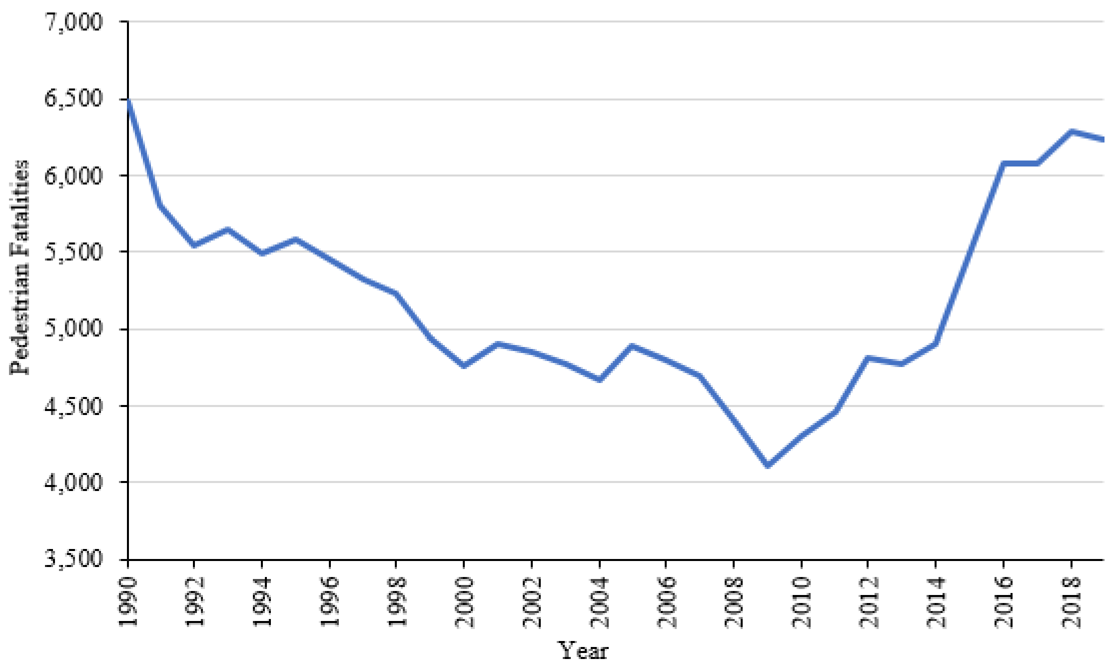
Introduction

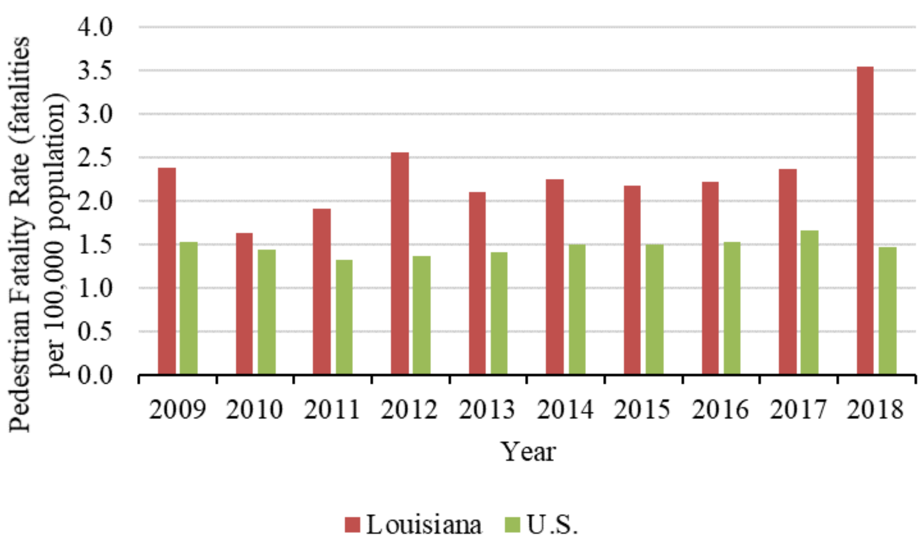
The National Center for Statistics and Analysis (NCSA) defines a pedestrian as any person on foot, walking, running, jogging, hiking, sitting, or lying down who is involved in a motor vehicle crash or event [1]. Pedestrians are considered the most vulnerable road users of the highway transportation system. While encouraging "Green Transportation" (i.e., any means of travel that does not negatively impact the environment [2]), a concerning fact emerges in the United States that pedestrian fatalities have increased drastically during recent years. According to the National Highway Traffic Safety Administration (NHTSA) Traffic Safety Facts, in 2018, there were 6,283 pedestrian fatalities across the United States. That is more than 17 pedestrian deaths every day, which represents the highest annual record of pedestrian fatalities since 1990 as shown in Figure 1 [3]. Though the total traffic deaths decreased by 2.4% from 2017, the pedestrian fatalities increased by 3.4% at the same time. The year 2018 was the fifth consecutive year in which pedestrians accounted for 15% or higher of the total traffic fatalities.

Figure 1. Pedestrian fatalities by year at the national level (1990-2019)



Pedestrian safety has been a long-standing problem in Louisiana. Although the total traffic deaths have declined significantly over 10 years (2009–2018), the progress within the state in reducing pedestrian fatalities has been much less significant than that for total traffic fatalities. The pedestrian fatalities in the state made up 23% of all traffic deaths in 2018 [3]. A total of 15,384 pedestrian crashes were reported to the police during the 10-year period of which 1,119, or 7.3%, were fatal crashes. Louisiana experiences a significantly higher pedestrian fatality rate (fatalities per 100,000 population) than the national average, as illustrated in Figure 2. The state has been identified as one of the most dangerous states for pedestrians [4]. According to the Fatality Analysis Reporting System (FARS) 2018 database, the state is ranked eleventh in the United States considering pedestrian fatalities per 100,000 population.

Figure 2. Pedestrian fatalities rate (per 100,000 population) in Louisiana and U.S. average (2009-2018)



One of the most dominant factors behind pedestrian crashes is visibility, especially at night. Visibility of the road from the driver's seat is significantly reduced at night, dusk or dawn, fog, and other heavy weather conditions. The vehicle's standard low headlight illuminates the road, no more than 500 ft. at night [5]. This distance is not always enough for the pedestrian or bicyclist to be seen in time by driver. During bad weather and darkness, the driver's sight distance often drops below 500 ft., which is less than the area lightened by the vehicle headlights (low beams). According to NHTSA, around 75% of pedestrian fatalities occurred under dark conditions [6]. During the 10 years (2009–2018), about 47% of pedestrian fatalities in Louisiana occurred between 6:00 p.m. and 12:00 a.m., and 28% between 12:00 a.m. and 6:00 a.m. Between 2009 and 2018, approximately 90% of the rise in pedestrian deaths occurred in the dark [7]. The growing prevalence of nighttime pedestrian crashes heightens prioritizing countermeasures to improve pedestrian safety at night.

To mitigate the impact of traffic on pedestrian crashes, various countermeasures are recommended. In the Federal Highway Administration’s (FHWA) list of 28 proven safety countermeasures, the following pedestrian safety countermeasures are promoted: leading pedestrian intervals, medians, pedestrian crossing islands in urban and suburban areas, crosswalk visibility enhancement, pedestrian hybrid beacons, rectangular rapid flashing beacons, road diets, and walkways [8]. The FHWA Every Day Counts (EDC) – Safe Transportation for Every Pedestrian (STEP) promotes countermeasures like crosswalk visibility enhancements, raised crosswalks, pedestrian refuge islands, pedestrian hybrid beacons, and road diets to reduce pedestrian crash rates [9]. As a part of the program, STEP recommended using countermeasures to improve nighttime lighting, high-visibility crosswalk marking, parking restrictions, advance stop or yield markings and signs, in-street stop or yield signs, and curb extensions.

To achieve Louisiana’s Destination Zero Deaths, it is necessary to reduce the fatalities and prevent further pedestrian crashes, especially at night. Therefore, it is crucial to understand the factors that contribute to pedestrian crashes, investigate the relationship between lighting conditions and pedestrian crashes, and the effectiveness of lighting in improving pedestrian safety.

Literature Review

The literature review is discussed in three sections: general guidelines and standards of lighting, the next on the effect of lighting on pedestrian crashes, and a short section on different data analytical methodologies frequently used by previous studies. The purpose of this whole section is to learn as much as possible from the past and ongoing practices.

Information on Roadway Lighting

Standards of Roadway Lighting in the USA and Europe

The quantitative recommendations for proper level (luminance value), color, and distribution of roadway lighting are provided in different consensus documents developed by a panel of experts [10]–[12]. According to the FHWA lighting handbook (2012), roadway lighting is a proven safety countermeasure that can reduce nighttime crashes, especially fatal and severe injury crashes [13]. AASHTO Highway Safety Manual (2010) reports a CMF value of 0.72 for highway lighting, which indicates a 28% reduction in nighttime injury crashes [14]. There are several design criteria for roadway lighting. Gibbons et al. (2014) documented three design criteria for roadway lighting as H (pedestrians generally not present), S (pedestrians normally present), and P (safety and security of pedestrians and not specifically for the drivers) [15]. Likewise, the European standard recommends three basic sets (M, C, and P) of design criteria [16]. Table 1 summarizes lighting design categories for both the United States and European standards.

Table 1. Lighting class with recommended areas (Source: [15] **and** [16]**)**

Standard	Lighting Class	Recommended areas
U.S.	H	Roadway lighting
	S	Street lighting
	P	Residential/Pedestrian areas lighting
European	M	Motorized traffic
	C	Conflict areas
	P	Pedestrian and low-speed areas

In 1995, the International Commission on Illumination (CIE) recommended six lighting categories for pedestrians with an average value of horizontal illuminance ranging from 1.5 lux to 20 lux [17]. Later in 2003, European standards recommended similar six lighting classes with a different range (2 to 15 lux) of illuminance for pedestrians [16]. In 2014, a report published by FHWA recommended five lighting classes with an average illuminance values ranging from 2 to 10 lux for pedestrians [15]. Table 2 summarizes lighting levels recommended for pedestrians based on FHWA and European standards. Letter ‘P’ in the table indicates the pedestrian lighting class. For example, class P1 needs more lighting and P6 the least.

Table 2. FHWA and European Standard of Lighting Class

FHWA Standard [15]		**European Standard** [16]	
Lighting Class	Average Illuminance (lux)	Lighting Class	Average Illuminance (lux)
P1	10	P1	15
P2	5	P2	10
P3	4	P3	7.5
P4	3	P4	5
P5	2	P5	3
–	–	P6	2

Guidelines for Lighting at Pedestrian Crossings

The FHWA report published in 2008 recommends the placement of on-crosswalk lighting with luminaire for both-way traffic on roadways without a median. Based on the report, the lighting should be located 10 ft. from the crosswalk with the capacity of 20 vertical lux to make the pedestrian visible [18]. Another FHWA report published in 2018 suggests placing streetlights 10 to 15 ft. in advance of the crosswalk in both directions to enhance the lighting in front of the pedestrian and avoid silhouette lighting [19].

AASHTO (2004) recommends lighting at the intersections and pedestrian crosswalks during dusk and nighttime. The report recommends providing a uniform distribution of light along wide arterials with sidewalks [20]. The roadway lighting design guide by AASHTO (2005) highlighted that a positive contrast for pedestrians should be considered during the design of intersections by providing lighting in advance of the crosswalk [21].

Especially at roundabout locations, the lighting should be placed 1 to 30 ft. before the crosswalk to increase the background's positive contrast [22]. The NCHRP report (2010) on roundabouts recommends providing adequate lighting for pedestrians and cyclists at those locations [23]. The *FHWA Handbook for Designing Roadways for the Aging Population* (2014) suggests installing fixed lighting at intersections, especially with potential wrong-way movements and high nighttime pedestrian volumes [24].

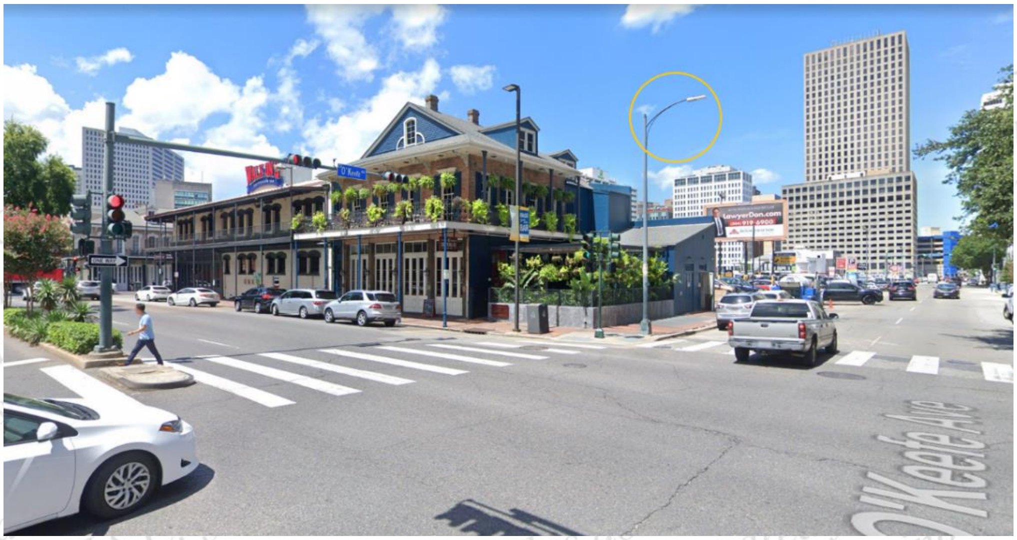
The FHWA (2014) also has specific guidelines for installing adaptive lighting systems for roadway lighting. The selection of the level of the illuminance of the streetlight is based on the peak hour pedestrian counts and the type of roadway (major, collector, and local). The area can be classified as high, medium, and low depending on the peak pedestrian count. Pedestrian volume greater than 100 is classified as high volume, between 10 and 100 as medium volume, and less than 10 as low volume [15]. The recommendation of average luminance based on roadway type and pedestrian volume is provided in Table 3.

Table 3. Recommended average luminance for roadway type and pedestrian volume (Source: [15])

Type of Road	Pedestrian Area Classification	Average Luminance (cd/m^2)
Major	High	1.2
	Medium	0.9
	Low	0.8
Collector	High	0.8
	Medium	0.6
	Low	0.4
Local	High	0.6
	Medium	0.5
	Low	0.3

The table shows that roadways in higher hierarchies need more luminance. For example, a major roadway with a low pedestrian area needs more illuminance than a local route with a high pedestrian area. Figure 3 shows an example of a streetlight over the pedestrian crosswalk at O'Keefe Avenue, New Orleans, Louisiana (29.950452, -90.074242).

Figure 3. Streetlight over pedestrian crosswalk (Source: Google Maps)



Street Lighting Policies/Guideline/Practice in Louisiana

Regarding lighting guidelines within the state, the Louisiana Division of Administration (DOA) provides Louisiana Administrative Codes (LAC) that must be formally adopted by Louisiana's state agencies. Specific requirements for lighting in state highways fall under title 70 (Transportation and Development) of LAC, which was last amended in December 2020 [25]. A few of the streetlight requirements and guidelines are as follows:

- The average initial illumination level shall be greater than 0.6 and less than 0.8 foot candles
- The ratio of average initial illumination to minimum initial illumination at any point on the roadway shall not be greater than 4:1
- Veiling Luminance Ratio (Glare) shall not exceed 0.3:1
- Minimum mounting heights for the luminaire shall be 30 ft.
- Light poles shall be manufactured from steel, aluminum, fiberglass, or other corrosion-resistant materials
- Light with high-pressure sodium (HPS) and induction
- Light poles within 40 ft. of the roadway shall conform to AASHTO criteria for breakaway supports
- Light poles shall not be located within 15 ft. from the edge of the traveled lane except when the posted speed limit is below 40 mph

To mention the sources of light, DOTD recommended the use of high-pressure sodium (HPS), metal halide (MH), induction, and light-emitting diode (LED) for state highways [26]. It also recommends a maximum color temperature of 4000K (K for Kelvin) for LED and induction lights. For lighting design and construction on interstate highways, it must be warranted by DOTD and FHWA policies.

Street Lighting Policy in Few Cities within Louisiana

In addition, various cities within the state also have their own lighting policies. The study chose a few major cities within the state and sent an email to the department of concern requesting a copy of their lighting policies. Table 4 summarizes the lighting policy/guidelines for some of the cities within the state. The project team did not receive any such lighting policies from the majority of the cities. Thus, most of the information in the table was extracted from different web sources as some of the cities have their policies directly available online. The study did not include information from a few major cities, as no such information on lighting policies was available publicly.

Table 4. Lighting policy in a few cities within Louisiana

City	Lighting Policy	Source
Lafayette	Residential areas • Lamps on vertical, round, tapered black, aluminum, or fiberglass poles. • High-pressure sodium lamps with 70 watts. • The mounting height of the pole shall be 23 ft. maximum.	[27]
	Non-residential areas • Lamps on round tapered steel poles, black in color, with mast arm. • Archetype fixtures with high-pressure sodium lamps. • The mounting height shall not exceed 40 ft.	
Bossier City	• The light source shall be high-pressure sodium or metal halide lamps. • Streetlights shall be located at all street intersections and on the right-of-way spaced not to exceed 300-ft. intervals.	[28]
Monroe	• Pedestrian scale lighting shall define pedestrian crosswalks, connections, bicycle parking, and other pedestrians/bicycle areas within the development. • Pedestrian-scale lighting shall be a maximum of 14 ft. in height. • All lighting shall be shielded from the sky and adjacent properties and structures, whether through exterior shields or optics within the fixture.	[29]

City	Lighting Policy	Source
Lake Charles	• Lighting shall be 100-watt high-pressure sodium bulbs with a metal pole. • Lights shall be spaced at 180 ft. measured along with the road plus or minus 20 ft. • Layout shall incorporate lights at all intersections. • In cases where spacing cannot be achieved with an intersection, 250-watt bulbs may be specified.	[30]
Baton Rouge	• The height of the light pole shall be 30 ft. maximum. • Lamp Lumens shall be 250-watt equivalent. The equivalent shall meet the nominal delivered lumens while reducing the wattage by a minimum of 50%. • Electrical Service shall be 120/240 volts, single phase, center grounded. 480 volts acceptable at interstate interchanges only.	[31]
Hammond	• Standard wattage shall be a 175-watt metal halide or 150-watt high-pressure sodium and 120 or 240 volts. • Bulbs shall be encased in an approved deflector head to direct light downward. • There shall be one standard lighting installed at each intersection, and the spacing of standards shall not exceed 150 ft. and shall not be less than 100 ft. • All lighting shall be shielded to direct light downward only. • Aluminum or fiberglass street light standards shall be approximately 25-30 ft. in length and shall be furnished with pole cap, anchor base bottom, and designed for mounting on a concrete base with anchor bolts.	[32]

When this study sent emails to major cities requesting lighting policies, the study also requested information on pedestrian lighting data. Based on the response, either the cities do not have such a database for pedestrian lighting or general street lighting, or the database is managed by a third party, especially a private company. Few of them responded with no such policies within their agencies. However, the City of Baton Rouge and the City of New Orleans have a streetlight database that can be openly accessed on their city web page, which the study used during the site selection.

Louisiana Statewide Bicycle and Pedestrian Master Plan

Louisiana has its statewide “Bicycle and Pedestrian Master Plan” published in 2009 [33]. Some agencies within the state developed their own plan following the Louisiana statewide “Bicycle and Pedestrian Master Plan”. The “Bicycle and Pedestrian Master Plan” developed by the City of Lake Charles recommends safety devices such as marked intersection crossings, lighting, and pedestrian signals to improve intersection safety [34].

Similarly, the “Bicycle and Pedestrian Master Plan” in East Baton Rouge Parish includes a unified development code (UDC) that proposes the appropriate contextual and lighting considerations within the parish [35]. The Regional Planning Commission (RPC) of the City of New Orleans published the “Metropolitan Bicycle and Pedestrian Plan” in September 2006, addressing specified goals for cyclists and pedestrians [36]. The report suggested strategies to improve the sight distance and visibility for motor vehicles and pedestrians. Some of these proven strategies are providing crosswalk enhancement and implementation of lighting and crosswalk illumination measures. Lafayette Metropolitan Planning Organization (MPO) developed the 2035 Pedestrian Plan published in 2010. This plan was designed to improve, prioritize, and balance standards that result in a good pedestrian environment [37]. The City of Shreveport has developed a unified development code (UDC), and this report recommends a maximum luminaire mounting height of 25 ft. with a provision of 0.2 foot candles (minimum) at the centerline of the street and a uniformity ratio of 4 to 1 (average to a minimum) [38].

Lighting Policies/Guidelines/Practices in Other States

In addition, the study collected information on intersection/crosswalk lighting guidelines from several other states and summarized them in Table 5. All the information was collected from a report published by the National Cooperative Highway Research Program (NCHRP) [39].

Table 5. Lighting installation guidelines

State	Lighting Guidelines
Texas	• Safety lighting-complete interchange/intersection lighting. • Started using LED luminaires in 2010. • Light poles should have an offset of at least 2.5 ft. from the curb face. • Average maintained illuminance: 2.0. • Illuminance emittance ratio 3:1.
New York	• High-pressure sodium (HPS) lamps. • Desirable length of the pole to under 16.75 m, where sidewalks are present or proposed, poles should be placed to allow continuous passage. • Installation of highway lighting is based on the facility type, accident rates, and traffic volumes.

State	Lighting Guidelines
Delaware	• No less than 5 ft. from the shoulder, not blocking the sidewalk. • Luminaires at least two lighting units poles, not placed on channelizing islands, medians if applicable. • 0.8 foot-candle. • A light pole should be located at 10 to 30 ft. before the crosswalk.
Arizona	• High-pressure sodium (HPS) light sources. • Pedestrian level light can be provided by poles shorter than streetlights (10 to 15 ft.; 3m to 4.6m) or by bollard lights. • Provide a minimum of 1 foot-candle of light from grade to 5 ft. (1.5m) above the walking surface.
New Jersey	• The minimum average maintained illuminance within the crosswalk area shall be between 1.2 foot-candles and 2.0 foot-candles. • Luminaires shall be placed approximately 10 ft. before the edge of the crosswalk in the direction of travel.
Kansas	• The typical standard pole height is 40 ft. (vs. 25-49 ft. in the U.S.). • Mast arm length for standard poles is often 15 ft. • The distance to the luminaire is no further than 6 ft. from the edge of the nearest traffic lane in the curb and gutter section, or 2 ft. from the shoulder
Minnesota	• The level of illumination at an intersection should be 1.0 greater than that between intersections with continuous lighting (1.5 m) above the walking surface. • DOT recommends that the illumination levels of conventional intersections should be approximately 1 foot-candle greater than that between intersections where there is continuous lighting.
Colorado	• Pedestrian luminaire mounting height: 10-15 ft. • A mounting height of 12 ft. is most common. • Spacing: Begin with a 5:1 spacing to mounting height ratio. Modify accordingly to meet lighting criteria and other critical design issues. • Pedestrian luminaires adjacent to residential properties should be shielded to minimize light trespass and glare.
Illinois	• Typical mounting heights for conventional highway lighting purposes range from 30 ft. to 55 ft. (9.1 m to 16.8 m). • Typical parameters for conventional lighting (interstate) are aluminum or steel pole, single or twin-arm mounting, and 45 ft. to 55 ft. (13.7 m to 16.8 m) mounting height. • LED Horizontal Mount Luminaire.

Lighting Policies/Guideline/Practices in Few Other Cities Outside Louisiana

To provide additional information on lighting policies from other pedestrian-friendly major cities, the study used online resources and explored such required information in detail, as shown in Table 6. The majority of the information was readily available on their webpage.

Table 6. Lighting guidelines in big cities

City	Guidelines	Source
Seattle, WA	• Mounting height 12-14 ft. • Spacing should be less than roadway streetlights space. • Light directed to the sidewalk. • It can be used alone or as a combination with the roadway. • At intersections, the streetlight should be located 10 ft. from the crosswalk. • Lighting should be located on the approach side at the midblock locations.	[40]
Lewiston, ME	• Streetlights shall be mounted on existing or future utility poles or light poles. • The height of the streetlight depends on the roadway type. • The height of the streetlight shall be based on the Illuminating Engineering Society (IES) Roadway Standard. • The streetlights shall be of the semi-cutoff type to reduce the glare and sky illumination.	[41]
Grand Chute, WI	• The illumination type is to be high-pressure sodium (HPS) or LED. • Streetlight shall be placed at all intersections and curves of at least a 45-degree deflection angle (Level 1). • The typical height of the street lighting poles shall be 30 ft. minimum (Level 2). • Spacing (225-300) ft. between fixtures (Level 2). • Spacing between 200-300 ft., and it shall consist of a smooth fiberglass pole with an acorn style fixture (Level 3). • The typical height shall be 15 ft. (Level 3). • 12 to 15-foot decorative pole with a full cutoff fixture at a spacing of 100 to 125 ft. (Level T). *Level depends on materials used to build lighting poles. For example, level 1 for wooden poles, level 2 for aluminum or fiberglass poles, level 3 for smooth fiberglass poles, and level T for decorative poles.	[42]
Minneapolis, MN	• Light intensity at the pedestrian areas shall be 0.8-1.2 foot-candle. • The uniformity ratio at pedestrian areas shall be 3 to 1 maximum. • Glare (Veiling Luminance) at pedestrian areas shall be 0.3 to 1 max. • Lights should be installed staggered or soldiered.	[43]
Sacramento County, CA	• Intersections shall have a minimum of one streetlight. • Streetlights shall be placed at both ends of pedestrian lanes	[44]

City	Guidelines	Source
Denver, CO	• The light source shall be high-pressure sodium, Metal Halide, or LED. • At high pedestrian activity areas, the spacing between streetlights shall be 150-200 ft. with a typical pole height of 30-40 ft. • In pedestrian areas, pedestrian lights should be located at a minimum of 30 ft. from an adjacent streetlight.	[45]

Effect of Lighting Condition on Pedestrian Crashes

Effect of Lighting at Pedestrian Crosswalks

Bullough and Skinner (2015) studied the potential of bollard crosswalk luminaires controlled by pedestrian activation. The study found that the bollard lighting system has the potential to enhance the visibility of pedestrians at crosswalk locations with relatively low glare-free light levels. Based on field investigation, the authors identified the performance specification of the bollard crosswalk lighting system. The study recommended a vertical illuminance value of a minimum of 10 lux from a height of 3 ft. above the ground and a maximum of 1 lux from a height of 5 ft. above the ground along the length of the crosswalk [46].

Nambisan et al. (2009) evaluated the effect of using smart lighting systems at midblock locations with an automatic pedestrian detector. The smart lighting system provides high-intensity light to notify the drivers when the sensor detects a pedestrian. The data were collected weekly during the morning and evening peak hours using three weeks of before-after study. This study revealed a 13 percent increase in drivers' yielding to pedestrians and a significant increase in pedestrians' observational behavior [47].

Gibbons et al. (2006) investigated the level of lighting required to identify the pedestrians at the crosswalk locations correctly. The study evaluated different illumination levels in the range of 5 to 60 vertical lux on pedestrian safety. Few significant variables included in the study were glare level, lamp type, and pedestrian clothing. The results indicated that 20 vertical lux could be adequate to correctly identify the pedestrian on the crosswalk. Also, the study found that type of lamp had no significant effect on identifying the pedestrian and the white clothing had the least influence by the changes in the lighting designs. However, the study had limitations because of the static status of the pedestrian. Thus, the authors suggested the movement of the pedestrian may improve the visibility of the pedestrian [48]. Figure 4 shows pedestrian crosswalks with and without streetlights around the university area in Lafayette.

Figure 4. Streetlight over pedestrian crosswalk (Source: Ahmed Hossain, University of Louisiana at Lafayette)

(a) Pedestrian crosswalk without streetlight (b) Pedestrian crosswalk with streetlight

Safety Benefits of Street Lighting on Pedestrian Crashes

The International Commission on Illumination designates a few primary purposes of street lighting — to permit all road users to proceed safely, allow pedestrians to see exposures, and provide a sense of safety [10]. Lighting condition plays a vital role in pedestrian injury severity. According to the FARS database, in 2018, 76% of pedestrian fatalities occurred in dark lighting conditions, which is the highest percentage between 2009 and 2018 [49]. Previous literature also revealed that fatal pedestrian crashes are more likely to occur during nighttime and non-fatal pedestrian crashes are more likely to occur during the daytime [50]. Studies have already found lighting can reduce pedestrian crashes at night by approximately 50% [51], [52]. Sullivan and Flannagan (2002) estimated the influence of ambient lighting levels on fatal pedestrian and vehicle crashes, and identified that the pedestrians are 3 to 6.75 times more vulnerable in the dark lighting condition than in daylight, depending on other circumstances [53].

Lighting along the streets, especially at crosswalks, increases visibility and improves pedestrian safety. Better street lighting can increase the visualization and attentiveness of the drivers, leading to a reduction in nighttime pedestrian crashes [54], [55]. Kim et al. (2010) evaluated pedestrian injury severity in pedestrian-vehicle crashes using crash data (1997–2000) from North Carolina. They reported that dark without streetlights increases the probability of pedestrian fatality by 400%, but the scenario could be different based on other factors [56]. Kim and Ulfarsson (2019) found that older pedestrians (age 65+)

are less likely to be involved in crashes compared to young-adult pedestrians (age 18–59) during dark with or without streetlights [57]. Another study by Zhang et al. (2016) explored drivers being more likely to be involved in fatigue-related crashes (odds ratio = 1.40) at night without streetlights [58]. Olszewski et al. (2015) explored various factors on pedestrian fatality risk and identified lighting conditions as the primary distinguishing factor in crash fatality. They reported that pedestrians are 4.1 times more likely to be hit in the darkness (no streetlight) than in daylight conditions [59].

Isebrand et al. (2006) evaluated the effect of street lighting on 34 rural intersections in Minnesota using a before-after observation. Their results showed a 41% reduction in late night and early morning crashes [60]. In the same state, a study by Preston and Schoenecker (1999), utilized a before-and-after study to explore the effect of the streetlight installation on 12 different rural intersections. They found that due to the installation of streetlights, late-night single-vehicle crashes decreased by 33%, and multiple-vehicle crashes decreased by 63% [61]. In Kentucky, a study on rural and urban intersections conducted by Green et al. (2003), showed a 45% reduction in the late night and early morning crashes after installing streetlights [62].

Lipinski and Wortman (1978) studied the effect of illumination on at-grade rural intersection crashes using seven different measures at the lighted and unlighted rural intersections. They reported that the illumination resulted in a 45% reduction in the nighttime crash rate and a 22% reduction in the nighttime crash/total crash ratio [63]. Walker and Roberts (1976) did three years of before and after study to investigate the crash frequency of 47 rural at-grade intersections and found a 49% overall reduction in nighttime crashes after street light provision [64]. Elvik (1995) conducted a meta-analysis of 37 studies to evaluate the safety impact of lighting in 11 different countries and found that public lighting reduced nighttime fatal and injury crashes by 60% and 30%, respectively [51].

A report published by the FHWA identified the impact of lighting levels on the roadway functional class. The study reported a drop in crash rate from 1.5 to 0.5 for minor arterials, and 1.5 to 1.0 for the freeways as the lighting level increases [65]. Box et al. (1970) applied cross-sectional analysis to identify the impact of lighting conditions using 203 miles of lighted and unlighted urban freeways. The study found a theoretical reduction in nighttime crashes (40%) with the addition of lighting [66]. Griffith (1994) conducted a cross-sectional analysis to evaluate the effect of lighting on urban freeways in Minnesota and reported a reduction of nighttime crashes by 16% for urban freeways with continuous lighting [67].

To analyze pedestrian crash data, some of the studies focused on the time of the day variable. A report published by the New York City Department of Transportation suggests that late-night (3-6 a.m.) crashes are twice as likely to lead to a fatal crash compared to other periods [68]. Another study performed by Guerra et al. (2020) revealed that pedestrian crashes reached a peak during the morning and evening rush hours [69]. Baltes (1998) categorized five years of pedestrian crash data in Florida from 1990 to 1994 by the time of the day. [70]. The study reported that the period (4 p.m. to 7.59 p.m.) accounted for the highest percentage of pedestrian crashes (28.5%), followed by the period (12 p.m. to 3.59 p.m.), accounting for 23.2% of pedestrian crashes. Aty and Lee (2005) detected that intoxicated drivers and pedestrians are correlated to more crashes at nighttime than at daytime [71].

Pedestrian Crash Countermeasures (other than Street Lighting)

Numerous research studies have been done to improve visibility at crosswalks. A study by Rea et al. (2009) studied three different scenarios – the first was the traditional lighting placed above the crosswalk; the second was to locate the lighting 15 ft. in front of the crosswalk; and the final one was using bollard lighting as the third scenario. The study found that the bollard lighting enhanced the visibility of pedestrians with lower operating costs. The study concluded that placing the overhead lighting with a 15 ft. offset provides better pedestrian visibility [72]. According to the pedestrian safety guide and countermeasure selection system by the FHWA, the luminaire should be placed 10 ft. from the crosswalk, in between the approaching vehicles and the crosswalk [73].

George Gadiel (2014) investigated the safety effectiveness of in-pavement warning lights using a before-after study and found an increase in yielding rates at crosswalks after using in-pavement warning lights [74]. Patella et al. (2020) studied the LED lighting effect on crosswalks using in-situ speed measurements. Their results showed that using this technology led to a 19.3% reduction in the mean speed, corresponding to lower fatal crashes and serious injury risk [75]. In Iowa, a before-after study was conducted by Kannel and Jansen (2004) to evaluate the effectiveness of using in-pavement flashlights at a crosswalk. Their results showed increases in the yielding rates by motorists to pedestrians [76]. Gates et al. (2004) investigated the safety effectiveness of LED embedded in stop signs. The study estimated a 28.9% reduction in the number of vehicles not fully stopping while a 52.9% reduction in the number of vehicles moving through the intersection without significantly slowing [77]. Table 7 summarizes different countermeasures installed on the roadway to improve pedestrian safety.

Table 7. List of countermeasures to mitigate pedestrian crashes

Countermeasure	Location	Features	Source
Automatic pedestrian detection device and smart lighting	Midblock	The automatic pedestrian detection detects pedestrians and prompts increased illumination (without the need for the pedestrian to press a button)	[47]
ARMS (Active Road Marking System for Road Safety)	Embedded in pavement	The system detects pedestrians near the crosswalk zone and warns drivers by employing flashing lights embedded in the pavement.	[78]
In-pavement flashing lights	In-pavement	In-pavement lights flashes as vehicles approach the crosswalk.	[79]
In-roadway warning lights	In-roadway	The flashing lights can be activated by either a push button or a passive detection technology, such as bollards, video, or microwave sensors.	[80]
Pedestrian crosswalk warning system	Midblock	Drivers were observed to apply their brakes earlier with the flashing crosswalks.	[81]
Crosswalk illumination	Crosswalk	A Built-in 250-Watt lamp and projector provided illumination at 30 lux on the roadway surface across the crosswalk's entire length.	[82]

Brewer and Fitzpatrick (2012) conducted a before-after study to evaluate the effectiveness of Rectangular Rapid Flashing Beacons (RRFB) with school signs in Garland, Texas. The researchers concluded that compliance rates of drivers yielding to staged pedestrians improved noticeably from less than 1 percent before installation to approximately 80 percent after installing the RRFB device (shown in Figure 5) [83].

Figure 5. A crosswalk with RRFB and streetlight [83]

Contributing Factors to Pedestrian Crashes

This study explored crash contributing factors other than the lighting in this section. Overall, contributing factors to pedestrian crashes can be categorized based on traffic exposure, traffic control, design features, land use patterns, public transit features, and demographic attributes [84]. A study by Zegeer and Bushell (2012) documented a comprehensive list of factors that affect the severity of pedestrian crashes. The study categorized factors into pedestrian, driver, vehicle, demographic, and roadway/environmental factors [85]. A list of a few factors from previous research studies are provided in Table 8. The upward arrow (↑) indicates an increase in the likelihood of pedestrian crashes with those variables, while the downward arrow (↓) shows the reverse.

Table 8. List of pedestrian crash contributing factors

Contributing Factors/Variables	Examples	Study
Lighting condition	Daylight (↓), dark (↑), dusk/dawn (↑)	[86]–[88]
Pedestrian factors	Alcohol/drug impairment (↑), pedestrian distraction (↑), pedestrian with disabilities (↑), pedestrian volume and mix, pedestrian behaviors, pedestrian age, and gender, walking direction, crossing type, moving violation (↑)	[89], [90]
Driver factors	Distracted driving (↑), young/novice (↑), and older drivers (↑), speed and unsafe driving practices (↑), alcohol/drug-impaired driving (↑), driver skills, and vision, driver age and gender, driver distraction (↑), driver action (failure to yield, running a red light) (↑)	[87], [91]
Vehicle factors	Type of vehicle, vehicle speed, impact speed, vehicle volume	[92], [93]
Demographic factors	Enforcement practices, land use and zoning, public parking policies and design, travel characteristics, income, race	[84], [94]
Roadway/Environmental factors	Roadway design, midblock crossing issues, intersection geometrics, roadway lighting, weather condition, traffic and pedestrian signals, signs and markings, weather condition, location (urban/rural, near school, residential/non-residential),	[95], [96], [97]–[99]
Other factors	Day of the week, month of the year	[100]

Exploring Data Analytics Procedure

Methodologies Used for Pedestrian Crash Analysis

Several previous studies have focused on modeling pedestrian crash data [84]. Some studies utilized the linear regression model to identify the association between pedestrian crash frequency and contributing factors [101]–[103]. But a simple linear regression model may not appropriately handle nonnegative, discrete, and overdispersed crash frequency features [104]. That is the reason behind the dominant use of the negative binomial model [105]–[107], Poisson regression model [108], and Poisson lognormal model [109]–[111] in pedestrian crashes analysis, which outclasses the linear regression model. Moreover, the autoregressive model [112] and conditional autoregressive (CAR) model [94], [113]–[115] were also utilized to account for the autocorrelation of pedestrian crash data. Table 9 documented a comprehensive list of methodologies used for pedestrian crash analysis.

Table 9. List of methodologies for pedestrian crash analysis

Methodology	Studies
Multinomial logistic regression	[93], [116]–[119]
Mixed logit model	[120]–[122]
Nested logit model	[123]
Ordered probit model	[86], [124], [125]
Bivariate ordered probit model	[126]
Heteroskedastic ordered logit model	[127]
Bayesian spatial model	[109], [128]
Logistic regression, binary logistic regression, multiple logistic regression	[92], [129], [130]
Log-linear model	[98]
Other models (Neural Network, Machine learning, generalized mixed linear)	[69], [131], [132]

Roadway Locations with Frequent Pedestrian Crashes

Adequate nighttime lighting can improve pedestrian safety at a particular location [50]. Intersection pedestrian crashes at night are primarily associated with visibility [72]. In addition, the probability of pedestrian injury severity is closely associated with the lighting condition at midblock and intersection crosswalks [133]. Therefore, crosswalk lighting and flashing crosswalks can effectively improve motorists' nighttime visibility of pedestrians [134]. DiMaggio and Durkin (2002) conducted a descriptive analysis of all motor vehicle crashes in New York City over seven years (1991–1997) to identify the factors related to pedestrian injuries of children and adolescents (age less than 20 years). The study found adolescents more likely to be hit at an intersection at night, whereas younger children are more likely to be struck at mid-block locations during daylight hours [135]. Siddique et al. (2006) evaluated the associations of crossing locations and lighting conditions in the severity of pedestrian injury crashes. The study identified that the probability of pedestrian fatalities is higher at the midblock locations than at the intersection for any lighting condition when struck by a vehicle. They also reported that daylight reduces the odds of fatal injury by 75% and 83% at midblock and intersection locations, respectively [95]. It demonstrates that intersections and midblock sections are more likely to have fatal pedestrian crashes at dark compared to daylight.

Site Selection Criteria for Pedestrian Crash Analysis

The study summarized the site selection criteria that have been utilized for pedestrian crash analysis from past studies (details are provided in Table 10). It is part of a key information review, which this study used as a reference for its several relevant tasks. The most frequently used information for the site selection is the type of pedestrian crossing treatment, crossing distance, presence of median, presence of lighting, access point density, presence of refuge island and crosswalk, number of lanes, and posted speed limit. This study's main criteria are to check the provision of the street or pedestrian lighting in the vicinity of crash locations.

Table 10. Site selection criteria for pedestrian crash analysis

Site Selection Criteria	Number of Sites	Study
Type of pedestrian crossing treatment, number of lanes, posted speed limit	Total 61 sites, including 7 traffic control signal sites, 22 Rectangular Rapid-Flashing Beacons sites, and 32 pedestrian hybrid beacons sites	[136]
Crossing treatment, crossing distance, median presence, pedestrian presence, lighting, speed limit, access point density	Total 66 sites, including 40 uncontrolled midblock crosswalks and 26 signalized intersections	[137]

Site Selection Criteria	Number of Sites	Study
Vehicular traffic flow, pedestrian density speed limit, conflict causing agents (lighting, crosswalks, signs, and signals)	Total 7 sites (all intersection)	[138]
The average length of any segment selected for the analysis is 0.10 mile	Total of 372 sites (188 segments, 184 intersections)	[139]
Ranking and selecting intersections by volume of crashes	Total 4467 pedestrian crash locations	[140]
Road width, number of traffic lanes, maximum number of crossing stages, number of traffic directions, presence of refuge islands, and presence of marked crosswalks.	Total of 25 selected locations	[96]

Objective

The primary objective of this study was to investigate the impact of lighting conditions on pedestrian crashes. The main objectives were:

1. Learning and documenting lighting policies/guidelines/practices in Louisiana and other states. Emphasis will be given to pedestrian focus street lighting policies.
2. Investigating lighting conditions at intersections, crosswalks, and segments with frequent pedestrian crashes and their impact on pedestrian safety in Louisiana.
3. Recommending the targeted practical lighting requirements based on the analysis.
4. Making suggestions on crash coding modification in the pedestrian crash report (lighting condition, type of lighting such as street, business, parking, or residential houses, etc.)

Overall, this research project was designed to perform an extensive analysis of existing pedestrian crash data to identify lighting-related factors associated with pedestrian crashes in Louisiana. This project focused on pedestrian crashes on all state-owned and locally owned roadways in Louisiana.

Scope

The study focused only on analyzing the nighttime crash data at all roadway types within the state. Interstate pedestrian crashes were tagged separately and removed from the modeling though used in data exploration. Though the study attempted to get the cost of lighting from multiple sources and preferred to use the average cost, the study eventually used the cost provided by Lafayette Utility System as it was the most recent updated local cost for streetlights.

Methodology

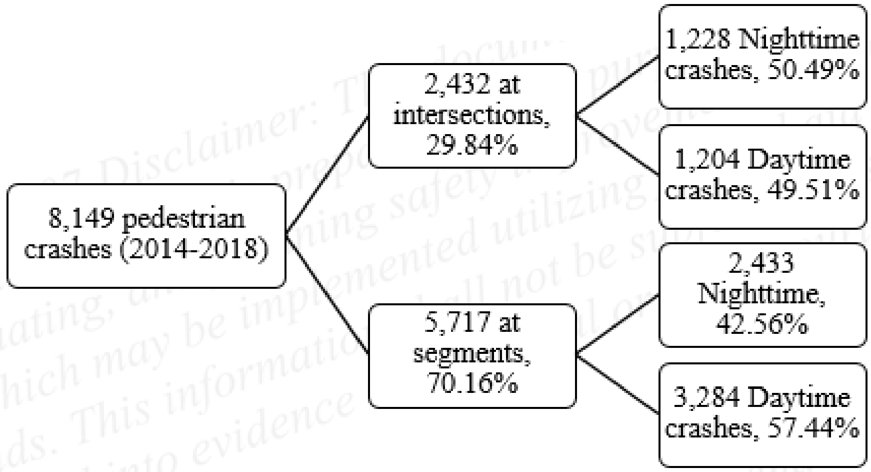
The chapter is divided into three different subsections. The first part "Data" includes the crash data source, site selection criteria, and information collected from each intersection and segment. The next section consists of a summary of the data reduction. The last section includes a brief overview of crash modification factors and methodologies used to determine the impact of lighting conditions on pedestrian crashes, followed by the cost-benefit analysis details. The word "Light" used in this study refers to different streetlights or light poles.

Data

Crash Data

The study extracted crash data from the Louisiana Department of Transportation and Development (DOTD) crash 1 and Access database. Crash 1 database provides a single row of information for each crash. In contrast, the Access database elaborates the data at each occupant level with other details like pedestrian age and experience. Thus, the Access database was only used when additional information was required for the study. Each of the crash incidents in the database was accompanied by a unique crash number. The study used 8,149 pedestrian crash data during a five-year period from 2014 to 2018. Out of 8,149 crashes, 2,432 occurred within 150 ft. of intersections, while the remaining 5,717 occurred at segments. Figure 6 depicts the distribution of pedestrian crashes at intersections and segments, as well as the distribution by day and night. Segments refer to any roadway feature, not a part of an intersection, such as a linear or curved roadway segment. A slightly larger proportion of total crashes occurred in daytime compared to nighttime conditions. Crashes during dawn and dusk were tagged as daytime crashes. As a note, hereafter, the term crashes within the report implies pedestrian crashes in general.

Figure 6. Pedestrian crashes with intersection and segment



The study further explored both intersections and segments based on pedestrian crashes during the aforementioned five-year study period. The following sections discuss the detailed procedure showing how the study came up with the list of intersections and segments to be used for the data analysis.

Intersection Data

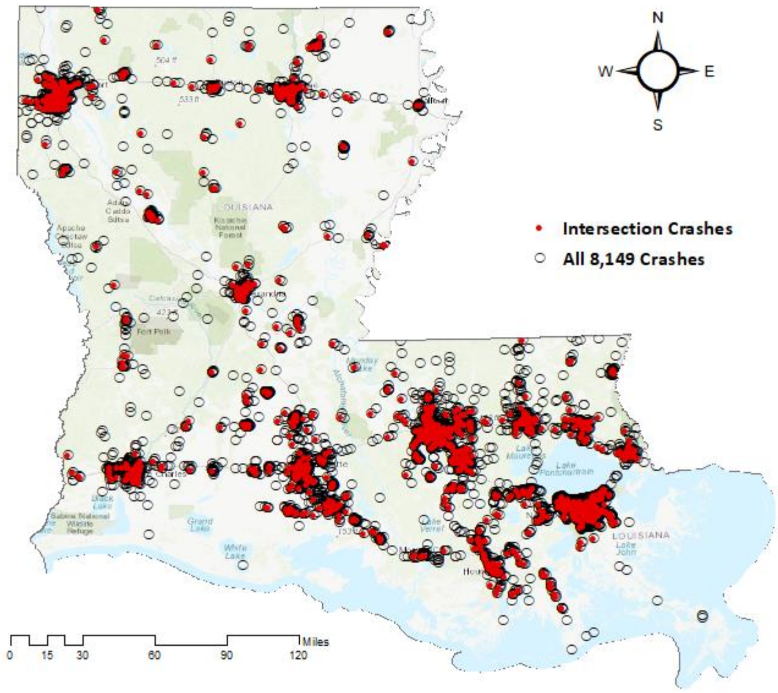
A total of 2,432 pedestrian crashes, including 1,228 at nighttime and the remaining 1,204 at daytime crashes, were used. Because the study only used crash data during the nighttime for the modeling purpose, some of the crashes with missing information were removed, making nighttime crashes down to 1,182, which accounts for 1,031 intersections as multiple crashes occurred at the same location. All the intersections were ranked according to the total number of crashes that occurred within each location during the entire five-year period. Table 11 shows an individual list of intersections and total pedestrian crashes by fatalities. It shows that out of 1,031 intersection locations, 923 (around 90%) of the locations have just one crash count during five years period. The remaining 10% of the sites were found to have crashes counting from 2 to 6. Four intersections were found to have more than or equal to 5 crashes during the study period. It indicates the potential issue that research studies need to be aware of, especially during the modeling.

Table 11. Number of crashes by severity

Severity	Crash Count on Sites						
	1	**2**	**3**	**4**	**5**	**6**	**Total**
Fatal	79	12	5	0	1	0	97
Severe injury	110	20	3	3	0	0	136
Moderate Injury	366	66	22	11	7	4	476
Complain	274	42	24	6	5	2	353
No Injury	94	18	6	0	2	0	120
Total Number of crashes	923	158	60	20	15	6	1,182
Total Number of Sites	923	79	20	5	3	1	1,031

After a quality check of each location and the crash data itself, the study removed a few locations due to missing attributes such as ambiguities around lights or pedestrian crosswalks or any of the other variables extracted using Google Maps and ArcGIS. The study used the street view function of the Google Maps and manually went through all 1,031 intersection locations to check the availability of lighting at those locations. After spending a significant amount of time, the study finally complied with 925 intersections (765 with and 160 without lighting) for the CMF estimation. Since the modeling required an equal number of with and without light sites, Statistical Analysis System (SAS) was used to randomly select 160 sites from 765 sites with light to match with the 160 sites without light. This way, a total of 320 intersection locations were finally selected for modeling purposes –160 with light and the remaining 160 with no light. Figure 7 shows the spatial distribution of pedestrian crashes at intersections during the 2014-2018 period in Louisiana.

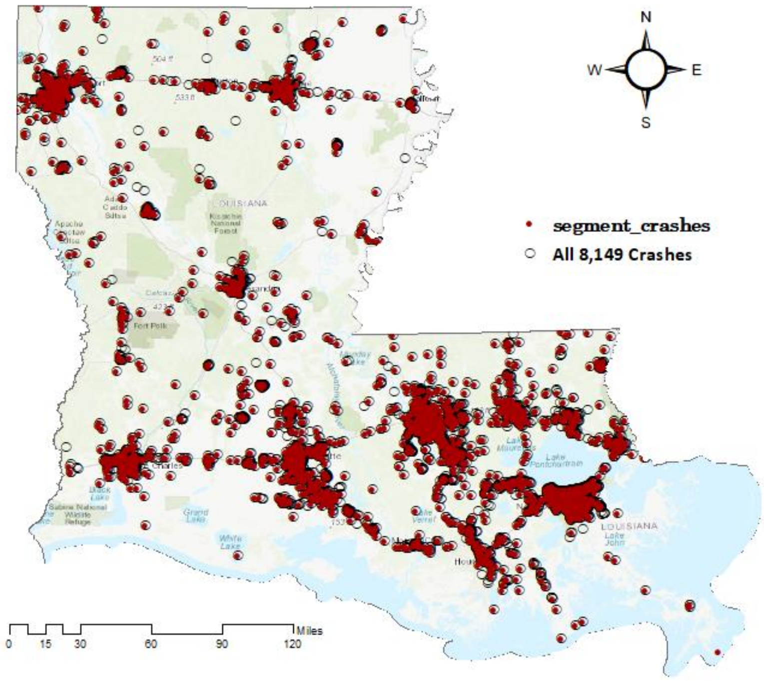
Figure 7. Pedestrian crashes at intersection in Louisiana from 2014 to 2018



Segment Data

As mentioned previously, out of the 5,717 segment crashes, the study identified segments with only nighttime crashes (count = 2,433). The study then checked the Linear Reference System (LRS) shapefile from the DOTD database, which depicts all the control sections on Louisiana roadways. Both the 2,433 nighttime segment crashes and LRS shapefiles were projected in ArcGIS, and the sections with crashes were only filtered. The study considered a linear segment of 500 ft. with 1 or more crashes and extracted LRS segments within a segment of 500 ft. with crashes of more than or equal to the threshold. Finally, the study sorted the data into 398 segments (134 with and the remaining 264 without a lighting source). Due to some missing attributes required for the modeling, the study took a few out of the list and selected 371 segments (121 with and 250 without lighting source) for the modeling purpose. Figure 8 shows the spatial distribution of pedestrian crashes at segments during the 2014-2018 period in Louisiana.

Figure 8. Pedestrian crashes at segment in Louisiana from 2014 to 2018



Data Reduction

Once all the 320 potential intersection and 371 segment locations were identified, a list of attributes was developed that could potentially affect pedestrian crashes. A review of the literature was conducted to get the proper attributes for this study. Data were extracted mostly from the DOTD database and the remaining from Google Maps. For example, data like average annual daily traffic (AADT) and roadway functional class were obtained from the DOTD database. Information like the presence of painted crosswalks, pedestrian signals, crossing island, median divided, median type, number of lanes, etc., were extracted from Google Maps. Appendix A includes the list of attributes extracted from each intersection and segment location.

Analysis

The analysis was conducted in four different folds — general crash analysis, crash modification factor, modeling that includes binary logistic regression and data mining, and cost-benefit analysis.

General Crash Analysis

Crash analysis was conducted using all 8,149 pedestrian crashes from 2014 to 2018. The pedestrian crashes were analyzed by different times of the day, pedestrian crashes by severity, crash severity by lighting conditions, crash severity by lighting conditions and area type, crash severity by roadway functional class, crashes by roadway functional class and lighting conditions, and crash severity by lighting condition at intersections. This task explores the dataset to check if any correlation exists between different parameters, especially with the lighting.

Crash Modification Factor

A crash modification factor (CMF) estimates the reduction in the number of crashes when a countermeasure is implemented at a certain location. With relevance to the study, lighting is considered a countermeasure. Thus, CMF is the ratio of the expected crash frequency with improvement or light to the expected crash frequency without improvement or no light [CMF clearinghouse] as shown in equation [1]. A CMF value of greater than 1 suggests an expected increase in crashes, whereas a value of less than 1 suggests an expected decrease in crashes. The measure (1 – CMF) * 100 shows the percent reduction in crashes.

$$\text{CMF} = \frac{\text{Average Number of Crashes per Site with Light}}{\text{Average Number of Crashes per Site without Light}} \qquad [1]$$

Binary Logistic Regression Model

One of the objectives of this project was to evaluate the association between the presence of lighting (yes/no) and the site-specific factors separately for intersections and segments. The dichotomous nature of the response variable (presence of light) facilitates the application of binary logistic regression. In this model, the logit is the natural logarithm of the odds ratio in which the dependent variable is 0 (light = no) as opposed to 1 (light = yes). A linear relationship between the n explanatory variables $x_1, x_2, \dots \dots, x_n$, and the log-odds of the event P = P (y = no light) can be expressed as,

$$y = logit\ (P) = ln\left[\frac{P}{1-P}\right] = \beta_0 + \beta_1 x_1 + \cdots + \beta_n x_n \qquad [2]$$

The z-statistic can be estimated by the following equation:

$$z = \frac{\beta_i}{SE(\beta_i)} \qquad [3]$$

Here β_i is the estimated ith coefficient and $SE(\beta_i)$ is the standard error of the coefficient.

The odds ratio can be estimated by the following equation,

$$\left[\frac{P}{1-P}\right] = \exp(\beta_0 + \beta_1 x_1 + \cdots + \beta_n x_n) \qquad [4]$$

The odds ratio in the logit model represents the constant effect of site-specific contributing factors on the likelihood that the pedestrian crash occurs with the absence of a light.

Machine Learning Model

Association Rule Mining (ARM), a rule-based machine learning method, helps to identify the group of items that appear together in a dataset. Agarwal et al. (1993) proposed the 'Apriori' algorithm to uncover the pattern in supermarket transactions to determine which items are often brought together [141]. After years of modification, ARM has become a more common approach for recognizing variable attribute patterns and interconnections in traffic safety-related research [142].

Let I = $\{i_1, i_2, \dots \dots \dots, i_n\}$ is a set of n crash attributes called items (set of crash characteristics for each pedestrian crash record) and T = $\{t_1, t_2, \dots \dots \dots, t_m\}$ is a database of pedestrian crash information such that each pedestrian crash record in T has a unique crash ID. Each $t_i \in I$ exemplifies each pedestrian crash record composed of a subset of items (chosen from I). An association rule can be written as Antecedent (A) → Consequent (K), where A and K are two separate subsets of all available items in the crash dataset. Three measures of significance are utilized in the generation of association rules. These are support, confidence, and lift, and the formulae provided in the following equations (Equation [5] to Equation [9]).

$$S(A) = \frac{\sigma(A)}{N} \qquad [5]$$

$$S(K) = \frac{\sigma(K)}{N} \qquad [6]$$

$$S(A \rightarrow K) = \frac{\sigma(A \cap K)}{N} \qquad [7]$$

$$C\,(A \rightarrow K) = \frac{S\,(A \rightarrow K)}{S(A)} \qquad [8]$$

$$L\ (A \rightarrow K) = \frac{S\ (A \rightarrow K)}{S(A).\ S(K)} \qquad [9]$$

where, N = number of crashes, $\sigma(A)$ = frequency of incidents with A, $\sigma(K)$ = frequency of incidents with K, $\sigma(A \cap K)$ = frequency of incidents with both A and K, $S(A \rightarrow K)$ = support of the association rule $(A \rightarrow K)$, $C\ (A \rightarrow K)$ = confidence of the association rule $(A \rightarrow K)$ and $L\ (A \rightarrow K)$ = lift of the association rule $(A \rightarrow K)$.

The support (S) implies how often antecedent (A) and consequent (K) of a particular rule appear together in the database, while the confidence (C) assesses the strength of the rule. The other measure lift (L) indicates the relationship between the antecedent-consequent co-occurrence frequency and expected frequency [143]. If L > 1, it implies positive interdependence, while L < 1 indicates negative interdependence between the antecedent and consequent. Lift value equal to 1 suggests that antecedent and consequent are independent, and there is no correlation [144]. The analysis was carried out with the help of the open-source program R version 4.0.1 and the R package ‘arules’ [145].

Cost and Benefit Analysis

A cost-benefit analysis is a systematic process for calculating and comparing the benefits and costs of countermeasures. The cost is considered a total of an initial cost, operation and maintenance cost, and utility cost (electricity power or solar panel) for the lighting. Other costs such as travel time, delay due to crashes, vehicle running expenses, reduced air pollutants, noise, and impacts on natural habitat and wetlands were not considered for this project. At the same time, the benefit includes a reduction in crashes in terms of monetary value. The term CMF would dictate the reduction of crashes due to a certain countermeasure – i.e., the lighting. A reduction in crashes, in monetary value, would be a reduction in cost due to a reduction in that specific crash type. Table 12 shows the cost per unit crash by different severity types within the state. The information on the crash cost by severity types was extracted from the statewide annual crash fact book [146]. The total estimated cost for Louisiana crashes is approximately $8.6 billion per year [147].

Table 12. **Louisiana specific cost of crashes by severity level** [147]

Crash Severity Type	Crash Report Injury Code	Unit Cost Per Crash
Fatal	A	$1,710,561
Severe Injury	B	$489,446
Moderate Injury	C	$173,578
Complaint	D	$58,636
No Injury (Property Damage)	E	$24,982

The major part of the benefit analysis is to consider a CMF that would dictate the number of reduced crashes due to lighting. CMF can either be derived from the data as discussed before or from a reliable source. Because of some ambiguities within the crash data, the study preferred to use CMF for the pedestrian crashes from the Clearinghouse website. The study checked the Clearinghouse website and explored CMFs available for pedestrian lighting at different locations. It was difficult to get CMF just for the pedestrian and nighttime crashes. Ultimately, after an extensive review of several available CMFs, the study decided to use CMF for 0.56 [148]. It indicates that installing lights would reduce traffic crashes at that location by 44% in rural areas.

Regarding the cost, it includes the construction cost of a single streetlight, including the cost of trenching and backfilling, conduit with conductors, directionally bored conduit with conductors, 28-ft. light pole aluminum; single 8-ft. arm and foundation, and luminaire 250 watts; high-pressure sodium. These costs are one-time costs. All the unit costs of all these items were taken from Lafayette Utility System for their most recent project with streetlights, as shown in Table 13. In addition, other costs include an average operation and maintenance cost of $150.93 per streetlight per year, which was also provided by Lafayette Utility Services as recurring costs. A streetlight charge of $10.30 per month was taken from the electricity charges schedule of the City of Alexandria utility rates for street lighting charges on private roads [149]. It includes all the required costs for installing and operating a single streetlight for one year. Items 1 to 5 are one-time costs, while items 6 and 7 are recurring costs.

Table 13. Construction and maintenance cost of a streetlight at intersection and segment

Item No.	Description	Cost Type	Quantity	Unit Measure	Average Price Per Unit	Total Price (for five years)
1	Trenching & Backfilling	One Time	307.5	Linear ft.	5.16	1,587
2	Conduit W/ Conductors (2" Sch.40 w/3#6 & 1#8)		305	Linear ft.	8.97	2,736
3	Directional Bored Conduit W/ Conductors		25	Linear ft.	24.94	624
4	28' Light Pole (Aluminum) (single 8'arm & Foundation)		1	Each	4,310	4,310
5	Luminaire (250 watt) (High Pressure Sodium)		1	Each	525	525
6	Cost of Maintenance per fixture per year average	Recurring	5 years	Each	150.93	755
7	Streetlight Charges per Month		12	Each	10.3	618
	The total cost of installing and maintaining one streetlight for five years					$11,155
	Total cost of installing and maintaining eight streetlights for five years on intersection					$89,240
	Total cost of installing and maintaining twelve streetlights for five years for 500 ft. segment					$133,860

Discussion of Results

This section includes an in-depth discussion on general crash analysis; CMF calculated from the crash data and its significance; statistical model and data mining results; and cost-benefit analysis. Table 14 shows the summary of the sample used for the analysis. For example, all 8,149 crashes were utilized for general crash analysis. Freeway pedestrian crashes were removed after the general crash analysis. Only nighttime crash data were used for CMF, binary logistic regression, and cost-benefit analysis, excluding data from daylight, dawn, and dusk. For the data mining, 4,401 crashes of the top three severity levels (fatal, severe, and moderate) were filtered from 8,149 crashes, and were utilized.

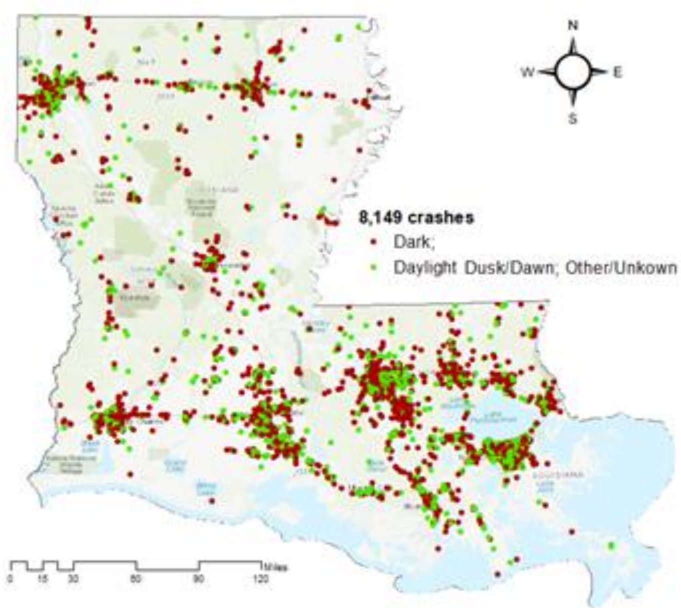
Table 14. Size and type of data used for analysis

Analysis	Analysis Based On	Location	With Light	Without Light	Total
General Crash Analysis	Crash	All 8,149 crashes			
CMF	Site	Intersection	765	160	925
		Segment	121	250	371
Binary Logistic	Site	Intersection	160	160	320
		Segment	121	250	371
Data Mining	Crash	4,401 crashes of fatal, severe, and moderate injury crashes			
Cost and Benefit Analysis	Site	Intersection	–	160	–
		Segment	–	250	–

General Crash Analysis

The general crash analysis explores the possible association of pedestrian crashes with many crash attributes related to the vehicle, roadway, environment, and human-related factors. Special focus was given to lighting conditions involved in the crashes — to evaluate whether any lighting or a specific type of lighting condition contributed to pedestrian crashes. A total of 8,149 pedestrian crash data from 2014 to 2018 were used for the analysis. The total number of crashes includes 622 (7.63%) fatal, 774 (9.50%) severe, 3,048 (37.40%) moderate, 2,869 (35.21%) complaints, and 836 (10.26%) no injury types. Of the total 8,149 pedestrian crashes, 1,507 (18.49%) occurred in 2014, 1,622 (19.91%) in 2015, 1,687 (20.70%) in 2016, 1,656 (20.32%) in 2017, and the remaining 1,677 (20.58%) crashes occurred in 2018. Due to the unavailability of data at the time of conducting the analysis, pedestrian crash data from 2019 was not used. The crashes were analyzed for several parameters like day with night conditions, the severity of the crash, time of the day, roadway functional class, and intersection with non-intersection crashes. Figure 9 shows pedestrian crashes in Louisiana according to lighting conditions from 2014 to 2018. As a note, the study did not consider the effect of pedestrian volume, and the introduction of several new treatments during the analysis.

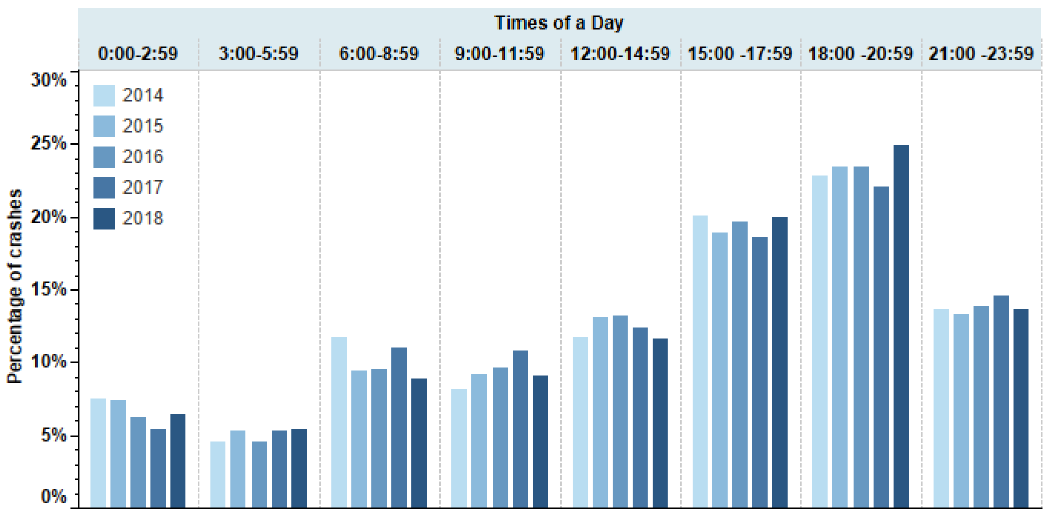
Figure 9. All pedestrian crashes within the state from 2014 to 2018



Crashes by Different Times of a Day

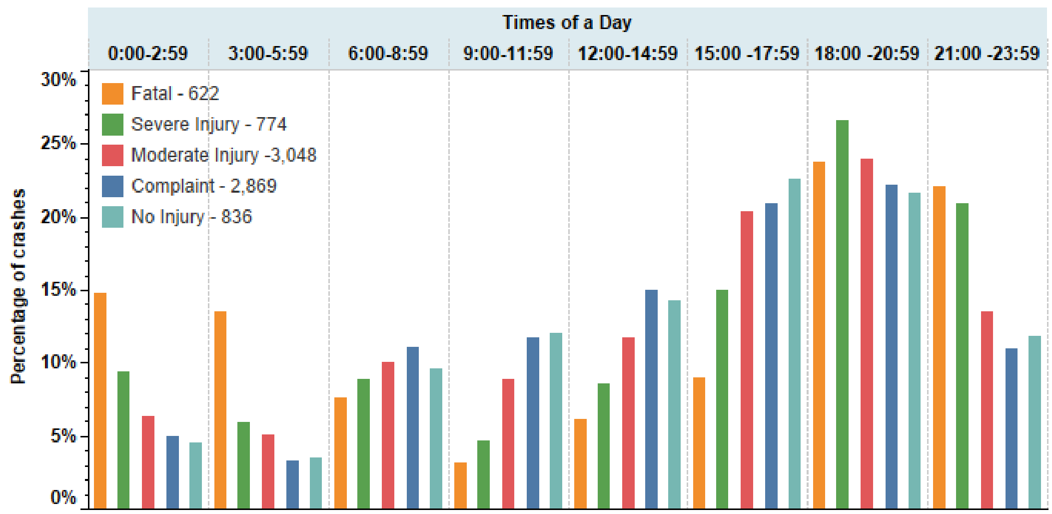
All 8,149 crashes were clustered in three-hour time intervals to visualize the distribution of crashes at different times of the day for each year, as shown in Figure 10. The plot helps to identify timeframes associated with peak crashes. As discussed previously, 1507, 1622, 1687, 1656, and 1677 crashes occurred each year from 2014 to 2018. Out of 8,149 crashes, 44.93% occurred at nighttime or dark, and the remaining 55.07% occurred during the daytime. Dawn and dusk data were included in daytime crashes. Figure 10 shows that above 18% of crashes occurred between 15:00 to 20:59 in each of the five different years. For example, 25% of crashes occurred between 18:00 to 20:59 during 2018, which indicates a total of 418 crashes of 1677 during that year. Crashes between 15:00 to 18:00 can be attributed to the rush hour traffic and increased pedestrian movement compared to other times of the day. In addition, crashes after 18:00 might be due to the poor lighting conditions. Overall, the crash statistics show that around 49% of crashes occurred after 18:00 and before 6:00 in the morning. However, pedestrian crashes were minimal during the morning traffic peak hours.

Figure 10. Crashes by various times in a day



The same time frame was then used to explore the trend of the severity of crashes. The objective was to show how severity levels change at different times in a day. Due to limited crash data in some categories, severity levels were explored using all the crash data from five-year periods instead of conducting by each year. The detail is shown in Figure 11. It shows that 14.79% of fatal crashes are between midnight and 3 a.m. The percentage was estimated as an average of 92 crashes out of 622 total fatal crashes within that timeframe. Overall, the figure shows significant proportions of fatal crashes occurred after 18:00, for which lighting might be a contributing factor. The timeframe between 18.00 to 23:59 recorded the most fatal crashes – 23.79% and 22.03% in two different time frames. Overall, the crash statistics show around 74% of fatal crashes occurred after 18:00 and before 6:00 in the morning. Significantly low fatal crashes were observed during the daytime. Figure 11 indicates the severity levels at different times of the day.

Figure 11. Severity levels at different times of a day



Pedestrian Crashes by Severity

Next, the study explores the severity of crashes by each year rather than combining everything. The objective of this section is to show the yearly trend of pedestrian crashes. Table 15 shows the percentage of crashes in each category in different years. It shows fatal crashes increased from 6.97% in 2014 to 9.84% in 2018. Fatal and severe injury crashes made up 16.46%, 16.83%, 16.12%, 15.88%, and 20.27% of total crashes for 2014, 2015, 2016, 2017, and 2018, respectively. The individual percentages in the tables were estimated using total crashes within that year as a baseline. For example, 6.97% of fatal crashes during 2014 were estimated as total fatal crashes of 105 during that year divided by the total number of crashes during that year, i.e., 1507. The table shows that though fatal and severe crashes slightly declined from 2015 until the end of 2017, 2018 recorded the highest fatal and severe crashes of around 20.27% since 2014.

Table 15. Percentage of crashes in each year by severity level

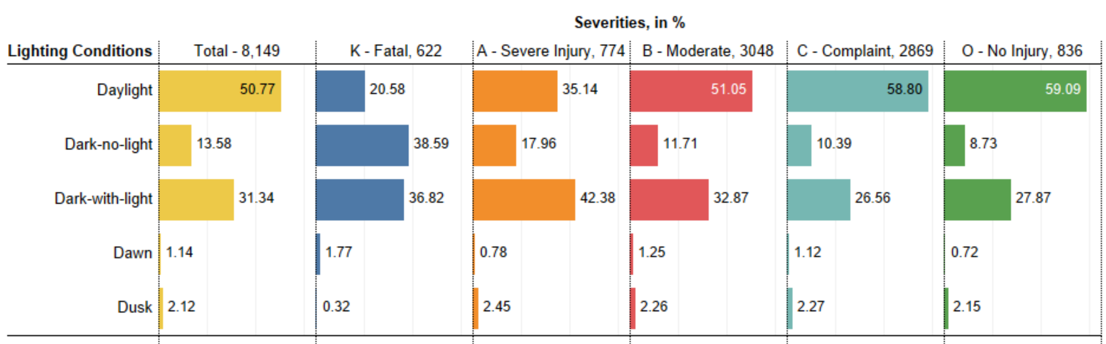
Years	Fatal	Severe Injury	Moderate Injury	Complaint	No Injury	Total Crashes	Fatal and Severe
2014	6.97%	9.49%	35.30%	36.23%	12.01%	1507	16.46%
2015	6.72%	10.11%	37.30%	34.65%	11.22%	1622	16.83%

Years	Fatal	Severe Injury	Moderate Injury	Complaint	No Injury	Total Crashes	Fatal and Severe
2016	7.59%	8.54%	37.46%	34.62%	11.80%	1687	16.12%
2017	6.94%	8.94%	38.95%	37.08%	8.09%	1656	15.88%
2018	9.84%	10.44%	37.81%	33.57%	8.35%	1677	20.27%

Crash Severity by Lighting Conditions

The study grouped crash data into different clusters, as shown in Figure 12, to check the distribution of severity of crashes by different lighting conditions. Out of 8,149 crashes, 55.07% occurred during daylight conditions, followed by 44.92% (13.58% plus 31.34%) of crashes during dark conditions. Out of 622 fatal crashes, the numbers are low at daylight (20.58%), dawn (1.77%), and dusk (0.32%). Most of the fatal crashes occurred in the dark (75.41%) – dark without lights (38.59%) and dark with lights (36.82%). Since moderate, complaint, and no injury crash types were recorded in more than 50% of crashes during the daytime, it shows crashes during daylight are less fatal and severe. Overall, the percentage was estimated based on the total crashes in each category. Sometimes, the total percentage did not sum up to 100% because the crash data with the missing time of a day was not included.

Figure 12. Crash severity by different lighting conditions

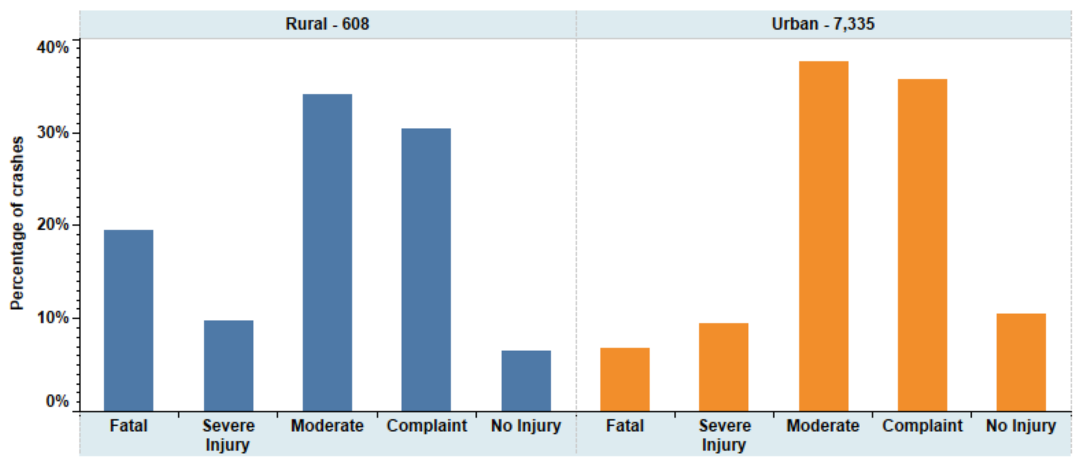


The study also went through all 622 fatal and 774 severe crash locations in Google Maps and determined if lighting information existed at those locations by checking lights within 150 ft. periphery of the crash locations. The study used the street view feature in Google Maps to get the required information. Overall, the study found all extracted information on lights matched with the lighting information from the crash data source. This also provides information on the accuracy of the crash data, especially on the lighting information.

Crash Severity by Area Type and Lighting Conditions

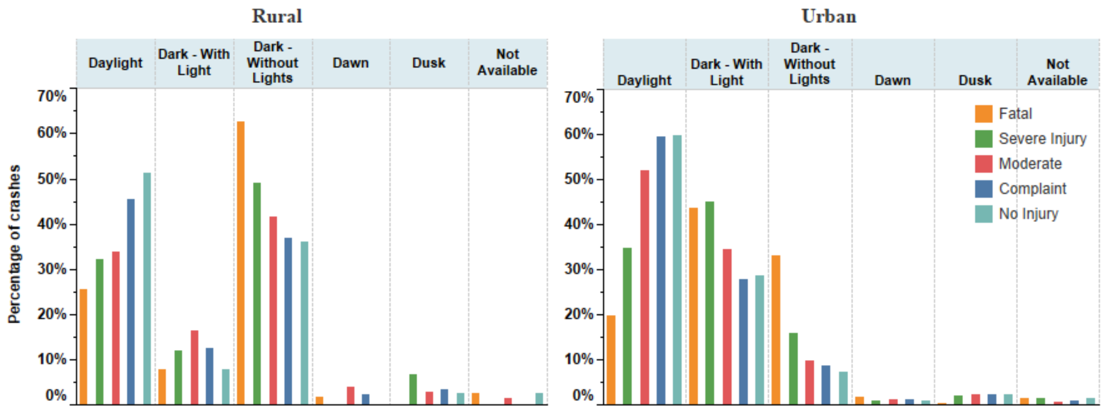
Out of 8,149 crashes, 90.01% (7,335) occurred in urban, and 7.46% (608) occurred in rural areas. The area type was unknown for around 2% of the crash data. Figure 13 shows the severity of crashes for two different area types. For instance, out of 608 total crashes within the rural area, around 20% were fatal compared to about 7% (499 of 7,335) crashes in the urban area. Overall, it shows a higher fatality rate in rural than in urban areas. Other remaining types of crashes are similar in both the area types.

Figure 13. Distribution of total crashes by severity levels at urban and rural areas



Out of 608 and 7,335 crashes in rural and urban areas, respectively, the study explored the effect of lighting on the crash severity in each area separately. The detail is shown in Figure 14. It shows around 25% of crashes in rural areas are fatal during daylight compared to 19.64% in urban areas. During dark conditions, both with and without light conditions, rural areas recorded a fatality rate of 70.34% compared to 76.76% in the urban area. Most pedestrian fatalities (62.71%) occurred in the dark without lighting conditions in rural areas. However, the urban area recorded similar fatality rates with (43.69%) and without lighting (33.07%) conditions. In both the area types, complaint and no injury types are dominant during daytime conditions.

Figure 14. Severity of crashes by lighting conditions in the rural and urban areas separately



Crash Severity by Roadway Functional Class

The study also explored crashes by different roadway functional classes, as in Table 16. It shows that most crashes occurred on local roads (28.43%), followed by principal arterial (23.01%), minor arterial (22.37%), and major collector roadways (14.93%). The data also recorded few crashes at interstates though more likely it might be vehicle occupants standing on the side of roadways during crashes or workers tagged as pedestrians. The study went through the crash reports of all fatal crashes to explore the exact reason, and the detail is included in a separate section. Such crashes at freeways were not included in the dataset for CMF and modeling. Though local streets recorded a higher crash rate, the fatality rate is higher at arterials – 23.01% at principal arterial and 22.37% at minor arterial. It shows roadways with a higher speed limit, except freeways, which show a higher fatality rate. Other severity levels of crashes like severe, moderate injury, complaint, and no injury types are dominant in local roadways.

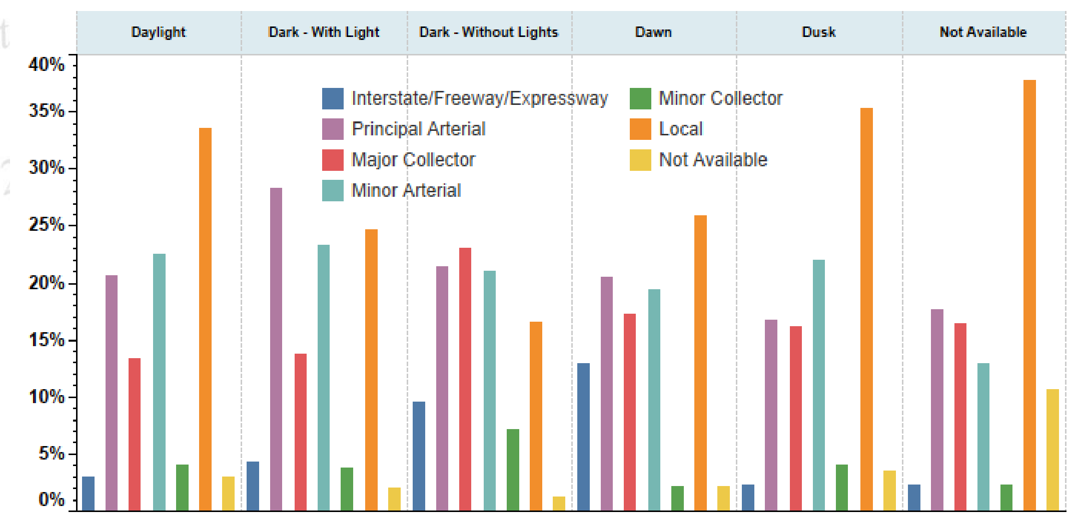
Table 16. Crash severity by roadway functional class

Roadway Type	Total	Fatal	Severe Injury	Moderate Injury	Complaint	No Injury
Interstate/Freeway	4.41%	12.86%	5.17%	3.71%	3.07%	4.55%
Principal Arterial	23.01%	34.57%	26.23%	23.33%	20.36%	19.38%
Minor Arterial	22.37%	22.99%	22.48%	22.41%	22.24%	22.13%
Major Collector	14.93%	13.50%	15.12%	15.22%	15.75%	11.96%
Minor Collector	4.32%	3.86%	4.65%	3.84%	4.78%	4.55%

Roadway Type	Total	Fatal	Severe Injury	Moderate Injury	Complaint	No Injury
Local	28.43%	11.41%	23.51%	28.81%	31.47%	33.85%
Not Available	2.53%	0.80%	2.84%	2.69%	2.34%	3.59%
Total	8,149	622	774	3,048	2,869	836

The same functional classes were then classified by different lighting conditions to check if any specific crash trend exists in a particular type of roadway. The details are shown in Figure 15, and they show that crashes were dominant on local and principal arterial roads regardless of the time of the day. However, crashes at interstates were higher during dawn and dark condition, especially at locations with no lights.

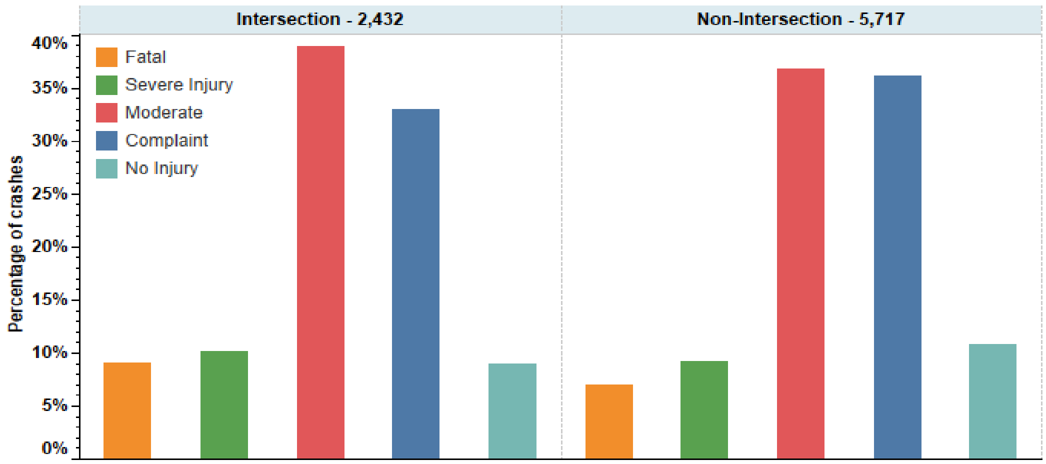
Figure 15. Crash rate by different lighting conditions and functional class of roadways



Crash Severity at Different Roadway Locations

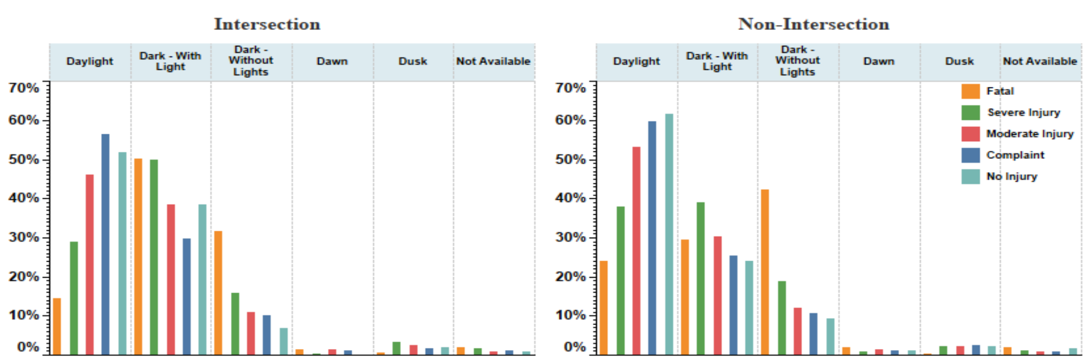
To study the effect of intersection and non-intersection locations and the lighting conditions on the severity of crashes, crashes were analyzed separately at both locations as shown in Figure 16. Out of 8,149 crashes, 2,432 (29.84%) were recorded at intersections or within 150 ft. periphery, and the remaining 5,717 (70.16%) crashes were recorded at non-intersections. Non-intersection implies any roadway features other than intersections and might be a linear roadway segment, curve, or mid-block segment. Intersections recorded a fatality rate of 9.09% compared to the 7.01% at non-intersections. Overall, the crash distribution across two different locations, as in Figure 16, shows no significant difference between the crash severities at two different places.

Figure 16. Crash severities by location types (Intersection vs. Non-intersection)



Similarly, the study explores the effect of different times of the day at both locations, as in Figure 17. Around 14.48% of the fatalities occurred during daylight conditions at intersections compared to 23.94% at non-intersections. Most of the fatalities at non-intersection are fatal during dark without light conditions (42.39% during dark without light and 29.43% during dark with light) compared to 31.67% and 50.23% at intersection locations. The disparity could be attributed to the fact that most intersections have lights as opposed to non-intersection areas. The percentage was estimated by the severity level. For instance, out of 221 fatal crashes at the intersection location, 32 or 14.48% occurred during daylight conditions.

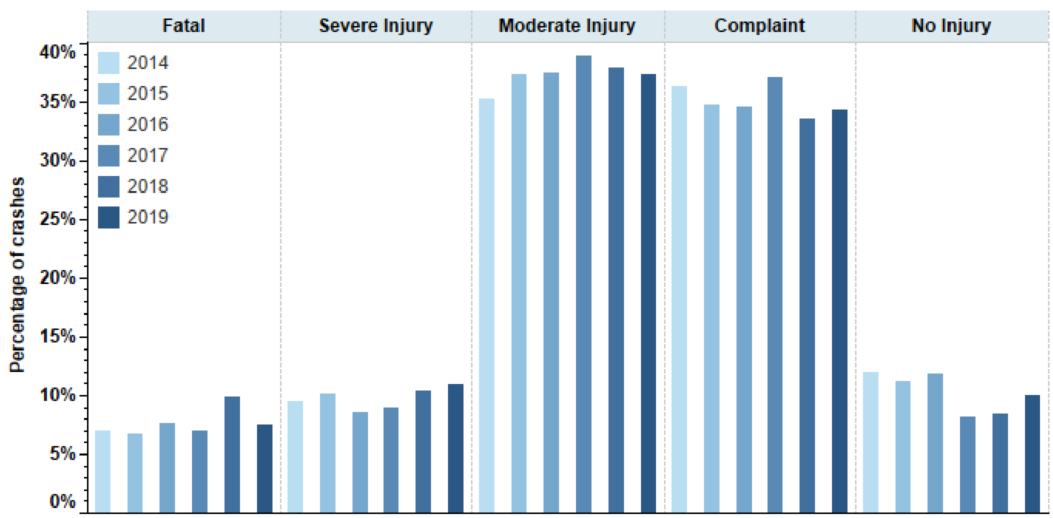
Figure 17. Crash severities by location types (Intersection vs. Non-intersection)



Pedestrian Crashes in 2019

Due to the availability of 2019 pedestrian crash data in the middle of the analysis, the study explored the data separately instead of redoing all the analysis from scratch. Previously, of the total 8,149 pedestrian crashes between year 2014 to 2018, 1,507 (18.49%) occurred in 2014, 1,622 (19.91%) in 2015, 1,687 (20.70%) in 2016, 1,656 (20.32%) in 2017, and the remaining 1,677 (20.58%) crashes occurred in 2018. In 2019, 1,594 pedestrian crashes were recorded, a decrease of around 4.94% from 2018. Of the 1,594 crashes, 7.47%, 10.85%, 37.39%, 34.32%, and 9.97% were respectively fatal, severe injury, moderate injury, compliant, and no injury types. Out of 7.47% of the fatalities, 23.53% occurred during daylight conditions, while the remaining 76.47% occurred during dark, dawn, and dusk conditions. Figure 18 shows pedestrian crash severities across different severity from 2014 to 2019.

Figure 18. Pedestrian crash severities from the year 2014 to 2019



Spatial Distribution of Crashes by Major Parishes

Figure 19 shows all 8,149 crashes by different parishes. It is evident that crashes are densely populated in major cities like New Orleans, Baton Rouge, Lake Charles, Shreveport, Alexandria, and Monroe. However, a significant number of crashes can be noticed in rural areas randomly scattered across the state.

Figure 19. All pedestrian crashes by parishes

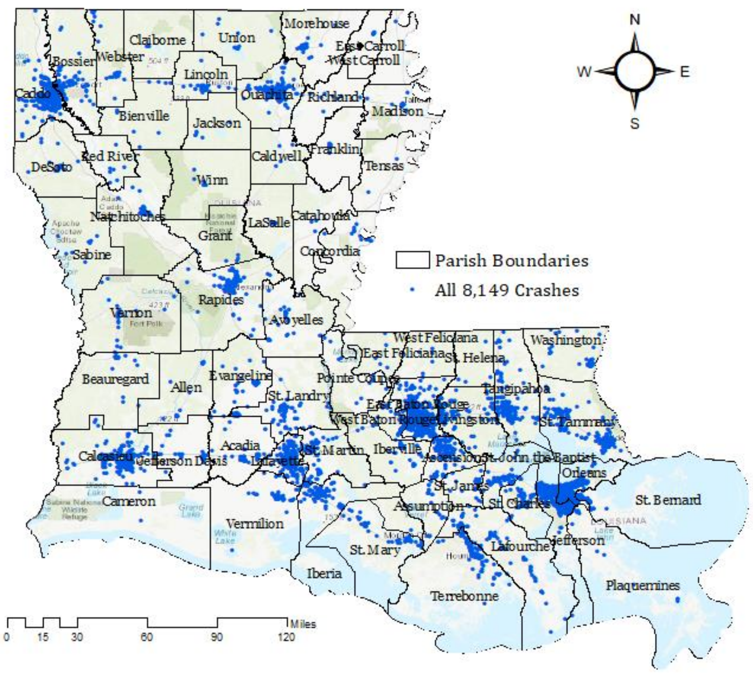


Table 17 shows the crash distribution in terms of ‘pedestrian crashes per 100k population’ in several major parishes within the state. It is obvious that the most accurate assessment would result from normalizing the pedestrian crash data by the pedestrian volume data. Since it is very difficult to get the pedestrian volume data, thus, the study opted to use the total population to normalize the crash data. The population data in each parish were extracted from the website https://www.louisiana-demographics.com [150]. Total pedestrian crashes in each parish within the five-year study period were divided by the total population within that parish to get crash distribution per 100k population. The parameter was estimated by different severity levels. The result shows that Tangipahoa Parish recorded the most fatality rate of 23.48 per 100k population, followed by 19.34 at Calcasieu, and 17.91 at Orleans Parish. However, Orleans Parish recorded the most for other remaining categories, followed by Caddo and East Baton Rouge parishes.

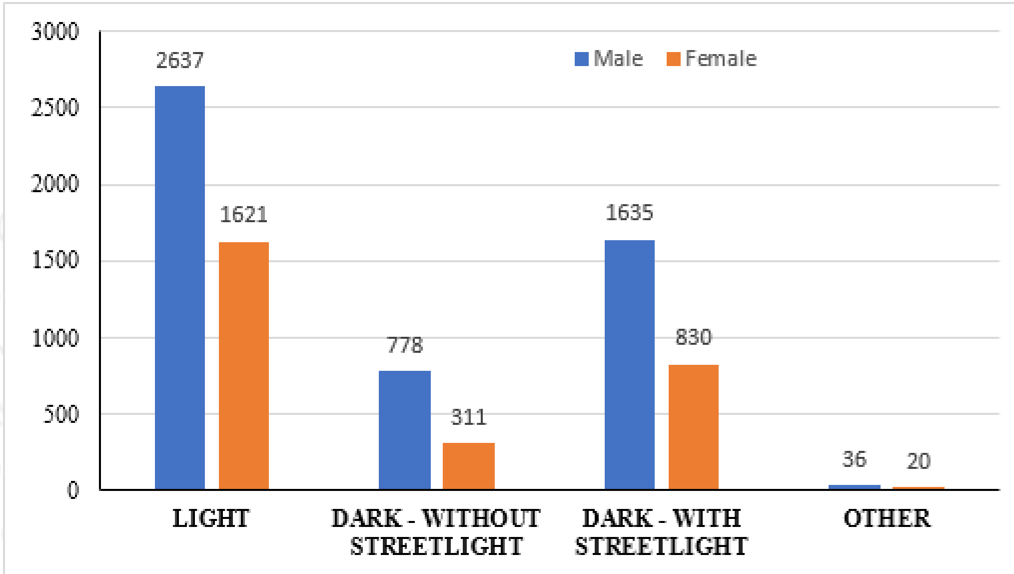
Table 17. Ranking of major parishes by pedestrian crashes per 100K population

Rank	Fatal		Severe Injury		Moderate Injury, Complaint, and No Injury		Total	
	Parish	Crashes per 100k Population	Parish	Crash distribution per 100k Population	Parish	Crash distribution per 100k Population	Parish	Crash distribution per 100k Population
1	Tangipahoa	23.48	Orleans	46.05	Orleans	430.90	Orleans	494.80
2	Calcasieu	19.34	Caddo	23.59	Caddo	201.00	Caddo	242.00
3	Orleans	17.91	East Baton Rouge	23.21	East Baton Rouge	165.90	East Baton Rouge	202.40
4	Caddo	17.49	Calcasieu	19.84	Jefferson	156.40	Calcasieu	177.60
5	East Baton Rouge	13.30	Jefferson	9.199	Calcasieu	138.42	Jefferson	172.50

Crashes by Gender

The general trend in pedestrian crashes by gender shows that the percentage of male pedestrian crashes is higher in all lighting conditions as compared to female pedestrians. Figure 20 shows the trend of pedestrian crashes by gender in different lighting conditions. There were 2,637 male pedestrian crashes and 1,621 female pedestrian crashes in the daytime; 778 male and 311 female pedestrian crashes in dark without streetlight; and 1,635 male and 830 female pedestrian crashes in dark with streetlights. Gender data for 281 crashes were not available. Overall, it shows more number of male pedestrian crashes compared to females.

Figure 20. Pedestrian crashes by gender in different lighting conditions



Crash Modification Factor (CMF)

The crash modification factor is the ratio of crashes with and without light. The CMF of less than one indicates the reduction in crashes due to the provision of light. The study developed CMF by various severity levels both at intersections and segments separately. Initially, the study tried to develop a safety performance model using the crash data, but due to the limited number of intersections with multiple crashes, it was not possible to do so. Around 90% of the intersection locations had just one crash in five years. The study used Equation [1] to develop the CMF. **Thus, the CMF estimated is less robust and cannot be used as a reference in the future. The study made no recommendations based on the estimated CMF.**

CMF at Intersections

The crash modification factor for the intersection was roughly calculated by adding the number of crashes in each location and then dividing it by the total number of sites for these crashes. The analysis was done by different severity levels: fatal, severe, moderate, complaints, and no injury crashes. Table 18 shows all the CMFs by different severity levels. It indicates that CMF of less than 1 for fatal and severe crashes (0.97 for fatal and 0.96 for severe crashes). However, a CMF of more than 1 was estimated for other severity levels. It indicates that the lighting can only reduce fatal and severe injury crashes at intersections. The CMF calculation is limited owing to the fact that there is no information related to pedestrian volumes available in the data set.

Table 18. Rough CMF at intersections

Crash Severity	Number of Crashes (a)		Number of Sites (b)		Average Crash per Site (a/b)		CMF
	Yes	No	Yes	No	Yes	No	
Fatal	53	32	53	31	1.00	1.03	0.97
Severe	89	28	89	27	1.00	1.04	0.96
Moderate	369	65	343	62	1.08	1.05	1.03
Complaint	279	38	261	38	1.07	1.00	1.07
No Injury	102	10	101	10	1.01	1.00	1.01
Total	892	173	847	168	1.05	1.03	1.02

CMF at Segments

A similar approach was used to estimate CMF at segments. Each segment site is roughly 500 ft. long with similar roadway geometry and lighting information. Slightly different from CMF at intersections, the CMF for fatal and complaint crashes at segments was less than 1, and for the rest of the crash severities, it is more than 1. It indicates lighting at segments only able to reduce fatal and complaint injury crashes by 1% and 2%, respectively. Overall, CMF was estimated to be 1.01. The details are shown in Table 19.

Table 19. Rough CMF at segments

Crash Severity	Number of Crashes (a)		Number of Sites (b)		Average Crash per Site (a/b)		CMF
	Yes	No	Yes	No	Yes	No	
Fatal	29	81	28	78	1.03	1.04	0.99
Severe	16	37	16	37	1.00	1.00	1.00
Moderate	48	78	45	77	1.07	1.01	1.05
Complaint	33	62	32	59	1.03	1.05	0.98
No Injury	13	13	13	13	1.00	1.00	1.00
Total	139	271	134	264	1.04	1.03	1.01

Modeling

Two different modeling techniques were utilized: binary logistic regression model for site-specific data and association rule mining for crash data. Data summary tables for both the models were prepared separately. Only nighttime crash data, excluding dawn and dusk data, were used for modeling.

Binary Logistic Regression Model

A binary logistic regression model was developed using light (yes/no) as a binary variable. The main objective of this model is to find different factors associated with lighting at intersections and segments. The model was fitted by using the generalized linear model (GLM) function in R programming software (version 4.1.0). The best fit model was selected based on the minimized Akaike Information Criterion (AIC).

Data Summary at Intersections

Intersection database includes total of 320 intersection sites (i.e., rows) and 22 variables (i.e., columns). It includes 160 intersections with light and the remaining 160 with no light. The majority of these variables were obtained by using Google Maps and ArcGIS. The variables include light information for each site (yes/no) along with geometric features of intersection, major and minor lane information, AADT, population, the prevailing area around the intersection, and the number of crashes. The description of each variable, along with the data summary, is provided in Table 20.

Table 20. Intersection data summary

Variable	Description	Summary
Categorical variables		
Light	Presence of light (for e.g. streetlight) within 150 ft. radius of an intersection.	Yes = 160, No = 160
Intersection type	The geometric configuration of an intersection.	T-intersection = 135, 4-legged = 185
Intersection control type	Type of traffic control used in an intersection	Signalized = 106, Unsignalized = 214
Painted crosswalk	Presence of a painted crosswalk in an intersection.	Yes = 87, No = 233
Crossing island	Presence of crossing island in an intersection.	Yes = 14, No = 306
Visibility of pedestrian	Visibility of pedestrian in an intersection (based on observation of street-view obtained from google map). For example, in some of the location tree/other objects restricts the view, it was coded as “no.”	Yes = 307, No = 13
Area type	Nearby residential/business area (within 150 ft. radius of an intersection)	Yes = 304, No = 16
Urban/Rural	Surrounding area type of an intersection.	Urban = 305, Rural = 15
Major lanes	The number of lanes in the major direction.	One lane = 15, Two lane = 139, Multilane = 166
Major through lanes	The number of through lanes in major direction.	One = 164, More than one = 156
Major turning lanes	Presence of turning lanes in major direction.	Yes = 111, No = 209
Minor lanes	The number of lanes in minor directions.	One lane = 37, Two lane = 230, Multilane = 53
Minor through lanes	The number of through lanes in minor directions.	None = 133, One = 157, More than one = 30
Minor turning lanes	Presence of turning lanes in minor direction.	Yes = 175, No = 145
Population	Number of populations in the surrounding area of an intersection (using ArcGIS)	<100k = 53, 101k-499k = 64, >=500k = 159, unk = 44

Variable	Description	Summary			
Prevailing area	Prevailing area type of an intersection (using ArcGIS).	Rural = 31 , CBD = 52, Fringe = 64, Residential = 72, Industrial/commercial = 87, unknown = 14			
Continuous variables		**Min.**	**Max.**	**STD.**	**Mean**
Major speed	Speed limit in major direction (mph)	15	65	10.04	36.39
Minor speed	Speed limit in minor direction (mph)	10	55	7.11	26.59
Major width	Width of roadway in major direction (ft.)	13.28	224.15	35.09	51.78
Minor width	Width of roadway in minor direction (ft.)	12.08	102.25	16.14	29.43
Major AADT	Average annual daily traffic in the major direction	300	107,100	15210.09	14,355
Total crash	Total number of crash in an intersection	1	6	0.51	1.15

CBD = CBDs are downtown areas characterized by moderate to heavy pedestrian volumes, lower vehicle speeds, and dense commercial activity. Fringe = Fringe areas include suburban and commercial retail activity areas and typically have moderate pedestrian volumes. These areas may also include high-rise apartments

Model Results at Intersections

Table 21 shows the model result at intersections in detail. The last column in the table shows the odds ratio (OR) that compares the benefit of lighting at intersections compared to no lighting at all. Consequently, all variables which were not significant at a 95% confidence level were removed. The process was done repeatedly to get the significant variables for each best-fit model.

Intersections with a painted crosswalk compared to intersections with raised median are more likely to be lighted [OR = 3.13]. Intersections are more likely to be lighted where the visibility of pedestrians is very low [OR = 10.38]. When there are multi-lanes at any intersections approach, it is more likely to be lighted [OR of 2.25 and 4.85]. With the larger population in the surrounding, intersections are less likely to be lighted [OR 0.47]. Higher speed indicates the possibility of lighted intersections [OR = 1.06]. Though the variable "Prevailing area" was not found to be significant in the model, it was used as it did not affect the goodness of fit of the model.

Table 21. Model results at intersections (Light = 1, No Light = 0)

Coefficients	Attribute	Baseline or Reference	Estimate	Std. Error	p-value	Odds Ratio (OR)
Intercept			−3.76	1.01	<0.001	0.02
Painted crosswalk	No	Yes	1.14	0.35	0.001	3.13
Visibility of pedestrian	No	Yes	2.34	0.76	0.002	10.38
Minor lanes	Two lane	Single Lane	0.81	0.53	0.12	2.25
	Multilane		1.58	0.63	0.01	4.85
Population	101k-499k	<100k	−0.76	0.43	0.08	0.47
	>=500k		−1.45	0.39	<0.001	0.23
Prevailing area	CBD	Rural	0.06	0.61	0.91	1.06
	Fringe		0.70	0.60	0.24	2.01
	Residential		−0.03	0.57	0.94	0.97
	Industrial/ Commercial		0.66	0.57	0.24	1.93
Major speed	Cont. variable		0.06	0.01	<0.001	1.06
AIC = 369.30, Log-likelihood = -170.65						

Data Summary at Segments

Segment database includes a total of 371 segments (i.e., rows) and 16 variables (i.e., columns). Table 22 shows information in detail. The majority of these variables were obtained by using Google Maps and ArcGIS. The variables include light information for each site (yes/no) along with geometric features of the segment, major and minor lane information, AADT, population, prevailing area, and the number of crashes. From the primary observation, the variable ‘population’ was removed as it had around 50% missing values. Two of the other variables (road type, special treatment) were also removed as they were highly skewed. The rest of the 13 variables were only utilized to develop the binary logistic regression model (light as dependent and all other variables as an independent).

Table 22. Segment data summary

Variable	Description	Summary			
Categorical variables					
Light	Presence of light (for e.g. streetlight) within 150 ft. radius of an intersection.	Yes = 121, No = 250			
Lanes	Total number of lanes of the roadway segment.	Two = 215, More than two = 156			
Road type	Type of roadway in terms of traffic direction	One-way = 4, Two-way = 367			
Functional classification	Functional classification of the roadway segment.	Arterial = 164, Collector = 122, Local = 85			
Median divided	Presence of median strip or central reservation area that separates opposing lanes of traffic.	Yes = 109, No = 262			
Median type	Type of median construction	Concrete = 32, Grass = 73, Painted = 266			
Sidewalk	Presence of sidewalk	Yes = 42, No = 329			
Visibility of pedestrian	Visibility of pedestrian in an intersection (obtained from google view).	Yes = 122, No = 249			
Area type	Nearby residential/business area (within 150 ft. radius of selected crash location)	Yes = 116, No = 255			
Urban/Rural	Surrounding area type.	Urban = 253, Rural = 118			
Population	Number of populations in the surrounding area of an intersection (using ArcGIS)	<100k = 61, 101k-499k = 52, >=500k = 79, unk = 179			
Prevailing area	Prevailing area type of an intersection (using ArcGIS).	Rural = 132 , CBD = 26, Fringe = 42, Residential = 112, Industrial/commercial = 59			
Special treatment	Any special treatment is provided within the segment for alerting drivers as well as pedestrians.	Yes = 11, No = 360			
Continuous variables		**Min.**	**Max.**	**STD.**	**Mean**
Speed limit	The posted speed limit on the segment (mph)	20	75	10.05	49.65
AADT	Average annual daily traffic in the segment	69	159200	21830	16972
Total crash	Total number of crashes that occurred on the segment	1	3	0.32	1.10

Model Result at Segments

The primary model identified visibility of pedestrians, prevailing area, number of lanes, AADT, and speed limit as statistically significant variables. All these significant variables were used to get the final model. Table 23 shows the final model. The results indicate that segments with more than two lanes are more likely to be lighted [OR of 3.13]. However, the effect of higher AADT is more inclined towards no lighting at segments [OR of 0.99]. An increase in the speed limit was more likely to increase the likelihood of having lighting at segments [OR of 1.12]. At segments where the visibility of pedestrians was very poor, the segments were more likely to be lighted [OR of 3.13]. Compared to the rural areas, all other area types were more likely to have no lighting [OR of less than 1].

Table 23. Model result at segments (Light = 1, No Light = 0)

Coefficients	Attribute	Control	Estimate	Std. Error	p-value	Odds ratio (OR)
Intercept			−2.65	1.06	0.022	0.07
Lanes	More than two	Two	1.14	0.35	0.001	3.13
AADT	Cont. variable	---	−4.42	<0.001	<0.001	0.99
Speed limit	Cont. variable	---	0.11	0.02	<0.001	1.12
Visibility of pedestrian	No	Yes	1.14	0.32	<0.001	3.13
Prevailing area	CBD	Rural	−3.00	0.74	<0.001	0.05
	Fringe		−1.54	0.65	0.018	0.21
	Residential		−2.06	0.59	<0.001	0.13
	Industrial/ Commercial		−2.63	0.65	<0.001	0.07
AIC value = 294.82, Log-likelihood = -138.41						

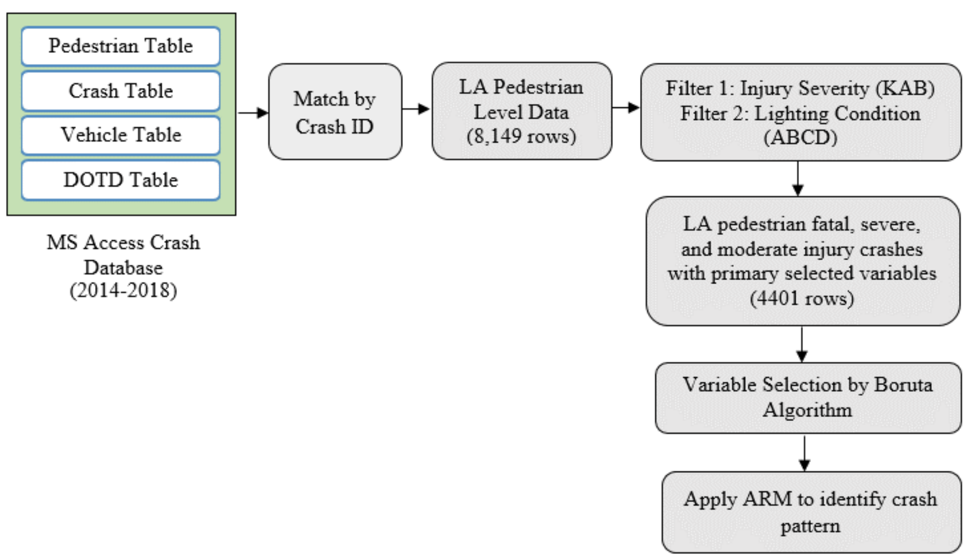
Data Mining

The previously used binary logistic regression model was performed based on site-specific data. The model identified important geometric attributes relevant to pedestrian crashes in the absence of light. In addition, to explore several contributing factors (human, vehicle, roadway, and environmental) to pedestrian crashes, the study utilized Association Rule Mining (ARM) as a data mining technique. The ARM helps to identify the hidden pattern of crash risk factors according to three different lighting conditions (daylight, dark with light, and dark without light). Unlike statistical models, the ARM model may be a better tool as no variables are assigned as dependent or independent.

Data Preparation

The same pedestrian crashes data between 2014 and 2018 (8,149 crashes) were initially considered for the ARM model, which includes 622 (7.63%) fatal crashes, 774 (9.50%) severe injury crashes, 3,048 (37.40%) moderate injury crashes, 2,869 (35.21%) complaints injury crashes, and 836 (10.26%) no injury types. The study used only the first three severity levels of crashes (fatal, severe, and moderate injury crashes) for the data mining. After checking the availability of variables required in each crash data for the data mining, the study filtered 4,401 injury crashes (fatal = 600, severe = 764, moderate = 3,037). Next, because of the different nature of the model, the data needs to be framed separately for the analysis. First, the primary database was created using a matching criterion (crash ID) by merging four data tables (pedestrian table, crash table, vehicle table, and DOTD table). The severity of crashes are define in a KABCO scale (K = Fatal, A = Severe, B = Moderate, C = Complaint, O = No injury). In addition, the lighting condition associated to each pedestrian crash is defined in an ABCDEFYZ scale (A = Daylight, B = Dark-no-light, C = Dark-continuous light, D = Light at intersection only, E = Dusk, F = Dawn, Y = Unknown, Z = Other). Lighting conditions ‘C’ and ‘D’ were merged to get the condition ‘dark-with-light’. Categories ‘E,’ ‘F,’ ‘Y,’ and ‘Z’ were not included in the analysis. Figure 21 shows the data preparation flow chart.

Figure 21. Data preparation flow chart



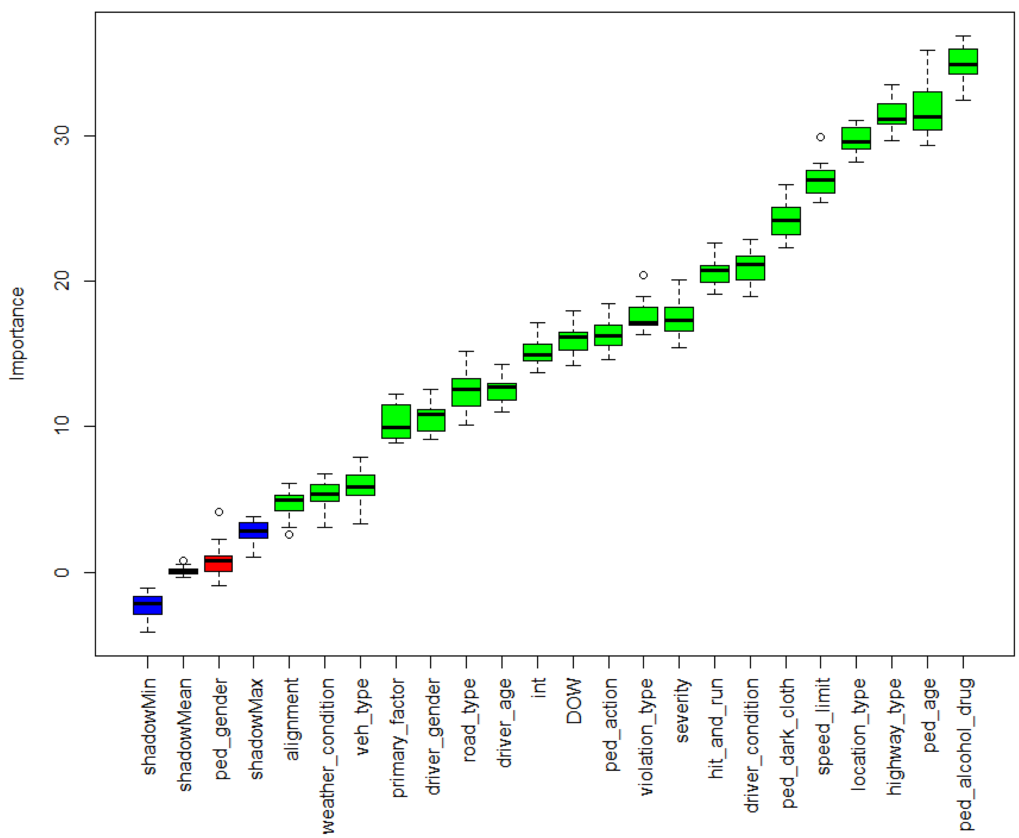
Descriptive Statistics

Appendix B shows the descriptive statistics that revealed several intriguing crash characteristics comparing three different lighting conditions: daylight, dark with light, and dark without light. Each variable was tagged separately as a label (variable label), which the study used during the data mining. The table shows that the majority of the pedestrians in dark conditions were reported with alcohol or drug use (14.81% in the daylight compared to 47.74% in dark with light and the remaining 37.46% in dark without light). Out of the 600 fatal crashes, 21.50%, 38.17%, and 40.33% were in the day, dark with light, and dark without light, respectively. It shows around 80% of the fatal crashes during the five years occurred in dark conditions. Pedestrians and drivers in the dataset represent the individuals involved in the crash.

Variable Selection by Boruta Algorithm

Boruta algorithm is used for variable selection based on the random forest (RF) model. This algorithm was utilized to select the top variables based on a classification model (using lighting condition as an outcome variable and all other variables as dependent). First, the algorithm adds randomness to the provided data by creating shuffled copies of all variables which are called shadow features (shown in blue color in Figure 22). At every iteration, the algorithm checks whether a real variable has higher importance than the best of its shadow features. Only the variable 'pedestrian gender' was rejected by the algorithm (shown in red color).

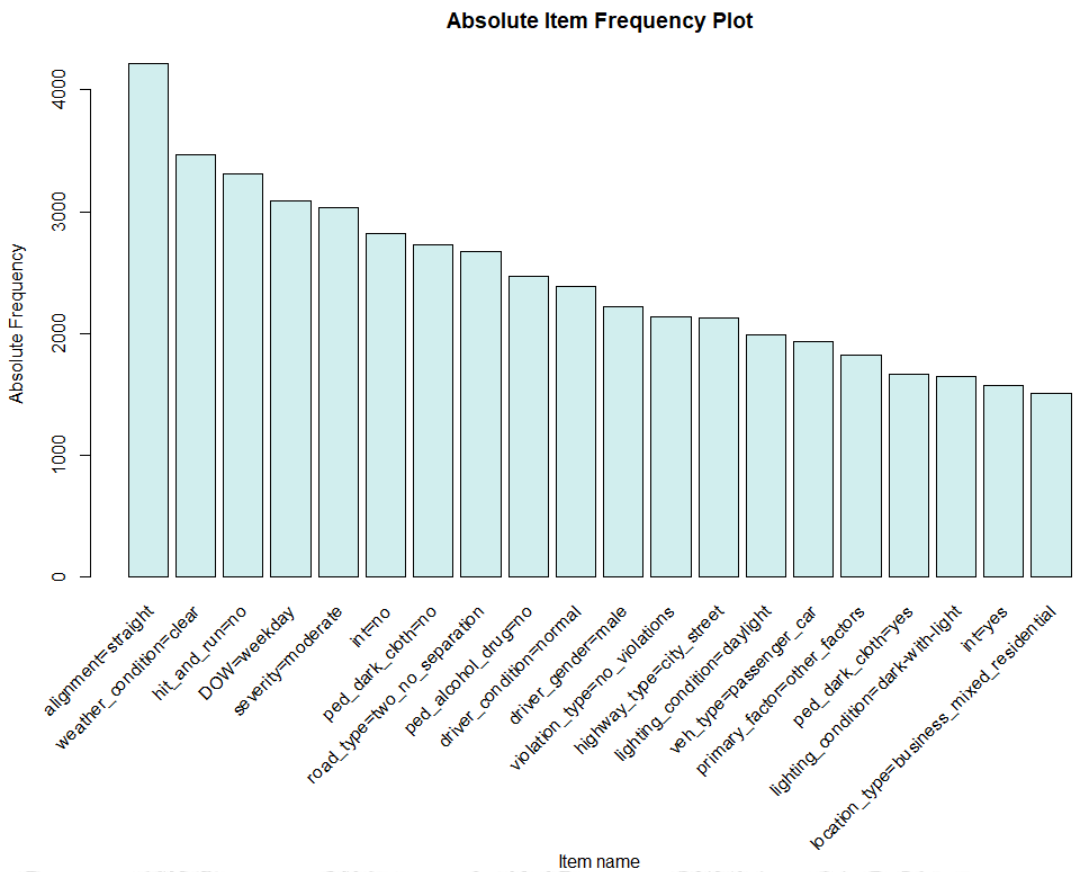
Figure 22 Variable Selection by Boruta Algorithm



Results from ARM Model

A total of 21 variables were finally utilized for further analysis. The final dataset comprised 4,401 crashes with 87 items or variable categories. Figure 23 is the absolute item frequency plot for the top twenty items that shows numeric frequencies of each item independently in the entire dataset. The top five most frequently occurring items in the dataset were alignment = straight (4,215), weather condition = clear (3,468), hit and run = no (3,307), DOW = weekday (3,094), severity = moderate (3,037).

Figure 23. Absolute item frequency plot (top 20 variable categories)



In data mining, the Apriori algorithm uses a ‘bottom-up’ technique to find the association rules [151]. To generate meaningful rules using ARM, it is critical to define an appropriate minimum level of support and confidence; otherwise, the algorithm could generate abundant rules. After a substantial number of trials and errors, the minimum support and confidence values were selected. It might be argued that the values of these parameters (support and confidence) were subjective and determined on a case-by-case basis [152]. In general, a high lift value suggests a stronger relationship between antecedents and consequents [153]. Considering this point of view, the minimum threshold for lift value was chosen as 1.1. The study was limited to up to four-itemset rules for ease of interpretation. A rule 'ID' was designed to identify and explain any given pattern associated with generated rules. Using the selected variables, ARM was applied to three separate scenarios (case 1: daylight, case 2: dark-with-light, case 3: dark-no-light).

Case 1: Lighting Condition = Daylight

The variable 'lighting_condition' was set to 'daylight' as the right-hand side (RHS) to mine the association rules for case 1. After several trials and errors, the minimum support and confidence values were set at 0.1% and 45%, respectively. Initially, the algorithm generated 23,150 rules, which contained many redundant rules. After pruning redundant rules [154], 107 rules remained and were sorted according to descending order of lift value. Table 24 lists the top 20 rules for this case. The variable labels were already defined in the data summary table. The first rule has a 'support' value of 0.11%, a 'confidence' value of 83.33%, and a 'lift' value of 1.84. Here, the itemset {ped_age = 15-24, weather_condition = rain, highway_type = us_highway} appeared 5 times in the daylight condition. Therefore, the support of this rule is 5 divided by 4401 (total rows of the entire database), which is 0.001136 or 0.11%. Again, the itemset {ped_age = 15-24, weather_condition = rain, highway_type = us_highway} appeared 6 times in the entire dataset. Therefore, the confidence of the first rule is 5 divided by 6, which is 0.8333 or 83.33%. Again, support of the itemset {ped_age = 15-24, weather_condition = rain, highway_type = us_highway} is 6 divided by 4401. Among all the 4,401 crashes, 1,994 crashes occurred in daylight conditions. So, the support of {daylight} is 1,994 divided by 4,401. Finally, the lift of the first rule can be found by support (X, Y)/ support (X)*support (Y), which is $(5 \div 4401)/[(6 \div 4401) \times (1994 \div 4401)]$. A lift (L) value of more than 1 suggests that 15 to 24 aged pedestrians are more likely to involve in crashes on U.S. highways during rainy weather conditions in the daylight.

Table 24. Top 20 Association rules for pedestrian crashes in daylight condition

ID	Antecedent	S (%)	C (%)	L
R1	{ped_age = 15-24, weather_condition = rain, highway_type = us_highway}	0.11	83.33	1.84
R2	{alignment = curve, driver_condition = alcohol_drug}	0.18	80.00	1.77
R3	{ped_age = <15}	9.73	73.67	1.63
R4	{violation_type = failure_to_yield}	4.29	72.97	1.61
R5	{driver_condition = alcohol_drug, veh_type = others}	0.14	66.67	1.47

ID	Antecedent	S (%)	C (%)	L
R6	{ped_age=15-24, alignment = curve, veh_type = light_truck}	0.14	66.67	1.47
R7	{driver_condition = illness_fatigued_asleep}	0.39	65.38	1.44
R8	{driver_condition = inattentive_distracted}	9.91	65.37	1.44
R9	{ped_age = >64}	4.66	64.87	1.43
R10	{speed_limit = <30}	17.66	62.81	1.39
R11	{driver_condition = normal, driver_gender = unk}	0.23	62.50	1.38
R12	{DOW = weekend, weather_condition = rain, highway_type = interstate}	0.11	62.50	1.38
R13	{DOW = weekend, weather_condition = rain, speed_limit = >55}	0.11	62.50	1.38
R14	{alignment=curve, location_type = open_country}	0.32	60.87	1.34
R15	{road_type = other_unk}	0.80	60.34	1.33
R16	{driver_age=>64}	5.75	59.39	1.31
R17	{location_type = business_mixed_residential, weather_condition = rain, highway_type = us_highway}	0.23	58.82	1.30
R18	{ped_action = xing_segment, alignment=curve, location_type = business_mixed_residential}	0.16	58.33	1.29
R19	{ped_age = 41-64, location_type = open_country , driver_age = 25-34}	0.16	58.33	1.29
R20	{ped_action = xing_int}	12.54	56.91	1.26

The first rule (R1) suggests that 15-24 years aged pedestrians are likely to be involved in crashes during rainy weather conditions on US highways. This age group is also more likely to be involved in light truck crashes on curves (R6). Pedestrian crashes on curve segments is also identified with driver alcohol/drug involvement (R2) and open country location (R14). Driver physical condition is also a key contributing factor to pedestrian crashes, such as illness/fatigued/asleep (R7), and inattentive/distracted (R8). The results also show the lowest and highest age groups of pedestrians (<15 years, >64 years) involved in crashes during daylight (R3, R9). Pedestrians are involved in crashes on both low-speed (under 30 mph) and high-speed (over 55 mph) roads (R10, R13). Pedestrians are involved in crashes on interstate highways during rainy weather on weekends, which is quite surprising (R12).

Case 2: Lighting Condition = Dark with light

To mine the association rules for case 2, the 'lighting_condition' variable was set to 'dark_with_light' as a consequence. Following multiple rounds of trial and error, the minimal values of support (0.5%) and confidence (50%) were selected. The program initially produced 4,605 rules, many of which were repetitive. After pruning, 856 rules remained, which were sorted by lift value in descending order. The top 20 rules for this case are listed in Table 25.

Table 25. Top 20 Association rules for pedestrian crashes in dark with light condition

ID	Antecedent	S (%)	C (%)	L
R1	{ped_alcohol_drug = yes, driver_age = 55-64}	0.84	72.55	1.93
R2	{road_type = two_separation, veh_type = light_truck, violation_type = careless_operation}	0.66	72.50	1.93
R3	{ped_alcohol_drug = yes, highway_type = city_street}	2.39	69.08	1.84
R4	{ped_alcohol_drug = yes, speed_limit = 30-35}	1.91	68.29	1.82
R5	{ped_alcohol_drug = yes, ped_action = xing_int}	1.16	67.11	1.79
R6	{ped_alcohol_drug = yes, road_type = one_way}	0.75	66.00	1.76
R7	{ped_dark_cloth=yes,primary_factor=ped_violation,driver_age=35-44}	0.66	65.91	1.76
R8	{ped_alcohol_drug = yes, int = yes}	2.23	65.33	1.74
R9	{severity = fatal, location_type = business_mixed_residential, violation_type = others}	0.93	64.06	1.71
R10	{location_type = business_mixed_residential, veh_type = light_truck, violation_type = careless_operation}	0.73	64.00	1.70
R11	{severity = severe, speed_limit = >55}	0.59	63.41	1.69
R12	{ped_alcohol_drug = yes, driver_age = 25-34, driver_gender = female}	0.61	62.79	1.67
R13	{road_type = two_separation, veh_type = others, int = yes}	0.57	62.50	1.67
R14	{road_type = two_separation, highway_type = city_street, speed_limit = 40-45}	0.68	62.50	1.67
R15	{ped_dark_cloth = yes, location_type = other_locality}	0.52	62.16	1.66
R16	{primary_factor = other_factors, road_type = two_separation, driver_age = 25-34}	1.55	61.82	1.65
R17	{ped_action = xing_segment, location_type = business_mixed_residential, violation_type = others}	1.14	61.73	1.64
R18	{ped_alcohol_drug = yes, location_type = business_mixed_residential}	2.95	61.61	1.64
R19	{ped_alcohol_drug = yes, speed_limit = <30}	0.91	61.54	1.64
R20	{ped_action = inappropriate, location_type = business_mixed_residential, driver_age = 25-34}	0.98	61.43	1.64

The item {pedestrian alcohol/drug = yes} appeared 9 times out of the top 20 rules implying that pedestrian intoxication is one of the key factors leading to crashes at dark with light. Other crash contributing factors associated with intoxicated pedestrians are driver age group 55 to 64 years (R1), city street (R3), speed limit (<30 mph, 30-35 mph) (R4, R19), pedestrian crossing at intersection location (R5), one-way street (R6), female drivers (R12), and business with mixed residential area (R18). Fatal pedestrian collisions are more likely to occur in businesses with mixed residential areas (R9), but severe pedestrian collisions are more common on high-speed highways with a posted speed limit of over 55 mph (R11).

Case 3: Lighting Condition = Dark without light

In this case, the 'lighting_condition' variable was set to 'dark_no_light' as RHS. After numerous trials and errors, the minimum support and confidence value was set at 0.4% and 55% correspondingly. Initially, the algorithm produced 1,006 rules, which contained many redundant rules. After trimming, 236 rules remained and were arranged according to descending order of lift value. Table 26 list the top 20 rules for this case.

Some intriguing crash patterns were identified in the dark with the absence of lights. Eight of the top twenty association rules identified dark-clothed pedestrians as a contributing factor in collisions (R5, R6, R8, R11, R14, R16, R17, and R19). Other contributing factors associated with this category were high-speed limit (>50 mph), fatalities on interstate highway type, pedestrian action as primary contributing factors, on a state highway in a residential area, and pedestrians walking with the traffic on parish road. Fatal crashes were associated with 25-40 years aged pedestrians in residential areas (R2, L = 4.07), dark-clothed pedestrians in the residential area (R19, L = 3.79), and inappropriate pedestrian action (R20, L = 3.79). Pedestrians walking with (R4, R10, R13, R17) or against (R1, R3) the traffic was also an important contributing factor to crashes in the dark-no-light conditions.

Table 26. Top 20 Association rules for pedestrian crashes in dark without light condition

ID	Antecedent	S (%)	C (%)	L
R1	{ped_action = walking_against_traffic, location_type = residential, highway_type = state_highway}	0.45	74.07	4.32
R2	{severity = fatal, ped_age = 25-40, location_type = residential}	0.68	69.77	4.07
R3	{ped_action = walking_against_traffic, speed_limit = 50-55}	0.61	69.23	4.04
R4	{ped_action = walking_with_traffic, highway_type = parish_road, violation_type = no_violations}	0.61	69.23	4.04
R5	{ped_dark_cloth = yes, primary_factor = ped_actions, speed_limit = >55}	0.55	68.57	4.00
R6	{ped_dark_cloth = yes, speed_limit = 50-55}	3.11	68.16	3.97
R7	{ped_alcohol_drug=yes, speed_limit=50-55}	1.93	68.00	3.96
R8	{ped_dark_cloth=yes,speed_limit=>55,violation_type=no_violations}	0.86	67.86	3.96
R9	{ped_action=inappropriate,speed_limit=>55,violation_type=no_violations}	0.48	67.74	3.95
R10	{ped_action=walking_with_traffic,ped_age=25-40,primary_factor=ped_actions}	1.00	67.69	3.95
R11	{ped_dark_cloth=yes, severity=fatal, highway_type=interstate}	0.52	67.65	3.94
R12	{highway_type=us_highway, speed_limit=>55}	0.57	67.57	3.94
R13	{ped_action=walking_with_traffic, speed_limit=50-55}	1.39	67.03	3.91
R14	{ped_dark_cloth=yes,primary_factor=ped_actions,highway_type=interstate}	0.55	66.67	3.89
R15	{ped_alcohol_drug=yes,primary_factor=other_factors,violation_type=no_violations}	0.45	66.67	3.89

ID	Antecedent	S (%)	C (%)	L
R16	{ped_dark_cloth=yes,location_type=residential,highway_type=state_highway}	1.61	66.36	3.87
R17	{ped_dark_cloth=yes,ped_action=walking_with_traffic,highway_type=parish_road}	0.66	65.91	3.84
R18	{location_type=residential,highway_type=state_highway,driver_age=25-34}	0.66	65.91	3.84
R19	{ped_dark_cloth=yes, severity=fatal, location_type=residential}	0.89	65.00	3.79
R20	{severity=fatal,ped_action=inappropriate,violation_type=no_violations}	1.14	64.94	3.79

Cost-Benefit Analysis

A cost-benefit analysis was conducted separately for intersections and segments. Eight streetlights were assumed for a typical intersection and twelve streetlights for a typical 500 ft. long segment as a source of light. At one intersection, at least two streetlights in each approach covering both ways of traffic were assumed, making eight for a typical four-legged intersection with two-way traffic movement. Cost includes the installation of light, its maintenance, and operation cost categorized as one-time and recurring costs. On the other hand, the benefit includes a reduction in crashes in terms of monetary value. After an extensive review of several available CMFs, the study decided to use CMF for 0.56 taken from the CMF Clearinghouse website. This CMF is for rural crashes for all crash severity types and was the most relevant CMF to our study on the website. CMF of 0.56 indicates that the installation of light would reduce traffic crashes at that location by 44%.

At Intersections

All 160 intersections with no streetlights were used for the analysis. To estimate the benefit of a reduction in the number of crashes (0.44 of current crash data), it was converted to the monetary value by multiplying by the average cost, as shown in Table 12. For example, a typical intersection with 2 fatal crashes would have a benefit of 2*0.44*1,710,561 [Crash type Fatal * (1-CMF) * Crash Cost for Fatal Crash]. As discussed previously, the cost is calculated by dividing all the items into two components. First is a one-time occurring cost, including the cost of the streetlight, all the fixtures, and excavation/backfilling. The second is the recurring cost that occurs every year. The total cost for the installation and maintenance of one streetlight for five years is $11,155 (previously calculated in Table 13). For a five-year period with eight streetlight poles, that would be $89,240. Table 27 below shows the cost-benefit ratio for ten different intersection sites. For instance, at intersection 4I-5 with the installation of streetlights, there would have been a reduction in crashes of $444,479, while the cost of installation, operation, and maintenance of streetlights for five years at that specific location is $89,240. With that, the ratio of benefit to the cost ($444,479/$89,230) would be 4.98. It indicates that the benefit far exceeds the construction and maintenance cost.

Table 27. Cost and benefit analysis at intersections

Intersection	Number of crashes for each severity					Clearing house CMF	Percentage reduction in crashes	Total Benefit Cost	Total cost of installing and maintaining eight streetlights for five years at Intersection	Cost-Benefit Ratio
	Fatal	Severe Injury	Moderate Injury	Complaint	No Injury					
4I-5	0	1	3	0	0	0.56	0.44	444,479	89,240	4.98
2I-73	0	1	1	0	0	0.56	0.44	291,731	89,240	3.27
2I-29	0	0	2	0	0	0.56	0.44	152,749	89,240	1.71
2I-25	0	0	1	1	0	0.56	0.44	102,174	89,240	1.14
2I-24	2	0	0	0	0	0.56	0.44	1,505,294	89,240	16.87
2I-21	0	1	0	1	0	0.56	0.44	241,156	89,240	2.70
2I-20	0	0	1	1	0	0.56	0.44	102,174	89,240	1.14
2I-19	1	1	0	0	0	0.56	0.44	968,003	89,240	10.85
2I-18	0	2	0	0	0	0.56	0.44	430,712	89,240	4.83
2I-12	0	0	1	0	1	0.56	0.44	87,366	89,240	0.98

Using cost-benefit data from all 160 intersections, a multiple linear regression model was developed to find the association of different severity levels of crashes at intersections to the overall benefit in monetary value. Independent variables were considered a benefit in terms of reducing crashes at each severity level, assuming crash value from Table 27 and CMF of 0.56. For example, any intersections with no light with 2 fatal crashes would benefit 2*1,710,561 *(1-CMF) in monetary value after the light installation. The measure (1-CMF) indicates the reduction in crashes due to lighting. Crash cost per crash was assumed as $1,710,561 for fatal, $489,446 for severe injury, $173,578 for moderate injury, $58,636 for complaint, and $24,982 for property damage only crashes. Table 28 shows the relation to estimating benefits due to crash reduction. All the independent or x-variables in the models were statistically significant (p of less than 0.05) at a 5% level of significance.

Table 28. Multiple linear regression model at intersections to estimate the benefit

Model Fitting	R-square – 0.42, Adjusted R – square = 0.40, Number of observations = 160
Multiple Linear Regression Model	Benefit, in $ = [0.463 * Number of Fatal Crashes * Cost for K + 2.339 * Number of Severe Crashes * Cost for A + 4.595 * Number of Moderate Crashes * Cost for B + 16.220 * Number of Complaint Crashes * Cost for C + 96.671 * Number of No Injury Crashes * Cost for O] * (1-CMF)
Fixed Estimates	where, Cost for K = $1,710,561, Cost for A = $ 489,446 , Cost for B = $ 173,578, Cost for C = $ 58,636 , Cost for O = $ 24,982 and 1- CMF = 0.44

At Segments

All 250 segments with no streetlights were used for the analysis. The same cost required for installing and operating one streetlight for five years is assumed for the segment too ($11,155). The number of streetlights for a segment of 500 ft. is calculated by multiplying the height of the pole by 3 (the spacing for streetlights is generally calculated by 2.5-5 times the height of the pole) times the streetlight height (28 ft.) on both ends of the road. So, 28*3 = 84 ft. and 500/84= 5.9, which is almost equal to 6 poles. For both sides of the road segment, the number would double. Hence, 12 poles for a 500 ft. segment of a road were used for a segment. With that, the total cost for 12 poles for five years on a 500 ft. length segment would be $133,860. A similar procedure was used to estimate the benefit using the CMF of 0.56. Table 29 below shows the cost-benefit analysis only at 10 different segments. For instance, at intersection S3 with the installation of streetlights, there would have been a reduction in crashes of $752,647, while the cost of installation, operation, and maintenance of streetlights for five years at that specific location is $133,860. As a ratio of benefit to the cost ($752,647 /$133,860), the ratio was estimated as 5.62.

Table 29. Cost and benefit analysis at segments

Segment	Number of crashes for each severity					Clearinghouse CMF	Percentage reduction in crashes	Total Benefit Cost	Total cost of installing and maintaining twelve streetlights for five years for 500 ft. segment	Cost-Benefit Ratio
	Fatal	Severe Injury	Moderate Injury	Complaint	No Injury					
S3	1	0	0	0	0	0.56	0.44	752,647	133,860	5.62
S4	1	0	0	0	0	0.56	0.44	752,647	133,860	5.62
S5	0	0	1	0	0	0.56	0.44	76,374	133,860	0.57
S6	1	0	0	0	0	0.56	0.44	752,647	133,860	5.62
S9	0	0	1	0	0	0.56	0.44	76,374	133,860	0.57
S10	1	0	0	0	0	0.56	0.44	752,647	133,860	5.62
S12	1	0	0	0	0	0.56	0.44	752,647	133,860	5.62
S13	1	0	0	0	0	0.56	0.44	752,647	133,860	5.62
S14	0	0	0	1	0	0.56	0.44	25,800	133,860	0.19
S20	0	0	0	0	1	0.56	0.44	10,992	133,860	0.08

Using data from all 250 segments without light, a multiple linear regression model was developed to find the association of different severity levels of crashes at segments to the overall benefit in monetary value. Independent variables were considered a benefit in terms of reducing crashes at each severity level, assuming crash value from Table 29 and CMF of 0.56. The same crash cost per crash was taken as $1,710,561 for fatal, $489,446 for severe injury, $173,578 for moderate injury, $58,636 for complaint, and $24,982 for property damage only crashes. Table 30 shows the relation to estimate benefit due to crash reduction. All the independent or x-variables in the models were statistically significant (p of less than 0.05) at 5% level of significance.

Table 30. Multiple linear regression model at segments to estimate benefits

Model Fitting	R-square – 0.33, Adjusted R – square = 0.32, Number of observations = 250
Multiple Linear Regression Model	Benefit, in $ = [0.616 * Number of Fatal Crashes * Cost for K + 2.161 * Number of Severe Crashes * Cost for A + 5.661 * Number of Moderate Crashes * Cost for B + 11.758 * Number of Complaint Crashes * Cost for C + 32.361 * Number of No Injury Crashes * Cost for O] * (1-CMF)
Fixed Estimates	Where, Cost for K = $1,710,561, Cost for A = $ 489,446 , Cost for B = $ 173,578, Cost for C = $ 58,636 , Cost for O = $ 24,982 and 1-CMF = 0.44

Takeaway from Crash Reports

It is a surprise to see that between 2014 and 2018, there were 12.9% of total pedestrian fatalities occurred on freeways or interstates based on the initial crash analysis. To investigate this further, the research team downloaded all available fatal pedestrian crash reports (97.6%) on interstates or freeways and went through each location. Google Maps was used to illustrate each fatal crash location characteristic. After going through each report, the study found mainly three types of pedestrian crashes at interstates.

Type 1: 26 fatalities occurred when driver/passenger(s) got out of their vehicles to check their crashed vehicle or to offer help to victims from a prior crash. Figure 24 (a) illustrates the location of such a crash where someone got out of his/her car trying to help two entrapped drivers from a two-vehicle collision that occurred two minutes prior and was killed by a fast-approaching truck. Figure 24 (b) illustrates the location of a fatal pedestrian crash where the first driver lost control of his/her vehicle and was involved in a crash that made his/her vehicle overturn and detached a connected trailer. The driver stepped out of his/her car, and another vehicle traveling on the roadway hit the trailer, which struck the first driver and killed him/her.

Figure 24. Locations of few fatal pedestrian crashes

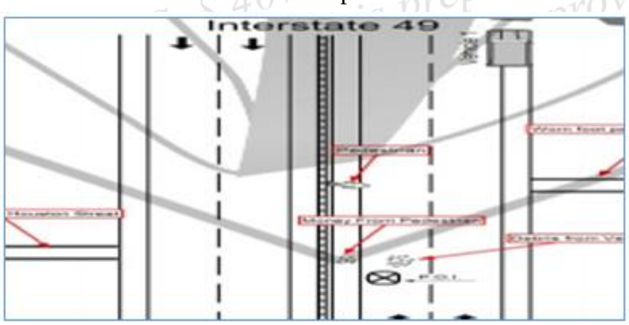
a. Location of a recorded fatal pedestrian crash at 3:30 a.m. on I-110

b. Location of a recorded fatal pedestrian crash at midnight on I-49

Type 2: 57 people died because they walked along or crossed a freeway. Figure 25 (a) illustrates the location of such a typical crash, and Figure 25 (b) is the collision diagram from the original crash report.

Figure 25. Location of another type of pedestrian crash

a. Location of fatal pedestrian crash when he was trying to cross the freeway at 2:30am



A pedestrian was attempting to cross over the interstate in dark conditions). The driver stated that she did not see the victim until the impact took a place.

b. Crash diagram of the same crash

Type 3: One fatal pedestrian crash was caused by a person intentionally jumping off an overpass to freeway traffic below, classified as suicide.

To reduce the number of so-called pedestrian crashes in Type 1, drivers and passengers must be aware of the extremely high risk of getting hurt when stepping out of the vehicle on the freeway, which can be done through education and safety campaigns. A reduction in the number of pedestrian crashes in Type 2 calls for targeted enforcement and education actions. Pedestrians should not use freeways. Apparently, the countermeasure to pedestrian crashes on an interstate/freeway is totally different from pedestrian crashes elsewhere since pedestrians are totally prohibited. Lighting is not the solution to such crashes, even though more than 74% of fatal crashes occurred at night.

Specific to fatal crashes at night that occurred at all roadway types, most of the drivers mentioned that they were not able to see pedestrians due to dark clothing, which is also a major part of the finding from the data mining analysis.

Conclusions

The primary objective of this study is to review lighting policies/guidelines/practices in Louisiana and other states, investigate the impact of lighting conditions on pedestrian crashes, and recommend targeted practical lighting requirements based on the analysis.

The collected lighting policies and guidelines show that the majority of the states and cities within the United States have similar pedestrian lighting or overall streetlight policies. Almost all previous studies on lighting and crashes concluded the positive impact of lighting on pedestrian or overall traffic crash fatalities. The analysis was conducted in four different folds – general crash analysis, crash modification factor, modeling that includes binary logistic and data mining, and cost-benefit analysis.

For the pedestrian general crash analysis, 8,149 pedestrian crashes from 2014 to 2018 were extracted from the DOTD database. Of 8,149 crashes, 44.93% occurred at nighttime or dark, and the remaining 55.07% occurred during the daytime. The study utilized all 8,149 crashes for the general crash analysis. The crash statistics show that around 49% of crashes occurred between 6 p.m. and 6 a.m. Out of 622 fatal crashes, almost 74% occurred between 6 p.m. and 6 a.m. Nearly 90.01% of the crashes occurred in urban while the remaining 7.46% occurred in rural areas, and 2% were with unknown area types. Surprisingly, 20% of rural crashes resulted in fatalities, compared to only 7% in urban regions. In rural areas, the majority of the pedestrian fatalities (62.71%) occurred in the dark without lighting. It indicates that pedestrians are at higher risk in the rural areas at dark without lighting. Looking at the fatality rate by lighting, the ratio of fatal crashes at non-intersection locations with no light is high compared to intersections with no light. The study investigated the data by parishes as well. It shows that Tangipahoa parish recorded the most fatal crashes, followed by Calcasieu, and Orleans parishes.

The spatial distribution of 2,432 pedestrian crashes by intersection locations shows that around 38% of the intersections had one crash during five years (2014-2018). It indicates the potential issue that research studies need to be aware of, especially during the modeling. The estimated CMF shows that fatal and severe pedestrian crashes decreased with the availability of lighting at intersection locations but not for other remaining injury severity levels. **The estimated CMF is less robust and cannot be used as a reference in the future.**

The binary logistic models were developed separately for intersections and segments to evaluate the association between the site-specific factors and the presence of light. The model for intersections revealed the presence of raised median, low visibility of pedestrians, multilane approaches, and higher approach speed are more likely to be lighted. At segments, the number of lanes, speed limit, and visibility of pedestrians was identified as significant factors affecting the presence of lights. Both models show that areas where the visibility of pedestrians is very low tend to have lighting.

The ARM was developed to identify the hidden pattern of crash risk factors under three different lighting conditions (daylight, dark with light, and dark without light). By mining data in the daylight conditions, factors such as rainy weather conditions, drivers' physical conditions like illness/fatigued/asleep, involvement of drugs and alcohol, both pedestrians of age <15 years and >64 years, and roadways of both low-speed (under 30 mph) and high-speed (over 55 mph) show a higher probability of pedestrian involvement in crashes. In particular, pedestrians were involved in crashes while crossing intersections or a midblock section in the daylight. At dark with light, pedestrian alcohol/drug involvement is identified as one of the key factors leading to crashes. Other crashes contributing factors associated with intoxicated pedestrians are driver age group 55 to 64 years, pedestrian clothing, speed limit (<30 mph, 30-35 mph), pedestrian crossing at intersection location, female drivers, and business with the mixed residential area. Fatal pedestrian collisions are more likely to occur in businesses with mixed residential areas. Still, severe pedestrian collisions are more common on high-speed highways with a speed limit of over 55 mph. At dark without light, 8 of the top 20 association rules identified dark-clothed pedestrians contributing to collisions. Other contributing factors were high-speed limit roadways (>50 mph), residential areas, and pedestrian alcohol use. Interestingly, pedestrians were involved in crashes while walking with or against the traffic on roadways at dark (with or without light). The fatal crashes during dark conditions (with and without light) are associated with roadway having a speed limit of 50 mph or higher, while dark cloth pedestrians also play a significant role. The information from the ARM model can be used to prioritize the locations for providing pedestrian lighting. Since the analysis did not find any specific factor relevant to lighting requirements and the literature review already revealed similar pedestrian lighting or overall streetlight policies across the majority of the states and cities within the United States, the study did not have any recommendations on the practical lighting requirements.

The cost-benefit analysis shows a significant benefit, especially at locations with only fatal and severe crashes. The study suggests including additional information like lighting source, the distance of it from the crash location, nearby pedestrian relevant countermeasures, and pedestrian cloth type in the crash report.

Recommendations

The study explored the hidden pedestrian crash causing factors using data mining techniques and detected several contributing factors, especially in the dark without lighting conditions. The information from data mining results can be used to prioritize the locations for providing pedestrian lighting. In the future, the study recommended to use some advanced data mining techniques to address the spatial distribution of pedestrian crashes.

Acronyms, Abbreviations, and Symbols

Term	**Description**
1-CMF	1-Crash Modification Factor
AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
AIC	Akaike Information Criterion
ARM	Association Rules Mining
ARMS	Active Road Marking System
AUC	Area Under the Curve
C	Confidence
CAR	Conditional Autoregressive
CIE	International Commission on Illumination
cm	Centimeter(s)
CMF	Crash Modification Factors
Crash ID	Crash Identification
DOA	Department of Agriculture
DOT	Department of Transportation
DOTD	Department of Transportation and Development
EDC	Every Day Counts
FARS	Fatality Analysis Reporting System
FHWA	Federal Highway Administration
ft.	feet
GLM	Generalized Linear Model
HPS	High Pressure Sodium
in.	Inch(es)
K	Kelvin
L	Lift
LAC	Louisiana Administrative Codes
LADOTD	Louisiana Department of Transportation and Development
lb.	Pound(s)

LED	Light Emitting Diode
LRS	Linear Reference System
LTRC	Louisiana Transportation Research Center
lux	luminous flux
m	Meter(s)
MH	Metal Halide
mph	mile per hour
MPO	Metropolitan Planning Organization
NCHRP	National Cooperative Highway Research Program
NCSA	National Center for Statistics and Analysis
NHTSA	National Highway Traffic Safety Administration
OR	Odds Ratio
PDI	Pedestrian Danger Index
PRC	Project Review Committee
RF	Random Forest
RHS	Right Hand Side
ROC	Receiver Operating Curve
RPC	Regional Planning Commission
RRFB	Rapid Rectangular Flashing Beacons
S	Support
SAS	Statistical Analysis System
STEP	Safe Transportation for Every Pedestrian
UDC	Unified Development Code

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Appendix A

Attributes for Intersections

Attributes	Definition (in short)	Locations	Levels of attributes	Source
Light	a light, usually supported by a lamppost, for illuminating a street or road	Both	Yes/No	Google Map
Intersection type	Three basic intersection types are three leg, four leg or multi-leg	Only Intersection	T/4-leg	Google Map
Intersection control type	Different control types are provided at intersections with respect to geometric design and usage	Only Intersection	Signalized/Stop /2-Stop/4-Stop/Yield/Roundabout/Other	Google Map
Painted Crosswalk	Crosswalk is painted so the pedestrians can easily identify it.	Only Intersection	Yes/No	Google Map
		Only Intersection	Crosswalk/ Parallel line	Google Map
Pedestrian Signal	Pedestrian signals are provided for major roadways	Only Intersection	Yes/No	Google Map
Crossing Island	Crossing island is provided in the middle of multi-lane roadway to provide refuge to pedestrians	Both	Yes/No	Google Map
Median Divided	Lanes are divided by a median	Both	Yes/No	Google Map
Median Type	It could have several types such as concrete or landscape	Segment	Yes/No	Google Map
Number of Lanes	Total number of lanes	Both	Through lanes	Google Map
		Both	Turning Lanes	
		Both	Total Lanes	
Width of roadway	Total width of the roadway measured in feet	Both	Major (distance in ft.)	Google Map
Shoulder	Presence of shoulder on the roadway	Both	Yes/No	Google Map
Visibility of pedestrians from the roadway	It was determined by looking at google images if pedestrians were visible	Both	Yes/No	Google Map
Speed Limit (Major)	The speed limit that is recommended for roadway type	Both	mph	Google Map
Speed Limit (Minor)	The speed limit that is recommended for roadway type	Only Intersection	mph	Google Map
Nearby Residential/Business Area (within 150 ft. distance)	If there are any residential areas or business areas visible in google images	Both	Yes/No	Google Map
Special Treatment	If any specific treatment is provided on intersection or segment	Both	Yes/No	Google Map
Major Roadway	For intersection the functional class determines the major and minor roadway	Only Intersection	Width of roadway, in ft.	Google Map
			Number of lanes (both way)	Google Map
Minor Roadway	For intersection the functional class determines the major and minor roadway	Only Intersection	Width of roadway, in ft.	Google Map

Attributes	Definition (in short)	Locations	Levels of attributes	Source
			Number of lanes (both way)	Google Map
Major Roadway	For intersection the functional class determines the major and minor roadway	Only Intersection	Through	Google Map
			Turning	Google Map
Minor Roadway	For intersection the functional class determines the major and minor roadway	Only Intersection	Through	Google Map
			Turning	Google Map
Area Type	Area type is defined as either rural or urban	Both	Rural/Urban	DOTD
Functional Class	Functional class is determined by the ratio of access and mobility categorized as 3-Principal Arterial, 4-Minor Arterial, 5-Major Collector, 6-Minor Collector, and 7-Local roads.	Both	Described in column 2	DOTD
AADT	Annual Average Daily Traffic	Both	AADT Number depending on functional class	DOTD
Population Code	The different population density categorized as 0 – Rural, 1 - Population < 2,500, 2 - Population < 5,000, 3 - Population < 25,000, 4 - Population < 50,000, 5 - Population < 100,000, 6 - Population < 200,000, 7 - Population < 500,000, 8 - Population < 2,000,000, and 9 - Population 2,000,000 +	Both	Described in column 2	DOTD
Prevailing Area	The most dominant area around the intersection or segment categorized as 0-Rural, 1-CBD - 3 Stories or Less, 2-CBD - 4 Stories or Less, 3-Fringe, 4-Outlying Business District, 5-Residential - Apartments and Rowhouses, 6-Residential - Single Family 1/2 Acre or Less, 7-Residential - Single Family Over 1/2 Acre, 8-Strip Commercial, and 9-Industrial	Both	Described in column 2	DOTD

Appendix B

Summary Statistics of All Crash Variables

Variable	Variable label	Variable categories	Daylight, N (%)	Dark with light, N (%)	Dark without light, N (%)
Pedestrian alcohol/drug involvement	ped_alcohol_drug	no	1425 (57.67%)	770 (31.16%)	276 (11.17%)
		yes	85 (14.81%)	274 (47.74%)	215 (37.46%)
		others	484 (35.69%)	608 (44.84%)	264 (19.47%)
Pedestrian dark clothing	ped_dark_cloth	no	1470 (53.81%)	917 (33.57%)	345 (12.63%)
		yes	524 (31.40%)	735 (44.04%)	410 (24.57%)
Pedestrian injury severity	severity	fatal	129 (21.50%)	229 (38.17%)	242 (40.33%)
		severe	271 (35.47%)	352 (46.07%)	141 (18.46%)
		moderate	1594 (52.49%)	1071 (35.27%)	372 (12.25%)
Pedestrian action	ped_action	inappropriate	636 (47.25%)	447 (33.21%)	263 19.54%)
		walking_against_traffic	50 (26.32%)	71 (37.37%)	69 (36.32%)
		walking_with_traffic	128 (26.28%)	180 (36.96%)	179 (36.76%)
		xing_int	552 (56.91%)	359 (37.01%)	59 (6.08%)
		xing_segment	523 (44.14%)	499 (42.11%)	163 (13.76%)
		unk	105 (47.09%)	96 (43.05%)	22 (9.87%)
Pedestrian age	ped_age	<15	428 (73.67%)	126 (21.69%)	27 (4.65%)
		15-24	359 (41.45%)	345 (39.84%)	162 (18.71%)
		25-40	396 (34.52%)	482 (42.02%)	269 (23.45%)
		41-64	571 (40.73%)	583 (41.58%)	248 (17.69%)
		>64	205 (64.87%)	74 (23.42%)	37 (11.71%)
		unk	35 (39.33%)	42 (47.19%)	12 (13.48%)
Pedestrian gender	ped_gender	female	770 (49.42%)	577 (37.03%)	211 (13.54%)
		male	1212 (43.19%)	1056 (37.63%)	538 (19.17%)
		unk	12 (32.43%)	19 (51.35%)	6 (16.22%)
Alignment	alignment	curve	60 (36.14%)	57 (34.34%)	49 (29.52%)
		straight	1924 (45.65%)	1585 (37.60%)	706 (16.75%)
		others	10 (50.00%)	10 (50.00%)	0 (0%)
Primary contributing factor	primary_factor	ped_actions	484 (36.89%)	507 (38.64%)	321 (24.47%)
		ped_condition	33 (25.00%)	56 (42.42%)	43 (32.58%)
		ped_violation	264 (47.40%)	213 (38.24%)	80 (14.36%)
		prior_movement	309 (53.65%)	210 (36.46%)	57 (9.90%)
		other_factors	904 (49.56%)	666 (36.51%)	254 (13.93%)
Day of week	DOW	weekday	1544 (49.90%)	1042 (33.68%)	508 (16.42%)
		weekend	450 (34.43%)	610 (46.67%)	247 (18.90%)

Variable	Variable label	Variable categories	Daylight, N (%)	Dark with light, N (%)	Dark without light, N (%)
Location type	location_type	business_industrial	557 (45.32%)	531 (43.21%)	141 (11.47%)
		business_mixed_residential	655 (43.52%)	667 (44.32%)	183 (12.16%)
		open_country	60 (28.44%)	25 (11.85%)	126 (59.72%)
		residential	670 (49.93%)	386 (28.76%)	286 (21.31%)
		other_locality	52 (45.61%)	43 (37.72%)	19 (16.67%)
Roadway type	road_type	one_way	287 (54.05%)	212 (39.92%)	32 (6.03%)
		two_no_separation	1206 (45.03%)	936 (34.95%)	536 (20.01%)
		two_separation	466 (41.09%)	482 (42.50%)	186 (16.40%)
		other_unk	35 (60.34%)	22 (37.93%)	1 (1.72%)
Weather condition	weather_condition	clear	1589 (45.82%)	1303 (37.57%)	576 (16.61%)
		cloudy	291 (50.26%)	188 (32.47%)	100 (17.27%)
		fog_sleet_snow	9 (25.00%)	9 (25.00%)	18 (50.00%)
		rain	96 (32.32%)	142 (47.81%)	59 (19.87%)
		other_unk	9 (42.86%)	10 (47.62%)	2 (9.52%)
Highway type	highway_type	city_street	1186 (55.81%)	821 (38.64%)	118 (5.55%)
		interstate	64 (30.48%)	74 (35.24%)	72 (34.29%)
		parish_road	239 (47.05%)	143 (28.15%)	126 (24.80%)
		state_highway	307 (31.55%)	374 (38.44%)	292 (30.01%)
		us_highway	169 (32.01%)	215 (40.72%)	144 (27.27%)
		others	29 (50.88%)	25 (43.86%)	3 (5.26%)
Driver age	driver_age	<15	3 (60.00%)	1 (20.00%)	1 (20.00%)
		15-24	300 (45.05%)	234 (35.14%)	132 (19.82%)
		25-34	363 (43.11%)	324 (38.48%)	155 (18.41%)
		35-44	285 (47.82%)	200 (33.56%)	111 (18.62%)
		45-54	258 (47.87%)	182 (33.77%)	99 (18.37%)
		55-64	222 (50.23%)	158 (35.75%)	62 (14.03%)
		>64	253 (59.39%)	118 (27.70%)	55 (12.91%)
		unk	310 (35.03%)	435 (49.15%)	140 (15.82%)
Driver condition	driver_condition	alcohol_drug	50 (22.73%)	115 (52.27%)	55 (25.00%)
		illness_fatigued_asleep	17 (65.38%)	6 (23.08%)	3 (11.54%)
		inattentive_distracted	436 (65.37%)	168 (25.19%)	63 (9.45%)
		normal	1058 (44.32%)	858 (35.94%)	471 (19.73%)
		other_unk	433 (39.33%)	505 (45.87%)	163 (14.80%)
Driver gender	driver_gender	female	734 (53.03%)	446 (32.23%)	204 (14.74%)
		male	995 (44.78%)	812 (36.54%)	415 (18.68%)
		unk	265 (33.33%)	394 (49.56%)	136 (17.11%)
Speed limit	speed_limit	<30	777 (62.81%)	383 (30.96%)	77 (6.22%)
		30-35	578 (46.20%)	566 (45.24%)	107 (8.55%)

Variable	Variable label	Variable categories	Daylight, N (%)	Dark with light, N (%)	Dark without light, N (%)
		40-45	309 (32.32%)	421 (44.04%)	226 (23.64%)
		50-55	99 (22.97%)	103 (23.90%)	229 (53.13%)
		>55	64 (29.36%)	67 (30.73%)	87 (39.91%)
		unk	167 (54.22%)	112 (36.36%)	29 (9.42%)
Vehicle type	veh_type	light_truck	425 (42.89%)	325 (32.80%)	241 (24.32%)
		passenger_car	909 (47.00%)	735 (38.00%)	290 (15.00%)
		van_suv	485 (47.60%)	386 (37.88%)	148 (14.52%)
		others	175 (38.29%)	206 (45.08%)	76 (16.63%)
Violation type	violation_type	careless_operation	263 (51.27%)	209 (40.74%)	41 (7.99%)
		failure_to_yield	189 (72.97%)	59 (22.78%)	11 (4.25%)
		no_violations	883 (41.22%)	784 (36.60%)	475 (22.28%)
		others	659 (44.32%)	600 (40.35%)	228 (15.33%)
Intersection	int	no	1175 (41.61%)	1008 (35.69%)	641 (22.70%)
		yes	819 (51.93%)	644 (40.84%)	114 (7.23%)
Hit-and-Run crash	hit_and_run	no	1621 (49.02%)	1096 (33.14%)	590 (17.84%)
		yes	373 (34.10%)	556 (50.82%)	165 (15.08%)

The variable category 'unk' in the above table indicates 'unknown' categories. Also, percentage in the above table may not add up to exactly 100% due to rounding errors.