RESEARCH

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NON-MOTORIST FATALITIES: A DEEP DIVE

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16. Abstract

Non-motorist fatalities pose a serious concern to traffic safety initiatives within the state of Utah. Past research has examined the characteristics associated with fatal pedestrian crashes in depth, however, considerably less study has been done to understand the contextual factors surrounding these incidents. Pedestrian crashes may be influenced by environmental factors, surrounding infrastructure, availability of crossing locations, and numerous other factors. This research consists of examining non-motorist crashes in a holistic way to identify characteristics which are present in areas where these crashes result in a fatality. This study utilized several different datasets and analysis techniques including multinomial logistic (MNL) regression to evaluate evidence with the goal of creating an effective representation of crashes. Analysis of data revealed that nearly 40% of pedestrian fatalities and 33% of cyclist fatalities occur within a geographic envelope where installing a safe crossing is prohibited. Approximately 7.3% of suspected serious bike crashes and only 6% of fatal bike crashes occurred in or near a bike lane. Additionally, suspected serious and fatal pedestrian crashes were even less likely to occur on roadways with bike lanes present. Fewer than 4% of serious and fewer than 2.5% of fatal pedestrian crashes occurred near a bike lane.

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LIST OF ACRONYMS

AADT	Annual Average Daily Traffic
AT	Active Transportation
ATSPM	Automated Traffic Signal Performance Metrics
BAC	Blood Alcohol Content
DTS	Department of Technology Services
LRS	Linear Referencing System
MNL	Multinomial Logistic Regression
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
OD	Origin - Destination
SMS	Speed Management Studies
TAC	Technical Advisory Committee
UDPS	Utah Department of Public Safety
UDOT	Utah Department of Transportation
UGRC	Utah Geospatial Resource Center
USDOT	United States Department of Transportation
UTA	Utah Transit Authority
VMT	Vehicle Miles Traveled

EXECUTIVE SUMMARY

Non-motorist fatalities pose a serious concern to traffic safety initiatives within the State of Utah. While research has examined, in depth, the characteristics associated with fatal pedestrian crashes, little has been done to understand the contextual factors surrounding these incidents. For example, are pedestrian crashes more likely to be fatal in locations where housing is located across a major roadway from services, but too far away from a convenient and safe crossing location? Additionally, because pedestrian and bicycle crashes are less frequent and do not tend to cluster, the Utah Department of Transportation (UDOT) has historically been limited regarding how to improve safety and reduce these fatalities. Effort has been made to look at these crashes more systemically. However, that effort has focused more on crashes in general, rather than fatalities, and has not focused on the characteristics of the areas surrounding these incidents. Spatial analysis of crashes provided additional insight into these crashes. This research examines non-motorist crashes in a holistic way to identify clusters of characteristics which are present in areas where non-motorized crashes result in a fatality.

The research team uses several different datasets and analysis techniques to evaluate circumstantial evidence to create a more holistic picture of each crash. This includes cross referencing Streetlight data and (Automated Transportation System Performance Measures) pedestrian actuations to better quantify volumes. Analysis methods also include multinomial logistic regression models to isolate significant factors that are not mutually exclusive but create an impact due to their presence together (e.g., lack of crossings and mix of land uses, time of day, etc.).

According to existing research, non-motorized fatalities are a significant concern within traffic safety, and many pedestrians and cyclists are struck and seriously injured or killed each year. Numerous environmental and infrastructural effects influence these crashes. Development of improved pedestrian infrastructure may help reduce non-motorist fatalities by providing safer roadside environments for non-motorists. However, behavior of both drivers and pedestrians has a significant influence on non-motorized fatalities as well. Unpredictable behaviors and impairment contribute to serious and fatal crashes. Greater understanding of these behaviors is needed in order to understand how to best reduce the possibility of a fatal non-motorist crash.

Research into the impact of behaviors and environment along with characteristics of non-motorist crashes may assist agencies in their pursuit of reducing these incidents.

This project collected statewide crash data for non-motorized crashes that are severe (suspected serious and fatal crashes) and coded the data into a geodatabase that contained other demographics, socioeconomic and roadway characteristics data. Additionally, the project team compiled the aggregate characteristics of each observed crash in a geodatabase for statistical analysis. The data essential for further statistical analyses were collected from open data sources available from UDOT and the Utah Transit Authority (UTA). Each data file provides unique and important information on non-motorist severe crashes.

Several analytical methods were used to evaluate the data. First, summary statistics are provided, followed by more complex statistical analysis, including multinomial logistic regression models. These analyses determined that a large majority of both pedestrian and bicycle crashes involved a single vehicle and weather did not seem to play a significant role, as a large majority of pedestrian crashes occurred in clear (77.6%) or cloudy weather (13.1%).

Approximately 37.4% and 35.7%, respectively, of fatal and suspected serious injury pedestrian crashes occurred 15-600 feet from an intersection. For cyclists, intersections tend to be more dangerous than for pedestrians. For example, 32.8% of fatal bicycle crashes occurred at an intersection while 26.9% occurred 15-600 feet from an intersection. UDOT has a current policy in place prohibiting pedestrian crossing within 600 feet of an intersection. However, nearly 40% of pedestrian fatalities and 33% of cyclist fatalities occur within that geographic envelope. Vehicle speed was not found to be a significant factor. In only 4.5% of suspected serious or fatal pedestrian crashes, excess speed, or speeds too fast for existing conditions were a factor. Additionally, vehicle speed was only a noted factor in 1.8% of bicycle crashes. Approximately 7.3% of suspected serious bike crashes and only 6.0% of fatal bike crashes occurred in or near a bike lane. Interestingly, suspected serious and fatal pedestrian crashes were even less likely to occur on roadways with bike lanes present. Fewer than 4% of serious and fewer than 2.5% of fatal pedestrian crashes occurred near a bike lane.

1.0 INTRODUCTION

1.1 Problem Statement

Non-motorist fatalities pose a serious concern to traffic safety initiatives in Utah. While research has examined, in depth, the characteristics associated with fatal pedestrian crashes, little has been done to understand the contextual factors surrounding these incidents. For example, are pedestrian crashes more likely to be fatal in locations where housing is located across a major roadway from services, but too far away from a convenient and safe crossing location? Additionally, because pedestrian and bicycle crashes are less frequent and do not tend to cluster, the Utah Department of Transportation (UDOT) has historically been limited regarding how to improve safety and reduce these fatalities. Effort has been made to look at these crashes more systemically. However, that effort has focused more on crashes in general, rather than fatalities, and has not focused on the characteristics of the areas surrounding these incidents. Spatial analysis of crashes will provide additional insight into these crashes.

1.2 Objectives

This research examines non-motorist crashes in a holistic way to identify clusters of characteristics that are present in areas where non-motorized crashes result in a severe crash (fatal or serious injury crash). It will provide UDOT the ability to identify these areas, subsequently providing an opportunity for a proactive approach to implement appropriate design treatments or mitigations to reduce risk of fatal crashes in the future.

1.3 Scope

This research uses several different datasets and analysis techniques to evaluate circumstantial evidence to create a more holistic picture of each crash. This includes cross referencing StreetLight data to better quantify volumes. Analysis methods also include multinomial logistic regression models to isolate significant factors that are not mutually exclusive but create an impact due to their presence together (e.g., lack of crossings and mix of land uses, time of day, etc.).

1.4 Outline of Report

The report is organized into five additional sections, as follows:

- Section 2 provides a brief literature review examining existing research on specific non-motorist characteristics, possible influences on non-motorist crash risk and different types of non-motorist crashes. It also includes a description of the study methods and justifications.
- Section 3 presents the data collected and provides summary characteristics for the study sample.
- Section 4 presents a quantitative analysis of non-motorist crashes.
- Section 5 provides conclusions based upon the data analysis.
- Section 6 outlines recommendations and the implementation plan.

2.0 RESEARCH METHODS

2.1 Overview

A comprehensive review by the National Cooperative Highway Research Program (NCHRP) identified five key factors that contribute to a higher risk of a pedestrian being involved in a collision resulting in severe injuries or death (USDOT, 2015). They include:

1. Excessive motor vehicle speed - Vehicles driving faster than the posted speed limit or too fast for existing roadway conditions increase their risk of hitting a pedestrian or pedalcyclist. As vehicle speed increases, the likelihood of a pedestrian fatality increases. For example, 90% of pedestrians will survive being hit by a car traveling at roughly 25 mph, but only 25% of pedestrians will survive being hit by a vehicle traveling 50 mph (Tefft, 2012).
2. Conflicts at crossing locations - When a crossing location does not adequately accommodate pedestrians, they are more likely to be hit. For example, a mobility-impaired pedestrian may not physically be able to cross a wide street in the allotted amount of signal time. Since 2010, in 38% of pedestrian involved crashes, drivers were turning, and in 60% of all crashes the pedestrian was in an intersection crossing area (UDPS, 2021).
3. Inadequate conspicuity - When pedestrians and cyclists are not visible due to time of day (light or dark, sun reflectivity) or wear dark clothing, it is difficult for drivers to see them and stop in time to avoid a collision. Nationwide in 2019, 76% of pedestrians and 49% of cyclists killed were struck in dark conditions (NHTSA, 2021a). A majority of these fatalities occur in the hours between 8 PM and midnight (USDOT, 2015).
4. Poor compliance with traffic laws and proper use of facilities - Drivers and pedestrians who do not comply with traffic laws put themselves and others at risk. Failing to yield to pedestrians at crosswalks, walking on the wrong side of the road or in the shoulder rather than on the sidewalk, crossing against a traffic signal, etc., can all lead to serious injury/death. Often poor compliance is the result of misunderstanding traffic control devices or inadequate/poorly designed facilities.

5. Inadequate separation - When pedestrians or cyclists do not have a dedicated travel space that is sufficiently separated from higher speed vehicular traffic, they may not be seen by drivers. When adequate infrastructure is not available, pedestrians can be forced to walk in the shoulder or on the roadway, which can result in a collision.

Pedestrian and driver travel behaviors play a critical role in determining if and when a fatal crash occurs. However, there is limited data available to UDOT and other agencies relating to traveler decision making and behavior, as well as contextual factors leading up to a crash, particularly regarding pedestrians and cyclists.

This research fills a critical gap in existing knowledge by examining not only the physical characteristics of suspected serious injury and fatal non-motorist crashes (speed, time, location, etc.) but also examining the travel behavior leading up the crash. By looking at the contributing factors holistically rather than independently, this research seeks to identify which combinations of characteristics are most likely to result in a fatal non-motorist crash.

2.2 Fatal Non-Motorist Crash Characteristics

2.2.1 National Statistics

Over 80% of people in the U.S. report walking at least once per week, and 92% report feeling safe while walking. Additionally, fewer than 3% of people report having been injured while walking in the past two years (Schroeder and Wilbur, 2013). However, in 2019, 6,205 pedestrians were killed in traffic crashes nationwide. On average, a pedestrian is killed every 85 minutes and injured every 7 minutes (NHTSA, 2021b). Approximately 3% of all pedestrian fatalities were children under the age of 14 (NHTSA, 2021c). National Highway Traffic and Safety Administration (NHTSA) data has shown that since 2011 there has been a steady increase in the number of pedestrian fatalities nationwide, rising nearly 20% from 2011-2019. Nationally, 87% of the pedestrians were killed in traffic crashes that involved single vehicles (2021d). Cyclist fatalities remain a concern as well, and despite a lower fatality rate than pedestrians, a significant number of cyclists are killed every year in crashes. Additionally, in 2019, there were 846 cyclist fatalities nationally, accounting for 2.3 percent of total traffic deaths; children under 14 accounted for 5% of cyclist fatalities (NHTSA, 2021e). 96% of cyclist fatalities occurred in a crash with a single motor vehicle (NHTSA, 2021f).

2.2.2 Utah Statistics

According to the Utah Department of Public Safety (UDPS), in 2020, 36 pedestrians were killed in motor vehicle crashes on Utah roads (UDPS, 2020). Pedestrian-related crashes account for only 0.1% of total traffic crashes in Utah, a comparatively small amount. However, pedestrian fatalities account for over 13% percent of traffic deaths, and nearly 5% of all crashes involving pedestrians result in a fatality (UDPS, 2021). In 2016, pedestrian crashes were 11 times more likely to result in a death than other motor vehicle crashes (State of Utah, 2016). Additionally, in 2019 Utah experienced six cyclist fatalities, accounting for 2.4% of all traffic fatalities within the state (NHTSA, 2021b). In fact, the first nine months of 2022 have been the deadliest on record for cyclists in Utah, with 15 cyclist fatalities reported (Imlay, 2022).

2.2.3 Common Characteristics

UDOT research examining pedestrian fatalities (Burbidge, 2016)) found that fatal crashes are most likely to occur in the early spring or late fall in lower light conditions when visibility is increasingly limited, and often in bad weather when a wide road is wet or icy. These crashes often involve a pedestrian who may be impaired, participating in illegal and unpredictable behaviors (such as improper crossing of the street), or wearing clothing that is not highly visible. Drivers are most likely to be impaired or distracted, and speeding straight ahead (Burbidge, 2016). Children are more likely to be involved in a fatal pedestrian crash during daylight hours (NHTSA, 2021b). Cyclist fatalities are slightly more likely to occur in the daytime hours when cycling is more frequent (49% vs. 47% at night), although the largest percentage of fatalities (26%) occur in the evening from 6 to 9 PM (NHTSA, 2021c). Nationally, both pedestrian and cyclist fatalities are much more likely to be male than female; 70% of pedestrian fatalities and 86% of cyclist fatalities were male, with a fatality rate of 2.69 vs. 1.19 per 100,000 people for females (NHTSA, 2021).

2.3 Non-Motorist Behavior and Fatal Crashes

The study of travel behavior examines the decision-making processes employed when people make transportation choices, including things as general as travel mode and route, or as specific as when to change lanes or whether to signal before turning. Numerous factors can influence an individual's travel behavior. Demographics such as gender, age, income, household size, home and auto ownership, occupation, etc., have all been shown to impact travel decisions (Burbidge and Goulias, 2009).

2.3.1 Non-Motorist Trends

Traditionally, researchers have identified children (ages 16 and under) and seniors (ages 65+) as those most likely to participate in walking as a mode of transportation (Burbidge and Yoon, 2010). However, this trend has begun to change. Young adults in the "Millennial" generation drive less and are more frequently dependent upon public transportation. Bicycles and other pedal-powered vehicles have become more popular, particularly in urban centers and metro areas. The U.S. Department of Transportation (USDOT) has found that "the number of miles driven alongside car ownership and licensing rates among young people have hit their lowest rates in decades" (USDOT, 2015). When coupled with the newfound popularity of rideshare apps such as Uber and Lyft, a large segment of the population is enhancing their mobility without being tied to a personal vehicle. As more transportation options become available, travel behavior and trends will inevitably change. Many cities in Utah and across the country are promoting multimodal facilities to accommodate these changes, which concomitantly encourage people to walk or use alternative means of transport more often. In turn, communities are becoming increasingly aware of the need to improve safety for non-motorists (USDOT, 2015).

2.3.2 Unpredictable Behaviors

Pedestrian and motorist behaviors can contribute to the likelihood of being involved in a crash, as well as the severity of the crash. One of the primary causes of motorist-pedestrian crashes is that pedestrians often behave differently than drivers expect when away from intersections (Habibovic et al., 2013). Crossing the street away from a marked crosswalk at an intersection significantly increases the risk of a crash. Data shows that 72% percent of pedestrian fatalities occur at non-intersection locations (NHTSA, 2021d). Likewise, 64% of cyclist fatalities occur outside of intersections (NHTSA, 2021f). Previous studies have also found that significant numbers of pedestrian fatalities occur on freeways, where such incidents are less likely to be expected and drivers may be less alert to the presence of a pedestrian (Fitzpatrick, 2014). The time of day in which pedestrians travel also contributes to the likelihood of crash involvement. Nationally, a vast majority of pedestrian fatalities occur in hours of low light and low visibility. Over 70% of pedestrian fatalities occurred from the hours of 6 PM to 6 AM, with most occurring from 6 PM to midnight (NHTSA, 2021c). Nighttime hours greatly increase the risk of a fatal pedestrian crash.

2.3.3 Non-Motorist Behavior in Utah

An analysis of Utah pedestrian fatalities found that in a large majority of fatal crashes there was a pedestrian contribution listed (78.8%). In 47% of all cases, at the time of the crash the pedestrian was entering or crossing the roadway (not implying fault, but still problematic). In 20% of all cases, the pedestrian was participating in some other activity in the roadway. Rarely was the pedestrian traveling on the shoulder or sidewalk (Burbidge, 2016).

2.3.4 Environmental Conditions

Similar to national trends, fatal pedestrian crashes in Utah are likely to occur during lower light conditions with limited visibility, particularly in the early spring or late fall (Burbidge 2016). Such conditions make visibility of non-motorists more difficult.

2.3.5 Impairment

Drug and alcohol impairment can have significant impacts on pedestrian behaviors. Alcohol consumption and/or drug impairment and their effects on driving and vehicle operators have been well-studied, but significantly less attention has been placed on impairment among non-motorists. As such, the effects of pedestrian impairment on pedestrian fatalities are not as well-known publicly. Data shows that the number of pedestrian fatalities in which the pedestrian had a blood alcohol level (BAC) of at least 0.08 g/dL has increased in recent years, and that persons with a history of high-BAC offenses are at greater risk to be killed as high-BAC pedestrians (Blomberg et al, 2019). While impairment can incorrectly be assumed as the driving factor or sole cause in a fatal crash while other factors are ignored, data shows that 31% of pedestrians and 20% of cyclists killed in traffic crashes had BAC of greater than 0.08 g/dL, indicating the serious risk that may stem from impairment among road users (NHTSA, 2021). While a positive drug test does not necessarily indicate pedestrian impairment (such as in the case of prescription medications), drug use and impairment have been found to correlate with factors found generally in pedestrian fatalities. Alcohol-related pedestrian fatalities often occur in areas with low visibility, at nighttime hours, and at non-intersection locations. An Alberta study (2018) found that impaired cyclists were less likely to wear a helmet while riding (Hezaveh and Cherry, 2018; Gaudet et al., 2015). Such studies reveal that alcohol consumption puts pedestrians and cyclists at greater risk of a fatal crash incident through influences on pedestrian and cyclist judgment and compounding the risks of other factors.

2.4 Driver Behavior and Fatal Crashes

Studies of driver behavior examine the various decisions that drivers make and the processes that follow as they operate their vehicle. Like non-motorists, driver travel behaviors are influenced by numerous factors in their environment and their demographic makeup. These factors contribute to the series of events leading to a potentially fatal crash between driver and non-motorists. Vehicle Miles Traveled (VMT) in the U.S. has increased 13% from 2020 through the first half of 2021 (USDOT, 2021). Even as more transportation options become available to individuals, personal vehicle use will continue to be the major mode of transportation in Utah and the U.S. into the future. As such, non-motorized crashes will continue to be an issue as the rights of way of pedestrians and motorists overlap on roadways throughout the U.S.

2.4.1 Distracted Driving

Driver behavior and the relationship between driver and pedestrian can increase the risk of a non-motorist fatality. Research has found that one of the primary causes of auto-pedestrian crashes is distracted driving (Habibovic et al., 2013). NHTSA defines a driving distraction as "a specific type of inattention that occurs when drivers divert their attention from the driving task to focus on some other activity" (2021a). Distracted driving includes the following, in addition to others:

- Distracting activities inside/outside the vehicle
- Activities performed by the motorist inside of the vehicle
- Driver focus on roadside advertising
- Distraction or inattention stemming from the emotional/physical state of the driver
- Use of a communication device while driving (Retting, 2018; NHTSA, 2021)

Cellphones are often thought of first when considering distracted driving, and the use of a cellphone has been found to greatly increase the chance of pedestrian crash severity (Khan and Habib, 2021). According to recent data, distraction-affected fatalities accounted for 15% of pedestrian fatalities and 2% of cyclist fatalities (NHTSA, 2021b).

2.4.2 Motorists at Signals

As drivers wait to turn right at red lights, they are expected to yield right of way to pedestrians and other non-motorists. However, drivers in this situation have often been found to accelerate to higher speeds while lowering their attention to surroundings, placing non-motorists crossing the street at greater risk of an incident with the driver (Wu and Xu, 2017).

2.4.3 Drunk/Impaired Driving

Much is understood about the hazards of driving while impaired by drugs or alcohol, and significant research exists on the subject. In 2012, 14% of drivers that were involved in a fatal pedestrian crash nationally were at or above the BAC of 0.08 g/dL, the legal limit in most states at that time (USDOT, 2015). That rate remained largely stable through the end of the decade, ending at 13% (NHTSA, 2021e). In Utah, data shows that drivers involved in fatal pedestrian crashes were most likely to be alcohol impaired or distracted (Burbidge, 2016). Despite the fact that driving with a BAC of over 0.08 g/dL is illegal in all U.S. states (0.05 g/dL in Utah), a large percentage of drivers involved in fatal pedestrian crashes are impaired by alcohol use. Impairment from drug use (whether illegal drugs or over-the-counter medicinal abuse) could be even more widespread; one study has suggested that up to 25% of general motor crashes may involve drug use by a driver (Kelly et al., 2009). As with pedestrian impairment, driver impairment is not the only factor in non-motorized fatalities. However, the impact of impairment on driver behavior has been found to be significant.

2.5 Environmental Contributions to Fatal Crashes

2.5.1 Environmental Statistics

Studies of pedestrian fatalities at the local level have determined that the number of pedestrian crashes (per population) is four times higher in large urban areas, and twice as high in small or midsize urban areas when compared to rural areas. Research has shown that while large cities experience the majority of pedestrian deaths, they are also home to the lowest income neighborhoods that experience a disproportionate number of fatalities (USDOT, 2015). This trend holds true in Utah. In 2018, urban areas accounted for a greater percentage (53%) of pedestrian fatalities than rural areas (46%). However, pedestrian crashes in rural areas are more than two times more likely to result in a fatality (1.29 per 100 million VMT) when compared to crashes occurring in urban areas (0.55 per 100 mil VMT) (State of Utah, 2014). Salt Lake County typically accounts for the greatest number of pedestrian fatalities and injuries in the state of Utah (State of Utah, 2016). Regarding cyclists, fatal cyclist crashes are much more likely to occur in urban areas. In 2019, 78% of cyclist fatalities occurred in urban spaces as opposed to 22% in rural areas (NHTSA, 2021b).

2.5.2 Light and Visibility

As mentioned previously, light and visibility play a critical role in the occurrence of non-motorist fatalities, particularly for pedestrians, as data shows fatalities are more likely to occur at night. One study found that pedestrian fatalities in the U.S. increased by 45.5% from 2009 to 2017, and of those additional fatalities 85% occurred during nighttime hours. These nighttime fatalities are most likely to occur in urban areas on arterial streets away from intersections in areas with poor lighting (Ferenchak and Abadi, 2021). Night conditions are correlated to an increase in crash severity; crashes at unlit intersections have an 83% greater chance of being fatal at night, with non-intersection areas holding a 75% greater chance of fatality (Siddiqui, 2006). This is reflected in the large numbers of pedestrian and cyclist fatalities at night (NHTSA, 2021). The environmental hazards created during nighttime hours can be reduced through effective street lighting. Data shows that street lighting can reduce the chances of fatal night crashes for pedestrians by roughly 30% (Siddiqui, 2006). Effective lighting increases visibility and can reduce some of the hazards created in low-light conditions, although nighttime remains significantly more dangerous for non-motorists.

2.5.3 Infrastructure

In addition to the effects of area type and time of day, built environment and infrastructure play an important role in non-motorized fatalities. Previous research has found an increased severity of non-motorist crashes associated with numerous factors, including:

- Lack of sidewalks
- Lack of buffers between pedestrians and the road (bike lanes, sidewalk buffer, etc.)
- Higher-speed roads
- Multiple lane roads
- Lack of or insufficient street lighting (Hanson et al., 2013)

Lack of safety features and more exposure to roadway traffic can place pedestrians and cyclists in danger. Sidewalks greatly increase pedestrian safety, but nearly a third of pedestrians say there are not sidewalks in their neighborhood, while almost half report there are limited numbers of sidewalks nearby (Schroeder and Wilbur, 2013). As discussed previously, many non-motorist fatalities occur at non-intersection locations, particularly as pedestrians attempt to cross the street and their behaviors become unpredictable (Burbidge. 2016). At signalized intersections, the placement of bike lanes may also put cyclists crossing through the intersection near the path of oncoming motorists who are turning left, many of whom will not yield to the cyclist even when traffic laws require it (Razavi and Furth, 2021). Poorly placed infrastructure can also contribute to crashes and fatalities. Obstruction of pedestrians from a driver's view by obstacles has been identified as a primary cause of pedestrian-related crashes (Habibovic et al., 2013). Infrastructure designed to provide safer environments for non-motorists can be successful at reducing crashes and by extension, fatalities.

A California study found that bike lanes reduce vehicle/bicycle crashes by 31%, and up to 53% in certain situations (Lott and Lott, 1976). Protected turn signal cycles, especially on left turns, can preserve right-of-way and allow for safer intersection crossings by non-motorists as well (Razavi and Furth, 2021). For street crossings, intersections increase safety for pedestrians and cyclists (since vehicles tend to slow down near intersections), and traffic controls at intersections can decrease the likelihood of pedestrian fatality or suspected serious injury by up to 98% (Yu, 2015). Proper maintenance of non-motorist infrastructure is also a necessity, as damage from the environment and other sources reduces safety and can create hazards for users (Corazza et al., 2016). Overall, developments in infrastructure designed to increase safety and reduce potential conflicts with motorized vehicles will reduce non-motorized fatalities and provide safer transportation options on streets for pedestrians, cyclists, and non-motorists generally.

2.6 Summary

Non-motorized fatalities are a significant concern within greater traffic safety, and many pedestrians are struck and seriously injured or killed every year. Numerous environmental and infrastructural effects influence these crashes. More development of pedestrian safety infrastructure may help reduce pedestrian fatalities. However, behavior of both drivers and pedestrians has a significant influence on non-motorized fatalities as well. Unpredictable behaviors and impairment play a role for drivers and non-motorists. Greater understanding of these behaviors is needed in order to understand how to best reduce the possibility of a fatal non-motorist crash. Additional research into the impact of behaviors and environment along with characteristics of non-motorist crashes may assist agencies in their pursuit of reducing these incidents.

3.0 DATA COLLECTION

3.1 Overview

This project evaluated statewide crash data for non-motorized crashes that include a suspected serious injury or fatality and coded the data into a geodatabase that contained other demographic, socioeconomic and roadway characteristics data. Eventually the project team compiled the aggregate characteristics of each observed crash in a geodatabase for statistical analysis. This chapter identifies how the data was collected and processed for evaluation in this study.

3.2 Data Collection

Based on the literature review, major variables were identified to be the driving factors for non-motorized crashes. The project team met with the Technical Advisory Committee (TAC) with an initial variable list, and based on their feedback, variables were shortlisted for further analysis. The variables are classified into the following categories.

1) People Characteristics: These variables clarify the correlation between the driver characteristics/presence of passengers and observed crashes. This information was collected from the crash database.

2) Crash Characteristics: These variables clarify the relationship between different crash attributes and the severe non-motorist crashes. Crash characteristics mean any attribute that helps describe the crash and is not infrastructure or people related. Crash attribute data was collected from the crash database.

3) Roadway Characteristics: These variables clarify the correlation between the driver/passenger characteristics and observed crashes. Roadway characteristics include roadway junction type, route type (state, county, federal), traffic control device type, pedestrian island (presence/absence), shoulder (presence/absence), shoulder width, number of lanes, speed limit, medians, driveway/access, right-turn lanes, and left-turn lanes. Data for roadway characteristics was collected from the UDOT open data portal.

4) Infrastructure Attributes: This includes transit, pedestrian, and bicycle facilities. Data for infrastructure characteristics was collected from UDOT, the Utah Transit Authority (UTA) and other open data sources.

5) Location and Demographics: Location data includes any boundary data that identifies the location of the crash data. Demographic data describes the demographics associated with those location boundaries.

The following subsections discuss each data type and their components in detail.

3.2.1 People and Crash Data

Crash data was downloaded from the AASHTOWare Safety Powered by Numetric crash database. Data for the Numetric website is derived from Utah crash reports (DI-9 Form). These reports are completed by Utah law enforcement officers who investigate crashes on public roadways. The crash events submitted by law enforcement officers later go through a manual quality control (QC) provided by the Utah Department of Public Safety (DPS) and the Utah Transportation & Public Safety (UTAPS) group.

For this study, 11-year crash data for severe non-motorist crashes was downloaded. The following filters were used in the crash query tool of the AASHTOWare Safety to extract the crashes relevant to this project:

1. Year = between 2010 and 2021 (both inclusive)
2. Crash Severity = fatal or suspected serious injury
3. Pedestrian involved = Y, or Bike involved = Y ~~F~~

With these filters, 2,525 severe non-motorist crashes were identified. A summary of the key variables collected from the crash database is given below:

Crash ID: Unique ID assigned to each crash record.

Time Information: Crash Date and Crash Time fields were extracted to identify the crash years, time of day, and day of week.

Location Data: Columns that were used to extract and validate location information were Full Route Name, Mile point, Latitude and Longitude.

People Data: This information was collected to evaluate the correlation between the driver characteristics and observed crashes. Columns that were used to extract characteristics information for the people involved were Age, Gender (Female/Male), and Person Type (Driver/Passenger).

Crash Characteristic: To capture the crash characteristics, the following fields were collected from the crash database:

1) Crash Severity: This column documents the severity of crashes into five separate categories - No Injury, Possible Injury, Suspected Minor Injury, Suspected Serious Injury, Fatal. Suspected Serious Injury and Fatal crashes together form severe crashes.
2) Light Condition: This column documents the light condition into seven separate categories – daylight, dark – not lighted, dark – unknown light, dark – lighted, dawn, dusk, and other.
3) Weather Condition: Based on the crash report, this field mentions whether it was clear, cloudy, rainy or snowing at the time of crash.
4) Roadway Surface Condition: This field provides information on the roadway surface condition (i.e., dry, wet, slippery, etc.).
5) First Harmful Event of Crash: This field lists the first event that results in any level of injury or damage. For pedestrian and bicycle-related crashes the first harmful event is “pedestrian” or “pedalcycle.”
6) Pedestrian Involved: This is a binary field (Y/N) used to identify the crashes that had at least one pedestrian involved in the crash.
7) Bicycle Involved: This is a binary field (Y/N) used to identify the crashes that had at least one bicyclist involved in the crash.
8) Estimated Travel Speed: This field includes the estimate of the travel speed for all the vehicles that are involved in a crash.
9) Speed Involved: This is a binary field (Y/N) used to spot crashes that were identified by the law enforcement officer to be excessive travel speed-related.
10) Intersection Involved: This is a binary field (Y/N) used to indicate if a crash occurred at an intersection.

11) DUI Involved: This is a binary field (Y/N) used to identify crashes that had Driver Condition described as "Under the Influence of Alcohol/Drugs/Medications," or where the alcohol drug test result is positive for the driver.

12) Vehicle Maneuver: This is the information on the controlled maneuver for the motor vehicle involved in a crash prior to the beginning of the sequence of events.

13) Non-Motorist Contributing Circumstances: This field lists any relevant condition of the non-motorist (first person listed) that is directly related to the crash as reported by the law enforcement officer.

3.2.2 Roadway and Traffic Characteristic Data

The eight roadway data files and maps used in this research are: AADT, Intersections, Shoulders, Lanes, Speed Limit, Medians, Driveway, and Functional Classification Shapefiles (for state routes only). All these files are accessible to the public via the UDOT Open Data Portal (UDOT 2022). Each of the eight roadway data files are discussed in more detail in the following subsections:

AADT Rounded Shapefile: Average Annual Daily Traffic (AADT) is the total volume of vehicle traffic of a highway or road for a year divided by 365 days. It is meant to represent traffic on a typical day of the year. AADT for crash locations were collected from the AADT Rounded Shapefile which is a line shapefile available through UDOT's Open Data Portal. The AADT reports and map are updated annually by UDOT.

Intersections Shapefile: This point shapefile was last updated in April 2020 and contains a record for every intersection on every Utah state route. The Intersections file provides the main route number and milepost of the intersection as well as a brief description of the intersection type and traffic control used, which are crucial variables identified by the research team. The file also contains columns that include intersection latitude and longitude, and the UDOT Region and maintenance station in which the intersection lies. This geolocation information is later used to connect intersection information to individual crashes.

Shoulders Shapefile: The shoulders shapefile was last updated by UDOT in April 2020. This is a line shapefile which contains detailed information on the presence/absence of shoulders, their locations, shoulder type and shoulder width.

Lanes Shapefile: The Lanes line shapefile contains information for homogeneous stretches of state routes based on their number of lanes and lane width. Each segment has a route number, direction, beginning milepost, and ending milepost. The roadway information collected for further analysis from this dataset was the presence of a pedestrian island and number of lanes for different lane types on that segment (e.g., through lanes, right-turn lanes, left-turn lanes, etc.).

Speed Limit Shapefile: The Speed Limit shapefile is a line shapefile that provides the speed limit along with the beginning and ending mileposts for segments on all state routes in Utah. This file was most recently updated in 2019.

Medians Shapefile: The Medians file contains information on homogeneous stretches of medians on state routes based on median type, width, and whether the median is protected or unprotected. This file also contains information on the traffic island type at that location. Presence/absence of median, median width and presence/absence of a traffic island is the information that was collected at the crash locations. This dataset was most recently updated in November 2019.

Driveway Shapefile: This dataset is in the form of a line shapefile showing the various access present on the state routes and their access categories. The file also has columns that include Route ID, beginning mile points, ending mile points and whether there was a sidewalk present at that location. This dataset was last updated by UDOT in November 2019.

Functional Classification Map: The UDOT Functional Classification Map shows the classes into which public streets and highways are grouped, based on their function within the overall roadway network. This dataset also defines the federal aid system. Within an urban boundary, roadways classified as “minor collector” or higher are federal aid eligible. In rural areas roadways classified as “major collector” or higher are federal aid eligible. This data along with “Route ID” from the crash database is used to associate the functional classification data with individual crashes.

Table 3.1 summarizes the datasets and sources for roadway and traffic characteristic data.

Table 3.1 Roadway Characteristics Data Sources

Data	Shapefile/Database Name	Source
Roadway Junction Type	Intersection Shapefile	UDOT Open Data Portal
Route Type	Crash Database	AASHTOWare Safety
Traffic Control Device	Intersection Shapefile	UDOT Open Data Portal
Pedestrian Island	Lanes shapefile	UDOT Open Data Portal
Shoulder Presence	Shoulder shapefile	UDOT Open Data Portal
Shoulder Width	Shoulder shapefile	UDOT Open Data Portal
Number of Through Lanes	Lane Shapefile	UDOT Open Data Portal
Speed Limit	Speed Limit Shapefile	UDOT Open Data Portal
Median Presence	Median Shapefile	UDOT Open Data Portal
Median Width	Median Shapefile	UDOT Open Data Portal
Traffic Island Presence	Median Shapefile	UDOT Open Data Portal
Driveway/Access Location	Driveway Shapefile	UDOT Open Data Portal
Right-Turn Lanes	Lanes shapefile	UDOT Open Data Portal
Left-Turn Lanes (protected/permissive)	Lanes shapefile	UDOT Open Data Portal
Roadway Volume (AADT)	AADT Rounded Shapefile	UDOT Open Data Portal
Functional Classification of Roadway	UDOT Functional Classification Map	UDOT Open Data Portal

3.2.3 Roadway Infrastructure Data

The six roadway infrastructure data files used in this research are: UTA Stops, UTA Routes, Pavement Messages, UDOT Structures, Utah Roads, and Bike Lanes. Transit-related files (UTA Stops, UTA routes) are available through the UTA Open Data Portal (UTA, 2022) and Roadway data is available through the Utah Geospatial Resource Center (UGRC, 2022). Pavement Messages, UDOT Structures, and Bike Lanes have previously been accessible to the public via the UDOT Open Data Portal (UDOT, 2022).

UTA Stops: This dataset shows the location for all UTA stops for bus, Light Rail (TRAX) and Commuter Rail (FrontRunner) as of April 17, 2022. Location data for the stops were used in further processing.

UTA Routes: This file shows the routes for all UTA bus, Light Rail (TRAX) and Commuter Rail (FrontRunner) lines as of April 17, 2022. Along with geolocation of all UTA routes this dataset contains Route Number (UTA's short name), route name, frequency in minutes, route type, average weekday ridership, and all cities and counties the route serves.

Pavement Messages: This dataset was used as a source of information for pedestrian crosswalks. As a pedestrian crosswalk inventory is not yet developed for Utah, crosswalk location information was collected from the Pavement Messages shapefile by looking for crosswalk-type messages in the “TYPE” column. It should be noted that this method was the best available option for researchers, but does not represent a fully vetted, designated dataset for crosswalk locations.

UDOT Structures: This dataset was used to collect the locations of pedestrian bridges by identifying pedestrian and underpass information under the “Struct_Name” column. This is the only source of pedestrian bridge location information that the project team was able to find. The project team consulted with the TAC to ensure that use of this dataset was appropriate.

Utah Roads and Highway System: This dataset contains the statewide roads centerline dataset for Utah. This is a good source of information for any road and highway-related data such as milepost locations, exit numbers and names, highway linear referencing system (LRS) routes, classification of different types of UDOT routes, active transportation data such as trails and pathways data and statewide bike data.

Bike Lane: The Bike Lanes file contains information on homogeneous stretches of bicycle lanes on state routes along with their location, route ID and number of lanes. This dataset was used in conjunction with the bike lane information found in the UDOT Roads file. It was most recently updated in November 2019.

Table 3.2 summarizes the dataset and sources from roadway infrastructure data.

Table 3.2 Roadway Infrastructure Data Sources

Data	**Shapefile/Database Name**	**Source**
UTA Stops	UTA Stops & Most Recent Ridership shapefile	UTA Open Data Portal
UTA Routes	UTA Routes & Most Recent Ridership shapefile	UTA Open Data Portal
Crosswalk	Pavement Messages shapefile	UDOT Open Data Portal
Ped Bridges	UDOT Structures shapefile	UDOT Open Data Portal
Sidewalk	Utah Roads and Highway System shapefile	UDOT Open Data Portal
Bike Lane	Bike Lanes Shapefile; Utah Roads and Highway System shapefile	UDOT Open Data Portal
Trails and Pathways	Utah Roads and Highway System shapefile	UDOT Open Data Portal

3.2.4 Geolocation Data and Demographics

Geolocation Data: Different boundary-related data were used to identify the problem locations within Utah. The following is the list of the boundary data collected from UGRC (2022) and Esri ArcGIS Services.

- Region boundary
- County boundary
- Municipality boundary
- Urban/rural classification

Demographic Data: This dataset contains 2020 Census data from U.S. Census Bureau Demographic data and includes population counts, household counts, ethnicity counts, etc. The data was collected from UGRC (2022) where the data is filtered geographically to the state of Utah. Table 3.3 summarizes the dataset and sources for boundary and demographic data.

Table 3.3 Demographic and Geolocation Data Sources

Data	**Shapefile/Database Name**	**Source**
Region	Regions shapefile	UGRC
County	Utah County Boundaries shapefile	UGRC
Municipalities	Municipalities shapefile	UGRC
Urban/Rural	USA Urban Areas, USA Rural Areas	Esri ArcGIS Services
Demographic Data	2020 U.S. Census Bureau Data (filtered for Utah)	UGRC

3.3 Data Compilation

After data collection, the raw data files were combined and analyzed to produce the input to the statistical models, which includes the crash dataset with the roadway, traffic and demographic data associated with them. To assign these data to the crashes, raw data files of crash, roadway, and demographic characteristics were brought into ArcGIS and analysis in ArcMap was performed to integrate the data. Table 3 outlines the data compilation that formed the geodatabase used for statistical analysis. The “Attribute” column mentions the information that was integrated into the crash database, “Shapefile/Database Name” identifies the data file used, “Column Names” indicates the fields used from the shapefiles, “Condition” mentions if there were any conditions used to filter out the data, and “Join Radius” shows the radius used for spatial joins.

Table 3.4 Data Compilation Plan

Data Type	Attribute	Shapefile/ Database Name	Column Names	Condition	Join Radius
Roadway & Traffic Characteristics	Intersections	Intersection Shapefile	INT_Type, TRAFFIC_CO	-	250 ft
	Pedestrian Islands	Lane Shapefile	PNT_ISL_CN	-	250 ft
	Shoulder Presence	Shoulder Shapefile	-	-	-
	Shoulder Width	Shoulder Shapefile	ShoulderWidth	-	-
	Number of Lanes	Lane Shapefile	TotCNT	-	-
	Speed	Speed Limit Shapefile	Speed	-	-
	Medians	Medians Shapefile	Median_Typ, TRFISL_Typ	-	-
	Driveway/Access	Driveway Shapefile	Access_Typ	-	-
	Right-Turn Lanes	Lane Shapefile, Intersection Shapefile	RT_CNT	Filter: Intersection Involved Crashes	-
	Left-Turn Lanes	Lane Shapefile, Intersection Shapefile	LT_CNT	Filter: Intersection Involved Crashes	-
Roadway Infrastructure	UTA Stops	UTA Stops & Most Recent Ridership Shapefile	Location, Mode, Stop_Abbreviation		250 ft
	UTA Routes	UTA Routes & Most Recent Ridership Shapefile	Route_Number, LineName, Frequency		-
	Bike Lanes	Bike Lanes Shapefile			-
	Trails and Pathways	Utah_Trails_and_ Pathways Shapefile	CartoCode		250 ft
	Crosswalks	Pavement Messages Shapefile	TYPE	Select: TYPE that contains "Crosswalk"	250 ft
	Ped Bridges	UDOT Structures Shapefile	STRUCT_NAM	Select: STRUCT_NAM that contains "Ped"	250 ft
	Sidewalks	Utah Roads Shapefile			-
Location & Demographic	Region	Regions Shapefile		-	-
	County	Utah Counties Shapefile		-	-

	Municipalities	Municipalities Shapefile		-	-
	Urban/ Rural	ESRI Shapefile		-	-
	Census Block	2020 U.S. Census Bureau Data		-	-

3.4 Summary

The data essential for further statistical analysis were collected from open data sources available from UDOT and UTA. Each data file provided unique and important information on non-motorist severe crashes. Crash data are important for understanding crash characteristics of individual crashes, whereas roadway and location characteristics are important to understand the implication of surrounding environment on a crash. Additionally, these data files were put through a data integration process that was summarized in this chapter.

4.0 DATA EVALUATION

4.1 Overview

This chapter describes analytical methods used to evaluate the data described in the previous chapter. First, summary statistics are provided, followed by more detailed and comprehensive statistical analysis, including multinomial logistic regression models. The analysis findings are presented and discussed.

4.2 Analysis Methods

Several statistical analysis methods were employed to evaluate the data described in the prior chapter. Each method is described below.

4.2.1 Summary Statistics

Summary Statistics are used to provide a quick and simple description of the data without any predictive component or significance testing. They may include mean (average), median (center point of data), mode (most frequently occurring value), minimum value, maximum value, value range, standard deviation, and frequency percentages. Summary statistics were used in this analysis to provide context for the crash data and demographics.

4.2.2 Chi Square Test

A Pearson's Chi-Square Test is used on categorical data to compare an observed distribution to a theoretical one (measuring goodness of fit) for one or more categories. The events included must be mutually exclusive (e.g., weather cannot be clear and raining at the same time) and have a total probability of 1 (Greene, 2015).

Model:

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

where

χ^2 is the chi-square value

Σ is the summation sign

O is the observed frequency

E is the expected frequency

4.2.3 Multinomial Logistic Regression Analysis

Multinomial Logistic Regression (MNL) is used to predict a nominal dependent variable (crash severity) given one or more independent variables (e.g., speed, distance from intersection, etc.). It is sometimes considered an extension of binomial logistic regression to allow for a dependent variable with more than two categories. As with other types of regression, MNL can have nominal and/or continuous independent variables and can have interactions between independent variables to predict the dependent variable (Greene, 2015). Dependent variables with M categories require the calculation of M-1 equations, one for each category relative to the reference category, to describe the relationship between the dependent and independent variables.

Model:

If the first category is the reference, then, for M=2,…,M,

$$\ln \frac{P(Yi = m)}{P(Yi = 1)} = \alpha_m + \sum_{k=1}^{K} \beta_{mk} X_{ik} = Z_{mi}$$

Hence, for each case, there will be M-1 predicted log odds, one for each category relative to the reference category. When there are more than 2 groups, for m=2,…,M,

$$P(Y_i = m) = \frac{exp(Z_{mi})}{1 + \sum_{h=2}^{M} exp(Z_{hi})}$$

For the reference category,

$$P(Y_i = 1) = \frac{1}{1 + \sum_{h=2}^{M} exp(Z_{hi})}$$

Assumptions:

- The dependent variable is measured at the nominal level
  - There are one or more independent variables that are continuous, ordinal, or nominal (including dichotomous variables)
  - Observations are independent and have mutually exclusive and exhaustive categories
  - There is no multicollinearity
  - There is a linear relationship between any continuous independent variable and the logit transformation of the dependent variable
  - There are no outliers, high leverage values, or highly influential points

When interpreting an MNL model, one of the response categories is used as a baseline or reference cell, log-odds are then calculated for all other categories relative to this baseline, and then the log-odds become a linear function of the predictors.

In this analysis Logit Models are used to identify any significant relationships between non-motorized crash severity and travel behavior and built environment characteristics.

4.3 Summary Statistics

To provide a better understanding of the dataset, preliminary summary statistics were run. First, crash severity was evaluated by mode. As shown in Table 4.1, 75.2% of the pedestrian crashes in the sample resulted in a suspected serious injury, while 24.8% were fatal. Among bicycle crashes, 90.6% resulted in a suspected serious injury, while 9.4% were fatal.

Table 4.1 Crash Severity by Mode

Crash Severity	Pedestrian Crashes	Bicycle Crashes
Suspected Serious	1,364 (75.2%)	645 (90.6%)
Fatal	449 (24.8%)	67 (9.4%)
N=2,525	1,813	712

A large majority of both pedestrian and bicycle crashes involved a single vehicle (>90%). Approximately 4% of suspected serious or fatal pedestrian crashes involved a parked car (including a driver who parks their car and upon exiting becomes the pedestrian), while only 1.3% of bicycle crashes involved a parked car (Table 4.2).

Table 4.2 Manner of Collision: By Mode

Crash Type	Pedestrian Crashes	Bicycle Crashes
Angle Crash	1.5%	(0.7%)
Front to Rear	1.7%	0.2%
Single Vehicle	91.9%	97.2%
Parked Vehicle	4.0%	1.3%
Other	0.9%	0.6%
N=2,525	1,813	712

4.3.1 Environmental Conditions

Environmental conditions at the time of the crash varied by mode. Among pedestrian crashes, nearly half occurred in the dark (25.4% lighted, 23.7% unlighted), with 44.5% occurring during daylight hours, and 4.7% during the transition period at dawn or dusk. Bicycle crashes predominately occurred during daylight hours (75.4%), with only 13.2% of crashes taking place in the dark, and 6.6% at dawn or dusk (Table 4.3).

Table 4.3 Lighting Conditions: By Mode

Lighting Conditions	Pedestrian Crashes	Bicycle Crashes
Dark-Lighted	25.4%	12.8%
Dark-Not lighted	23.7%	0.4%
Unknown Lighting	0.0%	0.7%
Dawn	2.1%	2.2%
Daylight	44.5%	75.4%
Dusk	2.6%	4.4%
Other	1.7%	4.2%
N=2,525	1,813	712

For pedestrian crashes, weather did not seem to play a significant role, with a large majority of crashes occurring in clear (77.6%) or cloudy weather (13.1%). Only 7.9% of pedestrian crashes and 3.7% of bicycle crashes occurred in inclement weather (raining or snowing) as shown in Table 4.4. Other weather conditions (fog, sleet, etc.) were only present in a very small percentage of serious and fatal crashes (1.2%).

Table 4.4 Weather at Time of Crash

Weather	Pedestrian Crashes	Bicycle Crashes
Clear	77.6%	85.7%
Rain	5.7%	2.9%
Snowing	2.2%	0.8%
Cloudy	13.1%	9.8%
Other	1.4%	0.8%
N=2,525	1,813	712

4.4 Geographic Statistics

Location characteristics have been shown to play a significant role in the prevalence and severity of non-motorized crashes and are the focus of this research. The first step in understanding these crashes is to determine where the crashes are occurring. Serious and fatal bicycle crashes occurred more often at intersections or driveways (36.1%) than equivalent pedestrian crashes (24.5%). Serious and fatal pedestrian crashes were more prevalent at mid-block locations (75.5%) as shown in Table 4.5.

Table 4.5 Crash Locations

Crash Location	Pedestrian Crashes	Bicycle Crashes
Intersection* or Driveway**	24.5%	36.1%
Midblock	75.5%	63.9%
N=2,525	1,813	712

*Crash occurred within 250’ of an intersection and was coded as “Intersection Related”
**Roadway Junction Type = Farm/Residential Drive or Business Drive

A deeper evaluation of crash location examined serious and fatal non-motorist crashes relative to roadway characteristics and proximity to an intersection. There was not a significant difference in the mean distance from an intersection between suspected serious injury or fatal crashes for pedestrians or cyclists. However, bicycle crashes, particularly fatal bike crashes, were more likely to occur at intersections than serious or fatal pedestrian crashes.

Currently UDOT has a policy in place (UDOT 06C-27) where mid-block crossings cannot be installed within 600 feet of an existing intersection or crossing. To investigate the efficacy and appropriateness of this policy crashes that occurred 15-600 feet away from the intersection were evaluated. As shown in Table 4.6, over one-third of both suspected serious and fatal pedestrian crashes occurred within 600 feet of an intersection, but not at the designated intersection crossing. This reinforces the hypothesis that even if a safe crossing is within what may seem to be a realistic walking distance, pedestrians still choose to cross in an illegal location.

The next step examined the AADT on the roadways where these serious and fatal crashes occurred. Table 4.6 shows that fatal pedestrian crashes occurred on higher volume roadways than suspected serious injury crashes, while fatal bicycle crashes occurred on substantially lower volume roadways than suspected serious injury bike crashes or the pedestrian crashes.

Table 4.6 Crash Location Characteristics

Location Characteristics	Pedestrian Crashes		Bicycle Crashes	
	Serious	**Fatal**	**Serious**	**Fatal**
Mean distance from intersection (feet)	1,073	1,066	1,155	1,165
Crashes occurring at an intersection	19.5%	19.6%	23.3%	32.8%
Crashes occurring 15-600 feet from an intersection	35.7%	37.4%	32.8%	26.9%
Distance to nearest crosswalk (feet)	1,095	1,073	1,263	1,053
Mean AADT	18,345	25,102	14,535	11,366
Mean Speed Limit	35	40.5	34	36
Pedestrian Island	8.8%	6.5%	10.0%	10.5%
N=2,525	1,364	449	645	67

It should be noted that this evaluation does not consider the roadway volume or traffic density at the time of the crash but rather AADT. As Table 4.3 showed, about half of serious and fatal pedestrian crashes occur in the dark (49.1%) when traffic volumes are likely to be lighter. Therefore, it is important to consider not just volumes, but other roadway conditions like speed limit. For example, the mean speed limit on roadways where fatal pedestrian crashes occurred was over 5 miles per hour higher than roadways where serious injury crashes occurred. Likewise, fatal bicycle crashes occurred on higher speed roadways than serious injury crashes (Table 4.6). Additionally, in a large majority of crashes, there was no center median present on the roadway, which could provide a pedestrian refuge while crossing higher speed, higher volume roads.

Next, the analysis turned toward access to common non-motorist destinations and points of interest such as transit stops, trails, and bike lanes. Table 4.7 shows the number of transit routes and stops located near the crash location. If crashes are occurring near transit stops, this could signify correlation between transit access and crashes. Table 4.7 shows that on average there is a transit stop very near all serious and fatal pedestrian crashes, while bicycle crashes occur slightly further away from stops.

Table 4.7 Proximity to Transit by Crash Type

Proximity to Transit	**Pedestrian Crashes**		**Bicycle Crashes**	
	Serious	**Fatal**	**Serious**	**Fatal**
UTA Route (within 250 Feet)	1.12	1.0	0.94	0.78
UTA Route (within 1000 feet)	1.83	1.54	1.53	1.10
UTA Stop (within 250 feet)	0.59	0.52	0.52	0.39
UTA Stop (within 1000 feet)	2.89	2.50	2.37	1.78
N=2,525	1364	449	645	67

The mean distance to a trail from a pedestrian crash site is about 1,400 feet (approximately ¼ mile). Table 4.8 shows the average number of trails and bike lanes near each pedestrian and bicycle crash location. The average distance to a bike lane from suspected serious injury bike crashes is 0.20 miles and only 0.15 miles for fatal bike crashes. Approximately 7.3% of suspected serious injury bike crashes and only 6.0% of fatal bike crashes occurred in or near a bike lane. Interestingly, suspected serious and fatal pedestrian crashes were even less likely to occur on roadways with bike lanes present. 3.7% of serious and 3.8% of fatal pedestrian crashes occurred near a bike lane.

Table 4.8 Proximity to Non-Motorist Facilities

Proximity to NM Facilities	Pedestrian Crashes		Bicycle Crashes	
	Serious	Fatal	Serious	Fatal
Bike lane within 1 mile	37.1%	29.6%	45%	34.3%
Distance to nearest bike lane (feet)	899	787	1070	823
Within 15 feet of bike lane	3.7%	3.8%	7.3%	6.0%
Trails (within 250 Feet)	0.41	0.25	0.26	0.19
Trails (within 1000 feet)	3.90	2.26	2.94	2.22
Distance to nearest trail (feet)	1,414	1,444	1,388	1,184
N=2,525	1364	449	645	67

4.5 Driver Contributions

Driver characteristics can also play an important role. In approximately 4.5% of suspected serious injury or fatal pedestrian crashes, excess speed, or speeds too fast for existing conditions, were a factor. Alternatively, vehicle speed was only a factor in 1.8% of bicycle crashes (Table 4-9).

Table 4.9 Non-Motorized Crashes Involving Speed

Speed Involved	Pedestrian Crashes	Bicycle Crashes
Yes	4.5%	1.8%
No	95.5%	98.2%
N=2,526	1,813	712

Impairment was also investigated. In suspected serious injury or fatal pedestrian crashes, approximately 4.8% of drivers were driving under the influence of drugs or alcohol. In suspected serious or fatal bike crashes, driver impairment was involved 12.2% of the time (Table 4.10).

Table 4.10 Non-Motorized Crashes Involving DUI

DUI Involved	Pedestrian Crashes	Bicycle Crashes
Yes	4.8%	12.2%

No	95.2%	87.8%
N=2,525	1,813	712

4.6 Logistic Regression Model

MNL was used to identify significant correlations between physical environment characteristics and crash severity. The reference category was "suspected serious" injury, meaning that the probabilities shown (*B*) are likelihood of a crash resulting in a fatality versus a suspected serious injury. Table 4-11 shows the results.

Table 4.11 Crash Severity and Environmental Conditions (MNL Regression)

Crash Severity		*B*	Sig.	Exp(B)	95% Confidence Interval for Exp(B)	
					Lower Bound	Upper Bound
Fatal Crash	Intercept	1.414	0.372			
	Speed Involved	0.321	0.289	1.379	0.762	2.496
	Crash occurred within 600 feet of intersection	0.004	0.975	1.004	0.765	1.319
	Distance to nearest crosswalk (meters)	0.000	0.546	1.000	1.000	1.000
	Lighting: Dark - Lighted	-0.979	0.195	0.376	0.086	1.649
	Lighting: Dark - Not Lighted	-0.516	0.495	0.597	0.136	2.628
	Lighting: Dark - Unknown	-0.647	0.440	0.524	0.101	2.708
	Lighting: Dawn	-1.022	0.216	0.360	0.071	1.818
	Lighting: Daylight	-1.848	0.015	0.158	0.036	0.694
	Lighting: Dusk	-1.461	0.074	0.232	0.047	1.152
	Lighting: Other	18.547	0.998	113,423,931.350	0.000	.
	Lighting: Unknown	0	.	.	.	.
	Weather: Blowing Snow	-16.05	0.996	1.061E-7	0.000	.
	Weather: Clear	-0.453	0.569	0.636	0.134	3.016
	Weather: Cloudy	-0.194	0.809	0.823	0.170	3.987
	Weather: Fog, Smog	1.013	0.418	2.753	0.237	31.915
	Weather: Other	0	.	.	.	.
	Weather: Rain	-0.410	0.639	0.663	0.120	3.676
	Weather: Severe Crosswinds	18.968	.	172,928,581.524	172,928,58 1.524	172,928,58 1.524

	Weather: Sleet, Hail	31.799	0.992	64,567,212,516,605.670	.000	.
	Weather: Snowing	.076	.937	1.079	.163	7.134
	Weather: Unknown	0	.	.	.	.
	Pedestrian Involved (No)	-.769	.001	.464	.343	.627
	Pedestrian Involved (Yes)	0	.	.	.	.
	On a road without a bike lane	-.046	.864	.955	.564	1.618
	On a road with a bike lane	0	.	.	.	.
	N=2,523					

As shown above, non-motorist crashes occurring during the daylight were nearly two times less likely to be fatal (-185%). Additionally, crashes involving a cyclist were found to be 24% less likely to be fatal.

4.7 Corridor Case Studies

4.7.1 StreetLight Data

StreetLight Data is a big data analytics company that processes geospatial data points to measure how motor vehicles, pedestrians and bicycles travel. StreetLight capitalizes on the massive volume of geospatial information created by mobile phones to generate estimates of ODs, trip purpose, and travel times for personal and commercial trips. The StreetLight platform enables the users to design, run, and visualize customized queries like OD and link flows that may be disaggregated by time of day and trip purpose. For this project, the research team utilized the pedestrian and bicycle data that recently became available for the years between 2019 and 2022. Selected output types were "StreetLight Pedestrian Volume (Pedestrian Trips)" for pedestrian data and "StreetLight Bicycle Volume (Bicycle Trips)" for bicycle data.

4.7.2 Data Collection and Analysis Methodology

Based on historic crash data derived from the UDOT Crash Database, corridor hotspot maps were constructed to identify the crash hotspots for each of the five most populated counties in Utah – Salt Lake County, Utah County, Davis County, Weber County and Washington County. Figure 4-1 shows the major crash locations in the form of heatmaps.

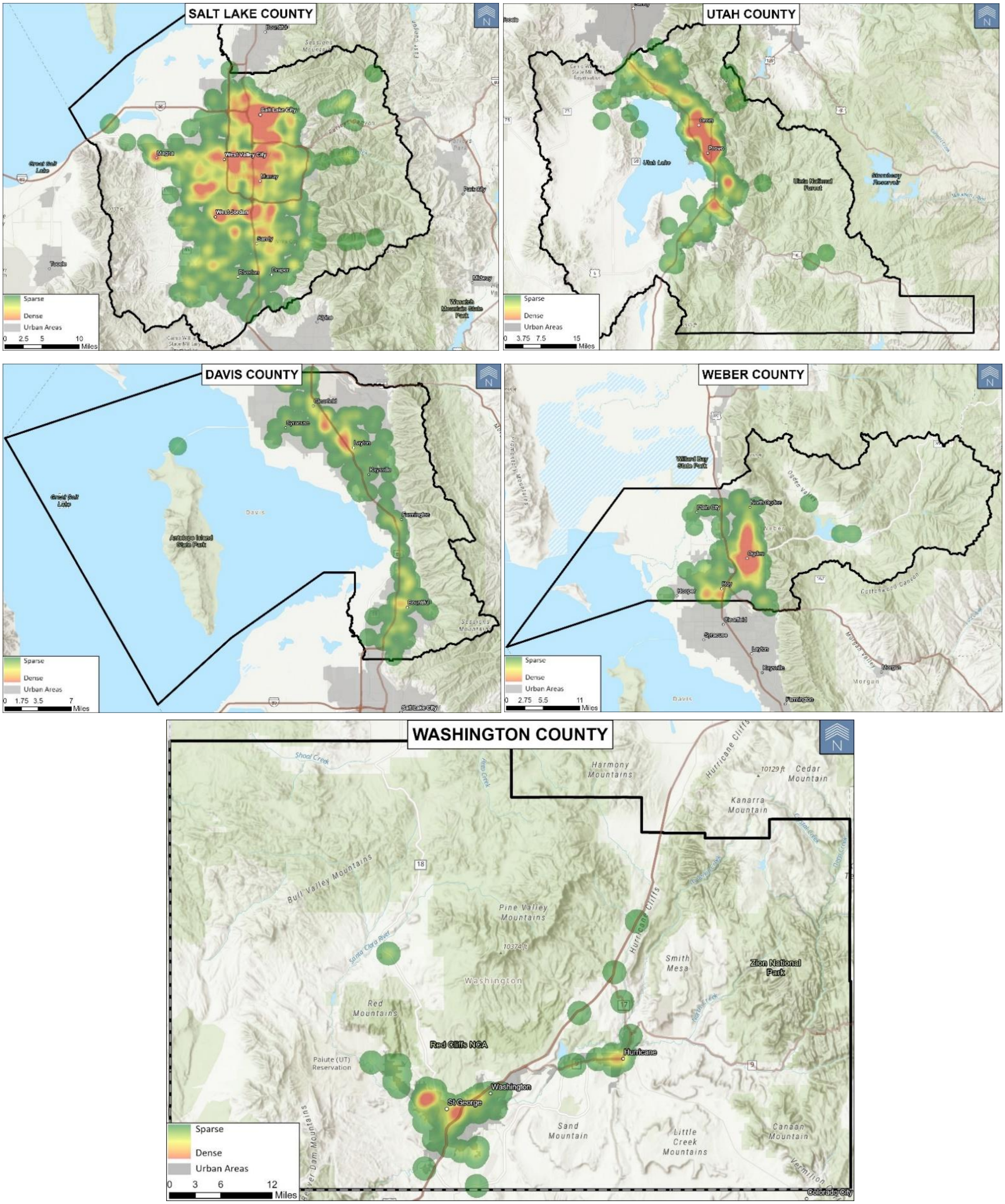


Figure 4-1. County Crash Heatmaps

Based on the heatmaps, hotspot corridors were selected from each of these counties for further case study analysis. Table 4-13 shows the hotspot corridors and their county-specific crash numbers for pedestrian and bicycle severe crashes. Additionally, it shows the number of severe non-motorized crashes standardized per 100,000 population.

Table 4.12 Number of Severe Non-Motorist Crashes Between 2019 and 2021

County Name	Number of Non-Motorist Severe Crashes	NM Severe Crashes per 100,000 pop.	Corridor with the maximum number of crashes
Salt Lake County	304	29.5	US-89 (0089P)
Utah County	98	16.1	US-89 (0089P)
Weber County	78	29.1	US-89 (0089P)
Davis County	57	15.8	SR-126 (0126P)
Washington County	41	22.7	SR-9 (0009P)

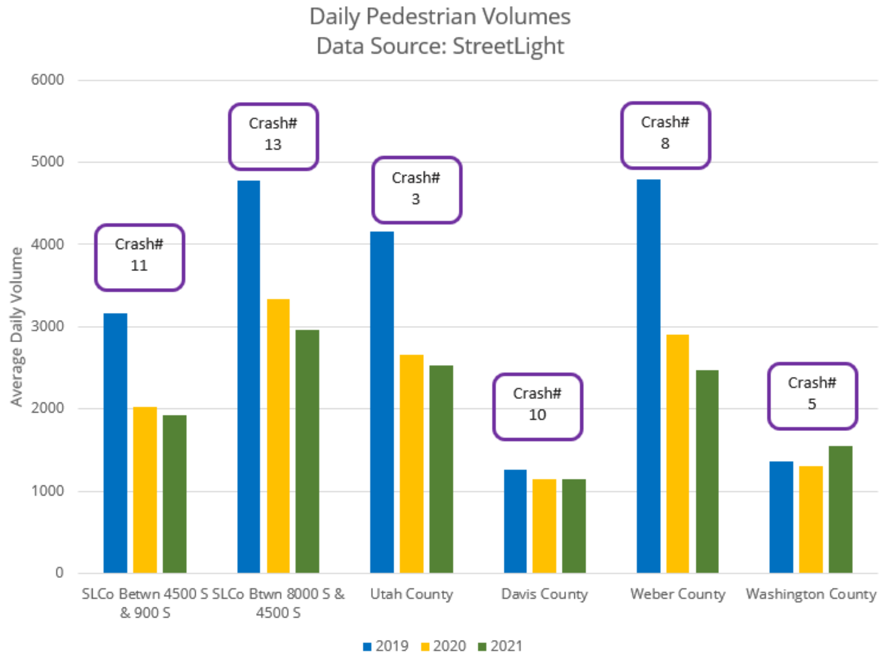
After the corridors with the maximum number of severe crashes were identified, a sliding window analysis (AASHTO, 2010) was performed to identify the 5-mile segment where the maximum number of crashes occurred along these corridors. These hotspot corridors were divided into 5-mile segments in 0.1-mile increments. For each corridor, a 5-mile segment with the maximum number of severe crashes between 2019 and end of year 2021 was selected. For some corridors, such as US 89 in Weber County and Utah County, and SR 126 in Davis County, 5-mile segments with the second highest crash numbers were chosen due to StreetLight only being able to analyze straight-lying segments of roadway (and the highest crash numbers were present on curved segment). As Salt Lake County has more than double the crashes of other counties in the table, two segments from Salt Lake County were chosen for case study analysis. These 5-mile segments and their number of crashes between January 2019 and December 2021 are presented in Table 4-14. The mile point information is derived from the UDOT Online Data Portal.

Table 4.13 Number of severe non-motorist crashes between 2019 and 2022 for the crash hotspot corridors

County	Corridor Name (Route ID)	Geographical Extents	Beg MP	End MP	Severe NM Crashes (#)
Salt Lake County	US-89 (0089P)	Between 8000 S & 4500 S, Salt Lake City	373.1	378.1	12
Salt Lake County	US-89 (0089P)	Between 4500 S & 900 S, Salt Lake City	374.7	379.7	14
Utah County	US-89 (0089P)	Between 1320 S & 1600 S, Orem	332.4	337.4	6
Weber County	US-89 (0089P)	Between 40th St and Southwell St, Ogden	411.6	416.6	11

Davis County	SR-126 (0126P)	Between Church St, Layton & Center St, Clearfield	1.1	6.1	8
Washington County	SR-9 (0009P)	Between Sand Hollow & Main St, Hurricane	5.9	10.9	5

These segments were drawn in StreetLight as pass-through zones to collect pedestrians and bicycle volume data. Figure 4-2 shows the county-wise yearly distributions for pedestrian and bicycle volume data based on StreetLight analysis. Overall, the crash trends follow the volume trend, except for Utah County where there is a high number of pedestrians and bicyclists, but the number of crashes is the lowest. Also, the number of severe bicycle crashes across all six hotspot corridors is half the number of pedestrian crashes while the bicycle volumes are one-third of pedestrian volumes.



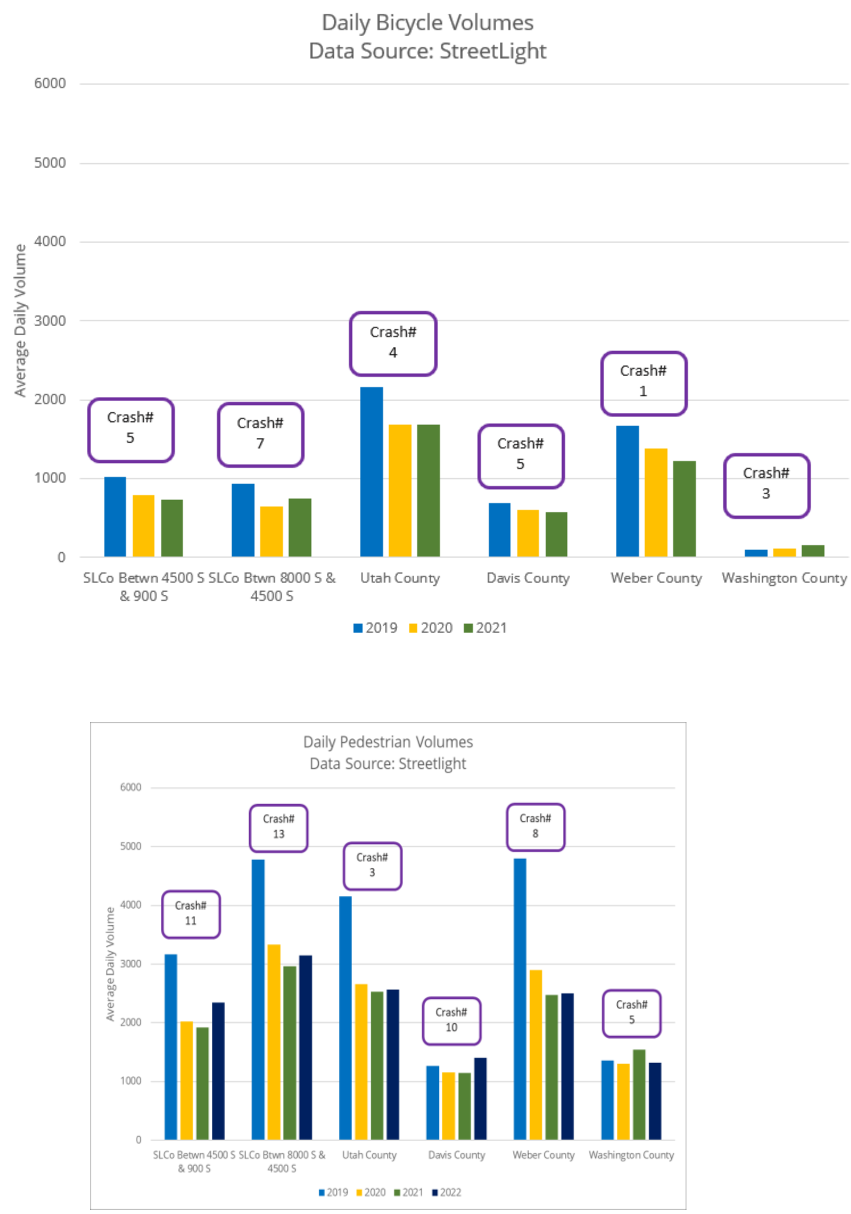


Figure 4-2. Pedestrian and Bicycle Volume and Crash Trends for Hotspot Corridors (2019-2022)

It should be noted that pedestrian and bicycle volumes derived from StreetLight are calculated through models and are estimates of the total number of pedestrian and bicycle trips that actually occur. According to StreetLight whitepaper, volume estimates are better along roads with especially high pedestrian volume. For lower volume roads the median absolute percent errors are observed to be as high as 388% (StreetLight, 2022).

4.8 Summary of Results

Summary statistics, and MNL analysis were conducted for each corridor to determine which variables significantly predicted the likelihood of non-motorized crashes resulting in a fatality or suspected serious injury. The analysis identified several significant variables and relationships for both pedestrian and cyclist crashes, such as the clustering of pedestrian fatal crashes near crosswalks and intersections, increased chances of a fatal crash during nighttime hours, significance of driver impairment on pedestrian and cyclist crashes, and other relationships. Hotspot corridor case studies were also illustrated to show corridors with the highest levels of severe non-motorist crashes in the five most populated counties in Utah. Findings are described in the following chapter.

5.0 CONCLUSIONS

5.1 Summary

Based on the analysis provided in Chapter 4, this chapter summarizes the findings of the research. Additionally, this chapter highlights limitations and challenges that were identified as the research was undertaken.

5.2 Findings

5.2.1 Overview of Findings

The data showed that a large majority of both pedestrian and bicycle crashes involved a single vehicle (>90%). Environmental conditions at the time of the crash varied by mode and weather did not seem to play a significant role, as a large majority of pedestrian crashes occurred in clear (77.6%) or cloudy weather (13.1%). Typically, inclement weather is a deterrent to non-motorists who would prefer more protected travel modes (vehicle, transit, etc.) when the weather is bad.

As described in Chapter 4, as of this writing (2022) UDOT has a policy in place where mid-block crossings cannot be installed within 600 feet of an existing intersection or crossing. However, over one third of both suspected serious injury and fatal pedestrian crashes occurred within 600 feet of an intersection, but not at the designated intersection crossing. This confirms prior research showing that pedestrians will not walk very far out of their way to get to a safe crossing. Rather, many pedestrians will take their chances crossing away from the intersection. These crossings can be particularly dangerous for pedestrians. Approximately 37.4% of fatal pedestrian crashes occurred 15-600 feet from an intersection (35.7% of suspected serious injury crashes). For cyclists, intersections tend to be more dangerous; 32.8% of fatal bicycle crashes occurred at an intersection while 26.9% occurred 15-600 feet from an intersection. Nearly 40% of pedestrian fatalities and 33% of cyclist fatalities occur within a geographic envelope where installing a safe crossing is prohibited. The table below provides additional insight into this idea, showing a breakdown of distances (within the 600-foot window) for severe bicycle and pedestrian crashes.

Table 5.1 Crashes Within 600 feet of an Intersection (%)

Distance	Pedestrian Crashes		Bicycle Crashes	
	Suspected Serious	Fatal	Suspected Serious	Fatal
At the intersection	40.7	37.9	48.4	51.0
16-50 feet	14.3	13.3	10.7	12.2
51-100 feet	8.4	9.8	8.2	14.3
101-150 feet	4.9	9.0	5.5	4.1
151-200 feet	3.5	5.2	4.0	2.0
201-300 feet	11.3	6.9	7.8	2.0
301-400 feet	4.6	6.9	4.6	4.1
401-600 feet	12.3	11.0	10.7	10.2
Total (n)	1057	346	475	49
Chi-Square	X^2=18.19 (p=0.02)		X^2=9.041 (p=0.60)	

As shown above, most crashes that occur within 600 feet of an intersection occur outside the intersection itself. For severe pedestrian crashes, 17.6% of suspected serious injury and 32.1% of fatal crashes occur 16-150 feet from an intersection, while 31.7% of suspected serious injury and 30% of fatal crashes occur 151-600 feet from an intersection. For severe bicycle crashes, 24.4% of suspected serious injury and 30.6% of fatal crashes occur 16-150 feet from an intersection, while 27.1% of suspected serious injury and 18.3% of fatal crashes occur 151-600 feet from an intersection.

When evaluating AADT on the roadways where these suspected serious injury and fatal crashes occurred, the analysis shows that fatal pedestrian crashes occurred on higher volume roadways than suspected serious injury crashes, while fatal bicycle crashes occurred on substantially lower volume roadways than suspected serious injury bike crashes or the pedestrian crashes. The mean speed limit on roadways where fatal pedestrian crashes occurred was over 5 mph higher than roadways where suspected serious injury crashes occurred. However, vehicle speed was not found to be a significant factor. In 4.5% of suspected serious or fatal pedestrian crashes, excess speed or speeds too fast for existing conditions were a factor. Additionally, speed was only a noted factor in 1.8% of bicycle crashes. In suspected serious injury or fatal pedestrian crashes, approximately 4.8% of drivers were driving under the influence of drugs or alcohol. In suspected serious or fatal bike crashes, driver impairment was involved 12.2% of the time. There has been a recent trend where cities identify corridors parallel to higher ADT routes on which to add bicycle facilities or bicycle routes. The idea behind this strategy is that moving cyclists away from higher speed, higher volume roadways will improve safety and reduce the probability of severe crashes. This strategy has been used in creating the Utah Statewide Bicycle Network. However, the most common pedestrian infrastructure is a sidewalk, which is typically present on even the highest volume/speed roadways. While technically separated from the vehicle right-of-way, there are often few buffers from traffic and many instances where pedestrians have been hit on the sidewalk. The findings of this research suggest that additional care should be taken to provide and promote pedestrian corridors further from high volume or high-speed roadways or protected with some kind of buffer (e.g., a park strip). Additionally, bulb-outs or pedestrian bridges and tunnels can be used at higher volume crossings to keep pedestrians away from vehicular traffic.

Approximately 7.3% of suspected serious injury bike crashes and only 6.0% of fatal bike crashes occurred in or near a bike lane. Interestingly, suspected serious injury and fatal pedestrian crashes were even less likely to occur on roadways with bike lanes present. Fewer than 4% of serious and fewer than 2.5% of fatal pedestrian crashes occurred near a bike lane. Bike lanes improve safety in several ways. First, they provide a dedicated area for cyclists to travel in outside of the vehicle right-of-way. Second, drivers on the roadway see a bike lane and consciously or subconsciously recognize that bicycles could be present in that area, thereby increasing their awareness. For pedestrians, a bike lane creates an additional buffer between vehicular traffic and the shoulder where pedestrians typically walk, particularly in areas without a sidewalk. Additionally, when crossing a road, bike lanes shrink the width of the roadway where motorized vehicles are typically present. On corridors with a bike lane, pedestrians are given an extra 5-10 feet of shoulder in which to stand while preparing to cross. Additionally, motorists can see pedestrians entering the roadway for a longer period of time before they enter a vehicle lane conflict point.

An MNL model was employed to identify any significant correlations between non-motorized crash severity and environmental factors. The pooled model (i.e., including both pedestrian and bicycle crashes) determined that non-motorist crashes occurring during daylight were nearly two times less likely to be fatal while crashes involving a cyclist were 24% less likely to be fatal.

5.3 Limitations and Challenges

As with any research, datasets come with limitations and challenges. The following limitations were identified within this project:

- **A lack of pedestrian and cyclist volumes for all locations.** While we were able to gather vehicle volumes for selected corridors and crash locations, accurate pedestrian and cyclist volumes were unavailable. Not having accurate volumes results in the inability to calculate crash rates for non-motorist crashes (e.g., *x* ped crashes per 1,000 peds). To dig deeper into the relationship with pedestrian and cyclist volumes, a case study was conducted on hotspot corridors to further examine the potential impact of non-motorist volumes using StreetLight data. However, this data is also prone to accuracy issues due to lack of pedestrian and bicyclist volumes to calibrate to.

- **A lack of land-use data.** Currently, there is no comprehensive land-use database for the State of Utah. While specific municipalities do have this data, it is not readily available. As it would have been time and cost prohibitive to collect data for all five counties examined in the hotspot corridor research, specific land-use data was not collected. Rather environmental characteristics, such as relative location, were evaluated. Future research is recommended to drill down on a smaller subsample of crash locations for in-depth contextual analysis.

- **A lack of pedestrian and cyclist travel behavior data.** As mentioned in the literature review, understanding both driver and non-motorist travel behavior and decision making is critical to understanding why crashes occur. The dataset evaluated for this project did not include comprehensive travel behavior data. While some basic elements of travel behavior data were included (vehicle maneuver, excess speed, etc.), this does not provide adequate information on decision making. For example, why did a pedestrian choose to walk across a busy street less than 600 feet from a crosswalk; or why did a cyclist choose to ride along a high-volume busy roadway rather than a parallel route with lower vehicular volumes and a bike lane? This information is not easily attainable as it would require on site interviews at the time a behavior is taking place.

6.0 RECOMMENDATIONS AND IMPLEMENTATION

6.1 Recommendations

Based on the analysis provided in Chapter 4 and the findings and conclusions presented in Chapter 5, the following recommendations have been identified:

- Identify appropriate higher volume roadways where pedestrian and cyclist crossings could be installed within the 600-foot intersection envelope, and brainstorm warrants for exceptions to the existing policy
- Identify moderate volume lower speed corridors for added bike lanes to encourage cyclists to travel safely on lower speed/volume roadways
- Identify higher volume pedestrian and bicycle crossing locations for improved crossings (bulb-outs, bridges, tunnels, etc.)
- Investigate methods for routing non-motorists toward and encouraging them to use existing safe facilities, including barriers; signage; high comfort facilities; etc.

6.2 Implementation Plan

1. Revisit existing UDOT mid-block crossing warrants, determining if current policy is appropriate and in line with FHWA best practices and standards (see https://safety.fhwa.dot.gov/ped_bike/univcourse/pdf/swless16.pdf).

2. Evaluate UDOT's current Marked Pedestrian Crosswalks policy (UDOT 06C-27) and identify options for adjusting the current criteria, which prohibits installation of a new marked crossing within 600 feet of an existing crossing. Evaluate the potential of reducing the prohibition to within 300 feet of an existing marked crossing.

3. Examine implementing pedestrian safety fencing at key locations (identify criteria) for areas within 150 feet of an existing marked crossing. Identify other appropriate measures that can be used in lieu of fencing to safely direct pedestrians (See Appendix A).

4. Conduct a before-and-after study to measure the safety and behavioral impact of key speed and travel behavior management characteristics (e.g., bulb-outs, center

medians, pedestrian fencing, low speed zones, etc.). This study should collect data prior to implementing new infrastructure and following the installation.

5. Integrate prior UDOT research on latent Active Transportation demand with current decision making. See:

    - Singleton, P.A., F. Runa, and P. Humagain. (2020). Utilizing archived traffic signal performance measures for pedestrian planning and analysis (UT-20.17). Utah Department of Transportation. https://rosap.ntl.bts.gov/view/dot/54924

      This project developed a method to get estimates of ped volumes from ASTPM push-button data.

    - Singleton, P.A., K. Park, and D.H. Lee. (2021). Utilizing ATSPM data for pedestrian planning and analysis – Phase II: Extending pedestrian volume estimation capabilities to unsignalized intersections (UT-21.32). Utah Department of Transportation. https://rosap.ntl.bts.gov/view/dot/60875

      This project related ped volumes to land use and built environment characteristics and developed a direct-demand pedestrian volume estimation model.

6. Integrate Speed Management Studies (SMS) in the decision-making process by identifying and implementing appropriate vehicular speed controls with pedestrian crossings. See:
https://drive.google.com/file/d/1n4NBMyx6nxL6ZnKPJxdUu5mNp7m1VCo5/view

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I. <u>Appendix A-Design Options</u>

This appendix provides visual representations of design options that can be used to implement the strategies discussed in the conclusions and implementation plan.

Figure A-1 Speed Management: 4S Ranch, CA

Figure A-2 Traffic Calming: Strathcona County, Canada

Figure A-3 Pedestrian Barrier: San Diego, CA

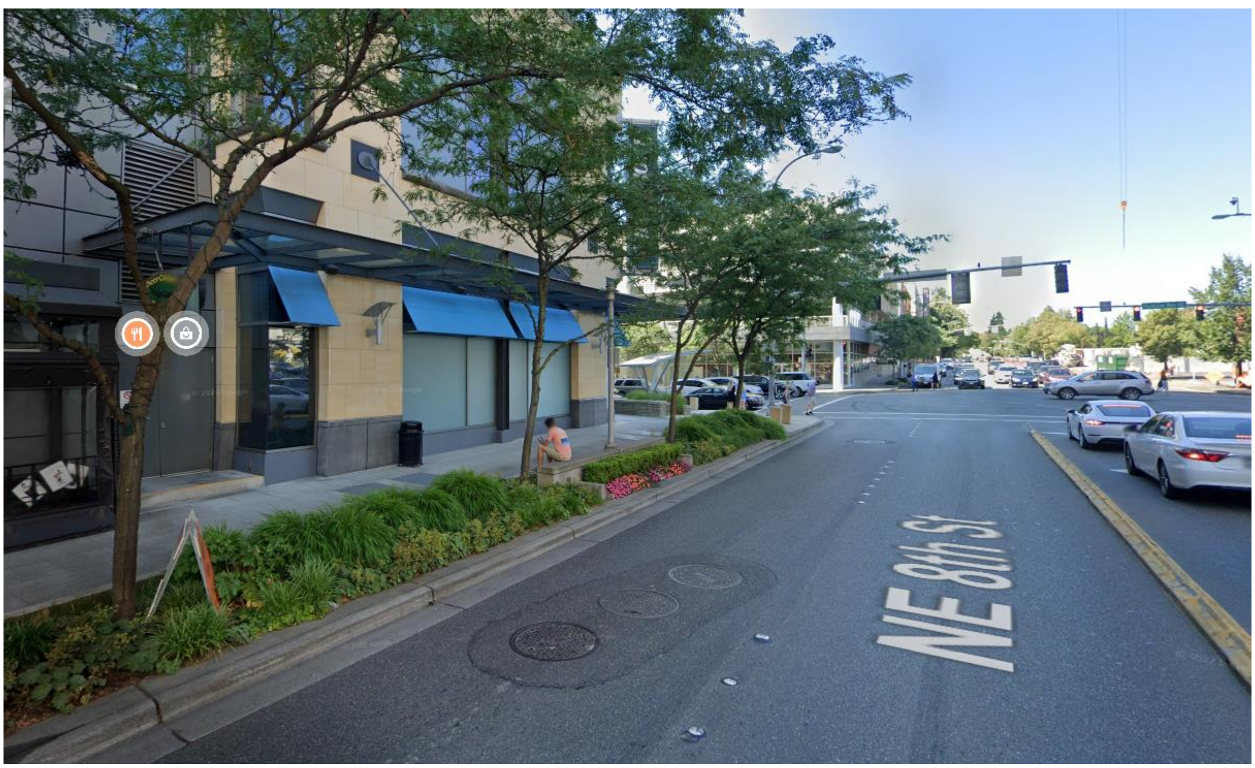

Figure A-4 Vegetation Pedestrian Barrier: Bellevue, WA

Figure A-5 Vegetation and Stone Pedestrian Barrier: Bellevue, WA

Figure A-6 Vegetation Pedestrian Barrier: Seattle, WA

Figure A-7 Bike Trail Adjacent to SR 56: San Diego, CA

Figure A-8 Bike Path Adjacent to WA-520: Bellevue, WA

Figure A-9 Speed Management and Pedestrian Deterrent: Del Mar, CA

Figure A-10 Bike Path Crossing Beneath Grade: Lehi, UT

Figure A-11 Travel Lane Converted to Sidewalk/Bike Path: Seattle, WA

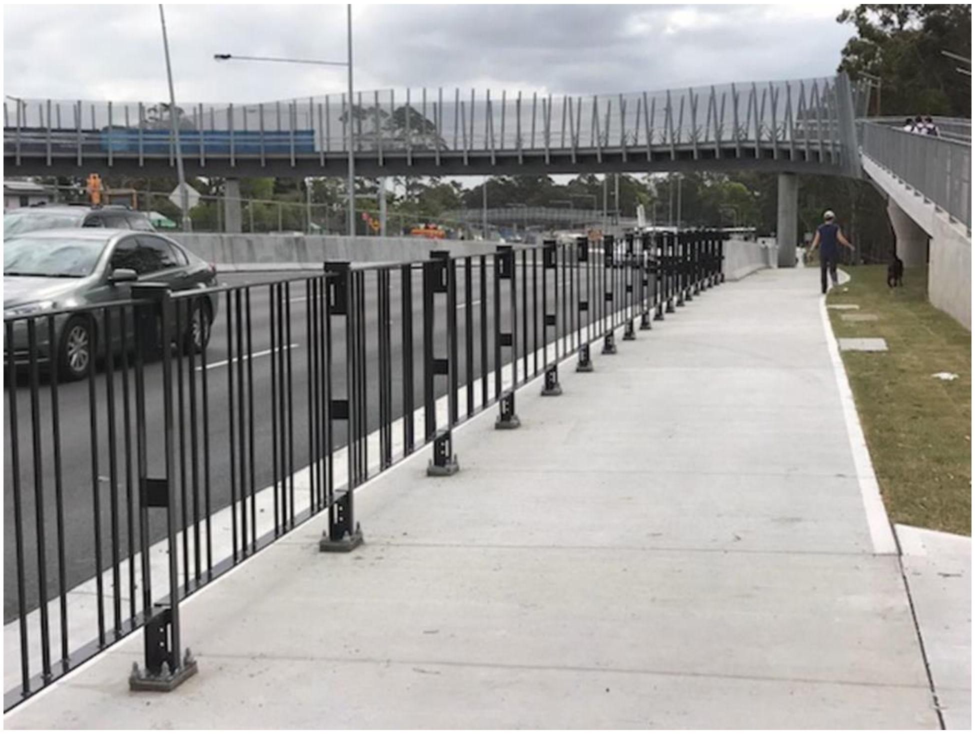

Figure A-12 Pedestrian Safety Fencing (Summit Fencing)

Figure A-13 Decorative Pedestrian Fencing; Pontypool, UK

Figure A-14 Crossing Island with Fencing (AASHTO)