RESEARCH

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MEASURING PEDESTRIAN EXPOSURE AND RISK IN HIGH-RISK AREAS

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UDOT Keeping Utah Moving
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16. Abstract

For the past three years, UDOT has been studying characteristics of high- and low-risk intersections for pedestrians and cyclists in an effort to better understand what creates a dangerous environment for non-motorized travelers. This research has resulted in a number of significant findings which have been incorporated by UDOT in design standards (i.e. creation of a mid-block crossing standard, increased signal times, etc.). While this work has been exhaustive in looking at the natural and built-environment surrounding and including each intersection, it has failed to capture the element of human behavior. Ultimately no matter how "safe" we design an intersection to be, we cannot directly affect the decision making and behavior of the pedestrians and cyclists traveling on the roadway. This research utilized video footage from 9 intersections identified as high-risk for pedestrian and cyclist crashes. 2,062 individual crossings by pedestrians were evaluated regarding the individual crossing behavior at each intersection. These crossings were coded based on the demographics of the non-motorized traveler, crossing behavior (time, distractions, illegal behavior, etc.), and any interaction or degree of conflict with vehicles. Findings include that a small number of crossing result in a minor or serious conflict (2%). A significant number of conflicts occur when a vehicle is turning right (48%) or stops in the crosswalk (17%). A pedestrian exhibiting no distractions is approximately 45% less likely to experience a potential conflict, while a pedestrian walking alone is over 400% more likely to experience a minor conflict with a vehicle. Three recommendations are provided for reducing pedestrian-vehicle conflicts including: improving the visibility of crosswalks, employing innovative treatments at crossings, and implementing exclusive pedestrian signal phasing.

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LIST OF ACRONYMS

FHWA	Federal Highway Administration
MNL	Multinomial Logit Regression
NHTSA	National Highway Traffic Safety Administration
PBIC	Pedestrian and Bicycle Information Center
TCT	Swedish Traffic Conflicts Technique
TOC	Traffic Operations Center
UDOT	Utah Department of Transportation
USDOT	United States Department of Transportation

EXECUTIVE SUMMARY

For the past three years, UDOT has been studying characteristics of high- and low-risk intersections for pedestrians and cyclists in an effort to better understand what creates a dangerous environment for non-motorized travelers. This research seeks to change that by better understanding pedestrian behavior at intersections. By observing pedestrians as they are actually navigating intersections in high-risk areas we will be able to better understand the risk and exposure that pedestrians face, as well as identifying what percentage of risk can be attributed to pedestrians versus motorized travelers. The decision was made to omit bicycle traffic from the scope of the analysis, focusing instead on higher data quality for the analysis of pedestrian interactions at each crossing.

This project collected data in two main ways; video observations and site visits. The first dataset included video of 1,221 pedestrian crossings at eight intersections collected from closed circuit cameras maintained and monitored by the UDOT Traffic Operations Center (TOC). Technicians were trained on a specific methodology and process for identifying, recording, and storing the video data. Data was collected on predetermined week days and weekend days for three to four hour blocks of time. The recordings were then transferred to the project staff for coding. A predetermined list of characteristics was used to hand code each individual crossing using a variation of the Swedish Traffic Conflicts Technique (TCT) based on the conflict level experienced as well as characteristics of the individual pedestrians. The second dataset included 841 on-site observations of pedestrian crossings conducted at each intersection on one predetermined week-day and one Saturday. Site observations were also collected regarding built environment and geometric characteristics of the intersection as well. Specific site data was included as well (e.g. building setback, intersections width, etc.) to help quantify factors that contribute to increased pedestrian risk when crossing. The research employs summary statistics to provide context for the pedestrian crossing data as well as more sophisticated Multinomial Logistical Regression (MNL) techniques to identify correlations.

Analysis of the observation data found that the large majority of the pedestrians observed were male. The age breakdown of observed pedestrians varied a small amount by site, however in most locations approximately 5% of the pedestrians observed were children, and fewer than

3% of pedestrians were seniors. A majority of pedestrians cross the roadway alone (74.1%). The exception to this pattern is again seen at Hill Field Rd. – Antelope Dr. Only 55% of pedestrians at this location crossed alone, with 21% observed as children crossing with a guardian and 23% crossing in a group.

A large majority of pedestrian crossings were “undisturbed” (83.5%), but nearly 14% of crossings had the potential for conflicts between pedestrians and vehicles (n=283). Minor or serious conflicts were observed in only 2% of crossings (n=42). An examination of signal timing revealed that a large majority of pedestrians began crossing during the walk phase of the signal (95.2%). A small percentage entered the intersection during the flashing phase (2.3%) or the steady phase (1.4%), and only 12 pedestrians were observed crossing against the light (jaywalking), suggesting that a large majority of pedestrians understand and obey the pedestrian signals at intersections. Nearly 12% of pedestrians were distracted during their crossing, most frequently by socializing or using an electronic device. For the 2% of crossings where a minor or severe conflict was observed, the vehicle maneuver at the time of the conflict was recorded. A majority of conflicts resulted when vehicles were turning right (48.8%). Vehicles also frequently stopped beyond the stop line into the crosswalk impeding the pedestrian’s crossing path (17.1%).

Statistical analyses identified that a pedestrian exhibiting no distractions is 45% less likely to experience a potential conflict as compared to a pedestrian who is socializing. Pedestrians who walk slower also have a slightly smaller likelihood (4.1% less) of experiencing a potential conflict during crossing. Additionally, someone walking alone is over 400% more likely to experience a minor conflict than someone walking in a group. The only characteristic correlated to the risk of a serious conflict was age, with adults facing only 4% of the likelihood of being involved in a serious conflict compared to seniors.

Based on the findings of this research, the following three recommendations have been identified: Improve visibility of crosswalks at high-risk locations using appropriate paint, pavement treatments, overhead signage, etc.; employ innovative crosswalk treatments such as leading arrows, advance yield markings, ergonomic design and safe zones as appropriate; and implement exclusive pedestrian phasing at high-risk locations to reduce the exposure between vehicles and pedestrians.

1.0 INTRODUCTION

1.1 Problem Statement

For the past three years, UDOT has been studying characteristics of high- and low-risk intersections for pedestrians and cyclists in an effort to better understand what creates a dangerous environment for non-motorized travelers. This research has resulted in a number of significant findings which have been incorporated by UDOT in design standards (i.e. creation of a mid-block crossing standard, increased signal times, etc.). While this work has been exhaustive in looking at the natural and built-environment surrounding and including each intersection, it has failed to capture the element of human behavior. Ultimately no matter how "safe" we design an intersection to be, we cannot directly affect the decision making and behavior of the pedestrians traveling on the roadway.

1.2 Objectives

This research seeks to change that by better understanding pedestrian behavior at intersections. By observing pedestrians as they are actually navigating intersections in high-risk areas we will be able to better understand the risk and exposure that pedestrians face, as well as identifying what percentage of risk can be attributed to non-motorized versus motorized travelers. To date we can only quantify the impacts that the environment has on safety and crash risk. Using real-time video data, this research will observe non-motorized travelers as they navigate high-risk intersections. This will provide a better understanding of what is happening in "near miss" situations as well as providing insight into human decision making by:

- Quantifying exposure and risk by identifying if a pedestrian or cyclists experiences a crossing that is 1) undisturbed, 2) potential conflict, or 3) minor/serious conflict
- Identifying reckless pedestrian and cyclist behaviors such as crossing in the wrong location (e.g. mid-block), violating rules of the road, crossing against the signal, etc.
- Creating a profile for pedestrian and cyclist safety outlining the hazards faced at high-risk intersections, including recommendations for mitigating risk and improving safety

1.3 Scope

This research utilizes data collected on 2,062 pedestrian crossings at 8 separate high-risk intersections. Crossing were observed using footage from UDOT traffic operations cameras and site visits. All crossings were evaluated based on the conflict level experienced as well as characteristics of the individual pedestrian. Specific site data was included as well (e.g. building setback, intersections width, etc.) to help quantify factors that contribute to increased pedestrian risk when crossing.

1.4 Outline of Report

The report is organized into 6 Sections, as follows: Section 2 provides a brief literature review examining pedestrian travel behavior and risk, as well as a summary of the current state of knowledge regarding near miss incidents. Section 2 also includes the research methods employed in this work, including a description of the study methods and justifications. Section 3 presents the data collected for this study and provides summary characteristics for the crash reports. Section 4 presents both qualitative and quantitative analysis of the non-motorized travel behavior observed in the sample. Section 5 provides conclusions based upon the data provided in the previous sections and Chapter 6 outlines the author's recommendations for implementation.

2.0 RESEARCH METHODS

2.1 Overview

A thorough literature review has been performed on non-motorized travel behavior with a particular emphasis on behaviors that increase crash risk. This chapter provides background information on pedestrian exposure and crash risk both nationally and internationally, and provides an overview of pedestrian travel behavior. This section also includes a discussion of the research methods employed and the justification for each.

2.2 Background

A wealth of research has been conducted examining non-motorized crash risk and severity. This work has included 2 major divisions. The first examines specific risk factors such as: pedestrian and driver characteristics, roadway geometry, built environment characteristics, neighborhood demographics, etc. that have been correlated to an increase in non-motorized risk (Lee and Absel-Aty, 2005; Loukaitou-Sideris, Liggett, and Sung, 2012). The second focuses on modeling accident risk exposure, and quantifying the risks faced by pedestrians and cyclists traveling under differing conditions (Green-Roesel, Diogenes and Ragland, 2010; McAndrews, Beyer, Gusec and Layde, 2013; Jonsson, 2005; and Lassarre, Papadimitriou, Yannis and Golias, 2007). A separate, but more limited line of research has focused on driver and pedestrian contributions or behavior at the time of or before a crash (Kim, Washington, and Oh, 2006; Lyon and Persaud, 2002).

One important area that has been relatively absent in the literature is the occurrence of near miss incidents. A crash is only classified as a crash if a pedestrian/cyclist and an automobile make contact and law enforcement is contacted. But there are a significant number of times on any given day when a pedestrian or cyclist and a vehicle narrowly avoid one another or experience a “near miss”. For every collision that occurs there may be a large number of near miss incidents. A better understanding of pedestrian, cyclist, and driver behaviors that result in near miss incidents or conflicts with vehicles could ultimately contribute to improved safety, as the margin between a near miss and crash can be as small as milliseconds and inches.

The need to reduce pedestrian deaths and injuries while promoting increased walking continues to be an important goal for the engineering profession (Zegeer, et al., 2002a). Pedestrian collisions are a serious concern not only because of the numbers but also because of the strong likelihood of injuries from these collisions. As a result, pedestrian safety programs usually are given high priority in most urban jurisdictions, and safety analyses usually are conducted in support of these programs. Unfortunately, the identification of individual locations at which countermeasures might be targeted often is hampered by the scarcity of pedestrian exposure data, and perhaps accidents (Lyon and Persaud, 2002).

2.2.1 Non-Motorized Safety and Crash Risk

While the number of traffic fatalities has been on the decline in recent decades, there has not been an equivalent decline in pedestrian fatalities. Some have argued that growing pedestrian fatality and injury counts may simply reflect population growth or people making more trips by walking and bicycling therefore increasing their exposure to traffic (Pucher, et al, 2011). According to the Pedestrian and Bicycle Information Center (PBIC, 2016) there is no reliable source of exposure data for pedestrians because of the difficulty in accurately estimating the number of miles people walk each year, or how much time people spend walking or crossing the street. This makes it difficult to calculate exposure and risk for pedestrians.

It has been estimated that presently Americans make up to 8.8 percent of their trips on foot (Beck, Dellinger, and O'Neil, 2007); yet more than 13 percent of all traffic fatalities are pedestrians (Jackson and Kochtitzky, 2001). Children under age 15 are the most overrepresented group in pedestrian crashes and people over age 65 have the most pedestrian fatalities (Zegeer et al., 2002a). Children (3–12) and the elderly had the highest levels of accident risk but only when distance travelled, duration and number of streets crossed were used as the exposure index (Jonah and Engel, 1983).

At higher speeds, motorists are less likely to see a pedestrian, and even less likely to actually stop in time to avoid a crash. At a mere 49.9 km/h (31 mi/h), a driver will need about 61.0 m (200 ft) to stop, which may exceed available sight distance; that number is halved at 30.6 km/h (19 mi/h) (Eckman, 1999). A 30% reduction in the traffic volume would reduce the total number of injured pedestrians by 35% and the average risk of pedestrian collision by 50% at the intersections under analysis (Miranda-Moreno, Morency, and El-Geneidy, 2011).

Existing research has identified 12 main types of pedestrian/bicycle crashes (Zeeger, et al, 2002a). They include:

- Midblock dart/dash,
- Multiple threat (crossing multiple travel lanes, one car stops, the next does not),
- Mailbox or other midblock,
- Failure to yield at unsignalized location,
- Bus related,
- Vehicle turning at intersection,
- Through vehicle at intersection,
- Walking along roadway,
- Working/playing in road,
- Not in road (sidewalk, parking lot, etc),
- Backing vehicle, and
- Crossing a freeway

2.2.2 Behaviors that Increase Risk

Pedestrian and driver behaviors can contribute to the likelihood of being involved in a crash, as well as the crash severity. Alcohol, drug use, or other impairment, as well as inattention and distraction can significantly increase driver and pedestrian reaction times and their ability to make decisions quickly (Brookshire, 2016).

Distracted driving has become a major focus in recent years due to its contribution to crashes. The most notable distraction in the current era is likely the use of an electronic device while operating a motor vehicle. Many have argued that pedestrians can be equally distracted while walking by texting, dialing, reading, etc., which can reduce their situational awareness and increase their risk of being hit by a motor vehicle (Thompson, et al, 2013). However, a comprehensive review sponsored by the National Highway Traffic Safety Administration (NHTSA) examined the potential impact of pedestrians who are distracted by electronic devices, including cell phones, tablets, personal music devices, etc. and found no significant scientific evidence to quantitatively measure the extent to which pedestrian safety is affected as a result of distraction among drivers and pedestrians (Scopatz and Zhou, 2016).

Impairment caused by alcohol or drug use is a major contributing factor to vehicle crashes. 31% of traffic related deaths can be attributed to alcohol impaired driving crashes (NHTSA, 2015). In recent years the data has revealed that walking while intoxicated can be just as dangerous if not more. In 2014 alcohol was present in the bodies of nearly 40% of pedestrians killed in motor vehicle crashes (compared to 17% of drivers). Nearly one-third of pedestrians killed had a blood alcohol level above the legal driving limit (.08 grams per deciliter (g/dL) or higher) (NHTSA, 2016). As a result of anti-drunk driving campaigns, many individuals are choosing to walk home after drinking. However, when pedestrians are under the influence of alcohol, they may make bad decisions such as trying to cross a road in the wrong place, crossing it against the light, or trying to beat a car that is coming toward them.

Recent Utah Department of Transportation (UDOT) research has focused on pedestrian and driver travel behavior in the moments leading up to a crash and which characteristics are more likely to result in pedestrian fatalities. The number one driver contribution in fatal pedestrian crashes was distracted driving (nearly 20% of cases). The most frequently cited distractions were: cell phones (texting or talking, 43%), adjusting the radio (14.2%), and the glare of the sun (14.2%). Driving under the influence, speeding, drowsy driving, and finally aggressive driving were also contributing factors. Pedestrians were also found culpable in fatal crashes. Crossing or standing in the roadway improperly were the top pedestrian contributing factors to fatal crashes (31.6%). In a majority of cases both the pedestrian and driver exhibited dangerous behaviors (Burbidge, 2016).

2.2.3 Near Miss Research

While comprehensive, existing research has captured the element of human behavior in the event of a crash, there are very few studies that have sought to capture data on crashes that did not happen. More specifically, circumstances where there was potential for a crash, but the driver or pedestrian was able to avoid a collision in some way. These near miss occurrences are referred to in the literature as "conflicts" (Islam, et al, 2012) and are more or less invisible to transportation officials and police; because technically nothing happened. Near-miss and minor crash data is almost impossible to find, because as The Atlantic's CityLab eloquently put it, "it does not exist. There is no way to capture it, because it is unofficial (Badger, 2013)". However, there could be real value in this data for its potential to reveal dangerous driver and pedestrian behavior patterns. Only a small number of researchers have shown interest in examining pedestrian conflict data.

Islam, et al (2012), investigated how roadway and roadside characteristics were associated with pedestrian-vehicle conflicts and crashes at various levels of severity, and also the extent to which pedestrian-vehicle conflicts are associated with crashes. Other research has evaluated how pedestrian-vehicle crashes could be estimated from the near-miss incident data which captured pedestrian behaviors (Matsui, et al, 2013), or even how conflict data can be used to improve automated braking in vehicles (Matsui, Hitosugi, Takahashi, and Doi, 2013). A majority of the limited research on near miss crashes seeks to use near miss crashes as a way to predict actual crash risk, rather than understand risky travel behavior.

This research will focus on better understanding pedestrian behavior at intersections using real-time video data. While a majority of crashes occur outside of an intersection (midblock connections, sidewalks, parking lots, etc.), intersection collisions still account for 40 percent of all pedestrian crashes (Campbell et al., 2004). In most cases non-intersection crossings are inconsistent and difficult to predict. Therefore this research will focus on travel behavior in marked crossings at intersections. By observing non-motorized travelers as they navigate high-risk intersections we will be able to better understand what is happening in "near miss" situations as well as being able to better evaluate human decision making by pedestrians.

2.3 Study Methods

This research will employ a number of statistical analysis methods to describe trends in the data as well as make predictions regarding correlation and causality between variables. Each method has been selected based on its appropriateness for use with this dataset relative to the research questions and hypotheses. These methods will include using summary statistics, and multinomial logistic regression models. Each of these methods is described in detail below.

2.3.1 Summary Statistics

Summary statistics are used to provide a quick and simple description of the data without any predictive component or significance testing. Summary statistics can include mean (average), median (center point of data), mode (most frequently occurring value), minimum value, maximum value, value range, standard deviation, frequency percentages, etc. Summary statistics will be used in this analysis to provide context for the fatal crash data. Specifically, this type of analysis will be used to describe the limitations of the crash reports and provide an overview summary of the common characteristics in fatalities, pedestrian fault and the day/time analysis.

2.3.2 Multinomial Logistic Regression

Multinomial logistic regression (MNL or Logit) is used to predict a nominal dependent variable given one or more independent variables. 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, multinomial logistic regression can have nominal and/or continuous independent variables and can have interactions between independent variables to predict the dependent variable (Greene, 2015). For a dependent variable with M categories, this requires the calculation of M-1 equations, one for each category relative to the reference category, to describe the relationship between the dependent variables and the 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 a Logit model one of the response categories as a baseline or reference cell, log-odds are calculated for all other categories relative to the baseline, and then the log-odds become a linear function of the predictors.

Multinomial Logit Models will be used to identify any significant relationships between individual travel behavior characteristics and conflict levels at crossings. Additionally, MNL will be used to determine if significant correlations can be established between built environment characteristics and pedestrian-vehicle conflict levels.

2.4 Summary

A wealth of research has been conducted examining non-motorized crash risk and severity. This work has included 2 major divisions. The first examines specific risk factors such as: pedestrian and driver characteristics, roadway geometry, built environment characteristics, neighborhood demographics, etc. that have been correlated to an increase in non-motorized risk. The second focuses on modeling accident risk exposure, and quantifying the risks faced by pedestrians and cyclists traveling under differing conditions. A separate, but more limited line of research has focused on driver and pedestrian contributions or behavior at the time of or before a crash, however very little research has examined near miss crashes and the travel behavior that accompanies them.

Pedestrian and driver behaviors can contribute to the likelihood of being involved in a crash, as well as the crash severity. Multiple research studies have shown that alcohol, drug use, or other impairment, as well as inattention and distraction can significantly increase driver and pedestrian reaction times and their ability to make decisions quickly.

While comprehensive, existing research has captured the element of human behavior in the event of a crash, there are very few studies that have sought to capture data on crashes that almost happened (near misses or pedestrian-vehicle conflicts). Of the research that has examined near miss conflicts, most have focused on how roadway and roadside characteristics are associated with pedestrian-vehicle conflicts and crashes at various levels of severity, and also the extent to which pedestrian-vehicle conflicts can be used to estimate crashes. A majority of the limited research on near miss crashes seeks to use near miss crashes as a latent variable for predicting actual crash risk, rather than as a tool to understand risky travel behavior.

This research will use summary statistics to provide context for the pedestrian crossing data. Specifically, this type of analysis will be used to describe the characteristics of each pedestrian crossing and provide an overview summary of all conflicts that occurred during the observations. Additionally, relationships between pedestrian travel behavior and conflicts, as well as the built environment and conflict level, will be examined using multinomial logit models with maximum likelihood estimation.

3.0 DATA COLLECTION

3.1 Overview

This project collected data in two main ways; video observations and site visits. The first dataset included video of pedestrian crossings collected from closed circuit cameras maintained and monitored by the UDOT Traffic Operations Center (TOC). The second dataset included in person observations of pedestrian crossings conducted at each intersection, as well as site characteristics documented by the project team. This chapter describes the planning and acquisition of the video and site data employed in this study.

3.2 Site Identification

Eight sites were selected by the Technical Advisory Committee (TAC) from a database of high-risk intersections (Burbidge, 2012, 2015a, 2015b) based on their location, spatial dispersion (by county), proximity to destinations (i.e. schools), and other special characteristics. They are:

- 12^{th} Street and Washington Blvd (Ogden)
- Antelope Dr. and Hillfield Rd. (Layton)
- 4500 South State Street (Murray)
- 9000 South 700 East (Sandy)
- 4700 South Redwood Rd. (Taylorsville)
- Bulldog Blvd. and Hwy 89 (Provo)
- Bulldog Blvd. and Freedom Blvd (Provo)
- St. George Blvd and Flood Street (St. George)

Consultations with the UDOT Traffic Operations Center (TOC) confirmed that all of these sites were equipped with traffic cameras and were capable of monitoring pedestrian crossings for at least 3 legs of the intersection (the view of the crosswalk on the fourth leg was sometimes blocked by the mast arm or by limitations in the camera angle in some locations). The sample contains at least one intersection from each UDOT Region.

3.3 Video Data Collection

3.3.1 Data Collection Constraints

The initial data collection plan anticipated collecting behavioral data during two separate time periods to help account for seasonal variation. However, after meeting with TOC staff it was determined that the level of labor intensity required for collecting the data on these sites was higher than anticipated, and the budget would not adequately allow for two separate data collection efforts. Therefore a single time period in early summer was identified for collecting data at each of the eight sites. Care was taken to ensure that the time period selected would include days when school was still in session, so as not to miss significant levels of student foot traffic.

It was also originally anticipated that video would be collected at each site in week long increments. Additional days for data collection were to be identified including days of inclement weather, special events, or other times of interest. This was not possible for two reasons: Because of the incredibly large file size of the video data, recording an entire week of video footage 24 hours per day at each site would have required over 100 Terabytes of storage space. Neither the TOC nor Active Planning had the capability to store that volume of video data. Additionally, the TOC was not willing to commit to focusing their cameras at these sites on a single angle and leaving it stationary for an entire week. Due to the nature of UDOT's TOC and the inherent purpose of the cameras, there would be times when camera angles would need to be changed and recording would need to be stopped. This occurred for several sites during the data collection period even during the more limited time frames as outlined below.

One additional step that was required prior to data being collected, was a need to seek permission from Provo City to record footage from the traffic cameras located along Bulldog Blvd. Because Provo City owns these cameras, the research contract with UDOT does not inherently allow access to those video feeds. Written permission was secured from Provo City to record video from their traffic cameras, and data collection at those sites was able to proceed unencumbered.

In light of these constraints, the research team worked with the TOC to identify specific windows (days and times) for recordings to be captured at each intersection. Appropriate days and times were identified for each individual location using UDOT's signal performance metrics, which track the number of times the "walk" button was pushed at each intersection (shown in Figure 1).

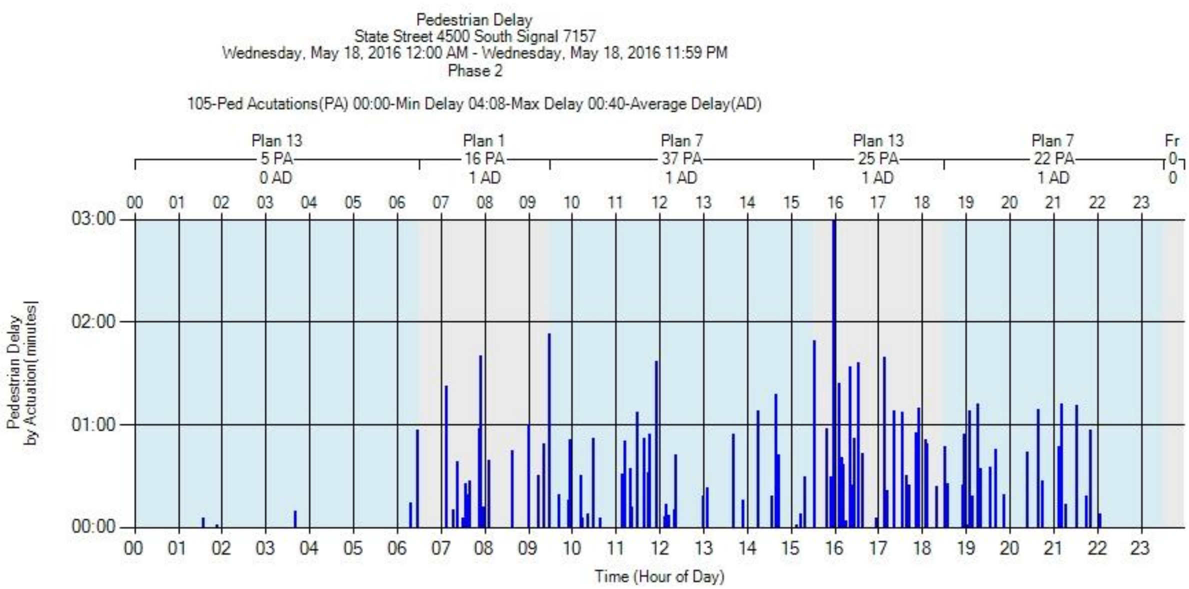


Figure 1. Signal Performance Metric- 4500 South State Street

This data provided the research team with insight into when pedestrian volumes would likely be the highest at each location, allowing for capture of the largest sample size possible. Days/times and specifics for data collection at each intersection are described in detail in Section 3.3.2.

3.3.2 Data Collection Schedule

The project team worked directly with the UDOT TOC to set up a detailed and specific data collection plan. Prior to the data collection period the project team coordinated with the Center to examine each intersection and all available TOC camera angles and potential obstacles/obstructions. Ideal camera angles were identified and screen shots were taken so that the TOC team members responsible for recording the data would be sure to adhere to the strict standards outlined in the methodology plan. For each intersection both weekday and weekend time periods were identified based on the signal performance metrics shown in Section 3.2 above. The goal was to identify periods with the highest pedestrian volumes in order to capture the largest sample possible. Table 1 below shows the data collection schedule for each intersection leg, including the signal phase (for the camera operator) and the directional view.

In some cases the cameras could not acquire a visual on the crosswalk located on one leg of the intersection due to the mast arm blocking the view or a limited camera angle. When that occurred, that leg was "skipped" which is indicated in the table. The day of the week and time of the recording are listed as well. All preliminary data collection took place the week of May 30th (Monday) to June 5th (Sunday). It is important to note that the TOC cameras are unable to record all legs of the intersection simultaneously. That is the reason for the varied days/times for each leg of the intersection. This required the cameras record one leg and then be repositioned at a separate time to record a different leg.

Table 1. Video Data Collection Schedule- by location

SIG#5030	Camera: Washington Blvd / US-89 @ 12th St / SR-39, OGD		
1	East View	Ph2 Ped	Wednesday, 7:00AM-11:00AM
2	North View	Ph8 Ped	Monday, 11:00AM-2:00PM Sunday 11:00AM-2:00PM
3	West View	Ph6 Ped	SKIP
4	South View	Ph4 Ped	Monday, 7:00AM-11:00AM
SIG#5108	Camera: Hill Field Rd / SR-232 @ 2000 N / Antelope Dr. LTN		
5	East View	Ph2 Ped	Monday, 7:00AM-11:00AM Sunday 2:00PM-6:00PM
6	North View	Ph8 Ped	Monday, 2:00PM-6:00PM
7	West View	Ph6 Ped	SKIP

8	South View	Ph4 Ped	Wednesday, 7:00AM-11:00AM
SIG#7157	Camera: State St / US-89 @ 4500 S / SR-266, MUR		
9	East View	Ph2 Ped	Monday 2:00PM-6:00PM
10	North View	Ph8 Ped	Monday 11:00AM-2:00PM
11	West View	Ph6 Ped	Wednesday 11:00AM-2:00PM
12	South View	Ph4 Ped	Wednesday 2:00PM-6:00PM Saturday 11:00AM-2:000PM
SIG#7197	Camera: 700 E / SR-71 @ 9000 S / SR-209, SND		
13	East View	Ph2 Ped	Wednesday 11:00AM-2:00PM
14	North View	Ph8 Ped	Wednesday 2:00PM-6:00PM Sunday 7:00AM-11:00AM
15	West View	Ph6 Ped	Tuesday, 7:00AM-11:00AM
16	South View	Ph4 Ped	Tuesday 2:00PM-6:00PM
SIG#7107	Camera: Redwood Rd / SR-68 @ 4700 S / SR-266, TAY		
17	East View	Ph2 Ped	Tuesday, 2:00PM-6:00PM
18	North View	Ph8 Ped	Thursday 2:00PM-6:00PM
19	West View	Ph6 Ped	Tuesday 11:00AM-2:00PM Saturday, 2:00PM-6:00PM
20	South View	Ph4 Ped	Thursday 7:00AM-11:00AM
SIG#6446	Camera: University Ave / US-189 @ Bulldog Blvd / 1230 N, PVO		
21	East View	Ph2 Ped	Thursday, 11:00AM-2:00PM
22	North View	Ph8 Ped	SKIP
23	West View	Ph6 Ped	Friday, 2:00PM-6:00PM
24	South View	Ph4 Ped	Friday, 7:00AM-11:00AM Saturday, 2:00PM-6:00PM
SIG#6614	Camera: Bulldog Blvd / 1230 N @ Freedom Blvd / 200 W, PVO		
25	East View	Ph4 Ped	SKIP
26	North View	Ph2 Ped	Thursday, 11:00AM-2:00PM
27	West View	Ph8 Ped	Friday 2:00PM-6:00PM Saturday, 7:00AM-11:00AM
28	South View	Ph6 Ped	Friday, 11:00AM-2:00PM
SIG#8119	Camera: St George Blvd / SR-34 @ 400 E, STG		
29	East View	Ph4 Ped	Friday, 11:00AM-2:00PM
30	North View	Ph2 Ped	Thursday, 2:00PM-6:00PM Saturday, 11:00AM-2:00PM
31	West View	Ph8 Ped	Friday, 7:00AM-11:00AM
32	South View	Ph6 Ped	Tuesday, 11:00AM-2:00PM

3.3.3 Collecting Video Data

Staff at the UDOT TOC were responsible for collecting the data (positioning cameras and recording the video feed during the specified times). Jamie Mackey created a guidebook for each Technical Operator to ensure consistency in data collection. The following specifications were included in the operator instructions:

- Identifying the approach number and time period on the schedule
- Moving the camera to match the screen shot of the approach
- Saving data using a specific naming convention and location
- Indicating time stamps on the video footage
- Moving files to an external hard drive (provided by project staff)
- Accounting for data collected by each team member

Specific Techs were pre-assigned to specific days/times for data collection. Each participating TOC employee was briefed and informed of their personal responsibility and assignment so that no data was duplicated or omitted.

As mentioned previously, the project staff and a TOC representative sat down and identified specific camera angles prior to the data collection period. Screen shots were then provided to the techs to ensure that the appropriate resolution, zoom and angle of footage was captured. An example of the screen shot is provided in Figure 2 below. In some cases a camera was not able to capture the entire crossing due to either the camera angle or an obstruction (Figure 3). When this occurred, care was taken to ensure the widest possible coverage given the available camera view. However, this is a limitation of using mounted traffic cameras for data collection, and is a main reason a second on-site data collection effort was conducted as well.

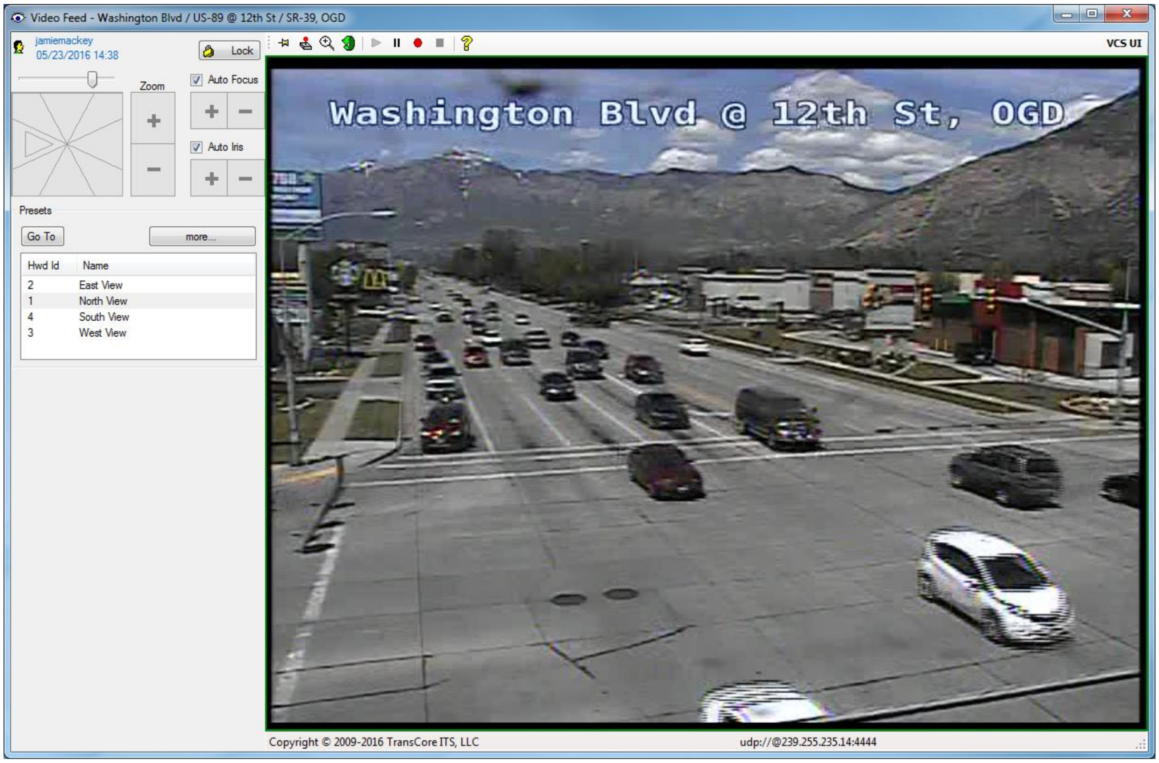


Figure 2. Sample Screen Shot of Intersection Camera View

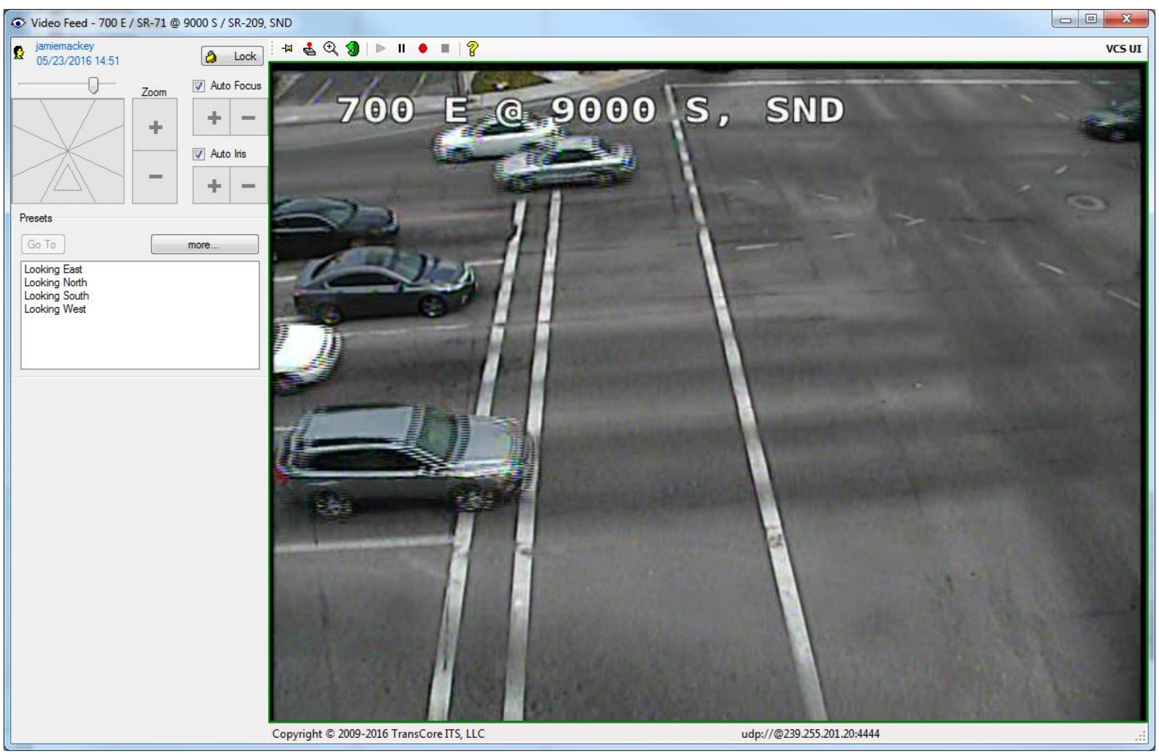


Figure 3. Example of Camera Angle Limitations

Prior to beginning data collection, the project team was informed by the TOC that there may be instances when the traffic cameras would need to be moved during the data collection time periods. This could be due to a crash or emergency, or a retiming project. Contingencies were put in place so that if cameras needed to be moved during a recording phase, a second time period would be recorded to ensure that an adequate time window was collected for each location/approach. Only three locations were impacted when cameras were needed for other purposes. The replacement video was recorded at the following times:

- Signal 5030 (Washington Blvd. and 12th St.) Approach 2- Saturday 11:00am-2:00pm (June 18th)
- Signal 7197 Approach 14- Saturday 7:00-11:00am (June 18th)
- Signal 6614 Approach 27- Friday 2:00-6:00pm and Saturday 7:00-11:00am (June 17th and 18th)

3.3.4 Data Coding

After the data was collected, the video footage was hand coded for every individual pedestrian crossing. Table 2 below shows the variables that were coded for each crossing. Each pedestrian received a unique ID regardless of if they were crossing alone or as a group. Information was recorded identifying: date, time of crossing, crossing direction, sex (male/female, if identifiable), age (loosely categorized if identifiable without bounding limits), group type (alone, child with guardian, or group), status of the signal when the crossing began (walk phase, flashing phase, steady or stop phase, or jaywalking), any visible distractions (cell phone, socializing, etc), clearance time, and any conflicts that arose.

Table 2. Variables Coded from Video Footage

Variable	**Description**
Date	Date of crossing
Time	Time stamp when crossing began (Hour:Minute)
Crossing Direction	North South East West
Sex (if identifiable)	Male Female

Age (if identifiable)	Child Adult Senior
Group	Alone Child with guardian Group
Entering Crossing	Walk Phase Flashing Phase Steady or Stop Phase Jaywalking= crossing against a red traffic light (against signal)
Distraction	Manipulating a cell phone or other electronic device Socializing or interacting with another pedestrian Other distraction (noted if identifiable)
Clearance Time	Amount of time (seconds) from crossing beginning to end
Conflict	Undisturbed crossing (no chance of collision occurring) Potential conflict (vehicle slowing to a stop during crossing, etc) Minor conflict (vehicle maneuvering out of pedestrian's path or stopping abruptly) Serious Conflict (collision course with evasive maneuvering by ped or vehicle) *If M or S vehicle maneuver is noted (e.g. left turn, right turn, straight)

Conflicts between pedestrians and vehicles at each location were observed using a variation of the Swedish Traffic Conflict Technique (TCT) (Hyden, 1987) introduced by Islam, et al (2012). The Swedish TCT is easy to use and does not require any complicated equipment. With a brief training an observer is ready to carry out observations. For this modified Swedish TCT, pedestrian crossings were categorized into four types: Undisturbed passages, Potential conflicts, Minor conflicts and Serious conflicts. If a conflict was classified as minor or serious, the vehicle maneuver at the time of the conflict was noted (e.g. left turn, right turn, straight).

3.4 Site Visits and Field Work

In addition to the video footage collected, two site visits were conducted at each location; one on a week-day afternoon (2:30-4:30pm), and one on a Saturday (11:30am-1:30pm). This was done in order to: 1) Ground truth built-environment data and create a comprehensive description of the intersection on site; 2) Allow for observation of pedestrian crossings for all four approaches in person during the time frame. This also provided an opportunity to code behavior in more detail adding any additional qualitative or descriptive data that may seem relevant but may not be readily available when viewing video (e.g. behavior prior to or subsequent to crossing, noise, etc.). Table 3 identifies the days/times of the site visits for each study intersection.

Table 3. Site Visit Schedule

Intersection	Site Visit Day/Time	Number of Peds Observed
12th Street and Washington Blvd	Saturday, July 16th	39
Antelope Dr. and Hillfield Rd.	Saturday, June 11th	21
4500 South State Street	Wednesday, June 1st Saturday, June 4th	69 45
9000 South 700 East	Thursday, May 26th Saturday, May 28th	37 19
4700 South Redwood Rd.	Wednesday, June 1st Saturday, June 4th	92 58
Bulldog Blvd. and Hwy 89	Thursday, June 2nd Friday, June 3rd	71 41
Bulldog Blvd. and Freedom Blvd	Wednesday, July 20th Saturday, July 23rd	134 91
St. George Blvd and Flood Street	*N/A*	-
	Total	2,062

No site data was collected for St. George Blvd. and Flood St. The decision was made not to travel to Southern Utah for a site visit based upon the cost of the trip weighed against the benefit of the small amount of additional data that would be collected. Also, additional video was not collected during the site visits, as it was determined that there was limited added benefit compared to the cost of purchasing and installing supplemental audio visual equipment.

During each site visit, trained observers documented each crossing using the same methodology as the video observation, with the additional opportunity to provide other pertinent information relating to the crossing or the pedestrian or drivers' behavior. In addition to crossing behaviors, the project staff collected data on the following site characteristics: Speed limit (both directions), on street parking, median or island, building setbacks, the presence of crosswalks/geometry, crosswalk length, number of travel lanes.

In addition to the data coded on site and during video observations, the project team was able to add two additional variables to the data file. Using the crossing frequencies and clearance times, the number of pedestrians per hour, and the average walking pace was calculated for each intersection.

3.5 Data Quality

Some of the inadequacies of the data have been described above. Two major drawbacks of this dataset come from the limitations of the TOC cameras. First, the cameras only have the ability to record at predetermined camera angles. Because of the locations and angles where they are mounted, they are unable to view all approaches and all angles of the intersection. While this is not a significant limitation for automobile traffic, it inhibits the ability to view the crosswalks where a majority of pedestrians will be crossing. The second major drawback of the TOC cameras is their reduced resolution and inability to zoom. In order to capture the entire crossing area, the cameras were zoomed out, substantially in some cases. While this did allow observation of crossing from one side to another, it restricted the ability of the observer to see key details relating to the crossing (e.g. Is the pedestrian holding a cell phone? How close did the vehicle come to touching the pedestrian?).

One additional restriction on the quality of the dataset was the limited time frames for data collection and the inability to record longer periods of time because of data storage limitations and the inability of the TOC to keep the cameras stationary for long periods of time (which would directly violate the purpose of the TOC cameras). Every effort was made to ensure that the time frames selected for data collection would be representative of the highest volumes of pedestrian activity. Since this research benefits from a larger sample of pedestrians and is not contingent upon accurate frequency and dispersion data (being representative across time). It is not known if the selecting time frames with higher anticipated pedestrian volumes may adversely affect conflict risk. For example, perhaps pedestrians crossing alone during a low volume time period may be at a higher risk of experiencing a conflict. However, there was no basis to make assumptions of this nature based on existing research and it was assumed that for the preliminary analysis this was not a major drawback impacting the internal or external validity of the final analysis.

3.6 Summary

This project collected data in two main ways; video observations and site visits. The first dataset included video of 1,221 pedestrian crossings at eight intersections collected from closed circuit cameras maintained and monitored by the UDOT Traffic Operations Center (TOC). Technicians were trained on a specific methodology and process for identifying, recording, and storing the video data. Data was collected on predetermined week days and weekend days for three to four hour blocks of time. The recordings were then transferred to the project staff for coding. A predetermined list of characteristics was used to hand code each individual crossing.

The second dataset included 841 on-site observations of pedestrian crossings conducted at each intersection on one predetermined week-day and one Saturday. Site observations were also collected regarding built environment and geometric characteristics of the intersection.

4.0 DATA EVALUATION

4.1 Overview

This section includes analysis of all crash reports and supplemental data. First, summary statistics are provided describing crossing characteristics and behaviors. Next, statistical methods are employed to analyze relationships between the pedestrian, driver, and environmental characteristics, and the occurrence of conflicts. The remainder of the section is devoted to addressing the research questions posed in Section 1 relating to fatal crash characteristics, pedestrian fault, and timing.

4.2 Descriptive Statistics

The pedestrian crossing volumes varied by intersection. Table 4 provides a breakdown of observed crossing at each site by video and site visits, as well as identifying the percentage of the sample that each intersection accounts for. Just under 60% of the sample data was collected from the video footage, while 40% was collected during site visits.

Table 4. Pedestrian Observations

Intersection	**Pedestrian Observations**			
	Video	**Site**	**Total**	**%**
Washington Blvd – 12th Street	181	197	378	18.3
Hill Field Rd – Antelope Drive	117	21	138	6.7
State Street – 4500 South	121	115	236	11.4
700 East – 9000 South	141	26	167	8.1
Redwood Road – 4700 South	174	150	324	15.7
University Ave – Bulldog Blvd	255	198	453	22.0
Bulldog Blvd – Freedom Blvd	189	134	323	15.7
St. George Blvd – 400 East	43	--	43	2.1
Totals	n=1,221	n=841	2,062	100.0

The largest pedestrian volumes were observed at University Avenue and Bulldog Boulevard (22% of all peds), followed by Washington Boulevard and 12th Street (18.3%). The lowest pedestrian traffic volumes were seen at St. George Boulevard and 400 East (2.1%) and Hillfield Road and Antelope Drive (6.7%).

4.2.1 Pedestrian Characteristics

First the characteristics of the observed pedestrians were summarized. As shown below (Table 5), for most of the high-risk intersections, the large majority of the pedestrians observed were male. The one exception was the two intersections located on Bulldog Boulevard in Provo. Those locations were split nearly even. The age breakdown of observed pedestrians varied a small amount by site, however in most locations approximately 5% or the pedestrians observed were children. The Hillfield Rd. – Antelope Dr. intersection was the one exception (31.9%). This is likely due to the proximity of Lincoln Elementary School and Northridge High School, both located just one block away.

It is worth reiterating that the age categories were loosely defined without bounding limits for observation. This means that no age limits were identified for each category. The observers were to determine, at face value, at what age they would classify the pedestrian. Placing bounding limits on age during observation can become problematic. For example, if the limit for the child category was placed at 12 or even 14 years old it would require the observer to be able to see the individual crossing well enough to estimate an actual age. It is easier to make a broader categorization, even if it is occasionally inaccurate, than to attempt to nail down specifics based on a granular video from a distance.

Table 5. Sex and Age

Intersection	**% Male**	**Age of Pedestrian (%)**		
		Child	**Adult**	**Senior**
Washington Blvd – 12th Street	68.0	3.7	93.1	3.2
Hill Field Rd – Antelope Drive	74.6	31.9	66.7	1.4
State Street – 4500 South	83.1	0.4	97.5	2.1
700 East – 9000 South	64.1	4.8	88.0	7.2
Redwood Road – 4700 South	73.1	5.9	91.7	2.5
University Ave – Bulldog Blvd	58.3	6.2	92.5	1.3
Bulldog Blvd – Freedom Blvd	53.9	1.5	97.5	0.9
St. George Blvd – 400 East	76.7	0.0	100.0	0.0
All Intersections (n=2,062)	66.5	5.8	91.8	2.3

The presence of senior pedestrians was also very low. For nearly all of the observed intersections, fewer than 3% of pedestrians were seniors crossing. However at the 700 East – 9000 South intersection over 7% of pedestrians were seniors.

Three intersections had a very high ratio of adult pedestrians. State Street- 4500 South, Bulldog Blvd. – Freedom Blvd, and St. George Blvd – 400 East were all observed to have over 97% adult pedestrians. For each of these sites, the built environment surrounding the intersection contributes a great deal to explaining this pattern. The area surrounding 4500 South – State Street is very urban in nature. There are few destinations that would attract children or seniors (e.g. parks, schools, recreational sites). A majority of the land-use is comprised of strip mall commercial, car dealerships, and fast food restaurants. The intersection of Bulldog Blvd - Freedom Blvd is located between Utah Valley Hospital and Provo High School at the West entrance of Brigham Young University. This area encompasses a large portion of the university's off campus housing and is a thoroughfare for students accessing campus. Additionally, the majority of pedestrians in this location are likely to be high-school or college students and hospital employees accessing the adjacent commercial locations, which also explains the even dispersion between males and females. The St. George Blvd – 400 East site is located in an urban, auto-centric commercial area. There are few destinations that would attract children or seniors to this destination as well.

4.2.2 Crossing Characteristics

An examination of crossing groups (Table 6) revealed that a majority of pedestrians cross alone (74.1%). The exception to this pattern is again seen at Hill Field Rd. – Antelope Dr. Only 55% of pedestrians at this location crossed alone, with 21% observed as children crossing with a guardian and 23% crossing in a group. University Ave – and Bulldog Blvd. also exhibited a higher number of children crossing with a guardian (10.6%), Redwood Rd – 4700 South also exhibited a high rate of group crossings.

Table 6. Crossing Groups

Intersection	Crossing Groups (%)		
	Alone	Child with Guardian	Group
Washington Blvd – 12th Street	69.8	6.1	23.5
Hill Field Rd – Antelope Drive	55.1	21.0	23.2
State Street – 4500 South	75.8	1.3	22.5
700 East – 9000 South	83.2	0.0	16.8
Redwood Road – 4700 South	65.7	2.5	31.8
University Ave – Bulldog Blvd	74.8	10.6	14.6
Bulldog Blvd – Freedom Blvd	87.3	2.5	7.7
St. George Blvd – 400 East	81.4	0.0	18.6

All Intersections (n=2,062)	74.1	5.8	19.6

4.2.3 Pedestrian Volumes and Walking Pace

Pedestrian volumes were calculated for each of the intersections. In order to fully understand risk and exposure, it was critical to quantify how many pedestrians were crossing at each location, per hour. This information would provide additional context. For example, perhaps motorists operating near intersections with consistently high volumes of pedestrians could be more astute or aware of pedestrians crossing. Alternatively, intersections that exhibit consistently low pedestrian volumes may result in motorists who are unsuspecting of people walking or crossing and higher conflict rates.

Table 7. Pedestrian Volumes

Intersection	Weekday (peds/hr)	Weekend (peds/hr)
Washington Blvd – 12th Street	22.91	16.33
Hill Field Rd – Antelope Drive	7.42	12.25
State Street – 4500 South	12.00	22.67
700 East – 9000 South	7.67	13.00
Redwood Road – 4700 South	16.53	19.00
University Ave – Bulldog Blvd	39.09	5.75
Bulldog Blvd – Freedom Blvd	29.90	6.00
St. George Blvd – 400 East	2.00	5.00
All Intersections (n=2,062)	16.73	12.28

As Table 7 shows, there is quite a bit of variation in the pedestrian volumes at each of the intersections. Average volumes also differ from weekday to weekend. The two Bulldog Blvd intersections had by far the highest pedestrian volumes during the week, however, on the weekend the volumes plummeted. Alternatively, several intersections had higher pedestrian volumes on the weekend (Hill Field Rd. – Antelope Dr., State Street – 4500 South, 700 East – 9000 South, Redwood Rd. – 4700 South, and St. George Blvd. 400 E.).

It was also important to identify how quickly pedestrians were able to navigate each intersection. Mean clearance times were calculated for each site. Using this data and the width of the crossing (for standardization), a mean pedestrian pace was calculated (crossing feet per second). As shown below (Table 8) for all intersections the average crossing pace was 5.4 feet per second (1.65 meters). This equates to approximately 3.68 miles per hour (5.89km per hour).

Table 8. Intersection Clearance Times and Walking Pace

Intersection	Clearance Time (Sec)	Int. Width (ft)	Pace (ft/sec)
Washington Blvd – 12th Street	17.27	105	6.08
Hill Field Rd – Antelope Drive	16.00	80	5.00
State Street – 4500 South	20.96	110	5.25
700 East – 9000 South	19.67	102	5.18
Redwood Road – 4700 South	20.02	115	5.75
University Ave – Bulldog Blvd	13.64	86	6.30
Bulldog Blvd – Freedom Blvd	13.90	86	6.19
St. George Blvd – 400 East	12.44	76	6.11
All Intersections (n=2,062)	16.82	91	5.40

The data also revealed that pedestrians walk much faster in some locations. For example pedestrians in Provo (Bulldog Blvd), most of whom are adults, average 6.19-6.3 feet per second (approx. 2 meters/sec.). This is substantially faster than the large number of child pedestrians at Hill Field Rd. and Antelope Dr. who averaged just 5 feet per second (1.52 meters/sec.), or the larger senior population at 700 East and 9000 South who averaged 5.18 feet per second (1.57 meters/sec.). This is why it is critical to understand the make-up of the pedestrians who are crossing.

4.3 Pedestrian Vehicle Interactions

The first main goal of this research is to better understand the preponderance of conflicts between pedestrians and vehicles during crossings. As described in Section 3.3.4, data on conflicts was collected using the Swedish Traffic Conflict Technique (TCT). This simplified technique allows each crossing to be classified in one of four ways. An Undisturbed Crossing is recorded for all clean crossings in which the pedestrian crosses from one side of the roadway to the other without any contact with vehicles in the roadway. A Potential Conflict includes all crossings where there is the potential for a conflict, such as a vehicle pulling up to a stop at the crosswalk while a pedestrian is crossing. Minor Conflicts include any crossing where a vehicle or pedestrian must maneuver out of one another’s way or stop abruptly to avoid a crash; such as when a vehicle pulls into the crosswalk and a pedestrian must walk around the vehicle to safely cross. Serious Conflicts include any instance where a vehicle and pedestrian are on a collision course and evasive maneuvering is required by one or both; such as when a vehicle pulls up to a red light and proceeds to turn right without yielding to the pedestrian in the crosswalk, requiring the pedestrian to jump out of the way or the vehicle to swerve to avoid a collision.

Table 9. Pedestrian-Vehicle Conflicts (%)

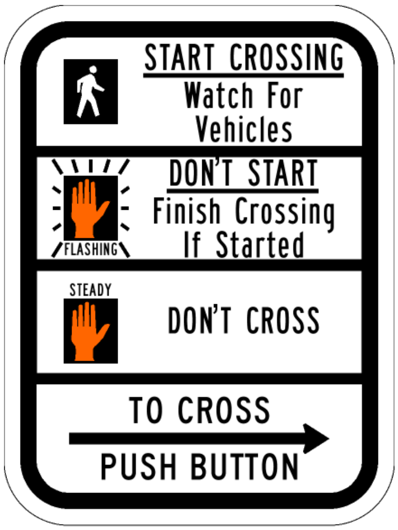
Intersection	Undisturbed Crossing	Potential Conflict	Minor Conflict	Serious Conflict
Washington Blvd – 12th Street	65.1	29.9	4.0	0.0
Hill Field Rd – Antelope Drive	94.2	2.9	0.0	2.9
State Street – 4500 South	90.7	7.6	1.7	0.0
700 East – 9000 South	98.2	0.6	0.0	1.2
Redwood Road – 4700 South	97.8	0.9	1.2	0.0
University Ave – Bulldog Blvd	79.2	19.2	1.1	0.0
Bulldog Blvd – Freedom Blvd	77.1	17.6	2.5	0.0
St. George Blvd – 400 East	100.0	0.0	0.0	0.0
All Intersections	83.5	13.7	1.7	0.3
n=2,062	n= 1,723	n= 283	n= 36	n= 6

Table 9 provides a classification of crossings by conflict type. A large majority of pedestrian crossings were "undisturbed" (83.5%), but nearly 14% of crossings had the potential for conflicts between pedestrians and vehicles (n=283). Minor or serious conflicts were observed in only 2% of crossings (n=42). It is important to note that of the 2,062 total crossings observed, none resulted in a crash. The only intersection where no conflicted crossings were observed during the study time period was St. George Blvd. – 400 East. Serious conflicts were only observed at Hill Field Rd. –Antelope Dr., and 700 East – 9000 South. It should be noted that in the prior sections these two locations were identified as having a larger number of children and seniors crossing.

4.4 Contributing Factors

The second goal of this project is to identify reckless behaviors or behaviors that may contribute to an increased risk of conflicts. A number of factors may contribute to the potential for conflict in a given pedestrian crossing. The first is pedestrian travel behavior. Probably the most recognized contributor to pedestrian safety at intersections is the frequency of pedestrians obeying the crossing signal prompts. A great deal of research and development has gone into identifying safe time periods within the overall intersection signal timing for pedestrians to cross the roadway (Kothuri, 2014; Tian, et al, 2001).

It is assumed that if pedestrians comply with the signal prompts that they will be able to safely cross in the allotted amount of time (Tian, et al 2000). In order to inform pedestrians regarding how much time they have available to cross, pedestrian signals are provided at a majority of urban intersections including all intersections in this study (shown in Figure 4 below).



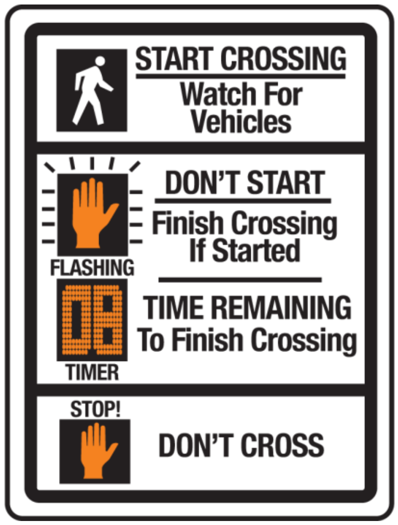


Figure 4. Descriptive Pedestrian Signal Signs

During the "walking person phase" symbolizing "Walk", pedestrians may enter the roadway with the expectation that they will be able to cross before the signal changes for oncoming traffic. Many signals provide a countdown display informing pedestrians about the time remaining to cross. Often, pedestrians may approach the crossing after the signal has already indicated to start crossing. Many pedestrians will enter the intersection during this "flashing upraised hand phase" symbolizing "Don't Walk". Although it is not lawful, except locally in Salt Lake City, when a countdown display is present and operating, many pedestrians will enter and attempt to cross the roadway. If they have the ability to move quickly, most will still be able to cross the roadway in the allotted signal time. The next phase, the "steady upraised hand" symbolizing "Don't Walk", indicates that a pedestrian shall not enter the roadway in the direction of the signal indication.

A majority of pedestrians observed in this sample began crossing during the walk phase of the signal (95.2%). As shown in Table 10, a small percentage entered the intersection during the flashing phase (2.3%) or the steady phase (1.4%). Only 12 pedestrians were observed crossing against the light (jaywalking).

Table 10. Signal Phase at Pedestrian Entry (%)

Intersection	Walk	Flashing	Steady	Jaywalking
Washington Blvd – 12th Street	96.3	1.6	1.1	0.5
Hill Field Rd – Antelope Drive	99.3	0.0	0.7	0.0
State Street – 4500 South	94.9	0.8	4.2	0.0
700 East – 9000 South	98.8	0.6	0.6	0.0
Redwood Road – 4700 South	91.4	3.7	2.2	2.8
University Ave – Bulldog Blvd	96.7	2.9	0.4	0.0
Bulldog Blvd – Freedom Blvd	92.3	4.0	0.6	0.6
St. George Blvd – 400 East	97.7	0.0	2.3	0.0
All Intersections (n=2,062)	95.2	2.3	1.4	0.6

Research has shown that distracted pedestrians are becoming a more common occurrence. Nearly 12% of pedestrians observed in this study were distracted in some way while crossing the roadway. Socializing or conversing with another pedestrian was the most common distraction (see Table 11), followed by usage or manipulation of an electronic device.

Table 11. Pedestrian Distractions while Crossing (%)

Intersection	None	Electronic	Socializing	Other
Washington Blvd – 12th Street	87.0	4.0	8.7	0.3
Hill Field Rd – Antelope Drive	91.3	2.9	5.8	0.0
State Street – 4500 South	97.5	0.0	2.5	0.0
700 East – 9000 South	87.4	1.8	10.2	0.6
Redwood Road – 4700 South	99.4	0.6	0.0	0.0
University Ave – Bulldog Blvd	78.4	7.7	13.5	0.4
Bulldog Blvd – Freedom Blvd	87.9	8.7	3.1	0.3
St. George Blvd – 400 East	75.8	0.0	16.3	7.9
All Intersections (n=2,062)	88.1	4.2	6.9	0.8

While pedestrian behavior may contribute to increased conflicts at crossings, driver behaviors may contribute just as much. For the 2% of crossings where a minor or severe conflict was observed (n=42), the vehicle maneuver at the time of the conflict was recorded. As shown in Table 12, a majority of conflicts resulted when vehicles were turning right (48.8%). Vehicles also frequently stopped beyond the stop line into the crosswalk impeding the pedestrian's crossing path (17.1%).

Table 12. Vehicle Maneuver at Conflict Point

Maneuver	% of Minor or Serious Conflicts
Vehicle in Crosswalk	17.1
Turning Right	48.8
Turning Left	17.1
Abrupt Stop	14.6
Vehicle sped up to miss pedestrian	2.4
(n=42)	100.0

Left turning vehicles often had to abruptly slow or break during their turn to yield to a pedestrian (17.1%) or even abruptly stop to avoid a collision (14.6%). In one case a vehicle sped up in order to avoid hitting a pedestrian.

4.5 Predicting Conflicts

Using the data collected regarding both the individual pedestrians and the built environment characteristics at each intersection, a more in depth analysis was conducted using multinomial logistic regression models (MNL) estimated with maximum likelihood techniques. Separate data models were used to examine correlations between built environment characteristics and conflict levels and individual pedestrian characteristics and conflict levels.

4.5.1 Built Environment and Transportation System

The first MNL model was developed incorporating built environment characteristics to identify any significant relationships with pedestrian conflict level when crossing. This model included speed limit, number of lanes (both North-South and East-West), building setbacks, crosswalk width and walking pace as covariates. Table 13 below shows the result of the data model.

Table 13. Logistic Regression of Built Environment Characteristics

Conflict Level	Covariates	β	Std. Error	Exp(β)	Sig.
Potential Conflict	Intercept	-4.414	1.695		0.009
	Speed Limit	0.009	0.045	1.009	0.842
	# Lanes NS	1.604	0.508	4.972	0.002
	# Lanes EW	-1.963	0.341	0.140	0.000
	Building Setback	-0.052	0.189	0.949	0.781
	Crosswalk Width	0.034	0.023	1.034	0.146
	Walking Pace	-0.048	0.019	0.954	0.012
Minor Conflict	Intercept	-265.356	2.864		0.000
	Speed Limit	-9.756	0.045	5.793E-5	0.000
	# Lanes NS	92.271	0.904	1.182E40	0.000
	# Lanes EW	-75.952	0.557	1.033E-33	0.000
	Building Setback	0.821	0.576	2.273	0.154
	Crosswalk Width	5.170	0.000	175.991	--
	Walking Pace	-0.065	0.052	0.937	0.213
Serious Conflict	Intercept	-114.186	1942.568		0.953
	Speed Limit	1.610	38.452	5.001	0.967
	# Lanes NS	35.514	376.664	2653E15	0.925
	# Lanes EW	-17.541	213.781	2.410E-8	0.935
	Building Setback	-3.131	191.134	0.044	0.987
	Crosswalk Width	-0.713	0.000	0.490	--
	Walking Pace	-0.264	0.338	0.768	0.435
	N=2,062	Pseudo R^2=0.207		Chi-Square =411.45	

* Parameter category (set to zero for redundancy)
**Undisturbed Crossing used as the reference category.

Potential conflicts were significantly correlated to the number of roadway lanes and pedestrian walking pace. Each additional North-South travel lane increased the likelihood of experiencing a potential conflict by nearly 500%. Alternatively, each additional East-West lane reduced the likelihood of a potential conflict by nearly 90%. A similar correlation was shown between the number of lanes and the likelihood of experiencing minor conflicts. When evaluating the correlation between speed limit and conflict, the model identified that for each additional mile per hour a speed limit allows the likelihood of a minor conflict is reduced. Prospective reasons for these results will be discussed in detail in Section 5.

Because serious conflicts were only recorded at Hill Field Road – Antelope Dr. and 700 East – 9000 South, this creates an internal validity problem for the statistical analysis when examining built environment covariates because there are only two values for each analysis. For example, as shown in Table 13, the standard error is zero for crosswalk width because the crosswalk width is the same at both intersections. That is why very little could be gleaned regarding serious conflicts within this sample. A larger sample or longer viewing times at each location may have yielded a larger sample of serious conflicts from which to correlate conditions.

4.5.2 Individual Behaviors

A second MNL model was developed incorporating individual characteristics and behaviors to identify any significant relationships with pedestrian conflict level when crossing. This model included age, sex, groups, signal status, and pedestrian distractions as factors, and pedestrian volumes and walking pace as covariates. Table 14 below shows the result of the data model.

Table 14. Logistic Regression of Individual Pedestrian Characteristics

Conflict Level	Covariates	Categories	β	Std. Error	Exp(β)	Sig.
Potential Conflict		Intercept	-17.532	242.861		0.942
	Age	Child	0.116	0.604	1.112	0.848
		Adult	-0.005	0.475	0.995	0.992
		Senior*	--	--	--	--
	Sex	Female	0.051	0.148	1.053	0.728
	Group	Alone	0.393	0.214	0.933	0.066
		Guardian with child	-0.069	0.351	0.933	0.844
		Group*	--	--	--	--
	Signal	Walk	11.143	242.860	69109.859	0.963
		Flashing	11.679	242.861	118034.559	0.962
		Steady/Stop	13.458	242.861	699466.965	0.956
		Jaywalk*	--	--	--	--
	Distraction	None	-0.600	0.288	0.549	0.037
		Electronic	0.537	0.369	1.711	0.146
		Other	0.308	1.125	1.361	0.784
		Social*	--	--	--	--
	Volume	Weekday	0.129	0.013	1.138	0.000
		Weekend	0.115	0.019	1.122	0.000
	Walking Pace	Feet Per Second	-0.042	0.021	0.959	0.041
Minor Conflict		Intercept	-6.542	2.196		0.003
	Age	Child	-10.574	197.039	2.557E-5	0.957
		Adult	0.074	1.059	10.76	0.945
		Senior*	--	--	--	--
	Sex	Female	-0.076	0.387	0.927	0.845
	Group	Alone	1.440	0.704	4.221	0.041
		Guardian with child	0.121	1.175	1.128	0.918
		Group*	--	--	--	--
	Signal	Walk	-1.776	1.099	0.169	0.106
		Flashing	0.029	1.249	1.029	0.981
		Steady/Stop	1.084	1.265	20956	0.391
		Jaywalk*	--	--	--	--
	Distraction	None	-1.402	0.873	0.246	0.108
		Electronic	-1.802	1.315	0.165	0.171

		Other	-11.319	427.788	1.214E-5	0.979
		Social*	--	--	--	--
	Volume	Weekday	0.118	0.032	1.125	0.000
		Weekend	0.145	0.048	1.156	0.003
	Walking Pace	Feet Per Second	-0.087	0.056	0.917	0.117
Serious Conflict		Intercept	-24.772	1002.864		0.980
	Age	Child	-3.329	2.106	0.036	0.114
		Adult	-2.289	1.129	0.043	0.101
		Senior*	--	--	--	--
	Sex	Female	1.012	0.968	2.752	0.296
	Group	Alone	8.646	125.829	5688.456	0.945
		Guardian with child	12.031	125.831	167804.569	0.924
		Group*	--	--	--	--
	Signal	Walk	7.692	971.059	2190.310	0.994
		Flashing	0.110	1135.560	1.117	1.000
		Steady/Stop	10.383	971.060	32289.669	0.991
		Jaywalk*	--	--	--	--
	Distraction	None	8.497	216.675	4902.190	0.969
		Electronic	11.118	216.678	67379.231	0.959
		Other	-3.781	937.224	0.023	0.997
		Social*	--	--	--	--
	Volume	Weekday	-0.280	0.242	0.756	0.248
		Weekend	-0.023	0.190	0.978	0.906
	Walking Pace	Feet Per Second	-0.232	0.309	0.793	0.454
		n=2,062	Pseudo R^2=0.220		Chi-Square =307.815	

* Parameter category (set to zero for redundancy)
**Undisturbed Crossing used as the reference category.

The model identified that a pedestrian exhibiting no distractions is 45% less likely to experience a potential conflict as compared to a pedestrian who is socializing. Pedestrians who walk slower have a slightly smaller likelihood (4.1% less) of experiencing a potential conflict during crossing. Additionally, someone walking alone is over 400% more likely to experience a minor conflict than someone walking in a group.

As would be expected, pedestrians crossing at intersections with higher pedestrian volumes (both weekday and weekend) are significantly more likely to experience a potential conflict (approx. 12-14%) or minor conflict (approx. 12-16%) than individuals crossing at intersections that have fewer pedestrian crossings per hour. However, pedestrian volumes were not significantly correlated to the occurrence of serious conflicts. The only characteristic correlated to the risk of a serious conflict was age category. Adults face only 4% of the likelihood of being involved in a serious conflict compared to seniors. This could be due to mobility issues among older individuals.

4.5.3 Video vs On-Site Observations

One last MNL regression was run to identify if there was a significant correlation between how the observation data was collected, and the conflict levels reported. Table 5 displays the results of that model. On-site observations increased the likelihood of observing potential conflicts by 73%. The likelihood of observing a minor conflict on site was nearly 7 times higher than observing a minor conflict via video observation.

Table 15. Logistic Regression of Site Observations* vs. Video Observations

Conflict Level	Covariate	β	Std. Error	Exp(β)	Sig.
Potential Conflict	Intercept On-Site	-2.053 0.550	0.091 0.129	-- 1.733	0.000 0.000
Minor Conflict	Intercept On-Site	-4.893 1.739	0.355 0.404	-- 5.693	0.000 0.000
Serious Conflict	Intercept On-Site	-5.363 -1.123	0.448 1.097	-- 0.325	0.000 0.306

* Video Observation was used at a parameter category (set to zero for redundancy)
**Undisturbed Crossing used as the reference category.

4.6 Summary

Very little research is available describing pedestrian behaviors while crossing at an intersection, and this section has shown that both pedestrian characteristics and crossing characteristics vary by intersection. This includes things such as pedestrian volumes and walking pace, pedestrian-vehicle interactions and conflicts. A description of contributing factors has been provided that identifies unique attributes for when pedestrians enter to cross (signal phasing) any distractions they exhibit, as well as which vehicles maneuvers are most often present when a crossing pedestrian results in a conflict.

Lastly, several Multinomial Logit models were employed to identify correlations between the factors described early in the section, and the various conflict levels observed in the study. A separate MNL was used as well to determine if there was a significant difference in the conflict levels based on different observation data (video vs. site).

5.0 CONCLUSIONS

5.1 Summary

This research seeks to provide a better understanding of pedestrian behavior at intersections. By observing pedestrians as they are actually navigating intersections in high-risk areas we will be able to better understand the risk and exposure that pedestrians face, as well as identifying what percentage of risk can be attributed to non-motorized versus motorized travelers. To date we have only been able to quantify the impacts that the environment has on safety and crash risk. Using real-time video data, this research observed non-motorized travelers as they navigated high-risk intersections. This provided insight and understanding regarding what takes place in "near miss" situations and provided insight into human decision making by:

- Quantifying exposure and risk by identifying if a pedestrian experiences a crossing that is 1) undisturbed, 2) potential conflict, or 3) minor/serious conflict.
- Identifying reckless pedestrian behaviors such as crossing in the wrong location (e.g. mid-block), violating rules of the road, crossing against the signal, etc.
- Creating a profile for pedestrian safety outlining the hazards faced at high-risk intersections, including recommendations for mitigating risk and improving safety.

Data for this project was collected in two main ways; video observations and site visits. The first dataset included video footage of 1,221 pedestrian crossings at eight intersections collected from closed circuit cameras maintained and monitored by the UDOT Traffic Operations Center (TOC). Data was collected on predetermined week days and weekend days for three to four hour blocks of time. The recordings were then transferred to the project staff for coding. A predetermined list of characteristics was used to hand code each individual crossing. The second dataset included in person observations of 841 pedestrian crossings conducted at each of the eight intersections on one predetermined week-day and one Saturday. Site observations were also collected regarding built environment and geometric characteristics of the intersection.

This research employed a variety of appropriate statistical analysis methods to describe trends in the data as well as make predictions regarding correlation and causality between variables. These methods include summary statistics and Multinomial Logistic Regression (MNL) Models.

Section 5.2 provides an overview of the findings from this research including a detailed discussion of the analysis presented in Section 4. Section 5.3 explains the limitations and drawbacks identified in this study and provides suggestions for future research.

5.2 Findings

This research has examined individual pedestrian crossings at high-risk intersections to better understand what factors contribute to pedestrian-vehicle conflicts.

5.2.1 Pedestrian Characteristics

The large majority of the pedestrians observed were male (66.5%). The one exception was the two intersections located on Bulldog Boulevard in Provo where the sex of pedestrians was split nearly even. The age breakdown of observed pedestrians varied a small amount by site, however in most locations approximately 5% or the pedestrians observed were children. The Hillfield Rd. – Antelope Dr. intersection was the one exception (31.9%). This is likely due to the proximity of Lincoln Elementary School and Northridge High School, both located just one block away. The presence of senior pedestrians was also very low. For nearly all of the observed intersections, fewer than 3% of pedestrians were seniors crossing. However at the 700 East – 9000 South intersection over 7% of pedestrians were seniors. Upon further investigation it was determined that the intersection is bordered by a retirement community (Willowwood), the U.S. Post Office, and the Sandy City Cemetery. It is likely that the larger presence of senior residents combined with an increased likelihood of seniors visiting the post office or taking walks along the cemetery grounds accounts for this higher representation of senior pedestrians.

A majority of pedestrians cross alone (74.1%). The exception to this pattern is again seen at Hill Field Rd. – Antelope Dr. Only 55% of pedestrians at this location crossed alone, with

21% observed as children crossing with a guardian and 23% crossing in a group. This is consistent with what would be expected near an elementary school. Redwood Rd – 4700 South also exhibited a high rate of group crossings. This is likely due to its proximity to Salt Lake Community College, which is located approximately ¼ mile (400m) to the North of the intersection. Many students do not park on campus, but rather park elsewhere and walk to campus or walk from surrounding residential areas. This often creates large groups of pedestrian queuing at the light waiting to cross towards campus.

There is quite a bit of variation in the pedestrian volumes at each of the intersections. Average volumes also differ from weekday to weekend. The two Bulldog Blvd intersections had by far the highest pedestrian volumes during the week, however, on the weekend the volumes plummeted. This suggests a high preponderance of student walking trips to school (both BYU and Provo High School). Alternatively, several intersections had higher pedestrian volumes on the weekend (Hill Field Rd. – Antelope Dr., State Street – 4500 South, 700 East – 9000 South, Redwood Rd. – 4700 South, and St. George Blvd. 400 E.). Again, the characteristics of each site provide context for why this is the case. For example, at State Street and 4500 South the number of pedestrians nearly doubles on the weekend. This area has a large number of car dealerships and fast food locations. A large number of people may prefer to shop for an automobile on the weekend when they are not working. They could easily cross at this location to move from one dealership to another or pick up some food.

The data also revealed that pedestrians walk much faster in some locations. For example pedestrians in Provo (Bulldog Blvd), most of whom are adults, average 6.19-6.3 feet per second (approx. 2 meters/sec.). This is substantially faster than the large number of child pedestrians at Hill Field Rd. and Antelope Dr. who averaged just 5 feet per second (1.52 meters/sec.), or the larger senior population at 700 East and 9000 South who averaged 5.18 feet per second (1.57 meters/sec.). This is why it is critical to understand the make-up of the pedestrians who are crossing. Knowing the demographic of the local pedestrians can help planners and engineers fine tune the signal programming at a given site to meet the needs of those crossing.

5.2.2 Quantifying Pedestrian-Vehicle Conflicts at Crossings

This research employed the Swedish Traffic Conflict Technique (TCT) to conduct observations of pedestrian-vehicle conflicts. A large majority of pedestrian crossings were identified as "undisturbed" (83.5%), but nearly 14% of crossings had the potential for conflicts between pedestrians and vehicles. Minor or serious conflicts were observed in only 2% of crossings (n=42). Serious conflicts were only observed at Hill Field Rd. –Antelope Dr., and 700 East – 9000 South. It should be noted that in the prior sections these two locations were identified as having a larger number of children and seniors crossing. The only intersection where no conflicted crossings were observed during the study time period was St. George Blvd. – 400 East. The limited sample size of minor and serious conflicts proved problematic when conducting the statistical analyses in Section 4. These drawbacks are discussed in detail in Section 5.3.

5.2.3 Conflict Contributing Factors

A number of factors may contribute to the potential for conflict in a given pedestrian crossing. Probably the most recognized contributor to pedestrian safety at intersections is the frequency of pedestrians obeying the crossing signal prompts (described in Section 4.4). A majority of pedestrians observed in this sample began crossing during the walk phase of the signal (95.2%). A small percentage entered the intersection during the flashing phase (2.3%) or the steady phase (1.4%). Only 12 pedestrians were observed crossing against the light (jaywalking). There has been some debate lately among transportation professionals as to the level of comprehension that pedestrians possess when it comes to signals and signage at crossings. This data reveals that a large portion of the walking public understands and adheres to the pedestrian signals. It should be noted that this data was only collected at signalized intersections where the level of compliance may be higher. Higher pedestrian volumes may also contribute to better adherence, as pedestrians are more likely to adopt a herd mentality and follow what everyone else is doing rather than cross based on their own outlook and motivations. This may also make it more dangerous for lone pedestrians who are crossing by themselves at low volume time periods when drivers are less likely anticipate pedestrians at a crossing.

The Utah Pedestrian Safety Action Plan emphasizes the need for pedestrians to "walk with awareness" (UDOT, 2016). This is a direct result of research showing that distracted pedestrians are becoming a more common occurrence. Nearly 12% of pedestrians observed in this study were distracted in some way while crossing the roadway. Socializing was the most common distraction. Pedestrians walking together often talk and interact, and this behavior likely continues throughout their crossing potentially reducing their situational awareness. Using an electronic device (e.g. cell phone, mp3 player, tablet, etc.) was the second most common distraction. Again, if a pedestrian is navigating a web page or texting on their phone while crossing, their reaction times will be delayed should the need arise to yield for some reason.

While pedestrian behavior may contribute to increased conflicts at crossings, driver behaviors may contribute just as much. For the crossings where a minor or severe conflict was observed (2%), the vehicle maneuver at the time of the conflict was recorded. A majority of conflicts resulted when vehicles were turning right (48.8%). A driver of a right turning vehicle may look left to yield to oncoming traffic and then proceed to turn directly into the path of a pedestrian as shown in Figure 5.

Figure 5. Right Turning Vehicle-Pedestrian Conflict

Vehicles also frequently stopped beyond the stop line into the crosswalk impeding the pedestrian's crossing path (17.1%). This is a very common occurrence. While the vehicle maneuver was only recorded for minor or serious conflicts, a large majority of potential conflict crossings involved a vehicle that had stopped beyond the stop line and into the crosswalk forcing the pedestrian to walk around the vehicle in order to cross the street (example shown in Figure 6 below).

Figure 6. Vehicle Stopped in Crosswalk

Left turning vehicles often had to abruptly slow or break during their turn to yield to a pedestrian (17.1%) or even abruptly stop to avoid a collision (14.6%). These findings are consistent with prior UDOT research which has identified turning vehicles and the presence of non-dedicated turn lanes as particularly hazardous for pedestrians (Burbidge, 2012; 2015a; 2015b).

5.2.4 Predicting Conflicts

Statistically complex data models were used to examine correlations between built environment characteristics and conflict levels and individual pedestrian characteristics and conflict levels. Potential and Minor conflicts were significantly correlated to the number of roadway lanes and pedestrian walking pace. Each additional North-South travel lane increased the likelihood of experiencing a potential conflict by nearly 500%. Alternatively, each additional East-West lane reduced the likelihood of a potential conflict by nearly 90%. While it is not immediately clear why lanes in one direction would make a conflict more likely while the other direction reduces the likelihood of conflict, some potential factors can be identified. All of the intersections included in this analysis are located along Utah's Wasatch Front Corridor. The street systems in the region are for the most part based upon a grid pattern oriented North, South, East and West. Because of the development patterns in the region, there are fewer main North-South corridors for vehicle traffic than East-West corridors. Therefore vehicles are afforded fewer alternatives when they wish to travel North or South. A majority of these intersections are located along these major North-South corridors. While vehicle volumes were not included in the models, it is likely that each intersection sees significantly more North-South vehicle traffic than East-West traffic which would increase the risk for pedestrian crossing simply based on exposure. Because there are a much larger number of East-West options for vehicle travel the volumes are not as high in a majority of these locations. It is also possible that the limited sample of intersections produced somewhat erroneous results for this specific variable. Future research including a larger more geographically diverse sample may be able to fine tune the impact of more lanes.

When evaluating the correlation between speed limit and conflict, the model identified that higher speed limits resulted in a reduced likelihood of a minor conflict. This is likely due to pedestrians who self-regulate. When a pedestrian comes up to a crossing at a major street with a higher speed limit, they may be more likely to wait for the appropriate crossing time and may be more mindful of watching for traffic while crossing. Conflicts on these higher speed roads may also have a higher likelihood of being serious. Because of the limited sample of serious conflicts this analysis was unable to identify those correlations.

An analysis of pedestrian contributions and crossing behaviors identified that a pedestrian exhibiting no distractions is 45% less likely to experience a potential conflict as compared to a pedestrian who is socializing. As mentioned above in Section 5.2.3, when pedestrians are socializing as they approach an intersection their situational awareness can be significantly reduced. They are focusing on the company and conversation as opposed to focusing on the vehicles traveling in the roadway. However, a pedestrian walking alone is over 400% more likely to experience a minor conflict than someone walking in a group. Pedestrians walking alone have less visibility than multiple pedestrians crossing together. A vehicle approaching the crossing may not immediately see a single person whereas a group of people may catch their attention. Additionally, pedestrians who walk slower have a slightly smaller likelihood (4.1% less) of experiencing a potential conflict during crossing. For these slower walkers, they will likely cross undisturbed having given vehicles enough lead time to see them coming, or experience a minor or serious conflict due to their reduced mobility.

As would be expected, pedestrians crossing at intersections with higher pedestrian volumes (both weekday and weekend) are significantly more likely to experience a potential conflict (approx. 12-14%) or minor conflict (approx. 12-16%) than individuals crossing at intersections that have fewer pedestrian crossings per hour. However, pedestrian volumes were not significantly correlated to the occurrence of serious conflicts. The only characteristic correlated to the risk of a serious conflict was age category. Adults face only 4% of the likelihood of being involved in a serious conflict compared to seniors. As people age their reaction time and mobility decreases significantly. They are not as agile and may not be able to walk as quickly, or may be reliant on a mobility assistance device. They may also lose situational awareness as their senses (vision, hearing, etc.) become less attuned to their surroundings (See Figure 7 below).

Figure 7. Senior Pedestrians Crossing the Street (Source: www.brooklyndaily.com)

5.3 Limitations and Challenges

Like most research, this analysis required the use of a sample of cases rather than the entire population. Any time a sample is used for analysis, the research runs the risk of sampling bias. Because we do not have accurate prior pedestrian volume counts for the intersections included or a breakdown of pedestrian characteristics for each site, it is not possible to identify if the sample that was observed in this research is representative of the population of individuals who cross in these locations over an extended period of time. Along with the inherent limitations of sampling, were limitations introduced by the limited time frame. Originally this research had planned to include observations for a complete week (7 days - 24 hours per day) for each intersection. The reasons for forfeiting that initial plan are detailed in the methods section of this report. Because of the limited amount of observation time available to us, due to TOC constraints on using the cameras as well as data storage limitations, the sample of observations may not be completely representative of pedestrians crossing on all days at all times. However, with that in mind, great care has been taken to identify sampling windows that could adequately capture a cross-section of behavior at each site. Future research would benefit from a large cross-section of video observation time frames for each site, including seasonal variation.

Because of the limited time frame for video data collection and subsequent on-site data collection, fewer observations were collected than originally anticipated. While the dataset was still rather large (2,062 pedestrians) the distribution among conflict levels was not even enough to allow for the complex statistical analysis that was employed which limited the internal validity of the analysis in some cases. Minor and Serious conflicts only occurred in 42 of the pedestrian crossings (2%). This made it impossible to identify strong statistical correlations and conclusions for a few of the variables tested. For example, because serious conflicts only occurred at two sites, it was not possible to draw useful conclusions regarding correlations between built-environment characteristics and conflict levels as the standard error of the variables was zero. Future research would benefit from including a large number of intersections with a wider variety of built-environment characteristics. Longer observation windows would also yield additional cases which would provide a large sample for analysis.

Next, there were several limitations inherent in using the UDOT TOC camera feeds for observing pedestrian crossings, some of which were identified in the methods section. The first was the location of the cameras and their focus angles. The cameras were semi-permanently mounted in a given location and could therefore not be relocated to a different point to observe the intersection. Because of this, the video footage was only available for specific angles. For many of the crossings, a portion of the crosswalk was cut off because the camera could not be manipulated to focus further down. Additionally, when the camera was refocused to view an adjacent leg of the intersection, there were occasions where the mast arm of the traffic signal blocked a view of the crosswalk completely. In these cases, no pedestrian observations were possible for that specific leg. If for some reason, pedestrians crossing in that location had a different experience on other legs, it was not recorded or evaluated in this research. Another limitation of the UDOT TOC cameras was their resolution and zooming capabilities. As mentioned the cameras could not be zoomed out beyond a certain point to capture a wider angle of a specific location. Alternatively, the cameras also could not zoom in far enough to clearly see every aspect of a pedestrian crossing the opposite leg of the intersection. Because of these limitations, it is likely that some of the potential or minor conflicts may have been missed due to the inability to clearly distinguish what was happening so far away on the video feed.

The last finding of this research speaks directly to the methodology employed. A MNL model examining the correlation between how the observation data was collected, and the conflict levels reported found that on-site observations increased the likelihood of observing potential conflicts by 73%. The likelihood of observing a minor conflict on site was nearly 7 times higher than observing a minor conflict via video observation. This directly identified a major limitation of the research. Observers viewing crossings on site and in person are more likely to see the details of a given crossing and to observe conflicts as they happen. The limitations of the video technology described above were shown in this case to limit the accuracy of the conflict coding.

Lastly, because cyclists may travel in a vehicle travel lane, on a shoulder, or even in the crosswalk, it is incredibly difficult to capture both pedestrians and cyclists concurrently using traffic cameras. Because the traffic cameras were trained on the crosswalks in order to capture pedestrian traffic, many cyclists riding in vehicular travel lanes would have been missed in the data collection process creating a threat to both internal and external validity. Therefore the decision was made to omit bicycle traffic from the scope of the analysis, focusing instead on higher data quality for the analysis of pedestrian interactions at each crossing. Future research should find an adequate way to observe bicycle interactions with vehicles at intersections, as their experience likely differs significantly from that of pedestrians.

6.0 RECOMMENDATIONS AND IMPLEMENTATION

6.1 Recommendations

Based on the findings of this research, the following recommendations have been identified:

1. Improve visibility of crosswalks at high-risk locations using appropriate paint, pavement treatments, overhead signage, etc.

2. Improve the visibility of Stop Bars and educate drivers about the importance of stopping at the stop bar. Also, employ innovative treatments such as leading arrows, advance yield markings, ergonomic design and safe zones as appropriate.

3. Implement exclusive pedestrian phasing at high-risk locations to reduce the exposure between vehicles and pedestrians.

4. Improve public education about distracted walking.

5. Implement "No Right Turn on Red" signage or "Turning Vehicles Yield to Pedestrians" signage at high-risk locations.

6.1.1 Improved Visibility of Crosswalks

Increasing the visibility of a crosswalk can improve driver yielding behavior and pedestrian safety. Recent research examining crossing locations that had incorporated high-visibility crosswalks found that the installation of high-visibility crosswalks and refuge islands result in a 48% increase in drivers yielding to crossing pedestrians drivers. Additionally, 40% more pedestrians walked out of their way to use the high-visibility crosswalks as opposed to crossing mid-block (USDOT, 2001).

There are a number of ways to improve the visibility of a crosswalk. The most cost effective and simplest is typically accomplished using paint. As shown in Figure 8, simply increasing the contrast of the striping using a brighter color scheme can make a crosswalk significantly more visible to pedestrians and traffic. When a crosswalk is more visible the likelihood of a vehicle taking notice of pedestrians in the crossing increases. It can be as simple as adding a contrast color (Fig. 8) or creating a work of art representing the culture of the local community (Fig. 9).

Figure 8. High-Contrast Crosswalk Paint (Source: www.urbanmilwaukee.com)

Figure 9. San Diego Artistic Crosswalk (Source: www.trbimg.com)

A second way to improve crosswalk visibility is to use specific pavement treatments that set it apart from the rest of the roadway. This can be in the form of stamped concrete/asphalt (Fig. 10), brick pavers, or even paint that looks like brick when applied to the asphalt (Figure 11). Simply distinguishing the pedestrian right-of-way from the vehicle right-of-way can improve crossing safety.

Figure 10. Stamped Asphalt Crosswalk (Source: myaspaltdr.files.wordpress.com)

Figure 11. Painted Design Crosswalk (Source: www.itd.idaho.gov)

Crosswalk visibility can also be improved by improving outside stimulus and awareness regarding the presence of a pedestrian crossing. This can include visual and audible warning and prompts such as additional signage, flashing lights (Fig. 12), audible signal warnings (beep, buzzer, etc) and even in ground illumination (Fig. 13).

Figure 12. Flashing Crossing Signage (Source: Texas Transportation Institute)

Figure 13. Illuminated Crosswalk (Source: www.27east.com)

<u>6.1.2 Innovative Crosswalk Treatments</u>

The second major recommendation of this research is to improve the visibility of Stop Bars and educate drivers about the importance of stopping at the stop bar; and also, employing innovative treatments such as leading arrows, advance yield markings, ergonomic design and safe zones as appropriate.

While Stop Bars are standard markings at all signalized intersections their visibility can differ depending on conditions. One way to improve visibility of the Stop Bar and encourage adherence, particularly in high-risk areas, is by adding additional visual cues prior to the stop bar. For example, in Figure 14 below, the word "Stop" was painted on the pavement ahead of the Stop Bar as a reminder to drivers.

Figure 14. Stop Bar text prompt (Source: www.reddit.com)

Incorporating increased stop line distances, and treatments such as leading arrows, advance yield warnings, and ergonomic crosswalks can also inform drivers and help to provide an increase in space for pedestrians at crossings. The main goal of these treatments should be to warn drivers of a pedestrian crossing ahead, to warn drivers of potential conflict areas, and to accommodate pedestrian travel behavior to increase safety.

Increasing the distance between the vehicle stop line and the crosswalk is one of the simplest ways to provide an additional buffer between pedestrians and vehicles. By requiring vehicles to stop further back, you can avoid some of the potential and minor conflicts that were observed in this research when vehicles pulled to far forward and stopped inside the crosswalk

(Fig. 15). Additionally, this improves second lane line of sight if a pedestrian has begun crossing and a vehicle has stopped in the first lane to yield.

Figure 15. Increased Stop Line Distance **(Source:www.wtop.com)**

Lead arrows and advance yield warnings have been employed across the country for a number of years in more rural areas and on higher speed corridors. However, they are gaining popularity in more urban landscapes (Fig 16). These pavement markings trigger a yield response for drivers as they approach a crossing making them aware that something is coming and they should anticipate and slow down. In fact research has shown that advance yield markings and prompt signs in multi-threat scenarios “lead to changes in drivers’ behaviors which are likely to reduce pedestrian–vehicle conflicts, including increases in the likelihood that the driver glances towards the pedestrian, increases in the distance at which the first glance towards the pedestrian is taken, and increases the likelihood of yielding to the pedestrian (Fisher and Garay-Vega, 2012). While these are particularly effective at mid-block crossings, they could also be utilized near high-risk signalized intersections to increase driver awareness of pedestrians.

Figure 16. Advance Yield Warning (Source: www.fhwa.dot.gov)

Another innovative approach to pedestrian crossing is the concept of ergonomic crosswalks. Ergonomic crosswalks are the brainchild of Korean designer Jae Min Lim. His concept, which was shortlisted at the Seoul Design Competition, suggested that crosswalks be designed to follow the actual routes that people walk. According to Lim, "When people cross roads, they tend to take the fastest shortcut. They sometimes do it intentionally, but mostly it is an unconscious act. This kind of action violates the traffic regulations and sometimes threatens the safety of the pedestrians. The 'ergo crosswalk' is a design that makes people follow the law, as well as consider their habits or unconscious actions." Lim argues that "if regulations cannot force people to follow the law, wouldn't it be more reasonable to change the law and fulfill the main purpose of keeping the safety and convenience of the pedestrian (Copenhagenize, 2010)?"

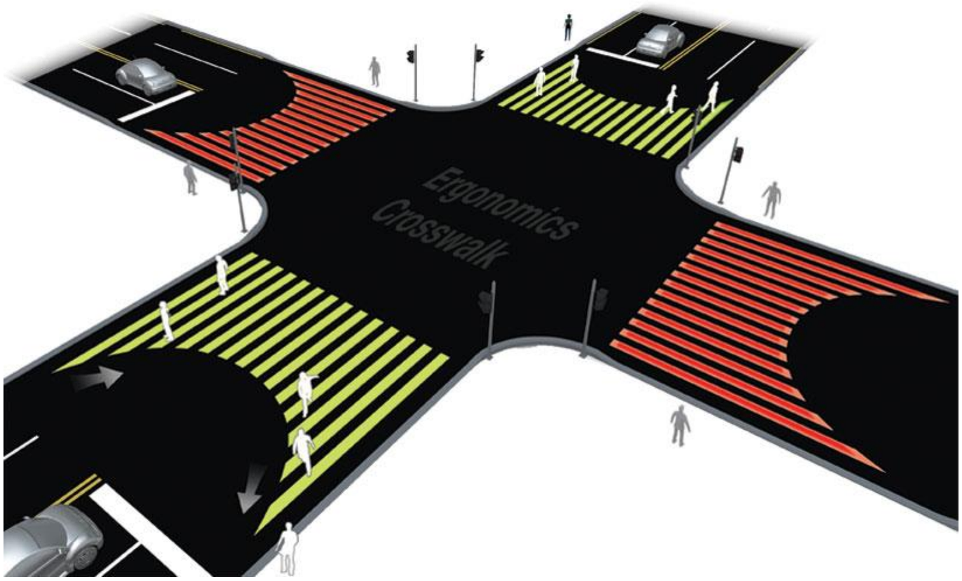


Figure 17. Ergonomic Crosswalk **(Source: Copenhagenize, 2010)**

As shown in Figure 17, ergonomic crosswalks curve the crossing radius along the edges where conflicts are most likely to happen. The stop lines for cars are pushed back to allow for a safe buffer zone.

<u>6.1.3 Exclusive Pedestrian Phasing</u>

The third recommendation of this research is the implementation of exclusive pedestrian phasing at high-risk intersections and other high-volume pedestrian crossings. An exclusive pedestrian phase occurs when traffic is stopped on all approaches to allow pedestrians to cross any leg of the intersection. UDOT currently employs concurrent phasing in most locations which allows pedestrians to cross in the same direction at the same time as parallel motor vehicle traffic receives a green indication. Concurrent phasing may be appropriate in areas with lower pedestrian volumes or areas without a significant number of demonstrated vehicle-pedestrian conflicts or collisions. However, concurrent phasing has a number of drawbacks. For example there can be large number of conflicts between turning vehicles and pedestrians (as identified in this research). Additionally, pedestrians must exercise more caution. Exclusive phasing provides a feeling of security for pedestrians due to the limitation of vehicle conflicts, and can eliminate pedestrians crossing against the traffic light concurrent with parallel traffic.

Figure 18. Exclusive Pedestrian Phasing: Los Angeles, CA

Perhaps the greatest benefit of exclusive pedestrian phasing is the ability for pedestrians to cross the intersection only once. Although pedestrians may have to wait longer at the signal before crossing, the exclusive phasing will allow them to cross in any direction (including diagonal) in one given cycle, which eliminates the need to cross multiple crosswalks to navigate around an intersection. This significantly reduces exposure to potential conflicts, as all vehicles are stopped during the exclusive phase. This may require a “no right turn on red” stipulation to ensure the elimination of turning conflicts.

6.1.4 Educational Campaigns

The final recommendation of this research is to improve public education about distracted walking. This analysis has found that individuals who cross while distracted (either by socializing and talking with other individuals or manipulating an electronic device) are at a greater risk to experience a conflicted crossing. While distracted driving has been a major focus of the Zero Fatalities Program (2016), distracted walking has not received the same level of attention. It is recommended that distracted walking be added to the current media campaign focusing on pedestrian safety. This focus should be included in all media components (TV, print, radio, school programs, etc). It is also recommended that as a part of this educational effort, UDOT should encourage pedestrians to walk with partners or in groups to increase safety.

6.2 Implementation Plan

For all of the recommendations provided above, the same general implementation plan should be followed. First, UDOT Traffic and Safety should work directly with the Utah Office of Highway Safety and the UDOT Regions to identify high-risk intersections that experience higher than average frequencies of pedestrian crashes, or intersections that experience high volumes of pedestrian crossings. A sample of intersections should be selected to study in greater detail. Taking into account the specific site and situation characteristics of each intersection, appropriate treatments should be selected from the menu provided in Section 6.1. The type of innovation to be employed will determine the number of sites for implementation. For example, installing or painting high contrast crosswalks involves a lower investment than other treatments and therefore UDOT could realistically make these types of improvements in a larger number of locations or test sites. Whereas, implementing an exclusive phase pedestrian crossing would more likely initially be installed in only one or two locations in order to test the technology and educate both pedestrians and drivers. The cost and labor required should be taken into account when identify both the frequency and dispersion of any new treatments.

As these treatments are implemented, before and after data collection should take place to evaluate the effectiveness of each treatment type in reducing conflicts and improving pedestrian safety. This evaluation would provide a necessary feedback loop for identifying additional sites and improvement techniques to be implemented elsewhere over time.

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