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DRIVER COMPLIANCE AT ENHANCED PEDESTRIAN CROSSINGS IN UTAH

Prepared For:

Utah Department of Transportation
Research & Innovation Division

Submitted By:

RSG

Brigham Young University
Department of Civil and Environmental Engineering

Authored By:

Kiavash Fayyaz, Ph.D.
Senior Transportation Analyst
Pablo Galvez de Leon
Undergraduate Research Assistant
Grant G. Schultz, Ph.D., P.E., PTOE
Professor

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16. Abstract

Since its creation, the Utah Department of Transportation (UDOT) has made safety its number one priority. Over a decade ago, UDOT began implementing technological enhancements to reduce the fatality rate of pedestrians involved in crashes. However, there is a need to evaluate the effectiveness of these enhancements. This study evaluates the safety impacts of several pedestrian crossing enhancements through comparing the compliance rates of drivers as a surrogate safety measure. This report analyzes enhanced pedestrian crossings to determine the factors that affect the compliance rate among drivers and provides a statistical analysis to prove the factor's significance on compliance. The results show that High-Intensity Activated crossWalks (HAWK) have a higher impact on reducing the probability of a non-compliant event compared with an Overhead Flashing Beacon (OFB) and that the OFB has a higher impact on reducing the probability of a non-compliant event compared with Rectangular Rapid Flashing Beacon (RRFB) and Overhead Rectangular Rapid Flashing Beacon (ORRFB). The results show adding a pedestrian enhancement to a marked crosswalk at location with 5 lanes and speed limit between 35 mph to 45 mph can increase compliance rate by 97 percent for HAWK, 77 percent for OFB, and 57 percent for RRFB and ORRFB. In addition, results show longer stopping sight distances and better walking scores increase the compliance rate.

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LIST OF ACRONYMS

AADT	Annual Average Daily Traffic
AAMVA	American Association of Motor Vehicle Administrators
ASSD	Adjusted Stopping Sight Distance
BYU	Brigham Young University
CO	Compliant
DCO	Dangerous Compliance Opportunity
FHWA	Federal Highway Administration
HAWK	High-Intensity Activated Crosswalk
HRO	Highway Reference Online
ID	Identification
ILCO	Inner Lane Compliant
ILNC	Inner Lane Non-Compliant
MUTCD	Manual on Uniform Traffic Control Devices
NACTO	National Association of City Transportation Officials
NC	Non-Compliant
OLCO	Outer Lane Compliant
OLNC	Outer Lane Non-Compliant
OFB	Overhead Flashing Beacon
ORRFB	Overhead Rectangular Rapid Flashing Beacon
PHB	Pedestrian Hybrid Beacon
RRFB	Rectangular Rapid Flashing Beacon
SSD	Stopping Sight Distance
SSDDP	Stopping Sight Distance Decision Point
TAC	Technical Advisory Committee
TWLTL	Two-Way Left-Turn Lane
UDOT	Utah Department of Transportation

EXECUTIVE SUMMARY

This study compares driver compliance at marked pedestrian crosswalks with or without select pedestrian enhancements. The primary pedestrian enhancements evaluated in this study include the Rectangular Rapid Flashing Beacon (RRFB), Overhead Rectangular Rapid Flashing Beacon (ORRFB), Overhead Flashing Beacon (OFB) and Pedestrian Hybrid Beacon (PHB) or High-Intensity Activated crossWalk (HAWK). Flashing beacons, signs and vertical and/or horizontal separation from the roadway are shared attributes of these pedestrian crosswalk enhancements. The Utah Department of Transportation (UDOT) Traffic and Safety Division has guidelines which recommend the implementation of these treatments at crosswalks but lacks provisions and research to further determine the best fit enhancement for a marked pedestrian crosswalk under prevailing conditions. This research evaluates compliance as a surrogate measure of safety to aid the agency's understanding of one component of the safety effectiveness of these pedestrian enhancements.

Data were collected via video and site visits for 17 marked crosswalk locations which met Annual Average Daily Traffic (AADT), number of lanes, and posted speed limit constraints. Of the 17 locations chosen, five have no pedestrian enhancements, three have an OFB, four have an RRFB, four have a HAWK and one has an ORRFB. The data collection process collected 400 total observations of compliance/non-compliance at each crossing location in addition to such factors as pedestrian volume, stopping sight distance (SSD), land use, and the presence or absence of yield markings.

From the data collected, an initial high-level comparison of compliance among the various pedestrian crossings was determined which assumes that the type of pedestrian enhancement is the only factor which impacts compliance and that other factors (such as SSD) have no impact on compliance. A second evaluation compared compliance among events in relation to additional factors/attributes of locations collected. Finally, chi-square analysis and binomial logit regression were employed to examine compliance between pairs of pedestrian enhancements and to examine the impact of the various factors collected on driver compliance rates.

The results of these analyses reveal some similarities in impacting compliance between RRFB and ORRFB and between HAWK and OFB and ORRFB pedestrian enhancements. In addition, results indicate that the HAWK has a higher impact on reducing the probability of a non-compliant event compared with OFB and that OFB has a higher impact on reducing the probability of a non-compliant event compared with RRFB and ORRFB. Lastly, results show a statistically significant impact to non-compliance based on SSD and area walk score (a built-environment characteristic).

This data evaluation also reveals data limitations inherent to the data collection process. Namely, data limitations are thought to preclude meaningful insight to discern how AADT, number of lanes, posted speed limit, presence of yield markings, land use, and other possible factors at a marked crosswalk location impact compliance.

1.0 INTRODUCTION

1.1 Problem Statement

The Utah Department of Transportation (UDOT) often provides enhancements at pedestrian crossings to minimize the risk of injury or death to pedestrians. Some treatments are relatively new, so the safety benefits of these treatments are not well documented, especially at the local level. However, these enhancements can be powerful tools to protect pedestrians from injury or even death. The goal of these enhanced crossings is to increase vehicle compliance with respect to yielding to pedestrians, thereby decreasing vehicle-pedestrian collisions. It is beneficial for UDOT to know how effective these crossings are, so they can provide appropriate improvements at high-risk locations.

1.2 Objectives

The primary objective of this research is to determine the Utah-specific compliance rates of vehicles at pedestrian crossings with different types of enhancements—such as Rectangular Rapid Flashing Beacons (RRFBs), Overhead Rectangular Rapid Flashing Beacons (ORRFBs), Overhead Flashing Beacons (OFBs), pedestrian hybrid beacons (PHBs) also referred to as High-intensity Activated crossWalK (HAWK) beacons, and standard pedestrian-activated beacons—relative to standard marked pedestrian crosswalks in Utah. The second objective is to determine if these compliance rates vary significantly based on roadway characteristics such as stopping sight distance (SSD), annual average daily traffic (AADT), pedestrian volume, the presence of yield marks, land use type, and other factors. This research will help the UDOT Traffic and Safety Division and Regions in determining the most effective crossings to use at high-risk crossing locations.

1.3 Scope

Task 1: Project Initiation, Steering Committee Meetings, and Project Management

RSG ("the consultant"), in conjunction with Brigham Young University (BYU) ("the research team"), held a kick-off meeting with the technical advisory committee (TAC) on December 4, 2017. The main objective of the kick-off meeting was to identify candidate crossing locations within the state of Utah for further evaluation. Additional TAC meetings were held to discuss the methodology, preliminary findings, and the final report.

RSG managed the research team throughout the project. In addition to ongoing communication and TAC meetings, the research team provided periodic progress reports throughout the duration of the project.

Task 2: Literature Review

The second task focused on reviewing previous studies on driver compliance, safety, and their relation at pedestrian crossings with different types of enhancements in Utah and nationally. The literature review also explored the methodologies for calculating compliance rates. One of the byproducts of the research being conducted in the state of Utah is the transfer of knowledge and information to help develop the next generation of transportation engineers. This task was critical in the ongoing workforce development effort.

Task 3: Develop Methodology

The third task for the project was to develop a methodology to determine compliance rates for pedestrian crossings including the generation of spreadsheets to collect and analyze data. The literature review provided helpful guidance to the research team in developing this methodology. The research team determined the appropriate sample sizes for this research. The methodology considered the posted speed limit of roadways studied to determine the point at which vehicles should yield to pedestrians based on an appropriate perception time and stopping distance.

Task 4: Data Collection

The fourth task was the collection of pedestrian and vehicle data using video cameras at pedestrian crossing locations identified in Task 1. Characteristics of the study sites were also documented including data such as speed limit, roadway cross section and width, AADT, pedestrian volume, type of pedestrian crossing, and adjacent land use. The research team reviewed the video data to identify instances where pedestrians crossed the street. Based on the methodology in Task 3, applicable vehicles were tabulated as compliant or non-compliant in terms of their activity yielding to pedestrians.

Task 5: Data Analysis

In this task the collected data were statistically analyzed to evaluate impact of each pedestrian crossing enhancement on compliance rate.

Task 6: Report

In this task the results of the data collection and analysis were summarized and overall compliance rates calculated for each type of facility. The resulting research report includes results of the literature review, methodology, and compliance rates. A PowerPoint presentation summarizing the findings of the research was also developed and presented to UDOT employees to report on the results.

1.4 Outline of Report

This report documents the findings of the research and includes the following chapters: Chapter 1: Introduction, Chapter 2: Literature Review, Chapter 3: Methodology, Chapter 4: Data Collection, Chapter 5: Data Evaluation, and Chapter 6: Conclusions. A References section follows the indicated chapters.

2.0 LITERATURE REVIEW

2.1 Overview

A comprehensive literature review was performed to gain additional knowledge on enhanced pedestrian crossings and associated topics. These topics include types of enhanced pedestrian crossings and the effects of enhanced pedestrian crossings on driver compliance.

2.2 Types of Enhanced Pedestrian Crossings

There are several types of pedestrian crossings implemented in the state of Utah. This study compares base pedestrian crossings to enhanced pedestrian crossings that have one of the following enhancements installed: HAWK, OFB, RRFB, or ORRFB. Each of the crosswalks will be discussed in the following subsections.

2.2.1 Base Crosswalk

The base crosswalk is a standard marked crosswalk where pedestrians have the right of way to cross the street and where drivers are responsible to allow pedestrians to cross. As illustrated in Figure 2.1, it is a crosswalk without any type of enhancement. For the sake of this study, crosswalks with pedestrian-wielded flags are included with base crosswalks.

Figure 2.1 Base crosswalk in Provo, Utah.

2.2.2 High-Intensity Activated Crosswalk (HAWK)

The HAWK signal was first introduced in the late 1990s by R. B. Nassi, in Tucson Arizona (Fitzpatrick and Park 2010). It offers a unique beacon configuration with two red lights and a single yellow light, as shown in Figure 2.2. The light cycle begins with the activation of the signal by a pedestrian, through automated or manual procedures, followed by a flashing yellow indication that turns into a solid yellow indication, informing drivers to prepare to stop. The solid yellow indication is then followed by a solid red indication during the walk period and finishes with a flashing red indication, which encourages drivers to stop and then proceed with caution if there are no pedestrians crossing. A study from 2010 suggests that this configuration works best in combination with high-visibility crosswalk markings, a stop bar located 30-50 feet away from the crosswalk, solid lane lines, and in some occasions, signs that read “Pedestrian Crossing” (Fitzpatrick and Park 2010).

Figure 2.2 HAWK in American Fork, Utah.

2.2.3 Overhead Flashing Beacons (OFB)

The OFB is an enhancement tool used to aid the visibility of pedestrians to drivers. As shown in Figure 2.3, the OFB is a rectangular pedestrian sign mounted overhead in conjunction with two round flashing lights. The lights can be yellow or red and they flash to indicate the presence of a pedestrian to motorists. This enhancement also has a round, yellow flashing light that announces its activation and deactivation to pedestrians on either side of the road.

Figure 2.3 OFB crosswalk in Heber City, Utah.

2.2.4 Rectangular Rapid Flashing Beacon (RRFB)

The RRFB is a safety enhancement tool used at unsignalized intersections and mid-block crossings. As shown in Figure 2.5, the RRFB is located at a marked crosswalk with two flashing beacons, which aid drivers in identifying the presence of pedestrians. This type of enhancement has been used across the United States and is currently being used at several locations in Utah. It was approved for optional use as a warning beacon under certain limited conditions on July 16, 2008 by the Federal Highway Administration (FHWA) (Furst 2008). The optional use of RRFBs is currently under interim approval by the FHWA.

Some variations of the RRFB exist across the United States. When RRFBs are requested from private sellers, the buyer can choose different specifications, such as the source of energy, LED module configurations, single or dual sided bars, different activation buttons, top-of-pole or side-of pole control cabinet mounting, pedestrian LED indicators to notify users of activation, and different wireless communication systems depending on the vendor chosen.

Figure 2.4 RRFB crosswalk in Ogden, Utah.

2.2.5 Overhead Rectangular Rapid Flashing Beacon (ORRFB)

The ORRFB is a safety enhancement tool used at unsignalized intersections and crosswalks. As shown in Figure 2.4, the ORRFB is a marked crosswalk with two sets of flashing beacons placed overhead and on the side at either mid-block crossings or unsignalized intersections. The ORRFB is a variation of the RRFB and it is utilized only at one location in Utah. This variation of the RRFB exists near a pedestrian generator and was installed as an experimental device. One of the major purposes of this research is to evaluate the compliance at this location since it is the only one currently in operation in Utah.

Figure 2.5 ORRFB crosswalk in Murray, Utah.

2.3 Effects of Enhanced Pedestrian Crosswalks on Driver Compliance

The effects of enhanced pedestrian crosswalks on driver compliance have not been examined extensively in recent years. Most of the available studies are related to pedestrian safety and not necessarily driver compliance at enhanced crosswalks. However, there are some studies that have been conducted to understand driver compliance at RRFB and HAWK locations. The following sections describe the impacts of enhancements at pedestrian crosswalks, the challenges of enhanced pedestrian crosswalks, and the direct impact pedestrian enhancement devices have on compliance.

2.3.1 Impacts of Enhancements at Pedestrian Crosswalks

Safety is one of the most important aspects considered in the development of transportation solutions. The website walkscore.com, dedicated to creating rankings for the walkability of major cities across the United States, rates Utah as the second least walkable state near the west coast, after Arizona (Kocher and Lerner 2018). The problem with pedestrian safety in Utah could also be related in part to the availability of walkable environments throughout the State, as well as pedestrian decisions, among other factors.

Chu (2006) illustrated the need for pedestrian crosswalk improvements in the United States by showing that Florida mid-block crossings accounted for 81 percent of the total deaths of pedestrians in the state between 1994 and 2001. The study was conducted to determine the safety difference between crosswalks at signalized intersections versus crosswalks at mid-block locations depending on the amount of light at the study locations at the time. The researchers used an electronic database of all pedestrian crashes reported on its Long Form Police Accident records from 1968 through 2003. The results show a higher probability of a pedestrian fatality when struck by a vehicle at mid-block locations than at intersections for any given lighting condition. The odds of sustaining a fatal injury at intersections are 49 percent lower than at mid-block conditions under daylight conditions (Chu 2006). With the installation of new safety features at mid-block locations, such as pedestrian crosswalk enhancements, it is hoped that this statistic has been reduced in recent years.

Pedestrian enhancements have been implemented to provide additional safety for pedestrians crossing at places other than signalized intersections. A study completed for the Oregon Department of Transportation states that several mid-block crosswalk enhancements, such as the RRFB and the HAWK, are associated with increased driver yielding rates and decreased pedestrian-vehicle crashes (Monsere et al. 2016). The researchers reported a statistically significant reduction in total crashes, a reduction in pedestrian crashes, an increase in driver yielding rates, and a change in the crash mitigation factor rating for the HAWK and RRFB enhancements. This result compares the causes of crashes at mid-block crosswalks before and after the implementation of an RRFB. Before the enhancement was installed, not yielding was the cause of 50 percent of all crashes, while pedestrians walking on the road at locations other than crosswalks were responsible for 30 percent of the crashes. After the treatment had been installed, the crashes caused by the presence of pedestrians on the road at locations other than crosswalks reduced to 7.7 percent, and the crashes caused by the lack of yielding increased to 73.1 percent. The crosswalks where a RRFB or a HAWK has been installed have also received higher safety ratings (Fitzpatrick and Park 2010). Additionally, a case study in Oregon (Foster et al. 2014) found driver yielding rates at two RRFB locations to be greater than 90 percent. Therefore, the RRFB is also believed to provide increased safety.

Among other effective pedestrian enhancement devices, Fitzpatrick and Park (2010) conducted a study to determine the effectiveness of the HAWK signal. In this study, the before-after evaluation used an Empirical Bayes method that considered nearby intersections without the HAWK treatment as reference sites in order to develop a safety performance function. The results of the research state that after the HAWK had been installed, there was a 29 percent reduction in total crashes and a 69 percent reduction in pedestrian crashes (Fitzpatrick and Park 2010). A 2006 study also supports the HAWK as an effective implementation. The researchers state that red signal or beacon devices (such as HAWKs) have compliance rates greater than 95 percent (Turner et al. 2006). The same study also states that base crosswalks where there was a crossing flag present had a yielding rate between 65 and 87 percent.

In summary, because some pedestrians will attempt to cross a street at locations with no marked crosswalk present, public authorities are looking for solutions that will increase the safety of pedestrians on the road without significantly compromising the operational effectiveness of roadways. The pedestrian enhancements have demonstrated, in general, an increase in vehicle compliance and in pedestrian safety.

2.3.2 Challenges of Enhanced Pedestrian Crosswalks

Even though the research has shown several positive impacts on pedestrian safety from installing pedestrian enhancements at crosswalks, there are certain considerations to be made before such installations should occur. A case study in Beijing, China (Shi et al. 2007) states that one of the biggest challenges with enhanced pedestrian crosswalks is helping pedestrians understand traffic rules and proper safety procedures. According to the United States Census Bureau report of June 2017, Utah is the youngest state in the country with a population where 29.1 percent of residents are under the age of 18 (U.S. Census Bureau 2018). Thus, it is likely to see high volumes of young motorists operating on Utah's roadways, who may not be as familiar with certain aspects of driving as the older population. If a crosswalk enhancement was to be installed, the enhancement would need to be easy to interpret and to operate for both pedestrians and motorists.

A study performed in Michigan states that the effectiveness of the HAWK was largely dependent on the motorists' understanding of the enhancement (Van Houten et al. 2012). Drivers are more likely to understand pedestrian enhancements if they are used in combination with other common features such as yield markings. Van Houten's study also provides additional insight by showing that motorists typically have a strong understanding of yield markings and therefore comply more frequently at locations where yield markings are present than locations where they are not (Van Houten et al. 2012).

Another challenge that exists when installing enhancements at crosswalks is knowing the appropriate conditions for their installation. In Utah, UDOT has established guidelines for installing crosswalks and crosswalk enhancements. The need for an enhancement where a marked crosswalk is warranted typically depends on the AADT, the speed limit, and the number of lanes and/or median type across a roadway (UDOT 2008). However, when a location warrants an enhancement, the type of enhancement to be used is a decision based on engineering judgement. In some instances, because of the lack of research to understand the compliance and the safety effectiveness of a given enhancement compared with other enhancements, an engineer may choose an OFB over an RRFB arbitrarily. It is expected that an installed enhancement provides additional safety, but there are no compliance reports in Utah that prove an OFB to be more effective than a RRFB. In fact, most of the studies reviewed in the literature compare the RRFB with the HAWK but very few include the OFB in their scope. Therefore, the lack of research on each enhanced crossing may result in choosing a type of enhancement that is not the most effective for a specific location.

The National Association of City Transportation Officials (NACTO) has attempted to define locations where enhanced crossings would be most beneficial. On the NACTO website, one can find a detailed list of recommendations to understand the land use type where enhanced crosswalks should be installed (Fitzpatrick et al. 2006). Further research from 2011 attempts to define when, where, and how to install mid-block crosswalks. The researchers state that mid-block crosswalks should not be installed in older neighborhoods, narrow streets, areas with slower moving vehicles, or areas with many intersections. Mid-block crosswalks should be installed, however, in suburbs, long blocks, and areas with heavy pedestrian traffic near major destinations (Vander Broek 2011).

The FHWA has also played an important role in defining the correct conditions in which to install high-level pedestrian enhancements. The HAWK is considered a high-level pedestrian enhancement and, therefore, the FHWA has provided additional criteria for its installation. As shown in Figure 2.6 and Figure 2.7, the 2009 Manual on Uniform Traffic Control Devices (MUTCD) provides guidance on conditions which warrant the installation of a HAWK. These figures are accompanied by other warrant methods to be considered when deciding if the HAWKs are necessary to install (FHWA 2009).

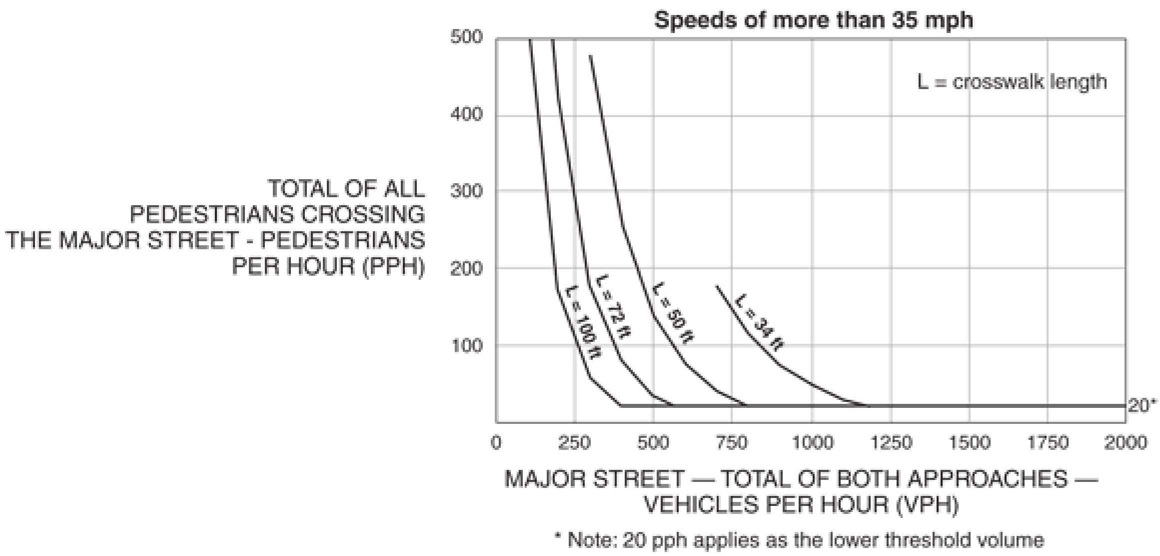

Figure 2.6 Guidelines for the installation of pedestrian hybrid beacons on high-speed roadways (Figure 4F-2, p. 510 FHWA 2009).

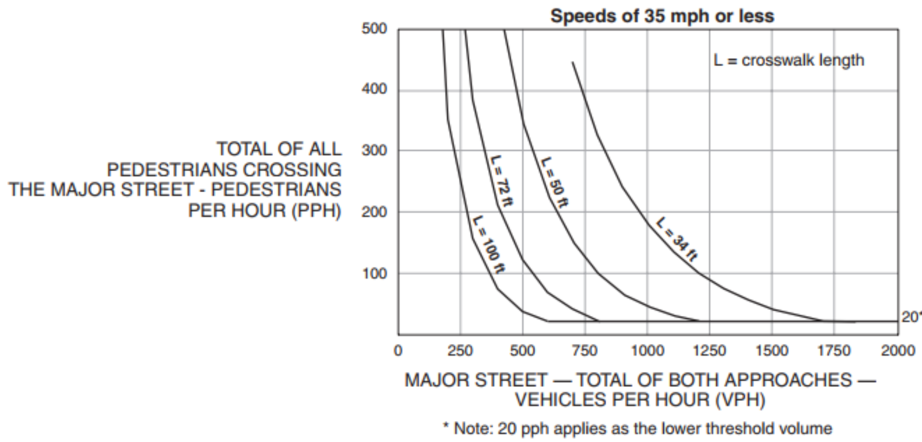

Figure 2.7 Guidelines for the installation of pedestrian hybrid beacons on low-speed roadways (Figure 4F-1, p. 510 FHWA 2009)

Once a low-level or high-level enhancement has been warranted, the third challenge, specific to Utah, is the understanding of compliance. The American Association of Motor Vehicle Administrators (AAMVA) Utah Driver License Handbook, states that the action to be taken by drivers when approaching a crosswalk is to “stop behind the stop line or crosswalk” and “[i]f [the] crosswalk [is]… not marked, then you must stop before the intersection or stop sign… [and] yield to pedestrians entering or in a crosswalk, even if it is not marked.” (AAMVA 2015). However, the Utah legislation states that “[t]he operator of a vehicle… shall yield the right-of-way… to pedestrians lawfully within… an adjacent crosswalk… [even] when traffic-control signals are not in place or not in operation… by slowing down or stopping if necessary… to a pedestrian crossing the roadway within a crosswalk when the pedestrian is on the half of the roadway upon which the vehicle is traveling; or (ii) when the pedestrian is approaching so closely from the opposite half of the roadway as to be in danger” [Utah Administrative Code 41-6a-902] (Utah Code 2018).

Given both definitions of compliance in Utah, there may be different perceptions of the definition of compliance among drivers. In simpler words, according to the Utah code, one does not have to wait for a pedestrian to clear the entire crosswalk if the pedestrian is on the opposite half of the road, where in the driver license manual it states that one must yield to pedestrians at crosswalks regardless of their location in the crosswalk.

An additional challenge to be considered is the budget available for pedestrian enhancements and deciding which one will be the most cost-effective. In 2013, an approximation was made on the average costs of pedestrian and bicyclist infrastructure improvements (Bushell et al. 2013). Table 2.1 shows the average costs for the studied enhancements compared with the base crosswalk (note that the costs for OFB were not included in the Bushnell et al. research). Additional costs may include the construction of median islands, chicanes, diverters, raised crossings, or curb extensions.

Table 2.1 Costs of Enhancements (adapted from Bushell et al. 2013)

Type of Enhancement	Median Price	Average Price	Minimum Price	Maximum Price	Number of Sources
Crosswalk	$340	$770	$600	$5,710	8
HAWK	$51,460	$57,680	$21,440	$128,660	9
Mid-Block Crosswalk	$N/A	$N/A	$2,700	$71,000	N/A
OFB	$N/A	$N/A	$N/A	$N/A	N/A
RRFB	$14,160	$22,250	$4,520	$52,310	3

It is difficult and challenging for a traffic engineer to differentiate between financial options. For example, a traffic engineer may want to install a HAWK at a location with a history of pedestrian-related crashes, but perhaps installing an RRFB with median islands will have the same effect on pedestrian safety and driver compliance as the HAWK does. In that case, the traffic engineer may save taxpayers up to $120,000, or may invest the budget in other traffic solutions. While this sounds appealing for taxpayers, this solution is only possible if there is enough evidence to suggest that other pedestrian enhancements have similar effects on pedestrian safety and driver compliance.

2.3.3 Driver's Compliance at Crosswalks

Compliance has been studied in many states in the United States and the factors that may contribute to compliance vary from one location to another. For example, a case study in Oregon claims that the most defining variable of yield rate is the speed of the drivers (Bertulis and Dulaski 2014). The case study analyzed nine different intersections and observed the behavior of pedestrians and drivers to determine the factors that affected the driver's yielding behavior. The study did not focus on enhanced pedestrian crossings but on unsignalized pedestrian crossings.

However, if their findings hold true in Utah, there may be higher yielding rates in areas with lower speed limits. Similarly, a study on the motorist yielding to pedestrians (Fitzpatrick et al. 2006) also supports this finding. The researchers for this study listed the speed limit and the number of lanes as the factors that determined the yielding behavior (or compliance) of drivers. In this study, the enhancements at crosswalks were categorized and considered as treatments. The researchers claim that mid-block signals, such as the low-level pedestrian enhancements, have the highest compliance rate of all treatments, followed by the half signal (a regular signal placed on the major road that can change phases based on pedestrian activation, such as the half signal located at 200 East and 300 South in Provo, Utah) and the HAWK. The study also listed the OFB as the treatment with the lowest compliance, followed by the high visibility signs and the median refuge island.

Another study performed in Las Vegas, Nevada (Kutela and Teng 2018) sought to understand the different rates of driver compliance at mid-block crosswalks after they have been altered by an enhancement. The types of treatments studied were the RRFB and the OFB. The methodology of the researchers was to record the given intersection at different hours to evaluate compliance temporally. They also considered other treatments at the crossing such as the addition of clearance time, distance to be crossed, and the presence of a push button to activate the enhancement. The findings indicate that drivers comply more often when there is a higher volume of pedestrian crossings and/or when the pedestrians push a button to cross.

In a study performed by the Massachusetts Department of Transportation, the effects of advance yield markings and symbolic signs on vehicle-pedestrian conflicts at marked mid-block crosswalks across multilane roads were evaluated. The researchers in this study performed four experiments in total, two on a driving simulator and two on the streets in the town of Greenfield, Maryland. The researchers did an experiment on the simulator that assessed the effectiveness of advance yield markings at mid-block crosswalks with a series of nine mid-block crosswalks built into a simulated town. The results showed that the advance notice of the crosswalk afforded by advance yield markings makes it more likely that drivers will scan for pedestrians in the crosswalk (Fisher et al. 2016).

In Canada, a research study was conducted to investigate the safety performance of two types of pedestrian crossing control systems (Lacoste 2015). The researchers examined the driver compliance at locations with these systems and measured the driver compliance as a function of type of treatment, weather conditions, pedestrian approach location, and site characteristics. The results of this study show, in general, a greater compliance in the summer than in the winter. This last factor is very important in Utah because the frequency of pedestrians crossing and driver's behavior in the winter are different than during the summer, which means that weather conditions may influence compliance.

2.4 Summary

There are several studies that have been conducted to determine the safety impact of enhanced pedestrian crosswalks in the United States but not as many that determine the driver compliance at these locations. Overall, enhanced pedestrian crossings have been shown to increase pedestrian safety regardless of the enhancement type. Even though there are challenges associated with installing pedestrian enhancement devices, the safety benefits of these enhancements prove them to be worthwhile. As shown through the studies cited in this report, crosswalk enhancements tend to increase pedestrian safety. This increase in safety is most likely due to increased driver compliance. Based on this assumption, this study aims to understand the impact of each crosswalk enhancement on driver compliance. It is believed that the factors which seem to have an effect on driver compliance are speed limit, yield markings, number of lanes, type of enhancement, pedestrian volume, pedestrian activation method, and weather. It is also hypothesized that Base crosswalks will have lower compliance rates to those where a pedestrian enhancement is installed.

3.0 METHODOLOGY

3.1 Overview

The following sections describe how the study sites were chosen, the data collection process, and the data collection methodology used to evaluate each study site for driver compliance.

3.2 Site Selection

Sites were selected in a four-step process. First, the research team, in consultation with the TAC, created a list of potential crossings where the specific crosswalk enhancements exist. Second, variables such as number of lanes and speed limit were isolated in order to identify the potential limitations of each study site, such as yield marks, pedestrian volume, and any additional treatments at the location that could affect the study results. Third, according to the limitations defined, the sites were classified as either “Good Fit” or “Bad Fit” based on the criteria to be outlined. Fourth, the sites that were classified as “Good Fit” were added to a list of sites to be studied.

The first step of the site selection process was to recognize and list all the potential sites available for study. During this process, the research team, including the BYU researchers, RSG representatives, and the UDOT TAC members created a list of potential locations based on the established criteria. The document created by RSG and UDOT was compiled and shared with the research team, and the potential locations the research team found were then added to the final list.

The second phase of the study site selection process was to define the limitations of the study. From the information acquired in the literature review, the research team created a list of criteria to be considered for inclusion in this project. The criteria for inclusion in this project are as follows:

1. The “Base Crosswalk” is to be the point of comparison of this study.

2. The types of enhancements to be studied are the following:
    a. HAWK
    b. OFB
    c. ORRFB
    d. RRFB
3. The number of lanes for the study sites is to remain constant and equal to 5 lanes.
4. The variable “speed limit” is to be noted and must remain within the range of 35-45 mph.
5. The variable “weather at time of study” is to remain constant and equal to “Good,” which means there will not be any inclement weather at the time of study.
6. The variable “activation method” is to remain constant and equal to “Manual Activation” (Note: Utah does not have any “Automatic Activation” enhanced crosswalks, making it impossible to have any variation in the activation method).
7. The variable “Land Use Type” is to be noted.
8. The variable “AADT” is to be noted.
9. The variable “Pedestrian Volume” is to be noted.
10. The variable “Yield Marks” is to be noted.
11. The variable “Additional Treatments” is to be noted.
12. The variable “Stopping Sight Distance” is to be noted.

The third phase began by identifying the speed limits of the selected streets on the UDOT Data Portal (UDOT 2016) and by looking at Google’s Street View (Page and Brin 2018) to confirm the number of lanes at each location. If the location had a speed limit between 35-45 mph and 5 lanes, the location was classified in an online workbook as “Good Fit.” If these two criteria were not met, then the location was classified in the same online workbook as “Bad Fit.”

Once the crosswalk was classified as “Good Fit” or “Bad Fit,” the crosswalks classified as “Bad Fit” were not considered, and the ones that were classified as “Good Fit” were selected to be studied. Then, the constant variables were added to the online workbook, such as the manual activation method, and the clear weather. Finally, Google’s Street View (Page and Brin 2018) was used to determine if the locations selected had any visible yield marks, or additional treatments. Once the study began, the presence of yield markings, the speed limit, and the number of lanes were confirmed, and the additional treatments were noted. The AADT was referenced from the UDOT Data Portal (UDOT 2016) for every location except for site R5, which was measured by RSG. Pedestrian volume was noted during the data collection period. The mile point information was obtained from an open source available from the UDOT Highway Reference Online (HRO). Some locations, however, did not have an exact mile point at the crossing, so it was approximated by one of the members of the research team.

After completion of the site selection process, the research team found 26 locations to evaluate. A crosswalk identification (ID) code was created for each location as a function of the type of crosswalk, identified by one or two letters, and a number to keep count of the crosswalks studied. The letters used for ID are "B, H, O, OR, R" which stand for Base Crosswalk (B), HAWK (H), OFB (O), ORRFB (OR), and RRFB (R). The numbers are organized in descending AADT order, making B1, H1, O1, and R1 the crosswalks with the highest AADT. Table 3.1, lists the possible data collection locations based on the site selection criteria. The information for the route names and the mile points were obtained from the UDOT Data Portal (UDOT 2016).

Table 3.2 provides additional details for each of the study sites. It is important to note that the SSD shown is the estimated sight distance required for a driver to perceive and react to a stationary person or object or warning and come to a stop safely if the slope of the road approaching the crosswalk is less than 3 percent. If the slope is greater than 3 percent, downhill or uphill, the SSD was recalculated according to details to be outlined in Section 3.3. The coordinates given in Table 3.2 were obtained from Google Maps (Page and Brin 2018) and the AADT from the UDOT Data Portal (UDOT 2016). The walk score shown in Table 3.2 was obtained from the official Walk Score website (Kocher and Lerner 2018). Walk score is a website dedicated to evaluating the walkability and transportation availability for future real estate property customers. The score combines the services readily available within a short walking distance and the availability of transportation options near the described area. The score ranges from 0 to 100, where 0 represents a completely unwalkable area, meaning an area where public transportation solutions are not readily available and the services available are not within walking distance. Therefore, a score of 100 would represent the opposite, an area where there are many services available such as grocery stores, recreational areas, restaurants, retail stores, and many others within walking distance or easily reachable by public transportation.

Table 3.1. Possible Data Collection Locations

Region	Type	Route	Mile Point	City	Description	Crosswalk ID
1	BASE	SR 91	33.589	Smithfield	200 S Main St	B1
1	BASE	SR 203	3.197	Ogden	35th St & Harrison Blvd	B2
2	BASE	FA 2172	4.503	West Valley City	2805 W 4100 S	B3
2	BASE	SR 36	54.214	Tooele	100 S Main St	B4
2	BASE	FA 2172	5.217	West Valley City	4100 S Acord Way	B5
2	BASE	SR 138	9.981	Grantsville	150 W Main St	B9
3	BASE	FA 3020	1.119	Provo	560 N 900 E	B6
3	BASE	SR 129	3.965	American Fork	385 N County Blvd	B8
4	BASE	SR 56	60.970	Cedar City	600 W 200 N	B7
2	HAWK	FA 2105	0.780	West Jordan	1120 W 7800 S	H2
2	HAWK	FA 2049	1.225	Sandy	900 E 11400 S	H3
2	HAWK	FA 2078	3.048	Sandy	1582 E 10600 S	H4
2	HAWK	FA 2292	7.298	Salt Lake City	2423 E Sunnyside Ave	H6
3	HAWK	US 40	34.293	Heber	250 S Main St	H1
3	HAWK	SR 129	3.641	American Fork	150 N & County Blvd	H5
1	OFB	SR 204	0.740	Ogden	33rd St & Wall Ave	O1
1	OFB	SR 273	2.214	Kaysville	Center St & Main St	O4
2	OFB	FA 2116	2.338	Cottonwood Heights	1600 E Fort Union Blvd	O2
2	OFB	US 40	16.829	Heber City	100 North Main St	O3
2	OFB	SR 138	10.594	Grantsville	Quirk St SR-138	O5
2	ORRFB	SR 71	13.674	Murray	900 East Southwood Dr	OR
1	RRFB	US 89	413.198	Ogden	2550 S Washington Blvd	R1
1	RRFB	US 89	413.778	Ogden	2450 S Washington Blvd	R2
1	RRFB	US 89	414.070	Ogden	2350 S Washington Blvd	R3
1	RRFB	US 89	414.216	Ogden	2250 S Washington Blvd	R4
3	RRFB	3200 N	n/a	Lehi	North Ashton Blvd	R5

Table 3.2. Possible Data Collection Location Details

Crosswalk ID	Speed Limit (MPH)	AADT 2016 (Veh/Day)	Coordinates	SSD (ft)	Yield Marks?	Walk Score
B1	45	30000	41.832445 N, -111.832801 W	360	No	45
B2	40	30000	41.199385 N, -111.948732 W	301	No	62
B3	40	28000	40.682137 N, -111.960073 W	301	Yes	25
B4	35	24000	40.528564 N, -112.298575 W	246	Yes	72
B5	40	24000	40.682083 N, -111.992094 W	301	Yes	38
B6	35	19000	40.241239 N, -111.643153 W	246	No	69
B7	35	18000	37.680870 N, -113.071489 W	246	No	54
B8	40	12000	40.384893 N, -111.769098 W	301	No	18
B9	35	9900	40.599940 N, -112.468107 W	246	No	39
H1	35	30000	40.504322 N, -111.413488 W	246	No	75
H2	40	25000	40.608965 N, -111.923919 W	301	No	36
H3	40	18000	40.544266 N, -111.866142 W	301	No	53
H4	35	14000	40.558660 N, -111.846902 W	246	No	36
H5	40	12000	40.380084 N, -111.769085 W	301	No	29
H6	40	4100	40.751032 N, -111.813927 W	301	No	19
O1	40	29000	41.203363 N, -111.979282 W	301	Yes	56
O2	35	28000	40.625366 N, -111.846189 W	246	Yes	61
O3	30	27000	40.508874 N, -111.413442 W	197	Yes	78
O4	35	16000	41.034948 N, -111.938631 W	246	Yes	78
O5	35	9900	40.599835 N, -112.456791 W	246	No	45
OR	45	28000	40.638035 N, -111.864515 W	360	Yes	44
R1	35	31000	41.219568 N, -111.970513 W	246	Yes	86
R2	35	31000	41.221677 N, -111.970466 W	246	Yes	86
R3	35	16000	41.223811 N, -111.970421 W	246	Yes	87
R4	35	16000	41.225882 N, -111.970372 W	246	Yes	85
R5	40	16000	40.428615 N, -111.894703 W	301	No	34

3.3 Data Collection Process

After identifying the necessary characteristics of the locations found, the study was divided into 48-hour periods. Two cameras per enhancement were installed at the beginning of the 48-hour collection period. The cameras recorded the crosswalks for approximately 50 hours. Then, the cameras were collected, and the video data were reviewed by the research team. During the video data analysis, the research team noted the AADT, if it had not been noted already, the presence of yield markings if they had not been noted, and any additional treatments that were not noted previously. The researchers then collected the pedestrian volume data and the compliance of the drivers. In the following subsections, the methods of data collection for the AADT, pedestrian volume, SSD, and compliance are discussed.

3.3.1 Average Annual Daily Traffic (AADT)

The AADT was noted in one of the following two methods: The first method was through the UDOT Data Portal (UDOT 2016). The second method was through a short-term data collection method of vehicle counts. For those locations where the AADT was not available, the research team set traffic counters at the sites to calculate the approximate AADT based on the data collected. The AADT of North Ashton Boulevard (R5) was calculated using the latter method.

3.3.2 Pedestrian Volume

Pedestrian volume in terms of pedestrians per day was measured throughout the data collection period by counting the total number of pedestrians during each day. Because the data were collected throughout 48-hour periods, the pedestrian volume was collected throughout each day and an average was calculated to estimate the usual pedestrian volume at the locations studied.

3.3.3 Stopping Sight Distance (SSD)

The SSD is calculated as outlined in Equation 3.1.

$$SSD = 1.47Vt + 1.075 * \frac{V^2}{a} \tag{3.1}$$

Where:

V = velocity in mph (speed limit of the roadway)

t = reaction time of 2.5 seconds

a = deceleration rate of 11.2 ft/s^2

During the installation or take down of the data collection cameras, the SSD was measured from the stop line of the crosswalk to the SSD quantity, a point which is referred to in this research as “Stopping Sight Distance Decision Point” (SSDDP). After the SSD was measured, a landmark or road characteristic (e.g., an intersection, tree, or other landmark) was chosen to identify the approximate location of the SSDDP during the data analysis. Other types of marks were considered, but preliminary analysis demonstrated that to reduce driver distraction, and because of the lack of visibility, a landmark was the easiest way to identify the location of the SSDDP.

Another method used to consider the SSD was the time a driver needs to clear the crosswalk. For example, assuming level grade, a driver going 45 mph would need 360 feet to stop safely. However, if the driver was located exactly 360 feet away from the crosswalk and decided to drive through the crosswalk, the driver would need 5.45 seconds to clear the crosswalk. Therefore, at locations where there is not a notable landmark, a time frame was calculated for drivers to clear the crosswalk and the driver would be counted simply as a Dangerous Compliance Opportunity (DCO). This time frame was observed using the timestamp on the video collected.

The last factor considered to calculate the SSD was the slope of the road. The SSD calculation in Equation 3.1 assumes minimal slope, no greater than 3 percent. Therefore, when the research team installed the cameras, they also measured the slope of both approaches. To measure the slopes, one of the members of the research team used a phone application called “My Altitude” at the beginning of the crosswalk to read and note the elevation. From that point the approximate SSD was measured from the beginning of the crosswalk in the direction of the approaching vehicles. The elevation was again determined at the second location and the slope was calculated using Equation 3.2.

$$G = \frac{\Delta Elevation}{Level\ SSD} \quad (3.2)$$

Where:

G = Grade

ΔElevation = Difference between the elevation at the beginning of the crosswalk and at the end of the approximated level condition SSD.

If the calculated slope is greater than 3 percent, the SSD was re-calculated to determine the adjusted stopping sight distance (ASSD) using Equation 3.3.

$$ASSD = 1.47Vt + 1.075 * \frac{V^2}{2g*(f \pm 0.01*G)} \quad (3.3)$$

Where:

ASSD = adjusted stopping sight distance

V = velocity in mph (speed limit of the roadway)

t = reaction time of 2.5 seconds

g = acceleration of gravity, 32.2 ft/s^2

f = design friction factor (for asphalt and concrete = 0.35)

G = slope (percent)

± depends on whether the slope is upwards (+) or downwards (-)

3.3.4 Compliance

To minimize confusion, compliance rates were calculated according to the Utah Code (as outlined previously in Section 2.2.2), where the driver yields but does not wait until the pedestrian approaches the other end of the crosswalk. Once every driver has been classified as "Compliant" (CO) or "Non-Compliant" (NC) the following ratios were calculated to determine the compliance rates for each enhancement:

For drivers classified as CO, the compliance rate is calculated using Equation 3.4.

$$\text{CO Rate (\%)} = \frac{\text{CO}\ drivers*100}{\text{CO}\ drivers + \text{NC}\ drivers} \quad (3.4)$$

For NC drivers, the ratio is calculated using Equation 3.5.

$$\text{NC Rate (\%)} = \frac{\text{NC } drivers * 100}{\text{CO } drivers + \text{NC } drivers} \quad (3.5)$$

Compliance rates depend on the approach of the pedestrian, which lane the vehicle is traveling in, and the travel direction of the vehicle. As shown in Figure 3.1, when the pedestrian approaches the road from the near side of the driver, the driver is expected to yield and wait before the crosswalk until the pedestrian reaches the two-way left-turn lane (TWLTL) median. Once the pedestrian approaches the TWLTL median, the driver can proceed. If the driver waited behind the crosswalk up to the arrival of the pedestrian into the TWLTL median, the driver is classified as either an outer lane compliant (OLCO) or inner lane compliant (ILCO). Similarly, as shown in Figure 3.2, when the pedestrian approaches the road from the far side of the driver, the driver is expected to yield and wait before the crosswalk once the pedestrian reaches the TWLTL median. Once the pedestrian clears the crosswalk, the driver can proceed. If the driver waited behind the crosswalk from the arrival of the pedestrian into the TWLTL median until the pedestrian's clearance of the crosswalk, the driver is classified as either an OLCO or ILCO.

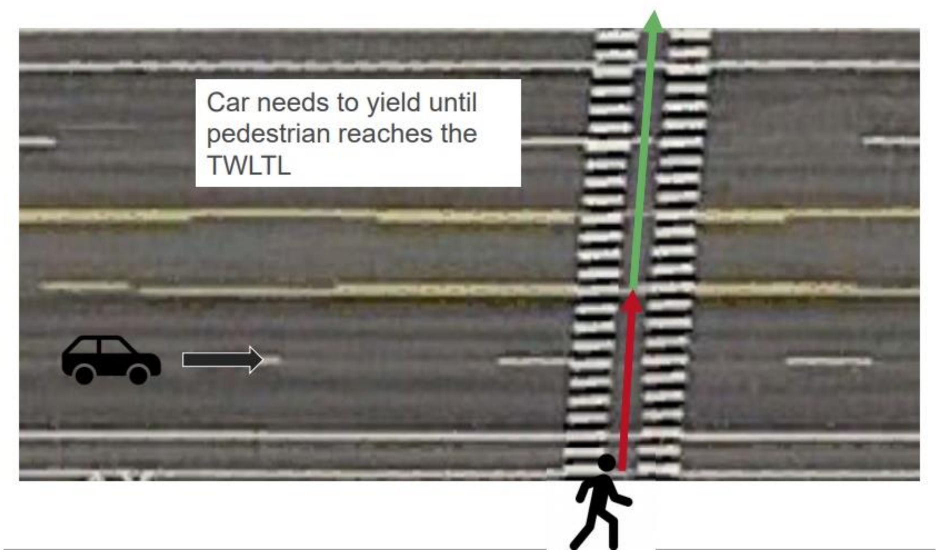

Figure 3.1 Driver compliance for near-side approaching pedestrians.

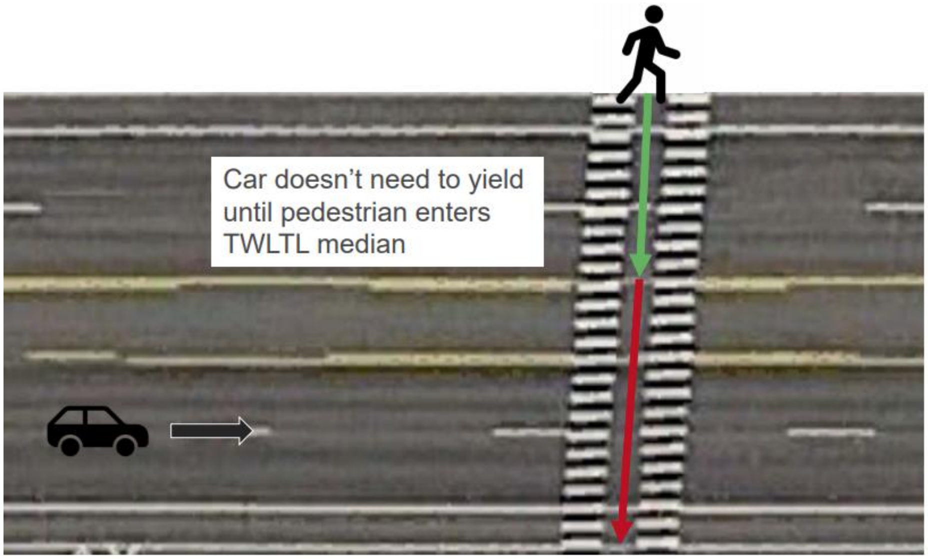

Figure 3.2 Driver compliance for far-side approaching pedestrians.

3.4 Data Collection Methodology

Once all the information was collected and calculated, the results were analyzed to identify the contributing factors to the compliance of drivers. In the following subsections, additional details on the data collection processes are explained. First, the difference between compliance counts at HAWK locations will be discussed. Finally, the sorting of data will be explained.

3.4.1 Compliance at Different Enhancements

Compliance depended on three different factors: the type of enhancement in the study, the SSD, and the yielding behavior of the driver. However, some patterns can be observed when the compliance tracked at base crosswalks is compared to compliance at RRFB locations or compliance at OFB locations. Therefore, compliance could ultimately be separated between compliance at non-HAWK and HAWK locations, both of which will be defined in the following subsections.

3.4.1.1 Non-HAWK Compliance

Compliance at non-HAWK locations, meaning at Base, OFB, ORRFB, and RRFB locations, depended first on the location of the driver when the enhancement was activated if the location had an enhancement. If it was a Base crosswalk location, compliance depended on the driver location when the pedestrians reached the median or the planter strip if a crosswalk ramp was not available. If a crosswalk ramp was available, the driver location was identified at the time the pedestrian approached the ramp before the crosswalk. Once the enhancement was activated or the pedestrian approached to the right location described previously, the driver's location would be noted as before the SSDDP or past the SSDDP. If the observed vehicle was past the SSDDP, the analyst could ignore the driver behavior if the driver chose to not stop before the crosswalk. If the driver did choose to yield, however, the analyst classified the driver as ILCO or OLCO if the driver yielded until the pedestrian reached the TWLTL median. If the driver yielded temporarily and did not wait until the pedestrian reached the TWLTL median, the driver would be classified as inner lane non-complaint (ILNC) or outer lane non-compliant (OLNC). A flowchart describing this process is shown in Figure 3.3.

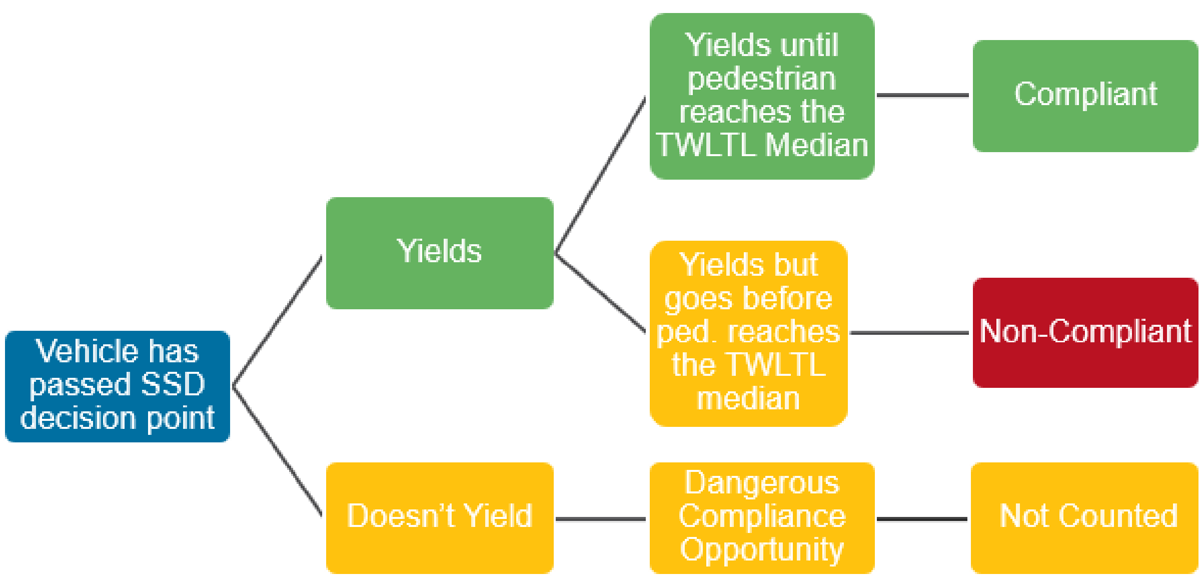

Figure 3.3 Non-HAWK compliance flowchart for drivers past the SSDDP.

If the observed vehicle was before the SSDDP, the analyst could not ignore the driver behavior if the driver chose to not stop before the crosswalk. If the driver chose to yield the analyst classified the driver as ILCO or OLCO if the driver yielded until the pedestrian reached the TWLTL median. If the driver yielded temporarily and did not wait until the pedestrian reached the TWLTL median, the driver would be classified as ILNC or OLNC. A flowchart describing this process is shown in Figure 3.4.

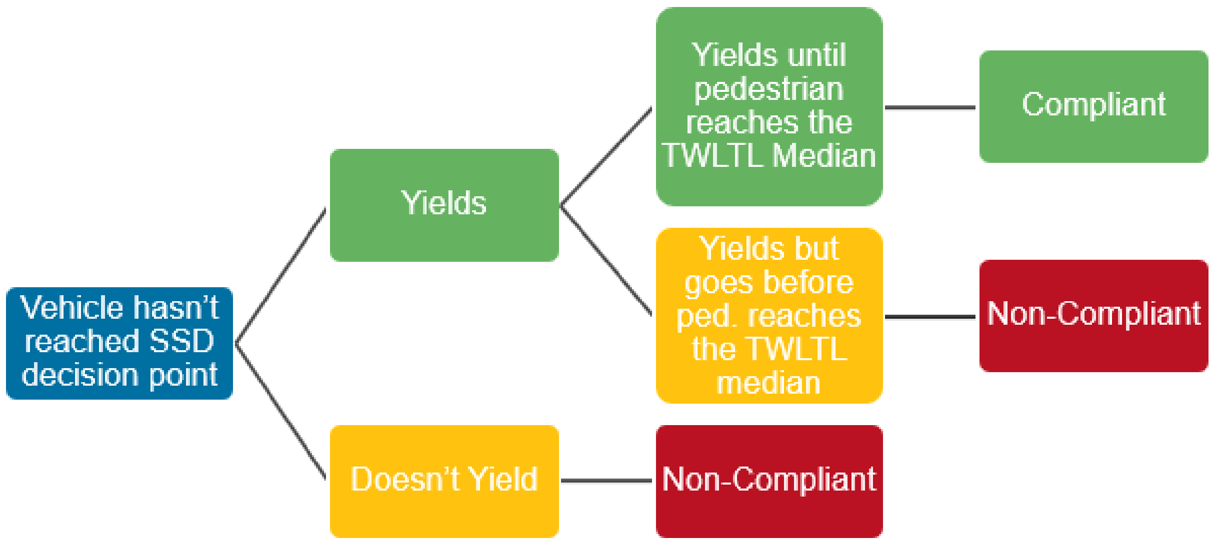

Figure 3.4 Non-HAWK compliance flowchart for drivers before the SSDDP.

3.4.1.2 HAWK Compliance

After preliminary analysis, it was determined that the HAWK locations have one interval within the phase that creates confusion for compliance: the red flashing interval. The recorded data for preliminary analysis shows that almost all drivers do not stop fully at the stop line during this interval unless there is a pedestrian approaching the driver or in the direct path of the driver. Therefore, during the data analysis, the HAWK compliance was determined to be modified so that drivers that slow down can be categorized as CO. However, if the driver does not slow down at all, the driver was categorized as NC. Additionally, compliance depended on whether the driver arrived at the solid red phase or at the flashing red phase. Since the HAWK takes into account the SSD necessary to stop safely before the crosswalk, the drivers who arrived during the flashing red phase were ignored unless the drivers stopped for pedestrian yielding.

If the driver arrived during the solid red phase, the driver would be categorized as ILCO or OLCO if the driver stopped and chose to remain stopped during the duration of the solid red phase. Once the solid red phase ended and the flashing red phase began, if there were no pedestrians on the road, or if the pedestrians approaching from the near side had arrived at the TWLTL and the pedestrians approaching from the far side had not arrived at the TWLTL, then the driver could proceed and be classified as an ILCO or OLCO. Otherwise, the driver would be classified as ILNC or OLNC. A flowchart describing this process is shown in Figure 3.5.

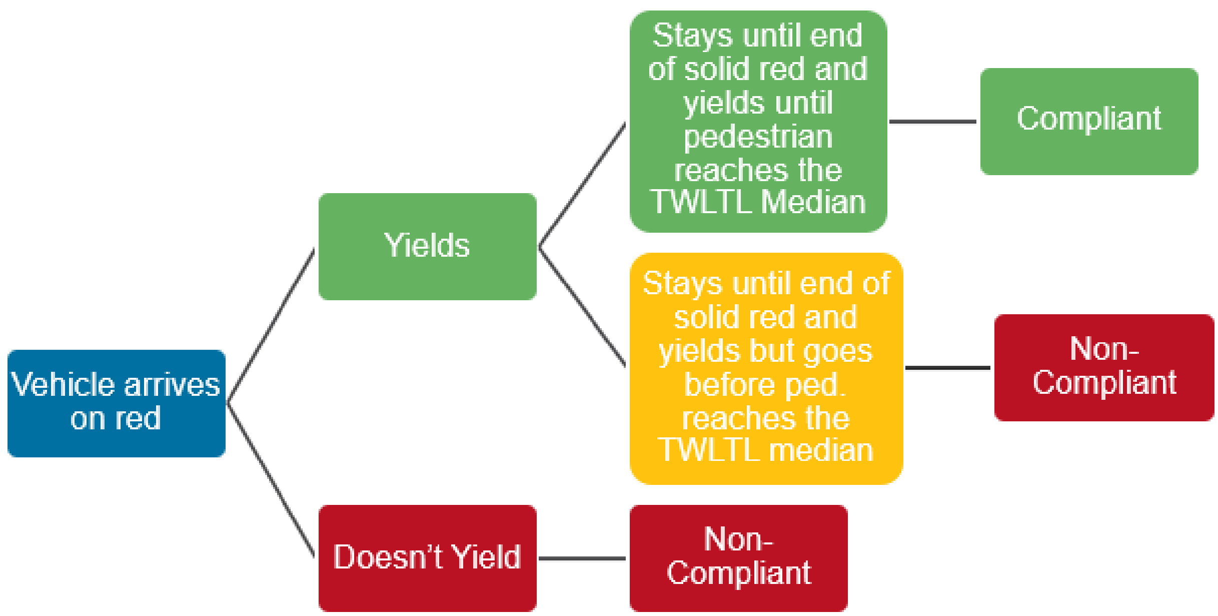

Figure 3.5 HAWK compliance flowchart for drivers arriving on solid red.

If the driver arrived during the flashing red phase, the driver would be categorized as ILCO or OLCO if the driver slowed down enough before proceeding and there were no pedestrians on the road, or if the pedestrians approaching from the near side had arrived at the TWLTL and the pedestrians approaching from the far side had not arrived at the TWLTL. Slowing down enough is defined as when drivers are visibly slowing down as the drivers approach the HAWK. Otherwise, the driver would be classified as ILNC or OLNC, even if there were no pedestrians on the road, meaning that if the drivers did not apply the brakes at all, allowing enough time for a pedestrian to be seen, the drivers would be classified as NC. A flowchart describing this process is shown in Figure 3.6.

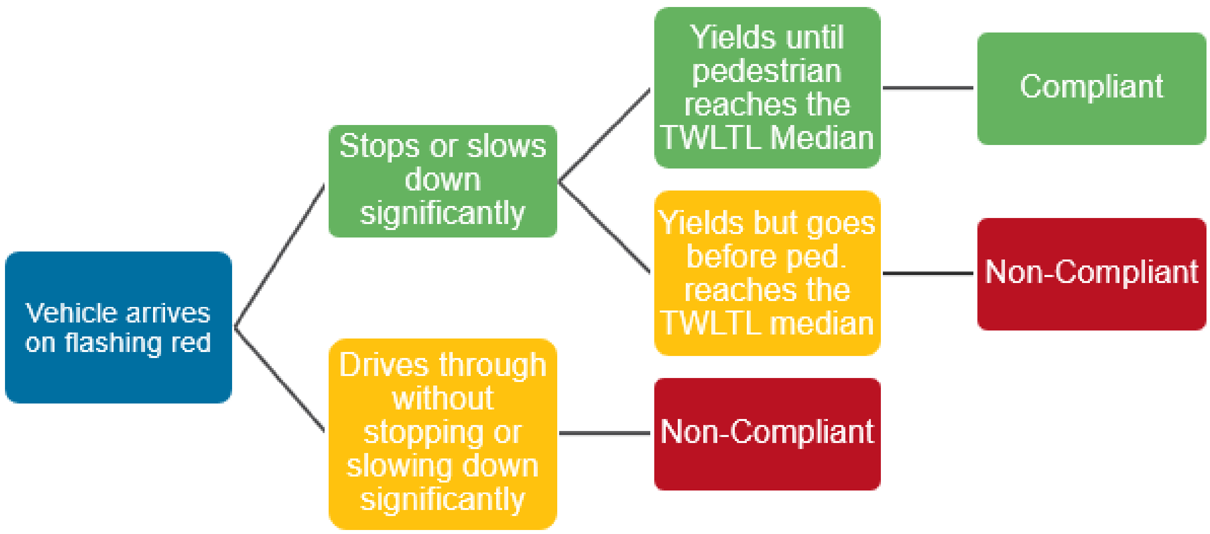

Figure 3.6 HAWK compliance flowchart for drivers arriving on flashing red.

<u>3.4.2 Sorting of Data</u>

Once all of the counts were reduced and posted online on the worksheet created by the research team, the data were sorted by compliance rate from highest to lowest. Then, the research team analyzed which factors were shared among the highest compliance rates. The pedestrian crossings were compared to other crossing locations with the same or similar factors to understand if those factors have an impact on the compliance rates. The hypothesis was that enhanced pedestrian crossings with high compliance rates shared at least one factor. If the results show that the crosswalk locations with high compliance rates do not share any common factors, the additional treatments and other additional factors may be considered to compare the compliance rates more accurately. The analysis and data collection details are provided in Chapter 4 and Chapter 5.

3.5 Summary

There are four steps in acquiring and analyzing the data to estimate compliance rates at enhanced pedestrian crosswalks. The first step was the selection of study locations, where the limitations of the study were defined, and the potential locations were gathered according to the pre-determined criteria. The second step was the determination of factors to be analyzed, where the definition of CO and NC drivers were provided. The third step was the development of a plan, which included the times when the sites were studied.

4.0 DATA COLLECTION

4.1 Overview

The data collection process for the analysis of factors that have the highest impact on driver compliance included an experimental data collection set, a data collection set, and a reference data collection set. Throughout all sets, the research team collected data at locations with pedestrian crossing enhancements installed. The following sections describe the selection of locations used, the data points selected, and the summary of data throughout the three data collection sets.

4.2 Location Selection

After creating a list of potential locations where data could be collected, the research team chose four sites local to the data collection team to initialize data collection and to test if the methodology would work well for the remaining locations. The following sections describe the data points collected during the experimental data collection process, the first data evaluation made by the TAC and the research team, and a QR code redirected to the data collection reference sheet, where all the information from the research was gathered.

4.2.1 Experimental Data Collection

Initially, the research team determined to collect data for different compliance types, defining compliance as it is stated in the Utah Code and the Utah Driver's License Manual as defined in Section 2.2.2. The objective was to differentiate which drivers were NC and which drivers were CO according to the Utah Code only or to both the Utah Code and the Utah Driver's License Manual. Table 4.1**Table 3.1** lists the locations where these data were collected.

Table 4.1 Experimental Data Collection Locations

Preliminary ID	Location	City	Collection Period (2018)
H1	10189 N 4800 W	Highland	Apr 9 – Apr 11
O3	250 S Main St	Heber City	Apr 23 – Apr 25
R5	3350 N Ashton Blvd	Lehi	Apr 16 – Apr 18
B6	590 N 900 E	Provo	Apr 23 – Apr 25

During the experimental collection period, compliance data points were created. Each compliance data point included identifiers such as: person collecting the data, speed limit, crosswalk ID, vehicle direction, study date, crossing time, pedestrian volume, and weather during the day. The presence of yield markings and other additional treatments were noted in another set of data. After the preliminary data collection was finished, a sample video was created for each compliance type at all four experimental data sites. The objective was to model each compliance type and determine if the methodology was sufficient to collect the required data as determined by the TAC and the research team.

4.2.2 Data Evaluation

During the initial data evaluation process, the research team presented the preliminary findings of the literature review and the TAC provided feedback on the data points collected throughout the experimental data collection period. The research team prepared a presentation where the types of compliance were demonstrated in 5-20 second video clips, and the data points to be collected were listed and shown to the TAC. After the conclusion of the presentation, time was given for the TAC to provide feedback. The feedback included the decision to focus on the Utah Code-compliance-based data points rather than the Utah Driver's License Manual-compliance-based data points. More details on the recommendations provided by the TAC are detailed in Section 4.3. Even though the research team would now only keep track of one type of compliance, many questions arose on which factors, additional to the factors already considered during the literature review analysis, were appropriate to add. Members of the TAC requested the research team add additional compliance factors, which significantly changed the data collection process compared to what was discussed in Section 4.2.1.

4.2.3 Reference Data Collection

A full spreadsheet of the data collected for the study can be found using QR Code 1. The information is ordered and named in tabs. Each tab has information from the research, from tables included in the literature review to every detail of data points collected throughout the research. This QR Code will also be referenced throughout the data collection section.

QR Code 1. Full Data Access

4.3 Data Point Selection

The preliminary data points collected during the experimental data collection were evaluated by the research team and the TAC. The decisions made as a result of this discussion were to focus only on the Utah Code-based compliance, collect the driver data points according to their location on the road (i.e., if the driver approached on the inner lane or on the outer lane), collect the pedestrian approach depending on the location, either near or far approach, disregard the drivers in the median lane if that was the approach the driver came in through, and count the drivers approaching from another road into the crosswalk being studied if the crosswalk in study was located at an intersection and the drivers coming from another road were headed to the crosswalk being studied at the time. Lastly, the TAC requested that data also be collected at a crossing location with the only ORRFB in Utah.

After a revision of the data collection sheet, the research team created a schedule to begin collecting data at locations in as many UDOT regions as possible. The following sections describe the locations where data were collected and the process used to collect data from video files, including storage locations, and other details.

4.3.1 Locations Selected to Study

Data collection locations were selected according to 2016 AADT, the amount of data necessary for the results to be statistically significant (which will be explained later in this section), date, and weather conditions. First, locations where roadways were clear of snow were considered if the 2016 AADT was among the highest volumes. Then, locations with a school crossing, where the corresponding school it served was still in classes at the time of the data collection, were considered. Next, locations with the highest 2016 AADT were considered if data points were still needed. Finally, locations where data points were still needed, even those locations that did not generate many compliance data points, were considered. Table 4.2 summarizes all the locations where data were acquired. It is organized by crosswalk ID, which takes into account the AADT and the type of location in study. The data collection period included in Table 4.2 shows only the dates where data were analyzed from each study site. The research team collected data for longer periods than the ones shown in Table 4.2. Additional analysis could be performed from the additional data collected, however, because the research team only needed to collect 400 compliance data points at each location; once there were enough data points the video analyst would stop collecting data points from the video files. Additionally, Table 4.2 shows several collection periods for two locations, O2 and OR. Several days were needed for O2 because of technical issues with the cameras at the time of pick-up or at the set-up. At the OR study location, however, many days of video data were needed in order to reach 400 data points since there is a lack of pedestrian activity around the area.

Table 4.2. Data Collection Locations

Crosswalk ID	Location	City	Collection Period (2018)
B2	35th St Harrison Blvd	Ogden	May 25 – May 27
B5	4100 S Acord Way	West Valley	May 3 – May 4
B6	560 N 900 E	Provo	Apr 23 – Apr 25
B7	600 E 200 N	Cedar City	Jun 25 – Jun 27
B8	385 N County Blvd	American Fork	Apr 16 – Apr 18
H3	900 E 11400 S	Sandy	Jul 23 – Jul 25
H4	1582 E 10600 S	Sandy	Jul 23 – Jul 26
H5	150 N County Blvd	American Fork	May 7 – May 9
H6	2423 E Sunnyside Ave	Salt Lake City	May 5
O2	1600 E Fort Union Blvd	Cottonwood Heights	Apr 30 – May 2, May 14 – May 16, Jun 1 – Jun 2
O3	100 N Main St	Heber City	April 23 – April 25
O4	Center & Main St	Kaysville	May 25 – May 28
OR	900 E Southwood Dr	Murray	Apr 30 – May 2, May 10 – May 12, May 30 – Jun 3, Jun 29 – Jun 30, Jul 2 – Jul 3
R1	2550 S Washington Blvd	Ogden	May 18
R2	2450 S Washington Blvd	Ogden	May 18 – May 19
R3	2350 S Washington Blvd	Ogden	May 18 – May 19
R5	3350 N Ashton Blvd	Lehi	Apr 16 – Apr 18

4.3.2 Video Analysis

After the video cameras were retrieved from each data collection site the research team organized the video files according to the type of enhancement and location. The video analysis was comprised of two phases; the data collection phase and the data verification phase. During the data collection phase, an analyst watched the recorded video at up to 10 times the original speed to find pedestrian crossing times. Once a crossing was found, the research team member recorded the analyst's initials, crosswalk ID, vehicle direction, study date, crossing time, pedestrian crossing volume, the pedestrian approach, amount of DCO drivers, ILCO drivers, OLCO drivers, turning vehicle CO drivers, total CO drivers per crossing, ILNC drivers, OLNC drivers, turning vehicle NC drivers, total NC drivers, and average weather per day. Some attributes were populated automatically such as compliance per day, average weather per location, and pedestrian volume per day.

Various software programs (e.g., VCL Video Player, Windows Media Player, Windows Movies &TV, and OpenShot Video Editor) were used to watch the recorded videos depending on the type of computer used. A screenshot of the typical view when the analyst was recording the results is shown in Figure 4.1.

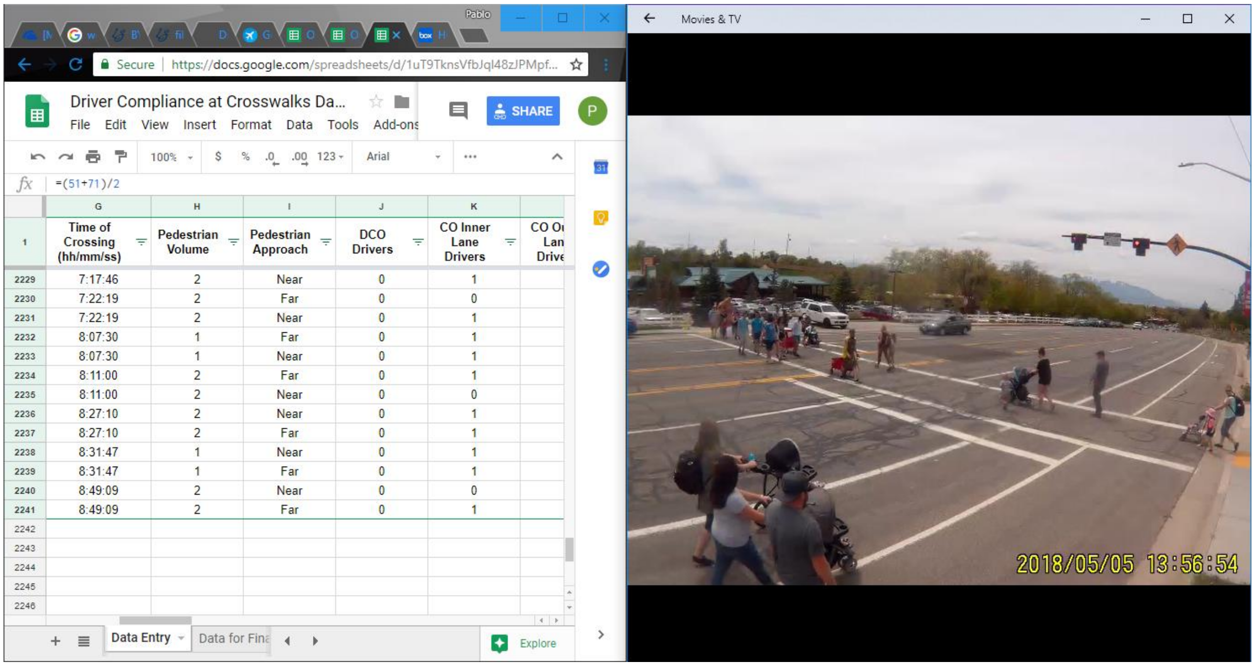

Figure 4.1 Typical screenshot for data collection.

4.4 Data Summary

Soon after the research team began collecting compliance data points, a statistician was consulted to provide guidance on the number of data points necessary to provide statistically significant results at a 95% confidence level. The statistician provided the research team with a sample size by using the sample size rule of thumb formula in Equation 4.1.

$$N = \frac{4}{e^2} \tag{4.1}$$

Where:

N = sample size

e = tolerance

The tolerance used for the study was that of 10 percent (0.10 in the equation). The estimated number of data points determined through this process was 400 per crosswalk type (e.g., HAWK, OFB, RRFB, ORRFB, Base), which meant at least 2,000 data points over all five types of crosswalks to be studied. For some enhancements, it took only one location to collect enough compliance data points. However, for the ORRFB, it took about 240 hours of collected data to meet the minimum number of data points required. Once all of the data points were collected and organized, a summary of the data process began.

Based on the data gathered, the research team created a simple data summary table to show compliance per type of enhancement and to identify factors that may influence compliance. The number of total drivers recorded represents the total number of compliance data points collected, whether that represented ILCO drivers, OLCO drivers, turning driver CO, ILNC drivers, OLNC drivers, or turning driver NC. Table 4.3 shows the preliminary results of the compliance per type of enhancement.

Table 4.3. Preliminary Compliance per Type of Enhancement

	Pedestrian Volume	CO Drivers	NC Drivers	Total Drivers	CO Rate	NC Rate
Base	504	294	547	841	35.0%	65.0%
HAWK	2141	1339	91	1430	93.6%	6.4%
OFB	511	454	77	531	85.5%	14.5%
ORRFB	271	418	45	463	90.3%	9.7%
RRFB	845	637	61	698	91.3%	8.7%

As shown in Table 4.3, the HAWK compliance rate is the highest, with the base crosswalk locations having the lowest compliance rates, as the hypothesis in the literature review states. Based on compliance calculated, as explained in Section 3.3.4, the order of compliance for each intersection from highest to lowest is: HAWK, RRFB, ORRFB, OFB, and Base. Further analysis and final compliance results will be provided in Chapter 5.

These compliance rates assume that the type of or absence of pedestrian enhancement at a marked crosswalk is the only factor which impacts compliance. It is important to note that the compliance rates presented above do not consider the impact of other factors on compliance rate.

This is addressed in Chapter 5 where the impact of all factors with statistically significant effect on compliance rates are evaluated.

4.5 Summary

The data collection process included a sample data collection process, the selection of locations for experimental data and usable data, the selection of data points to be used based on the factors found in the literature review, and a summary of the data collected. The data collected are stored in a spreadsheet that has been organized according to the data collection phase of the research.

5.0 DATA EVALUATION

5.1 Overview

It was observed during the data collection that the leading driver behavior has significant impact on the driver compliance of the following vehicles. In other words, it is more likely that following driver(s) be NC if the driver in the leading vehicle is NC. In addition, pedestrian safety is more compromised by the leading vehicle compared to the following vehicles. To minimize such effect, an event-based analysis instead of vehicle-based analysis was used.

An event is identified in this study as the moment when at least one pedestrian is crossing at the same time as one or multiple vehicles approach the crosswalk. A NC event is identified as an event where at least one driver is NC according to Utah code. A CO event is identified as an event where all drivers are CO according to Utah code.

To provide a better understanding of the impact of various factors collected in the data, the NC rates of events, inner lane vehicles, outer lane vehicles, turning lane vehicles, and total vehicles were visualized for:

1. Treatment types (Figure 5.1)
2. Sites (Figure 5.2)
3. Land-use and treatment types (Figure 5.3)
5. Yield mark and treatment types (Figure 5.4)
6. AADT and treatment types (Figure 5.5)
7. Walk-score and treatment types (Figure 5.6)

It is important to mention that the NC rates measured in Figures 5.1 to 5.6 are calculated based on a simple averaging method and do not consider multi-factor impacts and/or statistical significance of graphed factors. Thus, the NC rates are solely shown for visualizing the collected data and building an intuitive understanding of various factors. The graph results cannot be used to measure the actual impact of various factors (e.g., treatment types and walk-score) on NC rates.

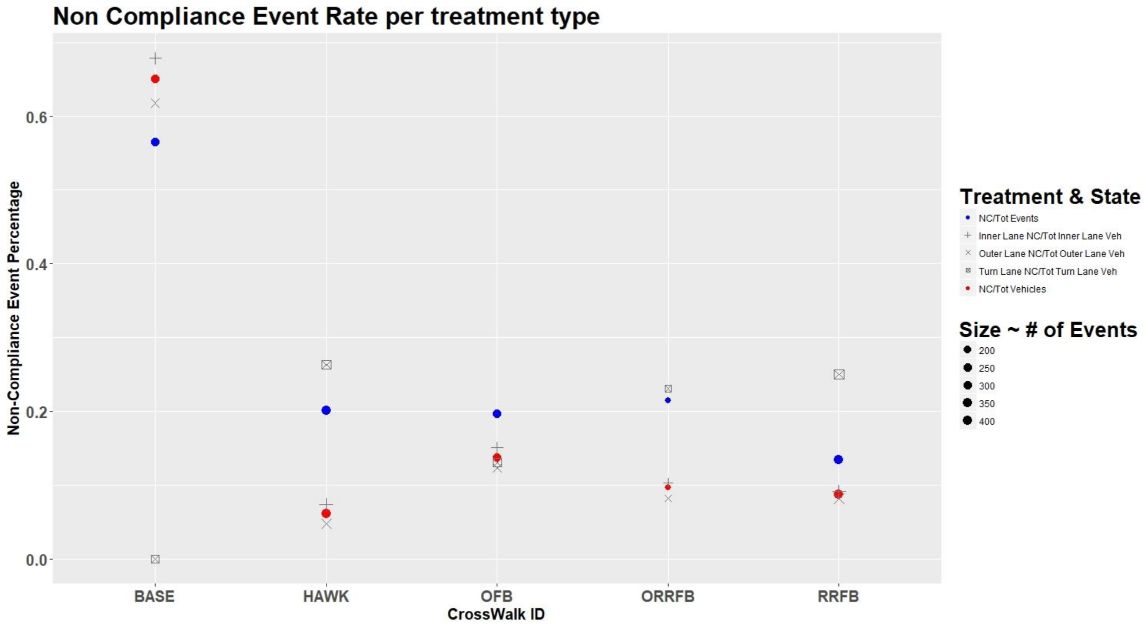

Figure 5.1 Non-compliance rates per treatment type.

Figure 5.1 shows that the NC event rate is much higher for a base crosswalk (~65 percent) compared to other treatment types (~15 percent to 20 percent).

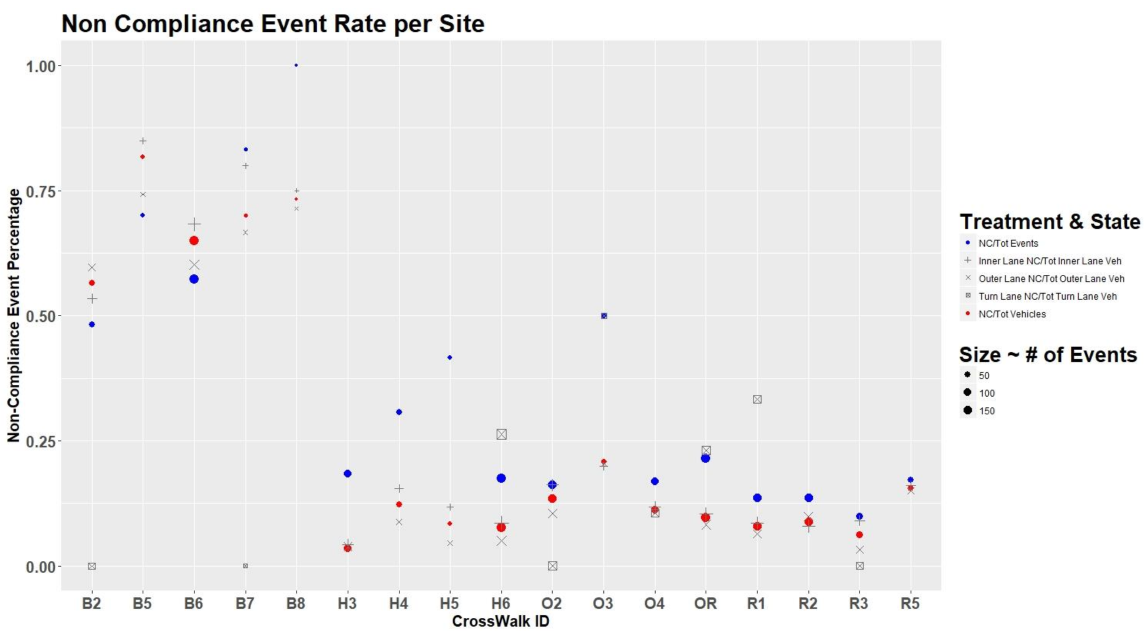

Figure 5.2 Non-compliance rates per site.

Figure 5.2 shows that there are considerable variations in NC rates between different sites with the same treatment type. This is interpreted to mean that treatment type is not the single factor impacting driver compliance rates.

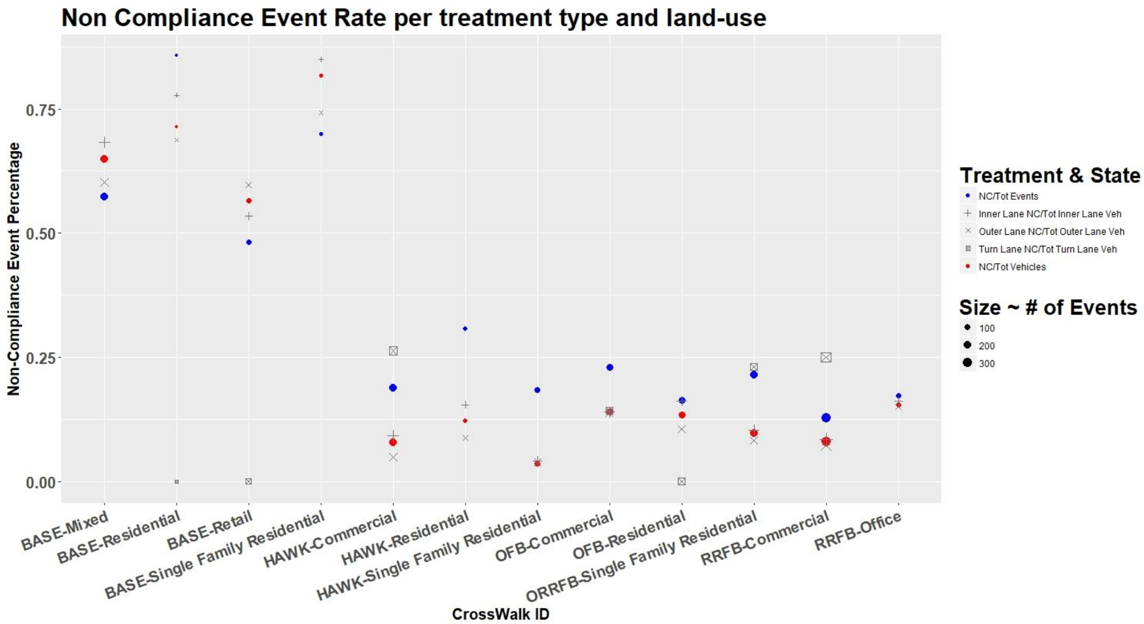

Figure 5.3 Non-compliance rates per treatment type and land-use

No obvious trend in impacts of land-use on compliance rates can be seen in Figure 5.3. It is hypothesized that there are two possible reasons for this:

1. Data limitations: more sites required; and/or
2. Land-use does not have a significant impact on compliance rate.

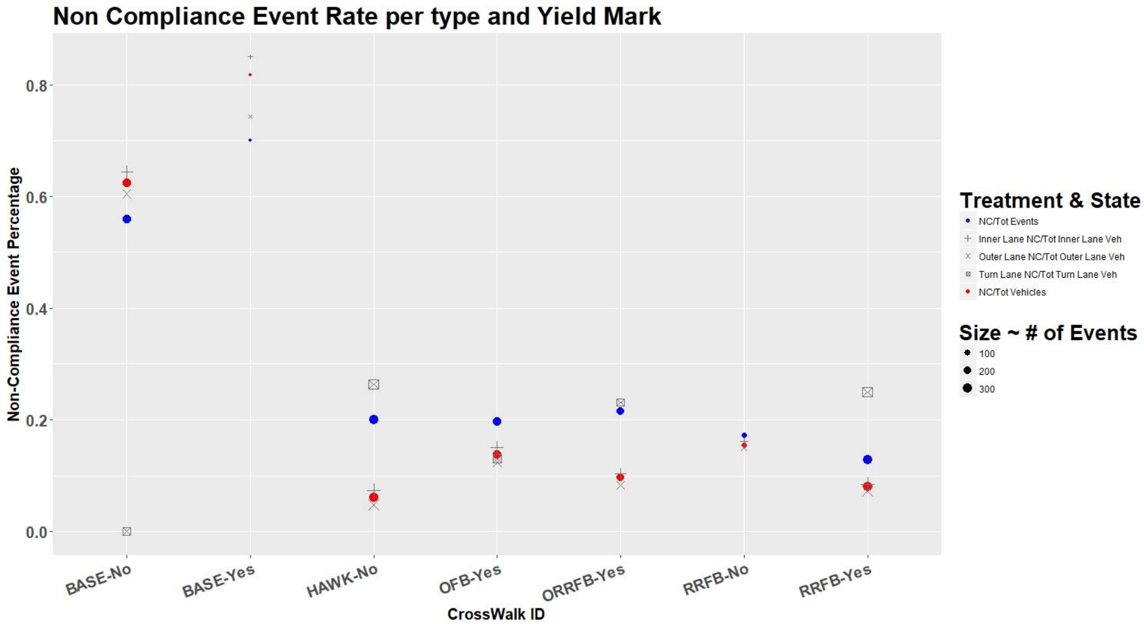

Figure 5.4 Non-compliance rates per treatment type and yield mark.

No meaningful trend in impacts of yield mark on compliance rates can be seen in Figure 5.4. It is hypothesized that there are two possible reasons for this:

1. Data limitations: more sites are required; and/or
2. Yield marks do not have a significant impact on compliance rate.

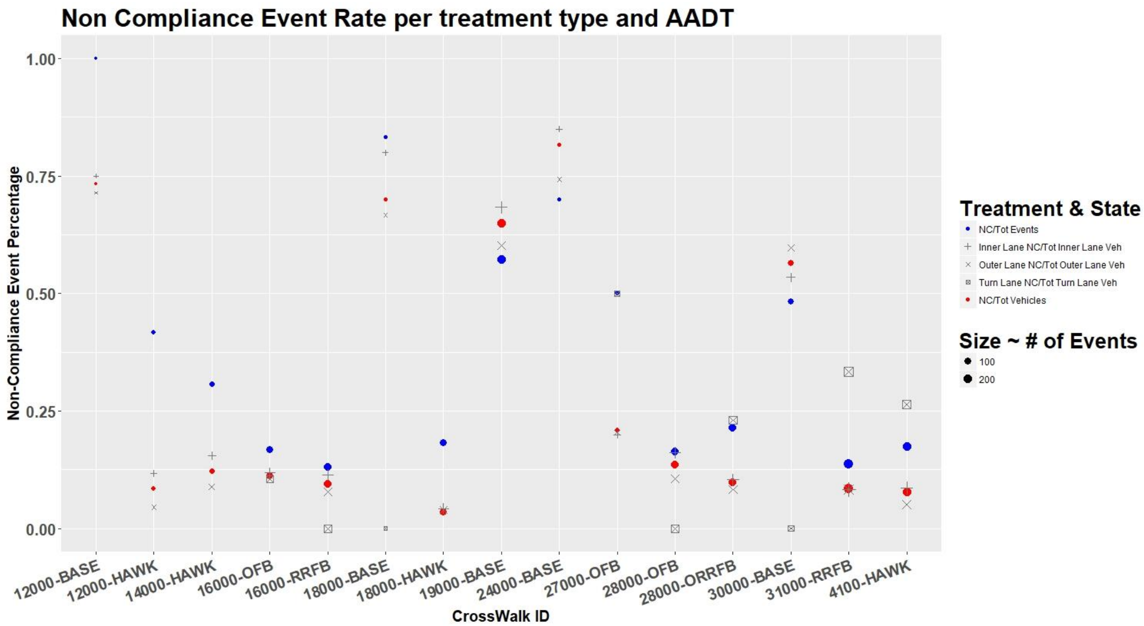

Figure 5.5 Non-compliance rates per treatment type and AADT.

No obvious trend in impacts of AADT on compliance rates can be seen in Figure 5.5. It is hypothesized that there are two possible reasons for this:

1. Data limitations: more sites required; and/or
2. AADT does not have significant impact on compliance rate.

It is more likely that AADT does not have significant impact on compliance rate since the collected data covers a wide range of AADTs.

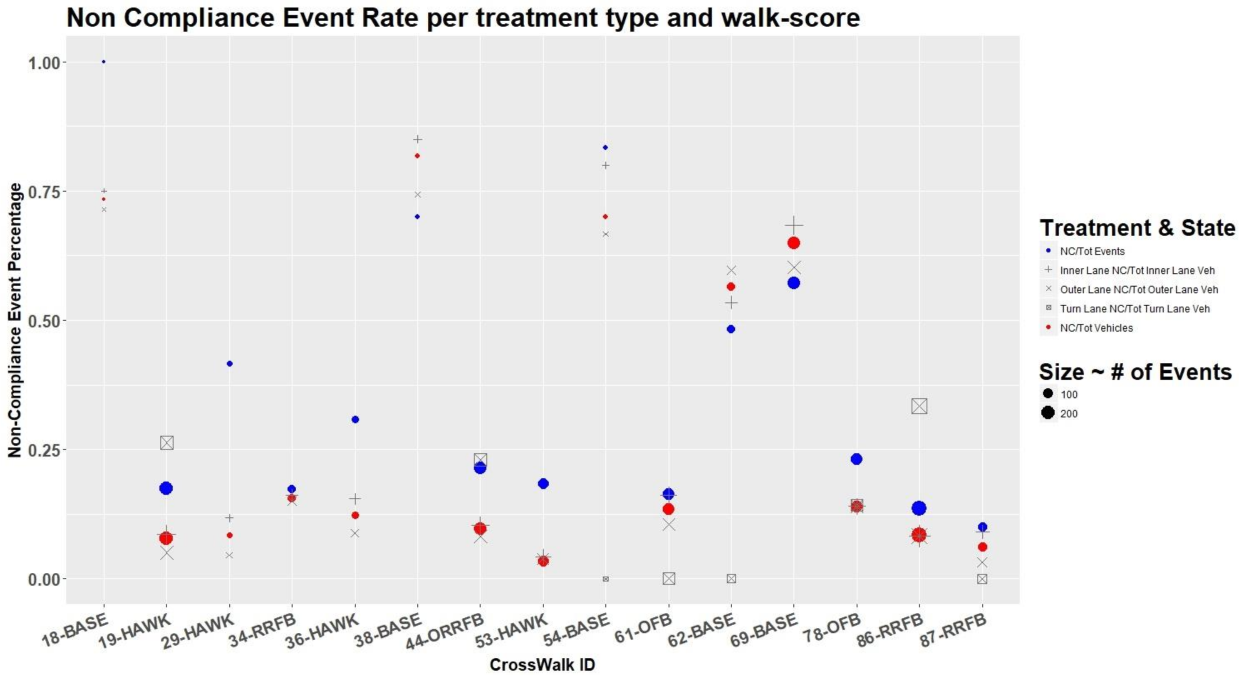

Figure 5.6 Non-compliance rates per treatment type and walk-score.

Figure 5.6 shows that increase in walk-score within sites with the same treatment type are usually associated with decrease in NC rates.

Figure 5.7 shows the compliance rate per vehicle and pedestrian approach (Inner-Outer lane/Near-Far approach). Figure 5.7 shows that when pedestrians are approaching from the far side, the NC rate of vehicles are higher. Generally, HAWK, OFB, ORRFB, and RRFB show much less sensitivity to vehicle-pedestrian approaches compared to the base. This is probably due to higher visibility provided by these treatments compared to a marked crosswalk without these treatments.

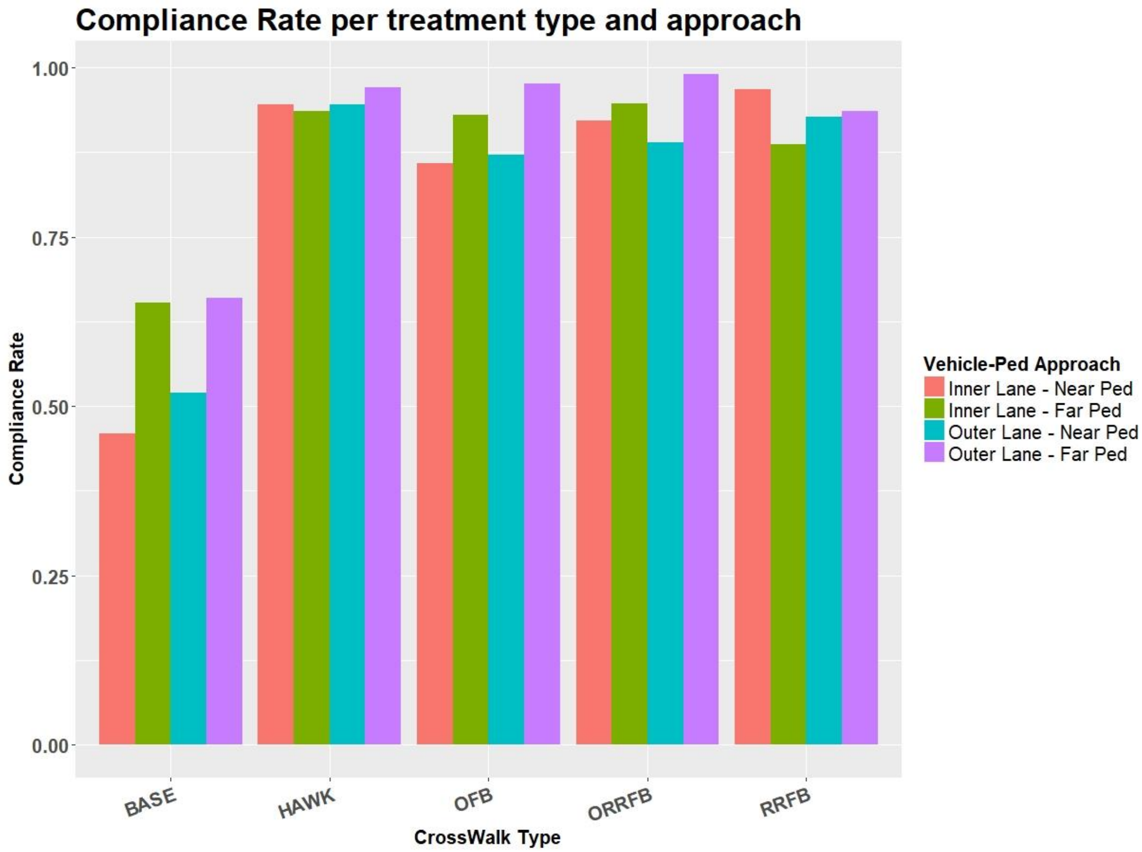

Figure 5.7 Compliance rates per treatment type and vehicle-pedestrian approach.

5.2 Statistical Analysis

In this section, a Chi-square test is first used to assess whether the impact of various treatment types is statistically significant on compliance rate, then binomial-logit regression is used to measure the impact of various factors on compliance rate.

5.2.1 Chi-Square Test of Statistical Significance

The Chi-square test is used to determine whether there is a significant difference between the expected frequencies and the observed frequencies of compliant events between each pair of treatment type. The null hypothesis is that the two treatment types in the test have the same impact on event compliance rate. The alternative hypothesis is that the two treatment types in the test have different impacts on event compliance rate. Thus, the difference between treatment types are more significant as the P-value of the Chi-square test becomes closer to 0 (null hypothesis is rejected), and the difference between treatment types are more significant as the P-value of Chi-square test becomes closer to 0 (null hypothesis is accepted).

Table 5.1 shows the P-values resulted from Chi-square tests for each pair of treatment types. The P-value for each pair of similar treatment type (e.g. OFB vs OFB) is equal to 1.0 meaning that the same treatment type has the same impact on compliance rate. The P-value for each pair of Base vs other treatment types (Base vs OFB) is 0.0 meaning that the difference between impact of base versus any other treatment types are statistically significant. This shows that all treatment types have statistically significant effect on reducing the compliance rate.

Table 5.1 also shows that RRFB and ORRFB have a similar impact on compliance rate (P-value = 0.711). In addition, the high P-values (i.e., 0.599 and 0.191) show that the HAWK has a similar impact as OFB and ORRFB on compliance rate.

Table 5.1 P-Values Results of Chi-Squared Tests

Type	OFB	RRFB	BASE	ORRFB	HAWK
OFB	1.000	0.010	0.000	0.079	0.599
RRFB	0.010	1.000	0.000	0.711	0.034
BASE	0.000	0.000	1.000	0.000	0.000
ORRFB	0.079	0.711	0.000	1.000	0.191
HAWK	0.599	0.034	0.000	0.191	1.000

Note: The high P-values are color-coded as green and low P-values are color-coded as red.

5.2.2 Binomial-Logit Regression to Estimate the Impact of Various Factors on Compliance Rate

The binomial-logit regression is used to estimate the impact of various factors such as treatment types and walk score on driver compliance rates. The binomial-logit regression can be described as outlined in Equation 5.1:

$$Logit(Y) = \alpha + \beta \quad (5.1)$$

Where:

Y = the dependent variable

α = the intercept or the log-odds when the predictors are all zero

β = the vector of parameter estimates

X = the vector of independent variables

In this study, the binomial-logit regression has the form outlined in Equation 5.2:

$$Logit(Y = is\ noncompliant\ event) = \alpha + \beta X \quad (5.2)$$

Where:

$Y = 1$ when the event is noncompliant and $Y = 0$ otherwise

α = the intercept or the log-odds of the base case (i.e., Base crosswalks)

β = the vector of parameter estimates

X = the vector of independent variables including:

- Treatment types
- Land use
- Speed limit
- Yield marks
- AADT
- Walk score
- SSD
- Total number of vehicles in an event

Several models have been estimated and any independent variables that showed statistically insignificant impacts on an event being NC were removed. The parameter estimates of the final model are shown in Table 5.2.

Table 5.2 Final Binomial-Logit Regression Model Estimates

Variable	Parameter Estimate	Std. Error	Z value	Significance
Intercept	5.013	1.104	4.539	***
HAWK	-3.629	0.328	-11.054	***
OFB	-1.469	0.218	-6.724	***
RRFB and ORRFB	-0.856	0.187	-4.585	***
Total # Drivers in an Event	0.977	0.065	15.077	***
Stopping Sight Distance (ft)	-0.018	0.003	-6.076	***
Walk Score	-0.041	0.006	-6.291	***

Table 5.2 shows that the HAWK (-3.629) has higher impact on reducing the probability of an event being NC than OFB (-1.469). Similarly, OFB has higher impact on reducing the probability of an event being NC than RRFB and ORRFB (-0.856).

The positive estimated coefficient (0.977) of total number of drivers in an event shows that the likelihood of the leading vehicle being NC increases as the number of following vehicles increase. Thus, it is expected to see more NC events in congested areas.

The SSD shows negative impact (-0.018) on probability of an event being NC. In other words, as SSD increases, the possibility of an event being NC decreases. This is hypothesized to be caused by drivers having more time to identify the pedestrian and stop.

Finally, the walking score shows negative impact (-0.041) on probability of an event being NC meaning that an increase in walk score results in a decrease in probability of an event being NC. This is hypothesized to be caused by drivers expecting more pedestrian crossings in walkable areas.

It is valuable to investigate the odds ratio of the factors. Odds ratio show the constant effect of a factor (e.g., HAWK) on the likelihood of an outcome (e.g., an event being NC). Table 5.3 shows the odds ratio and its 95 percent confidence intervals for various factors of the binomial-logit regression model.

The odds of an event being NC for HAWK crosswalks are 0.027 times that of Base crosswalks. Or, the odds of an event being compliant for HAWK crosswalks are 37.6 times that of Base crosswalks.

Table 5.3 Final Binomial-Logistic Regression Model Odds Ratio

Variable	Odds Ratio		
	2.5% Conf. Interval	**Mean**	**97.5% Conf. Interval**
Intercept	17.429	150.292	1328.250
HAWK	0.014	0.027	0.050
OFB	0.149	0.230	0.351
RRFB & ORRFB	0.294	0.425	0.612
Total # Drivers in an Event	2.347	2.656	3.026
Stopping Sight Distance (ft)	0.976	0.982	0.988
Walk Score	0.948	0.960	0.972

The regression results indicate that HAWK has a higher impact on reducing the probability of a NC event compared with OFB and that OFB has a higher impact on reducing the probability of a NC event compared with RRFB and ORRFB. The odds ratio table shows that adding a HAWK to a marked crosswalk will increase compliance rate between 95 percent and 98.6 percent. Similarly, adding a OFB to a marked crosswalk will increase compliance rate between 64.9 percent and 85.1 percent, and adding a RRFB or ORRFB will increase compliance rate between 38.8 percent and 70.6 percent.

In addition, total number of vehicles in an event, SSD, and walkability score showed statistically significant impacts on compliance rates. The odds ratio table shows that an additional vehicle in an event will increase the NC rate of that event by 134.7 percent to 202.6 percent. Similarly, a one-foot increase in SSD at a crosswalk location will increase the compliance rate of that location between 1.2 percent and 2.4 percent, and a one value increase in walk score of the location will increase the compliance rate of that location between 2.8 percent and 5.2 percent.

5.3 Summary

The data evaluation process included raw data visualization to provide a better understanding of collected data, Chi-square test of statistical significance to determine whether there is a significant difference in compliant events rates between each pair of treatments, and binomial-logit regression analysis to estimate the impact of various factors such as treatment types, SSD, and walk score on driver compliance rates. The results indicate that HAWK has a higher impact on reducing the probability of a NC event compared with OFB and that OFB has a higher impact on reducing the probability of a NC event compared with RRFB and ORRFB.

6.0 CONCLUSIONS

6.1 Overview

UDOT often provides enhancements at pedestrian crossings to minimize the risk of injury or death to pedestrians. Some treatments are relatively new, so the safety benefits of these treatments are not well documented, especially at the local level. In general, past studies have concluded that pedestrian enhancements at marked crosswalk locations provide safety benefits via crash mitigation as well as increased driver compliance at marked pedestrian crosswalks. While the safety and compliance of the enhancements have been considered in previous studies, very few studies offer explicit comparison of associated safety effects and/or compliance rates between these pedestrian enhancements, revealing a potential gap in knowledge that may assist practitioners, particularly within the State of Utah, in determining the most appropriate type of pedestrian enhancement(s) for a crossing location. The purpose of this study is to compare the effectiveness of these crossings, so UDOT can provide appropriate improvements at high-risk locations.

The primary objective of this research is to determine the Utah-specific compliance rates of vehicles at pedestrian crossings with different types of enhancements including RRFB, ORRFB, OFB, PHBs or HAWKs relative to standard marked pedestrian crosswalks in Utah. The second objective is to determine if these compliance rates vary significantly based on roadway characteristics such as SSD, AADT, pedestrian volume, the presence of yield marks, land use type, and other factors.

6.2 Summary

This research aimed to investigate differences in compliance rates associated with marked pedestrian crosswalks with existing RRFB, ORRFB, OFB, PHB or HAWK pedestrian enhancements as well as marked pedestrian crosswalks without enhancements. ORRFB, a pedestrian enhancement currently undergoing experimental use by UDOT, was also included to the list of pedestrian enhancements studied.

Vehicle-based and event-based analyses were performed on collected data using the definition of compliance according to Utah Code ([Utah Administrative Code 41-6a-902] (Utah Code 2018)). The vehicle-based analysis focused on the compliance condition of every vehicle approaching a crossing location for the duration that a pedestrian reached a marked pedestrian crosswalk or activated a pedestrian enhancement at the marked crosswalk then proceeded to cross and complete a crossing. Event-based analysis identified the condition of compliance for an event determined by the compliance condition of all vehicles approaching a crossing during a pedestrian crossing event (which includes one or multiple pedestrians). Event-based analysis was employed in order to minimize the effect of leading vehicle behavior on determining the compliance condition of succeeding vehicles along a crosswalk approach.

Vehicle-based analysis results yielded compliance rates for each marked pedestrian crosswalk type and showed that marked pedestrian crosswalks with enhancements were observed to yield higher compliance rates compared with a marked pedestrian crosswalk with no enhancements.

Event-based analysis involved determination of compliance rates as in the vehicle-based analysis then further examined to offer a high-level evaluation of non-compliance among pedestrian crosswalk types in relation to characteristics noted as part of the data collection effort for each location. These characteristics include location, land-use, yield mark presence, AADT, walk score, and vehicle-pedestrian approach type. Results of this high-level examination provided no obvious trends in compliance rates in relation to the characteristics described. From this result, it was inferred that data limitations constrain analysis or else that the individual characteristics have no significant impact on compliance rates.

Additionally, statistical analyses applied the Chi-square test to compliance events in order to determine the level of impact each pedestrian enhancement has on compliance and a binomial-logit regression was applied to various characteristics to understand the impact of these characteristics on compliance rates. Results of the Chi-square test indicate a significant difference in impact on compliance rates between a marked pedestrian crosswalk with no enhancements versus a marked pedestrian crosswalk with one of the enhancements in this study. In addition, results of the Chi-square test indicate that RRFB and ORRFB have a similar impact on compliance rates and that HAWK has a partly similar impact compared with OFB and ORRFB on compliance rate.

Binomial-logit regression was used to estimate the impact of various factors on compliance rates. The final model results indicated that HAWK has a higher impact on reducing the probability of a NC event compared with OFB and that OFB has a high impact on reducing the probability of a NC event compared with RRFB and ORRFB.

6.3 Findings

This section presents research findings from the vehicle-based analysis and the event-based analysis methods employed. Each of these are discussed in the following sections.

6.3.1 Vehicle-Based Analysis

Vehicle-based analysis results yielded compliance rates for each marked pedestrian crosswalk type and showed that marked pedestrian crosswalks with enhancements were observed to yield higher compliance rates compared with a marked pedestrian crosswalk with no enhancements.

6.3.2 Event-Based Analysis

The following crosswalk characteristics showed no statistically significant impact on compliance rates: location, land-use, yield mark presence, AADT, walk score, and vehicle-pedestrian approach type. From this result, it was inferred that data limitations constrain analysis or else that the individual characteristics have no significant impact on compliance rates.

6.3.2.1 Chi-Square Test

Results of the Chi-square test indicate a significant difference in impact on compliance rate between a marked pedestrian crosswalk with no enhancements versus a marked pedestrian crosswalk with one of the enhancements in this study. In addition, results of the Chi-square test indicate that RRFB and ORRFB have a similar impact on compliance rates and that HAWK has a partly similar impact compared with OFB and ORRFB on compliance rates.

6.3.2.2 Binomial-Logit Regression and Odds-Ratio

Binomial-logit regression was used to estimate the impact of various factors on compliance rates. The final model results indicated that HAWK has a higher impact on reducing the probability of a NC event compared with OFB and that OFB has a higher impact on reducing the probability of a NC event compared with RRFB and ORRFB. In addition, total number of vehicles in an event, SSD, and walkability score showed statistically significant impacts on compliance rates.

The Binomial-Logit regression model estimates show that adding a pedestrian enhancement to a marked crosswalk at a location with five lanes and a speed limit between 35 mph to 45 mph, can increase compliance event rate by:

- 97 percent for HAWK
- 77 percent for OFB
- 57 percent for RRFB and ORRFB

6.4 Limitations and Challenges

The limited diversity in collected data narrows the applicability of the results to broader pedestrian enhancement installation. As an example, the results of the presented study provide a good understanding of pedestrian enhancement impacts on compliance rates for locations with 5 lanes segments with speed limits between 35 mph to 45 mph, but the results are less reliable for segments with different numbers of lanes and/or speed limits. Based on the above discussion, the logical next step is a research study which looks at locations with differing speed limit and lane configurations to address the effects of AADT, number of lanes, posted speed limit, presence of yield markings, land use, and other possible factors on compliance rate.

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