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PEDESTRIAN WALKING SPEEDS AT SIGNALIZED INTERSECTIONS IN UTAH

Prepared For:

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16. Abstract

In 2018, it was decided that the current state guidance with regard to pedestrian walking speeds be evaluated for any needed changes, such as adopting the national guidance found in the 2009 *Manual on Uniform Traffic Control Devices* (MUTCD). To evaluate pedestrian walking speeds at signalized intersections, 15 sites throughout the state of Utah were studied, producing a total of 2,061 observations of pedestrian crossing events. These crossing events were evaluated to calculate walking speeds in relation to pedestrian demographics at each location. Evaluated demographics included pedestrian group size, gender, mobility status, age category, alertness, and potential distractions.

Upon completion of data collection, a statistical analysis was conducted to determine mean and 15th percentile pedestrian walking speeds by demographic. The data collection procedure, data analysis, and limited recommendations for pedestrian start-up delay and pedestrian walking speeds as used in signal timing are discussed in this report. The data suggest that Utah continue to maintain its guidance of 4.0 feet per second walking speeds at most signalized intersections, while exercising engineering judgment at locations containing high pedestrian volumes or locations containing high percentages of elderly or disabled pedestrians.

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LIST OF ACRONYMS

ANOVA	Analysis of Variance
APS	Accessible Pedestrian Signal
DF	Degrees of Freedom
FDW	Flashing Don't Walk
FHWA	Federal Highway Administration
HCM	Highway Capacity Manual
HSD	Honestly Significant Difference
MUTCD	Manual on Uniform Traffic Control Devices
PUFFIN	Pedestrian User-Friendly Intelligent
SD	Standard Deviation
SE	Standard Error
TAC	Technical Advisory Committee
UDOT	Utah Department of Transportation

EXECUTIVE SUMMARY

The 2009 edition of the *Manual on Uniform Traffic Control Devices* (MUTCD) recommends a pedestrian walking speed of 3.5 feet per second for use in the timing of pedestrian clearance intervals at signalized intersections (reduced from 4.0 feet per second in the 2003 edition). Jurisdictions across the state of Utah continue to maintain pedestrian walking speeds of 4.0 feet per second for normal intersections with guidance on engineering judgment for areas where a lower pedestrian walking speed should be considered.

In 2018, it was decided that the current state guidance with regard to pedestrian walking speeds be evaluated for any needed changes, such as adopting the national guidance found in the 2009 MUTCD. To evaluate pedestrian walking speeds at signalized intersections, 15 sites throughout the state of Utah were studied, producing a total of 2,061 observations of pedestrian crossing events. These crossing events were evaluated to calculate walking speeds in relation to pedestrian demographics at each location. Evaluated demographics included pedestrian group size, gender, mobility status, age category, alertness, and potential distractions.

Upon completion of data collection, a statistical analysis was conducted to determine mean and 15th percentile pedestrian walking speeds by demographic. The data collection procedure, data analysis, and limited recommendations for pedestrian start-up delay and pedestrian walking speeds as used in signal timing are discussed in this report. The data suggest that Utah continue to maintain its guidance of 4.0 feet per second walking speeds at most signalized intersections, while exercising engineering judgment at locations containing high pedestrian volumes or locations containing high percentages of elderly or disabled pedestrians.

1.0 INTRODUCTION

1.1 Background

Pedestrian safety is one of several areas that the Utah Department of Transportation (UDOT) Traffic and Safety Division focuses on as part of their goal toward Zero Fatalities. Part of the reason for this focus is that every trip includes a pedestrian trip at both the origin and the destination. Some trips are exclusively pedestrian trips, while others involve a variety of modes. Data for 2018 show that there were 494 pedestrian-involved crashes at intersections in Utah. Of these crashes, 10 resulted in fatalities and 60 resulted in serious injury (UDOT 2019).

When designing for pedestrian movements at intersections, one of the factors that must be considered is that of the pedestrian crossing time and the corresponding pedestrian walking speed at signalized intersections. Research conducted by Gates et al. (2006) recommended reducing the pedestrian walking speed at intersections from 4.0 feet per second to walking speeds of 3.6, 3.5, 3.4, and 3.3 feet per second for intersections where the proportion of pedestrians over the age of 65 exceeds 20, 30, 40, and 50 percent of the total pedestrians at a location, respectively. The research recommended pedestrian walking speeds as low as 2.9 feet per second for intersections where nearly all of the pedestrians are over age 65. The results of this and other research prompted a new walking speed guidance of 3.5 feet per second to be incorporated into the 2009 *Manual on Uniform Traffic Control Devices* (MUTCD) (FHWA 2009).

To promote roadway safety and efficiency by providing for the orderly movement of all road users, current practice for UDOT is to use engineering judgment in determining the walking speeds to use for timing of signalized intersection crossings, with the speed never exceeding 4.0 feet per second. The UDOT guidelines recommend pedestrian walking speeds of 3.0 feet per second for special cases, 3.5 feet per second for school crossings or areas where there are heavy concentrations of elderly persons or children, and 4.0 feet per second for normal circumstances, unless engineering judgment dictates otherwise (UDOT 2017). There was a need to determine if the current guidance for pedestrian start-up delay and walking speeds, and the associated pedestrian walk and clearance times, accommodate the mix of pedestrians in the state. The primary focus of this research is on pedestrian walking speeds; however, pedestrian start-up delay times were also evaluated where possible. This will allow for limited recommendations to be made on pedestrian walking speeds as used for signal timing at locations throughout the state of Utah.

1.2 Objectives

The purpose of this research was to identify current pedestrian start-up delay times and walking speeds of various pedestrian demographics and to make limited recommendations for pedestrian walking speeds for use in signal timing throughout the state of Utah. This was accomplished by:

- Completing a literature review to gain insight and understanding on current guidance with regards to pedestrian walking speeds and their effect on pedestrian clearance intervals, current understanding on pedestrian walking speeds and pedestrian crossing time data found in previous studies, and implementations that may provide flexibility in the pedestrian walking speeds as used in signal timing.
- Evaluating current pedestrian crossing time practices in Utah based on previously completed research, supplemented with new data collection to provide additional data as needed.
- Analyzing current trends in pedestrian walking speeds and start-up delay, by demographic, in the state of Utah to determine statistically significant relationships between pedestrian walking speeds and start-up delay of different demographics.
- Providing limited recommendations on pedestrian walking speeds and pedestrian start-up delay times for use in signal timing of pedestrian walk and pedestrian clearance phases in the state of Utah.

1.3 Outline of Report

This report is organized into the following chapters:

- Chapter 1 includes an introduction to the research, project objectives, and the organization of the report.
- Chapter 2 includes a literature review of federal and state guidelines with respect to pedestrian walk times, clearance interval times, and pedestrian walking speeds.
- Chapter 3 includes a discussion on the methods used for data collection and the types of data collected.
- Chapter 4 includes a discussion on the data analyses conducted on the pedestrian walking speeds data, which include preliminary analysis of the mean, 15^{th} percentile, and 85^{th} percentile walking speeds and start-up delay times found in the study, and formal statistical analysis on the least squares means and differences of least squares means of the pedestrian walking speeds data collected.
- Chapter 5 includes a summary of the findings of this research study, a comparison of these findings with previously conducted research, and limited recommendations for pedestrian walking speeds as they are used for pedestrian clearance interval timings in the state of Utah. Future research topics are discussed and concluding remarks given.
- References follow the main chapters.

2.0 LITERATURE REVIEW

2.1 Overview

Current practices regarding pedestrian walking speeds in relation to crossing times and clearance intervals were first evaluated in preparation for this research. These practices were found via Federal Highway Administration (FHWA) guidance as found in the MUTCD, as well as guidance from the Utah MUTCD. Second, previously conducted studies on pedestrian walking speeds were identified and evaluated with respect to age groups, disabilities, and pedestrian group size data. Lastly, current hardware options that allow for variability in pedestrian crossing speeds and clearance intervals were investigated. This literature review then concludes with a summary of these findings. The knowledge of the current information available on pedestrian walking speeds at signalized intersections has allowed the research team to identify specific methods of data collection and analysis so that this project can build upon previous findings as well as fill gaps in current knowledge.

2.2 Federal and State Guidance on Pedestrian Walking Speeds

Federal and state guidance for pedestrian walking speeds as they apply to pedestrian clearance intervals have been established by FHWA and UDOT, respectively. Both manuals are very similar, with the Utah MUTCD containing minor changes in guidelines, specific to the conditions in the state. The FHWA defines "guidance" in section 1A.13, paragraph IB of the MUTCD as "A statement of recommended, but not mandatory, practice in typical situations, with deviations allowed if engineering judgment or engineering study indicates the deviation to be appropriate… The verb 'should' is typically used" (FHWA 2009). The Utah MUTCD, which was adapted from the federal 2009 MUTCD, contains the same statement (UDOT 2011). Within each manual, there are specific guidelines that have been set forth to facilitate implementation and provide recommendations. These guidelines will be summarized in the following FHWA and UDOT subsections. In addition, recommendations from the United States Access Board related to pedestrian walking speeds are provided following the discussion on FHWA guidelines.

2.2.1 Federal Highway Administration

Guidance from the FHWA can be found in the MUTCD (FHWA 2009). Section 4E.06, paragraph 7 of the MUTCD states “the pedestrian clearance time should be sufficient to allow a pedestrian crossing in the crosswalk who left the curb or shoulder at the end of the WALKING PERSON (symbolizing WALK) signal indication to travel at a walking speed of 3.5 feet per second to at least the far side of the traveled way or to a median of sufficient width for pedestrians to wait” (FHWA 2009). The 2009 MUTCD further states that a 4.0 feet per second walking speed may be utilized to evaluate the efficiency of pedestrian clearance times at locations with extended push functions. These extended push functions are primarily implemented for those that need more time to cross. There is also provision in the 2009 MUTCD guidance for passive pedestrian detection to adjust clearance times based on actual pedestrian walking speeds, if available. Crossings where there are higher volumes of elderly pedestrians or school-age children may also utilize lower walking speeds as needed. It is important to note that previous editions to the 2009 MUTCD utilized a recommended walking speed of 4.0 feet per second rather than 3.5 feet per second for general cases (FHWA 2003). As with the 2009 MUTCD, the 2003 MUTCD provides guidance only, as defined in section 1A.13, paragraph IB (FHWA 2003).

The current national guidelines on pedestrian walking speeds are fairly specific when it comes to the general case for pedestrian walking speeds, but are less specific about special cases, such as intersections with high volumes of slower pedestrians. Paragraph 10 of the 2009 MUTCD states: “Where pedestrians who walk slower than 3.5 feet per second, or pedestrians who use wheelchairs, routinely use the crosswalk, a walking speed of less than 3.5 feet per second should be considered in determining the pedestrian clearance time” (FHWA 2009). These situations are largely up to interpretation and use of engineering judgment for such pedestrian crossings under each jurisdiction. In most cases, pedestrian walking speeds used for signal timing should range between 3.0 to 4.0 feet per second.

2.2.2 United States Access Board

The Public Rights-of-Way Access Advisory Committee released a 2001 report that stated in section X02.5.5.2 that, “All pedestrian signal phase timing shall be calculated using a pedestrian walk speed of 3.5 feet per second (1.1 m/s) or less… The committee recognized that the current standard for rate of pedestrian travel in a crosswalk is 4 feet per second, but was unconvinced that this rate is representative of the general population, particularly persons with disabilities." (United States Access Board 2001). Similarly, the *Revised Draft Guidelines for Accessible Public Rights-of-*Way, published in 2005, states in section R305.3 that, "All pedestrian signal phase timing shall be calculated using a pedestrian walk speed of 1.1 m/s (3.5 ft./s) maximum" (United States Access Board 2005). These documents, along with research studies, such as those conducted in Wisconsin by Gates et al. (2006), likely influenced the changes to walking speed guidelines for the federal 2009 MUTCD.

2.2.3 Utah Department of Transportation

The UDOT guidelines for pedestrian walking speeds at signalized intersections are based on the Utah MUTCD, a revised version of the federal 2009 MUTCD, which contains policy and guidance that has been approved by all jurisdictions in Utah. The majority of the signal timing guidance found in the Utah MUTCD is summarized in a document titled *Guidelines for Traffic Signal Timing in Utah*, which was published by UDOT in 2017. The general guideline for pedestrian walking speed states that, "walking speeds should be: 4.0 feet per second for normal circumstances, 3.5 feet per second for school crossings or areas where there are heavy concentrations of elderly persons or children, and 3.0 feet per second or lower for special cases (engineering judgment)" (UDOT 2017). This differs from the federal 2009 MUTCD, which recommends under guidance to give a pedestrian walking speed of 3.5 feet per second for the pedestrian clearance time in general cases. Utah has opted to keep their walking speed guidelines consistent with previous editions of the federal MUTCD; however, they have provided specific guidance for situations where pedestrian walking speeds less than 4.0 feet per second should be considered.

Guidelines for both pedestrian walk intervals and pedestrian clearance intervals can be found within the same signal timing document. The guidelines for the walk interval are (UDOT 2017):

- Walk interval shall never be below 4.0 seconds.
- 7.0 seconds should be the 'default' value. However, at many locations side- street

values will be lower to minimize disruption to mainline.

- Locations with frequent large groups of pedestrians should generally not be less than 7 seconds and may need to be higher, especially during special events.
- Walk times may be different by time- of- day if needed for efficiency or peak pedestrian volumes. But keep in mind the complexity this causes in controller programming.

These guidelines for walk intervals are consistent with the federal 2009 MUTCD. "…The walk interval should be at least 7 seconds in length so that pedestrians will have adequate opportunity to leave the curb or shoulder before the pedestrian clearance time begins. Option: If pedestrian volumes and characteristics do not require a 7-second walk interval, walk intervals as short as 4 seconds may be used" (FHWA 2009).

The Utah guidelines then establish the standard equation for calculating pedestrian clearance interval duration, which is also given in the *Traffic Signal Timing Manual* (FHWA 2008). The equation, as it is used in all Utah jurisdictions, is provided in Equation 2.1 (UDOT 2017).

$$PC = \frac{w}{pws} - (Y + R) \tag{2.1}$$

where:

PC = pedestrian clearance interval duration, seconds

w = crossing distance, feet

pws = pedestrian walking speed, feet per second

Y = yellow clearance interval, seconds

R = red clearance interval, seconds

The *Guidelines for Traffic Signal Timing in Utah* states that "When the pedestrian clearance interval begins, pedestrians should either complete their crossing if already in the intersection or refrain from entering the intersection until the next pedestrian walk interval is displayed" (UDOT 2017). The MUTCD also gives a similar statement in section 4E.06, paragraph 13 (FHWA 2009). The following guidelines are then provided by UDOT with regards to Equation 2.1 and its variables (UDOT 2017):

- The minimum pedestrian clearance interval should be 7.0 seconds.
- The crossing distance should be measured in the center of the crosswalk and extending curb to curb.
- The pedestrian clearance interval should be rounded up to the nearest second.
- The pedestrian clearance interval should not change by time- of- day or for special events, since this confuses the countdown pedestrian heads. If extra crossing time is needed, add to the ‘walk’ time. The only exception to this is where ‘pedestrian scramble,’ is used because the distance to cross the street changes. A ‘pedestrian scramble,’ also known as a ‘Barnes Dance’ temporarily stops all vehicular traffic, thereby allowing pedestrians to cross an intersection in every direction, including diagonally, at the same time.
- Typically, the ‘flashing don’t walk’ (FDW) ends at the beginning of yellow. However, some controllers allow the FDW to time through the yellow so more time can be displayed on the countdown for pedestrians. If the FDW extends into the yellow, please ensure the following:
    - Following the pedestrian change interval, a buffer interval consisting of a steady upraised hand (symbolizing don’t walk) signal indication shall be displayed for at least 3.0 seconds prior to the release of any conflicting vehicular movement.
    - The buffer interval (at least 3.0 seconds) shall not begin later than the beginning of the red clearance interval.
    - The difference in seconds from the beginning of yellow to the end of the FDW needs to be added to the Pedestrian Clearance equation.

It is important to note that the pedestrian clearance interval duration, as defined in Equation 2-1, does not take into account pedestrian start-up lost time. Individual pedestrian start-up lost time is used for the calculation of the walk interval itself, and not the pedestrian clearance interval duration. Individual pedestrian start-up lost time is set at a default value of 3.2 seconds in the *Highway Capacity Manual* (HCM) (TRB 2016).

2.3 National and Local Data on Pedestrian Crossing Times and Walking Speeds

Given the opportunity for engineering judgment in selecting pedestrian walking speeds for computation of pedestrian clearance phases, several studies have been conducted to analyze the behavior and walking speeds of various categories of pedestrians. These studies were done to evaluate current walking speeds and suggest changes to the current practices, if deemed necessary. Pedestrians in these studies were evaluated by distraction, age group, disabilities, and group size.

2.3.1 Distracted Pedestrians

A perceived problem at pedestrian crossings throughout the country is that many pedestrians are approaching and navigating intersections while distracted by mobile devices. Some research has been done regarding these pedestrians, who may present significant risk to both themselves and motorists.

A study conducted at Northern Arizona University, for example, sought to measure the impact that distractions, including the use of mobile devices, have on pedestrian behavior and walking speeds at crossings (Russo et al. 2018). The authors sought to quantify distractions that may inhibit adequate levels of alertness while crossing an intersection. Pedestrians were recorded as one of five categories: no distraction, talking on cell phone, texting on cell phone, listening to headphones, or other. The other category included behaviors other than those associated with mobile devices, such as looking in a purse, reading a newspaper, tending a young child, etc., that prevented pedestrians from focusing adequately on the task of safely crossing the street.

The researchers at Northern Arizona University found that pedestrians using headphones tended to exhibit faster walking speeds than undistracted pedestrians, which may have been due to them walking or jogging faster than normal, for exercise. Pedestrians in the ‘other’ group exhibited speeds at an average of 0.4 feet per second slower than undistracted pedestrians, which is to be expected. Pedestrians ages 60 years or older exhibited the slowest walking speeds, while pedestrians ages 16-29 exhibited the fastest walking speeds. Also, males tended to have slightly higher walking speeds than females in the study. It is interesting to note, that 13.5 percent of pedestrians observed in the study were deemed distracted by some type of behavior as they were crossing (Russo et al. 2018).

The concluding remarks in the Northern Arizona University study indicate that talking and texting behaviors were not statistically significant in correlation with changes in walking speed. It is theorized by these results that many pedestrians may be accustomed to walking while texting or talking. The study explains that this is important because engineers may not need to adjust pedestrian clearance intervals to accommodate these types of distracted pedestrians (Russo et al. 2018).

2.3.2 Pedestrians by Age Group

Researchers have found that different age groups perform differently when crossing at intersections. A study by Montufar et al. (2007) determined that the average walking speeds for younger (ages 20-64) and older (ages 65+) pedestrians were 5.3 and 4.5 feet per second, respectively. The same researchers found that that the 15th percentile walking speeds were 4.4 and 3.5 feet per second, respectively and that there were virtually no statistically significant differences between winter and summer walking speeds for either age group. As in other studies, average female pedestrian speeds were lower than those of males, all other variables controlled. The study concluded that 90 percent of younger pedestrians are accommodated by a 4.0 feet per second pedestrian speed, while 40 percent of older pedestrians would be excluded under a 4.0 feet per second pedestrian speed. In contrast, lowering the guidance to 3.0 feet per second would mean an exclusion of only 10 percent of older pedestrians (Montufar et al. 2007).

A research study conducted in Wisconsin by Gates et al. (2006) yielded similar findings. The researchers found that pedestrians over the age of 65 had mean walking speeds of 3.8 feet per second and 15th percentile speeds of 3.0 feet per second, suggesting that those in that age group who began walking at the end of the walk interval typically would not be accommodated by clearance intervals based on a pedestrian walking speed of 4.0 feet per second. Taking into account data from disabled pedestrians as well as pedestrians in groups, the researchers concluded that walking speeds at general locations where the pedestrian demographics are unknown should be set to 3.8 feet per second and that 4.0 feet per second walking speeds should only be utilized in areas with very few older pedestrians, such as college campuses (Gates et al. 2006).

Another research study by Fitzpatrick et al. (2006), which included 42 study sites in seven states, including Utah, found the 15th percentile speed for most adult pedestrians below age 60 to be 3.8 feet per second. The 15th percentile walking speed for older pedestrians, above the age of 60, was found to be 3.2 feet per second, which was the same as the finding in the Gates et al. (2006) research. Fitzpatrick et al. (2006) also projected a proportionally weighted 15th percentile speed for the 2045 population to be 3.6 feet per second. These findings led the researchers to recommend a 3.5 feet per second walking speed for the general population and a 3.0 feet per second walking speed for the ‘older or less able’ population (Fitzpatrick et al. 2006).

A study that was conducted at 16 sites in Virginia, District of Columbia, Maryland, and New York by Knoblauch et al. (1996) found that ‘younger’ pedestrians (ages 14-64) exhibited 15th percentile walking speeds of approximately 4.1 feet per second and ‘older’ pedestrians (ages 65+) exhibited 15th percentile walking speeds of approximately 3.2 feet per second. For design purposes, the authors recommended walking speeds of 4.0 feet per second for areas with predominately young pedestrian demographics and 3.0 feet per second for areas with large percentages of older pedestrians using the crosswalk. This study also recorded pedestrian start-up delay times at each of its study locations. The authors found mean start-up times of approximately 1.9 seconds for ‘younger’ pedestrians and 2.5 seconds for ‘older’ pedestrians. They recommended using mean design values of 2.5 seconds and 2.0 seconds for individual pedestrian start-up delay for younger and older demographics, respectively (Knoblauch et al. 1996).

The common consensus from these four studies was to decrease the then current MUTCD guidance of a 4.0 feet per second pedestrian walking speed at signalized intersections. These recommendations are based primarily on the walking speeds of the aging population, and not necessarily disabled pedestrians or school-aged pedestrians.

A study by Chang et al. (2018) conducted at various elementary, middle, and secondary schools in Idaho found that elementary school-aged children walked at speeds faster than 3.5 feet per second. This led to the assessment that current MUTCD guidance as applied to school crosswalks may be overly conservative and unnecessarily create added traffic delay at school crossing locations. An average speed of 4.9 feet per second, with a standard deviation of 1.6 feet per second was observed for elementary school children. This study, however, did not examine the walking speeds of school-aged children who were using wheelchairs, crutches, or other walking aids (Chang et al. 2018).

2.3.3 Disabled Pedestrians

Disabled pedestrians, particularly those who use motorized wheelchairs, have been found to exhibit speeds similar to those of older pedestrians (Gates et al. 2006). Other types of disabled pedestrians are those using walkers or canes. A study by Arango and Montufar (2008) on such pedestrians found that the mean walking speed of older pedestrians who were using walkers or canes at signalized intersections was 3.1 feet per second with a 15^{th} percentile speed of 2.4 feet per second. The use of the 4.0 feet per second pedestrian walking speed guidance from previous editions of the MUTCD would then exclude nearly 90 percent of all pedestrians with canes or walkers. If the walking speed were to be decreased to 3.0 feet per second, then the value would decrease to 55 percent (Arango and Montufar 2008).

2.3.4 Pedestrians in Groups

Various studies have also shown that there are significant differences in the speeds of single pedestrians versus groups of pedestrians, where groups are defined as platoons of people traversing a crossing at the same rate. At Northern Arizona University, it was observed that pedestrians walking in groups of two or more exhibited slower walking speeds (Russo et al. 2018). In Wisconsin, Gates et al. (2006) also observed that groups of pedestrians tended to walk at speeds 0.4 to 0.6 feet per second slower than individual crossers and that often 4.0 feet per second was not sufficient for the timing of the clearance intervals. Another study, looking exclusively at school-age pedestrians, found that groups of two, three, four, or more students walked slower than students that crossed by themselves; the study speculated that this was likely due to increased inattention (Chang et al. 2018).

A study by Park et al. (2014) on pedestrian crossings speeds at signalized intersections with high volumes of pedestrians was conducted in New York City. The researchers found that average speeds started to drop to less than 3.0 feet per second at higher pedestrian densities, which indicates a need to adjust pedestrian clearance intervals during periods of high pedestrian volume.

2.4 Options to Provide Variable Crossing Times

There is provision in the MUTCD for extended pushbutton functions at signalized intersections to provide variability in the pedestrian clearance interval duration depending on the needs of the pedestrians. Section 4E.06, paragraphs 08 and 09 of the MUTCD state: “A walking speed of up to 4 feet per second may be used to evaluate the sufficiency of the pedestrian clearance time at locations where an extended pushbutton press function has been installed to provide slower pedestrians an opportunity to request and receive a longer pedestrian clearance time. Passive pedestrian detection may also be used to automatically adjust the pedestrian clearance time based on the pedestrian’s actual walking speed or actual clearance of the crosswalk. The additional time provided by an extended pushbutton press to satisfy pedestrian clearance time needs may be added to either the walk interval or the pedestrian change interval” (FHWA 2009).

This section will elaborate on three options to provide variable crossing time. It should be noted that these options have not generally seen widespread implementation in the United States. The options are: extended pushbuttons feature, Pedestrian User-Friendly Intelligent (PUFFIN) crossings, and a new procedure developed by UDOT for variability in pedestrian crossing times in school zones.

2.4.1 Extended Pushbutton Features

The development of accessible pedestrian signals (APSs) has led to many improvements in signal performance and pedestrian safety. An APS is defined as a pedestrian pushbutton device that communicates information about pedestrian timing in a nonvisual format (i.e., audible tones, verbal communications, or vibration feedback). The primary purpose for these devices is to help visually-impaired pedestrians to safely navigate an intersection (Noyce and Bentzen 2005).

APSs, as well as regular push-buttons, can also be adapted and utilized to manually increase pedestrian clearance intervals for those that need more time to cross at an intersection. The 2009 MUTCD mentions these devices in paragraph 09 of section 4E.06: "the additional time provided by an extended pushbutton press to satisfy pedestrian clearance time needs may be added to either the walk interval or the pedestrian change interval" (FHWA 2009). Typically, the pushbuttons are pressed for 2 seconds in order to activate the extended crossing interval. The MUTCD has also designated specific signage for such pushbuttons that can be used to extend crossing time (FHWA 2009).

2.4.2 Pedestrian User-Friendly Intelligent Crossings

One technology which has seen a rise in use in the United Kingdom, Australia, and New Zealand, is the PUFFIN crossing. PUFFIN crossings are able to detect pedestrians through the use of either a pressure-sensitive mat or an infrared sensor in the crossing area. In the case of the pressure mats, they can be used for both initial detection as well as to confirm that the pedestrian has not departed the zone before the walk signal appears, in which case the call will be canceled. This allows for minimal effect on overall traffic operations as a result of false calls. PUFFIN crossings can also utilize sensors to detect pedestrians in the crosswalk and to extend the signal phase should the pedestrian need more time to cross. Additional studies have also shown that these types of crossings lead to reduced pedestrian/vehicle conflicts and aid in pedestrian compliance during walk intervals (Hughes et al. 2000). King (2015) found benefit-cost ratios as high as 6.1 at many locations where PUFFINs had been installed.

2.4.3 UDOT Procedure for Variable School Crosswalk Times

UDOT has developed and implemented a new procedure at various school crosswalk locations throughout Utah that allows crossing guards to add 10-15 seconds of extra walk time via a special key that connects to the traffic signal box. This key is used to add that additional walk time during hours before and after school so that students can more safely cross the streets at their own pace. This implementation is especially useful at locations that have large pedestrian groups of students crossing during the same cycle. Being the first in the nation to develop this new technology, UDOT Traffic Operations Center officials state that they are able to install the systems with only a $20 key cost and 30 minutes of installation time (UDOT 2016).

2.5 Summary

Pedestrian walking speeds can be quite variable depending on the demographics of the pedestrians who are navigating an intersection. Recent research on the topic has recommended a reduction in walking speed guidance from 4.0 feet per second to a pedestrian walking speed of 3.5 feet per second for general intersections where the pedestrian demographic is unknown. The Utah MUTCD, however, has opted to maintain the previous (pre-2009) MUTCD guidance and maintains a 4.0 feet per second walking speed for general cases with specific guidelines on when to consider reducing the pedestrian walking speed (UDOT 2017).

Knowing that the 4.0 feet per second pedestrian walking speed guidance has been reduced in many locations throughout the country, it is necessary to evaluate pedestrian walking speeds at intersections in Utah and recommend changes as appropriate. To accomplish this task, data relating to pedestrian behavior and walking speeds, as applied to pedestrian clearance intervals, must be gathered and evaluated from various locations throughout the state.

3.0 DATA COLLECTION

3.1 Overview

To evaluate pedestrian walking speeds throughout the state of Utah, a method for data collection was developed. Data collection sites were selected from across the state that had considerable pedestrian activity and a wide range of distinct pedestrian demographics. The research team used COUNTcam2 portable cameras and mounting equipment for video collection at each site. Permission was obtained from UDOT to mount these cameras along state roadways.

This chapter contains a discussion pertaining to the procedures used for data collection. First, the procedure used for site selection, including a list of sites selected for this study is discussed. Second, the procedure used for data collection and details regarding the camera placement and video data storage are provided. Third, data interpretation and the translation of video data into quantified data fields is provided. Finally, a summary of the tasks associated with the selected data collection methods is provided.

3.2 Site Selection and Sample Size

It was important to ensure that appropriate sites were selected to generate a diversity of data points related to various pedestrian demographics and their associated walking speeds. Signalized intersection sites were identified after incorporating the input of the UDOT Technical Advisory Committee (TAC). As part of the TAC recommendations, the results of an internal research study conducted by the Traffic Operations Center staff that analyzed 2,395 pedestrian crash narratives between the years 2014 and 2016 was reviewed in detail. The results of this effort had determined that there was no evidence to suggest that signal timings during this period were inadequate in any of those crashes. However, results from this study were reviewed and helped the TAC in recommending potential sites to be evaluated. Sites expected to yield useful data for some of the less-common demographics, such as disabled or elderly pedestrians, were also selected through TAC recommendations and online mapping services.

For this study, 15 signalized intersections were evaluated. These locations were located throughout Davis, Salt Lake, and Utah Counties, which correspond to UDOT regions 1, 2, and 3, respectively. Data were gathered during the summer months of 2018 to ensure maximum pedestrian activity during the recorded periods. Table 3.1 displays each signalized intersection location evaluated for pedestrian walking speeds, along with the associated sample size collected and dates studied.

To ensure data uniformity, a minimum sample of 60 random pedestrians was recorded at each location. This was determined after early data collection at one of the sites, which yielded a standard deviation of 1.0 feet per second. Using a meaningful difference of 0.5 feet per second, a statistical power analysis yielded a required sample size of 60 pedestrian crossing events for each site and for each category.

Table 3.1 Pedestrian Walking Speeds Study Sites

UDOT Region	County	City	Location	Sample Size	Dates (2018)
1	Davis	Layton	I-15 & Antelope Dr. SB Ramp (West)	81	May 25-26
1	Davis	Layton	I-15 & Antelope Dr. NB Ramp (East)	71	May 25-28
2	Salt Lake	Holladay	Holladay Blvd. & Murray Holladay Rd.	74	May 10, 14-16
2	Salt Lake	Salt Lake City	400 South & State St.	334	June 1-3
2	Salt Lake	Salt Lake City	600 South (one-way) & State St.	64	June 1-2
2	Salt Lake	Salt Lake City	North Temple & State St.	252	May 5-7
2	Salt Lake	Salt Lake City	South Temple & State St.	460	May 3-4
2	Salt Lake	Salt Lake City	100 South & 700 East	85	June 29-30
2	Salt Lake	Salt Lake City	500 South (Univ. Blvd.) & 1300 East	107	July 3-5, 23-26
2	Salt Lake	Sandy	9400 South & State St.	95	May 24-25
3	Utah	Lehi	SR-92 & Ashton Blvd.	63	May 8-9
3	Utah	Orem	1600 North & Main St.	107	Aug. 29-31
3	Utah	Orem	400 North & 800 West	84	Aug. 29-31
3	Utah	Orem	800 South & Main St.	80	Aug. 29-31
3	Utah	Provo	Center St. & Freedom Blvd.	103	May 29-31

Pedestrian crossing event categories were recorded in conjunction with specific locations as well. For example, 500 South (University Boulevard) and 1300 East in Salt Lake City is an intersection that is adjacent to a multi-story assisted living complex. This location was selected to gather an adequate sample size for elderly pedestrians as well as pedestrians with canes, walkers, and motorized wheelchairs. In addition to specific demographics of pedestrians, 60 random pedestrians were recorded at the location to evaluate the general walking speed for all pedestrian categories at the intersection.

3.3 Data Collection Procedure

A data collection procedure was developed to consistently obtain and organize data relevant to pedestrian categories, pedestrian start-up times, and pedestrian walking speeds. The following subsections contain discussions about the methods used for camera placement, intersection crosswalk measurement, and video download for observation.

3.3.1 Camera Placement

Cameras were placed in close proximity to pedestrian crossings at the predetermined signalized intersection study locations so that the entire length of the pedestrian crossing would be clearly visible and pedestrians could be spotted and identified in the video recordings. The cameras were also placed so that at least one of the pedestrian signal heads was visible to insure that only pedestrians who crossed legally, during the walk or pedestrian clearance phases, would be evaluated. Figure 3.1 displays the camera model and its associated accessories for mounting, charging, and data transfer.

Figure 3.1 COUNTcam2 Camera and Accessories (CountingCars.com 2019)

A mounting device was used to attach the camera to a telescoping aluminum rod, which was then attached to an existing pole at each location using metal straps, secured by screws. A small lock was also used to secure the camera and its hardware in order to prevent theft. The cameras were then programmed, via Wi-Fi connection to a smartphone device, to begin recording. Figure 3.2 displays research assistants demonstrating the camera mounting procedure.

Figure 3.2 Research Assistants Mounting a COUNTCam2 Camera

3.3.2 Intersection Crosswalk Measurement

To accurately calculate pedestrian walking speeds at each intersection, each crosswalk was measured in the field prior to recording. Crossing distances were measured at each study location in accordance with standard UDOT guidance: in the center of the crosswalk, from curb to curb (UDOT 2017). All distance measurements were taken with an analog measuring wheel. Crosswalk widths were also measured and noted.

The measurements collected on-site were then entered into individual spreadsheets for each intersection. These spreadsheets were programmed to use the measurements associated with each leg of the intersection for calculating the walking speeds of each pedestrian crossing event. More details on the walking speed calculation will be provided in section 3.4.6.

3.3.3 Video Download for Observation

After collecting the cameras at the end of each 48-hour period, the research team transferred the video files to a shared network drive. A notepad was kept with information about each camera deployment, verifying location with camera serial number so as to not confuse video data with its corresponding location. The drive was organized such that 30-minute videos were stored in folders which corresponded to their locations and observed intersection legs. Video data were then cleared off of the cameras and they were set to charge before the next deployment.

Each recording was automatically named according to dates and times, which facilitated storage and retrieval. Recordings included a timestamp in the camera frame that contained the date and time in 1.0 second increments. These timestamps were used to enter the ingress and egress times for pedestrian groups into data spreadsheets. Using the difference of those times and the crosswalk lengths the spreadsheet was programmed to calculate the walking speed for each pedestrian crossing event. Stopwatches were also used while developing the methodology. It was determined that using the timestamp data was more consistent than handheld stopwatches and would be more conducive to greater efficiency and accuracy in the data collection process.

Using the level of precision provided by the timestamps, pedestrian walking speeds and start-up delay times were both estimated using data in 1.0 second increments. The 1.0 second increments for start-up delay could have been reduced to provide more precision in the results; however, the camera angle and placement locations did not always allow for higher precision in this study. Figure 3.3 provides a screenshot of a pedestrian crossing event as recorded at a location in Holladay, Utah (note the timestamp in-frame).

Figure 3.3 Screenshot of Pedestrian Crossing Video with Timestamp

Recordings of night-time hours were stored in separate folders and not used for data collection, due to inability to adequately see and classify pedestrians during crossing events. Recordings during inclement weather such as rain or heavy winds, were uncommon, but also discarded to keep data consistent with mild weather conditions. Runners, joggers, skateboarders, and cyclists were never recorded because it was assumed that these individuals would be significantly faster than average pedestrians – for whom the timing of the signals is primarily designed.

3.4 Data Interpretation

Pedestrian data were interpreted through video observation and entered manually into customized spreadsheets. These spreadsheets facilitated rapid data entry as well as organized categorization and automatic speed calculations for each entry. Each pedestrian event constituted one data entry. For this study, a pedestrian event was defined as one or more persons moving at the same rate across a pedestrian crosswalk during the walk or pedestrian clearance (countdown) phases. If two pedestrians crossed during the same phase, but moved at different speeds or entered/exited the crosswalks at different instances, they were counted as two separate pedestrian crossing events.

Each pedestrian event was categorized by age group, mobility status, alertness, distraction, and gender. Start-up times were recorded, to the nearest second, for waiting pedestrians entering the intersection, where visible. Comments on potential outliers, such as pedestrians exhibiting abnormal behavior or vehicle conflicts affecting walking speeds, were also noted. Ingress and egress times were then entered into the spreadsheet for walking speed calculation. The following subsections explain the pedestrian categories and data input in detail. Category types and measurements to be defined include age categorization, mobility categorization, alertness and distraction categorization, gender categorization, and pedestrian start-up delay. Lastly, walking speed calculations, including the method used in this study, will be discussed.

3.4.1 Age Categorization

Due to the subjectivity of determining age using video footage from a distance, it was determined that three age categories would be used. These categories were: ‘0-12’ for children walking independently at the crosswalk, ‘13-60’ for adolescents and adults, and ‘60+’ for elderly adults. A ‘mixed group’ category was also used for pedestrian groups containing differing age categories. For instances in which an adult is holding a child’s hand while crossing, a ‘child with adult’ category was included. The baseline group for categorization was the most common ‘13 to 60’ age group.

3.4.2 Mobility Categorization

Mobility categories are perhaps of most concern when it comes to pedestrian walking speeds and their respective clearance intervals. The MUTCD leaves much of this up to engineering judgment in section 4E.06 paragraph 10: “Where pedestrians who walk slower than 3.5 feet per second, or pedestrians who use wheelchairs, routinely use the crosswalk, a walking speed of less than 3.5 feet per second should be considered in determining the pedestrian clearance time” (FHWA 2009). It was deemed important for this study that pedestrians of all mobility types be evaluated to determine appropriate speeds for use in signal clearance intervals at such locations.

The mobility category that constitutes most of the population was labeled as ‘regular,’ meaning there were no physical impediments to a pedestrian’s walking abilities while stepping into and crossing an intersection. The ‘regular’ category, being the most commonly observed, was considered to be the baseline for future comparisons. There was no difficulty in obtaining an adequate sample size in this category. A similar category was also made for pedestrians who were not disabled, but might have slowed down due to walking a pet at the intersection. People who had pets on a leash were identified in the data as being ‘pet’ mobility status in order to distinguish them from regular pedestrians.

Pedestrians using canes or walkers were categorized together and labeled in the data as ‘cane/walker.’ Due to the relative infrequency of these types of pedestrian crossings at intersections, some specific locations were identified to increase the sample size in this category. These locations were in close proximity to retirement homes and elderly assisted living facilities. At these locations, as with all other locations, 60 random samples of all categories were recorded prior to recording only elderly and cane/walker pedestrians.

Categories were also included for pedestrians in wheelchairs and motorized wheelchairs; these categories were labeled as ‘wheelchair’ and ‘motorized wheelchair,’ respectively. Few pedestrians in wheelchairs were recorded at any of the locations, but a larger sample size was found for those using motorized wheelchairs. Pedestrians who were pushing carts or strollers were categorized together as a ‘cart/stroller’ category. Any exceptions to these categories, such as those with observable limps, those carrying heavy items, or those exhibiting slowed movement due to some physical impediment associated with the individual were listed as ‘other.’ Pedestrian crossing events that contained multiple individuals of varying mobility were listed as ‘mixed group’ within the mobility category.

3.4.3 Alertness and Distraction Categorization

It was determined through discussion with the TAC that pedestrians should also be categorized as ‘attentive’ or ‘not attentive’ to evaluate how pedestrian attention or inattention to their surroundings may affect walking speeds. 'Attentive' pedestrians would have their heads up, no mobile device in use other than perhaps for making a traditional audio-only phone call, and appear to be attentive to what was happening around them. Inattentive, or 'not attentive,' pedestrians were not looking up, not alert to what was around them, and typically using mobile devices. Pedestrian crossing events containing groups of pedestrians with varying levels of alertness were classified as 'mixed group.' As alertness can be somewhat subjective to observe, it was also determined that a categorization should exist for potential distractions that were observed for both 'attentive' and 'not attentive' pedestrian events.

In the distraction categorization for pedestrians, certain behaviors were observed and noted that could be considered potentially distracting. Pedestrians who had headphones or earbuds and appeared to be listening to music were listed as 'headphones' distraction. Separate categories were made for pedestrians talking on cellphone as well as pedestrians texting or looking down at their mobile devices while walking; these were listed as 'talk on cellphone,' and 'text on cellphone,' respectively.

All pedestrians who did not exhibit distracting behaviors were classified as 'none.' As with other categorizations, mixed groups were noted as 'mixed,' and any pedestrians who were exhibiting other behaviors that could be distracting were noted as 'other.' Some 'other' behaviors that were noted by the research team were mothers tending to children, individuals getting items out of bags while walking, or individuals reading books while walking through the intersection. These behaviors were rare, however, and were thus aggregated into one category.

3.4.4 Gender Categorization

Pedestrian events were also categorized by gender ('male' or 'female') and group size (number of people entering and exiting the intersection at the same time, or moving together at the same speeds). Pedestrian events with multiple individuals of different genders were categorized as 'mixed group.' Any unusual behaviors that were not already categorized were also noted in case of potential outliers found in later analyses.

3.4.5 Pedestrian Start-Up Delay

Pedestrian start-up delay, in seconds, was also recorded at locations where the pedestrian walk sign was clearly visible to the camera. This was not always possible at every site evaluated, therefore, the sample sizes for pedestrian start-up delay are smaller in comparison to the overall sample sizes collected for pedestrian walking speeds. Information about the collected sample sizes of start-up delay by pedestrian categories will be provided in section 4.2.2. Start-up delay was measured as the time it took for a pedestrian, or group of pedestrians, to enter the crosswalk from the moment the walk phase begins, rounded to the nearest 1.0 second.

3.4.6 Walking Speed Calculation

Based upon the crosswalk lengths measured in the field (see section 3.3.2), and the times from the timestamps that were present on all videos, pedestrian speed was programmed to be calculated using custom spreadsheets. The spreadsheets were programmed so that each data entry had a field for the appropriate leg of the intersection being crossed. The spreadsheet was then programmed to reference the entered length of the crosswalk on the corresponding leg for use in the pedestrian walking speed calculation. Equation 3.1 shows the equation used for calculating walking speeds for each pedestrian event.

$$S = \frac{L}{E-I} \tag{3.1}$$

where:

S = walking speed, feet per second

L = length of crosswalk, feet

E = egress time, in hh:mm:ss

I = ingress time, in hh:mm:ss

* Note: the difference of egress and ingress time is calculated in seconds.

3.5 Summary

Data were collected via portable cameras at various signalized intersection sites in the state of Utah. Sites were determined through the help of online mapping services and the input of the TAC. Cameras were placed at each site for 48-hour periods, such that pedestrians could be observed crossing the entire length of the crosswalk during various day-time hours. Video data were then stored and analyzed by the research team.

Pedestrian data was interpreted and categorized using custom spreadsheets for each location. Pedestrian crossing events were categorized by age group: ‘0-12,’ ‘12-60,’ ‘60+,’ ‘child with adult,’ and ‘mixed group.’ Each crossing event was also categorized by mobility: ‘regular,’ ‘cane/walker,’ ‘cart/stroller,’ ‘wheelchair,’ ‘motorized wheelchair,’ ‘pet,’ ‘other,’ and ‘mixed group.’ Pedestrians crossing events were observed to contain ‘attentive’ pedestrians, or ‘not attentive’ pedestrians, while groups of varying levels of alertness were classified as ‘mixed group.’ Potential distractions were noted as: ‘headphones,’ ‘texting with cellphone,’ ‘talking on cellphone,’ ‘other,’ and groups of pedestrians with multiple distractions were noted as ‘mixed group,’ while non-distracted pedestrian crossing events were noted as ‘none.’ Pedestrian crossing events were also categorized by gender groups: ‘male,’ ‘female,’ or ‘mixed group.’ Start-up delay, in seconds, was noted, and pedestrian walking speeds were calculated using ingress and egress time-stamp values and the lengths of the crosswalks. These data allowed the research team to better quantify and evaluate pedestrian walking speeds as observed in each distinctive pedestrian category.

4.0 DATA ANALYSIS

4.1 Overview

The collected data were analyzed to better quantify the mean pedestrian walking speeds and start-up delay of each pedestrian demographic. The data from this project is meant to inform UDOT and other jurisdictions in Utah of current trends in pedestrian behavior throughout the state. The statistical analysis, consisting of least squares means and differences of least squares means, compares pedestrian walking speeds of each age, gender, mobility, alertness, distraction, and individual/group category. This chapter contains a discussion of preliminary pedestrian start-up delay and pedestrian walking speed resulting from the observed data, and a statistical discussion of the least squares means and differences of least squares means of pedestrian walking speeds, by category. A summary of the data analysis is then provided.

4.2 Preliminary Results and Observed Data

The raw data from all locations were combined into one large spreadsheet to consolidate and insure consistency of categories across the study. The raw data contained a sample size of 2,061 pedestrian crossing events. All labels were compared and any potential misnomers due to human error were resolved through careful revision and revisiting of video files when necessary. This section of the report contains discussions relating to pedestrian group sizes; 15th percentile, mean, and 85th percentile pedestrian start-up delay; 15th percentile, mean, and 85th percentile pedestrian walking speeds; and limitations of the preliminary results.

4.2.1 Pedestrian Group Sizes

Figure 4.1 displays a histogram of the pedestrian group size distribution. As shown, the spread was heavily centered around pedestrian crossing events of individuals (1 person), while a large number of events did involve groupings of more than one person. The median and mode values for the group size category were both 1 person, while the mean group size pedestrian events was 1.5. The maximum group size observed in a single pedestrian crossing event was 14.

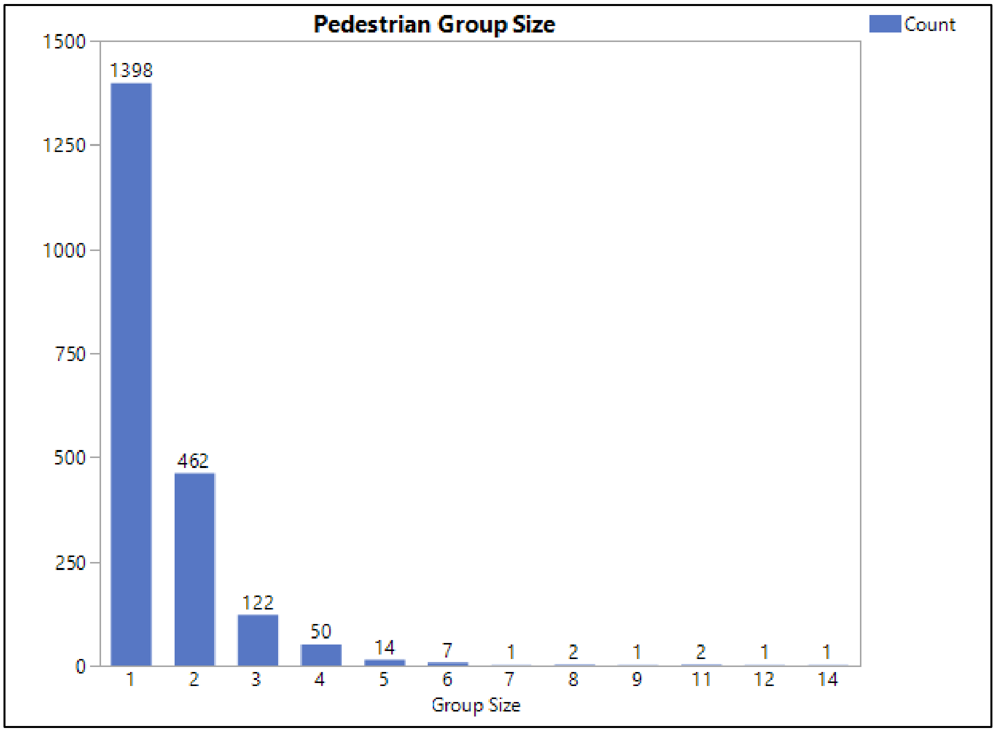

Figure 4.1 Distribution of Group Sizes in Observed Pedestrian Crossing Events

4.2.2 15th Percentile, Mean, and 85th Percentile Pedestrian Start-Up Delay Times

An analysis was conducted on the collected data to determine the 15th percentile, mean, and 85th percentile values associated with the pedestrian start-up delay times that were observed during data collection. These data were calculated in customized spreadsheets and summarized in tables and charts that facilitate data comparison between the pedestrian categories. A value of 3.2 seconds is generally used as the default individual pedestrian start-up time for the calculation of pedestrian walk intervals, as outlined in the HCM (TRB 2016). Equation 5.1 is the equation used by Roess et al. (2010) for calculation of pedestrian walk intervals when the crosswalk is less than 10 feet in width.

$$WALK_{min} = 3.2 + \left(2.7 * \frac{N_{ped}}{W_E}\right) \quad (5.1)$$

where:

$WALK_{min}$ = minimum pedestrian green, seconds

N_{ped} = number of pedestrians crossing per phase in a single crosswalk

W_E = width of crosswalk, feet

Because Equation 5.1 contains a separate term that adjusts the pedestrian green time according to the number of people entering the crosswalk, only pedestrian start-up times of individual pedestrian crossing events (not group crossings) were considered for analysis to compare with the default value of 3.2 seconds. The tables and charts displaying pedestrian start-up delay data are found in the age group, mobility, alertness, distraction, and gender subsections. Discussion will focus primarily on the mean individual pedestrian start-up delay. As noted previously in section 3.3.3, start-up delay times were estimated using data in increments of 1.0 seconds.

4.2.2.1 Age Group

The mean, 15th percentile, and 85th percentile pedestrian start-up delay times were calculated for each age group category. Table 4.1 and Figure 4.2 display the pedestrian start-up delay times, sample size, and percent of pedestrian observations that would be accommodated by the 3.2 second start-up delay for each category.

Table 4.1 Individual Pedestrian Start-Up Delay by Age Group

Age Group	15th Percentile (seconds)	Mean (seconds)	85th Percentile (seconds)	Sample Size	Percent of Observations ≤ 3.2 s
All Age	1.0	2.8	5.0	887	73%
0-12	1.0	2.7	5.0	24	69%
13-60	1.0	2.7	4.0	672	73%
60+	1.0	2.9	5.0	191	71%

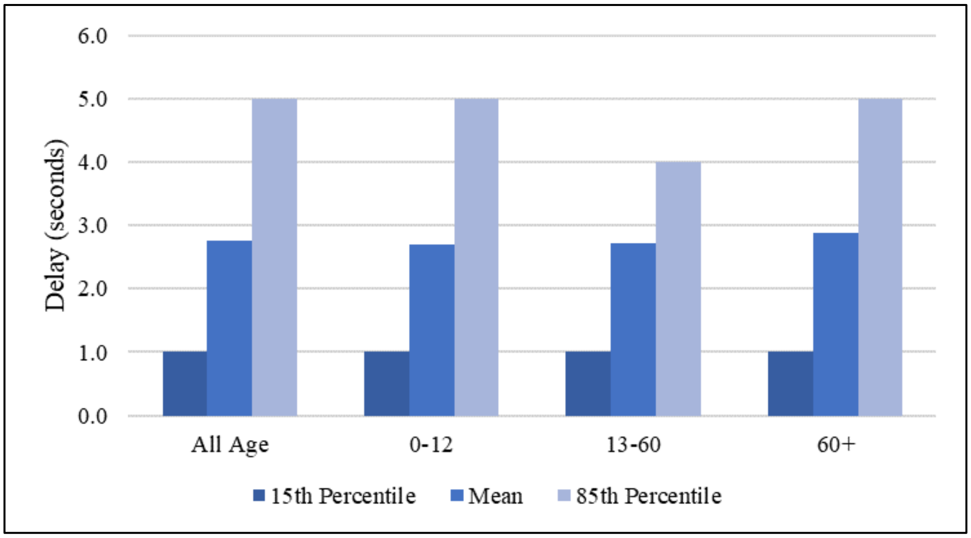

Figure 4.2 Individual Pedestrian Start-Up Delay by Age Group

It was found that there was little variation between age groups of individual pedestrian start-up delay. All mean start-up delay values were less than the current 3.2 second default value. The majority of pedestrian observations in each category (69 percent being the lowest percentage, for '0-12' age group category) would be accommodated by the 3.2 second default start-up time.

4.2.2.2 Mobility

The mean, 15th percentile, and 85th percentile pedestrian start-up delay times were calculated for each mobility category. Table 4.2 and Figure 4.3 display the pedestrian start-up delay times, sample size, and percent of pedestrian observations accommodated by a 3.2 second start-up delay for each mobility category. There were no start-up delay times recorded for the wheelchair category.

Overall, relatively little variation in pedestrian start-up delay was found between the mobility groups. 'Cane/walker' and 'motorized wheelchair' pedestrians exhibited the highest 85th percentile start-up delay times, at 6.0 seconds. This was observed to be due to having to maneuver their walking aids and wheelchairs down the ramp and into the crosswalk. 'Cart/stroller,' 'motorized wheelchair,' and 'cane/walker' each had mean start-up delay observations that were greater than the current 3.2 second default start-up delay. The ‘cart/stroller’ category contained the lowest percentage of pedestrian observations that would be accommodated by the 3.2 second default start-up value; at only 32 percent. The ‘pet’ and ‘cane/ walker’ categories both had the next lowest percentages at 57 percent.

Table 4.2 Individual Pedestrian Start-Up Delay by Mobility

Mobility	15^{th} Percentile (seconds)	Mean (seconds)	85^{th} Percentile (seconds)	Sample Size	Percent of Observations ≤ 3.2 s
All Mobility	1.0	2.8	5.0	887	73%
Cane/Walker	1.4	3.3	6.0	17	57%
Cart/Stroller	2.0	3.7	5.1	25	32%
Motorized Wheelchair	0.8	3.3	6.0	24	61%
Other	1.0	2.5	4.0	13	73%
Pet	1.6	3.1	5.0	36	57%
Regular	1.0	2.7	4.0	772	75%
Wheelchair	n/a	n/a	n/a	0	n/a

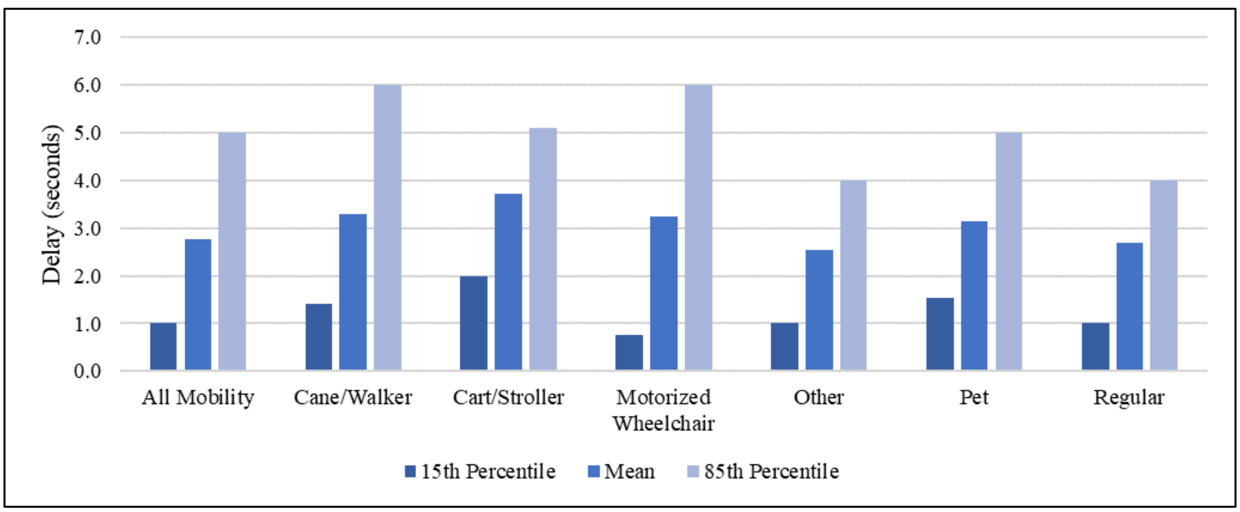

Figure 4.3 Individual Pedestrian Start-Up Delay by Mobility

4.2.2.3 Alertness

The mean, 15^{th} percentile, and 85^{th} percentile pedestrian start-up delay times were calculated for ‘attentive’ and ‘not attentive’ alertness categories. These start-up delay times, sample sizes, and percent of pedestrian observations accommodated by a 3.2 second default start-up time are displayed in Table 4.3 and Figure 4.4.

Pedestrian start-up delay times for ‘attentive’ and ‘not attentive’ pedestrians were very similar. Both mean start-up delays were less than the current 3.2 second default. The majority of all pedestrian observations in each of these categories would be accommodated by the 3.2 second default, with the lowest percentage of 66 percent observed for the ‘not attentive’ category.

Table 4.3 Individual Pedestrian Start-Up Delay by Alertness

Alertness	15th Percentile (seconds)	Mean (seconds)	85th Percentile (seconds)	Sample Size	Percent of Observations ≤ 3.2 s
All Alertness	1.0	2.8	5.0	887	73%
Attentive	1.0	2.7	4.0	832	73%
Not Attentive	2.0	3.1	5.0	55	66%

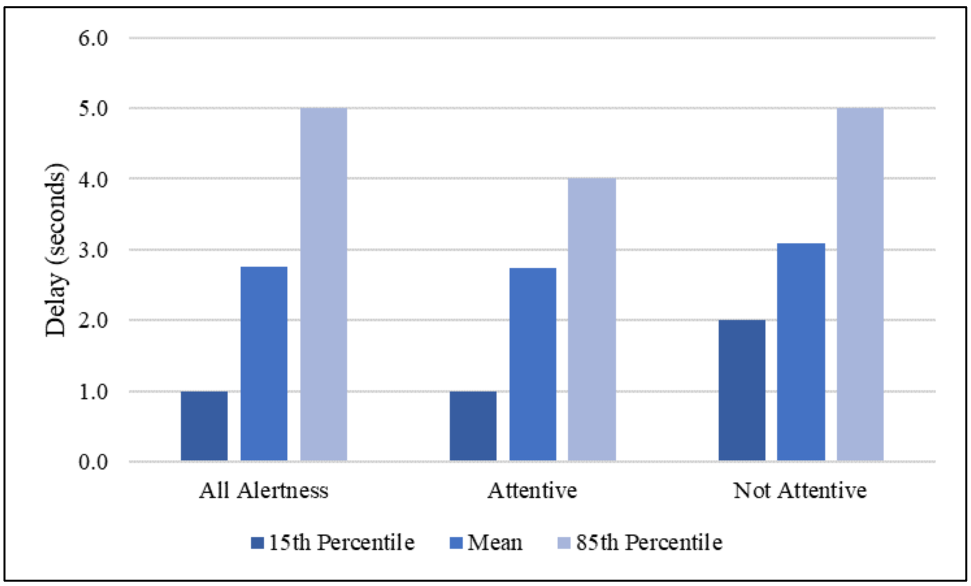

Figure 4.4 Individual Pedestrian Start-Up Delay by Alertness

4.2.2.4 Distraction

The mean, 15th percentile, and 85th percentile pedestrian start-up delay times were calculated for each distraction category. These start-up delay times, sample sizes, and percent of pedestrian observations accommodated by a 3.2 second default start-up delay are displayed in Table 4.4 and Figure 4.5. The 'all' distraction category indicates all groups compiled together, including 'none.'

Table 4.4 Individual Pedestrian Start-Up Delay by Distraction

Distraction	15^{th} Percentile (seconds)	Mean (seconds)	85^{th} Percentile (seconds)	Sample Size	Percent of Observations $\leq$ 3.2 s
All	1.0	2.8	5.0	887	73%
Headphones	1.0	2.8	5.0	22	70%
None	1.0	2.7	4.2	791	73%
Other	0.9	1.8	2.6	4	100%
Talking on Cellphone	1.3	3.0	4.0	21	74%
Texting on Cellphone	2.0	3.1	5.0	49	64%

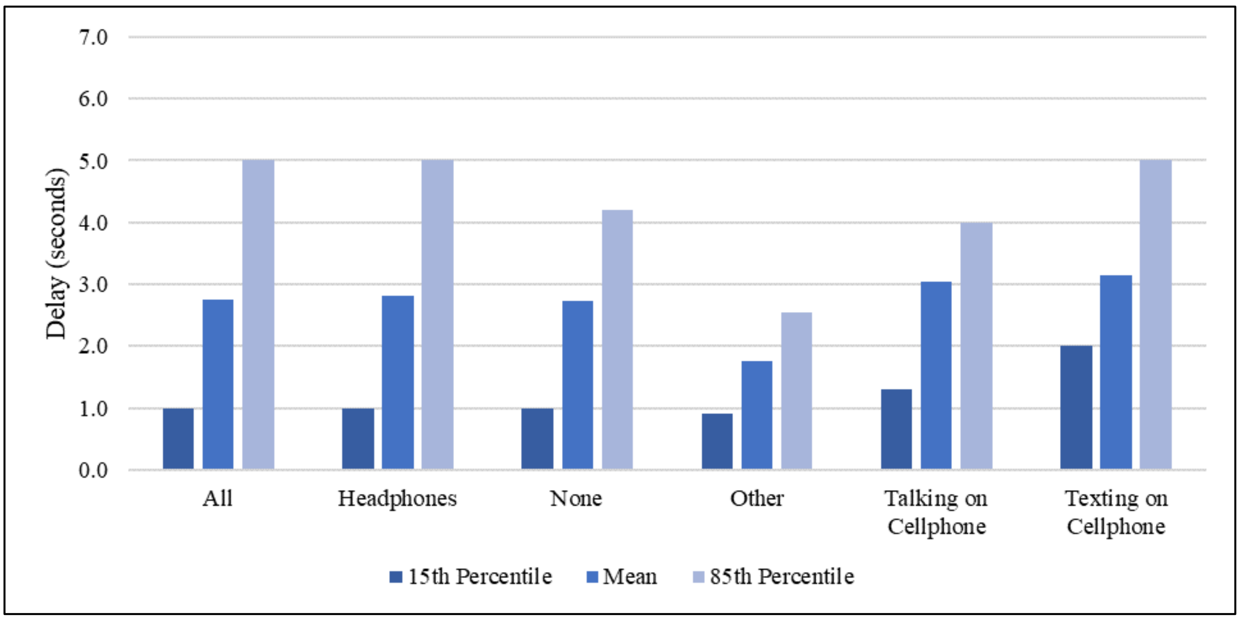

Figure 4.5 Individual Pedestrian Start-Up Delay by Distraction

The lowest start-up delay times were found in the 'other' category; however, it is of note that only a small sample size of four observations was collected. None of the mean start-up delay values were greater than the current 3.2 second default. The lowest percentage of pedestrian observations that would be accommodated by the 3.2 second default was 64 percent, for the 'texting on cellphone' category.

4.2.2.5 Gender

The mean, 15th percentile, and 85th percentile pedestrian start-up delay times were calculated for each gender group. These pedestrian start-up delay times, sample sizes, and percent of pedestrian observations accommodated by the 3.2 second default start-up delay are displayed in Table 4.5 and Figure 4.6. The 'all gender' category refers to the overall combined start-up delay times observed for both 'female' and 'male' categories.

Table 4.5 Individual Pedestrian Start-Up Delay by Gender

Gender	15th Percentile (seconds)	Mean (seconds)	85th Percentile (seconds)	Sample Size	Percent of Observations ≤ 3.2 s
All Gender	1.0	2.8	5.0	887	73%
Female	1.0	2.9	5.0	303	69%
Male	1.0	2.7	4.0	584	75%

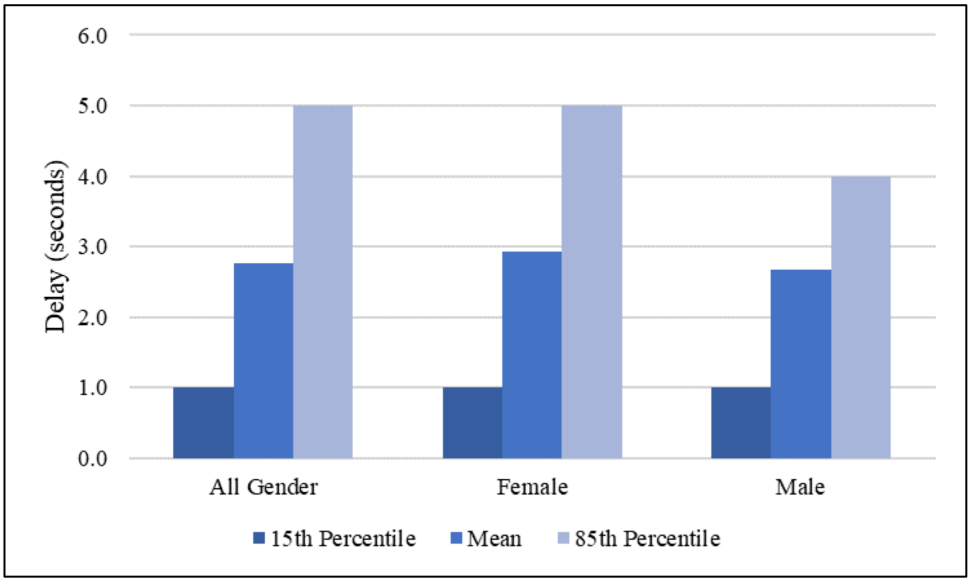

Figure 4.6 Individual Pedestrian Start-Up Delay by Gender

'Male' pedestrian events overall have slightly lower start-up delay times than 'female' events, with a tighter spread between the 15th percentile and 85th percentile values. 'Female' pedestrians had the overall lowest percentage of observations that would be accommodated by the 3.2 second default, at 69 percent.

4.2.2.6 Summary

Overall, little variation was seen in mean individual pedestrian start-up delay. The category groups that exhibited mean start-up delays greater than 3.2 seconds were ‘cane/walker,’ ‘cart/stroller,’ and ‘motorized wheelchair.’ The mean pedestrian start-up delay times for each pedestrian category were generally within 1.0 second of the current default of 3.2 seconds as defined by Roess et al. (2010) and the HCM (TRB 2016).

4.2.3 15th Percentile, Mean, and 85th Percentile Pedestrian Walking Speeds

A preliminary analysis was conducted on the collected data to obtain a relative approximation of the results of the pedestrian walking speeds. These data were calculated in customized spreadsheets and summarized in tables and charts that facilitate data comparison between pedestrian categories. These tables and charts are found in the age group, mobility, alertness, distraction, and gender subsections. As noted previously in section 3.3.3, pedestrian walking speeds were calculated using data in increments of 1.0 seconds.

The most critical value to be considered in each case, as is standard in the current industry, is the 15th percentile walking speed. A 15th percentile walking speed gives the walking speed for which 85 percent of pedestrians in a given demographic category would be accommodated. The HCM Fifth Edition states that “In calculating pedestrian crossing times, the 15th percentile crossing speed should be used” (TRB 2010). This is the pedestrian walking speed used in the calculation of pedestrian clearance intervals.

4.2.3.1 Age Group

The mean, 15th percentile, and 85th percentile pedestrian walking speeds were calculated for each age group category. Table 4.6 and Figure 4.7 display the pedestrian walking speeds, sample sizes, and percent of pedestrian observations that crossed at walking speeds of 4.0 feet per second or faster for each age group.

Table 4.6 Pedestrian Walking Speeds by Age Group

Age Group	15th Percentile (ft./s)	Mean (ft./s)	85th Percentile (ft./s)	Sample Size	Percent of Observations ≥ 4.0 ft./s
All Age	4.1	5.0	5.7	2061	89%
0-12	4.1	5.5	6.5	89	90%
13-60	4.3	5.1	5.8	1477	93%
60+	3.7	4.5	5.3	351	73%
Child with Adult	3.9	4.5	5.1	105	77%
Mixed Group	3.8	4.5	5.4	39	80%

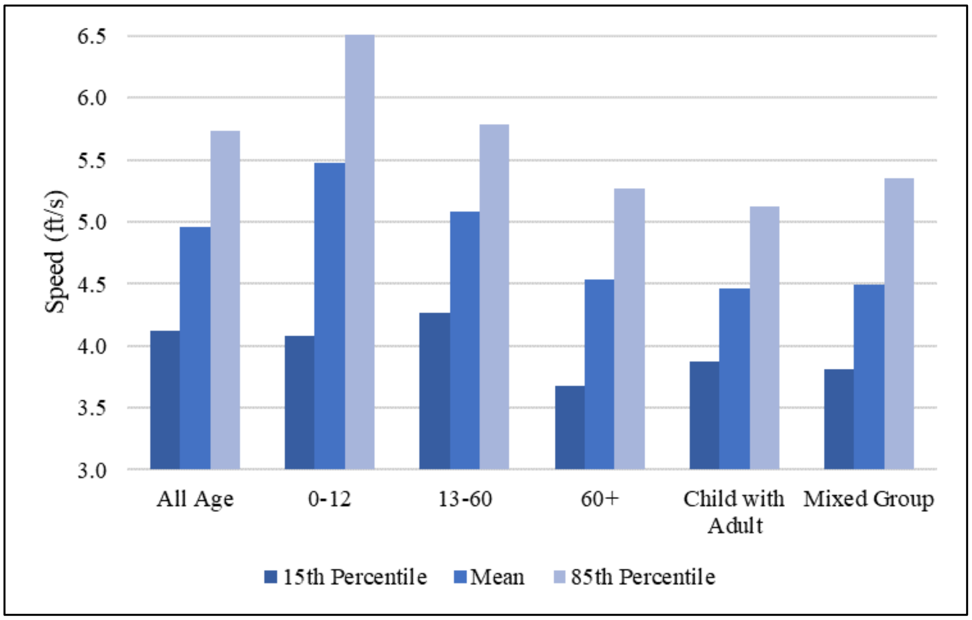

Figure 4.7 Pedestrian Walking Speeds by Age Group

The highest overall pedestrian walking speeds were observed in the '0-12' age group category. It was often observed during data collection that younger children, while unattended by adults, had a tendency to increase their walking speeds at intersections after the pedestrian count-down phase had begun. The '60+' age group exhibited the lowest 15th percentile walking speed, while 'child with adult' exhibited the lowest mean and 85th percentile speeds. 'Mixed group,' 'child with adult,' and '60+' age groups all exhibited 15th percentile walking speeds slightly less than 4.0 feet per second. The majority of pedestrian observations for all age categories (the lowest being 73 percent for the ‘60+’ age group) crossed at walking speeds of 4.0 feet per second or faster.

4.2.3.2 Mobility

The mean, 15th percentile, and 85th percentile pedestrian walking speeds were calculated for each mobility category. Table 4.7 and Figure 4.8 display the pedestrian walking speeds, sample sizes, and percent of pedestrian observations that crossed at walking speeds of 4.0 feet per second or faster for each mobility category.

The ‘motorized wheelchair’ pedestrian speeds were the highest observed among the mobility groups, while the ‘cane/walker’ and ‘mixed group’ pedestrians were observed to have the lowest walking speeds of any of the groups. The groups that exhibited 15th percentile speeds below 4.0 feet per second were the ‘cane/walker,’ ‘cart/stroller,’ ‘other’ (limping pedestrians, those carrying large items, or otherwise physically impaired pedestrians), and ‘mixed group’ categories. The mobility categories with the lowest percentages of observations that crossed at walking speeds of 4.0 feet per second or faster were ‘mixed group,’ and ‘cane/walker’, with 54 percent and 46 percent, respectively.

Table 4.7 Pedestrian Walking Speeds by Mobility

Mobility	15th Percentile (ft./s)	Mean (ft./s)	85th Percentile (ft./s)	Sample Size	Percent of Observations ≥ 4.0 ft./s
All Mobility	4.1	5.0	5.7	2061	89%
Cane/Walker	3.1	4.0	4.9	28	46%
Cart/Stroller	3.6	4.4	5.0	104	71%
Motorized Wheelchair	4.7	6.1	7.4	36	94%
Other	3.8	4.7	5.7	42	81%
Pet	4.2	5.0	5.8	69	89%
Regular	4.2	5.0	5.8	1768	91%
Wheelchair	4.1	4.8	5.6	3	70%
Mixed Group	2.7	4.0	4.9	11	54%

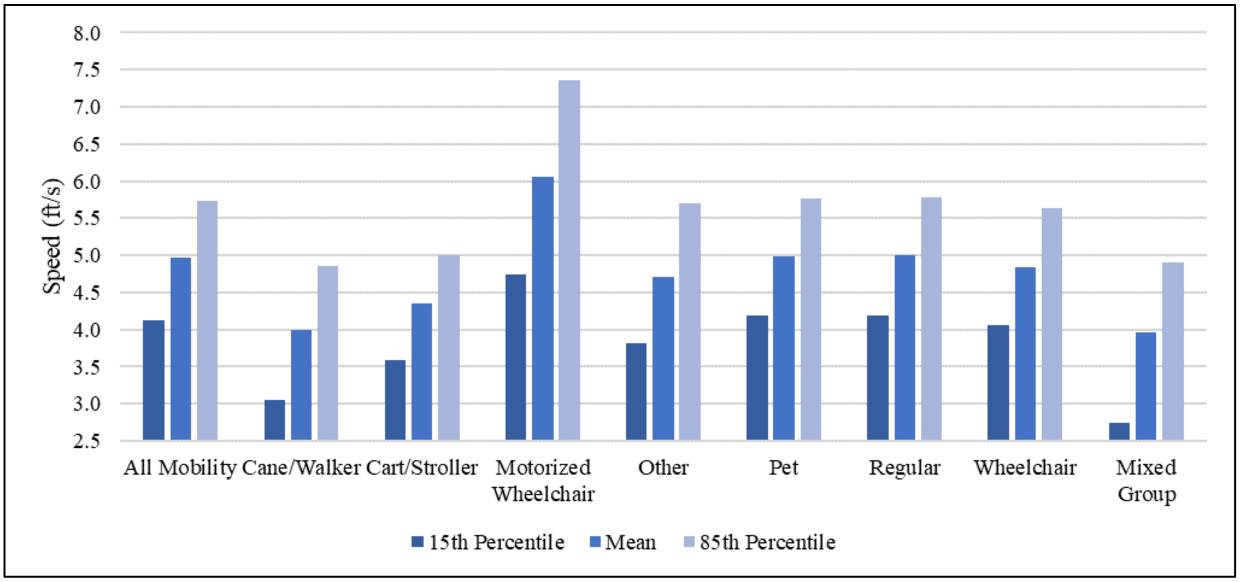

Figure 4.8 Pedestrian Walking Speeds by Mobility

4.2.3.3 Alertness

The mean, 15th percentile, and 85th percentile pedestrian walking speeds were calculated for each alertness category. Table 4.8 and Figure 4.9 display the pedestrian walking speeds, sample sizes, and percent of pedestrian observations that crossed at walking speeds of 4.0 feet per second or faster for 'attentive,' 'not attentive,' and 'mixed group,' alertness categories. An 'all alertness' category is also provided for reference to the entire sample population.

Table 4.8 Pedestrian Walking Speeds by Alertness

Alertness	**15th Percentile (ft./s)**	**Mean (ft./s)**	**85th Percentile (ft./s)**	**Sample Size**	**Percent of Observations ≥ 4.0 ft./s**
All Alertness	4.1	5.0	5.7	2061	89%
Attentive	4.1	5.0	5.7	1959	89%
Not Attentive	4.2	4.9	5.9	78	88%
Mixed Group	3.2	4.5	5.4	24	68%

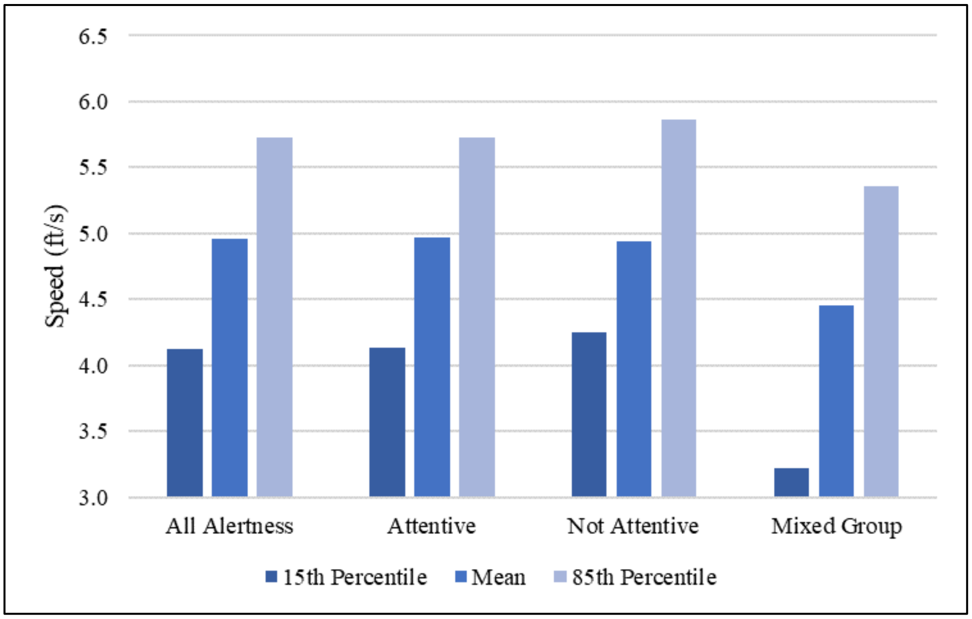

Figure 4.9 Pedestrian Walking Speeds by Alertness

Walking speed values for both ‘attentive’ and ‘not attentive’ values were observed to be very similar. ‘Mixed group’ walking speed observations were once again the lowest values for 15th percentile, mean, and 85th percentile walking speeds. By definition, ‘mixed group’ categories must contain a minimum of two pedestrians and are expected to yield slower speeds than individual events. The only category with a 15th percentile speed below 4.0 feet per second was ‘mixed group.’ ’Mixed group’ also had the lowest percentage of pedestrians that crossed at walking speeds of 4.0 feet per second or faster, at 68 percent.

4.2.3.4 Distraction

The mean, 15th percentile, and 85th percentile pedestrian walking speeds were calculated for each distraction category. Table 4.9 and Figure 4.10 display the pedestrian walking speeds, sample sizes, and percent of pedestrian observations that crossed at speeds of 4.0 feet per second or faster for each distraction category.

All distraction categories exhibited very similar walking speeds, with the exceptions of the ‘headphones’ and the ‘mixed group’ categories. ‘Mixed group’ had the lowest overall 15th percentile, mean, and 85th percentile speeds. The ‘headphone’ category exhibited the highest overall speeds. The categories with observed 15th percentile speeds below 4.0 feet per second were ‘other,’ and ‘mixed group.’ The ‘mixed group’ category also had the lowest percentage of pedestrian observations that crossed at walking speeds of 4.0 feet per second or faster, at 68 percent.

Table 4.9 Pedestrian Walking Speeds by Distraction

Distraction	15th Percentile (ft./s)	Mean (ft./s)	85th Percentile (ft./s)	Sample Size	Percent of Observations ≥ 4.0 ft./s
All	4.1	5.0	5.7	2061	89%
Headphones	4.7	5.4	6.5	33	100%
None	4.1	5.0	5.7	1880	89%
Other	3.9	5.0	6.1	16	81%
Talking on Cellphone	4.5	5.1	5.7	34	95%
Texting on Cellphone	4.2	5.0	5.9	75	88%
Mixed Group	3.1	4.4	5.4	23	68%

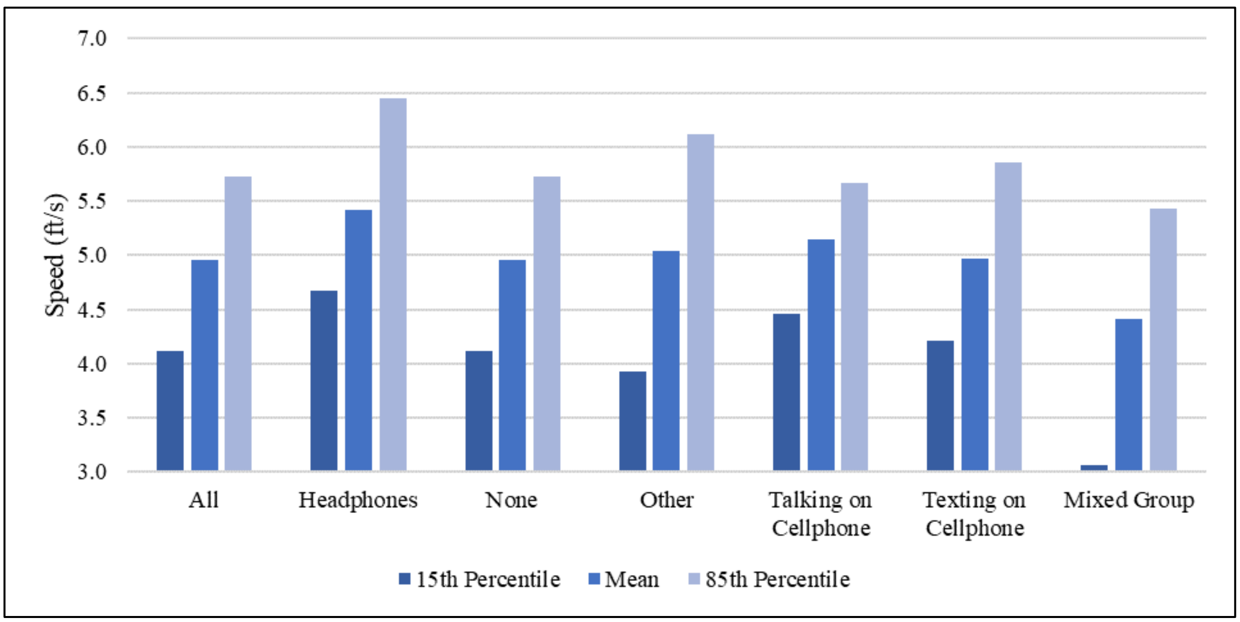

Figure 4.10 Pedestrian Walking Speeds by Distraction

4.2.3.5 Gender

The mean, 15th percentile, and 85th percentile pedestrian walking speeds were calculated for each gender group. Table 4.10 and Figure 4.11display the pedestrian walking speeds, sample sizes, and percentage of pedestrian observations that crossed at walking speeds of 4.0 feet per second or faster for the 'male,' 'female,' and 'mixed group' gender categories.

Table 4.10 Pedestrian Walking Speeds by Gender

Gender	15th Percentile (ft./s)	Mean (ft./s)	85th Percentile (ft./s)	Sample Size	Percent of Observations ≥ 4.0 ft./s
All Gender	4.1	5.0	5.7	2061	89%
Female	4.0	4.9	5.7	616	85%
Male	4.3	5.1	5.9	1096	93%
Mixed Group	3.9	4.5	5.2	349	82%

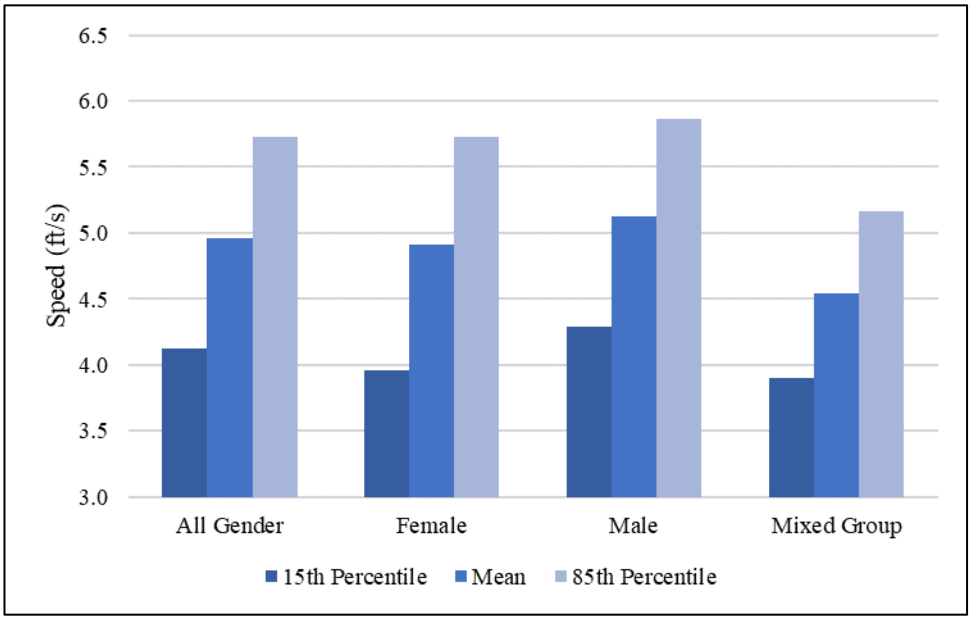

Figure 4.11 Pedestrian Walking Speeds by Gender

There was very little variation observed between gender group pedestrian walking speeds. The 'female,' observed speeds were slightly lower than 'male,' but the difference is minimal. 'Mixed group' was the slowest overall pedestrian event category and had a 15th percentile speed of 3.9 feet per second. Each category had relatively high percentages (greater than 80 percent) of pedestrian observations that crossed at walking speeds of 4.0 feet per second or faster.

4.2.3.6 Summary

Many observations were made with regards to 15th percentile, mean, and 85th percentile pedestrian walking speeds of each category. However, more analysis, through the use of statistical methods, was necessary to determine which groups could be expected to exhibit walking speeds lower than 4.0 feet per second or 3.5 feet per second and to determine which differences were statistically or practically significant. No conclusions about the observed speeds could be drawn prior to a formal statistical analysis.

4.3 Statistical Analysis

A one-way analysis of variance (ANOVA) was conducted with the raw pedestrian walking speeds and demographic categories. An ANOVA test allows the determination of statistically significant results from the pool of collected data. A post-hoc Tukey-Kramer procedure was then performed to compare all possible pairwise least squares means walking speeds of each demographic after making adjustments for varying sample sizes within demographic categories. The Tukey-Kramer procedure is a modification of Tukey's Honestly Significant Difference (HSD) test, which assumes an ideal normal model with equal spreads, but modified to adjust for uneven sample sizes (Ramsey and Schafer 2013). All statistical analyses were performed on *SAS 9.4* statistical software (SAS Institute Inc. 2019a). This section will discuss the least squares means statistical results, and the resulting differences of least squares means pedestrian walking speeds. Statistical analysis of pedestrian start-up delay found that observed sample sizes were too small to yield statistically significant results, therefore they were not included in this report.

4.3.1 Least Squares Mean Walking Speeds

The least squares mean values of each category were calculated using the linear ANOVA model. The 15th percentile speeds were then back-calculated based upon the pooled standard deviations such that the least squares model statistics could be compared to the 15th percentile and mean values in the preliminary observation analysis. The least squares mean values (labeled as ‘estimate’) of each pedestrian demographic category as well as the 15th percentile values (both in bold print) are displayed in their corresponding subsections: groups and individuals, age group, mobility, alertness, distraction, and gender categories. Other columns in the following tables contain standard error (SE), degrees of freedom (DF), t-values, p-values (Pr > |t|), sample sizes (n), and pooled standard deviations (Pooled SD).

4.3.1.1 Groups and Individuals

When comparing pedestrian crossing events involving groups of 2 or more persons in Table 4.11, it appears that individuals tend to walk, on average, at speeds of 5.1 feet per second. Pedestrian events involving groups of two or more people crossing at the same rate tend to exhibit mean walking speeds of approximately 4.7 feet per second. It can be concluded that at the study locations, pedestrians tend to travel slower in groups than they do as individuals. The 15th percentile walking speeds for individuals are just over 4.0 feet per second; however, the 15th percentile walking speeds for groups are lower, at 3.7 feet per second.

Table 4.11 Least Squares Mean and 15th Percentile Speeds of Groups and Individuals

Group	Estimate (ft./s)	SE (ft./s)	DF	t Value	Pr > |t|	n	Pooled SD (ft./s)	15th Percentile (ft./s)
Group (2+)	**4.7**	0.03	2059	135.94	<.0001	663	0.88	**3.7**
Individual	**5.1**	0.02	2059	216.30	<.0001	1398	0.88	**4.2**

4.3.1.2 Age Group

Walking speeds among the age group demographics are displayed in Table 4.12. It was noted during observation that many children tended to purposefully walk faster while in a crosswalk than they otherwise would, especially after the pedestrian clearance countdown had started. All least squares mean speeds in each category are well above the current 4.0 feet per second UDOT guidance. However, the 15th percentile walking speeds for the ‘60+,’ ‘child with adult,’ and ‘mixed group’ categories are all below 4.0 feet per second at 3.5 feet per second.

Table 4.12 Least Squares Mean and 15th Percentile Speeds by Age Group

Age Group	Estimate (ft./s)	SE (ft./s)	DF	t Value	Pr > |t|	n	Pooled SD (ft./s)	15th Percentile (ft./s)
0-12	**5.5**	0.09	2055	59.46	<.0001	89	0.87	**4.6**
13-60	**5.1**	0.02	2055	224.84	<.0001	1477	0.87	**4.2**
60+	**4.5**	0.05	2055	97.81	<.0001	351	0.87	**3.6**
Child with Adult	**4.5**	0.09	2055	52.35	<.0001	104	0.87	**3.6**
Mixed Group	**4.5**	0.14	2055	32.32	<.0001	40	0.88	**3.6**

4.3.1.3 Mobility

Walking speeds for mobility categories are displayed in Table 4.13. Motorized wheelchair crossings were the fastest, averaging at 6.1 feet per second. The 15th percentile speeds for ‘cane/walker’ and ‘mixed group’ were the lowest, at 3.1 and 3.0 feet per second, respectively. The ‘cart/stroller’ category had a 15th percentile speed of 3.5 feet per second.

Table 4.13 Least Squares Mean and 15th Percentile Speeds by Mobility

Mobility	Estimate (ft./s)	SE (ft./s)	DF	t Value	Pr > |t|	n	Pooled SD (ft./s)	15th Percentile (ft./s)
Cane/Walker	**4.0**	0.17	2053	24.15	<.0001	28	0.87	**3.1**
Cart/Stroller	**4.4**	0.09	2053	50.83	<.0001	104	0.87	**3.4**
Mixed Group	**4.0**	0.26	2053	15.01	<.0001	11	0.87	**3.0**
Mot. Wheelchair	**6.1**	0.15	2053	41.56	<.0001	36	0.87	**5.1**
Other	**4.7**	0.13	2053	34.97	<.0001	42	0.87	**3.8**
Pet	**5.0**	0.11	2053	47.36	<.0001	69	0.87	**4.1**
Regular	**5.0**	0.02	2053	240.57	<.0001	1768	0.87	**4.1**
Wheelchair	**4.8**	0.50	2053	9.59	<.0001	3	0.87	**3.9**

4.3.1.4 Alertness

Walking speeds for ‘attentive’ and ‘not attentive’ categories, as displayed in Table 4.14, both had similar means and 15th percentile speeds. It can be noted that the mean and 15th percentile speeds for the ‘mixed group’ alertness category were 4.5 and 3.5 feet per second, respectively. This is likely in relation to the tendency of group crossing events of two or more pedestrians being faster, on average, than individual pedestrian crossing events.

Table 4.14 Least Squares Mean and 15th Percentile Speeds by Alertness

Alertness	Estimate (ft./s)	SE (ft./s)	DF	t Value	Pr > |t|	n	Pooled SD (ft./s)	15th Percentile (ft./s)
Attentive	**5.0**	0.02	2058	242.91	<.0001	1959	0.91	**4.0**
Mixed Group	**4.5**	0.18	2058	24.10	<.0001	24	0.91	**3.5**
Not Attentive	**4.9**	0.10	2058	48.24	<.0001	78	0.91	**4.0**

4.3.1.5 Distraction

Walking speeds for each pedestrian distraction group are displayed in Table 4.15. ‘Headphones’ had the highest mean and 15th percentile values, at 5.4 and 4.5 feet per second, respectively. ‘Mixed group’ appeared to have the lowest walking speeds, at a mean of 4.4 feet per second and a 15th percentile of 3.5 feet per second, while all other categories had similar walking speeds close to 5.0 feet per second for the means and 4.0 feet per second for the 15th percentile.

Table 4.15 Least Squares Mean and 15th Percentile Speeds by Distraction

Distraction	Estimate (ft./s)	SE (ft./s)	DF	t Value	Pr > |t|	n	Pooled SD (ft./s)	15th Percentile (ft./s)
Headphones	**5.4**	0.16	2055	34.47	<.0001	33	0.90	**4.5**
Mixed Group	**4.4**	0.19	2055	23.43	<.0001	23	0.90	**3.5**
None	**5.0**	0.02	2055	237.81	<.0001	1880	0.90	**4.0**
Other	**5.0**	0.23	2055	22.29	<.0001	16	0.90	**4.1**
Talk on Cellphone	**5.1**	0.15	2055	33.20	<.0001	34	0.90	**4.2**
Text on Cellphone	**5.0**	0.10	2055	47.64	<.0001	75	0.90	**4.0**

4.3.1.6 Gender

Walking speeds for each gender group are found in Table 4.16. Males tended to have slightly higher walking speeds, with a mean value of 5.1 feet per second and a 15th percentile value of 4.2 feet per second. Females were slightly lower, having a mean walking speed of 4.9 feet per second and a 15th percentile walking speed of 4.0 feet per second. Mixed groups were the slowest, exhibiting mean walking speeds of 4.5 feet per second and 15th percentile walking speeds of 3.6 feet per second.

Table 4.16 Least Squares Mean and 15th Percentile Speeds by Gender

Gender	Estimate (ft./s)	SE (ft./s)	DF	t Value	Pr > |t|	n	Pooled SD (ft./s)	15th Percentile (ft./s)
Female	**4.9**	0.04	2058	138.08	<.0001	616	0.88	**4.0**
Male	**5.1**	0.03	2058	192.25	<.0001	1096	0.88	**4.2**
Mixed Group	**4.5**	0.05	2058	96.25	<.0001	349	0.88	**3.6**

4.3.2 Differences of Least Squares Mean Walking Speeds

The post-hoc Tukey test conducted on the data allows comparisons of all possible pairs of means within each category. These comparisons are generally known as differences of least squares means. Adjusted p-values were then computed, based on the Tukey-Kramer method, to determine which of the differences of least squares means are statistically significant. In this analysis, p-values of less than 0.05 were considered to be associated with 95 percent confidence intervals and statistically significant differences of least squares means. More information on multiple comparisons and the Tukey-Kramer method as used in *SAS 9.4* can be found in the literature (SAS Institute Inc. 2019b).

Upon determination of statistically significant values, it is also important to determine if those values carry any practical significance. For the sake of signal timings, increments of less than 0.5 feet per second are seldom used. For this analysis, only values with practically significant differences (approximately ±0.5 feet per second or more) will be considered. Statistically significant differences of each pedestrian walking speed, according to category, are displayed in their corresponding subsections: groups and individuals, age group, mobility, alertness, distraction, and gender categories. Some notable statistically insignificant differences of least square means for different categories are also displayed and discussed. Differences of least squares means are found in the ‘Estimate’ columns, while standard error values are found in the ‘SE’ columns and adjusted p-values are found in the ‘Adj P’ columns.

4.3.2.1 Groups and Individuals

The results from the differences of least squares means of ‘group (2+)’ and ‘individual’ crossing events, as displayed in Table 4.17, was determined to be statistically significant. It can be concluded that, at the locations observed, individual pedestrian events were approximately 0.4

feet per second faster than pedestrian events involving two or more individuals. Again, this appears to be consistent with other studies conducted (Gates et al. 2006, Knoblauch et al. 1996, Russo et al. 2018).

Table 4.17 Significant Differences of Event Type Least Squares Means

Effect	Event	Event	Estimate (ft./s)	SE (ft./s)	Adj P
Event	Group (2+)	Individual	-0.4	0.04	<.0001

4.3.2.2 Age Group

Many of the differences of least squares means by age group, as displayed in Table 4.18, were determined to be statistically significant (Adj P <0.05). The difference of least square mean walking speeds of the '0-12' category compared to the '60+' age group was approximately 1.0 feet per second (in practical comparison), while the difference between the '13-60' and the '60+' category least squares means speeds was 0.5 feet per second. The differences of least squares mean walking speed of the '13-60' compared to the 'Child with Adult,' and '13-60' compared to 'Mixed Groups' were both 0.6 feet per second.

Table 4.18 Significant Differences of Age Group Least Squares Means

Effect	Age Group	Age Group	Estimate (ft./s)	SE (ft./s)	Adj P
Age Group	0-12	13-60	0.4	0.09	0.0005
Age Group	0-12	60+	0.9	0.10	<.0001
Age Group	0-12	Child with Adult	1.0	0.13	<.0001
Age Group	0-12	Mixed Group	1.0	0.17	<.0001
Age Group	13-60	60+	0.5	0.05	<.0001
Age Group	13-60	Child with Adult	0.6	0.09	<.0001
Age Group	13-60	Mixed Group	0.6	0.14	0.0005

4.3.2.3 Mobility

Mobility categories in Table 4.19, which had the most groupings, also came out to have the most statistically significant differences of least squares means of any categorization. Pedestrians in the 'cane/walker' category were found to be 1.0 feet per second slower than ‘regular’ pedestrians. The ‘cart/stroller’ pedestrians were found to be 0.6 feet per second slower than ‘regular’ pedestrians. Pedestrian crossing events of ‘mixed group’ mobility status were found to be 1.0 feet per second slower than groups of ‘regular’ pedestrians. The ‘motorized wheelchair’ least squares means pedestrian walking speed, the highest of any mobility group, was 1.1 feet per second faster than ‘regular’ pedestrians and pedestrians with pets.

Table 4.19 Significant Differences of Mobility Least Squares Means

Effect	Mobility	Mobility	Estimate (ft./s)	SE (ft./s)	Adj P
Mobility	Cane/Walker	Mot. Wheelchair	-2.1	0.22	<.0001
Mobility	Cane/Walker	Other	-0.7	0.21	0.0154
Mobility	Cane/Walker	Pet	-1.0	0.20	<.0001
Mobility	Cane/Walker	Regular	-1.0	0.17	<.0001
Mobility	Cart/Stroller	Mot. Wheelchair	-1.7	0.17	<.0001
Mobility	Cart/Stroller	Pet	-0.6	0.14	0.0001
Mobility	Cart/Stroller	Regular	-0.6	0.09	<.0001
Mobility	Mixed Group	Mot. Wheelchair	-2.1	0.30	<.0001
Mobility	Mixed Group	Pet	-1.0	0.28	0.0073
Mobility	Mixed Group	Regular	-1.0	0.26	0.0020
Mobility	Mot. Wheelchair	Other	1.3	0.20	<.0001
Mobility	Mot. Wheelchair	Pet	1.1	0.18	<.0001
Mobility	Mot. Wheelchair	Regular	1.1	0.15	<.0001

4.3.2.4 Alertness

The only statistically significant differences between alertness categories, as seen in Table 4.20, were found to be between ‘mixed group’ and ‘attentive’ or ‘not attentive’ groups. This is believed to be associated with the tendency found in groups of pedestrians to be slower than individual pedestrians (the majority of attentive and not attentive groupings consisted of only one individual per event). The differences between ‘mixed group,’ compared to ‘attentive’ and ‘not attentive’ are both 0.5 feet per second, as was found between groups and individuals previously in Table 4.17.

Table 4.20 Significant Differences of Alertness Least Squares Means

Effect	Alertness	Alertness	Estimate (ft./s)	SE (ft./s)	Adj P
Alertness	Attentive	Mixed Group	0.5	0.19	0.0156
Alertness	Mixed Group	Not Attentive	-0.5	0.21	0.0527

4.3.2.5 Distraction

A few statistically significant findings were associated with differences of least squares means among the distraction categories, found in Table 4.21. Most of these findings were associated with mixed distraction groups being lower than other categories, most likely related to the relationship between pedestrian group crossing events and individual pedestrian crossing events. However, one notable difference was found between ‘headphones’ pedestrian crossing events and events involving no visible distractions (‘none’). Pedestrians using headphones were, on average, 0.5 feet per second faster than pedestrians who were observed as undistracted. This is theorized to be due to joggers who may be warming up or cooling down from their workouts, thus moving at faster speeds while walking. A study by Russo et al. (2018) yielded similar results.

Table 4.21 Significant Differences of Distraction Least Squares Means

Effect	Distraction	Distraction	Estimate (ft./s)	SE (ft./s)	Adj P
Distraction	Headphones	Mixed Group	1.0	0.25	0.0006
Distraction	Headphones	None	0.5	0.16	0.0392
Distraction	Mixed Group	None	-0.5	0.19	0.0500
Distraction	Mixed Group	Talking on Cellphone	-0.7	0.24	0.0335

4.3.2.6 Gender

Pedestrian crossing events consisting of only females were found to be 0.2 feet per second slower than exclusively male pedestrian crossing events, as displayed in Table 4.22. This, however, is not likely to be practically significant for application in areas that may have predominately female pedestrians. Again, mixed groups were the slowest, being 0.6 and 0.4 feet per second slower than male and female pedestrian events, respectively.

Table 4.22 Significant Differences of Gender Least Squares Means

Effect	Gender	Gender	Estimate (ft./s)	SE (ft./s)	Adj P
Gender	Female	Male	-0.2	0.04	<.0001
Gender	Female	Mixed Group	0.4	0.06	<.0001
Gender	Male	Mixed Group	0.6	0.05	<.0001

4.3.2.7 Insignificant Differences of Least Squares Means

Some differences of least squares mean walking speeds were found to be statistically insignificant, having adjusted p-values which were much greater than 0.05. Many of these differences were comparisons of groups with small sample sizes, such as ‘wheelchair’ crossing events, ‘mixed group,’ or ‘other’ categories. However, there were some notable insignificant differences of least squares means that may explain something about pedestrian behaviors and their effect on walking speeds. Table 4.23 displays some of these differences of least squares means, comparisons of pedestrian attributes that do not appear to affect walking speeds.

Table 4.23 Notable Insignificant Differences of Least Squares Means

Effect	Category	Category	Estimate (ft./s)	SE (ft./s)	Adj P
Category	Headphones	Talking on Cellphone	0.3	0.22	0.8093
Category	Headphones	Texting on Cellphone	0.5	0.19	0.1601
Category	None	Talking on Cellphone	-0.2	0.16	0.8329
Category	None	Texting on Cellphone	0.0	0.11	1.0000
Category	Talking on Cellphone	Texting on Cellphone	0.2	0.19	0.9385
Category	Attentive	Not Attentive	0.0	0.10	0.9715
Category	Pet	Regular	0.0	0.51	1.0000

There was no statistically significant difference between speeds exhibited by non-distracted pedestrians (‘none’) and those talking or texting on mobile devices, as shown in Table 4.23. This is theorized to be due to pedestrians being accustomed to such behaviors and therefore, not affected in terms of walking speed while exhibiting such behaviors. Again, this is consistent with research conducted by Russo et al. (2018). While there was a statistically significant difference between pedestrian walking speeds involving pedestrians with headphones and non-distracted pedestrians (see Table 4.21), there was no such difference between those with headphones and those talking or texting on mobile devices.

Both walking speeds for talking and texting on cellphones also appeared to have no statistical differences between them. The non-significant differences between distracted and non-distracted walking speeds correlate directly with the observed lack of difference in speeds between 'attentive' and 'not attentive' pedestrians observed. It is also of note that the least squares mean speeds of pedestrians who were walking pets on leashes were not statistically different from the speeds of 'regular' mobility pedestrians.

4.4 Summary

Preliminary results for pedestrian group size distributions; 15th percentile, mean, and 85th percentile pedestrian start-up delay times by category; and 15th percentile, mean, and 85th percentile pedestrian walking speeds by category were evaluated and discussed. Mean pedestrian start-up delay values observed were generally close to, or lower than, the default value of 3.2 seconds that is currently used in practice (TRB 2016).

Statistical analysis of the least squares means and differences in least squares means of pedestrian walking speeds allows for confirmation of observed trends that were found during data collection. Some 15th percentile speeds, based on the least squares model, were lower than the current base guidance of 4.0 feet per second. Among these groups were the '60+,' and 'child with adult' age group categories; and the 'cane/walker,' and 'cart/stroller' mobility categories. All of these categories were found to be statistically different from their respective '13-60' age and 'regular' mobility, baseline categories.

There were some pedestrian behaviors that were shown to have no effect on pedestrian walking speeds at these locations. Pedestrians who were potentially distracted by talking or texting behaviors on mobile devices were not found to have statistically different walking speeds in comparison with undistracted pedestrians. 'Attentive' pedestrians exhibited walking speeds that were not statistically different from 'not attentive' pedestrians. Pedestrians who were potentially distracted by headphones were, however, moving at statistically different speeds than undistracted pedestrians and pedestrians distracted by mobile devices.

5.0 CONCLUSIONS

5.1 Overview

There was a need to determine if current pedestrian start-up delay and walking speeds, and their associated pedestrian walk and clearance times, accommodate the mix of pedestrians in the state of Utah. The purpose of this research was to identify current pedestrian start-up delay and walking speeds of various pedestrian demographics and to make limited recommendations for pedestrian walking speeds to be used in calculating pedestrian clearance intervals throughout the state. This purpose has been accomplished with the data that have been collected and analyzed. This research has led to further additional research possibilities that can be accomplished in future projects. This chapter summarizes the project findings, makes limited recommendations on pedestrian start-up time and pedestrian walking speeds, and outlines future research topics that can add to the current knowledge obtained by the research.

5.2 Summary of Findings

Analyses were conducted on pedestrian start-up delay and on pedestrian walking speeds. To fully adjust for any interaction between pedestrian categories, a least squares means statistical procedure was conducted on each category of the collected pedestrian walking speeds data. This section contains a summary of the pedestrian start-up delay analysis, followed by a summary of the pedestrian walking speeds.

5.2.1 Pedestrian Start-Up Delay

An analysis was conducted on the start-up delay times of pedestrian crossing events of individuals to evaluate the study locations in Utah and determine if the 3.2 second default start-up delay time from the HCM is adequate at these locations. All mean pedestrian start-up delay times for individual pedestrian crossing events, by category are summarized in Table 5.1. Mean start-up delay times of 3.2 seconds or less are illustrated in bold font.

Table 5.1 Summary of Mean Individual Pedestrian Start-Up Delay

	Category	Mean (seconds)	Sample Size
	All Samples	**2.8**	887
Age	0-12	**2.7**	24
	13-60	**2.7**	672
	60+	**2.9**	191
Gender	Female	**2.9**	303
	Male	**2.7**	584
Mobility	Cane/Walker	3.3	17
	Cart/Stroller	3.7	25
	Motorized Wheelchair	3.3	24
	Other	**2.5**	13
	Pet	**3.1**	36
	Regular	**2.7**	772
	Wheelchair	n/a	0
Alert.	Attentive	**2.7**	832
	Not Attentive	**3.1**	55
Distraction	Headphones	**2.8**	22
	None	**2.7**	791
	Other	**1.8**	4
	Talking on Cellphone	**3.0**	21
	Texting on Cellphone	**3.1**	49

Nearly all mean values for individual pedestrian start-up delay are below the 3.2 second default. The three pedestrian categories that were observed with mean start-up delays greater than 3.2 seconds were ‘cane/walker,’ ‘cart/stroller,’ and ‘motorized wheelchair,’ with pedestrian start-up delay times of 3.3, 3.8, and 3.3 seconds, respectively. The practical difference between these values and the current 3.2 second default is anticipated to be negligible, especially when all jurisdictions in Utah have a current minimum walk interval timing of 4.0 seconds for signalized intersections (UDOT 2017). It is again noted that no samples were collected for ‘wheelchair’ pedestrian crossing events.

5.2.2 Pedestrian Walking Speeds

An analysis of least squares means and differences of least squares means of pedestrian walking speeds was conducted to determine which pedestrian categories can be expected, with 95 percent confidence, to exhibit walking speeds different than the current Utah pedestrian walking speed guidance of 4.0 feet per second for normal conditions (UDOT 2017). A summary of resulting least squares mean pedestrian walking speeds and 15^{th} percentile walking speeds is provided in Table 5.2. For reference, the sample sizes of each category are provided with the corresponding percentage of the sample population that is represented by each category. The 15^{th} percentile pedestrian walking speeds of 4.0 feet per second, or greater, are illustrated in bold font.

For each data grouping (age, mobility, alertness, etc.), the majority of the observed pedestrian samples exhibited 15^{th} percentile walking speeds greater than 4.0 feet per second. Preliminary analysis of pedestrian walking speeds (see section 4.2.3) showed that 89 percent of all observed pedestrian crossing events were measured at 4.0 feet per second or faster. A few notable categories did exhibit lower 15^{th} percentile speeds, but they make up relatively small percentages of the overall observations. These were '60+,' 'child with adult,' 'cane/walker,' 'cart/stroller,' 'other' mobility, 'wheelchair,' 'group (2+),' and each of the 'mixed group' categories.

Because, a 'mixed group' category must consist of a minimum of two or more individuals, it is logical that each of the 'mixed group' pedestrian categories would exhibit similar speeds to the 'group (2+)' category. This phenomenon of groups exhibiting lower walking speeds is observed in other studies as well (Gates et al. 2006, Knoblauch et al. 1996, Russo et al. 2018). It should be noted that this analysis took place after the research team had actively sought out specific minority categories during the data collection process to insure that sufficient sample sizes were obtained for those categories when possible.

Table 5.2 Summary of Pedestrian Walking Speeds Statistical Analysis

	Category	15th Percentile (ft./s)	Mean Estimate (ft./s)	Sample Size	Percentage of Sample Population
Age	0-12	**4.6**	5.5	89	4.3%
	13-60	**4.2**	5.1	1477	71.7%
	60+	3.6	4.5	351	17.0%
	Child with Adult	3.6	4.5	104	5.0%
	Mixed Group (Age)	3.6	4.5	40	1.9%
Mobility	Cane/Walker	3.1	4.0	28	1.4%
	Cart/Stroller	3.4	4.4	104	5.0%
	Mixed Group (Mobility)	3.0	4.0	11	0.5%
	Mot. Wheelchair	**5.1**	6.1	36	1.7%
	Other	3.8	4.7	42	2.0%
	Pet	**4.1**	5.0	69	3.3%
	Regular	**4.1**	5.0	1768	85.8%
	Wheelchair	3.9	4.8	3	0.1%
Alertness	Attentive	**4.0**	5.0	1959	95.1%
	Mixed Group (Alertness)	3.5	4.5	24	1.2%
	Not Attentive	**4.0**	4.9	78	3.8%
Distraction	Headphones	**4.5**	5.4	33	1.6%
	Mixed Group (Distraction)	3.5	4.4	23	1.1%
	None	**4.0**	5.0	1880	91.2%
	Other	**4.1**	5.0	16	0.8%
	Talk on Cellphone	**4.2**	5.1	34	1.6%
	Text on Cellphone	**4.0**	5.0	75	3.6%
Gender	Female	**4.0**	4.9	616	29.9%
	Male	**4.2**	5.1	1096	53.2%
	Mixed Group (Gender)	3.6	4.5	349	16.9%
Size	Group (2+)	3.7	4.7	663	32.2%
	Individual	**4.2**	5.1	1398	67.8%

5.2.3 Comparison to Data from Previous Research

Findings from previously conducted research on pedestrian walking speeds were summarized in Chapter 2. Pedestrian walking speeds found from these studies were explored in Chapter 2 of this report, but a summary table with findings from this research was created to facilitate comparison. Table 5.3 displays each of the previously conducted studies in chronological order, with their findings that can be most directly compared with data obtained from this study. Since not all categories from these studies aligned perfectly with those of this study; asterisks were used to denote values that are not direct comparisons. Values lower than the UDOT guidance of 4.0 feet per second are italicized. The highest walking speeds in each comparison are bolded.

5.3 Limited Recommendations

Limited recommendations based upon the current Utah MUTCD guidance, pedestrian start-up delay observations, and statistical findings for pedestrian walking speeds are provided in this section. Recommendations for start-up delay values will be discussed first, followed by recommendations for pedestrian walking speeds as used for pedestrian clearance timing.

5.3.1 Pedestrian Start-Up Delay

As none of the observed mean pedestrian start-up delays reached above the current Utah minimum walk interval of 4.0 seconds, no changes are recommended to the minimum 3.2 second pedestrian start-up delay value as found in the HCM (TRB 2016). It is recommended, as set forth in the appropriate equations for walk interval timing, that walk intervals be increased at locations that are expected to have large pedestrian volumes per signal cycle. This guidance is currently in practice by all jurisdictions in Utah and remains supported by the results of this study.

Table 5.3 Comparison of Outside Data with Findings from This Study

		Reference Results			Research Results		
Source	**Location Details**	**Reference Category**	**15th Percentile (ft./s)**	**Mean (ft./s)**	**Research Category**	**15th Percentile (ft./s)**	**Mean (ft./s)**
Knoblauch et al. (1996)	16 sites in VA, MD, NY, DC	Older (65+)	*3.2*	4.0	Age 60+	***3.6***	**4.5**
		Younger (14-65)	4.1	4.8	Age 13-60	**4.2***	**5.1***
		Alone (14-65)	**4.2**	5.0	Individual	**4.2***	**5.1***
		w/ Others (14-65)	***3.9***	**4.7**	Group (2+)	*3.7**	**4.7***
Fitzpatrick et al. (2006)	42 sites in AZ, CA, MD, OR, TX, UT, WA	Age 60+	*3.2*	4.4	Age 60+	***3.6***	**4.5**
		Ages 31-60	*3.8*	4.8	Age 13-60	**4.2***	**5.1***
		Ages 19-30	*3.8*	4.8	Age 13-60	**4.2***	**5.1***
		Ages 13-18	*3.8*	4.6	Age 13-60	**4.2***	**5.1***
		Ages 0-12	*3.5*	4.4	Age 0-12	**4.6**	**5.5**
Gates et al. (2006)	11 sites in WI	Ages 65+	*3.0*	*3.8*	Age 60+	***3.6***	**4.5**
		Ages 30-64	4.0	4.7	Age 13-60	**4.2***	**5.1***
		Ages < 30	**4.2**	4.8	Age 13-60	**4.2***	**5.1***
		Child with Adult	*3.4*	4.0	Child with Adult	***3.6***	**4.5**
		Male	4.1	4.8	Male	**4.2**	**5.1**
		Female	*3.7*	4.6	Female	**4.0**	**4.9**
		Individual	*3.9*	4.7	Individual	**4.2**	**5.1**
		Group 2 to 4	***3.7***	4.3	Group (2+)	***3.7****	**4.7***
		Group 5+	*3.5*	4.1	Group (2+)	***3.7****	**4.7***
Montufar et al. (2007)	8 sites in Winnipeg	Older (65+)	3.5	4.5	Age 60+	**3.6**	4.5
		Adults (<65)	**4.4**	**5.3**	Age 13-60	4.3	5.1
Arango and Montufar (2008)	8 sites in Winnipeg	60+ w/ Cane/Walker	*2.4*	*3.1*	Cane/Walker	***3.1****	**4.0***
Chang et al. (2018)	5 sites in ID	Age 6-12	-	4.9	Age 0-12	4.6*	**5.5***

* indicates speed from a similar category that is not differentiated the same way in this study

italicized values are below the 4.0 ft./s guidance, **bold** values indicate highest in category comparison

5.3.2 Pedestrian Walking Speeds

The 15th percentile pedestrian walking speed values that were found for the pedestrian categories observed in this study suggest that the current 4.0 feet per second UDOT guidance, as implemented in all jurisdictions throughout the state, is suitable for 89 percent of the observed population. Lowering of pedestrian walking speed values to 3.5 or 3.0 feet per second is currently recommended by UDOT guidelines at locations that are outside of normal circumstances. Locations outside of normal circumstances would include school crossings, areas where there are heavy concentrations of elderly persons or children, or special cases where engineering judgment is applied (UDOT 2017). This recommendation should be continued. Based on the observations of this research, many of the locations with larger pedestrian groups and ‘mixed’ category pedestrian crossing events, such as in downtown Salt Lake City, did exhibit lower speeds as well. It is recommended that these areas be evaluated and walking speeds lower than 4.0 feet per second be implemented under engineering judgment.

The 4.6 feet per second 15th percentile walking speeds for the ‘0-12’ age demographic suggest that 3.5 feet per second may be overly conservative for school crossings in the state of Utah. Findings from Chang et al. (2018) in the state of Idaho led to similar conclusions. It is recommended that more research on the topic of school-aged child pedestrians, with and without crossing guards, be conducted; however, before any formal changes to policy or guidelines are made.

5.4 Future Research

This research has demonstrated that there are topics in relation to pedestrian start-up times and clearance intervals that should be continued to be explored. These topics include:

- The psychology of Utah pedestrians; why are they faster than pedestrians in other states?
- Walking patterns of distracted pedestrians compared to non-distracted pedestrians.
- How do pedestrians change their walking speeds to keep up with existing countdown phases?

- How are pedestrian walking speeds different when crossing only half of an intersection, such as along transit routes or roadways with parking in the center?
- How does the length of buffer time affect pedestrian behavior?
- Comparison of pedestrian walking speeds and behaviors at signalized intersections in rural, suburban, and urban environments.
- Comparison of pedestrian walking speeds and behaviors at signalized intersections with and without light rail.
- Evaluation of pedestrian walking speeds at school crossings.
- Evaluation of current signal timings with observed pedestrian group sizes during pedestrian peak hours.

5.5 Concluding Remarks

Pedestrian safety is of high importance in the state of Utah. Having correct guidance for pedestrian start-up times and walking speeds at signalized intersections is a crucial component to ensuring maximum pedestrian safety. The data collected and analyzed in this study will assist all jurisdictions in Utah to make informed decisions about signal timings at locations throughout the state and insure that pedestrians are adequately protected. The continued implementation of current UDOT guidelines with regard to pedestrian start-up times and walking speeds at signalized intersection is recommended; including the continued use of engineering judgment at locations with high pedestrian volumes and high percentages of elderly or disabled pedestrians.

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