University of Nevada, Reno

Studying of Unused Pedestrian Phase Time at Signalized Intersections

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ABSTRACT

At signalized intersections, the time length of a pedestrian phase is usually determined based on a relatively low walking speed in order to accommodate most pedestrians (typically 3.5 ft/s). However, in a large number of cases, a part of pedestrian signal phases is not effectively utilized as all pedestrians can finish crossing most of the time before the pedestrian signal phase ends. Consequently, the operational efficiency at intersections would deteriorate with citizen complaints likely generated if the vehicles and pedestrians on other movements are forced to wait whereas the current signal phase serves no pedestrians.

In order to improve traffic operations at the urban intersection, it is necessary to study the so-called Unused Pedestrian Phase Time (UPPT). In this research, three factors were identified through the literature review and were selected to develop the UPPT model, which are pedestrian walking speed, pedestrian compliance rate, and pedestrian compliance distribution. A total of 25-hour videos including 1033 pedestrian data samples were collected in Reno, Nevada to analyze pedestrian behaviors.

Results indicated that the pedestrian walking speed is influenced by several factors, including pedestrian age, group size, road width, and compliance conditions. Results also showed that pedestrian compliance distribution is significantly different between the first half and late half of pedestrian FDW (Flashing Don’t Walk). Then a model was developed to estimate the UPPT as a function of the three factors. Finally, a case study was conducted to obtain the estimated UPPT at an intersection with long crosswalks.

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1. INTRODUCTION

1.1 Background

Signalized intersections are essential for urban transportation systems, where not only vehicular stops and delays usually happen, but also pedestrian movements are affected. Most established traffic engineering studies which aim to optimize traffic signal operations at intersections are dedicated to improving the efficiency solely from the perspective of vehicular traffic. However, pedestrian timing should be carefully considered as well, which is closely related to pedestrian safety and delay, meanwhile, it may change how the vehicular phases operate [1]. For example, in the United States, pedestrian phases typically run with the "concurrent vehicular signal phases", which means any pedestrian phase starts and ends at the same time when its nearest vehicle-through phase obtains and loses the right-of-way by the signal showing green or red. In order to ensure the safety of pedestrians, a pedestrian phase is supposed to sustain a clearance period for a long enough time. And because pedestrian safety is considered top prioritized, the concurrent vehicular phase may be forcedly extended to accommodate the pedestrian timing. Consequently, the waiting vehicles and pedestrians on the other movements may keep waiting until the end of the count-down period and experience additional delay times.

The duration time of the count-down period is determined by the divided crossing distance by walking speed. This walking speed is regarded as relatively slower than the normal walking speed for a protective purpose, in the US, which typically is a value ranging from 3.5 to 4 feet per second adopted by the local practitioners and recommended by widely recognized guidelines [2]. In terms of the impact of using a conservative walking speed on intersection operations, sometimes pedestrians have all finished the crossing but the pedestrian phase is still ongoing, and then the vehicles and pedestrians on the other movements must wait but no conflicts take place. As a result, citizen complaints may be caused since they could think they are experiencing "unnecessary delay" when facing the situation that there are no pedestrians walking on the crossing but the light keeps showing red.

In this study, this type of unused phase time is called Unused Pedestrian Phase Time (UPPT), and this study aims to analyze and model the UPPT to further investigate its impacts on traffic operations at signalized intersections.

1.2 Problem Statement and Research Motivation

Many practitioners are aware of the existence of the UPPT, and they are thinking about ways to eliminate or shorten the UPPT for improving the intersection capacity and reducing citizen complaints. However, addressing this issue is a very difficult undertaking. The local transportation authorities intend to use a conservative way to time pedestrian phase because many problems remain unsolved such as:

- The UPPT exists at most intersections, and the amount of the UPPT is always varying. For the majority of intersections, the UPPT does not affect much. But at some intersections such as the intersections with long crosswalks or with pedestrians mostly moving fast, the impact caused by the UPPT is obvious. How to identify those intersections is unknown, and for the decision-makers, it is challenging to precisely allocate the resources and implement countermeasures.
- To quantitatively model the UPPT at intersections requires a good understanding of its contributing factors such as the time distribution of finishing crossing for different groups of pedestrians. However, many of the factors are related to pedestrian behaviors, which

have not been well studied by the previous research. Without an estimate of the UPPT, decision-makers hardly conduct a cost-benefit analysis for deploying real-time pedestrian detection in order to improve the intersection operations.

In addition, ensuring safety is crucially required so that a relatively slow walking speed must be used in pedestrian timing development under some jurisdictions.

Nowadays, with emerging technologies rapidly evolving, dynamic pedestrian detection can be applied. The new sensor techniques like LiDAR implemented at intersections can detect and track pedestrians and vehicles accurately also in real-time. It holds great promise to improve the traffic operation as well as ensure pedestrian safety at intersections by early ending the pedestrian phase if no pedestrians detected on the crosswalk. Hence, it is necessary to comprehensively analyze the UPPT as a part of the benefit-cost analysis of next-generation pedestrian sensing and control.

1.3 Research Objectives

This research aims to investigate the factors that cause the UPPT and develop a model for the UPPT estimation. The information can potentially help transportation decision-makers improve local infrastructure planning, i.e., to decide whether, when, and where to implement dynamic pedestrian detection as a means of reducing the UPPT and increasing the intersection operational efficiency.

The factors such as pedestrian walking speed, pedestrian compliance rate, and the distribution of pedestrian compliance were mainly studied in this research. The following tasks and research objectives were conducted:

- Collecting the data of pedestrian walking speed and pedestrian compliance rate, etc. in different urban areas, and evaluating if these measures are statistically different.

- Analyzing the relationship between characteristics of pedestrians (i.e., age and gender) and the observed pedestrian behaviors.
- Developing a model to estimate the UPPT at intersections.
- Conducting a sensitivity analysis for the proposed UPPT estimation model

2. LITERATURE REVIEW

For most practices in the US, a pedestrian phase usually contains three intervals—Walk interval, flashing don't walk(FDW) interval, and steady don't Walk (SDW) interval [2]. During the walk interval, pedestrians who arrive at intersections can start to cross the crosswalk until the FDW interval begins. After the FDW interval starts, only the pedestrians who have already stepped on the crosswalk can keep proceeding to a sidewalk or safety island, and the newly arrived pedestrians are supposed to wait for the next pedestrian phase [3]. During the SDW interval, no pedestrians should walk on the crosswalk.

Figure 1 illustrates a typical pedestrian phase. The Walk interval starts with a sign of a white walking man, the FDW interval begins with a sign of a flashing hand and countdown numbers, and the SDW interval is shown by a steady hand. The walk interval starts with a sign of a white walking man, the FDW interval begins with a sign of a flashing hand and countdown numbers, and the steady don't Walk interval is shown by a steady hand. It should be noted that the time length of FDW interval equals the actual pedestrian clearance time minus the Yellow time and the Red Clearance time. And the pedestrian clearance time can be calculated by Equation 1[2].

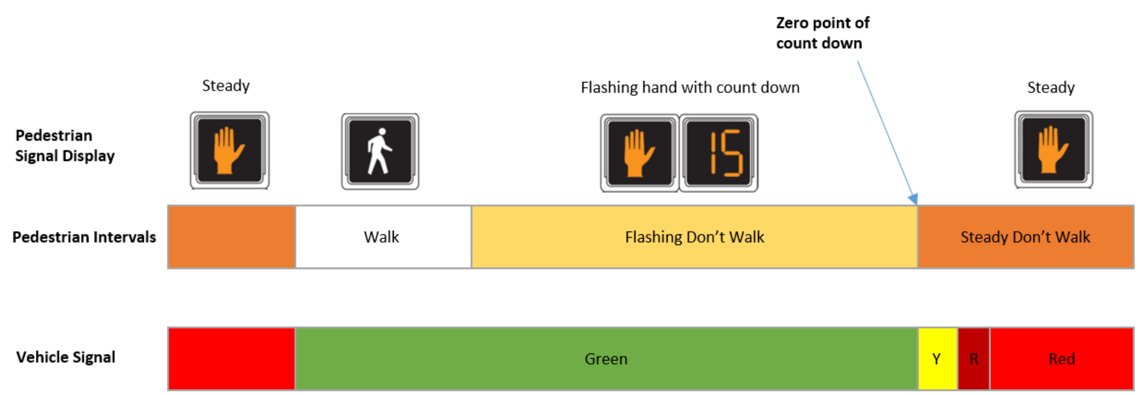


Figure 1. A Typical Pedestrian Signal Phase

$$PCT = \frac{D_c}{V_p} \qquad (1)$$

where

PCT = pedestrian clearance time (seconds); D_c = pedestrian crossing distance (feet); and V_p = pedestrian walking speed (feet per second).

Which is recommended by the *Signal Timing Manual* [2], Figure 2 illustrates that a 3.0 ft/s walking speed is used to calculate the time length of "Walk + Pedestrian Clearance" (the distance from the push button to the far side curb is used), while a 3.5 ft/s walking speed is used to calculate the time length of "Pedestrian Clearance" (the distance from one curb to the far side curb is used). As a lower walking speed even than 3.5 ft/s is considered, we can see a startup time is very important, which may consist of pedestrian reaction time, etc. Typically, the Walk interval is 7 seconds.

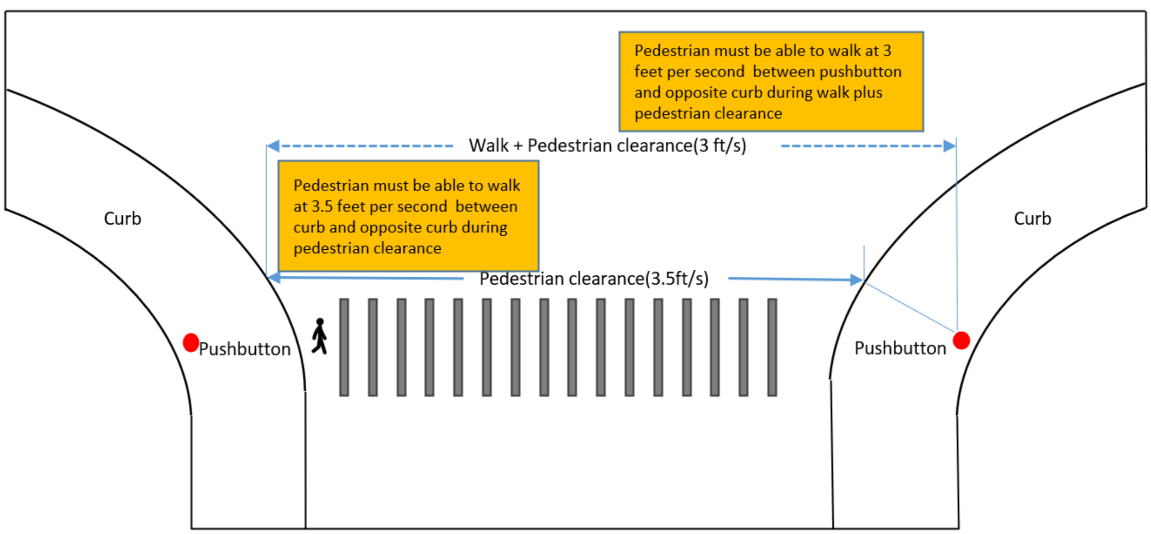


Figure 2. Pedestrian Interval Requirements Based on Walking Speed

Additionally, some pedestrians who start to cross after the beginning of FDW period may change the length of UPPT. Regardless of the rule of Flashing Don't Walk, some pedestrians would like to cross the intersection at a very high walking speed even if very limited time left for them to finish crossing.

Thus, pedestrian walking speed, pedestrian startup time, and compliance were selected as the influencing factors on UPPT. Startup time was defined as the time length from the moment when walk interval begins to the moment when pedestrians actually step on the crosswalk. And the compliance behavior refers to whether the pedestrians who arrive in FDW intend to obey the rule and keep waiting for the next phase. The literature review in this research was conducted with the following parts – pedestrian startup time studies, pedestrian walking speed research, pedestrian compliance behavior analyses, pedestrian impact studies, and automated pedestrian detection techniques.

2.1 Startup time

In the previous research, Knoblauch et al. [4] found the mean value of startup time for young pedestrians was identical for both single pedestrian and grouped pedestrians, which is 1.93 seconds. For the pedestrians at elder ages (typically over 65 years old), the mean of the startup time is 2.5 seconds for the single pedestrian and 2.43 seconds for grouped pedestrians. Laplante and Kaeser [5] ignored the startup delay under the assumption that most pedestrians chose to wait at the positions which are very close to the curb.

As an important part of the startup time, reaction time is defined as the time length needed for pedestrians to take action after they notice the pedestrian phase starts. In New York City, Peters et al. [6] found the average pedestrian reaction time for those who waited on the curb is 0.23 seconds, whereas the average reaction time for the pedestrians who waited on the sidewalk is 0.51 seconds. The study also found that many pedestrians waited on the curb rather than waiting on the sidewalk before crossing. Ma et al. [7] Studied the pedestrian perception–reaction time based on 520 field-collected samples and found that the average perception–reaction time for the pedestrians under age 50 is 0.23 seconds, for the pedestrians whose ages are over 50, the average perception–reaction time is 0.51 seconds.

According to the previous study, the pedestrian reaction time or the pedestrian startup time is very short compared with the length of typical pedestrian phases. And the startup time only changes slightly, which can be negligible. Hence, the startup time is defined as a constant value.

In order to develop a model to estimate the value of UPPT at intersections, field data were collected, the result showed that 85% of pedestrians' startup times are less than 2.5 seconds. Hence, 2.5 seconds are used in this research for the following analyses.

2.2 Walking Speed

Studies are devoted to determining pedestrian walking speed from many different perspectives. Laplante and Kaeser [5] reviewed pedestrian walking speed in *MUTCD* from 1948 to 2004 and recommended a 3 ft/s walking speed across the total crossing distance for walk interval plus clearance interval. Bosina and Weidmann [8] collected and reviewed more than 200 walking speed measurements available in the literature and confirmed that the average walking speed of 1.34 m/s (4.40 ft/s) could be a good estimation. Knoblauch et al. [4] conducted a field study on pedestrian walking speed and startup time. He found that the 15th percentile walking speed of young pedestrians in winter is 4.36 ft/s and 3.48 ft/s for old pedestrians. In summer, the 15th percentile walking speed for young pedestrians is the same as that in winter and 3.54 ft/s for older pedestrians. The study recommended 4 ft/s walking speed for young pedestrians and 3 ft/s walking speed for old pedestrians for design purposes. Fitzpatrick et al. [9] found that the 15th percentile walking speed for younger pedestrians is 3.77 ft/s and the 15^{th} percentile walking speed for old pedestrians is 3.03 ft/s. The study recommended a 3.5 ft/s walking speed for the general population and 3.0 ft/s walking speed for the older or disabled population. Arango and Montufar [10] focused on the walking speed of older pedestrians who use walkers or canes for mobility in Winnipeg and Canada. The average walking speed of those pedestrians is 3.11 ft/s, and the 15^{th} percentile speed is 2.39 ft/s. Coffin and Morrall [11] suggested a walking speed of 1.2 m/s (3.94 ft/s) for elderly pedestrians at signalized intersections.

Many factors can influence pedestrian crossing speed. Gates et al. [12] found that pedestrian walking speed was affected by age, disability, traffic control condition, and group size. Pedestrians over age 65 were the slowest among all age groups. The crossing speed of grouped pedestrians was slower than individual pedestrians by 0.4-0.6 ft/s on average. The pedestrian gender doesn't show a significant influence on pedestrian crossing speed. Zhang et al. [13] investigated the effects of pedestrian green time, crosswalk length and pedestrian crossing direction on pedestrian walking speed. They found that pedestrian crossing speed is higher on long crosswalks. Bosina and Weidman [8] used existing literature to study the factors influencing pedestrian walking speed and grouped the most important factors. They found that pedestrian age and pedestrian density has the strongest influence on pedestrian walking speed. Fitzpatrick's [9] found the walking speed of older pedestrians (over 60 years old) and younger pedestrians (under 60 years old) was statistically different in his study, but the effect of curb to curb crossing distance and gender are not statistically significant. In Jordan, Tarawneh [14] found age, gender, group size, and street width are significant factors for pedestrian speed. This study found that gender is a significant influencing factor on pedestrian walking speed, which differs from Gates [12]. Pedestrians with group sizes larger than three tend to walk slower than other pedestrians. Crossing speed on wider roads is more likely to be higher than that on narrow streets.

Knoblauch et al., [4] used a hand-held, digital electronic stopwatch to collect pedestrian crossing data on-site. This method works for intersections with low pedestrian volumes. However, when the pedestrian volume is high and several pedestrians are crossing at the same moment, it's hard to record all the information effectively and accurately at the same time. The video camera is still the most commonly used data collection tool.

For previous pedestrian walking speed studies, most of the recommendations range from 3 ft/s to 4.5 ft/s. Some studies give different advice based on different pedestrian characters. For the influencing factors, their conclusions on pedestrian age are pretty unified and proved. However, there are different conclusions in other influencing factors—street width and pedestrian gender. The influence of those two factors on pedestrian walking speed needs to be further verified and analyzed.

2.3 Compliance

In China, Zhuang et al.[15] found that pedestrians arriving during FDW were strongly unevenly distributed towards crossing over waiting -- 83.2 percent pedestrians choose to cross while 14.8% pedestrians choose to wait. Ma et al. [7] Found 12.4 percent pedestrians over age 50 decided to cross during countdown pedestrian signal display (the same as FDW) period and 92.7% for pedestrians under age 50. Xiong's [16] study found 25.7 percent of pedestrians chose to cross during the display of FDW. Fu and Zou [17] studied children's behavior at school intersections in Jinan, China. They found that 6.9 percent of children choose to cross during Flashing Green Man (the same as FDW). In Hong Kong, Lee and Lam [18] found that most pedestrians will immediately cross the crosswalk during the first 7s of flashing green(the same as FDW) when the flashing green time is 13 s while over half of pedestrians will not start to cross when they arrive in the last 6s of flashing green time. Pedestrians have a lower delay by entering crosswalks before the walk interval and saved more time by beginning to cross in FDW [19]. Iryo-Asano et al. [20] developed a quantitative model to estimate pedestrian compliance decisions during FDW in Japan.

The results of the compliance rate in these studies differ from each other, and no data is from the US. Due to different country cultures and different pedestrian signal principles, the result in the US may vary from other countries. Moreover, all the previous studies only gave a rough analysis of pedestrian compliance behavior during FDW, and no study has a detailed analysis of the passing FDW when pedestrians choose to cross or not to cross.

2.4 Pedestrian Impact Study

Studies have addressed the impact of pedestrians on intersections. Chen et al. [21] built an analytical model to analyze the influence of pedestrians on the capacity of right-turning traffic at signalized intersections. The results concluded that under low pedestrian volume, the right turn capacity is strongly impacted by the crossing pedestrian. The effects of additional pedestrians decrease as the pedestrian volumes increase. Milazzo et al. [22] developed a conflict-zone-occupancy (the fraction of the effective green time during which pedestrians occupy a conflict zone) approach to study the saturation flow rate influenced by the interaction between pedestrians and vehicles at signalized intersections. Feng and Pei [23] analyzed vehicle delay at signalized intersections on the condition when pedestrians are crossing at signalized intersections. Tian and Xu [24] proposed a probability model to investigate the effects of the pedestrian phase on intersection capacity and delay. Ishaquea and Noland [25] used the VISSIM micro-simulation model to study travel time costs for both vehicles and pedestrians in various pedestrian phasing scenarios. Results indicate that the strategy selection is different between considering pedestrian and just considering vehicular traffic. Yang et al. [26] built a model to estimate the expected delay for the major street through vehicles based on the pedestrian arrival time and motorist yielding behavior. Wei et al.[27] built a model to predict vehicular delay using vehicle volume, pedestrian volume and yield rate as the prediction factors. Wang and Tian [28] developed an improved pedestrian delay model for signalized intersections with a two-stage crossing design. Marisamynathan and Vedagiri [29] claimed that the generally used pedestrian delay models derived from HCM are not suitable in India and developed a new model to estimate pedestrian delay under mixed traffic conditions.

All the existing studies focused on the influence of pedestrian crossing period; however, it's impossible to forbid pedestrian from crossing intersections or directly remove the pedestrian phases. The delay/capacity decrease will always exist as long as pedestrians are allowed to cross. No study has stressed the phase time unused by pedestrian and the unnecessary delay/capacity decrease, nor was any model built to estimate the unused pedestrian phase time.

2.5 Automated Pedestrian Detection

The UPPT can be potentially eliminated if the sensor detects that all pedestrians have finished crossing and then actively terminate the ongoing pedestrian signal phase.

Some systems were developed as per this goal. Puffin (Pedestrian User-Friendly Intelligent) crossings can automatically cancel the walk signal if the pedestrians depart the crosswalks before the end of walk signal or the no pedestrians are present. Puffin crossing can also detect the presence of consecutive pedestrians on the crosswalk and extend the signal if the pedestrian could not finish crossing. In 1990, the first real-life test of Puffin was conducted on two intersections in the United Kingdom, and the results are sufficiently promising to merit installation at many more sites [30]. Pussycat (Pedestrian Urban Safety System and Comfort at Traffic Signals) Crossing in the Netherlands is a similar system as Puffin. It utilizes mat detectors and infrared detectors to replace the pedestrian's push-button, and the clearance interval is variable for slow pedestrians and groups of pedestrians. It was evaluated by Peter Levelt in 1993 based on observing the pedestrian crossing behaviors before and after the installation. Overall, he found the new pussycats were "the best choice at this moment," and "Lengthening the pedestrian clearance interval could further improve the signals at selected locations." [31].

These types of crossings have been successfully used in Europe for many years, but no document reports any practical implementation of the automated pedestrian detection system in the US. The study of UPPT will justify the necessity of using this system in the US.

3. FACTOR ANALYSIS

The amount of UPPT can be affected by pedestrian walking speed, pedestrian compliance rate and compliance distribution. However, the established research related to these three factors is scarce. In this study, a field investigation has been conducted in different locations in the urban environment in Reno, Nevada.

3.1 Data Collection

3.1.1 Site Selection

Seven signalized intersections were selected to perform a field study on pedestrian walking speed and compliance behavior. These intersections were chosen for the moderate pedestrian flow which is not too high or too low. If the pedestrian volume is too high, it’s hard for the author to identify the pedestrian one by one through the camera; if the volume is too low, it takes too much time to collect enough samples. Intersections were selected from different area types. Two intersections are located near school area: N Virginia St & Artemesia Way and 9th St& N Virginia St. Three intersections are in the busy downtown area: W 6th St & N Sierra St, W 4th St & Ralston St, and Center St & E Plaza St. The crosswalk lengths are similar between the school area and the downtown area. To find out if the pedestrian compliance behavior will be influenced by the long crosswalks, two intersections in the school area with long crosswalks up to 135 feet were selected: W 7th St & N McCarran Blvd and 15th St & N Virginia St. Site information is shown in Table 1, and the site location is illustrated in figure 3. The lengths of crosswalks range from 54.4 feet to 135.6 feet, and the walk intervals range from 7 seconds to 48 seconds, the FDWs range from 12 seconds to 35 seconds. All intersections have standard road markings that comply with MUTCD guidelines.

Table 1. Site Information

Intersection	Area type	Intersection type	Crosswalk 1 (ft)	Crosswalk 2 (ft)	Walk Interval (s)	FDW (s)
Artemesia Way & N Virginia St	School Area	3SG	59	59	7	17
9th St & N Virginia St		4SG	72.5	62.3	8	20
W 6th St & N Sierra St	Downtown Area	4SG	62.38	54.42	8	12
		4SG	79.83	/	7	21
W 4th St & Ralston St		4SG	64.2	63.4	8	15
			61.4	60.5	48	12
N Center St & E Plaza St		4SG	75.5	63.8	12	19
W 7th St & N McCarran Blvd	School Area (Long crosswalk)	4SG	135.55	/	12	35
			/	117.2	10	30
15th St & N Virginia St		4SG	95	92	7	23

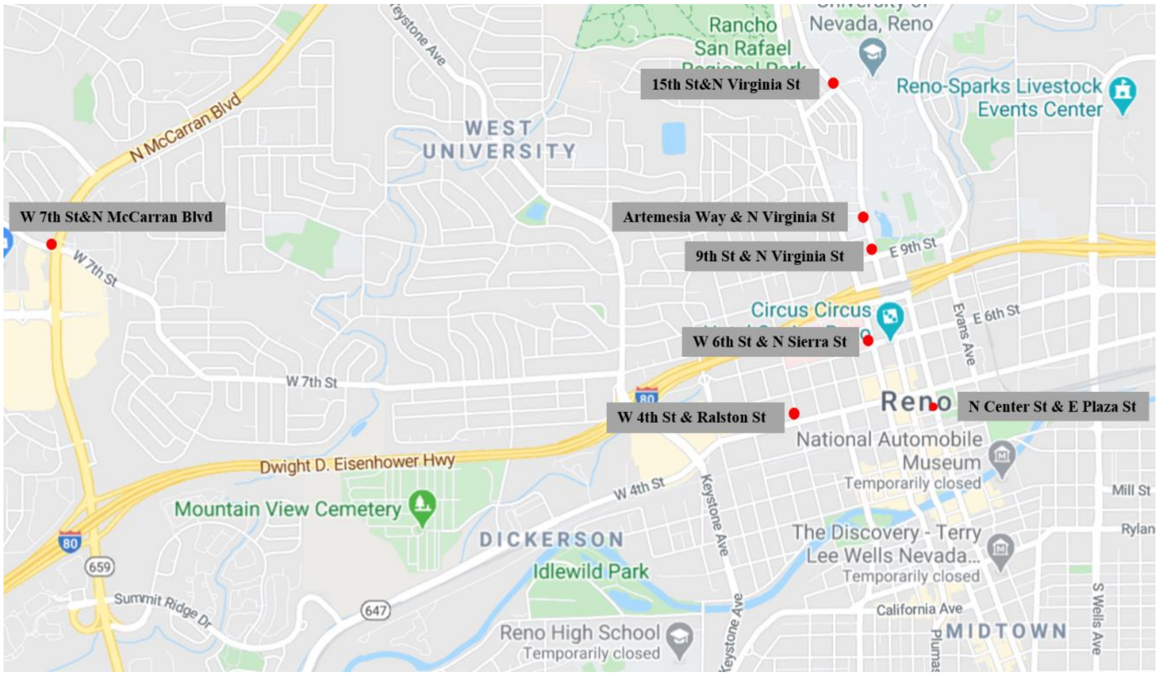


Figure 3. Site Location

To record the pedestrians walking speed, video cameras were used as the most inexpensive tool. Pedestrian compliance rate and pedestrian appearance also can be collected through the cameras. Twenty-five hours of video and a total of 1033 pedestrians' information were collected in the field. The data collection activities were conducted from 11 am to 1 pm during the day time in March 2020. The reason to select this time period is that the pedestrian flow is relatively high, and the light condition is good for the cameras to film good quality videos. The population composition is complicated in the downtown area, especially at the intersection near the bus station. From the perspective of the safety issue, the PM peak hour is not a good choice. Finally, the noon peak hour is the best choice when considering good light conditions, moderate pedestrian flow, and safety issues.

3.1.2 Pedestrian Information

Pedestrian crossing time, pedestrian gender, pedestrian age, group size, compliance rate, and compliance distribution in FDW were collected through cameras and were manually processed. The start time of pedestrian crossing was defined when the pedestrians step down the curb on one intersection side (Curb A), the end of pedestrian crossing time was defined when the pedestrians step on to the curb on the other intersection side (Curb B). Figure 4 illustrates the definition of curb A and curb B. The crosswalk length is the distance from the red curb A on one roadside to the red curb B on the other roadside. The pedestrian walking speed is then calculated by dividing the crosswalk length by the pedestrian crossing time.

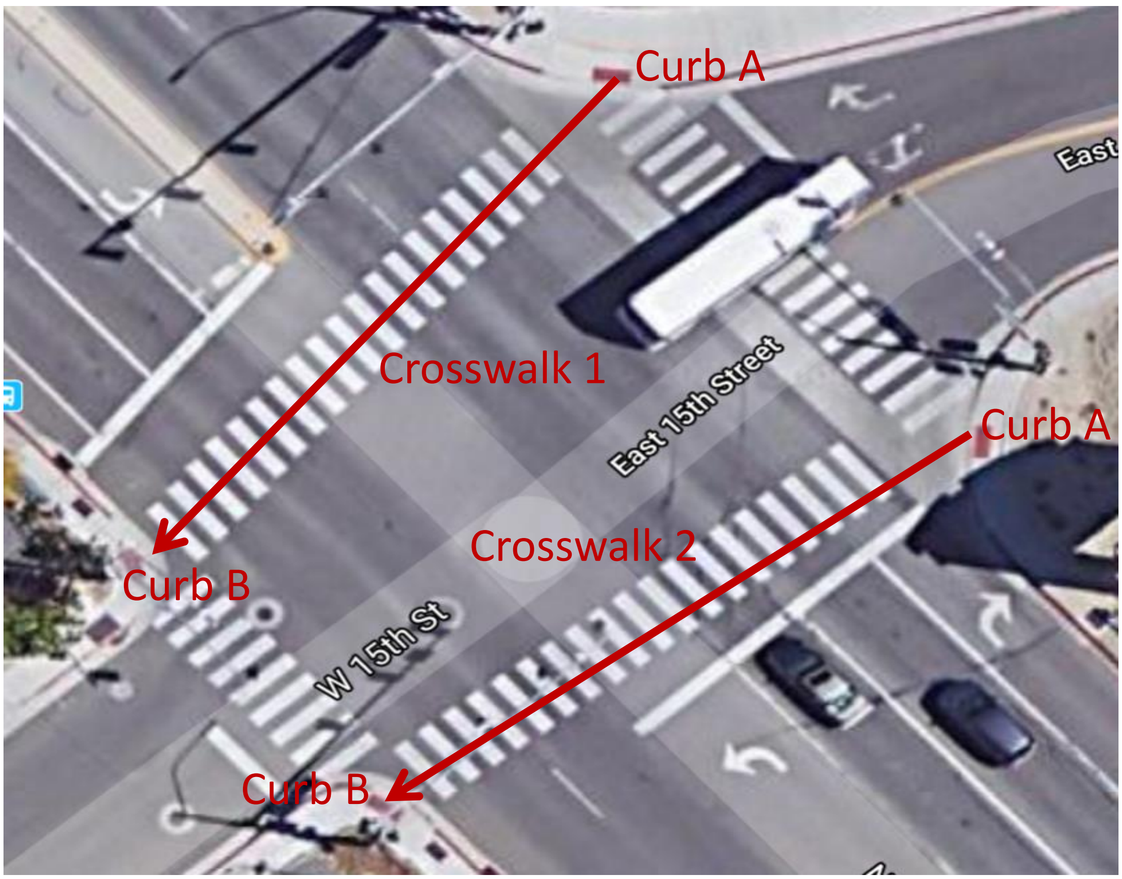


Figure 4. Layout of Intersection at 15th St and Virginia St

Group size is defined as the number of pedestrians walking together from the start of crossing to the end of crossing in on cycle. Pedestrians who are defined as a group should know each other, which is easy to judge from their body language and body distance. The start of pedestrians' crossing behavior in a group is defined by the first pedestrian who steps down the curb; the end of pedestrians' crossing behavior in a group is defined by the last pedestrian who steps on the other curb.

Gates et al. [12] used clearly defined age groups to study the pedestrian speed profile. However, such clearly defined age groups are based on estimation. In fact, it is impossible to estimate the age accurately only from pedestrians' appearance. The author used three age groups: young, middle and old, which are easier to estimate and more practical than using the clearly defined age groups.

When pedestrians arrive in FDW, their choices on crossing and not crossing are recorded, pedestrians who began to cross in FDW were defined as non-compliant pedestrians, pedestrians who waited for the next cycle were defined as compliant pedestrians. Compliance rate(c) was calculated by Equation (2):

$$\text{Compliance Rate}(c) = \frac{\text{Number of Compliant Pedestrians}}{\text{Number of Pedestrians Arrive in FDW}} \qquad (2)$$

Pedestrian compliant/non-compliant distribution is the time stamp in FDW when a compliant/non-compliant pedestrian arrives at the start curb. For instance, the distribution is at the 6th second of the FDW if the pedestrian arrives at the curb at the 6th second in the FDW. For compliant pedestrians, they will choose to wait for the next cycle; for the non-compliant pedestrians, they will begin to cross at the 6th second.

Because this study focused on getting the common pedestrian walking speed distribution, pedestrians with special crossing behaviors were excluded from the original data. The frequency of occurrence of those pedestrians is low, but their speed will be extraordinarily high or extraordinarily low. The walking speed of those pedestrians is not considered when evaluating common pedestrian crossing speed, so they were not included in the analysis. Pedestrians with the following conditions were excluded [12]:

- Pedestrians who crossed in red time;
- Diagonal crossing behavior;
- Pedestrians who have confronted with a turning vehicle;
- Pedestrians who didn't use the crosswalks;
- Group size larger than 10 people.

4.1.3 Data Summary

The pedestrian information is summarized in Table 2. In general, the number of male pedestrians is a bit higher than the number of female pedestrians. Young pedestrians count the most among all the age groups, and there is no significant difference between the number of old pedestrians and middle age pedestrians. The school area has the highest young pedestrians percentage, the downtown area has the highest old pedestrians percentage and middle age pedestrians percentage.

Table 2. Data Summary

Area Type	Intersection	Effective Sample	Male	Female	Old	Middle	Young	Average group size
School	N Virginia St & Artemesia Way 9th St & N Virginia St	354	42.66%	57.34%	3.39%	5.37%	91.24%	1.93
Downtown	W 6th St & N Sierra St W 4th St & Ralston St Center St&E Plaza St	440	59.77%	40.23%	14.77%	14.32%	70.68%	2.00
School (Long Crosswalks)	W 7th St & N McCarran Blvd W 15th St & N Virginia St	239	53.14%	46.86%	6.28%	1.26%	92.47%	1.41
Total		1033	52.47%	47.53%	8.91%	8.23%	82.87%	1.84

3.2 Analysis

3.2.1 Pedestrian Compliance Rate

When pedestrians arrive during FDW, they have two choices— to cross or not to cross. The pedestrian compliance rate in different area types is summarized in Table 3. From the total 1033 data samples, 183 pedestrians arrived in the FDW, which are only 17.8% of the total arrival pedestrians. The compliance rate during FDW is relatively low and the compliance rate in all area types is below 50 percent. The compliance rate is higher in the downtown area than that in the school area; the compliance rate is higher for long crosswalk intersections when both located in the school area.

Table 3. Pedestrian Compliance Rate Based on Area

Area Type	Sample Size	Pedestrians Arrive in FDW (%)	Compliance Rate (%)
School	66	18.6%	27.3%
Downtown	51	11.6%	42.4%
School (Long Crosswalk)	66	27.6%	35.3%
Total	183	19.9%	34.4 %

Table 4 presents the compliance rate during FDW for pedestrians under different age, gender, and group sizes. The compliance rate for all pedestrians is 34.4%, which indicates that most of the pedestrians arrive in FDW choose to cross. Female pedestrians have a higher compliance percentage than male pedestrians and pedestrian compliance rate increases as age increases. Pedestrians are less likely to cross in FDW when the group sizes become larger. The number of pedestrians who have a group size larger than three is very small. Therefore, pedestrians crossing in group sizes larger than three are summarized together.

Table 4. Pedestrian Compliance Rate Based on Character

	Sample Size	Factor	Compliance Rate
Gender	105	Female	40.00%
	78	Male	28.21%
Age	162	Young	32.21%
	8	Middle	48.88%
	13	Old	52.73%
Group Size	116	1	25.28%
	36	2	41.09%
	31	3+	60.71%
Total			34.39%

The pedestrian compliance rate in the first half of FDW and late half of the FDW is listed in Table 5. From the 183 pedestrians who arrived in FDW, 96 pedestrians arrived during the first half of FDW, and 87 pedestrians arrived in the late half of the FDW. The compliance rate is very different between the two time periods – 5.2 percent in the first half of FDW and 67.8% in the late half of FDW.

Table 5. Pedestrian Compliance Rate Based on Time Periods

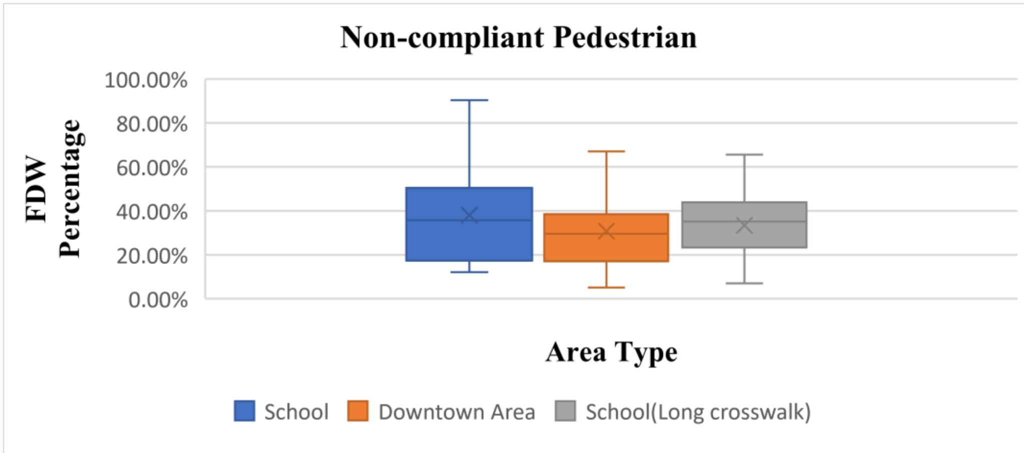
Time Period	Sample Size	Compliance Rate
Early Half FDW	96	5.2%
Late Half FDW	87	66.6%
Total	183	34.4%

3.2.2 Pedestrian Compliance Distribution

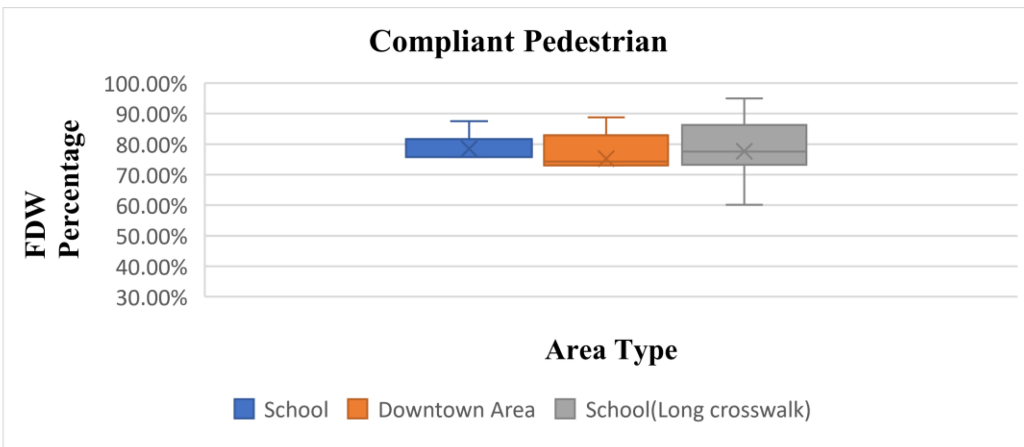
When pedestrians make decisions on crossing or not crossing during FDW, the main influencing factor is whether the remaining FDW is enough. When the remaining FDW is enough, pedestrians are more likely to cross, and if the time is not enough, their intention to cross will be very weak. The pedestrian compliance distribution could uncover the relationships between pedestrian crossing behavior and the passing FDW time. Due to different intersections and crosswalks have different FDW, this study used the percentage of FDW to unify the calculation unit. Figure 5 illustrates that the average distribution of compliant pedestrians is 76.8 percent of the FDW, while the average distribution of non-compliant pedestrians is 34.4 percent of the FDW. The arrow begins with 0 percent of FDW (timer begins to count) and ends with 100 percent of FDW (timer finishes count).

Figure 5. Pedestrian Average Compliance Distribution

The distribution of compliant pedestrians and non-compliant pedestrians in different area types is presented in figure 6. For most non-compliant pedestrians, the distribution ranges from 20 percent to 50 percent of the FDW; for most compliant pedestrians, the distribution ranges from 60 percent to 85 percent of the FDW. Non-compliant pedestrians from intersections with long crosswalks have a relatively lower FDW percentage than those from intersections with shorter crosswalks. But the difference is not apparent for compliant pedestrians. Intersections in the downtown area have the lowest FDW percentage among the three area types, and the FDW percentage in the school area with short crosswalks is the highest for both compliant and non-compliant pedestrians.



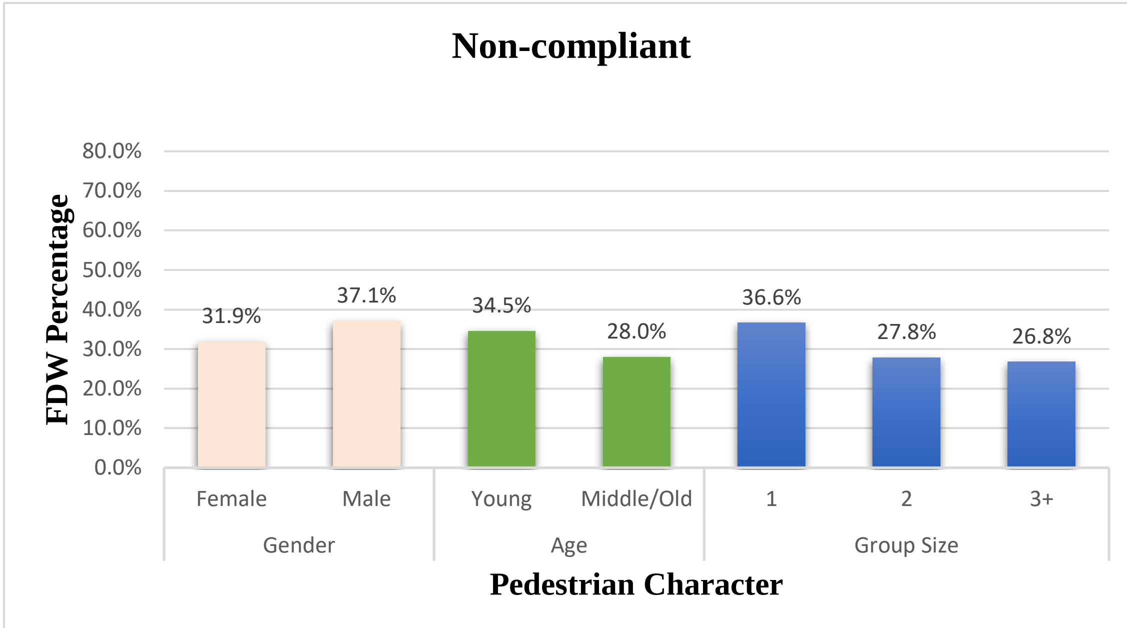
(a)



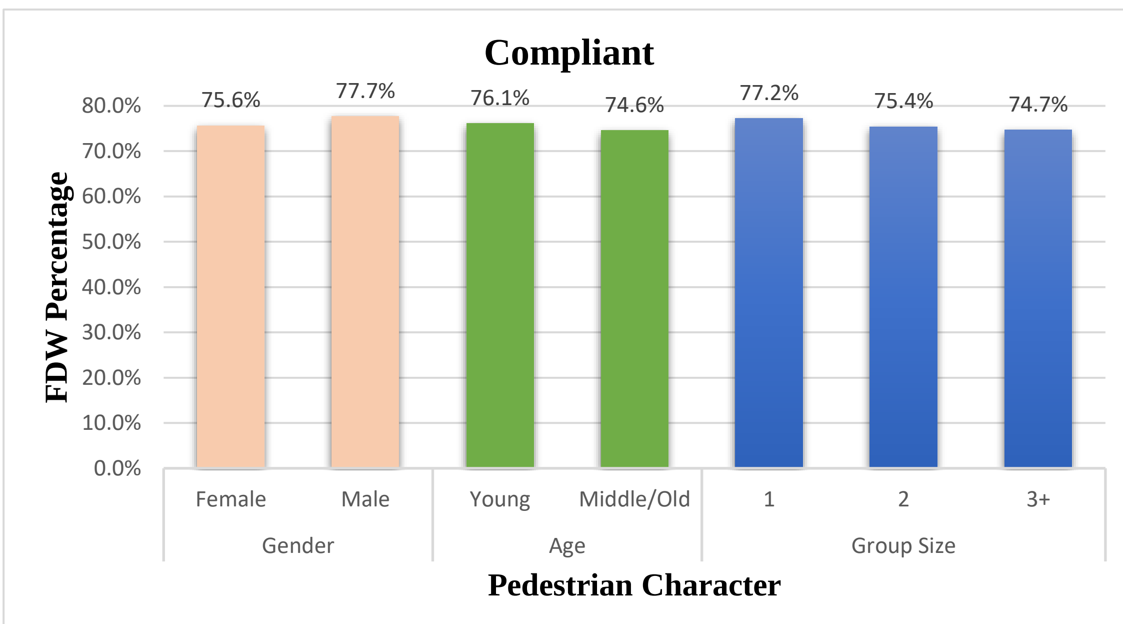
(b)

Figure 6. Pedestrian Compliance Distribution by Area Type:

(a) non-compliant pedestrian; (b) compliant pedestrian



(a)



(b)

Figure 7. Pedestrian Compliance Distribution by Pedestrian Character:

(a) non-compliant pedestrian; (b) compliant pedestrian

The distribution of compliant pedestrians and non-compliant pedestrians summarized by different pedestrian characters is illustrated in Figure 7. Male pedestrians have a slightly higher FDW percentage than female pedestrians under the compliant condition, and male pedestrians have a higher FDW percentage under non-compliant condition. For different age groups, because middle age pedestrians and old age pedestrians are much less than young age pedestrians, they are summarized together. Young pedestrians have a slightly higher FDW percentage than old/middle-aged pedestrians under the compliant condition and an obviously higher FDW percentage than old/middle-aged pedestrians under the non-compliant condition. For different group sizes, the single pedestrian has the highest FDW percentage for both compliant and non-compliant conditions, but the difference between group size two or group size more than three is not apparent.

3.2.3 Walking Speed

The walking speed mentioned in this study is calculated by the distance from the curb to the farside curb divided by the crossing time. The crosswalk distances at seven selected intersections were measured using Google Earth, and the crossing times were collected based on video recording.

Figure 8 shows the walking speed distributions of the 1033 pedestrian samples collected in the field. The shape of the distribution resembles a normal distribution [32]. Pedestrians with walking speed from 4.0 feet/s to 5.0 feet/s are most observed.

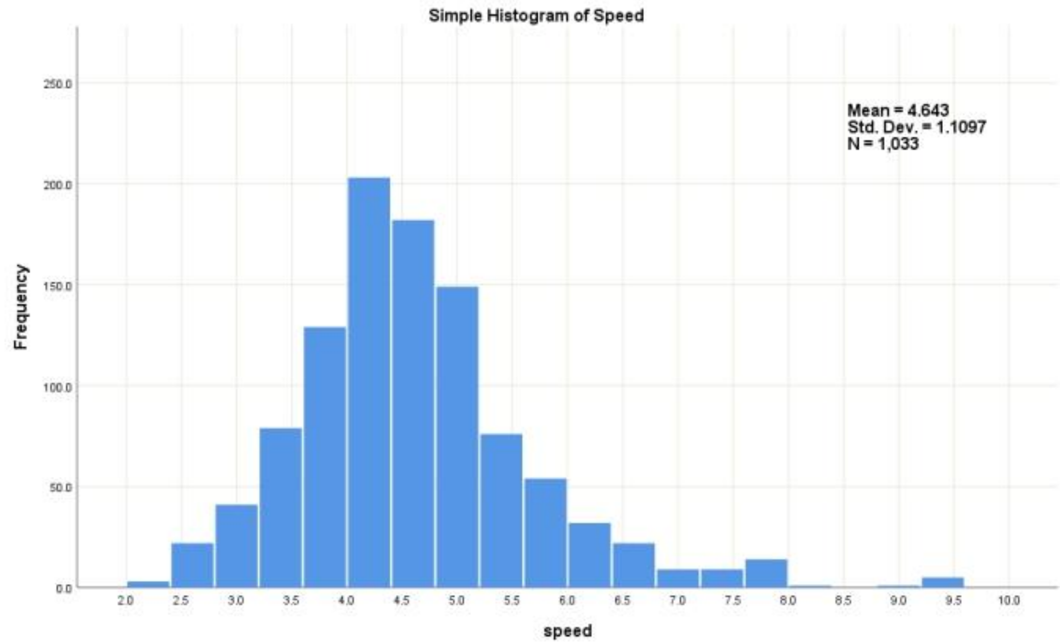


Figure 8. Walking Speed Distribution

Table 6 shows the pedestrian mean speed, $15^{th}/50^{th}/85^{th}$ percentile speed information for different groups with different characteristics i.e., pedestrian gender, road width, pedestrian age, and pedestrian group size.

The mean walking speed of male pedestrians is slightly faster than the one of female pedestrians, and the $15^{th}/50^{th}/85^{th}$ percentile speed data follow the same trend. Crosswalk widths are classified into two groups – over 90 feet and shorter 90 feet as 90-foot crosswalks typically exist at the intersections along major arterials (generally six-lane roadways). The mean walking speed for street widths (>90 feet) is faster than the one for street width (<90 feet), and the $15^{th}/50^{th}/ 85^{th}$ percentile speed data follow the same trend as well. The mean walking speed of young pedestrians is the highest among the three pedestrian age groups, middle-aged pedestrians walk slightly faster than the elder pedestrians, so do the $15^{th}/50^{th}/85^{th}$ percentile speed data. Additionally, it shows that the mean/$15^{th}/50^{th}/85^{th}$ walking speed becomes lower if the pedestrian group size extends. Only one exception can be seen where the 85th percentile walking speed for three-people group is slightly lower than the one for the four-people group.

Table 6. Walking Speed Information by Groups of Different Characteristics

Factors		Sample Size	Walking Speed (ft/s)			
			Mean Speed	**15th Percentile**	**50th percentile**	**85th Percentile**
Gender	Female	492	4.56	3.6	4.45	5.58
	Male	541	4.72	3.63	4.53	5.69
Crosswalk Width	below 90 feet	794	4.42	3.56	4.38	5.19
	over 90 feet	239	5.38	4.32	5.22	6.78
Age	Old (>65)	93	4.09	3.36	3.92	5.00
	Middle (45 to 65)	85	4.19	3.46	4.18	4.91
	Young (<45)	855	4.75	3.8	4.75	5.7
Group Size	Single one	661	5.00	4.03	4.83	5.86
	Two People	185	4.38	3.77	4.32	4.97
	Three People	60	3.97	3.62	3.92	4.33
	Four People	61	3.78	3.35	3.89	4.38
	Five People and more	66	3.20	2.71	3.16	3.57
Total		1033	4.64	3.63	4.52	5.59

In order to further verify whether these characteristics are the influencing factors of pedestrian walking speed, Analysis of variance (ANOVA) was conducted to examine the differences among groups for each characteristic from a statistical perspective. ANOVA is a collection of statistical models and their associated estimation procedures used to analyze the differences among group means in a sample. It should be noted that ANOVA mostly compares three or more groups such as for “Pedestrian Age” and “Pedestrian Group Size”, while it can be used for the comparison between two groups like “Gender” and “Crosswalk Width” although an independent-samples t-test is more commonly used for two groups. T-test and ANOVA function similarly, thus only ANOVA tests were used in this study.

In this study, Multi-factor and one-way ANOVA tests (one-way ANOVA only uses one independent factor) were conducted for: Pedestrian Group size (1, 2, 3, 4, 5 or 5+ people), gender (male, female), age (young, middle, old) and crosswalk width, pedestrian walking speed is the dependent variable. The analysis was conducted via SPSS software and the results are summarized in Table 7. The variances are homogeneous that satisfies the third pre-condition of ANOVA. Pedestrian age and group size are significant influencing factors at a 95 percent confidence level (significance<0.05), which verifies the former studies. But the result for road width is different from Kay Fitzpatrick [18], in this study, road width is a significant influencing factor. Pedestrian gender is not a significant influencing factor at a 95 percent confidence level, which is different from the study of Tarawneh [23].

Table 7. ANOVA Test Results

Factors	Sum of Squares	Degree of Freedom	Mean Square	F Value	Significance
Age	6.278	2	3.139	4.292	0.005
Gender	0.048	1	0.048	0.066	0.797
Group Size	46.252	4	5.781	7.904	0.000
Road Width	27.888	2	1.859	2.542	0.001
Total	23519.463	1032			

The walking speed in the school area and the downtown area is summarized in Table 8. Based on observation, most pedestrians in the school area are students. In the downtown area, there are more family groups with a higher percentage of old and middle-aged pedestrians. The average walking speed in the school area is slightly higher than that in the downtown area, the percentile walking speed follows the same trend as the mean walking speed except for the 15th percentile speed—the 15th percentile walking speed shows the same for the two area types.

Table 8. Walking Speed by Area Type

Area Type	Sample Size	walking speed(ft/s)			
		Mean speed	15th Percentile	50th percentile	85th Percentile
School	354	4.46	3.56	4.38	5.19
Downtown	440	4.39	3.56	4.31	5.12

Then the walking speed in the two area types is analyzed through a one-way ANOVA. In SPSS, the school area was assigned with code 1, the downtown area was assigned with code 2, the walking speed is the dependent variable and area type is the independent factor. The data samples passed the test of homogeneity of variance. The result of ANOVA analysis is shown in Table 9. The mean square between different groups is 1.081, the mean square within groups is 0.931, the F value is calculated by dividing the mean square of between groups by the mean square of within groups, which is 1.161, the significance value is 0.282, which is bigger than 0.05. Therefore, the walking speeds in the two areas are not statistically different at a 95 percent confidence level.

Table 9. One-Way ANOVA Test (School Area/Downtown)

	Sum of Squares	Degree of Freedom	Mean Square	F Value	Significance
Between Groups	1.081	1	1.081	1.161	0.282
Within Groups	736.239	791	0.931		
Total	737.319	792			

The walking speed of compliant pedestrians and non-compliant pedestrians is summarized in Table 10. The mean walking speed for the non-compliant pedestrian is higher than that for compliant pedestrians. The $15^{th}/50^{th}/85^{th}$ percentile walking speed follows the same trend as shown as the mean walking speed.

Table 10. Walking Speed by Compliance Behavior

Compliance	Sample Size	Walking Speed(ft/s)			
		Mean Speed	15th Percentile	50th percentile	85th Percentile
Yes	64	4.68	3.56	4.72	5.59
No	119	5.24	3.89	4.99	6.65

The result of the one-way ANOVA analysis is listed in Table 11. The ANOVA analysis shows that the mean square between different groups is 13.219, the mean square within groups is 1.787, the F value is calculated by dividing the mean square of between groups by the mean square of within groups, which is 7.399. The significance value is 0.007, which indicates the pedestrian walking speed is statistically different at a 95 percent confidence level.

Table 11. One-Way ANOVA Test (Compliant/Non-Compliant)

	Sum of Squares	Degree of Freedom	Mean Square	F Value	Significance
Between Groups	13.219	1	13.219	7.399	0.007
Within Groups	323.392	181	1.787		
Total	336.611	182			

4. MODEL DEVELOPMENT

The UPPT is defined as the time length from the completion of a pedestrian crossing behavior to the termination of FDW. If the time of pedestrian finishing crossing is later than the end of the FDW, the UPPT is 0. Pedestrians who begin to cross in SDW time are not within the scope of this study. When a pedestrian arrives at an intersection, the pedestrian signal head may present one of the three scenarios: walking man (walk interval), flashing don't walk (FDW), steady don't walk(SDW). The UPPT modeling process under the three scenarios is summarized in figure 9. The step by step calculation is discussed in the following part.

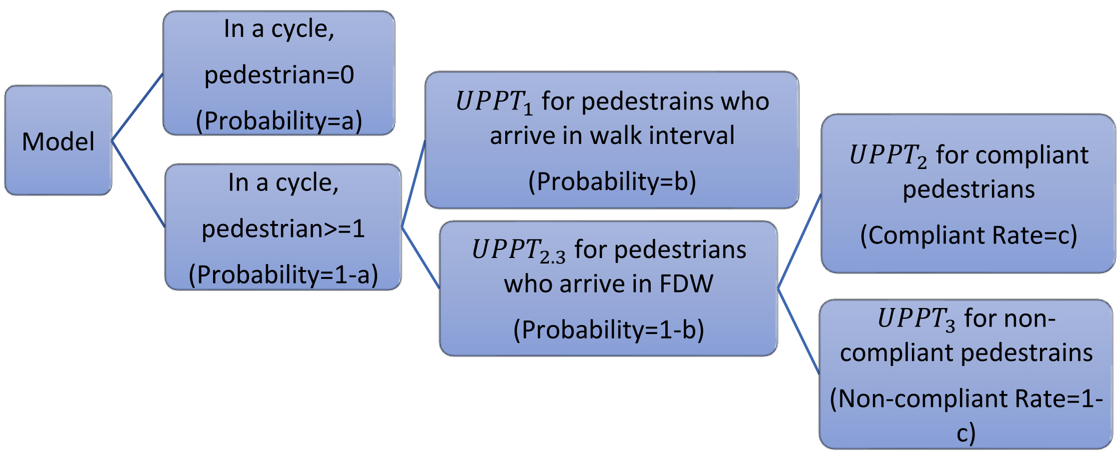


Figure 9. Model Summary

4.1 Pedestrian Arrival Pattern

This study assumed that all pedestrians arrive at the intersection randomly and pedestrian arrival pattern follows a poisson distribution [10], [33]. The probability of n pedestrians arrive at an intersection within one cycle is described as：

$$P(n) = \frac{\lambda^n e^{-\lambda}}{n!} \qquad (3)$$

Where

λ = average number of pedestrians who arrive during one cycle; n = number of pedestrians who arrive in one cycle, e= natural constant.

In a cycle, the probability of no pedestrian comes is represented by Equation 4. The probability of more than 0 pedestrians arrive in a cycle is represented by 1-a.

$$a = e^{-\lambda} \qquad (4)$$

Where

λ = average number of pedestrians who arrive during one cycle; e = natural constant; a = probability of no pedestrians come in one cycle.

4.2 Walk Interval

The walk interval corresponds to the walking person indicated on the pedestrian signal head and it starts at the beginning of a pedestrian phase. It provides pedestrians with enough time to react to the change of the signal and move to the crosswalk. Usually, the practical value of 7 seconds walk interval is typically used at intersections, and it can be shortened or extended to 4-11 seconds depending on different levels of pedestrian volume [3]. Pedestrians who arrive during the walk interval should begin to cross immediately. The $UPPT_1$ for pedestrians who arrive in walk interval is modeled by using the walk interval(WI) plus FDW, then minus the pedestrian crossing time(T_C), startup time(2.5 seconds) and half of the walk interval ($\frac{WI}{2}$) as pedestrians are assumed to follow a Poisson distribution [10],[33].

$$UPPT_1 = WI + FDW - T_{C1} - \frac{WI}{2} - 2.5 \qquad (5)$$

Where

WI = walk interval; FDW = flashing don't walk; T_{C1} = pedestrian crossing time;

Pedestrian startup time is usually small and will not have a significant influence on UPPT, So pedestrian startup time was assumed to be 2.5 seconds [5].

4.3 Flashing Don't Walk (FDW)

Pedestrian flashing don't walk (FDW) begins at the end of the pedestrian walk interval. According to MUTCD [3], When FDW begins, pedestrians are not allowed to start to cross the roadway, but pedestrians who are already on the road shall proceed to a sidewalk or safety island. However, in reality, many pedestrians choose to cross in FDW to save time. Pedestrians can save significant amounts of delay by using more than just the walk interval to enter the intersection [28]. If pedestrians follow the MUTCD recommendation strictly, the UPPT could be longer; if pedestrians choose to cross in FDW, the UPPT will be shorter. When building the UPPT model in FDW, the pedestrian compliance effect should be considered.

When pedestrians arrive in FDW, they have two choices: cross or wait. Compliant pedestrians will wait until the start of the next walk interval. The $UPPT_2$ for compliant pedestrians who arrive in FDW is calculated the same way as pedestrians who arrive in walk interval. Non-compliant pedestrians will begin to cross immediately once they reach the curb. The $UPPT_3$ for non-compliant pedestrians who arrive in FDW is modeled by using the FDW minus the pedestrian crossing time(T_{C2}) and the passing FDW(T_p). Because non-compliant pedestrians can begin to cross immediately once they arrive at the intersection, the startup time is not considered under this condition.

$$UPPT_3 = FDW - T_{C2} - T_p \qquad (6)$$

Where

FDW = the time length of Flashing Don't Walk; T_{C2} = non-compliant pedestrian crossing time; T_p = pedestrian average non-compliant distribution during the FDW period.

The total average $UPGT_{2,3}$ for pedestrians who arrive in FDW can be derived by summarizing weighted $UPGT_2$ and $UPGT_3$ using the pedestrian compliance rate (c). Which is expressed by Equation 7.

$$UPPT_{2,3} = UPPT_2 * c + UPPT_3 * (1 - c) \qquad (7)$$

Where

c = pedestrian compliance rate during FDW.

4.4 Steady Don't Walk (SDW)

The steady don't walk (SDW) interval shows up when the pedestrian FDW finishes, the yellow time is included in SDW. If the vehicular demand is insufficient to extend the green beyond the conclusion of the pedestrian FDW, pedestrians in the crosswalk will conflict with a vehicle phase. If the vehicular demand is sufficient to extend the green beyond the end of the pedestrian FDW, a don't walk will still be displayed, but pedestrians in the crosswalk will not conflict with a vehicle phase.

When pedestrians arrive in SDW, they can choose to cross or not to cross. However, crossing during SDW when pedestrians conflict with a vehicle phase is extremely dangerous, such behavior is regarded as abnormal crossing behavior in this study. When pedestrians are not in conflict with a vehicle phase, the time is no longer assigned to pedestrian phases, so it's outside the scope of this study. Thus, this study assumes that pedestrians who arrive in SDW will wait for the next walk interval and they are counted as pedestrians who arrive in walk intervals.

4.5 Total Average UPPT

The total average UPPT can be derived by summarizing the weighted $UPPT_1$ for pedestrians who arrive in walk interval and weighted $UPPT_{2,3}$ for pedestrians who arrive in FDW. Assume the weight of UPPT in walk interval (b) and FDW(1-b) is directly proportional to the time length. The weight of $UPPT_1$ in walk interval equals to the weight of SDW plus the walk interval in one cycle as pedestrians who arrive in SDW are assumed to wait until the next walk interval. The weight of $UPPT_{2,3}$ in FDW equals to the weight of FDW in one cycle. The calculations of the weight are presented in Equation 8 and Equation 9.

$$b = \frac{SDW+WI}{C} \qquad (8)$$

$$1 - b = \frac{FDW}{C} \qquad (9)$$

Where

SDW = the steady don't Walk interval; WI = the Walk interval; FDW = the Flashing don't walkinterval; C = cycle length; b=weight of $UPPT_{2,3}$ in FDW.

By summarizing the weighted $UPPT_1$ for pedestrians who arrive in walk interval and weighted $UPPT_{2,3}$ for pedestrians who arrive in FDW, the total average UPPT is calculated as

$$UPPT = [UPPT_1 * b + (1 - b) * UPPT_{2,3}] * (1 - a) \qquad (10)$$

Where

b = weight of $UPPT_{2,3}$ in FDW; a = probability of no pedestrians come in one cycle.

4.6 Sensitivity Analysis

To study the influence of each factors on the UPPT model, a local sensitivity analysis was conducted. Local sensitivity analysis, also known as one-time change method, is characterized by studying only one parameter, taking the center value of other parameters, and evaluating the change amount of model results in each change of the parameter.

The result of the sensitivity analysis on the compliance rate is illustrated in figure 10. The center value of other parameters are: a=0.2231, b=0.74, WI=7s, FDW=23s, T_{C1}=19s, T_{C2}=15.8s, T_p=3s. The relationship between UPPT and compliance rate（c） is expressed by Equation 11, according to the equation, the slope is a positive constant-- as the compliance rate increase 1, the UPPT increases 0.16s.

$$\text{UPPT}=3.72+0.16c \qquad (11)$$

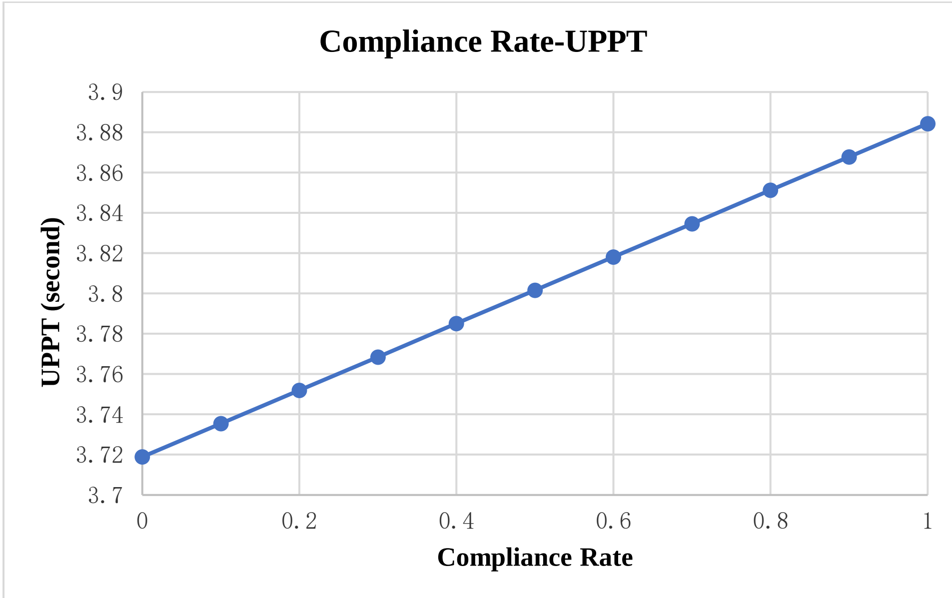


Figure 9. Sensitivity Analysis -- Compliance Rate

The result of the sensitivity analysis on compliance distribution is illustrated in figure 11. The center value of other parameters are listed: a=0.2231, b=0.74, c=0.3, WI=7s, FDW=23s, T_{C1}=19s, T_{C2}=15.8s. The relationship between UPPT and compliance distribution (T_p) is expressed by Equation 12. The Equation indicates that when compliance distribution is smaller than 7.2 seconds, the slope is a negative constant. When compliance distribution is bigger than 7.2 seconds, the slope is zero, and non-compliant pedestrians will use up the FDW when they finish crossing. When compliance distribution increases 1 second, the UPPT decreases 0.14s.

$$\text{UPPT}=4.19-0.14T_p \qquad (12)$$

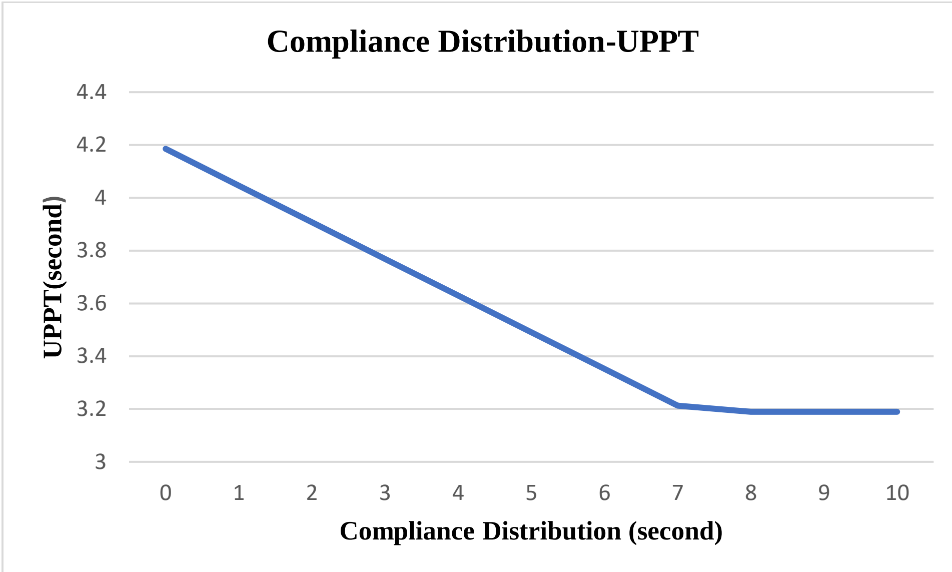


Figure 10. Sensitivity Analysis -- Compliance Distribution

The result of the sensitivity analysis on pedestrian walking speed is illustrated in figure 12. Observed from the figure, the UPPT is 0 when T_{C1} is slower than 3.7 ft/s, and UPPT increases as T_{C1} continues to increase. The average value of other parameters are listed: a=0.2231, b=0.74, c=0.3, WI=7s, FDW=23s, T_p=3s. The relationship between UPPT and walking speed (V_P) is expressed by Equation 13. Equation 14 was derived by taking the derivative of Equation 13 with respect to V_P , when V_P >3.7, the slope decreases as V_P increases. When pedestrian walking speed is 3.7 ft/s, the slope is the biggest, which indicates when the pedestrian walking speed increase 1 feet s, the UPPT will increase 5.7 seconds.

$$UPPT = 18.1 - \frac{(73.8 * V_P + 60.4)}{V_P * (V_P + 1)} \qquad (13)$$

$$\frac{\Delta\, UPPT}{\Delta V_P} = \frac{73.8}{{V_P}^2} + \frac{13.4}{(V_P + 1) * {V_P}^2} + \frac{13.4}{V_P * (V_P + 1)^2} \qquad (14)$$

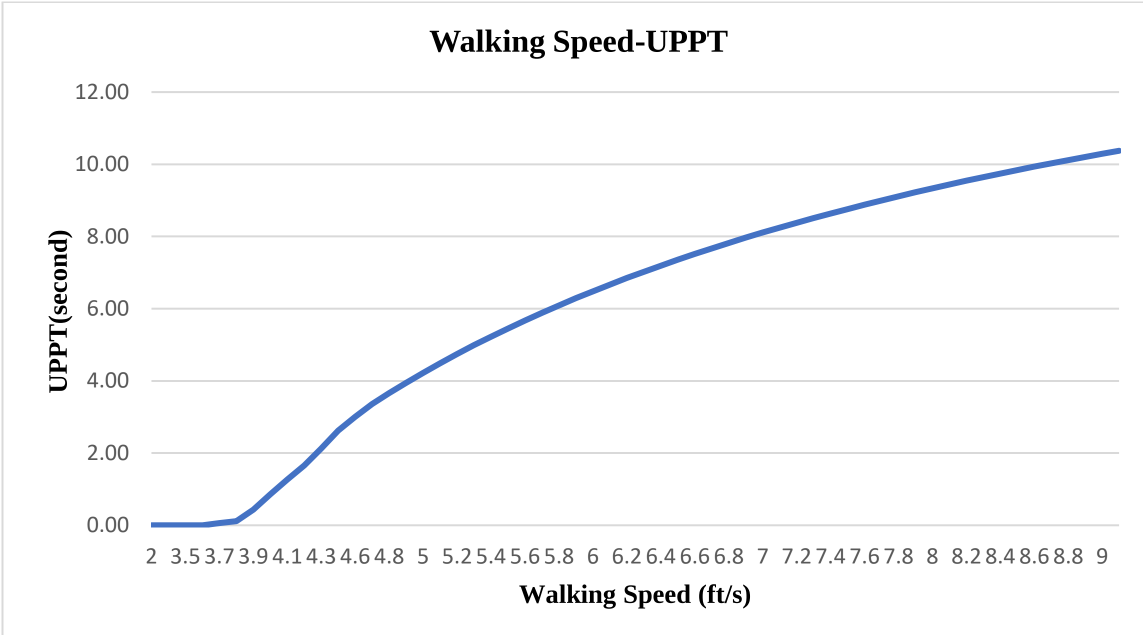


Figure 11. Sensitivity Analysis -- Walking Speed

5. CASE STUDY

From the seven intersections introduced in Table 1, six intersections were used to collect the field UPPT except for W 4th St & Ralston St. Because this intersection has an extraordinarily long walk interval, which may lead to a long UPPT. The comparison of the field UPPT with the modeled UPPT is listed in Table 12. In general, the field UPPT is slightly higher than the modeled UPPT, which may be caused by that the model assumes pedestrians who arrive in FDW will choose to cross the in the next walk interval, and the UPPT is calculated the same way as the pedestrians who arrive in walk time, which will minus an extra $\frac{WI}{2}$. But in all, the modeled UPPT doesn't differ much from the field UPPT.

Table 12 Case Study Result

Intersection	Modeled UPPT (seconds)	Field UPPT (seconds)
Artemesia Way & N Virginia St	5.4	4.5
9th St & N Virginia St	7.8	8.4
W 6th St & N Sierra St	4.8	6
N Center St & E Plaza St	6.7	7.3
W 7th St & N McCarran Blvd	6.4	8.4
15th St & N Virginia St	5.6	6.9

6. CONCLUSIONS

To study the UPPT, this study carried out a field study on pedestrian walking speed, pedestrian compliance rate and pedestrian compliance distribution. Then a model was developed to estimate the UPPT based on the experimental value of the three factors.

6.1 Research Findings

The findings are summarized below.

- Pedestrian distributions in the downtown area and school area are different. The School area has a higher young pedestrian percentage and the downtown area has a higher old/middle pedestrian percentage. The male pedestrians are more than female pedestrians in the downtown area while the condition is reversed in the school area.
- The pedestrian compliance rate is very low in FDW, though the compliance rate is higher in the downtown area (42.4%) than the school area (27.3%). Intersections with long crosswalks have a higher compliance rate (35.3%) than intersections with short crosswalks (27.3 %) when all intersections are located in the school area.

- Pedestrian compliance rates in FDW are different concerning different pedestrian characters. Female pedestrians' compliance rate (40%) is higher than male pedestrians (28%). Young pedestrians have a lower compliance rate (32%) than middle-aged pedestrians (49%) and old pedestrians (53%). The single pedestrian has the lowest compliance rate (25%) than two pedestrians' group (41%) and 3+ pedestrians' group (61%).
- Pedestrian distributions in FDW are obviously different. In the first half of FDW, pedestrians are more likely to cross while in the late half of the FDW, pedestrians are more conservative and choose not to cross. The average distribution of compliance pedestrians is at 76.8% of the FDW, and the average distribution of no-compliance pedestrians is at 34.4% of the FDW.
- Pedestrian compliance distributions are different based on pedestrian characters. Old pedestrians are more conservative than young pedestrians. Pedestrians in bigger groups are more conservative than pedestrians in smaller groups (single pedestrian included). Female pedestrians are more conservative than male pedestrians. When pedestrians are compliant, the difference is near 1%, which is considered very small. When pedestrians are not compliant, the difference is around 10%, which is more obvious.
- Pedestrian age, crosswalk width, and pedestrian group size are statistically significant influencing factors on pedestrian walking speed. Younger pedestrians walk faster than old pedestrians, and pedestrians in smaller group sizes walk faster than pedestrians in bigger group sizes. Walking speed on long crosswalk intersections is faster than that on shorter crosswalk intersections. Pedestrian gender is not a statistically significant influencing factor on pedestrian walking speed even if male pedestrians walk slightly faster than female pedestrians on average.
- The walking speed in the downtown area and school area are not statistically different. On average, walking speed is only slightly higher in school are than that in the downtown area.

The 15th percentile walking speed is 3.56 ft/s and the mean walking speed is 4.46 ft/s in the school area. The 15th percentile walking speed is 3.56 ft/s and the mean walking speed is 4.39 ft/s in the downtown area.

- The walking speed of compliant pedestrians and non-compliant pedestrians in FDW are statistically different. Non-compliant pedestrians walk faster that compliant pedestrians generally. For compliant pedestrians, the 15th percentile walking speed is 3.56 ft/s and the mean walking speed is 4.68 ft/s. For non-compliant pedestrians, the 15th percentile walking speed is 3.89 ft/s and the mean walking speed is 5.24 ft/s.
- For the UPPT model, the length of UPPT is most sensitive with the change of pedestrian walking speed, and the length of UPPT is least sensitive with the change of pedestrian compliance rate.

6.2 Limitations

The model is built based on the assumption that pedestrians arrive at intersections randomly and follow a Poisson distribution. In reality, the pedestrian arrivals are not randomly but follow a trend—in midday peak hour and PM peak hour, the pedestrian volume is the highest in the downtown area. In the school area, the pedestrian volume is the highest when the class is over.

The model also assumes that pedestrians make decisions independently, in fact, pedestrians are influenced by other pedestrians in the same cycle, which is called herd mentality. If one pedestrian chooses to cross in FDW, other pedestrians are more likely to follow the first pedestrian who is different than they would do individually.

Even if this study collected 1033 pedestrians crossing samples, the number of pedestrians arrive in FDW is 183, which is only 17.8 percent of the total sample. The sample size is considered relatively small and may skew some of the analysis results. For instance, there are only 8 middle-aged pedestrians and 13 old pedestrians arrive during FDW.

6.3 Future Study

This study developed a model to estimate the UPPT at signalized intersections, however, the influence of UPPT on traffic is not mentioned. Future studies can shed light on the impact of UPPT on traffic delay and intersection capacity. And if UPPT could be addressed, the influence on urban travel at intersections or nearby should be discussed. For instance, how will it change the travel time for vehicles and the change in traffic safety is a key point to evaluate the feasibility of addressing UPPT.

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