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Understanding Pedestrian and Bicyclist Compliance and Safety Impacts of Different Walk Modes at Signalized Intersections for a Livable Community

by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Civil Engineering
Department of Civil and Environmental Engineering
College of Engineering
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

With increasing energy costs as well as rampant congestion in major U.S. cities, the popularity of walk and bike mode choices have increased in recent years. Thus, the obtainment of a comprehensive knowledge of pedestrian and bicyclist behaviors is of great importance.

The National Highway Traffic Safety Administration estimates that 11.1% of pedestrian fatalities and 18.5% of bicyclist fatalities in the U.S. occurred in Florida in 2011, which accounts for just 6.1% of the nation's population. Additionally, intersections are hotspots for vehicle-pedestrian conflicts, which is confirmed by the Federal Highway Administration's estimate that nearly one in five pedestrian fatalities occur at intersections in the U.S. Since both signalized and non-signalized intersections are conflict points for vehicles, pedestrians, and bicyclists, it is essential that traffic control methods ensure that safety is not compromised.

To examine the safety effects of different walk modes at signalized intersections, four locations in the Tampa Bay area were chosen. Two of the locations operate with Rest in Walk and Pedestrian Recall and the other two operate without Rest in Walk and Pedestrian Recall. A total of 26 hours of data were collected in early 2013 at the four study sites, which yielded 202 pedestrian and bicyclist observations.

Upon modeling behaviors using a multinomial Logit model, the presence of Rest in Walk and Pedestrian Recall on minor street pedestrian phases, which operate concurrently with major street vehicle phases, was found to encourage higher pedestrian and bicyclist compliance rates than their absence. Additionally, the presence or absence of the combination of both Rest in Walk and Pedestrian Recall was found to be the most influential variable examined.

CHAPTER 1: INTRODUCTION

1.1 Background

The U.S. surface transportation system has focused on increased vehicular capacity for many years. Measures taken to decrease vehicular delays, congestion, and travel time have received much attention and funding due to the significant time, fuel, and infrastructure costs resulting from congestion. However, improvements aimed at reducing congestion are not always in pedestrians' best interests and in many instances have been shown to have negative effects on safety.

To improve the walkability of communities, safety action plans have been and are continuing to be implemented across the U.S. The National Highway Traffic Safety Administration defines the "4 E's" of traffic safety as Education, Enforcement, Engineering, and Emergency Response (1). Countermeasures aimed at preventing conflicts generally fall under the educational, enforcement, or engineering categories. While this study focuses on the engineering aspect of pedestrian crossing control, the importance of public education, enforcement, and emergency response cannot be overemphasized.

1.2 Control

Vehicle travel is the prevalent travel mode in the U.S. and many other developed countries, which means that it often receives more attention and funding than the pedestrian mode of travel. However, changes need to be made to this way of thinking, because regardless of the primary travel mode, everyone is a pedestrian at one point or another.

In its earliest stages, traffic and pedestrian signals were used without significant standardization or automation. However, as technology has developed through research and experimentation, traffic and pedestrian signals have become effective, automated, and standardized tools installed at intersections to regulate vehicle-vehicle and vehicle-pedestrian right of way.

The design of pedestrian signal control follows the Manual on Uniform Traffic Control Devices (MUTCD). There are three main segments of pedestrian signal control, which include walk (a permissive indication), flashing don't walk (a change interval), and steady don't walk (a prohibitive indication). Pedestrians are permitted to begin crossing at any point during the walk indication and the MUTCD states that a walk indication can be as low as 4 seconds depending on pedestrian volumes and behaviors, however in normal conditions a length of at least 7 seconds is recommended. When flashing don't walk begins, pedestrians that are already within crosswalks are permitted to finish crossing, however those that haven't begun crossing must wait until the next cycle to do so. Flashing don't walk is calculated based on assumed pedestrian walking speeds and crosswalk lengths. Assumed walking speeds generally range between 3 feet per second to 4 feet per second, with the lower half of the range primarily used near schools or in locations with high elderly populations. The steady don't walk indication is shown at all times that walk and flashing don't walk are not indicated. Steady don't walk indicates that vehicle movements conflicting with the pedestrian phase have the right of way and pedestrians must not attempt to cross.

1.2.1 Pedestrian Recall

Pedestrian Recall is a walk mode that is programmed into signal controllers. The start of pedestrian green (walk indication) coincides with the start of green for the through movement

parallel to the pedestrian movement and is called once per cycle. It is a popular choice because pedestrians are not required to use pushbuttons when it is present. Without Pedestrian Recall, pedestrians must push the pushbutton to call the walk phase, which gives them the right of way to cross at the intersection.

1.2.2 Rest in Walk

The Rest in Walk mode, which is programmed into signal controllers as a Walk Rest Modifier, displays a walk indication for minor street crossings from the onset of major street green until the yield point in coordination cycles. At the yield point, a flashing don't walk signal begins. The flashing don't walk is followed by a steady don't walk, which coincides with the start of yellow for major street vehicle movements. Additionally, for actuated signal controllers, once a vehicle arrives at the minor street, the flashing don't walk begins timing. Otherwise, major street green and minor street walk remains on indefinitely.

Figure 1 graphically depicts the difference between Rest in Walk operations and non-Rest in Walk operations for two hypothetical intersections that have all of the same characteristics except presence of Rest in Walk. The phases depicted on the top of each horizontal line are for major street motorist signals, and the phases at the bottom of each horizontal line are for minor street pedestrian signals.

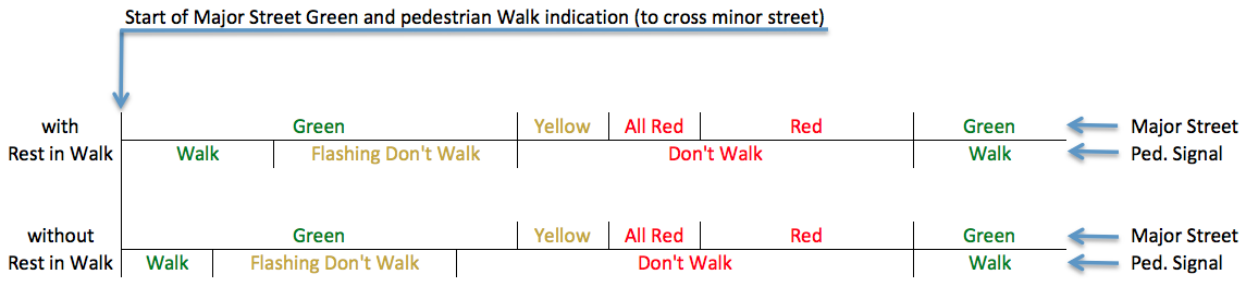


Figure 1 Rest in Walk description

When Rest in Walk is not present, don't walk for minor streets start earlier so that the right turn vehicles on the major streets receive the right of way for turning without being required to yield to pedestrians. Increased intersection efficiency, especially for intersections with a large number of right turn vehicles from major to minor streets, is one reason for the absence of Rest in Walk.

Nevertheless, in cases where the walk mode Rest in Walk is removed from intersections, Pinellas County Traffic Management usually receives citizen complaints (2). This is because less right-of-way (green) time is given to pedestrians. Once accustomed to the presence of Rest in Walk, it is difficult to adjust to its absence. Although traffic engineers have a good knowledge of vehicular efficiency of different walk modes, there is a lack of understanding of the safety impacts of these modes. Hence, it is valuable to quantify the safety impacts of the different walking modes.

While searching for comparable study sites in the Tampa Bay Area, intersections with both Rest in walk and Pedestrian Recall and intersections without both Rest in Walk and Pedestrian Recall were found. Thus, in this study, we compare the combination of Rest in Walk and Pedestrian Recall. For other regions with different combinations of walk modes, the methodology proposed in this study can also be applied to analyze the safety impacts.

1.3 Crash Statistics

The World Health Organization (WHO) estimates that the U.S. experiences the fourth most crash related fatalities, with only China, India, and Nigeria ahead. Globally, over 1.2 million people die and between 20 million and 50 million are injured on roads every year (3). Traffic related fatality is currently ranked the #10 cause of death in the world (4). Additionally,

crashes due to transportation-roadway causes are predicted to be the #4 cause of disability adjusted life-years (5).

When analyzing vehicle crashes there are three primary reportable types, which includes property damage only (PDO), injury, and fatal. Vehicle-on-vehicle crashes often result in PDO, due to the protection and safety features provided by automobiles. However, collisions involving vehicles and pedestrians frequently result in injury or fatality for pedestrians since they are unprotected. Risk of injury to pedestrians in the U.S. is 10% for vehicle speeds up to 16 mph, 25% at 23 mph, 50% at 31 mph, 75% at 39 mph, and 90% at 46 mph. Risk of pedestrian fatality in the U.S. is 10% at vehicle speeds up to 23 mph, 25% at 32 mph, 50% at 42 mph, 75% at 50 mph, and 90% at 58 mph (6).

The National Highway Traffic Safety Administration (NHTSA) estimates that 4432 pedestrian fatalities occurred due to collisions with vehicles in 2011 (7). The top four most dangerous large metropolitan areas for pedestrians in the U.S. are in Florida and include Orlando - Kissimmee, Tampa - St. Petersburg - Clearwater, Jacksonville, and Miami - Ft. Lauderdale - Pompano Beach (8).

Finally, intersections are hotspots for vehicle-pedestrian conflicts, which is confirmed by the Federal Highway Administration's estimate that nearly one in five pedestrian fatalities occur at intersections in the U.S. (9).

1.4 Proposed Research and Approach

Since current knowledge of Rest in Walk and Pedestrian Recall effects on pedestrian compliance is limited, the purpose of this study is to conduct research on pedestrians at signalized intersections. Additionally, Florida law states that bicyclists must adhere to pedestrian

laws when they use sidewalks and crosswalks. Thus, bicyclists that travel on sidewalks and crosswalks are included in this study.

This study focuses on signalized intersections operating with two specific control types. The first type is intersections with Rest in Walk and Pedestrian Recall. The second type is intersections with neither Rest in Walk nor Pedestrian Recall.

Onsite observational surveys and modeling using a multinomial Logit model were conducted to allow for a better understanding of pedestrian and bicyclist behaviors.

CHAPTER 2: LITERATURE REVIEW

It has long been known that many variables, both behavioral and site specific are responsible for pedestrians' actions when crossing at intersections. Gender determined to play a part when studied by Rosenbloom, with males being more likely to cross without right-of-way than women, however, age did not play a significant role in the same study. Additionally, the study concluded that groups of more than two individuals waiting on curbs are more likely to obey traffic laws and wait for pedestrian green, while people standing alone are more likely to cross on red (10). Possible reasons for behavioral differences between individuals and groups have been studied and discussed in detail by Travis Hirschi (11).

A study conducted for the AAA Foundation for Traffic Safety determined that older pedestrians are generally more compliant than younger pedestrians, where old pedestrians are defined as 65 years and older and young pedestrians are defined as less than 65 years old (12). It has been observed that middle-age males are more frequently involved as both drivers and pedestrians in pedestrian-vehicle collisions (13) and that non-compliance by pedestrians is frequently a cause of collisions (14). Tom and Granie also observed that males are over represented in vehicle-pedestrian collisions, which they attributed to males violating traffic rules more frequently than females (15).

Crosswalk length has been studied as a compliance factor, with mixed results (16). Additionally, turning vehicles are most dangerous to pedestrians, because the two often share the same phase and therefore provide significant opportunity for conflict. Research into

programming a Leading Pedestrian Interval into traffic controllers has shown positive results as well as cost effectiveness (17).

Signal timing is an important factor in crossing behavior. Studies have shown that the longer pedestrians are required to wait for a right-of-way, the more likely they are to cross illegally (18). Thus, proper signal timing is an important variable to be considered when encouraging a pedestrian friendly community. Sweden, Germany, and the Netherlands rely on short cycle lengths to better accommodate pedestrians (19). The Federal Highway Administration endorses shorter cycle lengths in the U.S., however, this is only recommended for signalized intersections with significant pedestrian noncompliance (20).

CHAPTER 3: METHODOLOGY

3.1 Intersection Characteristics

Since the overall purpose of this study is to compare differences in pedestrian compliance between different walk modes, it is necessary to either remove or account for as many factors that could contribute to the likelihood of compliance or noncompliance as possible.

Intersections were chosen based on the following criteria: walk mode, number of lanes (major and minor), lane types (major and minor), presence of pushbuttons, presence of countdown timers, clearly marked crosswalks, surrounding land uses, and absence of school zones. Due to the previously mentioned constraints, traffic volumes, signal timings, and pedestrian types (walk, bike, wheelchair, and skate) could not be controlled. Signal timing, vehicle volumes, lane configuration, crosswalk design, pushbutton presence, surrounding land uses, and school zones are specifically discussed in Sections 3.1.1 through 3.1.7.

Characteristics of intersections included in this study were determined through Google Earth and field inspections. Intersection field note sheets were filled out for each intersection for each day of data collection. Characteristics in the field notes include: location, traffic volume, date, time, presence or absence of Rest in Walk, miscellaneous notes, and an aerial view of each study intersection. Camera location and direction of view are marked on the aerial view contained in the field notes. Additionally, timing sheets downloaded from signal controllers were used to determine basic timings, cycle lengths, recall types, coordination, splits, etc.

3.1.1 Signal Timing

Cycle lengths have been shown to influence pedestrian delay at signalized intersections. The MUTCD defines cycle lengths as the time required for one complete sequence of signal indications and splits are defined as the sum of Green, Yellow, and All Red time.

Cycle lengths operating at study intersections during dates and times data was collected ranged from 70 seconds to 200 seconds. The ratios of walk time to cycle length, walk time to split time, and split time to cycle length were examined and compared to compliance rates, however, no trends were observed. Splits and cycle lengths at study intersections are discussed further in Section 4.1.

3.1.2 Traffic Volumes

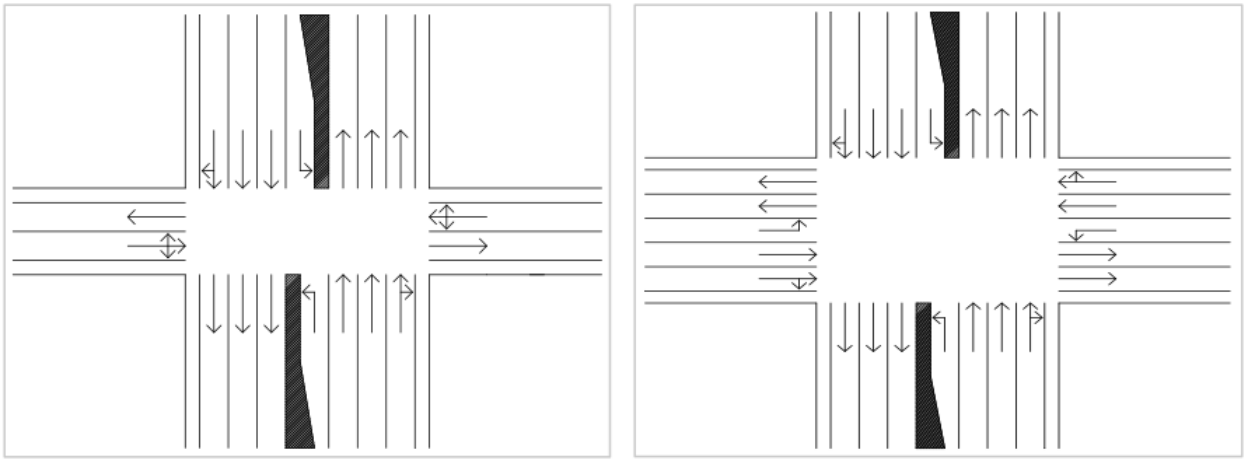
Traffic volume is an important factor in pedestrian crossing behavior. Directly related to length and frequency of gaps, pedestrians are more unlikely to cross against signal when heavy vehicle traffic exists (21), therefore it is important to account for this variable.

Vehicles were only counted and included in the volume variable if they crossed the crosswalk. The reason for this is because only vehicles that have the potential for conflict with crossing pedestrians can be expected to influence compliance. Therefore, through, left, and right turning vehicles on the minor approach street were counted as well as relevant right turning and left turning vehicles from the main street. Average hourly traffic volumes for each study site are shown in Table 2.

3.1.3 Intersection Geometry

Pedestrians tend to be more comfortable choosing gaps when oncoming vehicles are turning (21). Thus, lane configuration must be considered and controlled. Consequently, Sites A and C were chosen such that their geometries matched with one shared through, left, and right

turn in each direction. Likewise, Sites B and D matched, with one through, one shared through and right turn, and one left turning bay. Figure 2 illustrates study intersection geometries.



Site A & Site C Site B & Site D

Figure 2 Intersection geometry sketches

While not a significant factor on pedestrians crossing minor streets, major street lane configuration was also chosen to match for all study sites. All major streets have seven lanes with two through, one shared through and right turn, and one left turn for each direction.

The crosswalk length is expected to influence crossing behavior. Violations are expected to occur more frequently for shorter distances than for longer distances. Additionally, clearly marked crosswalks have been shown to result in an increased likelihood of compliance. Thus, choosing sites with similar distances, as well as clearly marked crosswalks, accounts for these variables.

3.1.4 Pushbuttons

Previous studies have shown that pedestrians that utilize pushbuttons are more likely to cross when given the right-of-way at signalized intersections. Therefore, the presence of

pushbuttons at all study sites is a requirement, though they do not influence operations at intersections with Rest in Walk.

Pushbuttons are present at the study intersections that have Rest in Walk and Pedestrian Recall, though they are unnecessary. One reason for this is because when intersections drop out of coordination during off-peak hours, pedestrian actuation becomes necessary. The presence of pushbuttons at each site was verified during the field review as well as the video recording reviews.

3.1.5 Crosswalk Visibility

Study intersections with visible crosswalks were chosen. The two design types located at sites included high visibility, which are also known as zebra crossings, and brick pavers outlined with white striping. Examples of design types at study sites are shown in Figures 3 and 4.

Figure 3 High visibility crosswalk

Figure 4 Brick paver crosswalk with white outline

3.1.6 Land Use

Surrounding land use is directly related to the type of pedestrians using the facilities. Thus, intersections with similar surrounding land uses were chosen for this study. Land use categories considered in this study include recreational, retail, industrial, and residential. The selected intersections are located in areas with mixed retail and industrial land use types.

3.1.7 School Zones

School zones offer unique conditions and introduce a number of additional variables that are beyond the scope of this project. Presence of school beacons, crossing guards, and high numbers of young children are just a few of the variables present in school zones but absent from intersections operating under normal conditions. Thus, intersections in school zones were not considered in this study.

3.2 Person Characteristics

The characteristics of each person observed using study intersections were collected for incorporation in a multinomial Logit model, as well as to examine compliance rate differences between genders, age groups, and races. A total of 26 hours of video recordings were collected over 16 days in early 2013. Data was collected during midday and evening peak periods. Additionally, data was only collected during daylight hours and good weather conditions. The recorded data was later reviewed to extract items of interest.

While significant efforts to accurately estimate person characteristics were made, some level of subjectivity is present in the age and race characteristic estimations since they were obtained from observation.

3.2.1 Gender

As discussed in the introduction, gender has been found in previous studies to influence compliance. In previous studies, men have been observed participating in more risky behaviors than women, are more frequently non-compliant when crossing intersections, and are over-represented in crash data. Therefore, observed pedestrians and bicyclists crossing at study intersections were classified as either male or female, recorded on site, and verified in video recordings.

3.2.2 Age

Ages were estimated for each pedestrian and bicyclist observed. As discussed previously, age has been found to be a factor in compliance in some studies. Previous studies have grouped ages in a variety of ways. For example, the study funded by AAA Foundation for Traffic Safety separated pedestrians into two groups, 65 years and older and less than 65 years. However,

Rosenbloom separated pedestrians into 20-40 years old, 40-60 years old, and over 60 years old and did not find significant difference between the behaviors of the various age groups.

3.2.3 Race

Observed pedestrians and bicyclists were classified as Group 1, 2, 3, or 4, which corresponds to White, Black, Hispanic, or Other, respectively. The predominant race of each person was estimated onsite and verified in video recordings.

3.2.4 Travel Modes

Individuals walking, skateboarding, or using wheelchairs are required to utilize sidewalks and crosswalks, and are defined as pedestrians. However, bicyclists may choose to either ride on roadways with vehicles or sidewalks with pedestrians. When cycling on roadways, bicyclists must comply with traffic laws. If bicyclists choose to ride on sidewalks and use crosswalks, they must comply with pedestrian laws.

3.3 Data Collection

Intersection characteristics, person characteristics, and crossing behavior were either collected onsite and verified offsite or collected offsite and verified onsite, depending on characteristics of interest.

A total of 26 hours of data was collected over 16 weekdays (Monday through Friday), which resulted in a total of 202 pedestrian and bicyclist observations.

3.3.1 Equipment Used

Crosswalk photos were taken with a Canon PowerShot SD 750 Digital ELPH (7.1 MP) and pedestrians and bicyclists were recorded using a Sony Handyman HDR-CX260 video camera with a 55X Extended Zoom (8.9 Megapixel). Additionally, crosswalk photos and all

video recordings were uploaded and reviewed on a MacBook Pro Notebook Computer. Miscellaneous items used in the field included tripods, safety vests, and stopwatches.

3.3.2 Forms Used

Intersection field notes were created prior to visiting each site. One field note form was used for each site and day that the site was visited. Field note sheets are shown in Appendix B.

An Excel spreadsheet was designed to allow each observation to be recorded in its own row and each characteristic of interest to be recorded in cells located in that row. The primary goal of the spreadsheet design was to simplify the process of modeling data using open source software, which is discussed in Section 3.4.1.

3.3.3 Procedure

Prior to each field review, the intersection of interest was researched using Google Maps and location, lane geometry, and surrounding land use characteristics were determined. Additionally, an aerial snapshot of each intersection was taken and included in the intersection field note forms. Using the existing intersection field note template, a field note was created and an aerial snapshot was inserted. Equipment batteries were then charged and loaded into vehicle.

Upon arriving at each intersection of interest, information gathered in Google, as well as walk mode type was verified. Once all characteristics were verified, a location with a good view of the study crosswalk was determined. The Sony Handyman camcorder was then attached to a tripod and positioned such that the crosswalk was within view. The camcorder was then turned on and recording was started. While recording, the field technician took pictures of crosswalk using the Canon PowerShot and counted vehicle volumes using the manual counter. After between one and two hours at each site, equipment was packed up and data collection was complete (note that all recordings were conducted during daylight and good weather conditions).

Each recording was next downloaded to the MacBook Pro Notebook computer from the Sony Handyman Recorder. Upon completion of the download, characteristics of each pedestrian and bicyclist as well as crossing behavior was reviewed and entered into the excel spreadsheet outlined in Section 3.3.2. Once data was extracted and entered into the excel spreadsheet, the data was ready to be modeled.

3.4 Modeling Technique

Collected field data was modeled using a multinomial Logit model. The model results were then assessed using a variety of tests. Both the model and the tests are discussed in the following sections.

3.4.1 Multinomial Logit Model

Logit models are statistical regression models that are used to estimate the probability that alternatives from a defined set will be chosen by decision makers. A choice set is the set of alternatives available to decision makers and there are three required characteristics for inclusion in the model. The first requirement is that the set must be mutually exclusive. In other words, the decision maker may only choose one alternative. Second, the choice set must include every possible alternative. The third and final requirement is that the number of choices available to decision makers must be finite. When all three of these requirements are met, the set of alternatives may be included in the Logit model discrete choice framework (22).

Logit models are widely used in a variety of fields to analyze and understand behaviors of individuals. Logit models can be either binary or multinomial. Binary means that only two alternatives are available and multinomial means that more than two alternatives are available. Additionally, Logit models are discrete. The Logit model is one of many discrete choice-modeling methods used in practice, however it is one of the most popular due to its simplicity.

The reason for this is that Logit models have simple, closed forms, which greatly simplifies calculations required to estimate probabilities of choosing alternatives.

Another aspect of Logit models, which is similar to other models, is that it uses the "Utility Maximization" decision rule. According to the Utility Maximization rule, the decision maker selects the alternative offering the highest utility, which is a scalar value that captures the overall attractiveness of each alternative and is therefore a function of the alternative's attributes as well as the decision maker's characteristics. Total utility for a decision maker's choice includes a deterministic (observed) component, which is a function of the individual's and alternative's characteristics.

A second part of the utility function is the random (unobserved) component. The probability distribution function of this component determines the type of method that can be used in the model estimation. The assumption of normal distributions for this component results in a "Probit" model, which does not have a simple, closed form for probability calculations. Assuming a "Type I extreme value (Gumbel)" distribution for this random error term results in a Logit model. The deterministic term in this model includes variables corresponding to the alternative attributes, variables related to the decision makers' characteristics, and a constant. Since it is impossible to quantify every attribute for the alternatives, the constant term, which captures the average impact of unobserved characteristics, must also be included in the model.

The deterministic component can also include interactions between alternative attributes and individual characteristics. Therefore the total utility function is

$$U_{in} = V_{in} + \varepsilon_{in} \qquad (1)$$

where U_{in} is the total utility, V is the observed utility, and ε is the unobserved utility for alternative i and person n and

$$V_{in} = \alpha_0 + V(X_{in}) + V(S_n) + V(X_{in},S_n) \quad (2)$$

where α_0 is the constant, $V(X_{in})$ is the utility from observed attributes, $V(S_n)$ is the utility from observed characteristics, and $V(X_{in},S_n)$ is the utility due to interactions between X_{in} and S_n for alternative i and person n. Thus,

$$P_{in} = \frac{e^{V_{in}}}{\sum_{j=1}^{K} e^{V_{jn}}} \quad (3)$$

where K is the number of alternatives and P_{in} is the probability of alternative i being chosen by person n. Therefore, Equation (3) is the multinomial Logit model probability function. In the case of two alternatives, this model can also be called a "Binary Logit Model".

The process of decision-making starts with defining the problem followed by generating a set of alternatives. These alternatives must be evaluated based on their attributes, and as a result, the outcome of this evaluation is a choice that will then be implemented by the decision maker. Since the purpose of this study is to model compliance with traffic signals, the model involves two choices, which are compliance and noncompliance. The explanatory variables that were recorded and considered in the models includes both person and intersection characteristics, which are described in Table 1.

Table 1 Person and intersection characteristics

Parameters	Description
OBSERVATION	Each person is assigned a unique number (1, 2, 3, etc.)
COMPLIANCE	Person complies if he/she crosses when given lawful right-of-way
AGE	Person's age
GENDER	Person's gender
RACE	Person's race (Group 1, 2, 3, or 4)
WAIT	Person's total wait time (rounded to nearest second)
GPA	Group arrival size
GPD	Group departure size
PUSHBUTTON	Pushbutton usage
REST&PED	Rest in Walk and Pedestrian Recall presence or absence
VOLUME	Traffic volume (vehicles per hour)
LANES	Number of lanes person must traverse to completely cross street
CYCLE LENGTH	Time required for signal to complete cycle (seconds)

For each observation, the attributes mentioned in Table 1 were recorded. Once the data was acquired and recorded, the model estimation process was performed. BIOGEME, which is an open source software package, was used to estimate the model.

During the estimation process it was necessary to consider some variables in categorized patterns since the exact values for those attributes showed considerable discreteness. While estimating the model, it appeared that the number of observations, as well as variations in some observations, were not adequate. Therefore, once the model was estimated, some of the explanatory variables that were initially expected to impact compliance were found to be insignificant.

3.4.2 Test Methods

The correlation of data was tested using Cramer's V and Pearson's Product-Moment methods in SPSS. These methods observe similarities between datasets to determine which sets

depict collinearity. The datasets that were significantly correlated were removed from the Logit model.

The confidence interval for each parameter estimate was determined in BIOGEME using a t-statistic. The t-statistic is the ratio of the departure of an estimated parameter from its notional value and its standard error. The goodness of fit of the logit model was also determined by BIOGEME using rho-square and adjusted rho-square values.

The rho-square value is the ratio of variance explained by the model to total variance. While rho-square depicts the model's overall goodness of fit, it does not account for the number of parameters utilized. Thus, to compare the goodness of fit between models, the adjusted rho-square value, which accounts for the number of estimated parameters, was used.

CHAPTER 4: ANALYSIS

4.1 Study Intersections

Intersections were chosen based on the criteria discussed in Section 3.1. Table 2 depicts the intersections chosen for this study, as well as their characteristics. Sites A and B are maintained by the City of St. Petersburg and Sites C and D are maintained by Pinellas County.

Table 2 Study intersections

Designation	**Site A**	**Site B**	**Site C**	**Site D**
Intersection	66th St & 26th Ave	34th St & Central Ave	34th St & 58th Ave	66th St & 54th Ave
Rest in Walk	Present	Present	Not Present	Not Present
Pedestrian Recall	Present	Present	Not Present	Not Present
Pushbutton	Present	Present	Present	Present
Countdown Timer	Present	Present	Present	Present
Lanes (Minor)	2	5	2	5
Average Volume (veh/hr)	120	932	252	1219

Pinellas County and the City of St. Petersburg provided timing sheets for all study intersections. Patterns for Sites A and B are constant. However, Sites C and D run different patterns that are dependent on the time of day. Data was only collected during the patterns shown in Table 3, however, timing was determined to not significantly influence the models estimated in Section 4.5.

Table 3 Cycle lengths and splits

Site	Splits (Seconds)								Cycle Length (Seconds)
	Φ1	**Φ2**	**Φ3**	**Φ4**	**Φ5**	**Φ6**	**Φ7**	**Φ8**	
A	0	91	0	49	0	0	0	0	140
B	0	39	0	31	0	39	0	31	70
C	19	96	0	45	19	96	0	45	160
	25	125	0	50	25	125	0	50	200
D	30	59	25	46	30	59	25	46	160
	35	85	26	54	35	85	31	49	200

4.2 Observations

Pedestrians and bicyclists who use sidewalks and crosswalks are considered in this study. Pedestrians were observed using wheelchairs, walking, and skateboarding. Shares of observed travel types are walk 44%, bike 53%, skate 1%, and wheelchair 2%. Skaters and wheelchair users are not included in this analysis or the following models due to an insufficient number of observations.

Once wheelchair users and skaters were removed from the data, a total of 202 observations at study intersections were left, with pedestrians comprising of approximately 46% of observations and bicyclists comprising of 54% of the observations. Observations between respective intersections are 40 observations at Site A, 57 at Site B, 43 at Site C, and 62 at Site D. Thus, there are a total of 97 observations at sites with Rest in Walk and 105 observations at sites without Rest in Walk. Among those observed, 36 are female and 166 are male. Distributions are shown in Figure 5.

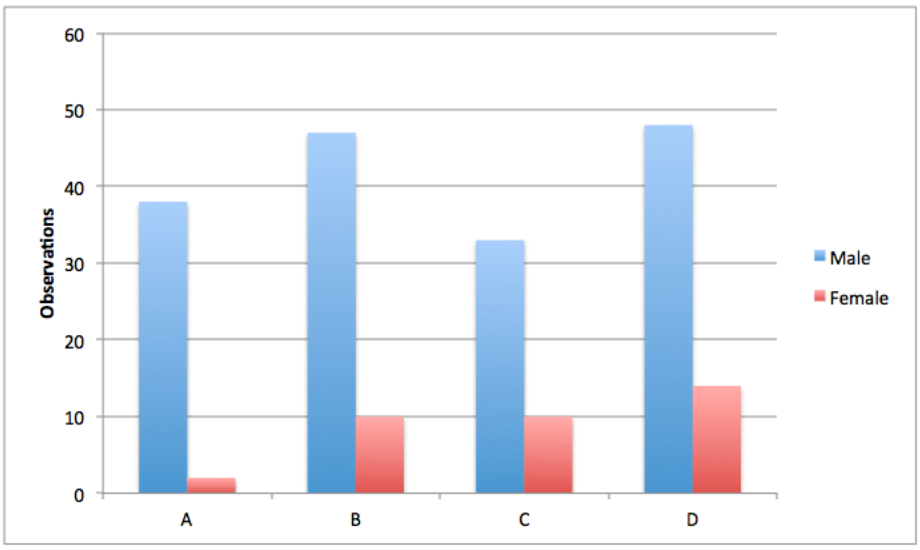


Figure 5 Observations by intersection

Estimated ages of observed people ranged from 5 to 65 years old with the majority of estimated ages within the range of 21 and 40 years old. Distribution of estimated ages is shown in Figure 6.

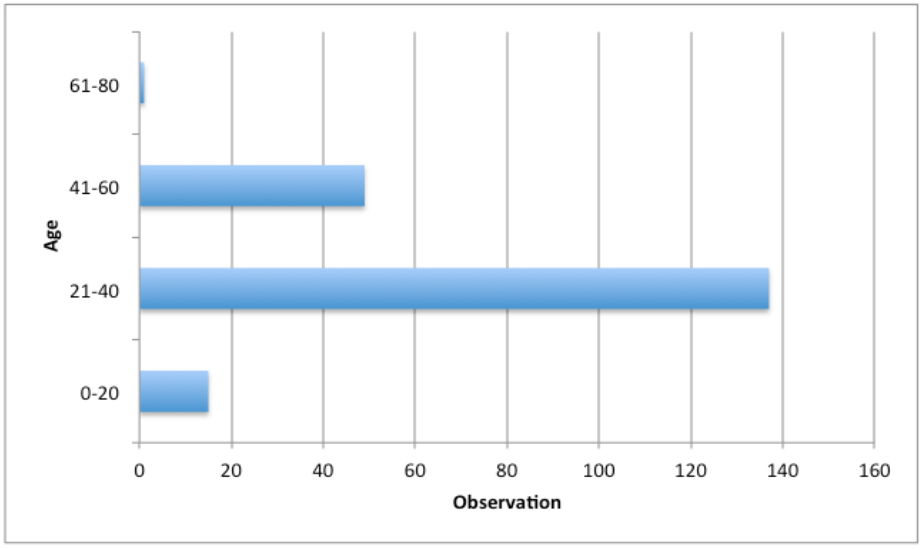


Figure 6 Age distribution

4.3 Compliance

Figure 7 shows the observed compliance rates at each intersection. The compliance rates are considerably different between intersections.

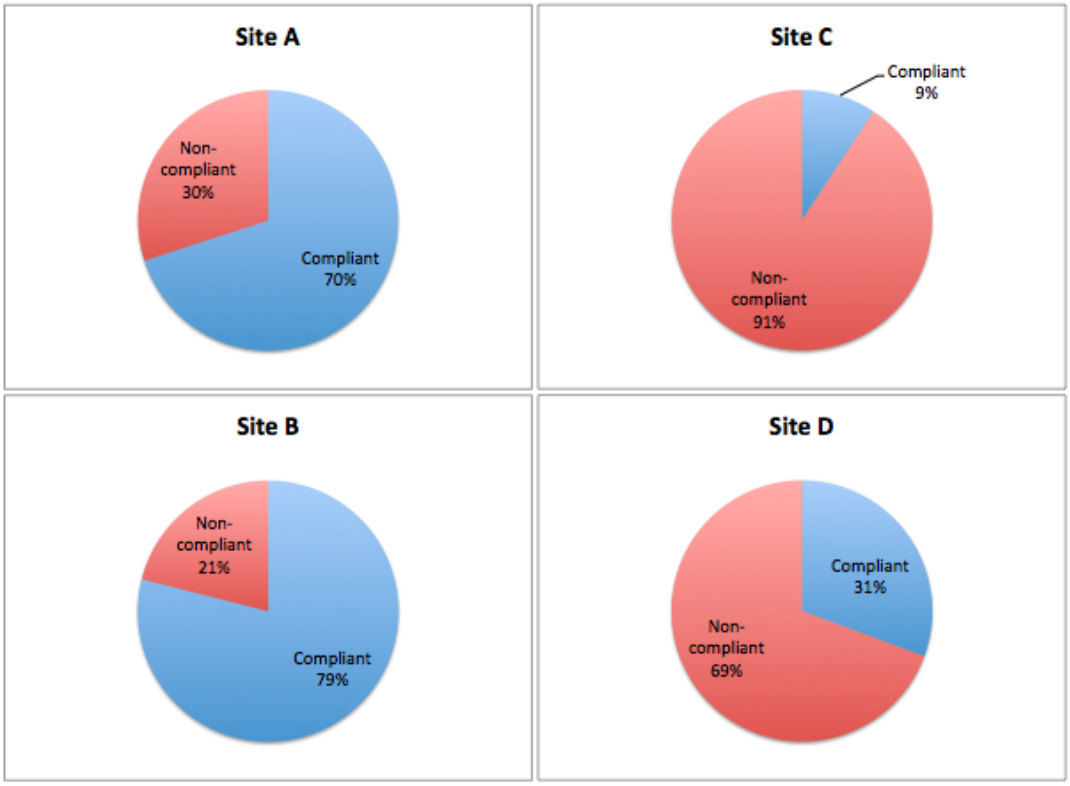


Figure 7 Compliance by intersection for all types

As previously discussed, the presence of Rest in Walk and Pedestrian Recall at Sites A and B result in longer walk time and requires no pushbutton use. As expected, Sites A and B were observed to have higher percentages of compliance than Sites C and D.

A comparison of Sites A and C, which have the same geometry (2 lanes in minor approach), but different walk modes, shows that pedestrians are also more compliant at Site A than Site C. Sites B and D, which have the same geometry (5 lanes in minor approach) show that people are more compliant at Site B than Site D.

Figure 7 also shows that number of lanes contributes to the compliance. Site B is observed to have a higher compliance rate than Site A, which is not surprising considering more lanes must be crossed at Site B than at Site A. Additionally, Site B has heavier vehicle traffic than Site A. The same is true between Sites C and D.

4.4 Correlation

Cramer's V and Pearson's Product-Moment correlation tests were performed on the dataset using SPSS. The tests determined that there is a strong correlation between cycle length and control type, number of lanes and traffic volume, and group arrival and departure sizes. Thus, variables that strongly correlated are not included in the model estimation and do not influence compliance or noncompliance predictions. Correlation values for variables included in each respective model are shown in Appendix A.

4.5 Logit Model Estimation

The constant only model is the starting point for Logit model estimations. The constant only model does not include any explanatory variables, thus, it is rarely a good fit for the data. Table 4 depicts the initial model estimates.

Table 4 Constant Only model estimation results

Variables	**Parameter Estimates PED. ONLY**	**Parameter Estimates BIKE ONLY**	**Parameter Estimates ALL TYPES**
Non-Compliance Constant	0.000	0.000	0.000
Compliance Constant	0.351	-0.482	-0.099
Likelihood Ratio Test	2.797	6.204	0.495
Rho-Square	0.022	0.041	0.002
Adjusted Rho-Square	0.006	0.028	-0.005

As indicated by rho-square values and the likelihood ratio test results shown in Table 4, the constant only models do not adequately explain the data. At this stage it is common practice to verify that the modeling software is performing estimations properly. This can be easily verified using Equation (3). Based on calculations using estimated constants, walk, bike, and all types compliance rates are 58.7%, 38.2%, and 47.5%, respectively. These findings are consistent with the data. The model is therefore estimating parameters correctly and more variables can be added.

The results shown in Tables 5, 6, and 7 were obtained after estimating several models for different combinations and variable categories. Only variables estimated within a minimum confidence interval of 85% (using t-statistics) are included as significant variables.

As can be seen in the Pedestrian Only model depicted in Table 5, compliance is positively influenced when Rest in Walk and Pedestrian Recall are present, pedestrians are less than 30 years old, vehicular volumes are greater than 1000 vehicles/hour, and pushbuttons are utilized.

Table 5 Pedestrian Only model estimation results

PEDESTRIAN ONLY	**Parameter Estimates**	**Standard Deviation**	**Confidence Interval**
Non-Compliance Constant	0.00	-	-
Compliance Constant	-3.46	0.976	0.99
REST&PED	3.55	0.916	0.99
AGEUNDER30	1.22	0.602	0.95
VOLUME1001	1.91	0.800	0.98
PUSHBUTTON	1.59	0.744	0.96
Likelihood Ratio Test	37.048		
Rho-Square	0.290		
Adjusted Rho-Square	0.212		

It is surprising to see that people less than 30 years old are more compliant than people greater than 30 years old. As discussed in the literature review, some previous research has concluded that younger pedestrians are consistently less compliant than older pedestrians. However, the opposite was observed in the data and consequently estimated by the proposed model. This could be due to the subjectivity of estimating pedestrians' ages by observation.

As previously discussed, groupings of pedestrians younger than 65 years old and older than 65 years old showed that the older group was more compliant than the younger group in one past study. However, another study that separated pedestrians into 20-40 years old, 40-60 years old, and greater than 60 years old did not yield significant results. A variety of groupings were examined in this study, however, the only groupings that showed significance in the model were 0-29 years old and 30-65 years old.

Only two data parameters are shown to be influential in the Bike Only model described in Table 6. However, rho-square and adjusted rho-square values are appropriate and indicate a slightly better fit to this specific dataset than the Pedestrian Only model does to its dataset.

Table 6 Bike Only model estimation results

BIKE ONLY	**Parameter Estimates**	**Standard Deviation**	**Confidence Interval**
Non-Compliance Constant	0.00	-	-
Compliance Constant	-3.33	0.720	0.99
REST&PED	4.72	0.821	0.99
PUSHBUTTON	4.03	0.945	0.99
Likelihood Ratio Test	79.784		
Rho-Square	0.523		
Adjusted Rho-Square	0.484		

Rest in Walk and Pedestrian Recall as well as pushbutton usage are strong positive indicators of compliance in the Bike Only model, with Rest in Walk and Pedestrian Recall being more influential to compliance than pushbutton usage, as evidenced parameter estimate magnitudes.

Finally, all pedestrians and bicyclists observed at study intersections are included in one model and shown in Table 7.

Table 7 All Types model estimation results

ALL TYPES	**Parameter Estimates**	**Standard Deviation**	**Confidence Interval**
Non-Compliance Constant	0.00	-	-
Compliance Constant	-3.62	0.625	0.99
RESTWALK	4.34	0.630	0.99
AGEUNDER30	0.840	0.420	0.96
RACE2	-0.708	0.500	0.85
VOLUME1001	1.17	0.504	0.98
PUSHBUTTON	2.69	0.604	0.99
Likelihood Ratio Test	112.526		
Rho-Square	0.402		
Adjusted Rho-Square	0.359		

The presence of Rest in Walk and Pedestrian Recall, people less than 30 years old, traffic volumes greater than 1000 vehicles/hour, and pushbutton usage positively influenced compliance for the all types model. Additionally, Race is a variable that is significant in the All Types model, however isn't significant in the Pedestrian Only and Bike Only models. Individuals that fall under the criteria of being in Race Group 2 exhibited lower compliance rates than individuals falling under the other 3 groups.

Only Rest in Walk and Pedestrian Recall, as well as pushbutton usage were found to significantly influence all three models. Additionally, as is evident by the magnitude of the estimated parameters, REST&PED is the most influential parameter modeled.

4.6 Estimation of the Benefit of Rest in Walk and Pedestrian Recall

To compare the benefit of Rest in Walk and Pedestrian Recall at study sites, the All Types model can be used to calculate the average probability of compliance for all pedestrian and bicyclist observations. The average probabilities of compliance for Sites A and B with existing conditions (with Rest in Walk and Pedestrian Recall) and Sites C and D (without Rest in Walk and Pedestrian Recall) are shown in Table 8.

Table 8 Average probability of compliance with existing conditions

Average Probability of Compliance	Existing Conditions
Site A	70.8%
Site B	77.9%
Site C	5.8%
Site D	33.0%

Removing Rest in Walk and Pedestrian Recall from Sites A and B and adding Rest in Walk and Pedestrian Recall to Sites C and D significantly changes the average probability of compliance, as is shown in Table 9.

Table 9 Average probability of compliance with modified conditions

Average Probability of Compliance	Modified Conditions
Site A	3.6%
Site B	10.8%
Site C	70.6%
Site D	92.2%

Thus, the removal of Rest in Walk and Pedestrian Recall from Sites A and B would result in significantly lower probabilities of compliance. However, the addition of Rest in Walk and Pedestrian Recall to Sites C and D would drastically increase the probabilities of compliance.

CHAPTER 5: CONCLUSIONS AND FUTURE RESEARCH

Four signalized intersections in the Tampa Bay area were chosen for this study, a procedure was established to observe and collect data concerning pedestrians and bicyclists at study intersections, and a Logit model was developed to study pedestrian and bicyclist behavior while crossing at signalized intersections.

Though intersections without Rest in Walk and Pedestrian Recall allow for more responsive control and higher vehicular efficiency, intersections with Rest in Walk and Pedestrian Recall have higher compliance rates for both pedestrians and bicyclists. For pedestrians, significant variables include Rest in Walk and Pedestrian Recall, age, traffic volume, and pushbutton usage. For bicyclists, Rest in Walk and Pedestrian Recall, as well as pushbutton usage are the only significant variables. Finally, for the overall model, which includes pedestrians and bicyclists, Rest in Walk and Pedestrian Recall, age, race, traffic volume, and pushbutton usage were determined to be significant parameters that affect compliance. For all models estimated, Rest in Walk and Pedestrian Recall were found to be the most influential variable examined, as evidenced by parameter magnitudes.

Pushbutton usage is positively related to higher compliance. Nevertheless, non-compliance after pressing pushbuttons was observed. Installation of working indicators for pushbuttons could help to alleviate this problem. Confirmation that the pushbuttons are working would increase pedestrian confidence in the control devices and cause pedestrians to endure longer wait times before violating the rules.

While this study accomplished the goals set out in the scope, there are areas that can be improved in future research. Sample size is the most significant limitation of this study. Only four sites in the Tampa Bay area were examined and only 202 pedestrian and bicyclist observations were collected. Thus, expanding the number of study sites to include sites with a variety of surrounding land uses and geometries would greatly improve this study.

In conjunction with increasing the number of study sites, additional observations would improve the significance of the estimated models. Additionally, wheelchair users were not included in the model. However, examining the effects that Rest in Walk and Pedestrian Recall has on handicapped users could be a worthwhile topic for future research. Furthermore, an assessment of the effects that Rest in Walk and Pedestrian Recall have on vehicle delays, stops, and emissions and comparing them with safety impacts would be a good topic for future research.

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APPENDICES

Appendix A Variable Correlations

Table A.1 Pedestrian Only variables in Final Model

	RESTWALK	AGEUNDER30	VOLUME1001	PUSHBUTTON
RESTWALK	1			
AGEUNDER30	0.055	1		
VOLUME1001	0.442	0.015	1	
PUSHBUTTON	0.358	0.214	0.325	1

Appendix A (Continued)

Table A.2 Bike Only variables in Final Model

	RESTWALK	PUSHBUTTON
RESTWALK	1	
PUSHBUTTON	0.265	1

Appendix A (Continued)

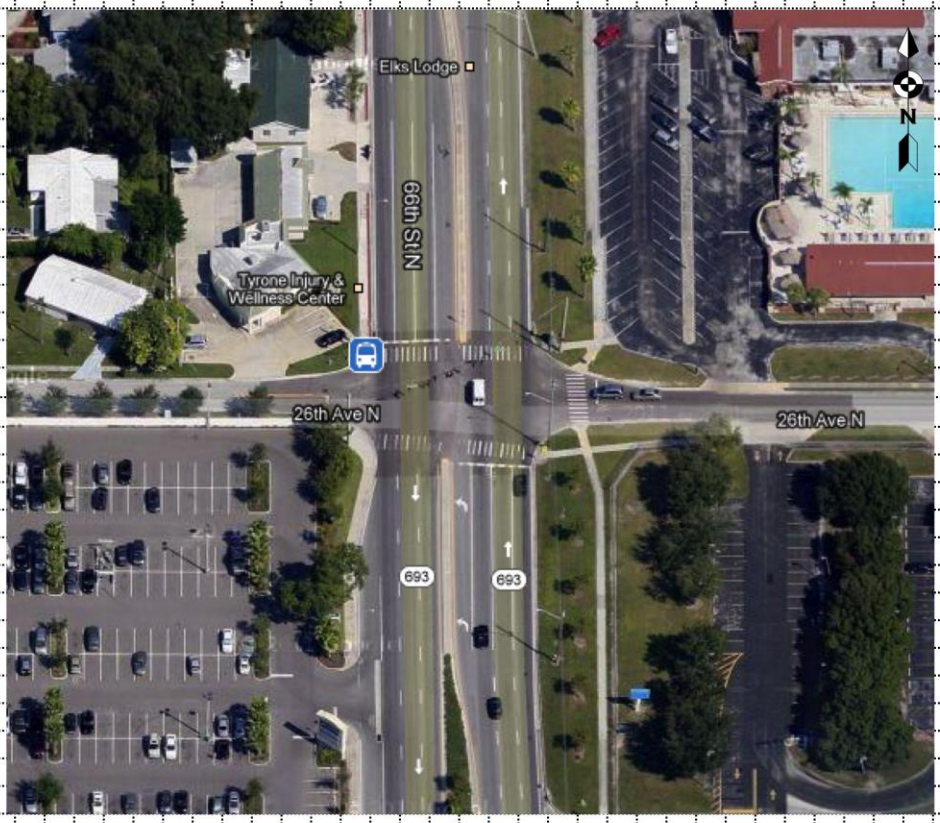
Table A.3 All Types variables in Final Model

	RESTWALK	AGEUNDER30	RACE2	VOLUME1001	PUSHBUTTON
RESTWALK	1				
AGEUNDER30	0.016	1			
RACE2	0.229	0.006	1		
VOLUME1001	0.325	0.120	0.021	1	
PUSHBUTTON	0.229	0.148	0.220	0.265	1

Appendix B Field Note Sheets

Traffic Volume: _____ Field Data Collection Date: _____ Time: _____

Location: 66th St & 26th Ave (Site A) Technician: _____



Walk Rest Modifier: Yes

Pedestrian Recall: Yes

Notes: _____

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Figure B.1 Field Note: Site A

Appendix B (Continued)

Traffic Volume: _____ Field Data Collection Date: _____ Time: _____

Location: 34th St & Central Ave (Site B) Technician: _____

Walk Rest Modifier: Yes

Pedestrian Recall: Yes

Notes: _____

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Figure B.2 Field Note: Site B

Appendix B (Continued)

Traffic Volume: _____ Field Data Collection Date: _____ Time: _____

Location: 34th St & 58th Ave (Site C) Technician: _____

Walk Rest Modifier: No

Pedestrian Recall: No

Notes: _____

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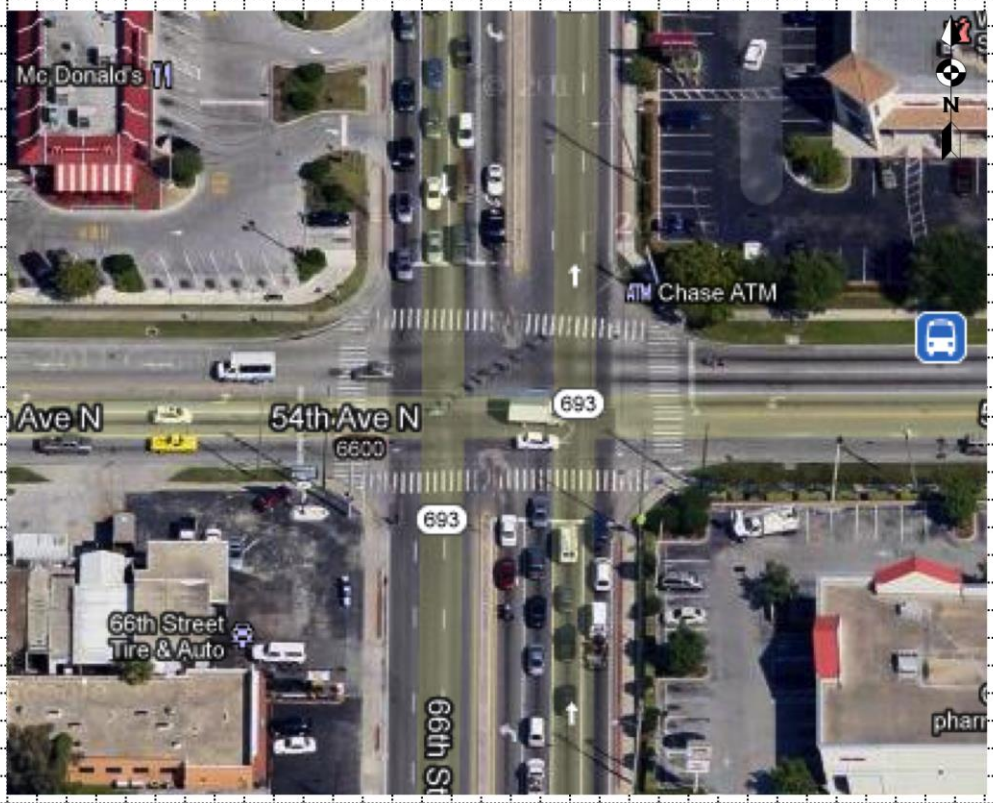
Figure B.3 Field Note: Site C

Appendix B (Continued)

Traffic Volume: _____ Field Data Collection Date: _____ Time: _____

Location: 66th St & 54th Ave (Site D) Technician: _____



Walk Rest Modifier: No

Pedestrian Recall: No

Notes: _____

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Figure B.4 Field Note: Site D