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

Jacob A. Mirabella and Yu Zhang

With increasing energy costs as well as rampant congestion in major U.S. cities, the popularity of walk and bike mode choices has increased in recent years. NHTSA has estimated that, in 2011, 11.1% of pedestrian fatalities and 18.5% of bicyclist fatalities in the United States occurred in Florida, although the state accounted for just 6.1% of the nation's population. In addition, intersections are hot spots for vehicle–pedestrian conflicts. This finding has been confirmed by FHWA's estimate that in the United States nearly one in five pedestrian fatalities occurs at an intersection. Because signalized and nonsignalized intersections are conflict points for vehicles, pedestrians, and bicyclists, traffic control methods to ensure that safety is not compromised are essential. For the examination of the safety effects of walk modes at signalized intersections, four locations in the Tampa Bay area were chosen. Two of the locations operated with rest in walk and pedestrian recall, and the other two operated without rest in walk and pedestrian recall. The study collected a total of 26 h of data in early 2013 at the four study sites, with a yield of 202 pedestrian and bicyclist observations. The behaviors were modeled with a multinomial logit model. The modeling found that the presence of rest in walk and pedestrian recall on minor street pedestrian phases, which operated concurrently with major street vehicle phases, encouraged higher pedestrian and bicyclist compliance rates. The presence or absence of the combination of rest in walk and pedestrian recall was found to be the most influential variable examined.

The U.S. surface transportation system has focused on increased vehicular capacity for many years. Countermeasures taken to mitigate congestion and vehicular delays have received much attention and funding because of the significant economic and environmental benefits incurred. However, improvements aimed at reducing vehicle traffic congestion are not always in pedestrians' best interests and in many instances have been shown to have negative effects on safety.

NHTSA has estimated that 4,432 pedestrian fatalities occurred in collisions with vehicles in 2011 (*1*). The top four most dangerous large metropolitan areas for pedestrians in the United States are in Florida and include Orlando–Kissimmee, Tampa-Saint Petersburg–Clearwater, Jacksonville, and Miami–Fort Lauderdale–Pompano Beach (*2*). Intersections are hot spots for vehicle–pedestrian conflicts, a finding that has been confirmed by FHWA's estimate that in the United States, nearly one in five pedestrian fatalities occurs at an intersection (*3*).

To improve the walkability of communities, safety action plans have been and are continuing to be implemented across the United States. NHTSA defined the 4 E's of traffic safety as education, enforcement, engineering, and emergency response (*4*). Countermeasures aimed at preventing conflicts generally fall under the educational, enforcement, or engineering categories. Although this study focused on the engineering aspect of pedestrian crossing control, the importance of public education, enforcement, and emergency response cannot be overemphasized.

BACKGROUND

Pedestrian Signal Control

Vehicle travel is the prevalent travel mode in the United States as well as many other developed countries, which means that vehicle travel 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 their 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) (*5*). There are three main segments of pedestrian signal control: "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. MUTCD states that a "Walk" indication can be as short as 4 s, depending on pedestrian volumes and behaviors; however, in normal conditions, a length of at least 7 s is recommended. When flashing "Don't Walk" begins, pedestrians who are already within the crosswalk are permitted to finish crossing; however, those who have not 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 and 4 ft/s, with

Department of Civil and Environmental Engineering, University of South Florida, 4202 East Fowler Avenue, ENB118, Tampa, FL 33620. Corresponding author: Y. Zhang, yuzhang@usf.edu.

Transportation Research Record: Journal of the Transportation Research Board, No. 2464, Transportation Research Board of the National Academies, Washington, D.C., 2014, pp. 77–85.
DOI: 10.3141/2464-10

the lower half of the range primarily used near schools or in locations with a high proportion of elderly population. 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.

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 vehicle through movement parallel to the pedestrian movement and is called once per cycle. Pedestrian recall is a popular choice because it does not require pedestrians to use push buttons. Without pedestrian recall, pedestrians must push a push button to call the walk phase, which gives the pedestrian the right-of-way to cross at the intersection.

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. In addition, 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 remain 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 the same characteristics except for the presence of rest in walk. The phases depicted on the top of each horizontal line in the figure are for major street motorist signals and the phases at the bottom of each horizontal line are for minor street pedestrian signals. When rest in walk is not present, "Don't Walk" for minor streets starts earlier so that right-turning 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 many right-turning vehicles from major to minor streets, is one reason for the absence of rest in walk. Nevertheless, in cases where the rest in walk mode is removed from intersections, Pinellas County Traffic Management usually receives citizen complaints (*6*). This is because less right-of-way (green) time is given to pedestrians. For pedestrians who are accustomed to the presence of rest in walk, it is difficult to adjust to its absence. Although traffic engineers have a good knowledge of the vehicular efficiency of various walk modes, there is a lack of understanding of the safety impacts of the modes. Hence, quantifying the safety impacts of walk modes not only fills the gap in the literature, but also provides practical guidance on walk mode applications.

Proposed Research and Approach

While searching for comparable study sites in the Tampa Bay Area, intersections with rest in walk and pedestrian recall and intersections without the two modes were found. The study evaluated 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. Florida law states that bicyclists must adhere to pedestrian laws when they use sidewalks and crosswalks. Thus, bicyclists traveling on sidewalks and crosswalks were included in the study. On-site observational surveys and modeling with a multinomial logit model were conducted to allow for a better understanding of pedestrian and bicyclist behaviors at intersections with various walk modes.

LITERATURE REVIEW

It has long been known that many behavioral and site-specific variables are responsible for the actions of pedestrians crossing at intersections. In Rosenbloom's study, gender was determined to play a part, with males being more likely to cross without right-of-way than females; however, age did not play a significant role in the same study (*7*). In addition, 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 (*7*). Possible reasons for behavioral differences between individuals and groups have been studied and discussed in detail by Hirschi (*8*).

A study conducted for the American Automobile Association (AAA) Foundation for Traffic Safety determined that older pedestrians are generally more compliant than younger pedestrians, where older pedestrians were defined as 65 years and older and younger pedestrians were defined as younger than 65 years old (*9*). It has been observed that middle-aged males are more frequently involved as both drivers and pedestrians in pedestrian–vehicle collisions (*10*) and that noncompliance by pedestrians is frequently a cause of collisions

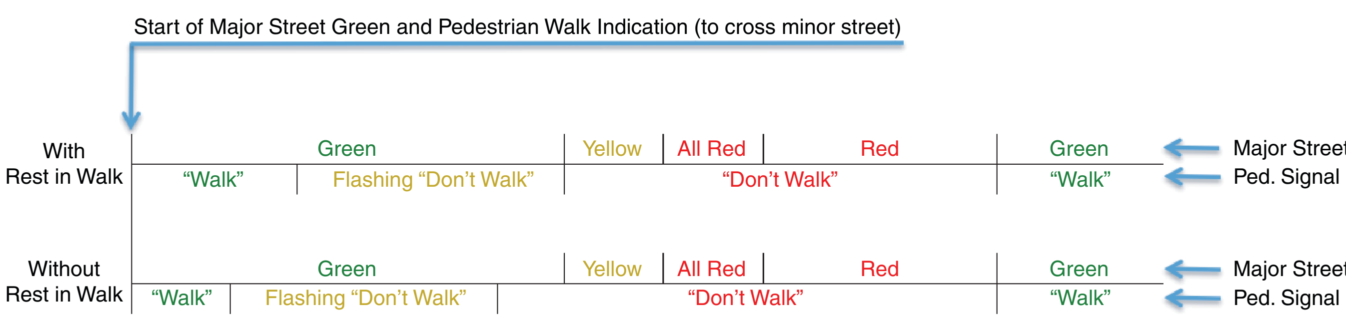


FIGURE 1 Rest in walk and non–rest in walk operations (ped. = pedestrian).

(*11*). Tom and Granié also observed that males are overrepresented in vehicle–pedestrian collisions, which the authors attributed to males violating traffic rules more frequently than females (*12*).

Crosswalk length has been studied as a compliance factor, with mixed results (*13*). Turning vehicles are dangerous to pedestrians, because the vehicles and pedestrians often share the same phase, which provides significant opportunity for conflict. Research into programming a leading pedestrian interval into traffic controllers has shown positive results as well as cost effectiveness (*14*).

Signal timing is an important factor in crossing behavior. Studies have shown that the longer pedestrians are required to wait for the right-of-way, the more likely they are to cross illegally (*15*). Thus, proper signal timing is an important variable to be considered in encouraging a pedestrian-friendly community. Sweden, Germany, and the Netherlands rely on short cycle lengths to accommodate pedestrians (*16*). FHWA has endorsed shorter cycle lengths in the United States; however, shorter cycle lengths were only recommended for signalized intersections with significant pedestrian noncompliance (*17*).

INTERSECTION CHARACTERISTICS

Since the overall purpose of this study was to compare differences in pedestrian compliance between walk modes, it was necessary either to remove or account for as many outside 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 and lane types at major and minor roads, presence of push buttons, presence of countdown timers, crosswalk types (if clearly marked or not), surrounding land uses, and presence of school zones. The characteristics of the intersections included in this study were determined through Google Earth and field inspections.

Signal Timing

Cycle lengths have been shown to influence pedestrian delay at signalized intersections. MUTCD defined cycle length as the time required for one complete sequence of signal indications and splits, that is, the sum of green, yellow, and all red time.

Cycle lengths at the study intersections ranged from 70 to 200 s. The ratios of walk time to cycle length, walk time to split time, and split time to cycle length were examined and compared with compliance rates. However, no trends were observed.

Traffic Volumes

Traffic volume is an important factor in pedestrian crossing behavior. Directly related to the length and frequency of gaps, pedestrians are more unlikely to cross against signal when heavy vehicle traffic exists (*18*). Therefore, it is important to account for this variable.

Vehicles were only counted and included in the volume variable if they crossed the study crosswalk, because only vehicles that had the potential for conflict with crossing pedestrians were expected to influence pedestrians' compliance. Therefore, through, left-turning, 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 1.

Intersection Geometry

Pedestrians tend to be more comfortable choosing gaps when oncoming vehicles are turning (*18*). Thus, the study had to consider and control for lane configuration. Consequently, Sites A and C were chosen so that their geometries matched with one shared through, left-turn, and right-turn bay in each direction. Likewise, Sites B and D matched, with one through, one shared through and right-turn, and one left-turn bay. Figure 2 illustrates the geometries of the study intersections.

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

The crosswalk length was expected to influence crossing behavior. Violations were expected to occur more frequently for shorter distances than for longer distances. And clearly marked crosswalks have been shown to result in an increased likelihood of compliance. Thus, the choice of sites with similar distances, as well as clearly marked crosswalks, accounted for these variables.

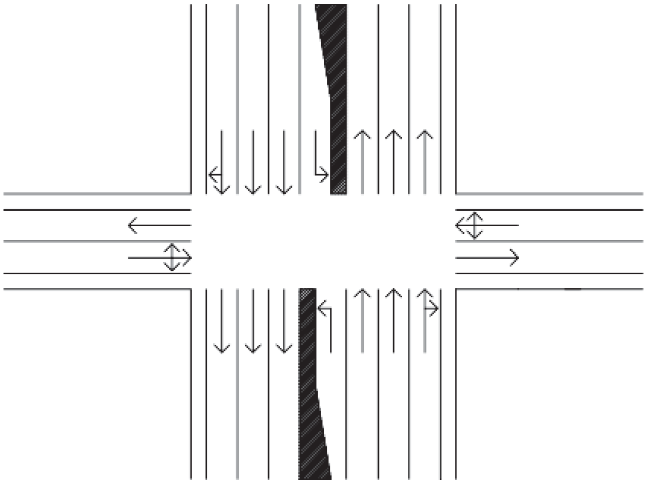
Push Buttons

Although push buttons are present at intersections operating with pedestrian recall, when the walk mode is in operation pushing the push buttons does not influence control. Regardless of whether push buttons influence the control of intersections, previous studies have shown that pedestrians who utilize push buttons are more likely to cross when the right-of-way at signalized intersections is given.

TABLE 1 Study Intersections

Designation	Site A	Site B	Site C	Site D
Intersection	66th Street and 26th Avenue	34th Street and Central Avenue	34th Street and 58th Avenue	66th Street and 54th Avenue
Rest in walk	Present	Present	Not present	Not present
Pedestrian recall	Present	Present	Not present	Not present
Push button	Present	Present	Present	Present
Countdown timer	Present	Present	Present	Present
Lanes (minor)	2	5	2	5
Average volume (vph)	120	932	252	1,219

NOTE: vph = vehicles per hour.



(a) (b)

FIGURE 2 Intersection geometry: (*a*) Sites A and C and (*b*) Sites B and D.

Thus, to ensure comparability, the presence of push buttons was controlled and only intersections with push buttons were chosen for the study. The presence of push buttons at each site was verified during the field review as well as the video recording reviews.

Crosswalk Visibility

The selected study intersections all had visible crosswalks. Crosswalk types at study intersections were either zebra painted walkways or brick pavers outlined with white striping.

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. The land use categories considered in the study included recreational, retail, industrial, and residential. The selected intersections were located in areas with mixed retail and industrial land use types.

School Zones

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

PERSON CHARACTERISTICS

The characteristics of each person observed crossing at the study intersections were collected for incorporation in a multinomial logit model, as well as to examine differences in compliance rates between genders, age groups, and races. Although significant efforts were made to estimate person characteristics accurately, some level of subjectivity was present in the age and race characteristic estimations, since they were obtained from observation.

Gender

In previous studies, gender has been found to influence compliance. Men have been observed participating in more risky behaviors than women. Men are more frequently noncompliant when crossing intersections and are overrepresented in crash data. Therefore, observed pedestrians and bicyclists crossing at the study intersections were classified as either male or female, recorded onsite, and verified in video recordings.

Age

Ages were estimated for each pedestrian and bicyclist observed, because 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 the AAA Foundation for Traffic Safety separated pedestrians into two groups, 65 years and older and less than 65 years (*9*). However, Rosenbloom separated pedestrians into 20–40 years old, 40–60 years old, and over 60 years old and did not find significant differences between the behaviors of the various age groups (*7*). Estimated pedestrian and bicyclist ages were partitioned into a variety of groupings and evaluated. Separating pedestrians and bicyclists into two groups, which were less than 30 years old and greater than 30 years, produced the best fit for the data.

Race

Observed pedestrians and bicyclists were classified as Group 1, 2, 3, or 4, corresponding to white, black, Hispanic, or other, respectively. The predominant race of each person was estimated on site and verified in video recordings.

Travel Modes

Individuals walking, skateboarding, or using wheelchairs are required to utilize sidewalks and crosswalks and were defined as pedestrians. However, bicyclists may choose to ride either on roadways with vehicles or on 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. Thus, bicyclists riding on sidewalks and using crosswalks were included in this study.

DATA COLLECTION

Intersection characteristics, person characteristics, and crossing behaviors were either collected on site and verified off site or collected off site and verified on site, depending on the characteristics of interest. Video recorders, digital cameras, and stopwatches were used to collect data. Intersection field note sheets were designed and filled out for each intersection for each day of data collection. Characteristics in the field notes included the following: location, traffic volume, date, time, presence or absence of rest in walk and pedestrian recall, miscellaneous notes, and an aerial view of each study intersection. Camera location and direction of view were marked on the aerial view contained in the field notes. Timing sheets downloaded from signal controllers were used to determine basic timings, cycle lengths, recall types, coordination, splits, and so forth.

The study collected a total of 26 h of video recordings over 16 weekdays in early 2013. Data were collected during midday and evening peak periods. Data were collected only during daylight hours and good weather conditions.

MODELING TECHNIQUE

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 (*19*).

Logit models are widely used in a variety of fields to analyze and understand behaviors of individuals. Logit models have a simple, closed form, which greatly simplifies the calculations required to estimate the probabilities of choosing alternatives. Another aspect of logit models, similar to other models, is that the utility maximization decision rule is used. 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 characteristics, the alternative's characteristics, and a random (unobserved) component. The probability distribution function of this component determines the type of method that can be used in the model estimation. Logit models assume a Type I extreme value (Gumbel) distribution for the random error term. The deterministic component can also include interactions between alternative attributes and individual characteristics. Therefore the total utility function is

$$U_{in} = V_{in} + \varepsilon_{in} \tag{1}$$

where

U_{in} = total utility,
V_{in} = observed utility, and
ε_{in} = unobserved utility for alternative *i* and person *n*.

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

where

α_0 = constant,
$V(X_{in})$ = utility from observed attributes,
$V(S_n)$ = utility from observed characteristics, and
$V(X_{in}, S_n)$ = utility from interactions between X_{in} and S_n for alternative *i* and person *n*.

Furthermore,

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

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, the 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. The 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. Because the purpose of this study was to model compliance with traffic signals, the model involved two choices, compliance and noncompliance. The explanatory variables that were recorded and considered in the models included person and intersection characteristics, which are described in Table 2.

TABLE 2 Person and Intersection Characteristics

Parameter	Description
Observation	Each person is assigned a unique number (1, 2, 3, etc.)
Compliance	Person complies if he or 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
Push button	Push-button usage
Rest and ped	Rest in walk and pedestrian recall presence or absence
Volume	Traffic volume (vph)
Lanes	Number of lanes person must traverse to completely cross street
Cycle length	Time required for signal to complete cycle (s)

For each observation the attributes mentioned in Table 2 were recorded. Once the data were 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. Once the model was estimated, some of the explanatory variables that were initially expected to affect compliance were found to be insignificant and were removed from the models.

Correlation Test and Goodness of Fit

The correlations of the data were tested with Cramer's V and Pearson's Product-Moment methods in SPSS. These methods observe similarities between data sets to determine which sets depict collinearity. The data sets that were significantly correlated were removed from the logit model.

The confidence interval for each parameter estimate was determined in BIOGEME with 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 with rho-square and adjusted rho-square values. The rho-square value is the ratio of variance explained by the model to total variance. Although 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.

ANALYSIS

Study Intersections

Intersections were chosen based on the criteria discussed in the section on intersection characteristics. Table 1 depicts the intersections chosen for the study as well as their characteristics. Sites A and B are maintained by the City of Saint Petersburg and Sites C and D are maintained by Pinellas County.

Pinellas County and the City of Saint Petersburg provided timing sheets for all study intersections. Patterns for Sites A and B were constant. However, Sites C and D ran patterns that were dependent on the time of day. Data were only collected during the patterns shown in Table 3; however, timing was determined so as not to influence significantly the models estimated.

Observations

The shares of observed travel types were walk, 44%; bike, 53%; skate, 1%; and wheelchair, 2%. Skaters and wheelchair users were not included in the analysis because of the 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 approximately 46% of the observations and bicyclists comprising 54% of the observations. Observations were distributed as follows among the respective intersections: 40 at Site A, 57 at Site B, 43 at Site C, and 62 at Site D. Thus, there were a total of 97 observations at sites with rest in walk and pedestrian recall and 105 observations at sites without rest in walk and pedestrian recall. Among the pedestrians and bicyclists observed, there were 36 females and 166 males. In addition, taking 30 years old as a threshold, 63 of the observed people were estimated below the threshold and 139 above. The age threshold of 30 years old was the only threshold to produce significant age parameter results.

Compliance

Figure 3 shows the observed compliance rates at each intersection. The compliance rates were considerably different between intersections. The presence of rest in walk and pedestrian recall at Sites A and B resulted in longer walk intervals and required no push-button 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 had the same geometry (two lanes in the minor approach) but different walk modes, showed that pedestrians were more compliant at Site A than Site C. Sites B and D, which had the same geometry (five lanes in the minor approach) showed that people were more compliant at Site B than Site D.

Figure 3 also shows that the number of lanes contributed to the compliance rates. Site B was observed to have a higher compliance rate than Site A, which was not surprising considering more lanes must be crossed at Site B than at Site A. Site B had heavier vehicle traffic than Site A. Similar trends were observed for Sites C and D.

Correlation

Cramer's V and Pearson's Product-Moment correlation tests were performed on the data set with SPSS. The tests found a strong

TABLE 3 Cycle Lengths and Splits

Site	Splits (s) Φ1	Φ2	Φ3	Φ4	Φ5	Φ6	Φ7	Φ8	Cycle Length (s)
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

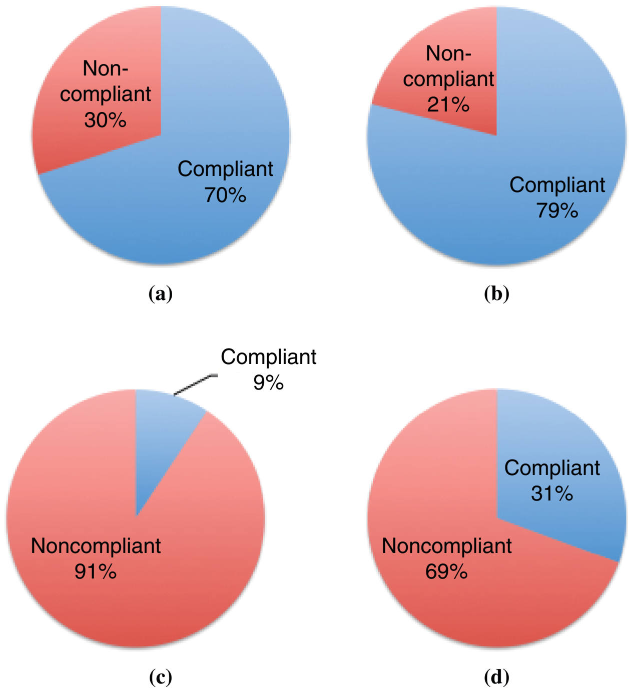


FIGURE 3 Compliance by intersection for all types: (*a*) Site A, (*b*) Site B, (*c*) Site C, and (*d*) Site D.

correlation between cycle length and control type, number of lanes and traffic volume, and group arrival and departure sizes. Thus, variables that strongly correlated were not included in the model estimation and did not influence the predictions of compliance or noncompliance.

Logit Model Estimation

The constant-only model is the starting point for logit model estimations. A constant-only model does not include any explanatory variables; thus, it is rarely a good fit for the data. The constant-only model is used in common practice to verify that the modeling software is performing the estimations properly, which can be easily verified with Equation 3. Based on calculations with the estimated constants, the compliance rates for walk, bike, and all types were 58.7%, 38.2%, and 47.5%, respectively. These findings were consistent with the data. The model therefore estimated the parameters correctly and more variables could be added.

The results shown in Tables 4, 5, and 6 were obtained after estimating several models for various combinations and variable categories. Only variables estimated within a minimum confidence interval of 85% (with *t*-statistics) were included as significant variables.

As can be seen in the pedestrian-only model depicted in Table 4, compliance was positively influenced when rest in walk and pedestrian recall were present, pedestrians were younger than 30 years old, vehicular volumes were greater than 1,000 vph, and push buttons were utilized.

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 a 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 younger than 30 years old and older than 30 years old.

Only two data parameters were influential in the bicyclist-only model described in Table 5. However, the rho-square and adjusted rho-square values were appropriate and indicated a slightly better fit of the bicyclist-only model to its data set than the pedestrian-only model to its data set. Rest in walk and pedestrian recall as well as push-button usage are strong positive indicators of compliance in the bicyclist-only model, with rest in walk and pedestrian recall having more influence on compliance than push-button usage, as evidenced by the magnitudes of the estimated parameters.

Finally, all pedestrians and bicyclists observed at study intersections were included in one model and the estimation results are shown in Table 6. The presence of rest in walk and pedestrian recall, people younger than 30 years old, traffic volumes greater than 1,000 vph, and push-button usage positively influenced

TABLE 4 Pedestrian-Only Model Estimation Results

Variable	Parameter Estimate	Standard Deviation	Confidence Interval
Noncompliance constant	0.00	na	na
Compliance constant	–3.46	0.976	0.99
Rest and ped	3.55	0.916	0.99
Age under 30	1.22	0.602	0.95
Volume 1,000+	1.91	0.800	0.98
Push button	1.59	0.744	0.96

NOTE: na = not applicable. Likelihood ratio test = 37.048; $\rho^2 = .290$; adjusted $\rho^2 = .212$.

TABLE 5 Bicyclist-Only Model Estimation Results

Variable	Parameter Estimate	Standard Deviation	Confidence Interval
Noncompliance constant	0.00	na	na
Compliance constant	–3.33	0.720	0.99
Rest and ped	4.72	0.821	0.99
Push button	4.03	0.945	0.99

NOTE: Likelihood ratio test = 79.784; $\rho^2 = .523$; adjusted $\rho^2 = .484$.

TABLE 6 All-Types Model Estimation Results

Variable	Parameter Estimate	Standard Deviation	Confidence Interval
Noncompliance constant	0.00	na	na
Compliance constant	–3.62	0.625	0.99
Restwalk	4.34	0.630	0.99
Age under 30	0.840	0.420	0.96
Race2	–0.708	0.500	0.85
Volume 1,000+	1.17	0.504	0.98
Push button	2.69	0.604	0.99

NOTE: Likelihood ratio test = 112.526; $\rho^2 = .402$; adjusted $\rho^2 = .359$.

compliance for the all-types model. In addition, race was significant in the all-types model, although it was not significant in the pedestrian-only and bicyclist-only models. Individuals in Group 2 for race exhibited lower compliance rates than individuals in the other three groups.

Only the rest in walk and pedestrian recall variable and push-button usage were found to influence significantly intersection crossing compliance in all three models. As is evident by the magnitude of the estimated parameters, the rest in walk and pedestrian recall variable was the most influential parameter modeled.

Estimation of Benefit of Rest in Walk and Pedestrian Recall

To compare the benefit of rest in walk and pedestrian recall at the study sites, the all-types model was 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) were 70.8%, 77.9%, 5.8%, and 33.0%, respectively.

Modifying the conditions by 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 changed the average probability of compliance. The average probabilities at Sites A, B, C, and D with the modified conditions were 3.6%, 10.8%, 70.6%, and 92.2%, respectively.

Thus, the removal of rest in walk and pedestrian recall from Sites A and B would result in significantly lower probabilities of compliance. In contrast, the addition of rest in walk and pedestrian recall to Sites C and D would drastically increase the probabilities of compliance.

CONCLUSIONS AND RECOMMENDATIONS

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 the study intersections, and a logit model was developed to study behaviors of pedestrians and bicyclists while they crossed at signalized intersections with various walk modes.

Although intersections without rest in walk and pedestrian recall allowed for more responsive control and higher vehicular efficiency, intersections with rest in walk and pedestrian recall had higher compliance rates for pedestrians and bicyclists. For pedestrians, significant variables included rest in walk and pedestrian recall, age, traffic volume, and push-button usage. For bicyclists, rest in walk and pedestrian recall and push-button usage were the only significant variables. Finally, for the overall model, which included pedestrians and bicyclists, rest in walk and pedestrian recall, age, race, traffic volume, and push-button usage were significant parameters affecting compliance. For all the models estimated, the rest in walk and pedestrian recall variable was found to be the most influential variable examined, as evidenced by the parameter magnitudes.

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

Although this study accomplished its goals, there are areas that could be improved in future research. Sample size was 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 at each study site would improve the significance of the estimated models.

Wheelchair users were not included in the model. However, examining the effects of rest in walk and pedestrian recall 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 the effects with safety impacts would be a good topic for future research as well.

ACKNOWLEDGMENTS

The authors thank Albeck Gerken, Inc., for providing equipment used in this study, as well as Peter Yauch and Pei-Sung Lin for providing valuable technical advice and comments. The authors acknowledge the contribution that Norman Jester, Glenn Weaver, and Timothy Funderburk provided by supplying timing sheets and valuable technical advice. University of South Florida students Akbar Zanjani and Vasili Kostakis assisted in analysis and data collection, and their help was vital to the study's success. The study was supported by the National Science Foundation.

REFERENCES

1. Fatality Analysis Reporting System (FARS) Encyclopedia. NHTSA, 2013. http://www-fars.nhtsa.dot.gov/Main/index.aspx. Accessed Feb. 1, 2013.
2. Ernst, M. *Dangerous by Design: Solving the Epidemic of Preventable Pedestrian Deaths.* Transportation for America, Washington, D.C., 2011.
3. Pedestrian Safety at Intersections. *Intersection Safety Issue Briefs, No. 9,* FHWA, 2009. http://safety.fhwa.dot.gov/intersection/resources/fhwasa10005/brief_9.cfm. Accessed Oct. 27, 2013.
4. Zegeer, C. V., R. Blomberg, D. Henderson, S. Masten, L. Marchetti, M. M. Levy, Y. Fan, L. Sandt, A. Brown, J. Stutts, and L. Thomas. Evaluation of the Miami-Dade Pedestrian Safety Demonstration Project. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2073,* Transportation Research Board of the National Academies, Washington, D.C., 2008, pp. 1–10.
5. The National Committee on Uniform Traffic Control Devices. *Manual on Uniform Traffic Control Devices,* 2009 ed. FHWA, U.S. Department of Transportation, 2009. http://www.gpo.gov/fdsys/pkg/FR-2009-12-16/pdf/E9-28322.pdf. Accessed June 15, 2013.
6. Jester, N. Rest in Walk Information, Interview by J. A. Mirabella, Sept. 25, 2013.
7. Rosenbloom, T. Crossing at a Red Light: Behaviour of Individuals and Groups. *Transportation Research Part F: Traffic Psychology and Behaviour.* Vol. 12, 2009, pp. 389–394.

8. Hirschi, T. *Causes of Delinquency.* University of California Press, Berkeley, 1969.
9. Stollof, E., H. McGee, and K. Eccles. *Pedestrian Signal Safety for Older Persons.* AAA Foundation for Traffic Safety, Washington, D.C., 2007.
10. Lee, C., and M. Abdel-Aty. Comprehensive Analysis of Vehicle–Pedestrian Crashes at Intersections in Florida. *Accident Analysis and Prevention,* Vol. 37, 2005, pp. 775–786.
11. Stutts, J.C., W.W. Hunter, and W.E. Pein. Pedestrian Crash Types: 1990s Update. In *Transportation Research Record 1538,* TRB, National Research Council, Washington, D.C., 1996, pp. 68–74.
12. Tom, A., and M.-A. Granié. Gender Differences in Pedestrian Rule Compliance and Visual Search at Signalized and Unsignalized Crossroads. *Accident Analysis and Prevention,* Vol. 43, 2011, pp. 1794–1801.
13. Ren, G., Z. Zhou, W. Wang, Y. Zhang, and W. Wang. Crossing Behaviors of Pedestrians at Signalized Intersections: Observational Study and Survey in China. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2264,* Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 65–73.
14. Van Houten, R., R.A. Retting, C.M. Farmer, and J. Van Houten. Field Evaluation of a Leading Pedestrian Interval Signal Phase at Three Urban Intersections. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1734,* TRB, National Research Council, Washington, D.C., 2000, pp. 86–92.
15. Kothuri, S.M., P. Koonce, C.M. Monsere, and T. Reynolds. Innovations for Pedestrians at Traffic Signals–Portland, OR Case Study. Portland, Ore. http://www.walk21.com/papers/405_Koonce_Innovations%20for%20Pedestrians.pdf.
16. FHWA. *Signalized Intersection Safety in Europe.* U.S. Department of Transportation, 2003.
17. FHWA. *PEDSAFE: Pedestrian Safety Guide and Countermeasure Selection System.* U.S. Department of Transportation, 2004.
18. Palamarthy, S., H.S. Mahmassani, and R.B. Machemehl. *Models of Pedestrian Crossing Behavior at Signalized Intersections.* University of Texas at Austin, 1994.
19. Train, K. *Discrete Choice Methods with Simulation.* Cambridge University Press, 2009.

The Pedestrians Committee peer-reviewed this paper.