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Pedestrian Compliance with Concurrent and Exclusive Phasing at Traffic Signals

Kevin R. McKernan
University of Connecticut - Storrs, kevin.mckernan@uconn.edu

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Kevin R. McKernan

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B.A., Emerson College, 2001

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Presented by

Kevin R McKernan

Major Advisor____

John N. Ivan

Associate Advisor ____

Nalini Ravishanker

Associate Advisor ____

Norman Garrick

University of Connecticut

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Abstract

Exclusive and concurrent phasing are the two primary traffic signal treatments for pedestrians in the state of Connecticut. Exclusive phasing, which shuts down an intersection to vehicular traffic, is commonly believed to be safer while concurrent phasing, which moves pedestrian and vehicular traffic at the same time, is often seen as more efficient. Research into the subject acknowledges that, while they exist, the safety benefits of exclusive phasing are only possible when pedestrians are compliant and cross roadways when told to by the traffic control device.

This thesis describes a comparison of pedestrian compliance between exclusive and concurrent phasing for a sample of signalized intersections in Connecticut. Pedestrians crossing each intersection were observed and classified according to what signal they crossed on as well as whether or not they were in a designated crossing area. Intersections were selected to represent both types of signal phasing while controlling for other physical characteristics. Comparisons were made using strict compliance rules, which follow the letter of the law, and relaxed compliance rules, where exclusive phased crossings were rated using concurrent phasing rules in order to see if pedestrians treaded the signal types differently. In addition to direct comparison, binomial regressions were performed with random effects to account for locational differences between sites which were not measured. It was found that not only did intersections with concurrent phasing see greater rates of pedestrian compliance, but that pedestrians in the study area appear to treat signals with exclusive phasing as though they had concurrent phasing.

Introduction

During the early half of the 20th century when the automobile began to displace the pedestrian as the dominant force on the streets, conflicts over who had the right of way were common. In the earliest days, the pedestrian was almost always given the right to cross where he pleased and attempts to control that freedom were often considered forms of tyranny. Eventually, the fact that the automobile was always the victor of any physical confrontation brought concessions from people on foot, and clever marketing campaigns created the “Jay-walker” – an uncivilized rube who meandered into traffic instead of crossing streets at the proper time and place [1].

At first, police officers were usually on hand to direct traffic and ensure that pedestrians could cross safely but, having a constable at every intersection was prohibitively costly. Consequently, in 1914, the first practical traffic signal was installed in Cleveland, Ohio. While this signal was controlled by an officer standing to the side of the road, it wasn’t long before automation stepped in. When engineers were brought into Chicago to deal with congested streets, the coordinated signal system was seen as miraculous by all. Except, that is, for the police who were forced to stop traffic in order to help pedestrians who, at many lights, hadn’t been left enough time to cross safely. Of course, even when sufficient crossing time was given, traffic specialists often found that the pedestrian would still ignore traffic signals whenever it was convenient [1].

Despite the passing of more than a century since the introduction of the traffic signal as a mediator to street traffic, engineers are still left with the problem of pedestrians refusing to act as automatons. While reviewing European and American practices in signal timing, Karsten Baas noted that pedestrians are often treated by engineers as light, non-motorized vehicles and that “as traffic engineers, we must understand the traffic behavior of the pedestrian, who because of his inherent mobility, will always try to shorten distances and reduce waiting times, often without adhering to the highway code and disregarding the risks involved,” [2].

In an effort to understand pedestrian traffic behavior, this paper examines pedestrian compliance at two forms of pedestrian phases at signalized intersections found in Connecticut. The first phase, which here will be called concurrent, is where both pedestrians and vehicular traffic are directed to move in the same directions at the same time. Exclusive pedestrian phases are the second type to be studied. At these signals all vehicular traffic is stopped and pedestrians are given their own signal phase to traverse the intersection across any of the approach legs. Exclusive phases are often considered safer since potential conflicts between motor vehicles and pedestrians are theoretically avoided, but, they are often less efficient for both motorists and pedestrians.

Compliance, in the context of this paper, is based on the laws put forth by Sections 14-300 and 14-300b of the General Statutes of the State of Connecticut as revised by January 1, 2013. The laws governing pedestrian behavior when crossing at signalized intersections pertinent to the observed intersections can be summarized as follows.

- At intersections where pedestrian control signals use the words “WALK” or “DON’T WALK,” a pedestrian may only cross when indicated by the signal.
- At intersections where such signals do not exist, pedestrians may not cross against a red signal.
- Pedestrians may not cross at any place that is not a marked or unmarked crosswalk.
- Any pedestrian beginning their movement on a “WALK” signal or green light has the right of way over all vehicles until a curb or safety zone has been reached.
- Pedestrians may not cross an intersection diagonally unless authorized by a pedestrian-control signal or police officer.
- Pedestrians may not cross roads between intersections where pedestrian-control devices exist.

Using these statutes as guidelines, two definitions for compliance at the intersections observed in this study will be used. At signals with concurrent pedestrian phases, pedestrians are considered compliant if they both crossed within a crosswalk and began their movement on a green light corresponding to their

travel direction. At signals with exclusive pedestrian phases, pedestrians are considered compliant only if they both crossed within a crosswalk and began their movement during the pedestrian phase prior to a flashing “DON’T WALK” light or similar warning.

Zhang et al, which uses the same data set as this paper, found that interactions between vehicles and pedestrians depended upon compliance and that signals with exclusive pedestrian phases, while having fewer collisions overall, tended to have more severe pedestrian vs. motor vehicle collisions [3]. Realizing that the benefits of exclusive signals depend upon pedestrians’ willingness to acquiesce the roadway to motor vehicles, this paper will attempt to see if there is any difference between pedestrian compliance at signals with exclusive phases versus those with concurrent signals and whether these differences continue to exist when exclusive signals are rated using the more relaxed compliance rules of concurrent signals. Finally, we will also see if differences between signal types continue to exist when counting only those pedestrians who crossed within the designated crossing areas. All this will be done with the objective of making data driven suggestions on where exclusive or concurrent pedestrian phasing should be used in a road network.

Literature Review

The behavior of pedestrians and the risks they face in the modern environment is a subject that has been studied for decades. Despite the amount of research that has been performed, though, there is still much work to be done. This seems to be mostly due to the flexible nature of walking combined with the inherent difficulty of predicting behavior.

Studies on pedestrians are generally performed through surveys, live observations, or video recordings. None of these methods is perfect as a pedestrian who notices that they are being observed may change their behavior, especially if they notice that they are being recorded by a camera. Surveys depend on the honesty and self-awareness of the respondent to achieve accurate results. Non-field experiments have also been performed by having randomly selected participants judging recordings or images of streets. This

latter method, as technology has improved, has even allowed some experimenters to set up simulated streets where a subject can cross as they desire without any physical risk.

There have, surprisingly, been relatively few studies performed comparing pedestrians at concurrent and exclusive phase signals. A 1977 study comparing exclusive signals and late release signals noted that pedestrian compliance at scramble signals, a variation of exclusive in which pedestrians are permitted to cross the intersection diagonally, was very low and, indeed, the safety benefits of such signals may be negated by compliance issues. [4] Bechtel et al. performed a study comparing intersections before and after the installation of exclusive signals and found that pedestrian violations increased after the exclusive signals were put in. They noted that the increased violations appeared to occur mostly on weekends [5]. In 1982, Zegeer, Opiela, and Cynecki conducted a study comparing traffic signals which had no pedestrian signals, concurrent pedestrian signals, and exclusive pedestrian signals. While pedestrian compliance was not noted, they did find that exclusive signals were safer than concurrent ones. The difference between the two signal types in terms of safety disappeared, however, when pedestrian volumes fell below 1,200 per day [6]. Garder, after studying signals in Swedish cities, found exclusive signals to be an efficient safety measure as long as the amount of people crossing against the light was low [7]. An analysis of crashes in three Israeli cities found that exclusive signals were safer than concurrent signals when vehicle volumes were high and pedestrian volumes were low but, where AADT values were below 18,000, there was little difference between signal types in terms of pedestrian safety. The study also found that where pedestrian volumes were high, there was little difference between signal types in terms of safety [8]. Interestingly, one of the earliest comparison papers encountered did not even consider pedestrians but found that when San Francisco introduced scramble signals in 1954 to improve safety and efficiency, driving times for the street with the new signals increased by 59% while connecting streets saw increases anywhere between 13% and 95%. Overall, motorists in the city saw their travel times increase by 48.4% [9].

Several studies have been performed to see how people act depending on the type of intersection control device with which they are presented. Orne’s 1959 study found that pedestrian heads used in combination

with traffic signals increased pedestrian compliance in both Bridgeport, CT and Lansing, MI by a small percentage [10]. A paper published by Mortimer reached a similar conclusions observing that crossings against red lights were 10% lower in Detroit where pedestrian specific signals were installed. In addition, a hazard index created from the data suggested that there were 27% fewer avoidance maneuvers performed by pedestrians and drivers at the intersections with pedestrian signals [11]. Since then, however, other studies have found no correlation between the inclusion of special pedestrian heads and pedestrian compliance [12] [13] [14]. This is important to note because no concurrent signals with accompanying pedestrian heads were located for the study presented in this paper. From work done on this subject it can be inferred that if the studied signals had pedestrian heads either no difference, or a slight increase, in compliance might have been observed at the concurrent signals.

Variations on pedestrian signals have also produced mixed results with Sterling finding that steady "WALK" signals resulted in higher pedestrian compliance than ones which flashed [15]. In 1981 Robertson and Douglass tested a variety of pedestrian signals under the premise that some might be more easily understood by pedestrians. This included the removal of a clearance interval, using flashing "WALK" signals during clearance intervals, and replacing "DON'T WALK" signals with ones that read "DON'T START". In most locations, little difference was observed in pedestrian compliance. Surveys found that pedestrians mostly understood the signals save for the flashing "WALK" option, indicating that those who crossed against the signal did so knowing that they weren't supposed to [16]. Zegeer et al., also hypothesizing that pedestrian compliance might be increased with easier to understand pedestrian signals, tested placing explanatory signs near crosswalks and signals which displayed a "DON'T START" legend. D.C. and Milwaukee saw decreased pedestrian violations after the introduction of these variations, but Ann Arbor saw pedestrian violations increase with the "DON'T START" signal [17]. Another study by Zegeer found no difference between intersections which had concurrent pedestrian phases with pedestrian signal heads and those without them [6]. Countdown signals have been found to be effective in several studies to reduce pedestrian non-compliance, at least when traffic volume is high

enough to be a deterrent [18] [19]. Alternatively, Rouphail, in a study of midblock crossings where twenty hours of signalized and non-signalized crossings were compared, reached the conclusion that the type of control, or even existence thereof, didn't really influence pedestrian behavior [20]. In terms of safety, it is also interesting to note that Jennings et al. observed that pedestrians tended to only look prior to crossing when "DON'T WALK" signals were lit and concluded that pedestrians may depend too much on the signals to keep them safe from harm [21].

In addition to variations in pedestrian heads, experiments have also been performed with different push button designs. The city of Ontario, attempting to assuage citizen concerns that call buttons did nothing, installed new buttons which included a light that lit up after being pressed. Huang and Zeeger, building upon an early study by Zeeger which found that only half of pedestrians bother with pushing call buttons and would usually begin to cross without waiting regardless of whether or not they did put in a call, were curious as to whether the visual feedback would encourage pedestrian compliance. Seven crosswalks were observed before and after the installation of the new call buttons, but the treatments were found to have little to no effect [22]. Following Huang and Zeeger's report, Van Houten et al. explored whether the addition of audible feedback would increase pedestrian compliance. Two intersections in Miami Beach with high traffic flows were chosen and observed. After a baseline was established, one of the intersections had its buttons changed to ones which gave visual and audio feedback when pushed. The new buttons not only seemed to increase compliance, but people seemed more willing to use them as well [23].

Another factor, one that complicates any study of pedestrian behavior, is that behavior appears to vary based on location regardless of which variables are controlled for. Differences in how pedestrians behave depending on location has been noted and commented on by several authors [24] [25]. Wide differences between pedestrian compliance have even been observed within single cities as Virkler saw during his study on pedestrian delay where compliance with signals in the central business district of Brisbane ranged from 33.3% to 97.4% [26]. This is important to note as, in this paper, statistical regressions with

random effects are used in an attempt to account for these location dependent variations on how pedestrians behave.

The effect of law enforcement on pedestrian behavior has also received some interest. In Orne's 1959 study, he noted that at one of the Bridgeport locations there was a police officer but that no one seemed to pay any attention to him. The people would jaywalk freely even with the officer in clear view [10]. While measuring the costs and benefits of separating pedestrian traffic from vehicular traffic through the use of footbridges and the like, Braun and MacRoddin observed that "efforts at reducing pedestrian accidents through stricter enforcement of pedestrian traffic laws have been largely ineffective," [27]. Wiener, in 1968, decided to study the effect of law enforcement directly by having police officers engage in a highly advertised ticketing campaign against jaywalking in Florida. Pedestrians were observed at intersections where officers were stationed during enforcement as well as several which were left without enforcement. Observation took place before, during, and after the ticketing campaign. During the campaign, compliance with crossing laws rose, but fell back to their previous patterns as soon as the ticketing campaign was over. Interestingly, around 66% of elderly pedestrians who were ticketed proceeded to cross illegally as soon as provided with another opportunity [28]. An Australian study on mid-block crossings by Maclean and Howie, which focused on attempting to find measures of effectiveness for crossings, found that crossings for schools had a much greater number of pedestrian violations except when crossing guards were present, in which case a lower than normal number of pedestrians crossed against the signal [29].

The effect that pedestrians have on each other has received attention as well. A 1973 study which took place in New York City had one of the researchers, casually observed by others, exit a doorway and arrive at an intersection just before a pedestrian did and either wait for the appropriate signal or jaywalk. Five hundred twenty five pedestrians were observed in this way and, overall, they tended to follow whatever course of action the control subject chose to take. [30] In Alberta, Harrell observed that pedestrians tended to be less cautious when crossing roads as the pedestrian volume increased. [31] This effect seems

to cross cultural boundaries. In Israel, Rosenbloom, using logistic regression on a sample size of 1,392 pedestrians, also found that the presence of other pedestrians waiting for a light increased the odds that a pedestrian arriving at an intersection would also wait, although the opposite effect, pedestrians crossing against the light influencing others to follow suit, was not found to be significant. Rosenbloom speculated that the greater number of people waiting at a light may signal to new arrivals that the signal is likely to change soon [32]. In China, Ren et al. observed 8,000 pedestrians across three cities and, at all locations, pedestrians tended to follow group behavior whether it was waiting for a traffic signal or crossing against one [24]. Das et al. also noted that pedestrians seemed to follow social cues both from other pedestrians and drivers as well, but did not go into detail as their experiment was not set up to study such interactions [33]. While measuring the effectiveness of countdown timers, O'Mahony and Keegan observed that people who were in groups crossed a road when they weren't supposed to more often than individuals did [19].

While data on how pedestrians react to others' behavior was not a focus of the present study, this effect was taken into account by considering the number of pedestrians crossing per hour as a possibly significant variable. Bechtel, Macleod, and Ragland found such a variable to be significant in their study on pedestrian compliance [5]. Another such study performed by Akin and Sisiopiku, who divided compliance into temporal and spatial components, found that the spatial component (whether or not a pedestrian crossed within a crosswalk) was influenced by pedestrian volume with a natural log of spatial compliance rates equaling $4.379 + 5.836 * 10^{-2} * ln\left(\frac{PV}{L_{CIA}}\right)$, where PV is pedestrian volume and L_{CIA} is the length of the crosswalk influence area [34].

As would be expected, vehicular traffic moving through an intersection has often been observed to have an effect on pedestrian behavior [35] [36] [14] [37] [38]. Barker, Wong, and Yue's study of pedestrian noncompliance in Australia which studied 33 intersections created two groups; one where pedestrians faced vehicular conflict, and one where they did not. Only 9% of those who faced conflict crossed against

the signal, whereas 49% of those who faced no vehicular conflict chose to cross against the signal. A regression of the data meant to predict the percentage of noncompliance gave the equation 22.92-0.44a, where a was the number of vehicles moving across the sidewalk [39]. Akin and Sisiopiku, whose approach to splitting compliance into two separate parts is detailed above, found that the temporal component (whether or not a pedestrian crossed against the signal) was heavily influenced by vehicle volume with temporal compliance rates equaling $26.680 + 2.212 * 10^{-2} * VV$, where VV is vehicle volume [40]. In Harrell's study, though, pedestrians were observed being less cautious on streets with higher vehicle volume than when crossing streets with low vehicle volume. Harrell speculated that the reason for this may have been that streets with lower volumes allowed individual cars to travel faster, creating a larger risk for any unlucky pedestrian who might be struck [31]. In Das et al's study in Delhi, India it was found that male and female pedestrians accept similar time gaps but that older people required larger gaps between vehicles to cross. Additionally, pedestrians seemed to accept smaller time gaps when faced with smaller vehicles, so it would appear that pedestrians consider the size of the vehicle approaching them when deciding on an acceptable level of risk [33]. Oaxley et al, however, found that time gaps were not significant in their models. Instead, their subjects seemed to depend more on distance gaps [41].

Various demographic factors and how they relate to pedestrian compliance have also been studied. In general, men and young to middle aged adults seem to be the most willing to take risks such as crossing illegally, [42] [18] [43] [14] [44] [45] [19] [46] [32] [31] [47]although studies where no difference or even the opposite effects were observed are not unknown [24] [25]. Yagil's study, based on 203 student responses to a questionnaire, found that women tended to believe that they were more vulnerable in a collision and that improper crossing habits would annoy drivers whereas men believed that "WALK" signals were intended to be used by children and the elderly [38]. Holland and Hill presented a study group of two hundred ninety three participants with different street crossing scenarios and asked them to respond to questions about how they would act. They found, like other studies, that the elderly

participants reported less intention to cross but no difference was observed between genders or between people who drove and those who did not [48]. Rosenbloom, conducting studies in Israel, found in one study that 84.3% of soldiers and 97.3% of military officers would wait for an appropriate signal as opposed to only 50.3% of civilians [49]. Rosenbloom, Nemrodov, and Barkan also compared an ultra-orthodox city with a normal Israeli city in order to see whether religiosity had an effect on pedestrian compliance. Pedestrians in the religious city were found to commit three times as many traffic violations although the authors note that, in addition to being highly religious, people in the ultra-orthodox city also tended to be in a lower socio-economic situation and less likely to have experience driving than their less religious counterparts [46].

Some studies on or involving elderly pedestrians have found interesting results. Liu and Tung, using an array of LCD monitors, created seventy two randomly sequenced virtual crossing scenarios for subjects to stand in and declare when they would cross. After measuring the walking speed of participants then comparing this data to when subjects chose to cross and how long they predicted a road would take to cross, they found that elderly pedestrians did not seem to realize that they walked slower than the younger pedestrians [50]. A similar study done by Oxley et al took advantage of a modified driving simulator to create scenarios within which to test subjects. Again, the elderly respondents had a much higher risk factor as they did not appear to realize that they walked slower than the younger groups. Additionally, while subjects around 65 years of age tended to cross more cautiously, the oldest subjects tested did not [41].

How much physical features of the roadway affect pedestrian behavior and safety has also been studied. The distance pedestrians have to cross often comes up as significant in whether or not they will be compliant [37]. Zaidel and Hocherman’s study found that the more legs that were within an intersection, the more likely it was that crashes would occur [8]. Eustace observed that, in a comparison between two intersections, the one that had a wider cross section saw a much smaller rate of noncompliance [35]. In their study which utilized three databases of pedestrian collisions across 13 cities, Robertson and Carter

found that road width, as well as the sight distance the intersections' alignments allowed, was one of the factors which affected pedestrian compliance [14]. Jiang et al. observed 103,956 pedestrians in Singapore and Beijing and found road width, as well as whether an intersection was a cross or a T, to be related to violations [25]. An extensive study performed by Balk et al. utilizing CCTV recordings in the D.C. metro area found that the crossing distance directly correlated with how often pedestrians followed the rules and that pedestrians were much more likely to cross during the "DON'T WALK" phase when presented with one way streets [51]. In one study, Hauck observed that newly painted crosswalks appeared to reduce the tendency of people to cross outside of the crossing area, although they had no effect on whether or not pedestrians crossed against traffic signals [52]. Wall observed that a crosswalk, after being painted green, saw both a reduction in the average speed of vehicles and a slight (6%) increase in the number of pedestrians crossing within the crosswalk [53]. In a study performed by Jacobs and Wilson on mid-block crossings it was found that 60% of pedestrians crossed within a marked crosswalk in London whereas, in smaller towns, only 32% did so. The authors speculated that this was due to the frequency of crossings available to pedestrians [47]. In response to collisions involving pedestrians, the U.S. Department of Transportation engaged in a study across seven cities to try and gauge the effectiveness of various countermeasures which, themselves, were chosen based on a study of two thousand pedestrian collisions across thirteen cities, to keep people from crossing illegally. In the end, only medians and median barriers were found to be effective for keeping pedestrians from jaywalking outside of the crosswalk. No countermeasures were found which kept pedestrians from crossing against the signal [54].

The question of why pedestrians opt to cross illegally has also been studied. In a survey study, randomly selected people from Michigan State University's mailing list suggested that convenience, time savings, and lack of perceived risk were reasons to jaywalk [34]. In order to see how beneficial jaywalking is in reducing delay, Virkler engaged in a study of eighteen crosswalks across the Brisbane, Australia central business district where signal compliance ranged from 33.3 to 97.4%. Pedestrians crossing against the signal tended to save an average of 7.9 seconds whereas those who entered during the clearance interval

tended to save nearly a minute of time [26]. A similar study performed in Kansas found that pedestrians crossing against signals saved between one and eighteen seconds [35]. Another study by Schroeder et al. found that only 30% of pedestrians waited for a walk phase at an exclusive signal, with 92% of those arriving during the flashing "DON'T WALK" phase crossing immediately, saving an average of 19.5 seconds [55]. Several studies, such as Hamed's observation of pedestrians in Jordan and modeling of how many attempts it would take for them to cross the road, found that the longer a pedestrian waits for a crossing signal, the more likely they are to attempt crossing the street [45]. In the study performed by Balk et al., it was found that the shorter the amount of time given in a walk phase, the more likely pedestrians were to cross outside of the intersection, so providing too little time to cross may also cause pedestrians to seek another way to cross a street which feels safer to them [51]. Another study performed by Van-Houten, Ellis, and Kim used a signalized mid-block crossing, eliminating the threat of turning vehicles, to study precisely how vehicle green time would affect pedestrians waiting for their own turn to cross. They found that while pedestrians seemed willing to wait 30 seconds, timings of 60 and 120 seconds produced significantly more illegal crossings [56]. In a review of signal timing practices, Karsten Baass noted that studies in Germany found that 38% of pedestrians crossed against a signal if wait times were between 40 and 60 seconds whereas only 18% crossed against the signal if wait times were below 30 seconds [2].

In addition to what has been discussed, a study performed by Guo, Dunne, and Black found that pedestrian routes are important to crossing behaviors as well. In their observations, which included 252 pedestrian crossings and 4,350 vehicle headways, it was seen that pedestrians choose to cross when they are presented with random vehicle flow. Instead of waiting for when they can cross, though, they observed that pedestrians continue walking parallel to traffic [57].

While most studies have used base descriptive statistics to analyze data, several have used modeling in an attempt to gain better insight into how pedestrians act. In his study mentioned above, Garder ran a multiple regression analysis on data from 152 crosswalks from 15 different towns in Sweden. The

regression produced a model to predict the percentage of pedestrians arriving at a red light who would cross against the signal. The model, which took the following form, $Y = 9.8T - 0.79W + 5.4R - 9.3P + 8.2F_G - 4.8F_R + 0.017X + 4.0S + 8.8A - 3.9$, where Y is the percent of pedestrians who arrive at a red signal and choose to cross on it. Town size (T), the presence of median refuges (R), the number of vehicles turning into the crosswalk during the pedestrian green (F_G), the length of the red signal (X), the presence of a fixed time signal (S), and the presence of pedestrian push buttons (A) were all found to increase pedestrian non-compliance. Street width (W), the number of pedestrians crossing in an hour (P), and the number of vehicles going through the crosswalk during the pedestrian red (F_R) were found to increase pedestrian compliance. Non-significant factors included how close to the city centers intersections were and whether or not the signals were exclusive; although it should be noted that only three exclusive signals were observed [7].

Bechtel et al. also used a multivariate linear model to study their data on comparing pedestrian violations at exclusive and concurrent signals. The type of signal, whether it was a weekday or the weekend, pedestrian volumes, as discussed earlier, and an interaction between time and the signal type were all found to be significant. In their study, vehicle volumes were not found to be significant to the regression [5].

Otis & Machemehl made use of multinomial logit regressions to analyze data gathered from nine hundred forty three intersections. For the signalized intersections, observed pedestrians were placed in groups depending on what signal indication they were presented with upon arrival. For pedestrians arriving during the steady “DON’T WALK” phase the street width, number of lanes, vehicle volumes and multiple turning lanes decreased the chance of non-compliance. The presence of medians and, surprisingly, increasing speed limits, increased the chance that pedestrians would be noncompliant. The authors suggested that this may be due to speed limits being associated with the vehicle volumes and street width. While a substantial data size for pedestrians arriving during the flashing “DON’T WALK” phase was not obtained, multinomial logit regressions were still used. For pedestrians arriving during this

phase, observers recorded whether they would cross right away, cross during the steady “DON’T WALK,” or wait for the “WALK” signal. Increasing vehicle volumes and the presence of medians increased the likelihood of crossing while increasing speed decreased the likelihood of improper crossings. Results also found that pedestrians were more likely to cross during the steady “DON’T WALK” as the crossing distance increased. The authors had no explanation for this effect. Finally, for pedestrians arriving at intersections without pedestrian signals, few productive results were found in this study. Pedestrians in these situations seemed more likely to be compliant as vehicle volumes increased, but it was less of an effect than what was seen at intersections with pedestrian signals. Speeds above 35MPH also made it more likely for pedestrians to wait for a green light [58].

In a study performed in Finland, Humanen and Kulmala used logit modeling to analyze both driver and pedestrian behaviors. Interestingly, Finnish laws did not, at the time of their study, give priority rules for either mode when they encountered each other. The model to predict whether a driver would yield found the number of pedestrians crossing, how far into the crossing they were, the city (Helsinki or Salo), and the speed of the vehicle to be relevant with the most significant factor being how far the pedestrians were into the crossing. Whether a pedestrian would yield depended on how far they were into the crossing, the city they were in, and the number of approaching vehicles. It was also found that the gender of the pedestrian was significant but with a very small effect. The authors were surprised that factors such as street width and the existence of pedestrian refuges were not found to be significant [59].

Zhou et al. also used multinomial logit models to analyze their data. The model, which predicted whether a street crossing would be successful, contained four parts representing compliant pedestrians, pedestrians who started late, sneakers (those who crossed during the red phase) and partial sneakers (those who had the signal change while they were crossing). Overall, the length of the crossing, the amount of green time, and whether or not there was an oncoming vehicle were the largest predictors for all crossings [60]. Kattan et al. used Poisson regression models to analyze data collected from video recordings of pedestrians crossing intersections before and after exclusive pedestrian signals were installed in the city of

Calgary. The regressions found that peak hours, situations where pedestrians wanted to cross two legs of an intersection as opposed to just one, and vehicle flow were found to be statistically significant. When modeling pedestrian/vehicle conflicts, though, these same factors were found to be insignificant. The authors reasoned that increased vehicle flow appeared to reduce pedestrian crossing violations and that drivers had learned to be observant of pedestrians during peak hours [61].

Studies using simulated environments have also used regressions. Liu and Tung, mentioned earlier, used a logistic regression to predict risk and found that the gap acceptance of the subjects was the largest influence on how much risk pedestrians exposed themselves to [50]. Granie et al. performed an experiment similar to Liu and Tung, but showed their subjects panoramic photographs instead of surrounding them with video screens. The subjects often responded that vehicle speed was what influenced their decisions the most – something that was impossible to tell on a still photograph. This suggested that the environment influenced how people felt about the balance of power between vehicles and pedestrians. A logistic regression with a random intercept was used in order to avoid under-estimating the standard errors on the coefficient estimates. This regression found that location was the only significant factor to whether pedestrians would cross the road. Age was also found to be significant, but the coefficients were so close to zero that they were deemed not worth keeping [62]. Oxley et al., after collecting data created a hierarchical logistic regression to model whether their subjects would say yes or no to crossing in certain situations. The time gap between vehicles was found to be the biggest predictor of the responses. Vehicle speed and walking time were also predictors, though less strong, and an interaction between time gaps and the age of the subjects was also observed as being significant. A second model found that distance gaps between vehicles, age group of the subjects, and the subjects' walking speed were all found to be predictors. The regressions were performed again on a second run of the experiment, only with less time available to the participants. The same results were found but the distance gap was found to be less significant than before, suggesting that vehicle speeds are more important when pedestrians make quick decisions [41].

Martinez and Porter used three logistic regressions in their research. The first, performed on crash data to determine the likelihood of a pedestrian in a collision dying, found that the location (rural vs. urban) and drinking were the most significant factors. Their second regression was performed on data gathered from a survey on pedestrian and driver rights and responsibilities. This found that the older a respondent was, the more likely they were to believe that a pedestrian has the right of way wherever they cross. Their final regression, using the survey data, found that education, gender, and location were predictors as to whether or not someone would cross a road unsafely [63].

Guo et al., building off of an earlier stochastic model for pedestrian delay found that adding factors to account for the type of vehicular traffic flow greatly affected the amount of time a pedestrian would have to wait for an acceptable gap. While observing pedestrians, they found that most would not wait for a gap but continue in the general direction they wished to go then cross whenever an opportunity presented itself [57].

Das et al. made use of probit models when analyzing their data on critical gap acceptance, the results of which were mentioned previously [33]. Statistical modelling was also used by Akin and Sisiopiku, also mentioned earlier, who made use of linear regressions to attempt to model their concepts of both temporal compliance and spatial compliance. While their models for the two forms of compliance, individually, did not have high goodness of fit values, they were able to combine them to create an overall compliance model which achieved an R^2 of 95.6% [34].

Yang and Sun, who gathered data at ten crosswalks in Shanghai using cameras as well as surveys which made use of the Theory of Planned Behavior, discussed in more detail below, used binary logistic regression models to analyze their data. They combined observational data with a questionnaire and created six models with different combinations of variables tested. The first model, which tested all available variables, found that a pedestrian's time spent waiting, the red time of the signal, the crossing distance, the time gap, vehicle speed, and the pedestrian's perceived control over their environment were

all found to be significant. Time spent waiting, red time of the signal, crossing distance, time gap between vehicles, and vehicle speed were found significant in the second model which tested all observed and measured variables. The third model tested only those variables which did not deal with vehicular traffic; time spent waiting, red signal time, crossing distance, and the number of lanes to be crossed. Out of these, only the signal red time and number of lanes to be crossed were found to be significant. The fourth model, which used only variables from the questionnaire, found that a pedestrian's perceived control of the environment and belief on how other people viewed illegal crossings were found to be significant. The fifth model, which used the same options as model 3 but had over one thousand more observations found that the time spent waiting and red time were the only significant variables. The authors suggested that the observed sites may have been too similar in crossing distance for it to be a relevant variable. The final model, based off of the questionnaire, only predicted self-reported illegal crossings. This model found that only the perceived social norms and willingness of an individual to cross against a red light were relevant [64].

Balk et al, in their study of intersections throughout the D.C. metro area made use of linear models created through stepwise selection to find which variables were most significant to whether a pedestrian would cross at a marked intersection or unmarked non-intersection. The first model created selected one or two way streets, the presence of physical barriers, the presence of right turn only lanes, and the presence, as well as type, of median. The distance to the next marked crosswalk, presence of physical barriers, presence of bus stops, and length of walk phase were also selected in subsequent regressions. Two more phases of observations were performed by the authors before a final model was created. Factor loading was used to identify which variables should be in the model. Factor one consisted solely of data relating to the phase of the traffic signal. The second factor dealt with traffic details such as AADT, one or two way streets, and curb to curb distance. Factor 3, called "Distance to safety," consisted of the distance to the next marked crosswalk, the presence and type of median, as well as the presence of cross streets between marked crosswalks. Factor 4 dealt with what, if any, physical barriers to prevent

pedestrian crossings existed in the road. Factor 5 consisted of objects on the side of the roadway such as parked cars, the presence of right turn only lanes, and whether or not the marked crosswalk was light controlled. A logit model created from these factors successfully predicted around 90% of the observed crossings [51].

Palamarthy et al. also used multinomial probit models to analyze data obtained from observations. Seven hundred twelve crossings at twenty randomly selected intersections in Austin, Texas were observed. Critical gaps were treated as random variables due to how varied gap acceptance was between crossings, even when the same pedestrian was observed. The models suggested that pedestrians paid the most attention to the nearest lane of traffic and were unlikely to use push-buttons, particularly when carrying something. The authors noted that, out of those who pressed the pedestrian call button, 70% actually waited for the appropriate signal [65].

In the past few decades, researchers have also looked at psychological approaches when attempting to explain pedestrian behavior rather than the pure utilitarian approach most often seen. These studies look at the Theory of Planned Behavior (TPB) which holds that there are three influences on an individual's choice to take an action. The first is whether the individual believes that an action will lead to a good or bad outcome. The second is what the perceived social acceptability of the action is. The final, referred to as "Perceived Behavioral Control" reflects how easy an individual believes a behavior to be such as quitting smoking or, in this paper's interest, crossing a street illegally.

Diaz used a non-random sample of one hundred forty six people in Santiago Chile that was balanced for gender, age, crash involvement and possession of a driver's license. The last, in Chile, represents that an individual not only drives, but is likely to have reached a higher level of education than those without a license. Diaz's results found no significant differences based upon gender, crash involvement, or license attainment, but did find that young people reacted more positively to illegal road crossings than adults while at the same time viewing themselves as having lower behavioral control [66].

Evans and Norman sent a TPB based questionnaire out to 300 residents in Wales, 210 of which were fully completed and returned. The questionnaire presented three road crossing situations and asked a series of questions about each. They found that people were more likely to cross if their perceived behavioral control was high, that is, if they thought the crossing would be easy. People who perceived a lack of social disapproval were also more likely to cross illegally than those who thought that there would be social disapproval. Additionally, people who responded that they viewed themselves as “safe pedestrians” were less likely to cross illegally, but only marginally than those who did not [67].

Xu, Li, and Zhang attempted to examine the validity of the social norm dimensions as dependent variables in predicting pedestrians’ intention to cross a road illegally as well as examine the contribution of past behavior to present choices. They conducted a survey of randomly sampled individuals from undergraduate and continuing education lists as well as a residential community. After analysis the authors concluded that past behavior explained a good deal of the variance in pedestrians’ tendency to jaywalk. They also put forward the suggestion that illegal crossing behavior starts off as a strategy to save time but, by older age, becomes an ingrained habit rather than something that is thought about [68].

It is evident that the pedestrian is a complex puzzle to figure out. Intuitively, we know how people on foot will behave as it is a mode of transportation we have been intimate with for nearly our entire lives. Placing exact numbers which are useful for decision makers, though, has been surprisingly difficult to accomplish. This paper, while offering no definitive answers, adds to the general knowledge and collected data on pedestrian behavior. Factors such as crossing distance, vehicle and pedestrian volumes, and even whether or not a pedestrian is elderly will be examined to see if previous findings are the same in the Hartford area as they are elsewhere in the world. The question of how pedestrians treat concurrent vs exclusive signal phasing is, in particular, looked at more deeply than in previous studies. This, in comparison with data gathered on the safety of the two signal types, will be used to mark a starting point where each design should be considered over the other.

Study Design

Training

Before any observations took place, all six observers took part in an afternoon training session. A meeting where all expected observation values were described in detail was followed with several pedestrian observations around Storrs, CT. During this time, observers also practiced estimating age groups that individuals belonged to by finding people near 65 years of age, having the observers guess at the subject's age, and then revealing the actual age. Additionally, the first day of observations were performed in groups of three. The groups were made up of two inexperienced observers and one observer who had taken part in a previous study. The experienced observer double checked the work of the inexperienced observers, clarified questions, and made suggestions where necessary. Meetings were held after the initial observations in order to clarify any methodological uncertainties which remained.

Intersection Selection

Two hundred seventy one potential study sites were visited and had their details, such as signal type, number of legs, and pedestrian presence recorded. Intersections with concurrent pedestrian phases, being the rarer design, were noted and placed into a list. Two exclusive signals, one which had experienced crashes involving pedestrians and one which had not, were matched with the concurrent pedestrian signals based on similar physical design characteristics. Due to the limited number of concurrent phase signals, it was not practical to find ones which had experienced pedestrian crashes and pair them with other concurrent lights which had not. Fourteen sets of three intersections were ultimately studied for a total of 42 intersections.

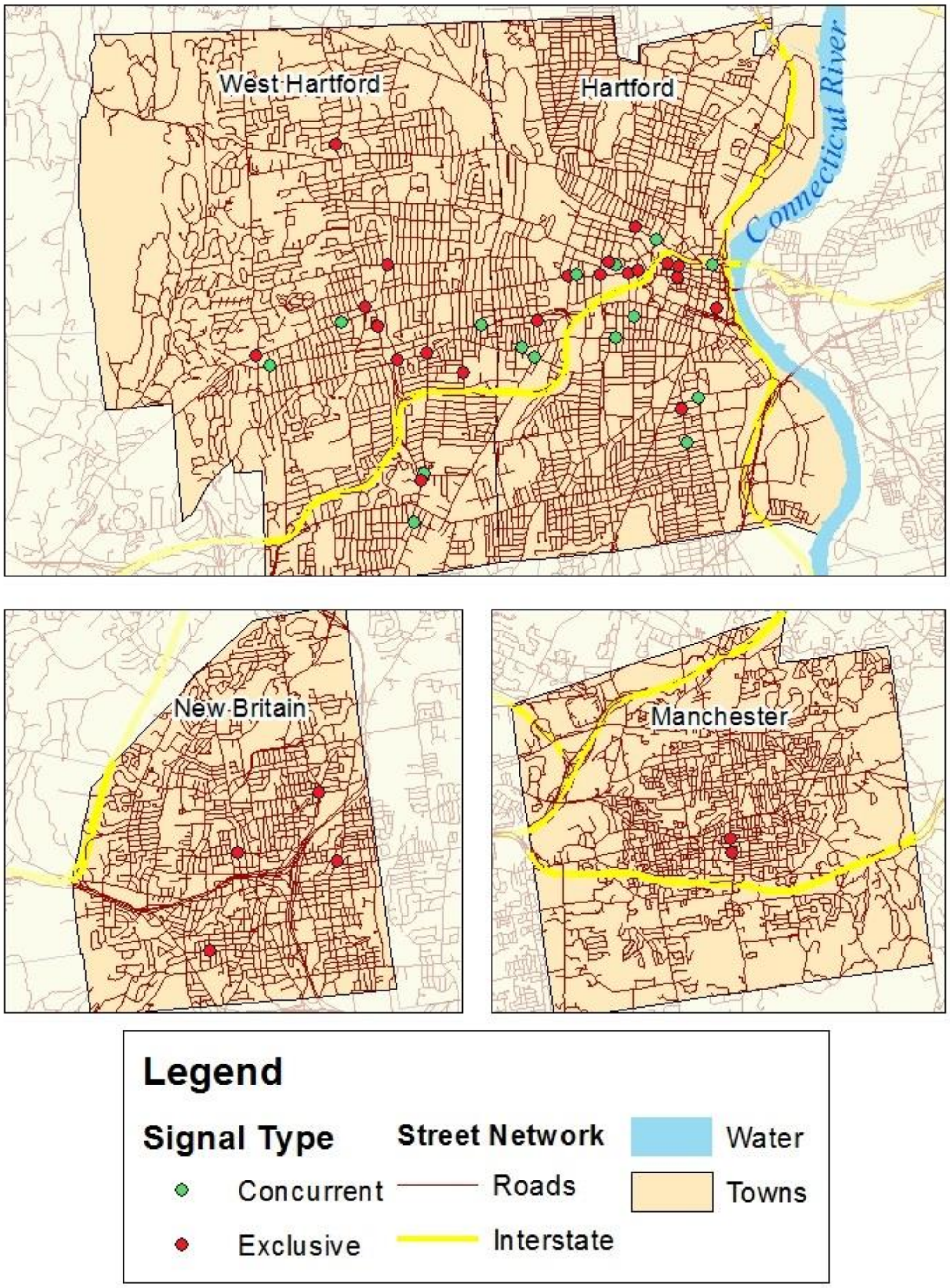

Figure 1: Observed Traffic Signals & Pedestrian Phase Type

Observations

Observations took place during the summer of 2013 on weekdays between 12:00PM and 6:00PM in order to capture behaviors during the time of day when pedestrian activity is expected to be greatest (including lunchtime and evening peak). Some intersections were studied for fewer than six hours due to inclement weather or lack of pedestrian traffic.

Observers most often worked in pairs to limit observer overload save for several low traffic areas where a single observer could comfortably record all pertinent data. For each leg of an intersection, hourly vehicle traffic counts were recorded for each intersection approach leg as well as the predominant weather (sunny, cloudy, or rainy) in addition to the pedestrian data. The pedestrian data recorded included:

- The signal phase when the action to cross a street began. This included green, yellow, and red for traffic signals as well as Don't Walk, Flashing Don't Walk, and Walk for mounted pedestrian signals.
- Whether or not a pedestrian appeared to be a senior (over 65 years of age).
- Whether a pedestrian had an "Undisturbed Passage" or if an interaction occurred with a vehicle. Interactions were classified, from least to most severe, as Potential Conflicts (nonverbal negotiation of who would yield, such as eye contact or hand gestures), Minor Conflicts (avoidance maneuvers such as slowing down or running with more than enough time before a collision would occur), or Severe Conflicts (avoidance maneuvers taken immediately prior to a collision).
- Whether or not any interactions occurred involving a turning vehicle.
- Which leg of the intersection was crossed by the pedestrian.
- Whether or not the pedestrian remained within the crosswalk area for the majority of their crossing.

Typically, observers either conducted the traffic count or observed pedestrians, switching jobs every hour in order to mitigate mental fatigue. All pedestrians who crossed within an observed intersection were

recorded. In addition to this, those who crossed outside of the intersection, but within 50 feet of it, were recorded in order to note pedestrians who were capable of, but chose not to, cross within the designated crossing area.

While at each intersection, observers also confirmed the land use (residential, non-residential, or mixed) as well as the pedestrian signal type that was recorded during the initial scouting. In addition, the following physical features were gathered;

- The presence of marked crosswalks.
- The presence of sidewalks marked as full, none, or partial for legs which had sidewalks on one side only.
- The presence of on-street parking.
- The speed limit of each street entering or exiting the intersection.
- The presence of a median or pedestrian refuge.
- Whether any of the streets were one way and, if so, whether it exited or entered from the intersection.
- The crossing distance, defined as the portion of the crossing area exposed to vehicular traffic.

Speed limit was included as a substitute for the actual travel speed of encountered vehicles. Recording vehicle speed during the hours of observation, while a desirable trait, was beyond the scope and practical abilities of the observation teams. Table 1 details the three continuous variables which were collected, Crossing Distance, Hourly Pedestrian Volume, and Hourly Vehicle Volume. These are further broken down by speed limit and pedestrian signal type.

Table 1: Descriptive Statistics for Continuous Variables

Continuous Variable	Mean	Std. Dev.	Min.	Max.
Crossing Distance *(ft)*	43.46	15.34	18.10	86.00
25MPH Speed Limit	41.96	16.52	23.70	86.00
30MPH Speed Limit	46.98	10.85	18.10	82.00
35MPH Speed Limit	49.09	9.61	35.00	72.40
Exclusive Pedestrian Phase	45.85	17.11	18.1	86
Concurrent Pedestrian Phase	37.77	7.25	27.5	62
Pedestrian Volume *(People Per Hour)*	52.82	48.28	1	266
25MPH Speed Limit	62.45	52.30	1	266
30MPH Speed Limit	29.72	19.41	1	79
35MPH Speed Limit	18.19	12.50	1	44
Exclusive Pedestrian Phase	58.27	54.07	1	266
Concurrent Pedestrian Phase	39.87	26.13	1	105
Hourly Vehicle Volume *(Vehicles Per Hour)*	415.33	392.25	18	1867
25MPH Speed Limit	337.67	394.65	18	1732
30MPH Speed Limit	569.91	273.22	41	1677
35MPH Speed Limit	807.26	316.75	197	1867
Exclusive Pedestrian Phase	460.80	428.57	18	1867
Concurrent Pedestrian Phase	307.15	257.56	57	1492

Table 2 details the discrete variables, Pedestrian Signal Type, Speed Limit, Median, Sidewalks, Crosswalks, On Street Parking, Land Use, Senior, Weather, as well as the Day and Hour of observations. The frequency of observations, that is, the total number of observed pedestrians is listed for each level of the discrete variable as well as the percentage of observations made in comparison to the other levels of the variable. The number of intersections where each level was observed is also recorded. While the total number of intersections was 42, most intersections had multiple levels of each variable. For example, an intersection where a 25 MPH street and a 30 MPH street meet would have observations for both levels.

Table 2: Descriptive Statistics for Discrete Variables

Discrete Variable (Levels)	Frequency of Observations	Percentage of Observations	Number of Intersections
Pedestrian Signal Type			
Exclusive	10447	70.41	27
Concurrent	4391	29.59	15
Speed Limit			
25MPH	10789	72.71	33
30MPH	3156	21.27	21
35MPH	893	6.02	13
Median			
Present	1261	8.50	2
Not Present	13577	91.50	42
Sidewalk			
Both Sides of Roadway	14670	98.87	41
One Side of Roadway	168	1.13	6
Crosswalk			
Marked	14487	97.63	40
Unmarked	351	2.37	5
On Street Parking			
Allowed	5313	35.81	30
Not Allowed	9525	64.19	32
Land Use			
Residential	1673	11.28	13
Non-Residential	8553	57.64	16
Mixed	4612	31.08	13
Senior			
Non-Senior Citizen	12959	87.34	42
Senior Citizen	1879	12.66	40
Day of the Week			
Monday	1201	8.09	7
Tuesday	3116	21.00	10
Wednesday	3386	22.82	9
Thursday	5458	36.78	11
Friday	1677	11.30	5
Weather			
Sunny	9069	37.99	33
Cloudy	5637	37.99	18
Rainy	132	0.89	4
Observation Hour			
Noon	2458	16.57	36
1PM	2817	18.99	40
2PM	2434	16.40	42
3PM	256	17.23	41
4PM	2466	16.62	37
5PM	2107	14.20	35

Descriptive Data Analysis

Derived Values

Before analysis began, several categories of data were derived from what was gathered. Hourly volumes for vehicle and pedestrians were normalized by dividing the values collected by the percentage of the hour the observer had actually recorded information. For instance, if an observer had recorded four pedestrians over the course of an hour, but had only recorded data for one half of an hour, the normalized volume would be eight. These normalized volumes were rounded to the nearest whole number. Additionally, vehicle volumes were divided by one-thousand in order to make the larger limits more manageable.

Compliance was also calculated under rules termed Strict Compliance and Relaxed Compliance. Under the Strict Compliance rules, pedestrians at exclusive signals were considered to have been compliant if they had begun their movement across the roadway during the “WALK” signal phase and remained within a few feet of the crosswalk while they were within the roadway. Under Relaxed Compliance rules, pedestrians at exclusive signals were considered to have been compliant if they began their movement across the roadway during the “WALK” signal phase or during the concurrent green light and remained within a few feet of the crosswalk. Under both sets of rules, pedestrians at concurrent signals were considered compliant if they crossed during the concurrent green signal and remained within a few feet of the crosswalk.

The distinction of ‘a few feet’ when it came to whether pedestrians remained within a crossing area generally meant that a pedestrian was considered spatially compliant if they were within two to three feet of crosswalk during their crossing. Many pedestrian movements across an intersection, however, can be considered an arc as people tend to step into the roadway before reaching the crosswalk, walk diagonally until they reach the crossing area and then, during the last several strides of their crossing, will again turn diagonally so that there are oriented towards their destination when the crossing is completed. By using ‘a

few feet' rather than a strict, linear definition, this allowed pedestrians who performed such crossing arcs to be considered compliant so long as the majority of their crossing was done near the crosswalk.

It should also be noted that the term crosswalk in this paper is used both for marked crosswalks as well as where crosswalks would be at locations which had no markings or markings which were not compliant with MUTCD standards. At such locations, observers would consider those crossing within a standard eight to ten feet crossing area to be compliant. If an intersection had a leg which was clearly not intended for pedestrians to cross, indicated by the existence of crosswalks, pedestrian signals, or sidewalks on all but one leg, data for that individual leg was removed from the set for the purpose of analysis in this paper.

Analysis was performed using SAS software. Prior to regression, compliance was compared against the variables collected and derived for each intersection. The Strict and Relaxed rules were looked at twice; once involving all pedestrians and once involving only pedestrians who crossed within the crosswalk in order to see if any difference existed.

Signal Type

Under strict compliance rules, there is a striking difference between pedestrian compliance at exclusive vs. concurrent signals. As shown in Table 3, 70.30% of all pedestrians observed at concurrent signals were compliant with the crossing rules whereas only 20.30% complied with crossing rules at exclusive signals. Under relaxed rules, compliance jumps by 30.39% for exclusive signals, suggesting that pedestrians may still act as though they are at concurrent signals. This is, however, still lower than what is seen for concurrent lights under relaxed rules, suggesting that while signal type plays a large role in whether or not pedestrians cross when expected to, it is not the only factor.

Ignoring pedestrians who chose to eschew the legally defined crossing areas gave similar results with, as would be expected, slightly higher rates of compliance.

Table 3: Pedestrian Compliance vs. Signal Type

	All Pedestrians			Within Crosswalks Only		
Signal Type	Count	% Compliant (Strict)	% Compliant (Relaxed)	Count	% Compliant (Strict)	% Compliant (Relaxed)
Exclusive	10,447	20.3	50.69	9,300	22.81	56.95
Concurrent	4,391	70.33	70.33	4,069	75.89	75.89
Total	14,838	35.11	56.5	13,369	38.96	62.71

Senior

Table 4 shows that surprisingly little difference was observed between the compliance rates of seniors and non-seniors. This was unexpected since, as mentioned earlier, most previous studies found seniors more likely to follow traffic laws than non-seniors. Interestingly, under relaxed compliance rules, seniors were slightly less compliant than non-seniors but neither case was found to be statistically significant.

Table 4: Pedestrian Compliance vs. Senior Citizen

	All Pedestrians			Within Crosswalks Only		
	Count	% Compliant (Strict)	% Compliant (Relaxed)	Count	% Compliant (Strict)	% Compliant (Relaxed)
Senior	1,879	36.24	59.23	1,727	39.43	64.45
Non-Senior	12,959	34.94	56.11	11,642	38.89	62.45
Total	14,838	35.11	56.5	13,369	38.96	62.71

Speed Limits

Under strict compliance rules, there was no observed statistical difference in pedestrian behavior on streets with speed limits between 25 and 30 MPH, but at 35 MPH there is a dramatic increase in compliance as shown in Table 5. When only pedestrians who crossed within the crosswalk are examined, there is a clear relation between speed limits and compliance in that as the speed limit increases, so too does the pedestrian compliance.

Under relaxed compliance rules, 25 MPH and 35 MPH zones see similar rates of compliance while there is a large dip in compliance at roads with 30 MPH speed limits. This relational pattern still exists when considering only the pedestrians within crosswalks.

Table 5: Pedestrian Compliance vs. Speed Limit

	All Pedestrians			Within Crosswalks Only		
	Count	% Compliant (Strict)	% Compliant (Relaxed)	Count	% Compliant (Strict)	% Compliant (Relaxed)
25 MPH	10,789	33.9	58.45	10,035	36.45	62.84
30 MPH	3,156	33.08	48.67	2,574	40.56	59.67
35 MPH	893	56.77	60.69	760	66.71	71.32
Total	14,838	35.11	56.5	13,369	38.96	62.71

One Way Streets

Under strict rules, considering all pedestrians crossing near the intersection, two way streets see higher rates of compliance than one-way streets. This can be expected as pedestrians crossing a one-way street have only one direction to be concerned with and will, most likely, feel more comfortable crossing them regardless of what signal they have. Under relaxed rules the compliance rates for two way and one way streets rise. The highest increase is seen in one-way roads which exit into the intersection, 30.87% to 65.71%, as detailed in Table 6. This is reasonable as, under the relaxed rules, the crosswalk should be empty of motor vehicles whenever that leg does not have the green, making compliant crossing especially safe and attractive to pedestrians. When looking at only those who crossed within crosswalks, the same pattern emerges. In all cases, under strict compliance rules, no statistical difference between one way streets which enter from the intersection and one way streets which exit into the intersection is seen.

Table 6: Pedestrian Compliance vs. One Way Street

	All Pedestrians			Within Crosswalks Only		
	Count	% Compliant (Strict)	% Compliant (Relaxed)	Count	% Compliant (Strict)	% Compliant (Relaxed)
Two Way Street	12,630	35.99	55.75	11,337	40.1	62.11
One Way Exit	747	28.38	51.27	677	31.31	56.57
One Way Entrance	1,461	30.81	65.71	1,355	33.28	70.85
Total	14,838	35.11	56.50	13,369	38.96	62.71

On Street Parking

Table 7 shows that under strict rules there is not much difference between compliance rates on streets which have on street parking vs those that don’t, and for those who crossed within crosswalks there is no

statistical difference at all. A difference in compliance rates is seen, however, under relaxed rules. Under the relaxed rules, streets with on street parking see compliance rates 8.39% lower than those without on street parking. This could be due to pedestrians feeling safer entering an intersection with the buffer of a parked car between them and the approaching traffic.

Table 7: Pedestrian Compliance vs. On Street Parking

	All Pedestrians			Within Crosswalks Only		
	Count	% Compliant (Strict)	% Compliant (Relaxed)	Count	% Compliant (Strict)	% Compliant (Relaxed)
Parking	9,525	35.78	53.50	8,616	39.55	59.15
No Parking	5,313	33.90	61.89	4,753	37.89	69.18
Total	14,838	35.11	56.50	13,369	38.96	62.71

Crosswalks

The existence of crosswalks did not play a statistically significant role in pedestrian compliance regardless of the rules used. Under strict rules, as can be seen in Table 8, pedestrians were only 4.98% more likely to be compliant where crosswalks exist. This difference drops to 3.01% under relaxed rules. This difference drops, but is still present, when considering only pedestrians who crossed where crosswalks should have been although this difference was also not found to be statistically significant.

Table 8: Pedestrian Compliance vs. Marked Crosswalks

	All Pedestrians			Within Crosswalks Only		
	Count	% Compliant (Strict)	% Compliant (Relaxed)	Count	% Compliant (Strict)	% Compliant (Relaxed)
Marked	14,487	35.21	56.57	13,064	39.05	62.74
Not Marked	351	30.77	53.56	305	35.41	61.64
Total	14,838	35.11	56.50	13,369	38.96	62.71

Sidewalks

A difference between compliance is seen on sections that have sidewalks on both roadsides (Full) as opposed to those with sidewalks on only one side of the road (Partial). Table 9 shows that under strict rules the compliance for legs with partial sidewalks are 13.86% higher than those with full sidewalks. Under relaxed rules the compliance rate for legs with partial sidewalks are 7.88% greater than those with full sidewalks. These differences are even larger when looking at only those pedestrians who crossed

within the designated crossing area. Despite the relatively low numbers of pedestrians observed in areas with partial sidewalks, the differences were found to be statistically significant. Pedestrians, seeing that there is no sidewalk on one side of the road, may interpret these areas as not being intended for walking and, as a result, are more cautious in their crossings.

Table 9: Pedestrian Compliance vs. Sidewalks

	All Pedestrians			Within Crosswalks Only		
	Count	% Compliant (Strict)	% Compliant (Relaxed)	Count	% Compliant (Strict)	% Compliant (Relaxed)
Full	14,670	34.95	56.41	13,217	38.79	62.62
Partial	168	48.81	64.29	152	53.95	71.05
Total	14,838	35.11	56.50	13,369	38.96	62.71

Medians

Table 10 shows that medians appeared to offer a disincentive to pedestrian compliance as 17.31% fewer pedestrians were compliant at intersections with medians under strict rules and this difference increases to 21.80% for relaxed rules. This is most likely due to medians acting as a place of refuge for pedestrians, allowing them to take the measured risk of jaywalking while only worrying about one direction at a time rather than having to cross the entire length of road in one attempt. It is interesting to note that there is almost no difference between compliance rates between the All Pedestrians group and the Within Crosswalks Only group when medians exist. Indeed, only three people out of 1,261 appear to have crossed outside the designated crossing area when medians were present, suggesting that they may be an effective way of reducing undesired mid-block crossings.

Table 10: Pedestrian Compliance vs. Median

	All Pedestrians			Within Crosswalks Only		
	Count	% Compliant (Strict)	% Compliant (Relaxed)	Count	% Compliant (Strict)	% Compliant (Relaxed)
Median	1,261	19.27	36.56	1,258	19.32	36.65
No Median	13,577	36.58	58.36	12.111	41.00	65.42
Total	14,838	35.11	56.50	13,369	38.96	62.71

Land Use

Table 11 details the percentage of pedestrian compliance seen at the three different forms of land use. Under strict rules, compliance rates are similar, but statistically different, in areas that were considered mixed use or residential with rates at 51.46% and 56.72%. Commercial areas, however, only saw pedestrians complying with crossing rules 20.25% of the time. With relaxed rules the rates of pedestrian compliance in residential, mixed use, and commercial rise to 58.76%, 66.78%, and 50.25% respectively. This seems to suggest that pedestrians, in all cases, are more compliant with crossing rules in areas that include housing. The 30.00% increase in commercial area compliance may be due to the fact that many exclusive signals are located in dense, commercial areas such as downtown Hartford.

Table 11: Pedestrian Compliance vs. Land Use

	All Pedestrians			Within Crosswalks Only		
	Count	% Compliant (Strict)	% Compliant (Relaxed)	Count	% Compliant (Strict)	% Compliant (Relaxed)
Mixed	4,612	56.72	66.78	4,138	63.22	74.43
Residential	1,673	51.46	58.76	1,488	57.86	66.06
Non-Res.	8,553	20.25	50.52	7,743	22.37	55.81
Total	14,838	35.11	56.50	13,369	38.96	62.71

Day of the Week

Different days of the week saw different rates of pedestrian compliance as shown in Table 12. Care was taken to ensure that field work was spread out amongst observers, temporally, to avoid any observer bias on certain days. Most days were statistically different from each other, but both strict and relaxed compliance saw no statistically significant difference between rates on Monday and Tuesday. Relaxed rules, both considering all pedestrians as well as those within the crossing area only saw no statistical difference between Friday and Tuesday. There was no statistically significant difference between Friday and Wednesday under relaxed rules but, when considering only pedestrians within crosswalks, no statistically significant difference between Friday and Monday was seen. With strict compliance rules, Mondays, Tuesdays, and Wednesdays all had approximately 30.00% compliance rates with Thursday nearing 50.00% and Friday seeing a sharp decline to 16.22%. Under the relaxed rules Monday, Tuesday,

Wednesday, and Friday were all around 50-55% compliance while Thursday still held a higher rate at 64.02%. The change in Friday compliance rates may again be explained by exclusive signals in the downtown area of Hartford as workers, eager to begin their weekends, ignored the "WALK" signals and chose to cross on the vehicle green out of convenience.

Table 12: Pedestrian Compliance vs. Day of the Week

	All Pedestrians			Within Crosswalks Only		
	Count	% Compliant (Strict)	% Compliant (Relaxed)	Count	% Compliant (Strict)	% Compliant (Relaxed)
Monday	1,201	31.97	55.12	1,015	37.83	65.22
Tuesday	3,116	30.68	53.40	2,787	34.30	59.71
Wednesday	3,386	27.44	50.35	3,073	30.23	55.48
Thursday	5,458	48.88	64.02	5,108	52.23	68.40
Friday	1,677	16.22	51.22	1,386	19.62	61.98
Total	14,838	35.11	56.50	13,369	38.96	62.71

Hour of the Day

Table 13 shows the differences in pedestrian compliance rates based on the hour of the day. In terms of the hour of the observations, all compliance rates with strict rules were in the 30-38% range. 12:00PM to 1:00PM and 4:00PM to 5:00PM saw the lowest compliance rates with 32.55% and 30.82%, respectively, and the only statistically different hour appeared to be the 4:00PM-5:00PM period. Compliance rates for relaxed rules were between 55-59% with the lowest rate of 54.50% occurring between 4:00 and 5:00PM. Unlike the strict rules, the lunch hour had a relatively high rate of relaxed pedestrian compliance, 58.38% and, also opposed to what is seen under the strict rules, the only statistically significant difference between hours occurs between 2:00PM and 3:00PM. The compliance rates within crosswalks saw a similar pattern. This may be another commercial area phenomenon as people, during lunch hours and end of the day commutes, proceed to ignore exclusive pedestrian signals and cross whenever an opportunity arises.

Table 13: Pedestrian Compliance vs. Hour of the Day

	All Pedestrians			Within Crosswalks Only		
	Count	% Compliant (Strict)	% Compliant (Relaxed)	Count	% Compliant (Strict)	% Compliant (Relaxed)
12:00-1:00	2,458	32.55	58.38	2,253	35.51	63.69
1:00-2:00	2,817	36.63	55.09	2,506	41.18	61.93
2:00-3:00	2,434	37.10	59.61	2,165	41.71	67.02
3:00-4:00	2,556	37.68	56.10	2,327	41.38	61.62
4:00-5:00	2,466	30.82	54.50	2,189	34.72	61.40
5:00-6:00	2,107	35.64	55.43	1,929	38.93	60.55
Total	14,838	35.11	56.50	13,369	38.96	62.71

Regression Analysis

A binary logistic regression was chosen to analyze the data due to its appropriateness when dealing with an outcome which only has two possibilities; in this case, compliant or non-compliant. Linear regression, which assumes a real-valued response, is incorrect when the response is binary-valued. [69]

Let Y_i denote the recorded compliance for pedestrian i. Then Y_i=1 if compliance is observed. Otherwise Y_i=0. We further define X=(X_1, X_2, …, X_k) to be a set of explanatory variables each of which can be discrete or continuous. x_{ji} is the observed value of the j^{th} explanatory variable for the i^{th} pedestrian. The binary logistic regression model is a generalized linear model (GLM) which is specified as:

$$\pi_i = \Pr(Y_i = 1 | X_{1i} = x_{1i}, \dots, X_{ki} = x_{ki}) = \frac{\exp(\beta_0 + \beta_1 x_{1i} + \cdots + \beta_k x_{ki})}{1 + \exp(\beta_0 + \beta_1 x_{1i} + \cdots + \beta_k x_{ki})}$$

or, equivalently,

$$logit(\pi_i) = \log\left(\frac{\pi_i}{1 - \pi_i}\right) = \beta_0 + \beta_1 x_{1i} + \cdots + \beta_k x_{ki}$$

We used the SAS procedure NLMIXED for fitting this model. We created a SAS program for carrying out variable selection. Specifically, the program tested the significance of each variable individually within PROC NLMIXED. The program reported which variable, when added to the model, returned the lowest AICc score from the “Fit Statistics” and which variable scored the lowest Probability > Chi

Squared. This information was used to choose which variable to add to the model at each step. While the two criteria often agreed, AICc score was the favored means of selection whenever a discrepancy occurred. Once a variable was chosen to add to the model, the program was run again with the remaining unchosen variables. After each step, similarities in discreet variable values were examined to see whether they could be grouped into one variable; for example, if both two pm and five pm had point values that were close to each other, a single variable for both times would be tested. If the model returned a lower AICc, then the merged variable was kept. We used this approach because the SAS procedure does not have an automatic stepwise selection procedure.

As noted earlier, other studies have observed variation in pedestrian behavior from location to location, even within a single city. To account for this, adding each individual intersection as a variable was considered, but this would have prevented any useful observations between different types of pedestrian signals as the Concurrent vs Exclusive might have become confounded with noise. Instead, as was done by Palamarthy et al. [65] and Granie et al. [62], we used a generalized linear mixed model framework. This allowed for the variance between individual intersections to be accounted for by including them as random effects while the measured variables were tested as fixed effects. To be specific, let $X=(X_1, X_2, \ldots, X_k)$ be the fixed effects and $Z=(Z_1, Z_2, \ldots, Z_m)$ be a set of random effects, then a generalized linear mixed model (GLMM) can be expressed as follows [70]:

$$logit(\pi_i) = \log\left(\frac{\pi_i}{1-\pi_i}\right) = \beta_0 + \beta_1 x_{1i} + \cdots + \beta_k x_{ki} + \alpha_1 z_{1i} + \cdots + \alpha_m z_{mi}$$

In addition to this, pedestrian and vehicle volumes were also modified to include the squares and natural logarithms of the volumes. These were tested alongside the raw volumes in order to determine if a non-linear relationship between vehicle or pedestrian volumes and compliance exists. Interactions between speed limits and vehicle volumes were also introduced into the regressions to account for the possibility that the volumes, split according to the speed limits of each street, was a better fit than vehicle volumes as a whole.

The following tables list the parameter estimates which were found through the regression for each selected variable for each of the four models as well as their odds ratios. If a variable was selected for one model, but not another, "NS" is placed in the point value field for the model in which the variable was not significant. The odds ratios were obtained through the equation $Odds\ Ratio = \ e^{x}$ where "x" is the point value in question. Odds ratios greater than 1 indicate that the variable increases the chance that a pedestrian would be compliant where odds ratios less than 1 indicate that the variable decreases that chance. A Kendall tau test was performed on the discrete explanatory variables which were selected to ensure that no two had too great a degree of association between them, thus avoiding the issue of multicollinearity.

Table 14 lists the parameter estimates for the strict and relaxed models using data from all of the pedestrians who were observed. Table 15 lists the parameter estimates for strict and relaxed models using observations of pedestrians who crossed within crosswalks only.

Table 14: Parameter Estimates for All Pedestrians

Parameter	Level	Strict Compliance Model			Relaxed Compliance Model		
		Estimate	Odds Ratio	t-Value Pr>|t|	Estimate	Odds Ratio	t-Value Pr>|t|
Intercept	-	-0.3599	0.698	-0.79 0.4335	-1.2347	0.291	-4.31 0.0001
Signal Type	Concurrent	1.7752	5.901	4.88 <0.0001	NS	NS	NS
Pedestrians *(Pedestrians Per Hour)*	-	-0.00500	0.995	-4.96 <0.0001	-0.001748	0.998	-2.20 0.0335
Ln(Pedestrians) *(Pedestrians Per Hour)*	-	0.5292	1.698	9.11 <0.0001	0.4025	1.496	8.36 <0.0001
Speed Limit	30	-1.9775	0.138	-12.09 <0.0001	-1.9749	0.139	-13.73 <0.0001
	35	-4.0798	0.017	-14.61 <0.0001	-3.1021	0.045	-11.59 <0.0001
Vehicle Volume (1000 VPH)	25 MPH Streets	-2.6447	0.071	-9.99 <0.0001	-2.1162	0.120	-16.05 <0.0001
	30 MPH Streets	-0.1576	0.854	-0.62 0.5395	0.6946	2.003	3.99 0.0003
	35 MPH Streets	1.9383	6.947	5.72 <0.0001	2.3188	10.16	7.15 <0.0001
Ln(Vehicles) (1000 VPH)	-	0.7055	2.25	8.07 <0.0001	NS	NS	NS
One Way Street	Entrance	NS	NS	NS	0.8315	2.297	10.07 <0.0001
	Exit	1.2020	3.327	8.57 <0.0001	0.8315	2.297	10.07 <0.0001
Crosswalk	Marked	NS	NS	NS	0.5773	1.781	2.90 0.0060
Crossing Distance (ft)	-	0.02508	1.025	5.87 <0.0001	0.02728	1.028	7.92 <0.0001
Sidewalk	On Both Sides	-0.6911	0.501	-2.94 0.0054	NS	NS	NS
Parking	On Street	0.3341	1.397	3.94 0.0003	NS	NS	NS
Median	Present	-0.5260	0.591	-2.44 0.0217	NS	NS	NS
Land Use	Non-Residential	-1.0946	0.335	-3.07 0.0059	-0.5569	0.573	-2.04 0.0478
Weather	Cloudy	-0.4125	0.662	-4.49 <0.0001	NS	NS	NS
Day	Friday	-0.7405	0.477	-1.44 0.1570	NS	NS	NS
Observation Hour	1PM	NS	NS	NS	-0.04762	0.953	-5.19 <0.0001
	3PM	0.1709	1.186	2.58 0.0137	NS	NS	NS
	5PM	0.1709	1.186	2.79 0.0137	NS	NS	NS
AIC		13469			17589		
-2 Log Likelihood		13429			17561		

Table 15: Parameter Estimates for Pedestrians Within Crosswalks Only

Parameter	Level	Strict In Crosswalk Only Compliance Model			Relaxed In Crosswalk Only Compliance Model		
		Estimate	Odds Ratio	t-Value Pr>|t|	Estimate	Odds Ratio	t-Value Pr>|t|
Intercept	-	-0.7663	0.465	-0.33 0.7409	-15.2924	2.283E-07	-7.21 <0.0001
Signal Type	Concurrent	1.6276	5.092	4.20 0.0001	NS	NS	NS
Pedestrians *(Pedestrians Per Hour)*	-	-0.00418	0.996	-3.97 0.0003	-0.00213	0.998	-2.44 0.0191
Ln(Pedestrians) *(Pedestrians Per Hour)*	-	0.5190	1.680	8.48 <0.0001	0.4352	1.545	8.21 <0.0001
Speed Limit	30	-2.0112	0.134	-10.93 <0.0001	-1.7884	0.167	-10.77 <0.0001
	35	-4.2037	0.015	-13.88 <0.0001	-2.7484	0.064	-9.50 <0.0001
Vehicle Volume (1000 VPH)	25 MPH Streets	-3.3705	0.034	-11.46 <0.0001	-2.2529	0.105	-13.44 <0.0001
	30 MPH Streets	-0.6545	0.520	-2.39 0.0216	0.3447	1.412	1.69 0.0993
	35 MPH Streets	1.5249	4.595	4.21 0.0001	1.6190	5.048	4.62 <0.0001
Ln(Vehicles) (1000 VPH)	-	0.9786	2.661	10.25 <0.0001	NS	NS	NS
One Way Street	Entrance	NS	NS	NS	1.1799	3.254	8.54 <0.0001
	Exit	0.9966	2.709	6.51 <0.0001	0.6920	1.998	5.78 <0.0001
Crosswalk	Marked	NS	NS	NS	0.4281	1.534	2.08 0.0437
Crossing Distance (ft)	-	0.01992	1.020	1.09 0.2807	-0.07729	0.926	-4.47 <0.0001
Ln(Crossing Distance) (ft)		0.3612	1.435	0.46 0.6501	5.0998	163.99	6.72 <0.0001
Sidewalk	On Both Sides	-0.7158	0.488	-2.89 0.0061	NS	NS	NS
Parking	On Street	0.3876	1.473	4.33 <0.0001	NS	NS	NS
Median	Present	-1.1020	0.332	-4.69 <0.0001	-0.4536	0.635	-2.16 0.0366
Land Use	Non-Residential	-1.2364	0.290	-3.25 0.0023	-0.5701	0.565	-2.09 0.0424
Weather	Cloudy	-0.3636	0.695	-3.76 0.0005	NS	NS	NS
Observation Hour	1PM	0.3118	1.366	5.76 <0.0001	-0.1796	0.836	-3.34 0.0018
	2PM	0.1528	1.165	2.09 0.0428	NS	NS	NS
	3PM	0.3118	1.366	5.76 <0.0061	NS	NS	NS
	4PM	NS	NS	NS	0.1374	1.147	2.77 0.0084
	5PM	0.3118	1.366	5.76 <0.0001	0.1374	1.147	2.77 0.0084
AIC		12176			15251		
-2 Log Likelihood		12134			15215		

As can be seen, whether a signal is concurrent or not plays a significant role as to whether or not a pedestrian will cross in accordance to the rules. This is in agreement with what was seen earlier with the descriptive statistics. Under strict compliance, a pedestrian faced with a concurrent pedestrian phase is several times as likely to cross legally than one faced with a signal that has an exclusive phase, all other factors being equal. What is most interesting, though, is that under relaxed compliance rules the option of concurrent vs. exclusive signals was never found to be statistically significant. That is to say; pedestrians in our observed study set appear to treat all signals as having a concurrent phase regardless of what the pedestrian signals tell them.

Vehicle volumes and speeds have unexpected results. A pedestrian crossing at a street with a 30 or 35 mile per hour speed limit is much more likely to cross non-compliantly in all models than one crossing at a street with a 25 mile per hour speed limit. When combined with traffic volume, which was found to be more strongly correlated when separated by speed limit, as well as the natural logarithm of the vehicle volume for the models using Strict rules, the effects appear more reasonable.

Figures 2, 3, 4, and 5 show the predicted compliance for pedestrians on an imaginary ‘average’ street using the mean values of the continuous variables, listed in Table 1. The intersection contains crosswalks on both sides of the road and marked crosswalks; all other features are assumed to be absent. Figures 2 and 3 display the models using all pedestrian data where figures 4 and 5 show the results of the models which used observations of pedestrians within crosswalks only. Compliance vs. vehicle volumes are, for the most part, what we expect to see which is to say that as the presence of vehicles on a roadway increases, particularly high speed roadways, the more compliant pedestrians become. This effect is not followed on 25 MPH roads, however. This could be due to lower volume streets having shorter cycle lengths, allowing pedestrians shorter wait times and encouraging compliance. It is also possible that this is an effect from downtown Hartford intersections, which saw very little pedestrian compliance despite

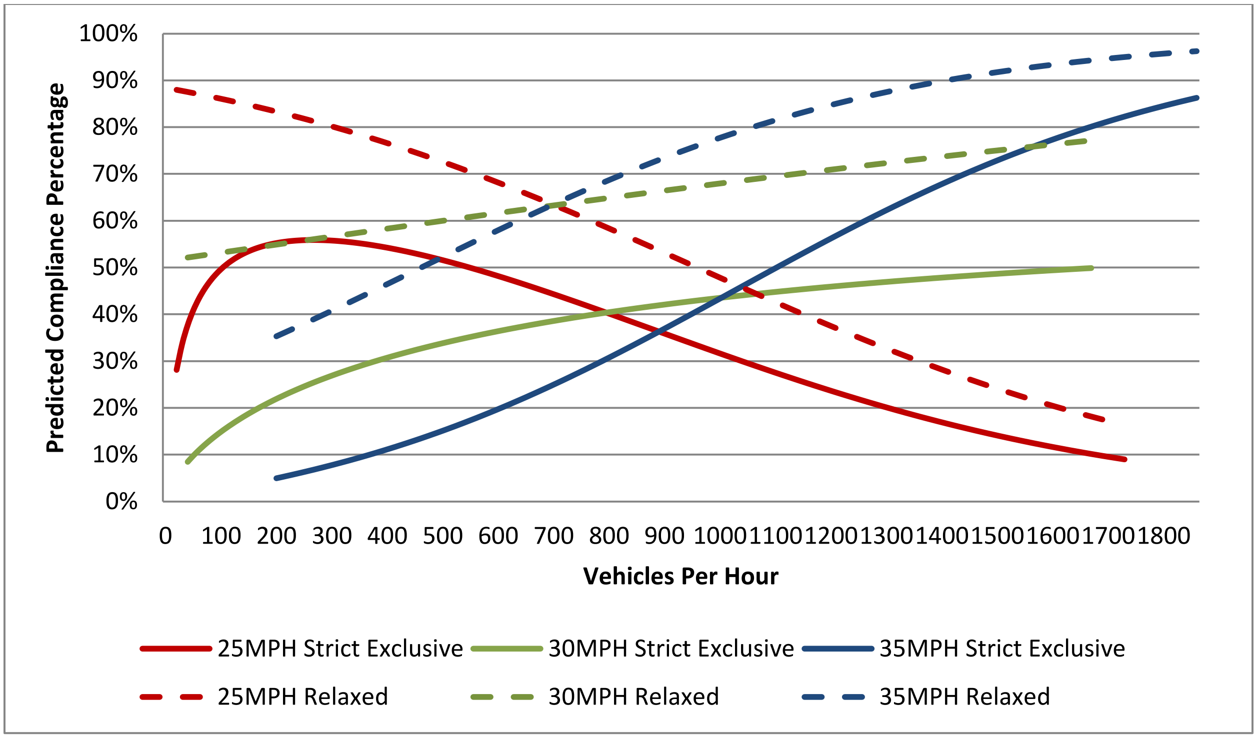

Figure 2: Strict with Exclusive Signal and Relaxed Model Predictions for Pedestrian Compliance vs. Vehicle Volume

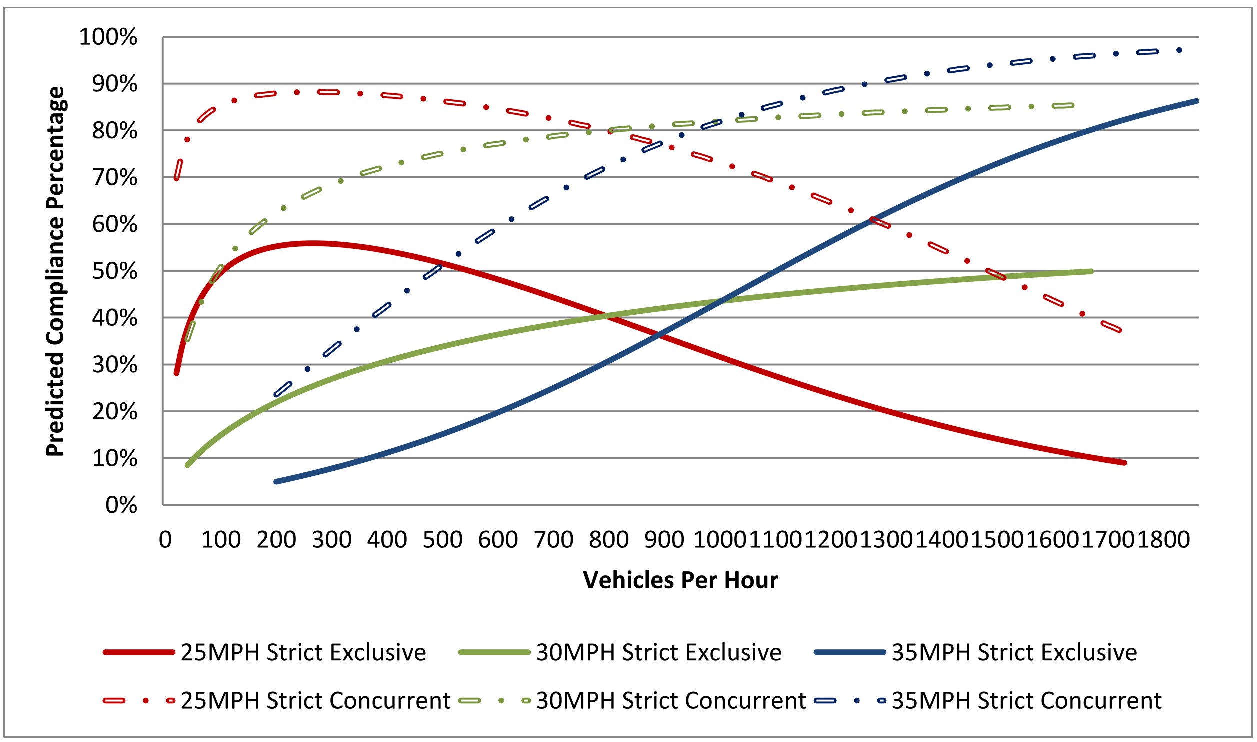

Figure 3: Strict with Exclusive Signal and Concurrent Signal Model Predictions for Pedestrian Compliance vs. Vehicle Volume

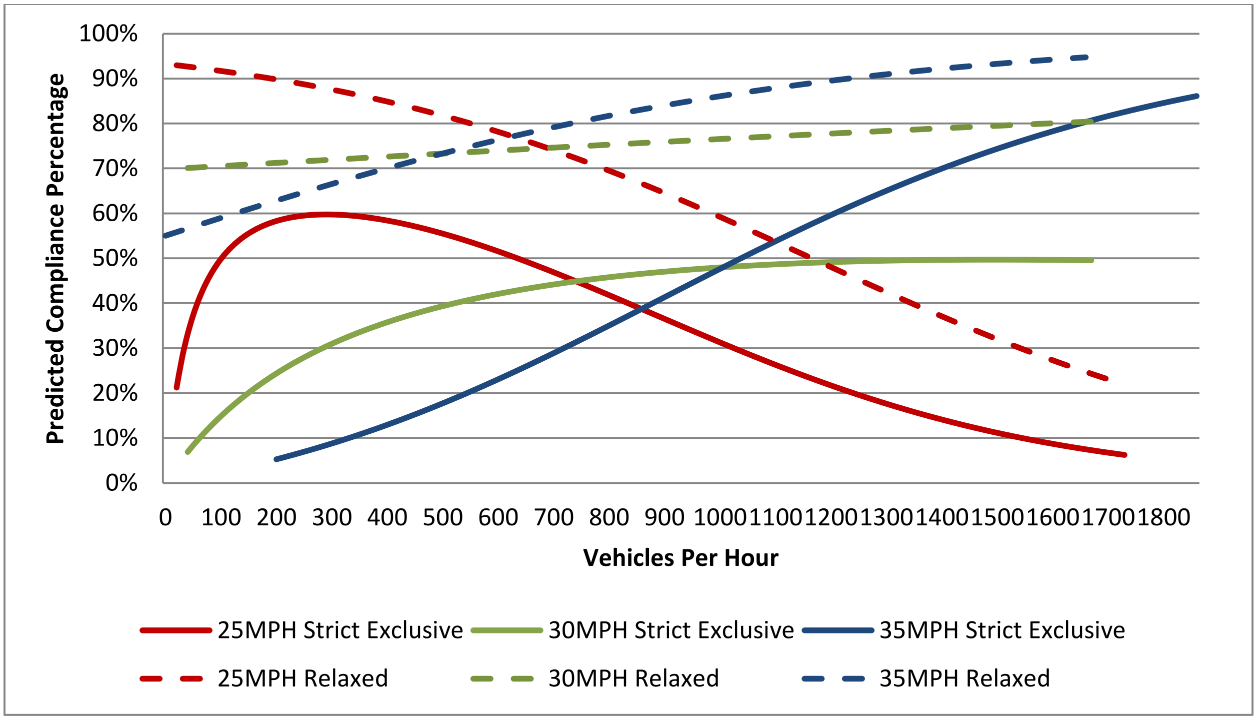

Figure 4: In Crosswalk Only Strict Exclusive Signal and Relaxed Model Predictions of Ped. Compliance vs. Vehicle Volume

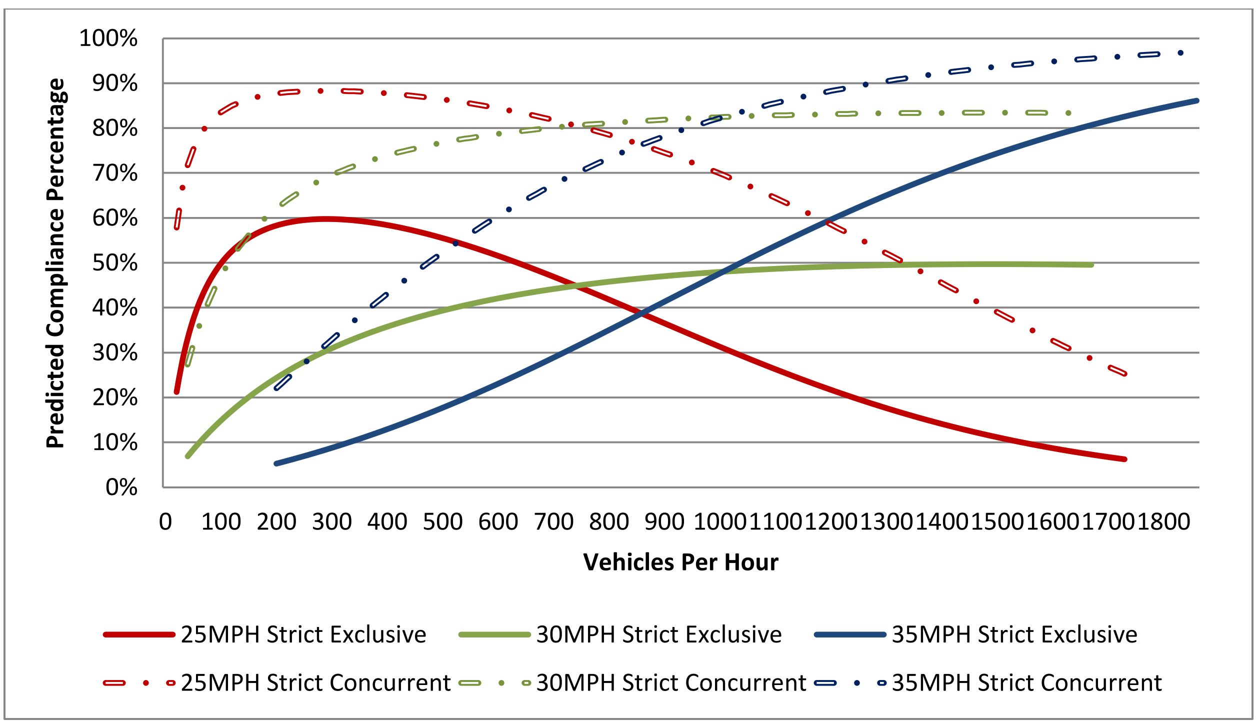

Figure 5: In Crosswalk Only Strict Exclusive and Concurrent Signal Model Predictions for Ped. Compliance vs. Vehicle Volume

high vehicle volumes. All of these roads are designated as having 25 MPH speed limits and, due to the number of pedestrians, may have strongly influenced the predicted effect of vehicle volumes on 25 MPH streets.

Figure 6 shows pedestrian compliance vs. the volume of pedestrian traffic an intersection saw. Figure 7 displays the same but for the models which used observations of pedestrians inside crosswalks only. These graphs take place on the same imaginary ‘average’ road as the previous graphs only they are assumed to be 25 MPH roadways (the most frequently observed) with a number of vehicles per hour equal to the mean of what was observed. These results are surprising as it was expected that pedestrians would become less compliant with signals as their numbers grew. Instead we see, in both cases, that pedestrian compliance grows until a point at around 100 to 125 pedestrians an hour (or higher for the relaxed models) where compliance is predicted to decrease. It could be that this volume is a sort of critical level where enough pedestrians are present that they feel more comfortable challenging motor vehicles to the right to cross the road. The low rates of compliance seen where pedestrian volumes are below 10 people per hour may be due to signals which were designed without pedestrians in mind due to how few of them appear. Such signals may leave pedestrians feeling as though they have to take it upon themselves to cross when they can if they do not want to be unduly delayed. It is also possible, if people do influence each other’s behavior as discussed in previous sections, that pedestrians at these intersections feel comfortable breaking the rules as no one is there to observe.

Crossing distance, as displayed in figure 8 for models using all pedestrians and figure 9 for models using only pedestrians who appeared in crosswalks, appears to have a predictable effect on pedestrian compliance which is that the further a pedestrian has to traverse and, thus, expose themselves to

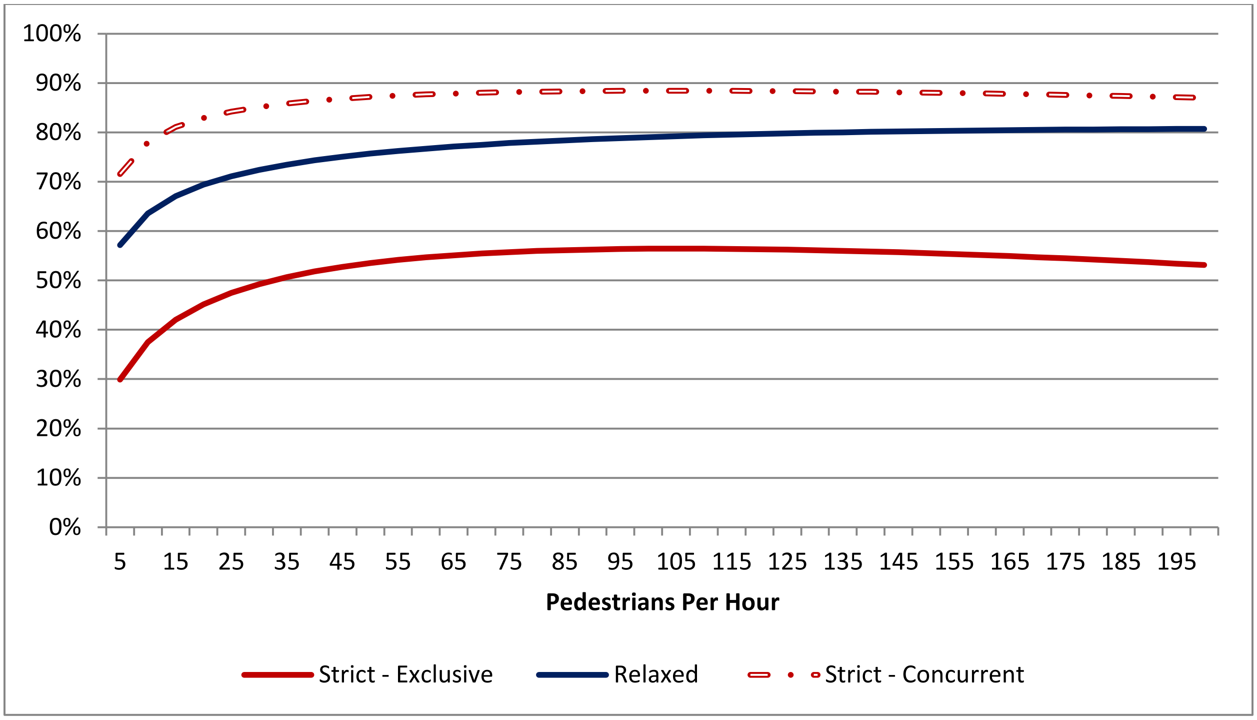

Figure 6: Pedestrian Compliance vs. Pedestrian Volume

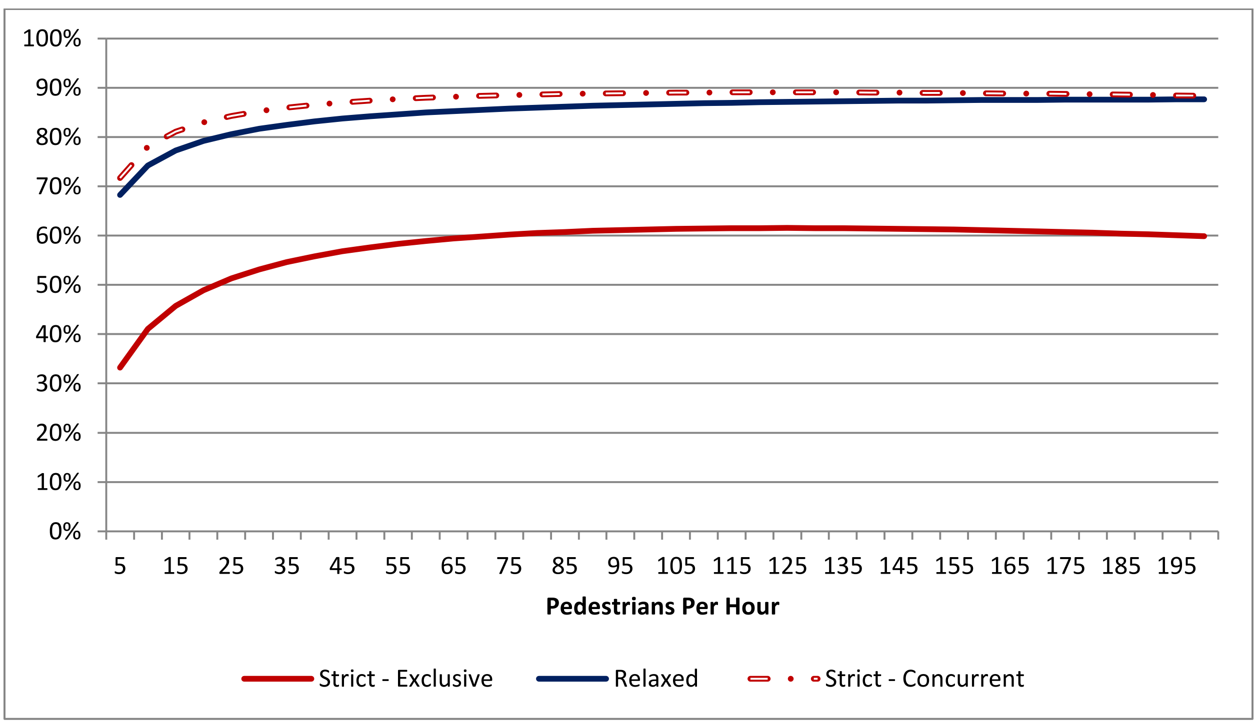

Figure 7: In Crosswalk Only Pedestrian Compliance vs. Pedestrian Volume

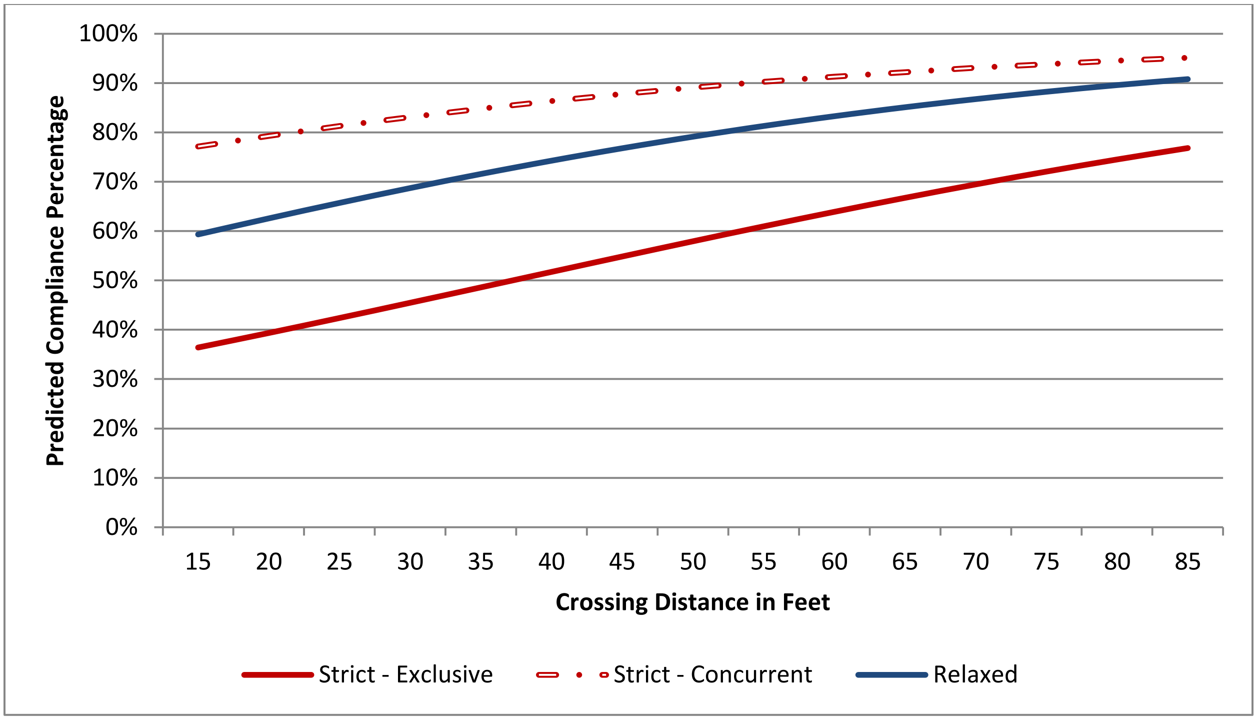

Figure 8: In Crosswalk Only Predicted Pedestrian Compliance vs. Crossing Distance

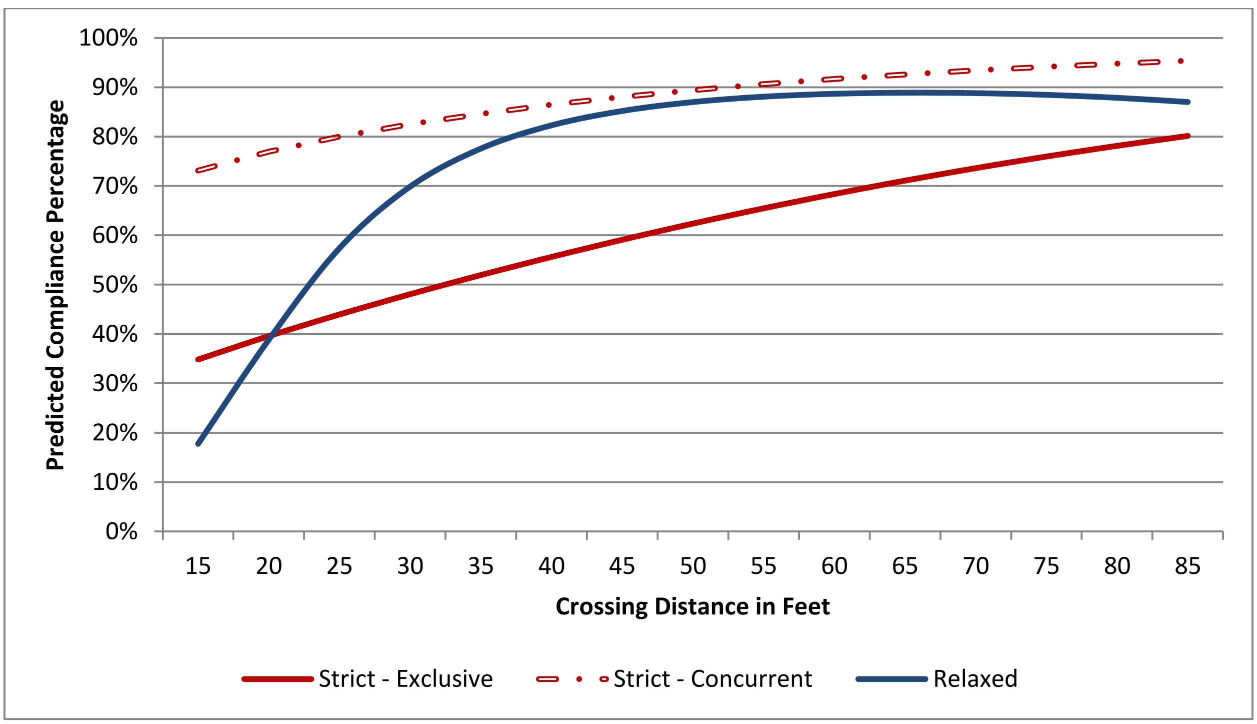

Figure 9: In Crosswalk Only Predicted Pedestrian Compliance vs. Crossing Distance

danger, the more likely they are to cross a road in compliance with the signal. The relaxed model using the in-crosswalk pedestrian data only appears to have a peak crossing distance at around 67 feet after which pedestrian compliance appears to drop off. This is likely due to 86 feet being the maximum crossing distance observed and the model, observing a sharp rise in compliance as crossing distance grows from 15 to 35 feet, found the natural logarithm of the crossing distance to be the best fit. It is hard to imagine that pedestrians faced with street widths 70 feet and wider, would feel emboldened and attempt to cross against the signal more than they would at a 60 foot wide roadway.

Another item to note in the relaxed pedestrian compliance model using in-crosswalk only data is just how strongly the model depends upon crossing distance. For this model, this factor is likely the strongest influence over whether or not a pedestrian crosses with the signal.

Looking again at the non-continuous variables, medians appear to encourage non-compliant crossings, most likely by providing an area of refuge which allows a jaywalker to cross in two steps rather than one. On street parking and sidewalks, which were only salient enough to be selected under strict compliance rules, were associated with an increase and a decrease in pedestrian compliance, respectively. It is reasonable to suspect that pedestrians who were in areas without sidewalks saw the street design as more auto-oriented and, as a result, less safe to jaywalk in. Why on street parking would result in a higher rate of compliance is not clear, though it may be due to parked vehicles acting as a barrier for crossing outside of the crosswalks or reducing pedestrian line of sight to a degree where more caution is exercised. Marked crosswalks, which were only selected under relaxed compliance rules, also increased compliance which is likely due to a reduced number of pedestrians crossing outside of the designated crossings.

Conclusions

The most important finding from this research is that the pedestrians studied appear to treat all signals, even those with only exclusive phases, as though they have concurrent pedestrian phases. This is very important since, as Abrams & Smith pointed out back in 1977 [4], the safety benefit of exclusive

pedestrian phases over concurrent pedestrian phases depends entirely on pedestrian compliance. This is compounded by Zhang et al's finding that collisions which occurred at signals with exclusive pedestrian phases tended to be of a more severe nature than those at similar intersections with concurrent phases [3].Before making recommendations, though, it is important to look into why exclusive pedestrian signals are so widely used throughout the Hartford area. Anecdotally, there has been no document ordering the use of exclusive pedestrian signals within the state of Connecticut; it is something that is simply normal practice. The two major concerns that are brought up are driver expectations and compliance with requirements set forth by the American's with Disabilities Act (ADA).

The first concern of driver expectation is the belief that drivers within the state have been conditioned to exclusive pedestrian signals. When given a green light they are likely to think that it is their turn to go and any pedestrian within the crosswalk is intruding or, worse, a driver will simply fail to look for a pedestrian. Inattentiveness in these situations could lead to a collision.

One possible solution to this expected problem are Leading Pedestrian Interval Phases, or LPI. At a signal with an LPI, pedestrians at concurrently phased signals are given a 'WALK' signal a few seconds prior to vehicles being given the green light. This allows pedestrians to get into the crosswalk, establish their priority, and be well within the field of view for turning vehicles. In 2000, Van Houten et al. ran a study at three intersections in St. Petersburg FL where LPIs were installed. Their study found that LPI signals significantly reduced conflicts between pedestrians and turning vehicles while also reducing the incidences of pedestrians having to yield to vehicles [71]. In its online Urban Street Design Guide, NACTO even states that, "LPIs have been shown to reduce pedestrian-vehicle collisions as much as 60% [72]." There are, of course, additional treatments which could be used to address the problem of drawing drivers' attention to pedestrians, but this is not intended to be an exhaustive examination of potential treatments.

ADA compliance is another matter, and a very important one. In order to provide walkability to pedestrians who can't see, newer pedestrian signals often give audial cues in the form of beeps, clicks, or even voices telling pedestrians to "Wait," or "Walk." This is easier to accommodate at intersections with exclusive pedestrian signals because the designing engineer no longer has to be concerned with what direction the blind individual is walking in. These problems can be solved with a little more work on the part of the designer. The American Council of the Blind suggests the use of tactile arrows on pushbuttons, audio cues which state the name of the street it is safe to cross, and pushbutton boxes which vibrate when it is time for the pedestrian to cross [73]. Again, other solutions may exist; this is just meant to illustrate that ADA Compliance is not a barrier to the implementation of concurrent pedestrian signals.

Warrants for when concurrent pedestrian signals should be used instead of exclusive ones is beyond the scope of this paper and something that should be attempted when a clear consensus has been reached on the effectiveness and drawbacks of each type of control. With this in mind, a starting point can be attempted by looking back at the data in the previous section. It can be seen that concurrent signals consistently have a higher rate of compliance when compared with exclusive signals. Considering figure 9, which shows pedestrian compliance vs. crossing distance for people in crosswalks only, we see that there is a sharp upward trend in compliance in the relaxed model. This upward trend is well on its way to levelling out when crossing distances reach 50 feet. It is also observed, in both figure 8 and figure 9, that the compliance rate for exclusive signals reaches 60% at around this distance. Furthermore, we observe, in figures 4 and 5, that pedestrian compliance is significantly higher at concurrent signals than at exclusive signals for all roadways which had 25 MPH and 30 MPH speed limits. For this reason, it is suggested that concurrent pedestrian phases be considered at all signalized intersections where the crossing roadways have vehicle speed limits of 30 MPH or less.

Roadways which have speed limits of 35 MPH also see a higher rate of pedestrian compliance at concurrent signals, but the gap between compliance rates appears to reduce at about 1400 vehicles per hour. As a result, this paper recommends considering concurrent signals only at intersections where

roadways have speed limits of 35 MPH when the crossing distance is less than 50 feet wide and vehicle volumes are below 1400 vehicles per hour.

As discussed, there appears to be a point where pedestrian compliance versus pedestrian volume appears to peak and a decrease in compliance is seen. If this is indeed the case, it may be that signals which see high pedestrian volume (100 pedestrians per hour and above) should be made concurrent in order to avoid decreases to intersection capacity. In all cases it is recommended that signal types in an area be consistent so as to avoid the possibility of confusing drivers and pedestrians.

That marked crosswalks appear to encourage compliance, even with pedestrians who are already within the crossing area, agrees with what Hauck [52] and Wall [53] observed in their studies. This suggests that one of the simplest strategies for transportation officials to increase pedestrian compliance is an option which also helps to make pedestrians stand out to motorists; well-marked crosswalks [74].

It is also worth noting that the negative effect of medians on compliance is much more strongly pronounced in the models which used in-crosswalk pedestrian data only. That it was not even selected as being significant in the relaxed model using all pedestrian data suggests that they may deter out of crosswalk crossings even as they encourage crossing against the traffic signal. This would seem to be in agreement with Berger's findings that barrier medians were an effective countermeasure to pedestrians crossing outside of the crosswalk [54]. As a result, this report urges caution to any designer considering the usage of medians in a setting where pedestrians are to be expected. Thought should be put into which problem is better for an area to have; pedestrians crossing out of place or out of time.

Further Research

One of the limitations of this study was the geographic location. All observations were made in the metro area of Hartford, CT and it remains to be seen how valid the results are beyond this area. It is reasonable to assume that many other locations within Connecticut would have similar results as many signals, even

if owned by a municipality, are likely influenced by the State Department of Transportation. Other states, however, have different design standards. Concurrent pedestrian phases are the norm for New York City, for example, and this may result in pedestrians who are even more likely to ignore exclusive signals which cause them to wait an undue amount of time.

The types of intersections studied could also be expanded upon. The intersection designs were always three or four legged which met at approximately 90 degrees. Connecticut, having been settled before the invention of the automobile, does have many intersections where streets meet at odd angles or have more than four legs. The method of live observation also limited the amount of information which could be gathered at one time. Large intersections, those with multiple lanes of heavy traffic in all directions did not tend to make it into the study as counting vehicles as well as noting pedestrian behavior would have proved impossible to accurately record with two person teams.

A similar study which included data on functional properties of studied traffic signals may yield interesting results. Information on cycle length, phases, ring and barrier designs, pedestrian crossing timings, or even whether or not as well as for how long a vehicle signal can be extended may give additional insight when compared to pedestrian behavior. It is assumed, and has been observed in other studies, that pedestrians will become more likely to cross the longer they are made to wait. This would be good to prove or discredit for this region.

Vehicle speed, as mentioned earlier, is another variable which was not gathered during this study. While the speed limit was included as a substitute it is commonly assumed, even by transportation engineers, that drivers in Connecticut pay little attention to the posted limit and drive as fast as they feel comfortable. It is likely reasonable to assume that streets with higher speed limits will see higher overall speeds, but greater accuracy in predicting pedestrian behavior may be achieved if true 85^{th} percentile speeds were gathered during pedestrian studies.

Another way upon which this study could be improved would be to gather additional data on pedestrian behavior. No attempt in this study was made to differentiate pedestrians based on when they arrived at a signal. A good number of pedestrians who were compliant at exclusive signals were so only because they happened to arrive at the intersection while the WALK signal was lit. As a result, they were not presented with any choice on whether to be complaint or not and it may be that they would have chosen to ignore the signal if they found it inconvenient.

Additionally, no attempt was made to gauge how attentive pedestrians were during their crossings. It is possible that those who choose to ignore the signal take greater caution when crossing an intersection. It is also possible that pedestrians in certain areas pay no mind to the surroundings and cross without watching for traffic or whether the WALK signal is lit, instead depending on their numbers and the unwillingness of drivers to present a challenge to keep them safe.

Another consideration, in opposition to what has been attempted in this paper, is the assertion that pedestrian compliance, by itself, cannot be accurately studied. Papadimitriou, Yannis, and Golias, in a discussion of route choice & crossing models, argue that the two cannot be separated from one another. Pedestrians, they argue, will comply with traffic control systems if doing so is convenient to reaching their destination. In a city with a good grid, a pedestrian blocked from crossing at one intersection may choose to turn down a side road then turn again, travelling in their original direction, upon reaching a point where it is safe to cross. Naturally, as they close in on their destination, their choices on where they can cross becomes more limited. This ultimately results, they assert, in route choice and compliance being indivisible [75]. This notion harkens to Peter Norton's claim that pedestrians, even after the automobile had won the road, continued to fight for their place by the unmatched nimbleness and flexibility of their mode [1]. While a study which combines route choice and compliance behavior would likely be very difficult to perform, the results of such an undertaking would be extremely interesting.

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